INTERNATIONAL CONFERENCE ON
Solid Waste 2023
Waste Management in Circular Economy and Climate Resilience

31 May – 3 June 2023
Hong Kong

Conference Proceedings

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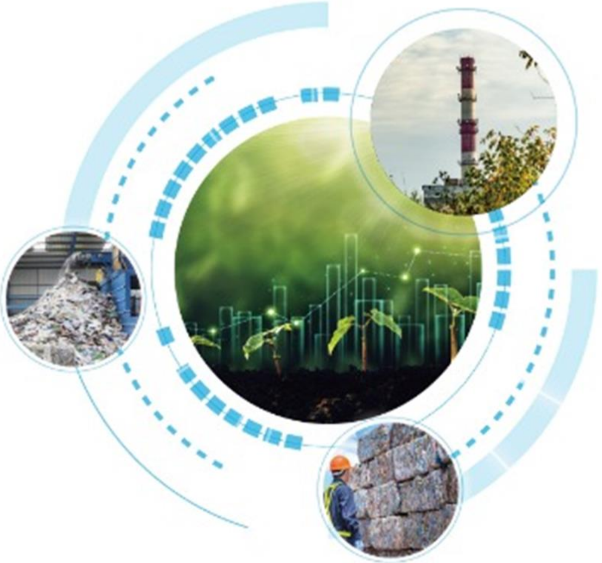

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WELCOME MESSAGE

It is my great privilege and pleasure to welcome you all, new and old friends, to the "International Conference on Solid Waste 2023: Waste Management in Circular Economy and Climate Resilience (ICSWHK2023)" here in the beautiful city of Hong Kong. I would like to take this opportunity to express my sincere thanks for your support for the last five International Conferences, ICSWHK2011, ICSWHK2013, ICSWHK2015, BioWCHK2016, and SBM2021; and 'YOU' made the events grand successful. Similar to the previous conferences, we have received overwhelming response from all over the world to participate in the ICSWHK2023 conference. Leveraging internationally renowned researchers and practitioners, the event has attracted nearly 400 abstracts from over 40 countries in the various disciplines of the conference themes. Several stakeholders working in waste management such as academicians, researchers, policy makers and companies have submitted their abstracts to showcase the innovative waste management practices around the world. We are expecting around 500 participants, including local and international members seating together and sharing experiences. Further, we are encouraging local postgraduate students to participate in the conference by providing free registration to catalyze networking opportunities for young researchers to exchange ideas and interact with eminent scientists working in waste management and circular economy around the world.

Adaption of circular and green economy in waste management sector is the key factor to curb the environmental pollution along with effective mitigation of climate change. However, the present global economy is only 8.6% circular as per Circularity Gap Report 2021 indicating a huge potential for promoting the circular economy across the world. The recent outbreak of the Covid-19 pandemic has further hindered sustainable waste management practices and resulted in elevated waste generation. Hence, green recovery and circular economy could be the cornerstone for future waste management practices to achieve United Nations Sustainability Development Goals. Focusing with these themes, ICSWHK2023 includes 10 keynote speeches, 32 plenary lectures, 24 invited letures, 158 oral and 120 poster presentations. Further, two pre-conference workshops titled "Enhanced Landfill Mining: Technologies, Products, and Costs" and "Biochar for Sustainable Management of Urban Biomass Waste" and technical field trips to the state-of-the-art treatment facilities in Hong Kong, Y-Park, T-Park, Eco-Park and O-Park are also arranged.

ICSWHK2023 will definitely provide you a great opportunity and platform to exchange your views, visions, and experiences on waste treatment technology, sustainable waste management and environmental issues among scientists, academics, practitioners and policy makers from all over the world. We also wish this conference can be a turning point for companies involved in waste and environment issues to build up a network. In order to remove the monetary barrier to attend the Conferences, we have provided complete or partial sponsorship to some participants from developing countries. Thanks to our generous sponsors who make us meet at least certain demands of the participants. I do hope that with the limited available resources we can encourage more young researchers, especially those coming from development countries can join this conference to meet renowned waste management experts from all over the world.

We strongly believe this conference will offer you ample chance to gain new insights about the latest environmental technology. This is a unique opportunity for the young scientists and researchers who are specialized in waste management. Outstanding papers will be published in a special issue of SCI journals such as Bioresource Technology and Environmental Technology after review. Best Poster Award, and Young Researcher Award are also waiting to acknowledge and embrace your knowledge and potential.

Finally, we are here today to actively share experiences, learn the developments and seek for collaborations on various issues of sustainable waste management. Your presence and contributions are vital in making this conference a truly international platform for sharing ideas and experiences. I am certain that along with having an enriching experience at the conference you will also enjoy the most pleasurable experience in visiting one of the most dynamic and vibrant cities in the world. It will be a memorable event for colleagues and friends from all over the world to establish friendship to promote academic exchanges at an international level and to contribute to the development of new approach for solid waste management. We hope our participants will have a fruitful conference and find time to explore Hong Kong, a dynamic metropolis steeped in unique blends of East and West.

HEARTY WELCOME TO HONG KONG!

Conference Chair
Prof. Jonathan W.C. Wong, PhD, BBS, MH, JP
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Hong Kong

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Keynote Speeches

Manufacture of Organic-Based Fertilizers to Ensure Development of Sustainable Agriculture

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Here, we performed four parts of work related to the development of organic fertilizers and bio-organic fertilizer, as well as their regulation effect on soil microbiome. (1) Developed a high-quality compost manufacturing technology: we developed a pH-adjusting technology to reduce ammonia volatilization and improve nitrogen nutrition levels during composting. A compost inoculum was established that can significantly promote rapid temperature rise and humus synthesis, leading to a 40% increase in composting efficiency. Furthermore, we designed a new composting and fermentation process that combines static oxygen supply and stack-type tilting oxygen supply, reducing the composting period from 2 months to 20 days. This fertilizer promotes the synchronization of soil nitrogen supply and crop nitrogen demand, improving nitrogen usage rates from 30% to 40% by stimulating microorganisms to fix fertilizer nitrogen in the early stage and release nitrogen in the later stage. (2) Developed the manufacturing process of secondary solid fermentation technology for *Bacillus* biofertilizer, which has played a significant role in the development of China's biofertilizer industry: we screened *Bacillus velezensis* SQR9, which promotes plant growth by 30%. It was discovered that Bacillomycin D functions as the signal substance that determines the formation of biofilm on the root surface of *Bacillus* and that the strength of biofilm formation determined by the phosphorylation level of the regulatory factor DegU. Furthermore, it was found that after colonizing the root surface, SQR9 synthesizes IAA mainly through the indole pyruvate, tryptamine, and indole acetonitrile pathways, thus promoting root growth. The high pH of the product resulted in ammonia volatilization and suffocation of functional bacteria, which limited their survival in biological fertilizer products. To address this issue, he developed a second solid fermentation technique to produce Bacillus bio-organic fertilizer by adding 10% acidic amino acid solution to the compost before *Bacillus* inoculation. This method increases the content of beneficial bacteria in the product to more than 10 billion spores/gram, and the product's pH is controlled at 6.5–7.5 to ensure that the content of beneficial bacteria meets or exceeds industry standards through the product's shelf life. (3) Developed a low-cost solid fermentation process for Trichoderma, providing continuous support for technological innovation and product upgradation in China's biofertilizer industry: we screened the *Trichoderma harzianum* fungus (NJAU4742), which significantly promotes plant growth and controls pathogen growth, and found that NJAU4742 promotes the development of plant lateral roots through the secretion of expansion proteins and auxin from the mycelium, resulting in improved nutrient and water absorption by the host plant. Based on the acid resistance of NJAU4742 and its inability to grow under low pH conditions, a solid-state fermentation process for the efficient production of *Trichoderma* spp. spores using straw amino acids and acid-hydrolyzed animal protein wastes were developed. This technology has reduced the production cost of Trichoderma by 40%. (4) Formed a theoretical and technical system for the regulation of soil microbial flora: The cultivation of disease-resistant soil is crucial for the sustainable development of the economic crop industry, and the microbial flora in the soil plays a vital role in the development of disease-resistant soil. We pioneered research on the characteristics and manipulation of disease-suppressive soil microbiomes domestically and internationally. By applying bio-organic fertilizer in conjunction with soil fumigation, more niches become available for the colonization of exogenous beneficial strains in the soil. Additionally, the application of organic fertilizer provides additional niches for the effective colonization of beneficial strains, thus achieving the goal of soil microbial community assembly manipulation.

The Role of Biogenic Waste and Residues in the Bioeconomy & Energy System – Strategic, Technical, Ecological & Economical Aspects

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ABSTRACT. It may be difficult in the face of the brutal Russian attack on the Ukraine, but other global challenges continue demand our attention. This especially holds true for the transformation of our society into a climate-neutral one – bearing in mind that this is also one key prerequisite for preventing future armed conflicts. Put very simply, climate neutrality will only happen if the following formula is observed: Climate neutrality (CN) = Renewable energies (RE) + Circular economy (CE). As explained in the present paper, Germany still has a long way to go towards its 2045 goals. In 2021, the country emitted 762 Mg CO2, and reduction rates compared with 1990 are back to below 39 %. On the one hand side, the share of RE in both primary energy consumption (PEC) – currently just under 16 % – and total final energy consumption (FEC, <20%) is still quite low. For PEC as well as for FEC, the share of bioenergy in total RE was about 60% in 2021. This means we must halve our current energy consumption as fast as possible. Both rigorous energy saving actions and substantial increases in energy efficiency will be required to achieve this. Germany's energy supply must switch to RE completely and in all sectors over the next decades. This will require a massive expansion and optimised integration of wind, solar, bio-, geothermal and hydro-energy for heating/cooling, electricity and transport. Bioenergy will primarily be required to close the gaps where other RE cannot guarantee security of supply. Moreover, energetic use of biogenic resides and wastes will continue to increase in importance. On the other hand side, our linear economic system must become a true circular economy. Currently, we are still far from achieving this. Organic raw materials for industry need be bio-based instead of petroleum-based, as far as possible. Again, an optimised use of biogenic residues and wastes for materials and energy will be key here. Such integration of biomass into a sustainable bioeconomy and energy system can only be realised in the long term if the former is used efficiently, in an environmentally compatible way and to a maximum total economic benefit. This will require new technological concepts, increased coupled and cascading usage as well as negative emissions, which are generated by storing "green" carbon. The biomass must also come from biogenic residues and wastes, or from sustainable cultivation. The current technical potential of biogenic residues and wastes in Germany amounts to 85.6 to 139.6 Mt dry mass. Between 67 and 85 % of this are already being used for material or energy production. The DBFZ assumes that, one the one hand side, the existing usage can still be optimised, and on the other hand side, an additional 12.8 to 45.5 Mt dry mass could and should be mobilised for further processing. These are also central research areas of the German Biomass Research Centre (DBFZ-Deutsches Biomasseforschungszentrum gGmbH) and the Chair of Waste and Resource Management at the University of Rostock.

Keywords: Organic waste, Bioenergy, Bioeconomy, Energy system, Climate neutrality

Introduction

The Department for Waste and Resource Management at the University of Rostock has tackled engineering challenges concerning the waste management industry for 30 years, from reducing waste over recycling technologies to remediation. The focus of the Department is on treating biogenic wastes and, geographically speaking, increasingly on international projects: The past 15 years have seen more and more projects in Europe, MENA (Middle East and North Africa), China, India, and Africa. The DBFZ (Deutsches Biomasseforschungszentrum, German Biomass Research Centre) was founded in Leipzig in 2008 and has developed into the central federal research institute for the material and energetic use of biomass. One thematic focus is on utilisation of biomass residues and wastes, which provides options for close collaboration with University of Rostock. Michael Nelles has been Head of Department of the Institute of

Waste and Resource Management since 2006, and since 2012, he also serves DBFZ as scientific director. Since 2018, he has been head of the working group ISWA Germany, which coordinates national ISWA activities, and, since 2022, also represents Germany as national ISWA member.

Against this background, this contribution describes the current and future role of material and energetic uses of biogenic residues and wastes. The aspects of climate and resource protection are discussed as well as energy supply, bio- and circular economy, and developments in Germany and in Europe, using the biogas sector as an example. The information is based on a number of current publications [1, 2, 3, 4, 5], which are recommended for additional input. This contribution is a short version of [11]. Climate and resource protection are our key, global challenges for the future. However, current results and trends do not look good, neither at national nor at international level. Since the 1970s, global consumption of resources (including energy) has exceeded the planet's capability to regenerate these resources. In 2022, the environmental footprint was 75% too high. This means 1.75 Earths would be required to regenerate the resources consumed. In Germany, the ratio is twice as high – which indicates that three Earths would be needed if everyone on the plant had our lifestyle. The USA are ranked last place, at 5.1 Earths. On the other hand, the two most populous nations look somewhat (China at 2.4 Earths) or significantly (India, at 0.8 Earths) better [10]. Germany will only reach its goal of climate neutrality by 2045 if we radically lower our consumption of both materials and energy. This will require both significant increases in efficiency and sacrifices in consumption. Moreover, energy supply needs to shift entirely to renewable energy carriers over the next few decades. This will require a tremendous increase in installations and optimised integration of all renewables: wind, solar, bio-, and geothermal energy and hydropower, as well as of all sectors, electricity, heating/cooling, and transport. Furthermore, our "linear" economic system must develop into a true circular economy. And last but not least, industry supply with organic raw materials must shift from petrochemical to bio-based resources.

Put simply this means we need to work along the following formula:

Climate-neutral society = renewable energies + circular economy

Over the past years, Germany has created a so-called "intergenerational contract for climate", which sets the background for several legislative changes and tightened climate protection targets. The latter currently stipulate that Germany lower its GHG emissions by at least 65% by 2030, and by 88% by 2040 (both compared to 1990 figures). From 2045, the Federal Republic must be climate-neutral, and from 2050 onwards, less greenhouse gases should be emitted than can be fixed by natural means.

How does this compare to the status quo? In 2022, both the share of renewable energies in primary energy consumption and the share of waste-based secondary resources used in production were well below 20%. "Energiewende" (energy turnaround) and "Rohstoffwende" ("raw material turnaround") stand at the end of a long road, while legislative targets are clear and time to achieve them is getting short. Thus, Germany is not the forerunner it likes to see itself as, but stands at global average. And this in turn indicates the enormous global task in front of all of us on the way to worldwide climate neutrality.

Using biogenic residues and wastes: contribution to climate and resource protection

Biomass is already is high demand today, for food, feed, materials and energy (see Fig. 2). It is, therefore, a valuable and limited resource, and global demand is set to increase over the next 30 years at least, as it is the cornerstone of the current and future bioeconomy, which also includes all material and energetic uses of bio-based residues and wastes. Energetic biomass usage will remain an integral part of a „future-proof" global energy system. However, this will require us to produce biomass in a sustainable way and use it in the most efficient and environmentally as well as economically beneficial way possible. New technological concepts for co-production and cascading uses are needed as well as for negative emissions, which can be generated by storing "green" carbon.

Optimising the material and energy usage of biogenic residues and wastes is therefore key to a sustainable bioeconomy.

Central national and international stakeholders have already taken up this challenge, e.g. DGAW, RETech, ISWA and IWWG. Especially ISWA WG Biological Treatment of Waste has made the topic a priority and contributes substantially to a sustainable use of bio-waste at global level. In Germany, the Federal Government aims to finalise its National Biomass Strategy (NABIS) by end of 2023. NABIS will also highlight the important role of material and energetic use of biogenic residues and wastes.

The technical potential of biogenic residues and wastes in Germany amounts to about 113 M tons of dry mass (DM). This comprises agricultural and forestry by-products, industrial and communal wastes and sewage sludges (DBFZ monitoring of biogenic residues, see Fig. 3). 74% of this potential is already being used as material or energy, but usage may not always be efficient or make sense from a systemic viewpoint. DBFZ assumes that, on the one hand, current value chains could be optimised and, on the other hand, an additional amount of about 29 M tons DM could still be mobilised, of which ~23 M tons DM would be suitable for fermentation, i.e. for biogas/bio-methane production. It must be noted here that, since figures are given in DM, the actual volumes are much higher. For instance, the 20 M tons DM of liquid and dry manure generated by animal husbandry in Germany per year equal about 138 M tons wet mass.

Bioenergy currently makes an important contribution to Germany's energy mix. In 2022, its share was 9.9% of total primary energy consumption. All other renewable energies (RE) together only made up 7.3%. Despite significant decreases in energy consumption in 2022, the share of renewables of final energy consumption only increased from 19.2 to 20.4%. Biomass is still the most important RE carrier in Germany and is in demand in all sectors, heating, transport and electricity [6]. In consequence, energetic biomass use saved about 74 M t CO2 eq – a large contribution to climate protection [6].

Biogas/Biomethane in Germany and Europe

By the end of 2022, about 8,700 biogas plants were running in Germany. 98% of these were agricultural plants with energy crops, e.g. corn, and residues such as liquid and solid animal manure as input substrates. 240 plants upgrade their biogas to biomethane. More than half of all plants are situated in the three federal states of Lower Saxony, Bavaria and Baden-Wuerttemberg. Since 2012, the number of newly installed plants has not been significant. Any expansions mostly increase the capacity of existing plants, motivated by the so-called flexibility premium. This instrument gives an incentive to provide additional electric capacity via new and/or more powerful CHP for flexible, demand-oriented electricity production, and to sell any electricity produced directly on the market. The few new installed plants are either small (≤ 75 kWel), liquid manure-based ones or ferment bio-waste (see Fig. 5 and 6).

By end of 2022, 148 plants for fermentation of bio-waste were in operation in Germany. These produce biogas from household bio-waste, garden and park waste, food leftovers, wastes from the food industry and other organic wastes (organic share ≥ 90 % of total mass). 123 of these plants produce electricity on-site, the others upgrade the biogas to biomethane. Since the introduction of dedicated incentives for the fermentation of municipal bio-wastes with the Renewable Energy Act of 2012, about 40 such plants started operating in Germany, 30 of which produce electricity on-site and 10 biomethane. Other new plants use food, industrial or similar organic waste. The average capacity of plants which stated operating from 2012 onwards is about 960 kWel. Roughly half of these plants act as upstream fermentative treatment prior to composting. By end of 2022, just under 60 such fermentation units with downstream composting were in operation. Looking at the energy balance, agricultural residues and biogenic wastes only made up about 23% (21 TWh) of input material for the 8,700 biogas plants, while 77% (70 TWh) are provided by energy crops, especially corn. DABFZ estimates that an additional 17.5 TWh could be mobilised from biogenic residues and wastes in the short to medium term, if suitable mobilisation strategies are implemented. Such are large, almost two-fold, increase would serves climate protection goals [7]. However, it must be emphasised that the contribution of residues and wastes to biogas/biomethane production must be increased significantly in order to guarantee their sustainable contribution to material and energy supply. In future, biomethane and products from the biogas process will also be in demand in different industries as a raw materials. Classic biogas plants will therefore develop into biorefineries, with multiple output products. A number of R&D projects in Germany are working on such processes, including at DBFZ and UFZ. With regard to electricity production, biogas plants should increasingly and quickly act as highly flexible power plants for peak demand. In this role, they have the highest systemic value for grid stabilisation. This is especially relevant in the current situation, as a flexible operation of existing biogas plants could replace up to 22% of fossil-gas based plants for demand peaks. By DBFZ estimates, suitable measures could increase this to 46% and thus provide a substantial contribution to security of supply [7]. Biomethane is also increasingly in demand as an advanced biofuel. Again, production should focus residues and wastes as raw materials for sustainability reasons. One example of the DBFZ's manifold R&D activities in this area is the BMDV-funded research and demonstration project „Pilot-SBG – bio-based resources and hydrogen to methane as fuel. Planning and realisation of a pilot plant". The "Pilot-SBG", short for "pilot plant synthesised biogas", will convert currently under-utilised residues and wastes (straw and liquid manure from agriculture plus urban green and bio-waste) to renewable methane as the main product. This methane could contribute to de-fossilise the transport sector. Construction of the pilot plant at the DBFZ will be complete by mid-2023. The individual modules will then serve as an R&D platform for industry and academia.

Compared to other European countries, Germany has put the highest number of biogas plants into operation over the past years and produces the most energy in the sector by far. However, developments in Europe are very dynamic, and other countries will close the gap over the next years, with fermentation of residues and wastes taking prime role everywhere. Moreover, countries such as Denmark, France and the Netherlands have ambitious aims regarding upgrading to biomethane.

Outlook

Summing up, the transformation into a climate-neutral society which is urgently required by mid-century can only be achieved if primarily the more developed countries radically reduce their consumption of materials and energy. This will require both efficiency increases and sacrifices in consumption.

Other necessary field of action are the shift to renewable energies in all sectors, the development of a true circular economy instead of linear waste management, and the shift of industrial supply of organic raw materials from fossil to bio-based resources. All of this is put simply in the formula “climate-neutral society = renewable energies + circular economy”. An optimised material and energetic usage of biogenic residues and wastes is key to such a sustainable, bio-based circular economy (bioeconomy) as well as to a 100% renewable energy system. If implemented successfully, this will contribute substantially to material and energy supply and thus to climate and resource protection. The residues and wastes that accrue globally have a high share of fermentable contents and could be converted very efficiently into methane, green CO2, and fertilisers from the digestate. Waste-based biogas plants will increasingly become biorefineries and as such serve the circular bioeconomy currently under development. The biogas sector is especially well developed in Germany and other European countries, but there is also a dynamic development in Asia (especially China and India), the Americas, Africa, and Australia. ISWA experts are in demand to accompany this development, and DBFZ and University of Rostock are looking forward to cooperating on this.

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Sustainable Treatment and Utilization of MSWI Fly Ash

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Municipal solid waste (MSW) encompasses a significant fraction of food waste, paper, plastic, wood, textile, etc., and the global yield of MSW is constantly increasing with rapid urbanisation and improvement of people's living standards. Incineration is one of the mainstream MSW treatment approaches, which could utilise renewable energy from waste. However, municipal solid waste incineration (MSWI) fly ash is inevitably generated and the MSWI fly ash is classified as hazardous waste in many countries due to its high contents of heavy metals and other contaminants (dioxins, furans, sulphate, chloride and acids, etc.). To maximize environmental, social, and economic benefits, the development of low-carbon and sustainable stabilization/solidification (S/S) technologies for MSWI fly ash has attracted extensive interest in recent years. In this work, the latest understanding of S/S mechanisms was elaborated for guiding the design of S/S binder. Various cementitious materials, such as ordinary Portland cement (OPC), calcium aluminate cement (CAC), and magnesium oxysulfate cement (MOSC) were designed for low-carbon S/S of MSWI fly ash. Results showed that single use of OPC showed low compatibility with MSWI fly ash, however green materials incorporated binder could effective immobilization of toxic elements. Besides, CAC had an excellent immobilization efficiency of toxic elements in MSWI fly ash and the incorporation of phosphates enhanced the S/S performance of CAC-treated samples. Moreover, MOSC could generate favorable reaction products (e.g., 5-1-7 phase) for S/S of toxic elements in MSWI fly ash. Pb^{2+} in MSWI fly ash coordinated with SO_4^{2-} and substituted Mg^{2+} ions in the 5-1-7 phase internal structure, whereas AsO_3^{3-} replaced SO_4^{2-} in the large interlayer spaces of 5-1-7 phase. Therefore, MOSC is low-carbon and high-efficiency cementitious materials for the S/S of MSWI fly ash containing both metallic and metalloid elements. Moreover, catalytic pyrolysis combined with mechanochemical treatment has been established to remove the dioxins and heavy metals in MSWI fly ash for subsequent resource utilization. Results showed that removal efficiency higher than 97% for dioxins was achieved by pyrolysing at temperature 350℃ for 10 mins. The fingerprint of the dioxins indicated that dechlorination dominates dioxin degradation in the pyrolysis process. Besides, water washing can effectively reduce chloride content in MSWI fly ash and lower the pyrolysis temperature to even 250℃. Toxic equivalent quantity (TEQ) concentrations of dioxins in pyrolyzed fly ash were lower than the European end-of-waste criteria (20 ng TEQ/kg) and met Chinese resource utilization standards. The mechanochemical (MC) treatment as a green method shows excellent stabilization of heavy metals and improved the reactivity of fly ash for resource utilization. The MC treatment with NaH_2PO_4 as an additive showed a significant inhibitory effect on heavy metals, the leaching concentration of Cd, Cr, Cu, Ni, Pb, and Zn. In addition, the modified fly ash by MC treatment can be used as supplementary cementitious material due to the enhanced pozzolanic effect. Therefore, catalytic pyrolysis combined with mechanochemical treatment can effectively remove the dioxins and stabilize the heavy metals, delivering a promising method for green fly ash disposal. Furthermore, a novel technology of converting MSWI fly ash into insulation material through oxygen-enriched melting is developed. By combining MSWI fly ash melting process and the insulation material production process, a new insulation material is produced from MSWI fly ash. Results show that the dioxin is reduced by 98.3% after melting, whereas heavy metals are successfully immobilized. The utilization of oxygen-enriched melting saved fossil fuel consumption during the melting process and reduced the flue gas emission and energy loss. The production of insulation material with the addition of MSWI fly ash not only saves the consumption of ore resources but also generated extra economic benefits, which can be an effective and sustainable approach for the utilization of MSWI fly ash.

Keywords: MSWI fly ash, Hazardous waste treatment, Stabilization/ solidification, Oxygen-enriched melting, Sustainable construction materials

Microplastics and Nanoplastics Pollution and Their Sustainable Management

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The countries around the world are suffering with the ubiquitous influence of plastics. From polar regions to deep oceans, aquatic ecosystems and terrestrial areas, plastic proliferation is everywhere. They remain in the environment for a very long time and their surfaces gets weathered resulting in numerous micro- and nanosized plastics. Due to their small size, these microplastics and nanoplastics have the potential to be ingested by the biota thus, entering into the food webs and causing adverse biological effects. In addition, they can travel globally and have the potential to accumulate and interact with toxic pollutants existing in environment.

The pollution and health hazards caused by the microplastics (MPs) and nanoplastics (NPs) in the environment (freshwater, marine water and terrestrial ecosystems) have become serious concerns globally. The microplastics have been detected around the globe and have impacted seriously to biota and humans. In order to understand the possible risks, provide recommendations for future studies and develop technologies to eliminate the micro/nanoplastics, it is important to understand their sources, distribution and occurrence, interactions with other contaminants, interactions with biota and their sampling and detection methods. The term ‘microplastic’ was introduced in 2000; while initial studies focused on marine sources, the focus during 2010-2015 shifted on the estimation of MPs from freshwater and soil, impacts on environment, adsorption of co-pollutants, bioplastics as potential alternate and during 2015-2020, it has on the estimation of MPs from air, snow, ecotoxicity, impacts on health, fate and migration, policy development. The current trend is on atmospheric transport and impacts on air, micro-nano-plastics (MNPs), economy, feasible solutions. This lecture will discuss the recent advancements and research in the field of micro-/nano-sized plastics and future research perspectives to tackle the plastic pollution.

Enhanced Landfill Mining – Technologies, Products and Costs

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The mining of landfills (LFM) is, or has been operated for different reasons, like the reduction of environmental impacts or an alternative, higher-value use of landfill areas. Most of the projects carried out in the past have focused on groundwater protection and land reclamation for infrastructure measures. These measures were generally based on the relocation resp. repositioning of the landfilled waste. In the more recent past, landfill mining projects have increasingly been implemented with the aim of gaining landfill volume. The volume generation is not only achieved by more efficient installation methods, but in particular by measures for recycling and energy recovery. Because of the fact that a shortage of resources is to be expected in the future as well as an increase in prices, the aspect of mining of recyclable fractions from landfills is becoming more and more into consideration. The feasibility of landfill mining, especially the economic viability, is subject of many discussions. The paper will show the potential – quality and quantity - of resources in landfills and evaluate the contribution of these secondary raw materials to energy and material supply. In addition, details about suitable technologies for deconstruction, processing and confectioning of the deconstructed waste from landfills are given. Of great importance for landfill mining are information about achievable product qualities, as a basis for the marketing of the secondary raw materials that have been extracted.

The experiences from LFM show that (as a worldwide average) more than 60 % of the deposited waste consists of minerals, which usually are not reused, because of the often highly contaminated finer soil parts. On the other hand, the demand for building materials, especially in Asia, is currently high and will continue to be so in the future The recycling of parts of the mineral-rich fine fraction (< 60 mm) and the production of alternative fuels (RDF) are a key focus in this context.

Valorization of Wastes to Bioplastics: Challenges and Opportunities

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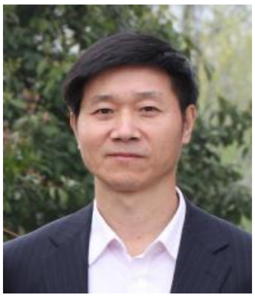
The hazardous effects of synthetic plastics can be prevented by using biopolymers which are biodegradable, environment-friendly and naturally produced by microbes. Among them, polyhydroxyalkanoates (PHAs) have achieved a greater attention due to their biodegradable nature and properties similar to petro-plastics. PHAs can be produced by a variety of micro-organisms and get accumulated as carbon and energy reserves under nutrient imbalance. They have applications in biomedical implants, tissue engineering, drug and nutritional supplements, packaging materials, agriculture, and biofuels industry. Despite their numerous benefits, the large-scale production of PHA is restricted due to its high production cost. The high PHA cost is due to the high raw material cost, low PHA yield, low PHA productivity and high recovery cost. Wastes and industrial by-products (waste lipids, crude glycerol, wastewater, sewage sludge and agro-food wastes) have been investigated to lower the production cost.

However, the heterogenous nature and presence of impurities in the waste substrates may result in low biomass and product yield. Low utilization of wastes by the microbial strains can be overcome by developing pre-treatment strategies for waste feedstocks, optimizing growth and operational parameters, supplementing nutrients and using efficient and robust microbial strains. The PHA produced using wastes may also contain several impurities that can impede their applications, therefore, stringent and efficient downstream processing is required. Designing the downstream processing depends on several factors like feedstock type, biomass concentration, biomass PHA content, type and properties required.

The combination of utilization of inexpensive carbon substrates and recovery of useful co-products is a significant step to make the process cost-effective and sustainable. Integrative approaches to valorize industrial waste streams to PHA and recover value-added co-products such as microbial proteins, extracellular polymeric substance (EPS) and lipase synthesized along PHA will be discussed. After fermentative PHA production and downstream processing, various liquid streams (such as waste stream generated after treatment of PHA-rich biomass and wash waters) are released which are generally discarded. Various recycling strategies were developed for these streams to be recycled in the subsequent PHA production process. The opportunities of recovering high value-added co-products during PHA production as well as minimizing the ecological risks by recycling precarious waste streams generated during the process in more than one fashion to maintain circular bioeconomy will be presented. Therefore, the various technical, biological and economical challenges along with the future perspectives for sustainable valorization of wastes to PHA will be discussed. Furthermore, the key insights on pre-treatment techniques, process optimization, technological approaches, recovering value-added co-products and recycling of waste streams generated in the process will be presented. The integration of pilot-scale biorefineries with PHA production technologies which is required for sustainable production of bioenergy, biofuels and biochemicals will also be discussed.

Keywords: Polyhydroxyalkanoates, Biopolymers, Bioprocess, Downstream processing, Waste streams, Co-products.

Pristine and Modified Biochars Derived from Urban Green Waste for Remediation of Contaminated Environments



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With continuous improvement of the urban environment, urban green wastes have increasingly become a management challenge faced by many municipal governments. On the other hand, woody green wastes have the potential to be converted to biochar with pyrolysis technology. Pristine and engineered biochars have been proven to be effective materials for the remediation of environments contaminated with a wide spectrum of (in)organic pollutants. In this presentation, we will report recent research progress in our laboratory on using green waste-derived biochar materials for decontamination of polluted water and soils. Our research focused on using designed-biochar materials for environmental remediation associated with typical contaminants, e.g., enhanced sorption of trivalent antimony by chitosan-loaded biochar in aqueous solutions: characterization, performance and mechanisms; the adsorption mechanisms of oriental plane tree biochar toward bisphenol S: a combined thermodynamic evidence, spectroscopic analysis and theoretical calculations; biochars improved nutrient bioavailability, enzyme activity, and plant growth in metal-phthalic acid ester co-contaminated soils: a trial for reclamation and improvement of degraded soils; iron-modified biochar and water management regime-induced changes in plant growth, enzyme activities, and phytoavailability of arsenic, cadmium and lead in a paddy soil; elucidating the redox-driven dynamic interactions between arsenic and iron-impregnated biochar in a paddy soil using geochemical and spectroscopic techniques; effect of biochar aging and co-existence of diethyl phthalate on the mono-sorption of cadmium and zinc to biochar-treated soils; and pristine and iron-engineered biochars enhanced bacterial abundance and immobilized arsenic and lead in a contaminated soil.

Keywords: Engineered biochar, Biowaste, Adsorption, Soil remediation, Wastewater treatment.

Influences of Waste Segregation Policy on the Climate Change Impact of Waste Management Systems

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The implementation of waste segregation in China has impacted the waste management systems, both in urban and rural areas. However, whether the change is positive or negative is still inexplicit. In this study, influences of waste segregation on the climate change impact of waste management systems in both urban and rural areas were quantified using life cycle assessment method based on field investigations and literatures. In the urban cases, two scenarios representing the waste management systems before and after the implementation of waste classification in Shanghai were set up. And in the rural case, two scenarios with either a landfill site or a waste-to-energy (WTE) incineration plant to treat all mixed waste were built to represent the most common situation before the implementation of wastesegregation in rural areas. Besides, two scenarios in which waste segregation is implemented and waste are divided to organic fraction and residual fraction were established. The organic fraction was treated by composting and anaerobic digestion (AD), and the residual fraction is disposed in either a landfill site or a WTE incineration plant. Sensitivity analysis was also performed. The results showed that for treating 1000 kg waste, 208 kg CO_2-eq GHG was emitted in average before waste segregation and 40.4 kg CO_2-eq GHG in average after that in urban areas. It was indicated that waste segregation helps mitigate the climate change impact of waste management systems in urban areas. The largest contributor was the avoidance of directly landfilling waste because waste segregation separated organic fractions for AD and the capacity of WTE plants became enough for residual fraction. In rural areas, the average values of climate change impact of landfilling and incinerating 1000 kg mixed waste were 226 kg CO_2-eq and -32.4 kg CO_2-eq, respectively. Those of landfilling and incinerating residual waste from 1000 kg mixed waste were 119 kg CO_2-eq and 18.0 kg CO_2-eq, respectively. It was indicated that after waste segregation and organic fraction separated from mixed waste stream, the climate change impacts of scenarios with a landfill site decreased and those of scenarios with a WTE plant increased. The common conclusions for both urban and rural areas are that avoiding direct landfill of organic fraction can decrease the climate change impact of waste management systems and that the climate change impact of incinerating residual fraction is higher than that of incinerating mixed waste when all conditions are the same. Based on this study, it can be concluded that waste segregation helps mitigate the climate change impact of waste management systems and that improving the energy recovery in WTE plants in China simultaneously will further decrease the impact.

Keywords: Climate change impact, Waste management, Rural, Urban, Landfill, Waste-to-energy.

Sustainable Biowaste Management: Opportunities and Challenges in Circular Economy

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ABSTRACT. Unscientific disposal of biowaste is a major cause of environmental pollution including greenhouse gas (GHG) emissions, water, soil and air pollution. Besides, biowaste is a resourceful material with abundance of nutrients and metal elements. Hence, converting biowaste into value added products can address both its disposal and resource recovery which can reduce the dependence on depleting natural resources. Through biorefinery approaches, biowaste can be recycled into bioenergy (biofuels, biogas, biohydrogen etc), bioproducts (organic acid, biopolymers, biopesticide, biofertilizer etc). Besides biorefinery approaches, biowaste can also be converted into value added products through chemical conversion technologies such as catalysis. Although these biorefinery and chemical conversion technologies are well established, further research is required to optimize the process conditions and pretreatments. Further, many countries have developed framework/regulations to progress the biowaste management through circular economy approach.

Keywords: Biowaste, Organic resource, Circular Bioeconomy, Bioenergy and bio-products

Introduction

Solid waste is one of the main sources of greenhouse gas (GHG) emissions in the present world (Behrooznia et al., 2020). The increasing population has resulted in the solid waste generation in large quantities. Furthermore, the increasing demand for global food has increased the agricultural activities resulting in the production of agricultural residues. Currently, annual generation of ~100 billion m metric tons of biowaste is estimated globally (Cho et al., 2020). Food waste is a major contributor of environmental pollution accounting for nearly 50% of global MSW. It is estimated that the current global food waste generation is 931 million tons/year in which 61% comes from households, 26% from food services and 13% from retail sector (Figure 1) (UNEP, 2021).

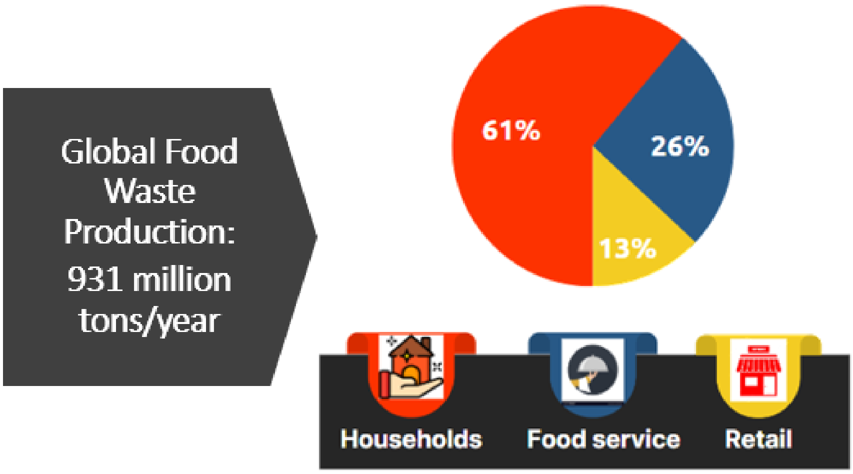

Fig. 1. Global food waste production

The global food waste causes several environmental and economical consequences such as ~8-10% of global greenhouse gas (GHG) emissions and wastage of 25% of the world's freshwater. The direct economic consequences of food waste estimated by UN is ~1 trillion USD, hence, the smart waste management market is projected to be worth ~6.5 billion USD by 2026. The carbon footprint of food waste is estimated to be 3.3

billion tons of CO2 equivalents released into the atmosphere a year. Apart from the food waste, other biowaste such as agricultural residues, animal manure, sewage sludge, anaerobic digestate, etc can also produce in large quantities and create negative impact on the environment, hence their treatment is also necessary (Table 1). The unscientific disposal of biowaste consumes valuable land along with polluting water, soil and air. Hence, proper management of biowaste is necessary (Shah et al., 2022). Considering the depleting natural resources, biowaste can be used as a potential resource due to the presence of intact energy, carbon, nutrients, vitamins, minerals, and metals that need to be recycled back into our fossil-based economy (Guo et al., 2022).

Table 1. Generation of different types of biowaste (Adapted from Khan et al., 2022)

Type of waste	Waste generation	Reference
Food waste	931 million tons/year	UNEP, 2021
Agricultural waste	2 billion tons/year	Duque-Acevedo et al., 2020
Animal manure	120 million tons/year	Loyon, 2018
Sewage sludge	16.4 million tons/year	Mohajerani et al., 2019
Anaerobic digestate	180 million tons/year	Bartocci et al., 2020

Hence, it is the need of the hour to develop the efficient and innovative technologies to convert food waste biologically and chemically into energy and value-added products such as biofertilizers and industrial biochemicals such as pigments, bioplastics, etc. Currently, energy from biomass is the leading renewable energy source accounting for 55% of renewable energy and over 6% of global energy supply. However, significant technological efforts are needed to accelerate modern energy production from biowaste. Further, the global biofertilizers market is estimated to grow significantly due to the physical barrier against pests, pathogens, increasing demand for organic food and rising prices of chemical fertilizer. Besides, bioproducts from biowaste such as biosurfactants, biopolymers etc. has attained increased attention to replace the fossil-based sources demanding for the development of novel and integrated approaches. Apart from biological approaches, chemical conversion technologies are progressing in the past decade for valorisation of biowaste into hydrogen and other value-added products such as precursors of biopolymers, bio-insecticides, medicines etc. To achieve this, development of commercially viable conversion technologies with efficient catalysts are needed to comply with the principles of green chemistry. Overall, the sustainable biowaste management provides several benefits such as mitigation of GHG emissions, improvement of soil quality, reduced waste disposal cost, alternative for fossil-based sources and job creations. However, the efficient management of biowaste should consider the suitable technological approaches based on the availability of resources, local economy and need to cater for the increasing circular economy.

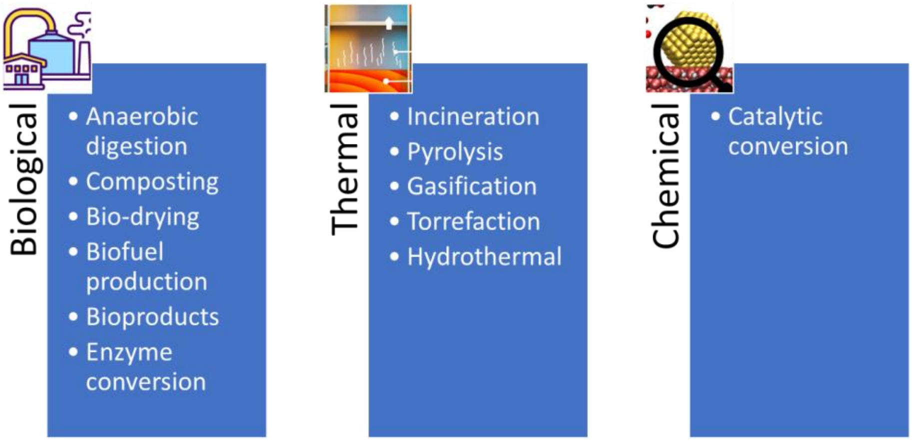

Fig. 2. Biowaste treatment technologies

Circular economy

Conversion of biowaste into bioenergy and bioproducts through biorefinery approaches are increasing due to the adoption of circular economy (CE) regulations/framework (Ranjbari et al., 2022a). The concept of CE is a globally accepted which is providing a platform to explore advanced technologies to utilize the biowaste as a resource to produce value added products, at the same time treating the biowaste to mitigate the burden on the environment. In many countries CE policies have promoted to utilize local resources to achieve net zero emissions and to create job opportunities along with economical benefits.

Table 2. Circular economy framework/regulations in different countries

Country	Regulation
China	Circular economy promotion law and five-year plans, CE model base, CE taskforce
Japan	CE model base, home recycling base
South Korea	Act on the promotion of saving and recycling of resources, CE model base
Vietnam	3R policies
Laos	National CE policy
India	Strategy paper on resource efficiency
Rwanda	CE model with WEF
South Africa	EU dialogue on CE
UK	CE taskforce
Europe	Ellen MacArthur Foundation’s Project MainStream, CE action plan
Turkey	EBRD initiative
Morocco	White paper on CE
Uruguay	Foro de Economia Circular
Brussels	Be.brussels
Scotland	CE investment fund
Wales	CE fund
Vancouver	2020 goal
US	US BCSD work
Cuba	CE activities
Columbia	EU trade mission

Biowaste conversion to bioenergy significantly reduces waste volume along with addressing the depletion of natural resources, energy security, etc. (Soltanian et al., 2022). The energy from the biowaste can be divided into gas and liquid energy. The gaseous energy includes biogas and biohydrogen which can be produced through different biotechnological approaches. The liquid energy from biowaste includes biofuels, biodiesel, and butanol. Apart from bioenergy, biowaste can also converted into several high valued products such as organic acids (including lactic acid, volatile fatty acids), biopolymers (polylactic acid (PLA), polyhydroxyalkaloate (PHA)), proteins (single cell protein), biopesticide, bioflocculant and biofertilizers (Manu et al., 2021; Xu et al., 2022).

Future challenges and perspectives

The integration of biorefinery approaches can significantly yield higher conversion rates through circular economy approach (Xiong et al., 2019). The challenges associated with the biowaste management includes financial implications as the current approaches are still not cost effective. Further, technical obstacles to utilize the maximum biowaste is a concern to develop circular economy. Besides, government policies and social acceptance could play a major role in adopting these technologies and their product which results in the sustainable biowaste management.

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Total Recycling of Concrete Waste Using Accelerated Carbonation

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The world is facing critical environmental challenges due to climate change which is believed to be related to CO_2 emissions. Also, accelerated urbanisation and redevelopment generate huge amounts of concrete waste. Carbonation of waste concrete can utilise concrete as a carbon sink due to the rapid chemical reaction between CO_2 and the hydration products of cement. This presentation will focus on applying carbonation technologies to achieve the total recycling of concrete waste. Different approaches and technologies to carbonate the recycled coarse aggregates (RCAs), recycled concrete fines (RCFs) and recycled concrete powders (RCPs), depending on their particle sizes, will be introduced. The research results at the Hong Kong Polytechnic University show that carbonation of waste concrete with different particle sizes can generate carbonated coarse aggregate, carbonated fine aggregate, and high-value products, including novel supplementary cementitious materials, nano-silica gel, micro-fibre, etc., achieving the total recycling of concrete waste.

International Conference on
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Waste Management in Circular Economy
and Climate Resilience

Plenary Lectures

Pretreatments of Organic Substrates and Their Indigenous Bacteria for Dark Fermentation

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Anaerobic digestion is particularly attractive for renewable energy production and biogas sector is currently facing strong development for agricultural, municipal and industrial waste valorisation. However, intermediates products such as biohydrogen and volatile fatty acids, that can be obtained by dark fermentation, present higher economic value than biomethane. Inoculum of dark fermentation is usually thermally pretreated to inactivate methanogens and on the other hand, substrate pretreatments such as thermal-acid or sonication can be used to promote sugar solubilisation. The objective of this study was to analyse the impacts of pretreatments of substrates and their indigenous bacteria on further dark fermentation performance and bacterial communities. The impact of thermal pretreatment (90°C for 15 min, usually applied to inoculum) was studied on 7 substrates (dates, corn silage, sorghum, microalgae, sewage sludge, organic fraction of municipal solid waste (OFMSW) and food waste). Biochemical hydrogen potential tests (BHP) were carried out in different conditions: 1) untreated substrate without inoculum, 2) pretreated substrate without inoculum, 3) with inoculum and without pretreatment, and 4) substrate and inoculum were pretreated simultaneously. Except for protein-rich substrates (sewage sludge and microalgae), hydrogen yields, total metabolite production and metabolic pathways were similar for indigenous bacteria (both thermally pretreated and non-pretreated) and pretreated inoculum. In order to have further insights on the role of substrate indigenous bacteria, they were inactivated by gamma irradiation of sorghum and OFMSW samples. In comparison to non-irradiated substrates, irradiated samples led to equal or lower hydrogen yield, different metabolite pathways, final microbial consortia and higher variability among quadruplicates. Finally, thermal-acid (90°C- 30 min, 10% TS with [HCl]=11.0 mmol/gVS or [H_2SO_4]= 22.8 mmol/gVS) and ultrasound (59.4 kJ/gTS) pretreatments were carried on OFMSW. Both pretreatments were inefficient to improve H_2 yield although significant increase in soluble sugars. Nevertheless, pretreatments induced metabolic changes from acetate toward butyrate or ethanol, correlated to a decrease in *Enterobacter cloacae* and an enrichment in *Clostridium sp*. When indigenous bacteria were de-activated, metabolite and bacterial compositions were identical with or without acid pretreatment. In conclusion, the present results show the importance of substrate endogenous bacteria for dark fermentation process. Their thermal-acid or sonication pretreatments led to some changes in the distribution of metabolites and bacteria at the end of fermentation and to the increase of the variability of batch fermentation results. For some feedstocks, cost effective fermentation can be carried out without inoculation nor pretreatment.

Keywords: Biohydrogen, Volatile fatty acids, Organic fraction of municipal solid waste, Thermal, acid, ultrasound pretreatment, fermentation.

Composting Microbes: Past, Present and Future

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Composting is a biological and natural process that driving by microbes, and then degrading organic wastes into mature compost to become stable and valuable. The whole composting process could separate into three periods following different temperatures, mesophilic, thermophilic and cooling phases, at the same time, the dominant microbes were also distinct during these periods. With the development of analyzing technologies, studies on composting microbes had already gone through three stages: traditional microbial culture, molecular biology and integrated meta-omics. The methods of the traditional phase were using microbial isolation, cultivation, and microscopic counting to study the changes of CFUs in bacteria, fungi, and actinomycetes, while the steps of these methods were so complicated and had huge workloads. Molecular biology technologies, for instance, denatured gradient gel electrophoresis (DGGE), phospholipid fatty acid (PLFA), terminal restriction fragment length polymorphism (T-RFLP) and high throughput sequencing, could reveal the dynamics of microbial communities during the composting process, no matter whether the microbes alive or not. The review found that Firmicutes, Proteobacteria, Actinobacteria and Bacteroidetes were the dominant phyla during the composting process, and the priority of phylum in different kinds of manures was distinct. For example, Proteobacteria was prevalent in sheep and cow manure, while Firmicutes was dominant in swine and chicken manure. For fungi, the highest relative abundance of phylum was Ascomycota in all kinds of livestock manures. However, the other disadvantages of these technologies were poorer repeatability and lower sequencing accuracy. Integrated meta-omics, based on bioinformatics could deeply attain so much information about microbial composition, gene function, metabolic pathways and key substances during the composting process, and then estimate the biological mechanism of functional microbial succession. Using PICRUSt and FUNGuild based on metagenomics analysis could found that the cellulase activity generally increased first and then decreases, while the protease activity gradually decreases, and the dehydrogenase activity was related to the microbial activity. Firmicutes was preferring to live in a low C/N environment, Bacillus was the most active genus, and Actinobacteria was prevalent in a higher C/N environment. For composting microbes, the advanced research was focused on two aspects, the mechanism of indigenous or inoculating microbes. A lot of research was implying that additives were highly useful and likely to maintain the thermophilic phase, shorten fermentation time, accelerate the degradation of organic wastes, enhancing nutrient content. In this review, we aimed at introducing the history of microbes in composting, and the development of inoculants, and then provide technical support in order to push functional composting by adding inoculants and prompting indigenous microbes.

Keywords: Compost, Microbes, Inoculant, Traditional microbial culture, Molecular biology, Integrated meta-omics.

Moving Plastic Waste Management from Liner to Circular Economy: Role of Dumpsite Plastic Mining

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ABSTRACT. Most developing countries commonly dispose solid wastes in open dumps and landfills. Plastic wastes in these dumpsites pose several health hazards as it takes longer time to biodegrade. Dumpsite mining projects are being carried out to separate these plastic wastes for co-fuelling and waste to energy applications. This study aimed to analyse the composition of municipal solid waste (MSW) in a dumpsite in Thailand and carry out in-depth classification of plastic waste dumped between 2012-2020. The excavated plastic wastes were classified according to the resin codes. The brand analysis carried out to understand different types of branded and unbranded plastic waste products and facilitate responsible dumpsite mining practices. The analysis highlights that unbranded single-layer packaging namely Low-density polyethylene (LDPE) of various sizes dominate the overall composition of plastic wastes. This study concluded that stringent implementation of EPR policies, promotion of dumpsite mining and reducing the consumption of unbranded plastics crucial for circularity of plastic wastes in Thailand.

Keywords: Dumpsite mining, Refuse Derived Fuel (RDF), Open dumpsite, Plastic wastes

Introduction

Globally, nearly 33% of solid waste is still openly dumped among the low-income countries and 40% waste goes to landfills. With the increase of global waste generation projected at 2.59 billion tonnes in 2030 and 3.4 billion tonnes in 2050, the open dumpsites will be stretched beyond their capacities if the circumstances are business as usual [1]. There are a few practical options that are considered by the policymakers, local government, and engineers to rehabilitate the dumpsites and to reduce the environmental burden associated with it. Among these, Dumpsite mining is commonly practiced in the developing countries like Thailand, India, Sri Lanka, Vietnam, Indonesia because of its advantages in Waste to Energy recovery options [2]. The state-of-the-art heavy and stationary/mobile machineries are used to excavate wastes and segregate the waste components. A large quantity of incinerable materials such as Refuse Derived Fuel (RDF) consisting of plastics, clothes, leather and other incinerable fractions, recyclables are usually separated using material segregating equipment [3]. The recovered materials are scientifically tested and utilized in compliance with national/local regulations. This environmental pollution remediation method can provide wider environmental advantages in addition to the local societal benefits. The aim of this study is to carry out in-depth plastic waste classification from excavated MSW in an open dumpsite and classify the brands which caused the plastic pollution.

Material and Methods

Open dump at Klong Sam, Pathum Thani province of Thailand was taken for the study. At four selected sampling locations within the dumpsite area, backhoe excavators were used, and wastes were excavated at different intervals of depth (0-1m, 1m-2m, 2m-3m, and 3-4m). This is in line with the method followed by studies that carry out old and fresh MSW classification [4]. In this study, solid waste samples were collected separately by excavation. Approximately, 100-150 kg of MSW samples were collected at each depth interval. At different depths, the collected solid waste samples were be coned and quartered to find the different type of wastes. For plastics in particular, different types of plastic products were visually identified and classified according to the Resin codes such as Polyethylene, Polyvinyl chloride, etc. and types of packaging materials (Single layer and multi-layer packaging).   It is difficult to find the timescale during which MSW were dumped. It was carried out using a proxy i.e., the expiry dates mentioned in the products. For example, the Fast-Moving Consumer Goods (FMCG) products are consumed and discarded within the same time period. Hence, it is logical to correlate the timescale of MSW dumping using the expiry dates of the FMCG products.

A portable siever was used for a separation of plastics according to the sieve size of 200 mm,150 mm, 75 mm, 50 mm, 25 mm. At each of the sieve size, the plastic samples were collected and packed in a separate polythene sheet and labelled for identification of brands. Dumpsite mining operations were carried out on the dumpsite. Trommel and plastic shredders were used to remove the RDF from soil and other non-combustible particles.

Results and Discussion

MSW Classification

MSW classification was made based on the composition of wastes obtained during sampling. The major waste composition at Klong Sam dumpsite was wet organic wastes consisting of non-combustible waste mixed with soil fractions followed by plastic wastes. However, change in trend was observed between 2012 and 2013 where major waste composition is plastic followed by organic waste. This is due to degradation process at the dumpsite due to the influence from heat, rain, internal biological process, and chemical oxidation of organic waste material. In addition to this, multitude of factors might have resulted in organic waste decomposition while plastic composition remains relatively the same. It might also be due to level of compaction, type of dumping practices and waste management practices. This is in line with the compositional studies that deal with the old MSW dumped in open dumps [4].

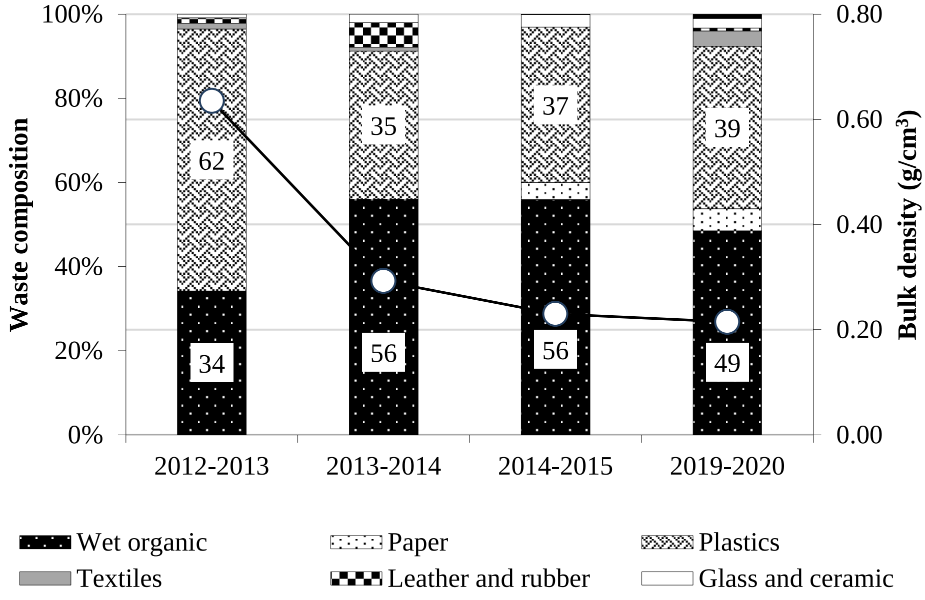

Figure 1: Waste composition of the excavated waste from Klong Sam dumpsite

Plastic classification based on the resin codes

Plastics is mainly categorized into thermosetting plastic and thermoplastics. Thermoplastic are classified into PET, HDPE, PVC, LDPE, PP, PS, and other. A combination of more than 1 layer of plastic to improve the quality of packaging has often been carried out resulting in multilayer plastic packaging. **Figure 2** shows the change in type of plastic consumption in different years. The plastic type variation was the highest between 2019 and 2020 followed by 2012 and 2013, and 2013 and 2015 respectively. The majority type of the excavated waste was LDPE followed by HDPE, PP, PS, multilayer, PET, and PVC as shown in **Figure 2.** LDPE generated between 2019 and 2020 had decreased by half when compared with the average consumption between 2012 and 2015 as Thai government imposed the restriction on banning plastic bag with the target of achieving 30% reusing [5]. **Figure 2** shows that LDPE has decreased from 86% i.e., the average between 2012 and 2015 to 43% in the period of 2019 and 2020 which accounted for 50% reduction. The reduction in the quantity of LDPE might be an indicated the success of the policy in banning plastic in Pathum Thani province. However, Thailand has not substituted multilayer, HDPE, and PP to other type of plastic as multilayer plastic ensures hygienic quality to food products while PP and HDPE observed at the dumpsite were straws and garbage bags which possess the irreplaceable features such as the strength to withstand high temperature and heavy load [6].

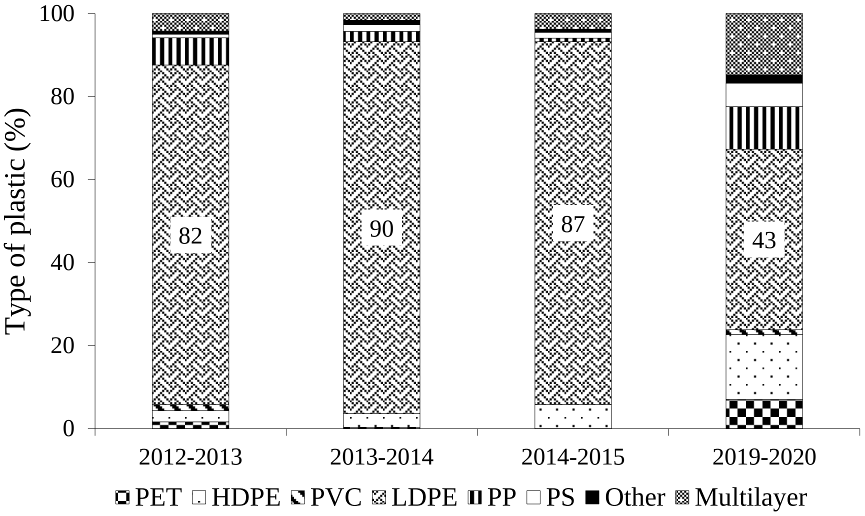

Figure 2: Type of plastics (% Count)

Type of Plastic Brand

The plastic composition at Klong Sam dumpsite between 2012 and 2013, 2013 and 2014, 2014 and 2015, and 2019 and 2020 were 62%, 35%, 37%, and 39% respectively. Brand auditing was carried out to categorize the plastic products into multinational company (MCNs), large size company, medium size company, local company, and unidentified brand as shown in **Figure 3**. **Figure 3** shows the majority of the plastic excavated were unknown brand as it is plastic bag with no label. The branded products accounted for 6%, 4%, 5%, and 17% between 2012 and 2013, 2013 and 2014, 2014 and 2015, and 2019 and 2020 respectively. The increase in the use of branded product observed was significant as it increased by 3 times between the two periods i.e., between 2012 and 2015, and 2019 and 2020. One of the major reasons might be due to increase in the use of branded products for hygiene and food packaging during COVID-19. Based on the brand auditing, the top brand polluters were mainly food product such as Pamira, Ajinomoto, CP, Wall's, Nescafé, coffee-mate, MAMA, Tao Kae Noi, and Mitrphol. The majority of these products were multinational company (MNC) and large size company as it could be commonly found in all the grocery store, 7-eleven, and department stores.

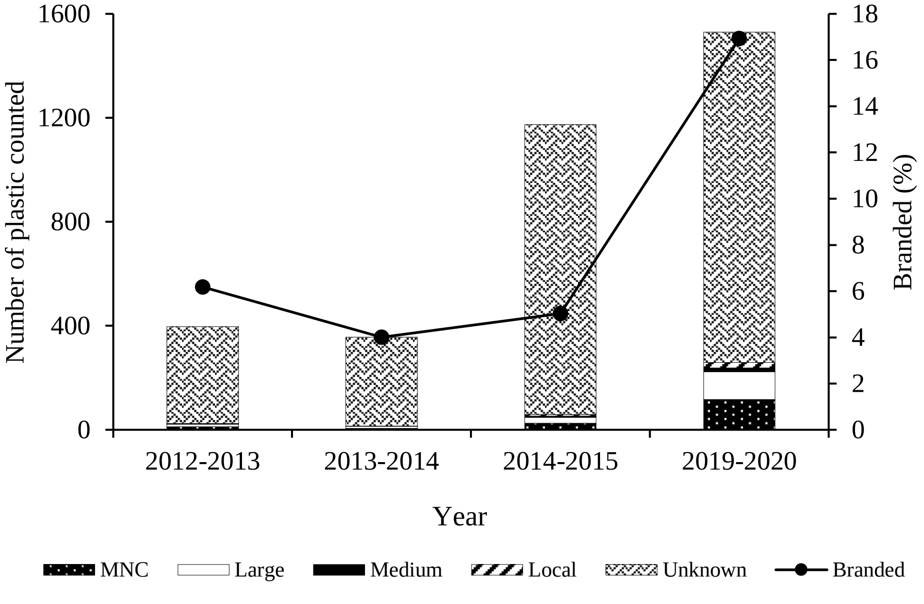

Figure 3: Type of plastic brand (%)

The Dumpsite mining operations carried out at the dumpsite separated the plastic components from the non-combustible products and plastic shredder aided in reduction of size of plastic products. The size-reduced plastic products are baled and packed for co-fueling applications in cement kilns. This ensures reduction of Greenhouse gas emissions (GHG) and elimination of plastic issues in open dumps in developing countries.

Conclusion

Plastic waste composition formed the major component as the wet organic fraction decomposes over time. In our study, we observed that the plastic composition of waste decreased by 37% when comparing the plastic portion in 2012 with the plastic portion in 2020 while organic waste increased by 44%. This is due to the fact that the heavy wet organic fraction degrades quickly, and the plastic fraction takes longer time to biodegrade. The majority type of the excavated waste was LDPE followed by HDPE, PP, PS, multilayer, PET, and PVC. Unbranded LDPE plastic packaging constituted majority of plastic products. In branded plastic products, the top 3 brand plastic polluters observed from the excavated waste at Klong Sam dumpsite were MNCs and large size company. Major type of plastic used for product packaging was multilayer plastic with size of 150 mm. This is contrary to the normative belief that MNCs are the major plastic polluters. The limitation of the study was that it was not practically feasible to separate the plastic waste fractions and conduct waste composition, plastic composition and brand auditing between 2016-2018. We recommend further studies could combine the waste analysis and capturing public attitudes and practices to reflect the consumption behaviour in the past years. Overall, this study highlighted the role of stringent implementation of EPR policies, promotion of dumpsite mining and reducing the consumption of unbranded plastics could be crucial in long-term circularity of plastic wastes in Thailand.

Acknowledgement

We acknowledge and appreciate Mr. Boonchai Pongnaravan, Miss Piyachat Chaiaroon and Mr. Sukit Bejrsuwana for coordinating and assisting in carrying out sampling at Klong Sam dumpsite.

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Gasification of Municipal Solid Waste as a Disposal Route for Circular Economy

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Producing H_2-rich syngas from municipal solid waste using oxygen-lean thermal treatments presents a promising waste-to-energy pathway for realizing the circular economy of modern society. This presentation overviews the contemporary research efforts, particularly on developing syngas upgrading and gasification processes, to make thermal treatment a sustainable and affordable option for final disposal of the municipal solid waste.

Metabolic Insights of Carboxydotrophics in Syngas Fermentation for Low-carbon Chemicals/Fuels

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Carboxydotrophic mediated syngas fermentation regulates by the Wood–Ljungdahl pathway (WLP) for bioconversion of syngas to C2-C4 chemicals. Lab scale and semi-pilot scale systems were operated with the metabolically active carboxydotrophic consortia and isolated strains. Comparative bioprocess monitoring will be performed to predict the conversion abilities of the different biocatalysts with varying operational conditions. Enzyme regulation studies (CooC2, adhE1, Fdhl) and profiles of the biobased products in the medium will be analysed at regular intervals. The metagenomic analysis will be performed to know the diversity changes under the different experimental conditions.

Keywords: Syngas fermentation, Platform chemicals, C1 fixation, Metabolic shift.

Nitrogen Transformation During Pig Manure Composting with Diatomite Addition

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Composting is an economical and effective way to recycle livestock and poultry manure harmlessly. However, due to the harmful effects of aerobic composting on atmospheric environment and the negative effects on the efficiency of compost products, reducing nitrogen loss has attracted more and more attention. Recently, the application of mineral additive to increase nitrogen conservation was a prosperous filed. Diatomite (DM), siliceous materials, which has a large specific surface area and abundant surface functional groups, had been used as a novel mineral additive to reduce nitrogen loss during pig manure composting. Whereas, nitrogen conservation mechanism and optimum added dosage of DM are not clear, which are crucial for composting technology in theory and practice. In this study, the 0%, 2.5%, 5%, 10%, 15% and 20% of DM were added into initial mixtures of pig manure and sawdust for 42 days aerobic composting. Results showed that adding DM facilitated the conversion from NH_4^+-N to amino acid nitrogen and hydrolysis undefined nitrogen, and then reduced NH_3 and N_2O emission by 8.63−35.29% and 14.34−73.21%, respectively. Moreover, the maximum value in nitrogen conservation was observed in treatment with 10% DM addition, and it was confirmed that adding DM amendment reduced the relative abundance of nifH, nirK, nirS, nosZ and narG. Furthermore, C/N (57.30%) was supposed to control the reduction of nitrogen loss among all physio-chemical parameters. Therefore, adding DM was a practical way to enhance nitrogen conservation and improve quality of end products, and the optimum added dosage was 10%.

Keywords: Pig manure, Composting, Diatomite, Nitrogen transformation.

Assessing the Baseline of Food Waste Generation in Greek Households

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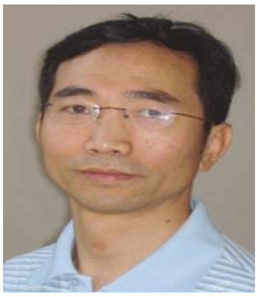
According to the Directive 2018/851/EC the member states of European union (MS-EU) should take measures to promote prevention and reduction of food waste in line with the 2030 Agenda for Sustainable Development of the United Nations. In addition, MS-EU should record the progress they make towards this goal, through the use of a common measurement methodology, which is set out in Commission Delegated Decision EU (2019) 1597 of 3 May 2019. The EU committed its member states to measure and report the amount of food waste produced at each stage of the food supply chain during a full calendar year on an annual basis. At the same time, the MS-EU must measure and report the amount of food waste produced at each stage of the food supply chain (at least) once every four years, using the methodology of Annex III of the Delegated Decision. In the first submission period, which was completed by 30/6/2022, MS-EU measured the amount of food waste for all stages of the food supply chain for the year 2020, using the set methodology. This study aimed to set a baseline for the food waste generated in Greek households, in context to the EU legislation and guidelines. It was based on a study assigned by one of the largest supply chains in Greece, AB Vassilopoulos, to the Sustainable Environmental Mangement & Technology Team of Harokopio University (HUA). The approach of detailed self-reported food waste diaries was used to determine the amount of food waste. The design of the online diary was based on the food waste diary, which was used by HUA for the first food waste generation study of Greek households in 2013-2014. The participants were instructed to keep track of the type and quantity of the edible and inedible food waste of their households. Given that there does not exist a common knowledge base regarding conversion factors of food waste volume/items to mass, the processing of the collected data was based on data from international nutrient and food component databases, and the database of the Department of Nutrition and Dietetics, HUA, for Greek foods. A total of 1,102 respondents completed the diary for a period of 1-7 days. Participants were required to classify their edible food waste into eight different food type categories, record the weigh or volume of each item discarded, as well as the reason for not consuming it. Inedible food waste was classified into two types: of plant or of animal origin. Recent studies have shown that the number of household members has a direct impact on the food waste generation. On this basis, the average food waste quantities were calculated for each household size class and values multiplied by the estimate of the Hellenic Statistical Authority for the size distribution of Greek households. The analysis of the results indicates that households in Greece generated 930,323 t/y (95.5 kg/y/ca) of food waste, of which 403,628 t (38.7%) could have been avoided. “Fruits & vegetables”, “bakery products”, and “pasta, rice & cereals” were responsible for the largest part of edible food waste, corresponding respectively to the 51.8%, 18.6% and 7.6%.

Keywords: Food waste, Households, Greece.

Catalytic Microwave-Assisted Pyrolysis of Organic Solid Waste for Fuels, Chemicals, and Materials Production



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Catalytic microwave assisted pyrolysis/gasification of renewable biomass and recycled plastic wastes for green fuels, chemicals, and materials provides an attractive solution to alleviate the climatic changes and achieve the 1.5 ºC Paris climate goal. To improve feasibility and scalability of the microwave-assisted pyrolysis process, a novel system of continuous microwave-assisted pyrolysis (CMAP) featuring a mixing SiC ball bed was developed and first tested for hydrogen-rich gas production from biomass. At temperature of 800 ˚C, gas with a high energy content of 18.0 MJ/ Nm^3 and a high syngas (H_2+CO) content of 67 vol.% was obtained at a gas yield of 72.2 wt.% or 0.80 Nm^3/kg d.a.f. wood pellets. Downstream condensation and physical adsorption lowered the tar concentration from 7.83 g/Nm^3 at the exit of pyrolysis reactor to below the detection limit at the end of the process. Energy balance analysis showed that a cold gas efficiency of 73.3% was achieved at 800 ˚C, which consumed 7.2 MJ electrical energy per kg of wood pellets, outperformed many other technologies. In addition, this CMAP technology is developed to achieve the conversion of waste plastics to high quality naphtha, that can be injected to new plastic manufacturing, with the hope of creating a circular economy and minimizing greenhouse emission. The key for catalytic cracking of waste plastics is to mitigate the coke formation and improve the catalyst lifetime. First, the relationship between the catalyst structure and catalyst lifetime was studied comprehensively by fine-tuning the acidity and pore structure of zeolites. It was confirmed that proper acid density and larger pore size significantly improved the catalyst lifetime. Considering that the pore size of conventional ZSM-5 catalyst is too small for plastic pyrolysis intermediates entering into the pore system, which will limit the diffusion of intermediates, block the pore opening, and result in fast deactivation of catalyst, the hierarchically macro-meso-microporous high Si/Al ratio ZSM-5 zeolite was developed and tested. It was confirmed that the catalyst lifetime of hollow ZSM-5 is over five times longer than the conventional ZSM-5 due to the better diffusion channels and improved accessibility of acid sites inside the modified catalysts. After producing fuels or chemicals, 30~40 wt.% non-condensable gases (mainly composed of hydrogen and C_1-C_4 hydrocarbons) will be left, to be further utilized. So, we have used a three-dimension metal foam to catalytically decarburize the non-condensable gases for carbon material and hydrogen production. When the non-condensable gas products pass through a high temperature reactor packed with an effective Ni-Fe/Al_2O_3 catalyst, high yield of hydrogen (over 88% hydrogen selectivity) can be achieved, with carbon products being produced. In summary, our studies indicated that the CMAP is a low-cost and highly efficient technology to convert waste plastics and biomass to valuable fuels, chemicals, and materials.

A Novel approach for Purifying Anaerobic Food Waste Digestate Through Bio-conditioning and Dewatering Followed by Activated Sludge Process: A Case Study

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ABSTRACT. Food waste anaerobic digestate (FWAD) poses challenges for the subsequent biochemical treatment such as activated sludge process. In this study, taking a typical food waste treatment plant as an example, we analysed the reasons behind the difficulties in treating FWAD and tested a new process called as bio-conditioning and dewatering followed by activated sludge process (BDAS) to purify FWAD. Results showed that high influent load was the main factor affecting the purification efficiency of FWAD by the conventional activated sludge process. By implementing bio-conditioning and dewatering, nearly 100% of suspended solids (SS), 90% of chemical oxygen demand (COD), 100% of total phosphorus (TP), 38% of total nitrogen (TN), and 37% of ammonium-nitrogen (NH_4^+-N) could be effectively removed from FWAD, consequently generating the transparent filtrate with relatively low pollution load and dry sludge cake (<60% of moisture content). Furthermore, after ammonia stripping and biochemical treatment, the effluent met the relevant sewage discharge standard regulated by China. This proposed BDAS approach exhibited stable performance and low operating costs, offering a promising solution to purify FWAD and simultaneously realize efficient resources recovery.

Keywords: Food waste; Anaerobic digestate; Bio-conditioning and dewatering; Promising solution

Introduction

Anaerobic digestion is the mainstream technology for treating food waste (FW). However, a large amount of food waste anaerobic digestate (FWAD) with high concentration of pollutants are inevitably produced after anaerobic digestion of FW. The direct farmland application of FWAD or treating FWAD with conventional wastewater technologies is challenging in practical engineering due to the poor purification effectiveness, low resource recovery efficiency, and high operation costs [1]. Therefore, it is of great significance for developing a novel approach for achieving dual-goals of recovering nutrients from FWAD and subsequently purifying FWAD to meet the discharge standards.

To overcome the difficulty of FWAD treatment, we developed a novel approach for purifying the digestate, call as bio-conditioning and dewatering followed by activated sludge process (BDAS) [2]. In practical applications for treating swine wastewater/digestate and cattle slurry, the BDAS process has achieved satisfactory results, which can directly recover near 100% of SS and P, more than 80% of COD, and around 50% of N from these wastewater in a very short time (1-3h). The transparent filtrate by mechanical dewatering can be purified and its water quality meets the discharge standard after only 1-2 weeks treatment by conventional activated sludge process [3]. However, its feasibility in FWAD treatment has yet to be reported.

Therefore, the purposes of this study are to take a typical FW treatment plant as an example, (1) to analyse the reasons for the difficulty in treating FWAD based on conventional treatment approach such as activated sludge process, (2) to verify the feasibility of the BDAS for purifying FWAD, and (3) to evaluate the engineering operation stability and economic efficiency of this novel process.

Material and Methods

FWAD and microorganism inoculum

The microorganisms inoculum, i.e., compound bacteria mainly composed of *Acidithiobacillus ferrooxidans* LX5, *Acidiphilium* sp. j6, and *Klebsiella* sp. F1, was cultured in MS medium. The microbial nutrient agent was provided by BACT Environmental Solutions Co., Nanjing, China. Industrial grade lime as coagulant aiding agent were purchased from the local company in Chongqing, China. The concentration of prepared lime slurry was about 167 g/L. The properties of tested FWAD was listed in Table 1.

The conventional treatment process of FWAD

The FW treatment plant located in Chongqing, China (29°22' N and 106°29' E) was constructed and operated since 2014. The FWAD, obtained from the solid-liquid separation by the mixtures of digestate and biogas residue through a horizontal screw dehydrator, is directly fed into the two-stage A/O activated sludge process system, and the effluent from the secondary sedimentation tank eventually enters the ultrafiltration membrane treatment system. About 150t/d of FWAD was generated in the plant.

The novel treatment process of FWAD

The novel process called as bio-conditioning and dewatering followed by activated sludge process (BDAS) was developed and applied in the upgraded FWAD treatment system, which mainly composed of three units including bio-conditioning and dewatering, ammonia stripping, and biochemical treatment (typical activated sludge process). Unit I: A certain amount (13% of the volume of treated FWAD) of microorganism inoculum is added to FWAD that has been aerated for 1 day, and then mixed with appropriate amount of lime slurry (12% of the volume of FWAD) for about 1 h, the mixed liquid is pumped into the diaphragm recessed chamber filter press for solid-liquid separation. Unit II: The separated filtrate is introduced to the stripping system that composed of successive two-stripping units for the partial removal of NH_4^+-N. Unit III: The stripping liquid is fed into the activated sludge process with two-stage Anaerobic-Anoxic-Oxic (A2/O) process in series with a total effective tank capacity of approximately 1367 m^3 and HRT of 16 days.

Analytical methods

The pH was measured by a BJ-260 pH meter (Shanghai Leici Co., China). Standard methods were used to determine total solids (TS), SS, mixed liquor suspended solids (MLSS), COD/soluble chemical oxygen demand (SCOD), TP/soluble total phosphorus (STP), TN/soluble total nitrogen (STN), NH_4^+-N/soluble ammonia nitrogen (SNH_4^+-N), and salinity.

Results and Discussion

The actual removal efficiencies of typical pollutants by conventional FWAD treatment process

Conventional activated sludge process used to treat FWAD resulted in low removal efficiencies for SS, COD, TN, and NH_4^+-N with only 33.7%, 52.9%, 18.2%, and 14.9%, respectively (Table 1). The concentration of these pollutants in the effluent from secondary sedimentation tank were far from reaching the water quality standards regulated by China (SS, 400 mg/L; COD, 500 mg/L; TN, 70 mg/L; NH_4^+-N, 45 mg/L; TP, 8 mg/L). In addition, the MLSS concentrations in aerobic tanks kept constantly at 8500-9000 mg/L, while their SV_{30} values were all above 90, implying a severe sludge aging and an extremely low microbial activity in biochemical system. Furthermore, the sedimentation function of the secondary sedimentation tank could not be achieved. The effluent with high SS often blocked rapidly ultrafiltration membrane in the subsequent unit. Consequently, the overall paralysis of the conventional FWAD treatment system occurred. In order to ensure the normal operation of the FW treatment plant, the FWAD had to be transported out for disposal.

Table 1 Concentrations of typical pollutants at different units of the conventional FWAD treatment process.

Parameter	pH	TS (mg/L)	SS (mg/L)	COD (mg/L)	TN (mg/L)	NH_4^+-N (mg/L)	TP (mg/L)
FWAD	8.2±0.1	23282±2045	16439±475	24642±1301	3157±128	2641±52	423.8±6
Effluent	8.7±0.1	-	10902±315.5	11611±656.6	2581±92.56	2247±99.09	74.73±5.4

"-" represents below the detection limit.

Difficulty in treating FWAD: Cause analysis

The ammonification generated by anaerobic digestion significantly raised NH_4^+-N concentration in FWAD compared to FW hydrolysate (FWH) (Table 2) and drastically reduced C/N of FWAD, which further greatly affected the nitrogen removal efficiency by activated sludge process. In addition, high concentration of salinity (7852 mg/L) and NH_4^+-N (2641 mg/L) in the influent (FWAD) would inhibit the activity of activated sludge, resulting in a poor settling performance in the settlement tank and low nitrogen removal efficiency during the limited time of the biochemical system. Moreover, it was found that a significant amount of the typical pollutants (COD and TP) existed in the form of particulate or SS (Fig. 1). These particulate pollutants had a lower bioavailability and difficult to be biodegraded than soluble pollutants. Undoubtedly, excessive SS, COD, and N in FWAD reduced the purifying effectiveness of FWAD by the conventional activated sludge process. Thus, If SS or fine particles in FWAD could be removed as completely as possible prior to its entry to the biochemical system, these “inertia” or “particle” pollutants that prevent biochemical treatment could be dramatically reduced.

Table 2 Preliminary properties of the FWH and FWAD.

Parameter	SS (mg/L)	COD (mg/L)	SCOD (mg/L)	TP (mg/L)	STP (mg/L)	TN (mg/L)	STN (mg/L)	NH_4^+-N (mg/L)	SNH_4^+-N (mg/L)
FWH	41616±799	86796±1271	59008±985	885.7±34	773±18	4432±109	1829±131	581.4±38	250.3±7.8
FWAD	16439±475	24642±1301	4047±75.2	423.8±6	23.4±3	3157±128	2747±69	2641±52	2566±57.7

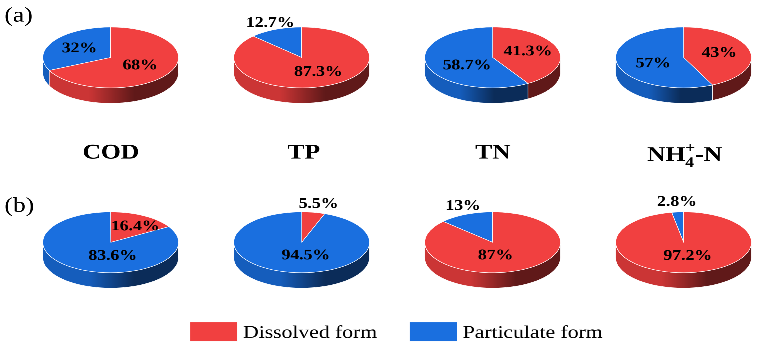

Fig. 1 Existing forms of typical pollutants in (a) FWH and (b) FWAD.

Operating performance of the novel FWAD treatment process

During six months of BDAS operation, we monitored periodically the water quality index of the influent (FWAD) and the effluent (see Fig. 2). The average concentrations of COD, TN, NH_4^+-N, and TP in effluent were 281.1, 31.33, 10.8, and 0.59 mg/L, respectively. As expected, the novel process performed admirably in removing these typical pollutants, and the pollutant concentrations in effluent were far lower than the

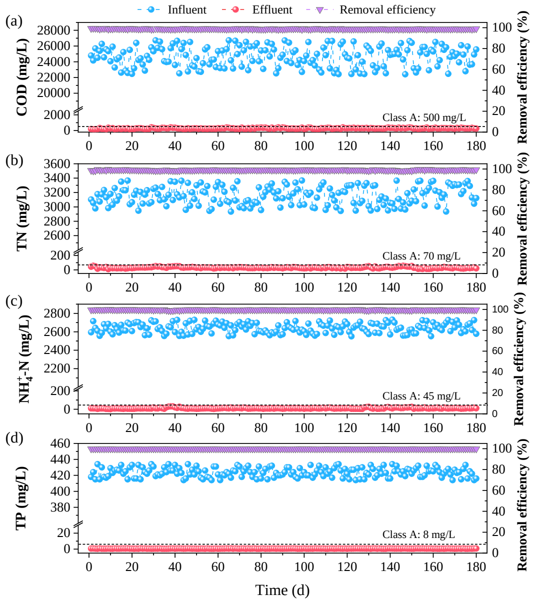

Fig.2 Concentrations of (a) COD, (b) TN, (c) NH_4^+-N, and (d) TP in the influent and effluent during 180 days of BDAS

operation discharge standards. Specific microorganism inoculum used in bio-conditioning process could generate a substantial quantify of biological flocculants. These flocculants are effective in capturing SS in FWAD. When combined with diaphragm recessed chamber filter press, the solid-liquid separation process nearly completely removed SS from FWAD (Table 3). Accordingly, COD and TP in particulate form in FWAD (Fig. 1b) were efficiently removed or recovered by 88.69% and 99.65% in the form of sludge cake, respectively. In other words, a successful bio-conditioning and dewatering can directly recover nearly 100% of SS and P, 90% of COD, and 40% of N from FWAD (Table 3). The original FWAD as a black and viscous slurry was converted into clear or transparent filtrate with low pollutant load after bio-conditioning and dewatering. The resultant sludge cake had a low moisture content (<60%) and high organic matter, which could be used to composting materials to produce organic fertilizer. In addition, after bio-conditioning and dewatering, the pH of filtrate increased to 12 due to the addition of lime (Table 3), creating a favourable condition for the removal of NH_4^+-N by following ammonia stripping unit. Correspondingly, 78.4% of the NH_4^+-N was removed from the filtrate.

Thanks to the satisfactory operating performance of the early-stage units, the concentration of the pollutants in the influent prior to the biochemical system have been effectively reduced and the final effluent after activated sludge process could met the relevant discharge standard. Moreover, the BDAS novel process showed a sustainable improvement in FWAD treatment capacity with eventual 132 t/d.

Table 3 Concentrations of typical pollutants at different units of the novel FWAD treatment process.

Parameter	pH	SS (mg/L)	COD (mg/L)	TN (mg/L)	NH_4^+-N (mg/L)	TP (mg/L)
FWAD	8.2±0.1	16439±475	24642±1301	3157±128	2641±52	423.8±6
Press filtrate	12±0.7	-	2787±458.4	1947±85.1	1663±165.1	1.5±0.1
Ammonia stripping liquid	10.8±0.3	-	2608±121.2	428±18.5	359±36.9	1.33±0.04
Effluent	7.1±0.1	-	281.1±56.1	31.3±9.3	10.8±5.5	0.59±0.1

“-” represents below the detection limit.

Economic benefit analysis

The direct operating costs of the novel BDAS process included mainly the costs from reagents, power consumption, and labour. The total operating costs by using the novel process for FWAD treatment was approximately 8.47 USD/t, which was much lower than those FWAD or manure-based digestate treatment technologies reported in the literatures [4]. By contrast, due to the unsatisfactory FWAD treatment performence by using conventional technology, the FWAD still had to be transferred to a local municipal wastewater treatment plant for further treatment, incurring a substantial cost of 29.2 USD/t.

Conclusions

In the light of the detailed investigation for a full-scale FWAD treatment plant, it was concluded that the high concentration of pollutants in FWAD were responsible for the poor performance observed in conventional treatment for FWAD. In BDAS novel process, after bio-conditioning and dewatering, SS, COD, TN, NH_4^+-N, and TP in FWAD were removed by 100%, 88.7%, 38.3%, 37%, and 99.7%, respectively, and generated the clear or transparent press filtrate and relative dry sludge cake. Subsequent activated sludge process successfully and easily reduced the concentrations of pollutants in the press filtrate to meet the relevant sewage discharge standards regulated by China. Moreover, the BDAS novel process operated stably and effective-costly.

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China’s Livestock Transition: Driving Forces, Impacts, and Consequences

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China’s livestock industry has experienced a vast transition during the last three decades, with profound effects on domestic and global food provision, resource use, nitrogen and phosphorus losses, and greenhouse gas (GHG) emissions. We provide a comprehensive analysis of the driving forces around this transition and its national and global consequences. The number of livestock units (LUs) tripled in China in less than 30 years, mainly through the growth of landless industrial livestock production systems and the increase in monogastric livestock (from 62 to 74% of total LUs). Changes were fueled through increases in demand as well as, supply of new breeds, new technology, and government support. Production of animal source protein increased 4.9 times, nitrogen use efficiency at herd level tripled, and average feed use and GHG emissions per gram protein produced decreased by a factor of 2 between 1980 and 2010. In the same period, animal feed imports have increased 49 times, total ammonia and GHG emissions to the atmosphere doubled, and nitrogen losses to watercourses tripled. As a consequence, China’s livestock transition has significant global impact. Forecasts for 2050, using the Shared Socio-economic Pathways scenarios, indicate major further changes in livestock production and impacts. On the basis of these possible trajectories, we suggest an alternative transition, which should be implemented by government, processing industries, consumers, and retailers. This new transition is targeted to increase production efficiency and environmental performance at system level, with coupling of crop-livestock production, whole chain manure management, and spatial planning as major components.

Keywords: Manure, Sustainable livestock production, Nutrient loss, Biofertilizer.

Technological Barriers of MSW Classification, Reduction and Resource Utilization in China

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With the continuous progress of municipal solid waste (MSW) classification in China technological problems in resource utilization of classified waste have become increasingly prominent.

At the front end, the intelligent level of the collection, storage, and transportation system does not meet the criteria of MSW classification resulting in low classification quality and serious odor pollution. As for transportation, the lack of transportation facilities matched with the “Four- category classification method” has led to difficulties in the reduction of waste and secondary pollution.

In terms of resource utilization, kitchen waste after classification has a high impurity rate, which challenges pretreatment equipment, results in low biomass recovery rate, poor biogas productivity, and high residues in anaerobic digestion. On the other hand, high energy consumption and operating costs have become obstacles in practical aerobic treatment. Furthermore, due to the lack of relevant application standards, it is almost impossible for compost products to be used in lands.

In addition, with the concentration of kitchen waste, its utilization facilities are also facing the problems in the treatment of male-odor and high-concentration wastewater. Therefore, in order to smoothly progress the MSW classification in China, nowadays, it is critical urgent to improve its classification, reduction, and resource utilization technologies.

Novel Step Pyrolysis Technology for Recovery Valuable Products from Waste Tires

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The black pollution caused by waste rubbers, especially waste tires, has attracted extensive attention all over the world in recent years. According to statistics, about 1.5 billion units of waste tires were produced annually, which gave rise to around 17 million tons of waste tires. Owing to the stable molecular structure of rubber, waste tires have strong heat resistance and biodegradation resistance, which make them difficult to degrade naturally. Recycling high-value chemical products from waste tires by pyrolysis was a promising and attractive method. The pyrolysis behaviour of rubber particles under different heating rate was detailed examined based on delicately designed furnace and the pyrolysis product was carefully analysed through Py-GC-MS. Innovative stage pyrolysis system was developed based on a hollow-auger reactor with a capacity of 1 ton per day. The pyroysis reaction was separated into three steps with temperatures of 475ºC, 500ºC, and 550ºC respectively. The whole system was heated by burning hydrogen and methane enriched pyrolysis gas and the pyrolysis efficiency reached 99% after 72 hours continuous test. Volatile was cooled down to get high quality oil which can be used as fuel or raw chemical feedstock for BTEX production. After milling, the raw black-carbon could replace the N660 commercial black carbon for tire manufacture.

Keywords: Waste tires, Step pyrolysis reactor.

Biomass to Green Energy: An Asian Perspective

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Biomass has become progressively important as a renewable alternative energy source. One of the most critical aspects associated with the use of biomass is its management. Indeed, in order for the use of this type of energy resource to become viable, its supply chain and management, from collection and transport to storage and distribution, needs to be well structured and optimized. In this context, Issues related to depletion of conventional fuel resources and environmental concerns have become the driving force to explore an eco-friendly, renewable, economical and sustainable alternate energy source. Massive quantities of agriculture biomass are being produced globally which can be transformed to biofuels by utilizing various procedures. However, issues for example environmental damages and competing uses of agriculture biomass need to be investigated factually considering the short as well as long-term acuity considering its effect on the soil and conversion to biofuels. This paper provides an insight into the potential of various biomass as an energy source. Presently available conversion techniques to convert biomass to energy in various phases are discussed. The review also addresses the technical, socio-economic and environmental concerns and limitations with the appropriate control measures. The information provided will help stakeholders, energy managers and decision makers working in the sustainable and renewable energy sectors to consider agriculture biomass for energy production at a larger scale. The utilization represents reuse, composting, energy recovery, bio-methanation and other techniques carried out in Asia and Pacific region. Resource circulation of agricultural biomass waste through 3R (reuse, recycle, recover) depends on the type of agricultural biomass waste and other characteristics such as moisture content, energy content, and others. Reusing of agricultural biomass waste includes livestock fodder, mulching, mushroom cultivation, incorporating into the field and others. It is also used as fuel for domestic and industrial sectors and recycling includes aerobic and anaerobic digestion of agricultural biomass waste. It must be noted that recycling of horticulture waste is higher in Singapore (80%) as compared to food waste (19%) in 2020. Similarly, utilization of agricultural biomass waste in Hong Kong SAR includes food waste, yard waste and livestock waste where recycling of livestock waste is relatively higher than recycling of putrescible waste. Among the countries of Asia and Pacific, Japan has relatively higher resource circulation of agricultural biomass waste where about 70% of waste is utilized as fertilizer, feed, fuel and generation of heat and energy. Several initiatives have been taken and schemes have been formulated that have circular economy at its core. For instance, a biogas plant and composting facility was built near sludge treatment facility in Shikaoi Town, Tokachi District, Hokkaido, in 2007, which is known as ‘Hokkaido Shikaoi Environmental Preservation Centre’. The sewage sludge from sludge treatment facility, livestock waste and food waste are treated in Hokkaido Shikaoi Environmental Preservation Centre. Biogas plants generates power which is used within the facility and remaining power is sold to Hokkaido Electric Power Corporation under FIT (Feed-in-Tariff) scheme. Additionally, digested liquid is used as biofertilizer and heat is utilized by aquaculture and fruit culture, thereby creating a local-level recycling-based society. Japan is also aiming towards establishing Biomass Industrial Areas that will build an integrated system of economy and development of village/town centred biomass industry. Agricultural biomass waste is generated more in agriculture intensive countries of Asia and Pacific than the industrial intensive ones. Based on the national legislations, plans, and strategies, as well as management practices, agricultural biomass waste is seen more as a commodity for energy extraction than a resource to be reused and recycled. Partly, it is influenced by the shortages of energy in developing countries of Asia and Pacific and by the willingness to shift from non-renewable energy to renewable energy in developed countries of Asia and Pacific. Therefore, technologies such as bio-gasification, cogeneration, co-firing and fermentation for biofuels are commonly deployed in Asia and Pacific. Anaerobic digestion is the most commonly deployed technology for the treatment of agricultural biomass waste, the use of cogeneration, gasification, composting, and incineration may still contribute to the generation of GHG emissions, albeit less. Moreover, several countries in the Asia and Pacific region

have been putting efforts into improving the socioeconomic and environmental situation of rural areas which are also supported by national legislations in the respective countries.

Spatial Distribution of Fecal Pollution Indicators in Sewage Sludge Flocs and Their Removal and Inactivation During Sludge Conditioning Processes

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Fecal contamination in wastewater treatment system may pose severe threats to human health, while sludge reuse and utilization is one of important routines of disseminating fecal pollution to surface water and groundwater. However, it remains unclear the spatial distribution of fecal bacterial and viral pathogens in sludge flocs and their reductions during sludge treatment processes. In this study, the abundances of fecal pollution indicators including cross-assembly phage (crAssphage), JC and BK polyomavirus (JCPyV, BKPyV), human adenovirus (HAdV), the human-specific HF183 Bacteroides (HF183) and *Escherichia coli* (EC) in soluble extracellular polymeric substances (S-EPS), loosely-bound EPS (LB-EPS), tightly-bound EPS (TB-EPS), and pellets of sludge flocs were determined, and the effect of sludge conditioning treatments on their removal and inactivation was investigated by using both qPCR and viability-qPCR. We found that the serial tenfold dilution effectively reduced the PCR inhibition effect when determining the abundances of fecal markers, while the utilization of negatively charged HA membrane was effective to recover fecal markers from sludge supernatant. The results of a six-month monitoring revealed that gene markers of CrAssphage, JCPyV, HF183, BKPyV, HAdV, and EC can be detected in municipal sewage sludge collected from a local wastewater treatment plant, and all investigated indicators were detected in each fraction of sludge flocs. Among the investigated five chemical conditioning methods, i.e., chemical conditioning with polyacrylamide (PAM), Fe[III]/CaO, potassium ferrate (PF), or Fenton's reagent, and chemical acidification conditioning, chemical conditioning with PF was much more effective than the other conditioning methods to reduce the abundances of fecal markers in the supernatant and solid of conditioned sewage sludge. The overall reductions of human fecal indicators in sludge determined by qPCR were 0 to 1.30 logs, which were 0-2 orders of magnitude lower than those of 0.69 to 2.39 logs detected by viability-qPCR. Therefore, it is feasible to alleviate the human health risks associated with fecal pollution in sewage sludge via selecting suitable sludge conditioning approaches.

Keywords: Municipal sewage sludge; Conditioning treatment; Fecal pollution indicators; Spatial distribution; Inactivation.

Microwave Processing of Waste for Circular Waste Management

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Microwave processing involves the use of microwave radiation as a heat source in an inert environment that can break down and convert waste materials to produce useful liquid oil, gases, and char products. This technique has been applied for recovering the energy and chemical value of various types of waste materials, comprising forestry waste, furniture waste, fruit waste, waste cooking oil, agricultural waste, palm oil waste, etc. This technique shows advantages in providing a fast heating, relatively shorter process time and lower energy consumption, representing a method that is potentially faster and more energy efficient compared to that shown by the method commonly performed using conventional heating source. The technique produces liquid oil product that can potentially be re-used as fuel for power generation, hence representing and promoting a circular approach for waste management, and the oil product is potentially cleaner with promising features to also be used as feedstock for bioplastic production. The technique also produces solid products such as biochar and activated carbon that can be refined for use as catalyst in pyrolysis process, which is also a potential route for circular waste management. The solid products also possess beneficial features for application in waste treatment. Our findings show that microwave processing shows potential as a promising approach with improved heating performance and generation of useful products with desirable properties for circular waste management. These have led to outputs such as joint research with international partners, patent filing, company licensing, journal publications, awards and industrial partnership for prototype development, distribution and application.

Green Technology with Biochar for Waste Recycling and Carbon Reduction

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Biochar, a carbon-rich material made from partial combustion of biomass wastes, is an emerging material of interest as it can serve as a negative carbon emission technology and tackle environmental problems in diverse applications. In this talk, we will discuss the applications of biochar in soil environment, brownfield decontamination, low-carbon construction, sustainable biorefinery, and water pollution control. By adequate engineering the biomass feedstock and pyrolysis conditions, biochar can be designed to manifest desirable physicochemical properties targeting at various reactions and green technologies. The feasibility of scaling up biochar production with versatile, application-oriented functionalities must be actualised in collaboration with multidisciplinary stakeholders to maximise the ESG value.

Sustainable Strategies to Overcome Inhibition of Biomass Hydrolysates and Get More Value from Lignocellulosic Biomass

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Lignocellulosic biomass has a huge potential to be used as a feedstock for the sustainable production of fuels and chemicals through fermentation. However, toxic compounds present in the hydrolysates produced from such materials during the biomass pretreatment step represent a significant challenge for the efficient utilization of hydrolysates by microorganisms. Overcoming the toxicity of these compounds is crucial to achieve an efficient fermentation of lignocellulosic hydrolysates. To this end, sustainable pretreatment strategies should be developed to selectively release sugars with reduced or no formation of toxic compounds. Detoxification of the hydrolysate can also be an alternative to reduce the concentration of toxic compounds, resulting in hydrolysates more suitable for fermentation by microorganisms. However, detoxification may increase the final technology's cost. Alternatively, the performance of the fermentation process could also be improved by using microbial strains with better tolerance to toxic compounds or by using a combination of different microbial species for fermentation. This lecture will discuss all of these strategies, including their advantages and disadvantages, and potential contributions to improve the fermentation of hydrolysates and get more value from lignocellulosic biomass.

Green Processing of Cottonseed Oil Soap-Stock for Sustainable Waste Management

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Cotton is a source of fibre (s), protein, and oil. During the process of oil refining, a dark brown, gelatinous, and unpleasant chemical compound known as soap-stock is eliminated. A significant concentration of fatty acids is present in soap-stock, which can be utilised to produce lipase. Cottonseed oil soap-stock has been referred as a biobased feedstock for producing high-value products. *Actinomycete*(s) from cottonseed soap-stock were used in the study. Submerged fermentation was used to produce lipase using efficient lipolytic bacteria. Response surface methodology was used to investigate maximum lipase production, maximising the influence of several parameters including pH, temperature, nitrogen- & carbon- source. This presentation will cover important developments in the biotreatment of industrial effluent (s), with a particular emphasis on work done by the presenter's team on lipase-producing *Nocardiopsis alba* for the reduction of pollution load from textile industry reject.

Keywords: *Nocardiopsis alba*; Biodegradation; Central Composite Design; Lipase.

Soil Remediation and Resource Utilization of Red Mud

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The passivation effect of red mud-based materials of different proportions was studied by the index of available Cd content in the soil. After 56 days, available Cd content in the soil decreased significantly by 19.65%- 54.89% while 0.97~1.31 increase of pH was achieved. Result of the passivation test suggested an optimum ratio of red mud, diatomite and calcium oxide was 5:3:2. Adsorption test was conducted to study the adsorption mechanism of Cd by red mud based passivator. Comparison of the passivator before and after adsorption indicated that the red mud passivator had a high specific surface area with -OH, Si-O, Fe-O and other groups involved in the adsorption process of Cd^{2+}; however, the structure of passivator was not damaged and the adsorption of Cd^{2+} was proposed as physical and chemical adsorption.

Phosphate Adsorption of Mg and Ca-Biochar and Its P Bioavailability

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ABSTRACT. Biomass is an important alternative to address resource and energy shortages. Metal impregnated Korean pine cone residue (KPCR) is pyrolyzed to develop biochar (BC) as an adsorbent for phosphorus removal during wastewater treatment. Adsorption kinetics of Mg, Ca, Fe, and Al-BCs with 50 mg P/L at pH 8 showed the maximum phosphate adsorption capacity of 24.1, 14.4, 7.5, and 9.4 mg PO_4^{3-}/g BC, respectively. Langmuir isothermal adsorption showed the maximum phosphate adsorption of 146.6, 57.1, 34.6, 18.6 mg PO_4^{3-}/g BC of Mg, Ca, Fe, and Al, respectively. Percentages of phosphorus released in the distilled water by desorption from the phosphorus saturated Mg, Ca, Fe, and Al-BC for 48 hours were 12.0, 13.4, 7.6, and 2.2% of the total phosphorus in the BCs, respectively. Assessment of phosphorus bioavailability of the Mg. Ca, and Al-BCs were performed with 2% citric acid (pH 2.5), neutral ammonium citrate (pH 7), and alkaline ammonium citrate (pH 9.4) gave 38.3, 75.9, and 8.6% (pH 2.5), 22.2, 22.6, and 7.9% (pH 7), 9.9, 11.9, and 6.9% (pH 9.4), respectively. Overall, metal-BC was very effective in phosphorus recovery and the phosphorus bioavailability showed a potential application as an environment-friendly fertilizer.

Keywords: Adsorption/Desorption, Bioavailability, Biochar, Phosphorus recovery.

Introduction

Biochar is a residual solid carbon material that remained after gas and oil are produced during the pyrolysis of biomass [1], and has attracted much attention as a soil conditioner and carbon fixation material. In addition, biochar helps protect water quality in water systems by retaining pollutants and nutrient components such as phosphorus and nitrogen contained in soil runoff. Since biochar has abundant functional groups, it is promising as an adsorbent that removes pollutants from wastewater in a cost-effective and eco-friendly way [2].

Pristine biochar has limitations in adsorption and removal of anionic substances in wastewater, and as a way to overcome this, the surface of biochar is modified through metal impregnation. When biomass is impregnated with cationic metals (Mg, Ca, Al, Fe, etc.) and pyrolyzed, metal oxides supported biochar is produced and its anionic adsorption is improved [3]. Therefore, studies on removing phosphate from wastewater through surface modification of biochar using various biomass and metals are being actively conducted [4-9].

Phosphorus is a raw material for fertilizers and various chemical products, and is particularly essential for the growth of agricultural crops and livestock. However, its excessive use may cause eutrophication of water systems. Phosphorus reserves are expected to be depleted in the next 100 years or so, it threatens the sustainability of mankind since there is no substitute for phosphorus. Therefore, its recovery and recycling are becoming important issues. The purpose of this study is not only to remove phosphorus from wastewater by using metal-biochar, but also to reuse the phosphorus saturated biochar as a fertilizer. To this end, we investigated the release (desorption) characteristics of adsorbed phosphorus when metal-biochar saturated with phosphate on the soil as well as the adsorption and removal of phosphate to confirm the efficacy and effectiveness as an eco-friendly slow-release phosphorus fertilizer.

Materials and methods

Preparation of metal-biochar

Korean pine cone residue (KPCR) after oil extraction was used as a raw material for biochar. It was pulverized and filtered to a size of about 1 mm using a standard sieve, washed three times with distilled water, and dried in a 105°C dry oven for 48 hours. For metal loading of Mg, Ca, Fe, and Al, 50 g of dried pine nuts was placed in a 500 mL solution of 1.0 M metal ions and stirred at 300 rpm for 24 hours to ensure sufficient loading of metal ions. After stirring, the solution was removed, and the KPCR sample was dried again for 48 hours in a 105°C dry oven. Dried metal-supported KPCR (25 g) was pyrolyzed by heating at 10 °C/min from room temperature to 500 °C and maintaining at 500 °C for 15 minutes to produce metal-impregnated biochar. During the pyrolysis nitrogen gas (1 L/min) was injected as a carrier gas to produce an oxygen-free atmosphere.

Phosphate adsorption of metal-biochar

Adsorption kinetics and isotherm experiments were conducted to confirm the phosphate adsorption characteristics of metal-biochar. First, the adsorption kinetics experiment was performed in an incubator at 200 rpm at room temperature for 48 hours in a 500 mL Erlenmeyer flask after adding 0.5 g of biochar to 250 mL of 50 mg P/L phosphate solution at pH 8. In the isothermal adsorption experiment, the concentration of phosphate solution was 12.5~800 mg P/L, pH 8, 0.1 g of biochar in 50 mL of phosphate solution for 48 hours. The pH of the solution used in adsorption kinetics and isothermal adsorption experiments was adjusted using 0.1M HCl and 0.1M NaOH.

Evaluation of phosphorus desorption and bioavailability of metal-biochar

After filtering the phosphate-saturated biochar, it was dried in a dry oven at 105°C for 24 hours. 1 g of phosphate-saturated biochar was added to 500 mL of distilled water, and the mixture was stirred at room temperature in a shaking incubator at 200 rpm for 48 hours. Metals concentration in the water confirmed the metals dissociated from the biochar through ICP-OES. Phosphorus desorption characteristics in biochar were analyzed by adding 1 g of saturated biochar to distilled water (500 mL) stirring at 200 rpm at room temperature by measuring the T-P of the solution. The bioavailability of phosphorus adsorbed on biochar was measured by T-P eluted from acidic, neutral, and alkaline solutions using 2% citric acid solution (pH 2.5), neutral ammonium citrate solution (pH 7), and alkaline ammonium citrate solution (pH 9.4), respectively.

Results and discussion

Fig. 1-(a) shows the kinetics of phosphate adsorption on biochar loaded with Mg, Ca, Fe, and Al. The metal-impregnated biochar(metal-BC) showed a fast adsorption rate and a high amount of phosphate adsorption (24.1, 14.4, 7.5, 9.4 mg PO_4^{3-}/g BC, respectively), whereas the control biochar that did not contain metal hardly adsorbed phosphate. In particular, in the case of Mg-biochar, it can be seen that phosphate adsorption rapidly increased up to 12 hours and reached saturation after 24 hours. Other Mg-biochars in the previous study also showed similar phosphate adsorption [6,7]. Ca-biochar has a slightly slow adsorption rate, showing 9.3 for 12 hours and 14.4 mg PO_4^{3-}/g BC after 48 hours, but lower than Mg-biochar. Fe and Al-biochars showed much lower adsorption than Mg and Ca-biochars.

In the phosphates adsorption isotherm of biochar loaded with control and Mg, Ca, Fe, and Al, the maximum adsorption amounts of phosphate were 0.6, 110.7, 49.4, 30.3, and 18.9 mg PO_4^{3-}/g BC, respectively. As a result of applying the Langmuir isothermal adsorption model to Mg, Ca, Fe, and Al-biochar, the theoretical maximum phosphate adsorption amount was 146.6, 57.1, 34.6, and 18.6 mg PO_4^{3-}/g BC, respectively. Fitting the isothermal adsorption results to the Langmuir and Freundlich models showed that Mg and Ca-biochar were more suitable to the Langmuir model, and Fe and Al-biochar were more suitable to the Freundlich model. It is known that the Langmuir model is suitable for mono-molecular layer chemisorption and the Freundlich model is suitable for multi-molecular layer physical adsorption, indicating that the adsorption methods of Mg/Ca-biochar and Fe/Al-biochar are somewhat different.

To investigate the characteristics of phosphate-adsorbed biochar as a phosphorus fertilizer, its metal dissolution and phosphorus desorption characteristics were investigated. As a result of the 48-hour metal dissolution experiment, 15.7% of Ca-biochar and 14.1% of Mg-biochar were dissociated, while Al and Fe-biochar were hardly dissociated (Fig. 2-(a)). Phosphate may simply be desorbed when phosphate is desorbed from metal-biochar, but metal-phosphate complex may be desorbed from biochar. Therefore, it is meaningful to compare the desorption amount of metal and phosphorus. Phosphorus desorption from Mg, Ca, Fe, and Al-biochar was rapid within the first 30 minutes, and 12.0, 13.4, 7.6, and 2.2% of phosphorus were desorbed after 48 hours, respectively (Fig. 2-(b)). However, compared to 14.1 and 15.7% of Mg and Ca dissociation, phosphorus desorptions are relatively less.

As a result of the three phosphorus bioavailability test (pH 2.5, 7, 9.4), Mg-biochar showed 38.3, 22.2, 9.9%, Ca-biochar 75.9, 22.6, 11.9%, Al-biochar 8.6, 7.9, 6.9%, Fe-biochar showed 15.6, 13.1, 5.9%, respectively

(Fig. 3). It can be seen that the bioavailability of each biochar shows a high value in common under acidic conditions and decreases in the order of neutral and alkaline conditions. The reason is thought to be due to the solubility of $Mg_3(PO_4)_2$, $Ca_5(PO_4)_3OH$, $AlPO_4$, $FePO_4$, etc., which are the compounds produced by combining Mg, Ca, Fe, Al with phosphate [10]. These metal-phosphates complexes have high solubility at low pH and low solubility at neutral or weakly alkaline pH.

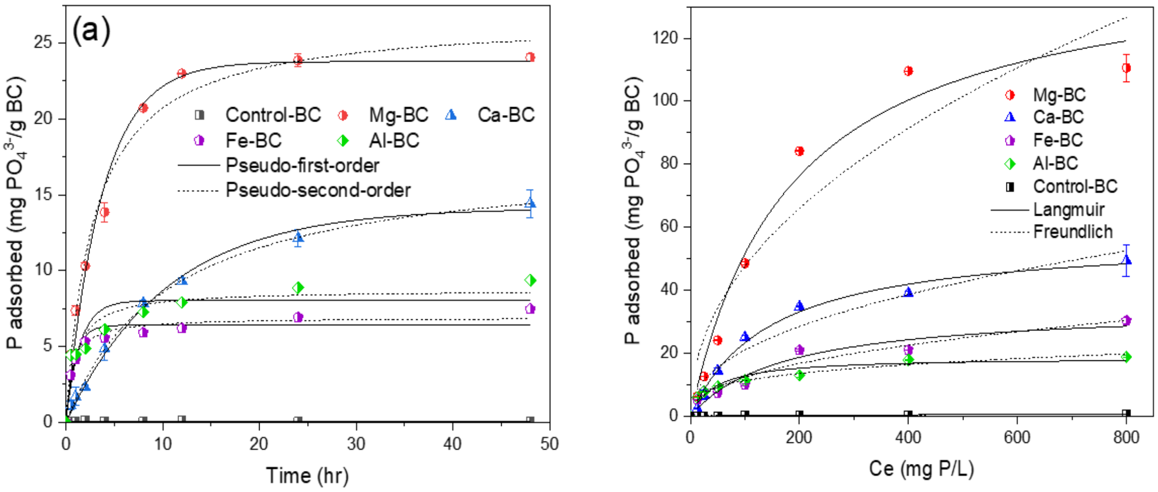

Fig. 1. Adsorption of phosphates on the metal impregnated KPCR biochar: (a) phosphates adsorption kinetics, (b) phosphates adsorption isotherms.

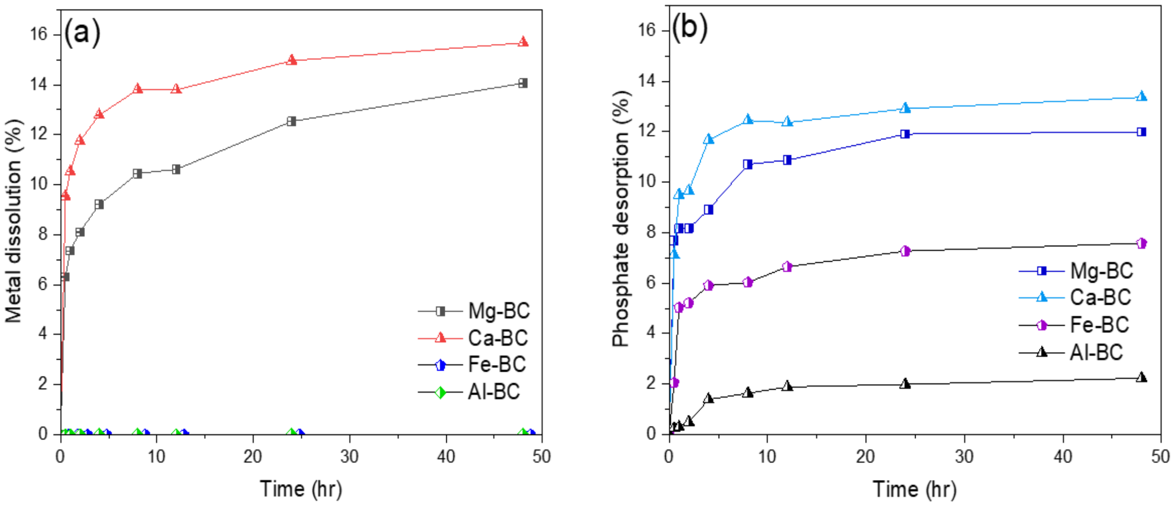

Fig. 2. Metal dissolution (a) and phosphates release (b) from phosphates saturated metal impregnated biochar.

In order for phosphate-saturated biochar to have value as an eco-friendly fertilizer, the amount of phosphate adsorption and desorption should be large, so the amount of phosphate delivery should be high, and the desorption rate should not be too fast or too slow depending on the crop. If phosphorus efflux from biochar is too fast and large, phosphorus may be lost by runoff from the soil [11], and if the amount of metal desorption is large, the amount of phosphate adsorbed upon reuse may decrease, resulting in poor performance as an adsorbent. There is also a risk of adverse effects on soil and crops. Based on these criteria, Mg or Ca-biochar seems to have better properties as a fertilizer than Fe or Al-biochar.

Conclusions

As a result of evaluating phosphate adsorption capacity of metal-biochar at pH 8, Mg-biochar showed higher phosphate adsorption than the biochars loaded with other metals (Ca, Fe, Al). The results of phosphate desorption from the saturated biochar as a fertilizer confirmed that Mg-biochar delivered the most phosphate to the soil, followed by Ca-biochar while Fe and Al-biochars delivered very low phosphorus. When compared with the phosphorus bioavailability test, the desorption of phosphate increased as the pH decreased due to the difference in solubility of the metal-phosphate complex.

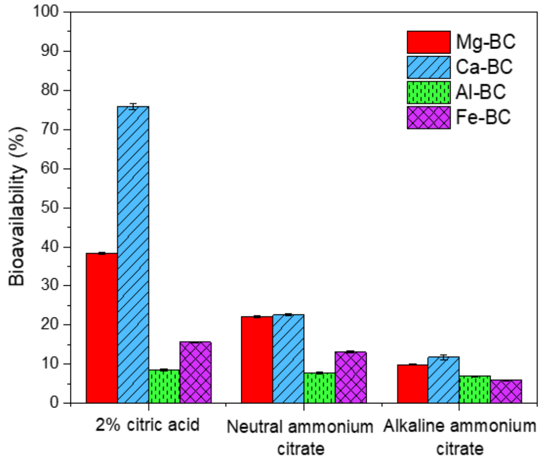

Fig. 3. P bioavailability(%) from Mg, Ca, Fe, Al-biochar with different methods (2% citric acid

Acknowledgement

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Approaches for Valorisation of Biodegradable Organic Fraction of Domestic Solid Waste

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In developing countries, biodegradable organic fraction constitutes a major fraction of municipal solid waste (MSW). For instance, it accounts for 40-60% of the total MSW generated in an urban city or town in India. Due to its biodegradable nature, the putrescible waste causes bad odour due to release of obnoxious emissions in the form of nitrogenous and sulphur compounds present in the waste, if it is not stored properly. Nevertheless, the waste has great potential to produce a range of value-added products. Composting and anaerobic digestion are the conventional treatment processes for waste recycling and energy recovery, respectively. These processes have their own limitations in terms of applicability and extent of valorisation. Therefore, it is prudent to review the existing and futuristic approaches for the treatment of biodegradable waste to ensure maximization of resource recovery with minimal environmental impacts. One of the potential methods for the uncooked source-segregated waste is installation of the decentralized composting systems without or with provision for air supply. Using this method, substantial reduction in cost of waste transfer and processing can be achieved. At the same time, waste recycling at source will also be promoted. In addition, hydrothermal pretreatment is considered an emerging technology for the treatment of cooked food waste particularly produced from restaurant kitchens or hostel mess. The waste is generally treated by anaerobic digestion however, hydrolysis is often a rate limiting step. During hydrothermal pretreatment, the solid particles are solubilised and biogas generation and recovery is generally improved. At the same time, energy and nutrient rich hydrochar may also be produced depending upon the pretreatment conditions which can further be utilized either for energy recovery or as a soil conditioner. However, the challenges with these processes should be identified and addressed before implementation.

Keywords: Biodegradable wet waste, Circular economy, Resource Recovery.

Green Recovery from and Sustainable Management of Solid Waste Generated in Electrolytic Manganese Production

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The manganese (Mn) production process generates gasses, wastewater, and solid wastes, and these wastes have caused serious pollution to the environment. This paper focuses on the recovery and reuse of valuable elements in the liquid and solid wastes from Mn production industry. The paper first introduces the production processes of electrolytic manganese metal (EMM), generation of electrolytic manganese residue (EMR) and electrolytic manganese wastewater (EMW). Then, the paper describes several systems and processes for selective separation and recovery of Mn, silicon, and other value-added products from EMR. The paper also introduces innovative methods for the safe reutilization of EMR or for stabilizing heavy metals in EMR. Finally, the paper summarizes the current research and provides insight of future extended work and directions. By adopting the novel methods introduced in this paper, the electrolytic manganese industry can 1) reduce CO_2 emissions and the release of soluble manganese; 2) recover and reuse manganese carbonate; and 3) produce value-added products (e.g., environment-friendly material for construction and manganese-silicon fertilizer) from EMR and EMW.

Odours and Other Airborne Contaminants of Emerging Concerns Relating to MSW Storage and Transportation

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In recent years, the generation of domestic garbage in urban and rural areas has steadily increased. With the continuous progress of urbanization, municipal solid waste (MSW) storage stations and transfer stations, which are key points for garbage collection and transportation, have moved to residential areas than before. As a result, the gaseous pollution related to the front end of the garbage removal chain has attracted much attention. However, existing studies on gaseous pollution are more on the terminal facilities for MSW treatment and disposal, e.g. in composting plants or landfilling sites, while the studies oriented to the stage of MSW collection and transportation are still rare. Especially, under the new situation of MSW source segregation, it is wondered whether the gaseous pollution will change compared with the mixedly collection in the past.

Except for the traditional appreciable pollutants- odorous compounds, diverse emerging contaminants are of high concern. It would then be interesting to know the presence of airborne emerging contaminants. The emission characteristics of gas-phase emerging contaminants should be comprehensively assessed considering their health threats to workers and environmental risks.

Therefore, this study will present the results about the emission of different gaseous pollutants from odours to bioaerosols, airborne microplastics and airborne antibiotic resistance genes, during the process of storage, collection and transportation of MSW.

Keywords: Odorous compounds, Microplastic, Bioaerosols, ARGs.

Conversion of Biomass to 5-hydroxymethylfurfural-Derived Chemicals Using Carbon-Based Catalysts

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Biomass is a renewable natural resource with rich chemical components and diverse structural characteristics, and is widely used to produce biofuels, bio-based materials, etc. The utilization of biomass resources can reduce dependence on fossil energy and promote sustainable development. Therefore, biomass resource utilization plays an important role in addressing climate change and achieving carbon neutrality. The use of biomass raw materials to prepare high-value-added chemicals has also become one of the research hotspots. Biomass catalytic conversion is a technical process in which biomass raw materials are reacted under the action of a catalyst, and a series of separation and purification operations are performed to obtain the target product. Compared with traditional biomass conversion technology, biomass catalytic conversion has the advantages of abundant resources, environmental friendliness and sustainable development. At present, the research on the catalytic conversion of biomass to produce high-value-added chemicals has covered the range from single compounds to complex mixtures, and has made remarkable progress. Catalyst is one of the important factors affecting the catalytic conversion of biomass. Commonly used catalysts for biomass conversion include solid acid catalysts, basic metal catalysts, transition metal complex catalysts, etc. In addition, the control of reaction conditions also has an important impact on product distribution. In this study, a series of carbon-based composite catalysts were developed to be successfully used in the conversion of biomass raw materials to 5-hydroxymethylfurfural, 2,5-dimethylfuran, furandicarboxylic acid, etc. These chemicals are widely used in the production of plastics, fibers, paints, medicines, etc, and have good market prospects. Therefore, the research on the catalytic conversion of biomass to produce high-value-added chemicals is of great significance. In the future, on the one hand, it is necessary to further improve the biomass catalytic conversion technology to increase the yield of target products; on the other hand, it is also necessary to combine the biomass catalytic conversion technology with other technologies to achieve a more efficient and sustainable biomass resource utilization. At the same time, with the increasing demand for environmental protection and sustainable development, the research and application of biomass catalytic conversion to produce high-value-added chemicals will be more extensive in the future.

Keywords: Biomass, Catalysis, Carbon-based catalyst, 5-hydroxymethylfurfural.

Material Utilization of Straw Biomass as a Kind Agricultural by-products, the Acquirement and Practice

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Industrial utilization of straw biomass and other agricultural by-products, provides a very potential model for bioresource technology. Material utilization of straw is emphasized and several techniques have been developed, for producing water-free pulp, for biomass enriched rattan and furniture-making materials. New materials composited with straw biomass, starch and biodegradable plastics is of high value and environmental friendly.

Keywords: Straw biomass, bio-degreatabe plastics, Material utilization, Industry.

Measuring the Extent of Biodegradation of Plastics

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Measuring the extent of biodegradation by evolved biogas is suitable for estimating potential methane yields from natural organic material or the stabilisation of compost. Biogas evolution is not suitable for measuring the biodegradability of bioplastics because it does indicate whether the unaccounted carbon is biomass (microorganisms) or undegraded plastic. Solid residues from natural organic material are an import source of organic carbon in soils, while undegraded plastics are harmful, both aesthetically and ecologically. Both fossil-based plastics and bioplastics can form micro- and nano-plastics (MNPs) which cannot be accurately quantified by visual analysis. A plastic that is composed of one polymer can be demonstrated to be fully biodegradable by biogas evolution even if only a portion of the plastic biodegrades. The same inference cannot be made if a plastic is a composite material or if the plastic is an unknown proprietary material. In these cases, tests are needed to demonstrate that the plastic will not degrade to refractory MNPs. This paper presents a biodegradation study on a proprietary bioplastic. Five samples of bioplastic were digested at 55 °C in 180 mL serum vials using digested sludge as an inoculum. A bottle was opened after 15, 26, 50, 81 and 216 days. The bioplastic pieces remained intact and were fully recognisable. Despite this, significant biodegradation had occurred with 20.3±2.4% and 38.4% of the bioplastic carbon converted to biogas after 81 and 216 days respectively. The extent of biodegradation according to the volatile solids loss of the bioplastic pieces was 30.2% and 38.5% after 81 and 216 days respectively. The discrepancy between the biogas and gravimetric methods for the 81 Day sample indicates transient production of MNPs and soluble organic compounds. The recovered bioplastic pieces from the 15, 26, 81 and 216 day digestions were then enclosed in individual mesh bags and placed in the middle of a 40kg bed of garden waste that was composted at a temperature of between 55 and 60°C for up to 67 days. The rate of VS loss during the composting phase was not significantly different to the rate of VS loss during the digestion phase. The VS loss of the sample digested for 216 days and composted for 67 days was 38.5 and 15% relative to the fresh VS content. The extent of degradation of the samples was also estimated by extracting the residual plastic in the composted samples by a pressurised dichloromethane wash. These results will be presented at the conference.

Keywords: Bioplastic, biodegradation, dichloromethane extraction.

Nanobubble Technology Applications in Environmental Remediation and Controlled Environment Agriculture

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Nanobubbles are an emerging gas delivery technology with potential opportunities in environmental remediation and the agriculture. Due to their several unique properties, such as their high gas solubility, high electrostatic interaction, and their potential formation of reactive oxygen species, nanobubbles can provide opportunities in various environmental remediation applications and different microbial-mediated processes where poorly soluble gases are difficult to supply using conventional technology. The perpetual generation of reactive oxygen species could also offer new avenues in pathogen and biofilm control. With rising population growth and soaring food demand, controlled environment agriculture has gained interest in recent years as a sustainable food production system. Due to the limitations of conventional aeration methods to increase the oxygen solubility threshold, applying an innovative nanobubble technology could bring dissolved oxygen levels beyond normal saturation, thus bringing improvements in plant yields. This presentation will showcase some of his efforts in diverse applications of nanobubble technology.

Landfill In-situ Aeration and Improvement of Landfill Gas Extraction Systems- Ways to pollution control and climate protection

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Landfills significantly contribute to climate change. Relevant amounts of gas escape from landfills during operation when no gas extraction systems are in place. But even during gas extraction from landfills without surface liner gas collection efficiencies are often not higher than 40- 50%. After landfill closure, gas and polluted leachate will still be produced over many decades. Depending on the size of a landfill, for more than 10 years landfill gas is produced in amounts suitable for gas utilisation. Afterwards landfill gas is still produced escaping in most into the atmosphere increasing climate gas emissions. Dependent on the specific landfill these emissions may amount to 20-30% of the total gas production potential. Since 1 m^3 of methane contributes about 25 times more to global warming than $1m^3$ of CO_2 the emission of these residual gases should be largely avoided. One reduction method is the largely extraction of gas during landfill operation by means of horizontal gas extraction systems. Necessary in many cases is also the remediation of vertical gas extraction systems which may be partly clogged and /or broken after many years of operation; these effects reduce the gas extraction efficiency significantly. The other method to reduce climate gas emissions from landfills is in-situ aeration. This technology where air is injected at low pressure into the landfill has proven its effectiveness in Germany for more than 10 years. Due to the installation of aerobic conditions the degradation of organics to mainly CO_2 will be enhanced. As a result large amounts of climate gas emissions have been reduced so far. The German Government included in-situ aeration in its climate protection program and co-finances through its climate fund technical equipment. More than 70 landfills participate in this program, more are in preparation. In addition to the positive effect of in-situ aeration on climate gas reduction the emission potential of a landfill will also be reduced at a much shorter time compared to anaerobic conditions. By these means the long-term risks arising from landfills over up to ±100 years after closure are by about ± 90% reduced.

Thermo-Mechanical Treatment of Nonrecyclable Muncipal Solid Waste to Enhance Organics Recovery and Biochemical Processing

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The United States Environmental Protection Agency estimates that about 270 million tons of municipal solid waste (MSW) is generated annually. Despite years of efforts to divert waste from landfills by implementing source separation of recyclables and separate collection of green waste, still about 52% was landfilled. Half of the landfilled waste was organics made up of paper and cardboard (13.1%), yard trimmings (6.2%), food (21.9%) and wood (8.7%). The organic fraction of this stream can be potential resource for manufacturing biofuels and bioproducts through enzymatic solubilization or anaerobic digestion. However, the challenge is to produce a contaminant free organic stream from this heterogeneous mixture. The BurCell Technologies Inc. patented and proprietary BurCell® system processes raw, but size reduced nonrecyclable municipal solid waste (MSW) via a thermo-mechanical process. The raw material is wetted and heated. A rapid depressurization of the process vessel ensures the rapid formation of steam, which, while trying to reach thermodynamic equilibrium, builds up pressure in the vessel. The fast phase transition of moisture in the organics helps to break down their fiber structure, like a steam explosion process. Unlike a conventional steam explosion process, the BurCell® process starts under vacuum and therefore, never reaches the absolute pressure and temperature of a typical steam explosion process. Limiting the temperature is critical to prevent the degradation of plastics and minimize chemical contamination. The mechanical action further enhances the physical impact of the steam explosion. During the process, the BurCell® vessel rotates, and its contents are lifted and dropped by six large flights uniformly distributed on vessel inner surface. Plastics, glass, and metal are mostly unaffected by the BurCell® system operating conditions and become more easily separable from the bulk of the now sanitized and pulped organic material via screening. The organic streams produced by an industrial scale BurCell® system were sampled over a two-year period. During this period the facility processed MSW from various locations and sources. The proximate and compositional (cellulose, hemicellulose and lignin) characteristics of the samples were analyzed. Both enzymatic solubilization and anaerobic digestion experiments were performed on these samples. The visible contaminant content in the BurCell® system processed organic stream ranged between 3-5%, and on a dry matter basis the volatile solids content ranged between 75-90%, cellulose between 30-35%, and hemicellulose between 10- 18%. A C^{14} isotope characterization of the organic stream showed 100% of carbon of biogenic origin indicating no leaching and chemical degradation of compounds from plastics and other non-organic materials. About 80% of the volatile matter in this stream was solubilized by addition of a cellulase enzyme cocktail whereas only 40% was solubilized in non- BurCell® system processed samples. Both the methane yield and methane production rate were more than doubled from BurCell® system processed samples compared to non- BurCell® system processed samples. The BurCell® process produces a sanitized, and largely homogeneous organic stream with very little contaminants from a highly heterogeneous non-recyclable MSW feedstock. Thermo-mechanical processing also boosts the enzymatic solubilization and anaerobic digestability of the organics.

Keywords: MSW, Thermo-mechanical, Enzyme, Anaerobic Digestion, Biogas.

Microplastic Contamination in Compost Produced from Solid Waste

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ABSTRACT. This study investigated the plastic and microplastics (MPs) contamination in compost derived from mixed municipal solid waste, canteen waste, and compound biodegradable waste in Thailand. Meso plastics (5-25 mm), larger MPs (1-5 mm), and smaller MPs (<1 mm) were extracted using a series of organic matter digestion and density separation method. MPs were identified using a microscope, FTIR (Fourier transform infrared spectrometry), and µ-FTIR. Composted mixed municipal solid waste had the highest MPs contamination (23100 ± 3615 items/kg dry weight), while composted canteen waste showed the lowest contamination (100 ± 65 items/kg dry weight). White (53 %) colour and sheet (31%) shaped MPs were dominant in compost samples. Smaller MPs (<1 mm) abundance was high in all compost samples. Polystyrene, polyethylene, and polypropylene were the dominant polymer types. Compost application can become a potential source of plastics and MPs addition to soil demanding new rules to tackle the problem.

Keywords: *Compost; Microplastics; Mixed municipal solid waste; Food waste; FTIR.*

Introduction

Currently, MP analysis research mainly focuses on marine environments across the globe though most of the marine MPs have a land-based origin [1]. Still very little is known about terrestrial MPs pollution. Soil has been discovered as a huge plastics and MPs reservoir. Compost application has been identified as a major pathway of MPs entering agricultural soil. However, there is a large knowledge gap about the data on plastic and MPs contamination in compost and its contribution to agricultural soil [2]. Potential plastic pollution in agricultural soil in Germany caused by compost application has been calculated as 84,000–1,610,000 plastic items ha^{-1} per year. Fertilizer regulations in many countries allow a certain amount of plastics larger than 2 mm in fertilizers while nothing is mentioned about the MPs smaller than 2 mm [3]. Hence, it is time to update the existing rules and regulations on the substrate utilized for compost production and the existing permissible limits on MPs in compost products. This study aimed to quantify and characterize the meso plastics (>5 mm), larger MPs (1-5 mm) and smaller MPs (<1 mm) contamination in compost produced from different solid waste substrates and the potential contribution to soil pollution.

Material and Methods

Sample description and Contamination control

Compost produced from mixed municipal solid waste was obtained from a mechanical–biological treatment plant in On Nut, Thailand. Compost produced using separately collected canteen food waste from school and university canteens was obtained from a privately-owned compost manufacturing company. Another commercially selling compost produced from mixture of biodegradable waste such as vegetable waste, fruit waste, and food waste, was collected from a fertilizer shop. Here onwards compost derived from mixed municipal solid waste, canteen waste, and compound biodegradable waste are referred as CMSW, CCW, and CBW, respectively. Maximum care was taken to avoid the external plastic and MPs contamination of samples during collection and laboratory handling. CCW samples were collected using clean glass jars and stored at 4 °C until processing. CMSW and CBW samples were commercially sold in paper bags and plastic packaging, respectively. Steel or glass devices cleansed with Ethanol (50%) and deionized water (DI) were always used during laboratory extraction. Samples were covered with aluminium foil and experiments were performed inside a clean fume hood to avoid air borne contamination. The researcher worn a cotton lab coat. Three lab blanks were performed parallel to the analysis. No MPs contamination were found in the 1-5 mm size range. Transparent and blue colour MPs fibres and fragments were found in the blanks of <1 mm size fraction. Lab blanks were reduced from the real samples and average values are presented.

Plastics and Microplastic extraction and identification

Two kilograms of each sample were checked for meso plastics analysis. The suspected plastics were manually picked using tweezers and cleaned using a sonicator to remove the adhered impurities. Then the particles were dried at 60 °C for 24h and polymer composition was checked with FTIR analysis.

MPs extraction and analysis were conducted following a previous method with modifications [4]. Compost samples were dried at 60 °C for 24h to 48h. Homogenized samples were first sieved with a 5 mm sieve to remove meso-plastics. Next 20 g of the samples were sieved via 5 mm and 1 mm sieve to separate the sample into two size fractions and were transferred to separate beakers. Both size fractions were treated separately as follows. Density separation was performed with two different solutions, first with 300 mL of NaCl (5 M; $\rho = 1.20$ g cm^{-3}) and after that with 150 mL of $ZnCl_2$ ($\rho = 1.7$ g cm^{-3}). After adding a density separation solution, the mixture was stirred for 15 min, sonicated for 30 min, and allowed for sedimentation for 24h. The supernatant with MPs and other lighter organic impurities was filtered using a 20 µm sieve and transferred to an Erlenmeyer flask by washing with DI water. Density separation with one solution was repeated twice. The organic matter digestion was conducted by adding 15 mL of 2 mol/L HCl and 20 mL 30% H_2O_2 into the samples and shaking in an incubator (120 rpm, 12h – 24h, 50 °C). If much organic matter remained after the digestion, another density separation with $ZnCl_2$ was conducted. The treated solution was filtered through a 20 µm sieve by washing with DI water, and all the treated solutions on the filter were vacuum filtered onto GF/C filter papers. MPs particles in 1-5 mm size fraction were picked up by tweezers and checked for polymer composition with FTIR. Total MPs count in the size fraction smaller than 1 mm were counted under an optical microscope based on the visual characteristics of the particles. FTIR and micro FTIR confirmed the polymer composition of selected smaller MPs. Microsoft Office 2016 was used to perform statistical analysis.

Results and Discussion

Abundance of plastics and MPs in the compost

CBW, which is a granular compost type had no meso plastics. Abundance of meso plastics in CMSW and CCW was 113 items/ kg (dry weight) and 2 items/ kg (dry weight), respectively. Meso plastics found in CCW were food packaging materials which might have accidentally incorporated into the food waste due to careless disposal. Fragments of single use plastic bags, food packaging materials, plastic film wraps, and some other meso plastics were identified in CMSW compost. Post compost treatment technique of size sieving to remove foreign matter larger than 4 mm utilized in CMSW compost production process was less effective in the meso plastics removal. These meso plastics in compost are fragmented into smaller micro and nano plastics over the time.

MPs were abundant in all the analyzed compost samples with 100% detection frequency and abundance among different compost samples showed a high variation. Hence long-term compost application can lead to MPs accumulation in soil [3]. Compost produced from mixed municipal solid waste showed the highest MPs contamination of 23100 ± 3615 items/kg (dry weight) while compost produced from canteen waste showed the lowest as 100 ± 65 items/kg (dry weight). Canteen waste compost showed 231 times less MPs contamination compared to CMSW compost. MPs abundance in CBW was 1050 ± 339 items/kg (dry weight). CBW was in granular form and previous studies have observed a lower MPs contamination in granular compost than powder form compost [4]. MP abundance in compound compost (CBW) was higher than the single raw material compost (CCW). Comparison of the abundance of MPs in compost with previous studies is very challenging due to the scarcity of the studies and differences in compost types analyzed in the existing studies. The highest average MPs abundance in stabilized organic output after mixed municipal solid waste treatment in Lithuania and in food waste was 17407 ± 1739 particles kg^{-1} and 4066 ± 658 particles kg^{-1}, respectively [5]. MPs abundance in CMSW compost in our study is higher than that study though the procedure of compost production from mixed municipal solid waste is mostly the same. This can be due to the difference in plastic concentrations in the incoming mixed municipal waste used for composting. Production of compost from mixed municipal solid waste is prohibited in Europe though developing countries practice it. Europe only allows using that organic output as a landfill cover or for incineration [6]. MPs concentration in food waste compost was significantly lower in this study (CCW) compared to that study. In our study CCW compost was derived only from the separately collected food waste generated in school and university canteens. Higher abundance of MPs in the food compost analyzed in Lithuanian study is due to the large range of sources of food waste such as food factories, supermarkets, canteens, and households. Therefore, food waste analyzed in that study was not just only the left-over foods from canteens, but also many other things such as fruit and vegetable residues, tea leaves, tea bags, coffee grounds and their filters, food-coated paper etc. This can be the reason for higher MPs abundance in food waste in that study compared to this study. The differences in methodologies applied to extract MPs, and different compost manufacturing techniques can be reasons for differences in MPs quantities [6]. Plastic and MPs concentration in compost highly varied with the substrate utilized and the different composting technologies used. Smaller MPs (<1 mm) were dominant in all compost samples (Figure 1). In CCW, only smaller MPs were detected. Smaller MPs (<1mm) accounted for more than 60% of the total MPs quantity in all the compost samples. MPs can be generated and concentrated during the composting processes itself [7]. Most of the MPs are produced at the shredding at the mechanical pre-treatment and biological treatment stages of the mechanical-biological treatment plants. Smaller MPs particles have the ability to migrate and accumulate in the food chain when compost is applied into soil [8].

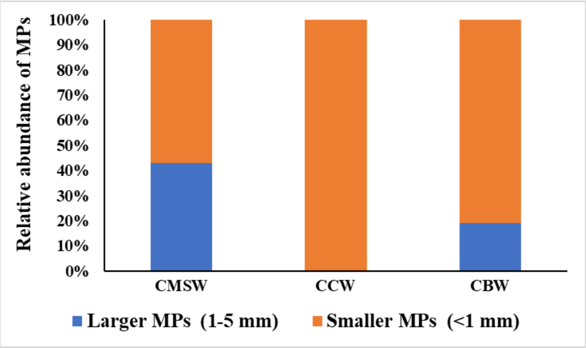

Fig.1. Relative abundance of MPs in compost samples.

Morphology, color and polymer composition of plastics and MPs.

Only fibers and fragments, meso plastics were found in compost samples with fragments being the dominant. Nine different variety of meso plastics were found in CMSW samples while PE (42 %), PP (27%), PS (10%), and PET (10%) were dominant. CCW was detected only with PET and PVC meso plastics. Transparent, white, red, and black meso plastic particles dominated compost samples. CCW was only detected with two different MPs morphotypes (sheets and fragments) while CMSW samples were found to be contaminated with a larger variation of MPs morphotypes (Figure 2). The dominant MPs in CMSW and CBW were sheets (31 %) and films (77 %), respectively. No pellets MPs were detected in any of the samples. Sheets and films MPs in CMSW samples can be formed from fragmentation of hard plastic waste in the incoming waste such as plastic bottles, plastic bags, or plastic packaging materials. Once added to the soil, these sheet MPs can also be degraded into smaller MPs over time which displays a greater impact. Different shapes and polymer types of MPs affect the soil's physical, chemical, and biological properties and plant growth in different ways [9]. MP fibers and films (linear MPs) may significantly affect soil more than MP beads and spheres with similar shapes as soil particles. Larger plastic films create cracks in the soil resulting in the evaporation of deep soil moisture, transporting MPs to groundwater, and affecting the vertical transport of pollutants. Foam and fragment shape MPs can increase soil aeration and microporosity. Fiber shape MPs which are similar to plant roots, improve soil aggregation [10]. White, transparent, and blue color particles were mainly found in all compost samples. Especially, multicolor candy wraps and other food packaging MPs smaller than 1 mm, were identified. Gradual release of colored dyes from MPs over the time have been reported to adversely affect soil microorganisms [7]. Altogether 798 larger and smaller MPs particles were checked for the polymer composition using FTIR and micro-FTIR in three compost types. PS, PE, and PP were the dominant MPs polymers in CMSW samples. Polyurethane (PU), acrylonitrile butadiene copolymer, styrene/butadiene copolymer, polyester (PES), and polycarbonate were found in minor quantities which together accounted for 10% of MPs in CMSW samples. In addition, some plastic additives were also found. CBW was found to be contaminated with two different MPs polymers, PE (86 %) and PES (14 %) which is mentioned as other in the figure 2 (c). PS MPs were found to occupy soil pores inhibiting soil fauna's movement. PE increases, decreases, or causes no significant changes in soil pH. PP reduces the soil bulk density. The same type of MPs in different sizes, shapes, and doses affect soil differently [10]. Soil MPs have many adverse effects on plant growth, such as reduction of shoot-to-root biomass ratio, chlorophyll content, and soluble sugar. Plants can uptake nano plastics, entering the food chain and threatening human health [8].

Conclusions

This study explored the occurrence and characteristics of plastic and MPs in compost derived from mixed municipal solid waste, canteen waste, and compound biodegradable waste. The use of mixed municipal solid waste as a substrate to produce compost is dangerous since MPs and other adhered contaminants can enter the food chain and finally human. Hence existing rules on substrate utilized for compost production should be updated. Compost produced from separately collected food waste (CCW) was also detected with plastic and MPs even though it was significantly less. Hence public awareness of proper source segregation of waste and compost pretreatment to remove plastics from the final compost product, should be encouraged.

Compound compost (CBW) detected with higher MPs abundance compared to single raw material compost (CCW). Smaller MPs were dominant in all the compost samples. Hence existing rules and regulations on permissible limits of smaller MPs in compost should be included in the standards. Moreover, there is an urge to introduce novel techniques to remove plastics and MPs from substrate and the final compost products.

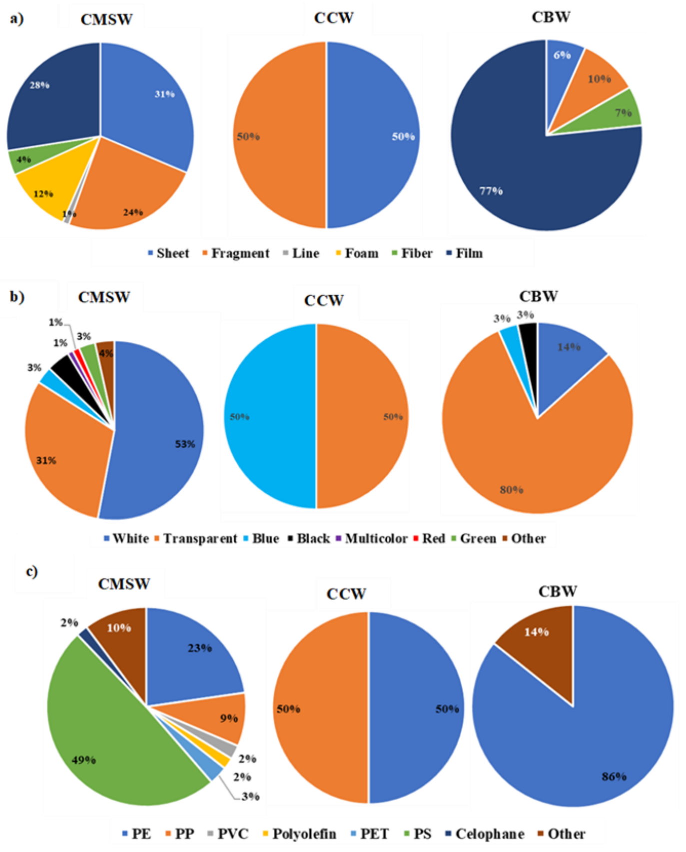

Fig.2. a) Morphology b) color and c) polymer types of MPs in compost samples.

Acknowledgement

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Emerging Pollutants in Wastewater Sludge: Lessons Learned from Perfluorochemicals

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Perfluorochemicals (PFCs) are a type of emerging pollutants with high-energy carbon-fluorine (C-F) bonds that make them structurally persistent. Different forms of PFCs are used in a wide range of industrial and consumer products, and they subsequently end up in the environment through waste streams, such as wastewater and its treatment sludge (biosolids). This finding has triggered a great concern in PFCs entering the food chains with agricultural activities employing biosolids and/or affected by the PFC-containing soils. Many studies have also revealed the adverse effects of PFCs toward human health. Therefore, a clear understanding of the fate and transport of the environmental PFCs and proper management technologies for this type of pollutants are crucial in reducing the PFC threat to our environment, agriculture, and public health. This presentation will first report our findings on the discharge characteristics of PFCs from municipal wastewater and its sludge. Then, the results of adsorption experiments for the selected PFC compounds on mineral surfaces will be demonstrated as an example of our understandings on the consequence of using PFC-containing biosolids for land applications or having agricultural activities on PFC-contaminated lands. Our results clearly indicate that, in addition to the mineral surface property, the PFC adsorption behavior is also influenced by solution chemistry. For example, the increase of pH can lead to a moderate decrease of perfluorooctanesulfonate (PFOS) and perfluorooctanoate (PFOA) adsorption, owing to the decrease of electrostatic attraction. The compression of electrical double layers and the calcium ion bridging effect between PFCs will also decrease the PFOS and PFOA adsorption on boehmite surface. Alternatively, thermal treatment (such as incineration) offers another management technology for wastewater sludge, and it can effectively break the robust halogen-carbon bonds in PFCs. However, the final products of thermally treated PFCs were found to be potent greenhouse gases, tetrafluoromethane (CF_4) and hexafluoroethane (C_2F_6). We introduced calcium-based minerals to assist the thermal treatment of the PFC-contained sludge and successfully achieved the fluorine mineralization with CaF_2 (calcium fluoride) and $Ca_5(PO_4)_3F$ (fluorapatite) to substantially reduce the emission of CF_4 and C_2F_6. The use of the state-of-the-art quantitative X-ray diffraction (QXRD) technique to analyze the fate and thermal transformation of fluorine in the PFC-contained sludge was demonstrated to obtain the detailed processing parameters for this new treatment design.

Keywords: Perfluorochemicals, Adsorption, QXRD, Wastewater Sludge, Thermal Treatment.

Sharing Construction Waste Materials Across Different Jurisdictions: Prospects and Challenges for a Smarter and Greener Greater Bay Area

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Construction waste, also called construction and demolition (C&D) waste, is the stream of solid waste generated from construction activities such as new building, renovation, and demolition. More than 95% of the construction waste materials (CWM) are inert and can be reused or recycled, e.g., for land reclamation, sub-base of road pavements, and recycled aggregates. As Hasegawa (1983) puts it, construction waste is just misplaced material. However, no matter how hard one tries, it is difficult for a single place to digest all the CWM generated from the locality. Visionaries are thus looking across different places for sharing such materials, as they could provide a bigger buffer in absorbing the materials for different beneficial reuse or recovery. Encouraging CWM sharing cases have been observed in the connections of Italy and Switzerland, particularly their Lombardy and Canton Ticino regions; of Singapore and its adjacent Southeast Asian countries; and of Hong Kong and the Pearl River Delta cities. Despite the prospects, numerous challenges are facing the innovative initiative of sharing CWM across different jurisdictions. For example, even under the Basel Convention not on the toxic waste, trading CWM can be stigmatized or lead to a predatory economy. Different jurisdictions will have different standards governing the CWM reuse or recovery. These jurisdictions will be too easy to work under different silos and treat this as a ‘zero-sum’ game. By situating it in the Greater Bay Area (GBA) of China, which is a city cluster witnessing exciting economic vibration, Prof. Lu will talk about the prospects and challenges facing the CWM cross-border sharing initiative. He will share his research on how to address the challenges, e.g., by certifying CWM as a sharable commodity, waste material passports, blockchain non-fungible token, and other innovative technical-institutional arrangements to boost the sharing economy to achieve a smarter and greener GBA.

International Conference on
Solid Waste 2023:
Waste Management in Circular Economy and Climate Resilience

Invited Lectures

Pre-treatment of Food Waste for High-rate Hydrogen Production

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Hydrogen is a clean fuel and estimated to meet 14% (i.e., 8.4 billion MMBTU per year) of the US final energy demand by 2050. The clean hydrogen R&D program funded by Department of Energy supported 22 Hydrogen hubs across the US with the clear road map of developing hydrogen economy and reduce the CO_2 emissions. Specifically, the set goal is to achieve the Clean Hydrogen Production Standard of less than $1 per kilogram of hydrogen with CO_2 emission less than 4 kg (i.e., 4 $kgCO_2e/kgH_2$) before 2030. Currently, more than 10 million metric tons of hydrogen are produced in US, in which 95% comes from steam methane reforming, 4% from partial oxidation of natural gas and 1% from electrolysis. The cost of production and carbon emissions from each technologies varies and still under debate. For example, electrolysis method is carbon intensive process, if wind or nuclear energy was not used, and cost of hydrogen will be $5-6 per kilogram. Therefore, alternative methods such as bio-waste (e.g., food waste) recycling need to be explored to meet the set goals.

In the US, more than 292.4 metric tons of municipal solid waste is collected every year, in which 22% are food waste (~ 63 metric tons). Utilization of food waste for hydrogen production and diverting from landfill is attractive and less carbon intensive, however, the characteristics of bio-waste (e.g., high carbon and moisture, etc) limits the process and product recovery. Here, the effect of different pre-treatment conditions is evaluated with the aim of high-rate hydrogen production from food waste. Among the pre-treatment methods tested and optimized, Ozonation and ultrasonication are found to be best pre-treatment options. But limitations in scaling up and commercializing these processes, heat and/or acid treatment are proposed as reliable technology for food waste to hydrogen recovery projects. With the heat and/or acid treatment, the recovery of hydrogen per ton of food waste increased threefold higher than the control tests without pre-treatments. Additionally, the pH of the initial reactor conditions is a key for high-rate hydrogen recovery. Based on a number of experiments under varying pH conditions, the best hydrogen production was achieved at an acidic pH of 5 or lower. In conclusion, food waste pre-treatment is necessary to improve the process and product recovery. The techno-economics of the different pre-treatment options also need to be taken into consideration otherwise, the process cost will be normalized for the total energy recovered.

Keywords: Hydrogen, Food Waste, Pre-treatment, Ozonation, Heat and Acid treatment.

Dynamics of Nutrients and Gaseous Emissions During Co-composting of Food Waste and Poultry Manure with Different Amendments

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Developed countries are generating a large amount of food waste (FW) about 1.3 billion tonnes, world-wide annually and is expected to rise more in the next two decades. Prohibition of land filling of FW, threats of greenhouse gases (GHG) emissions during incineration and increased administrative costs urges augmentation of newer strategies based on sustainable waste management instead of disposal strategies. On the other hand, Poultry manure(LM) is an organic matter and a rich source of macro and micro nutrients required for plant growth. Anyhow, the raw PM wastes has malodours and is ponderous, making it costly to transport and concomitant risks associated with it which may lead to severe ecological problems. Composting of FW is also not very productive because of its low porosity, high bulk density, poor C:N ratio, easy acidification, among other factors. The concepts of co-composting help in reducing the time and labour and also benefit economically. The present study proposes a system for co-composting of food waste and poultry manure amended with rice husk biochar, saw dust, and salts. Totally six different sets of compost treatments were prepared, as T1 (FW + PM+SD), T2 (FW + PM+SD+ BC), T3 (FW + PM+SD+ Salts), T4 (PM+SD+ BC+ salts), T5 (FW+SD+ salts) and T6 (FW + PM+SD+ BC+salts) in individual containers. All the compost treatments were degraded for 50 days and reached the good manural stability and maturity index after 90 days. Among the six treatments, the T6 treatment Carbon dioxide, methane and ammonia emissions were reduced and the nitrogen conservation was achieved at a greater level. This study implies that the biochar and salts addition for co-composting food waste and poultry manure is beneficial to enhance the property of the compost.

Keywords: Biochar, Composting, Food waste, Nitrogen conservation, Poultry manure, salts.

Oil Palm Biomass – Waste to Wealth Circular Approach

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The scarcity of conventional fossil-based energy (which will lead to eventual depletion) and the ever-increasing demand for new bio-sources have resulted in the world moving into efficient resources conservation. The Malaysian oil palm industry has been one of the largest contributor of oil palm biomass, with more than 90% of the country's total biomass deriving from 5.81 million ha of oil palms. The abundantly available oil palm biomass – totaling around 80 million tonnes (dwb) annually – are mainly obtained from oil palm plantations (oil palm trunks and oil palm fronds) and palm oil milling activities (mesocarp fibre, palm shell and empty fruit bunches). These biomass sources are anticipated to increase further in the future with increased world population, and thus higher productivity of oil palms for fresh fruit bunches mainly via biotechnological approach for palm oil extraction. Optimum biomass resource use efficiency, recycling and diversification, be it for energy or non-energy applications, present a huge business opportunity for developing a circular palm oil economy. This paper details the oil palm biomass availability, important physicochemical characteristics and potential waste to wealth circular approach, plus resources assessment in totality – in terms of economic and environmental impacts – for commercial exploitation. Relevant biomass to biomaterial and bioenergy conversion technologies, combustion-related problems and greenhouse gas profile, etc. will also be discussed. Overall, oil palm possesses huge potential as one of the largest alternative sources for biomass and bioenergy. Biomass business endeavors can be standalone or integrated along the supply chain, and ideally be centralized in a mill as a biorefinery to demonstrate a balanced impact on the environment, society and economy.

Keywords: palm oil, biowaste, bioenergy, biomaterial, biorefinery, circular economy.

Conversion of Waste Face Mask into Carbonized Functional Materials for Environmental Applications

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ABSTRACT. Adsorption is an efficient method for rapid removal of wastewater contaminants. This study developed a potential carbon-based adsorbent (CC) from disposable facemasks (DFMs) through controlled pyrolysis for wastewater applications. FTIR, XRD, SEM, and EDX analyses were done to characterize the CC and then CC was evaluated for its pollutant removal potential with different synthetic dyes, namely Malachite Green (MG) and Congo Red (CR). FTIR spectra of adsorbed CC surface C=O, C=C, and C–N functional groups confirm dye-CC interaction. XRD spectra indicated the disordered graphitic plane's peaks at 2 = 26.629, 27.488, 27.810, and 29.404. SEM results showed excellent porosity of CC. Response surface and Box–Behnken design tests produced a quadratic model. These model variables passed ANOVA testing at 0.05. The quadratic model's lower P-value (<0.0001) and higher F-value (44.54) suggested dye removal relevance. Finally, the desirability function showed that CC 1000, MG 212 mg/L, and 180 min were optimal for MG removal (>99%). Adsorption kinetics fit a pseudo-second-order kinetic model with $R^2= 0.999$.

Keywords: Disposable face mask; pyrolysis; adsorption; Box-Behnken design; Malachite green; Congo red

Introduction

Industrial and municipal pollution severely contaminates the waterbodies. Textile dying industry wastewater is one of the causes of water pollution in India. Various synthetic dyes are employed in various dying processes, including textile, medicinal, paper printing, leather, and cosmetic dye suppliers. This process releases residual dyes in wastewater. Even trace levels of residual dyes or their metabolites make the water unfit for industrial or human use. Water containing trace harmful dyes affects the ecology and aquatic life. Malachite Green (MG), a cationic textile and aquaculture fungicide, and Congo Red (CR), a diazo anionic textile colour. MG is a toxic dye used in textiles, paper, rubber, leather, and fisheries as an antiprotozoan and fungicide. At 0.05 mg/L, MG is hazardous to freshwater organisms. Congo red, another anionic azo dye, stains silk and cotton. It stains biological cells. Synthetic dyes harm water. Thus, dyestuff removal from coloured effluent is essential for a healthy environment [1]. Dye removal methods included physical, chemical, and biological. Unlike degradation, adsorption cleans wastewater without toxic byproducts[2, 3]. Physical dye removal removes 86.8-99%. Reusable adsorbents make dye removal promising. Pyrolyzed sewage sludge, forest, residential, animal, algal, and plant biomass have been reported as potential adsorbent of dyes [4]. Disposable face masks (DFMs) production, use, and demand have skyrocketed recently to prevent the spread of the COVID 19 virus. Poorly managed DFMs can transmit infections. Degenerated DFM with fewer than 5 mm fragments that impair terrestrial (disturb soil parameters, block sewers, infiltrate food chain) and aquatic environments (entanglement, disease-causing agent, bio-accumulation, ingestion). In this study, DFM was pyrolyzed to obtain CC and used as a novel adsorbent for the removal of hazardous synthetic dyes[5]. RSM and kinetic models optimize pollutant adsorption processes. Thus, Box-Behnken design with RSM optimized for MG dye removal. XRD, FTIR, and SEM analysis were carried out to confirm the dye interaction with CC and, kinetic studies were assessed for dye adsorption rate.

Material and Methods

Preparation, and Characterization of Carbonized compound

DFM was placed in a muffle furnace, where the temperature was steadily raised to 600°C and pyrolysed for 6h[5]. X-ray diffraction (XRD) was used to determine the phase purity and crystal structure of the samples under a powder X-ray diffractometer (Model: Rigaku D/Max Ultima III) with Cu K radiation source (l = 0.154 nm) operating at 40 kV. To identify the functional groups, present in CC, the Fourier-Transform Infrared (FTIR) analysis was done in the wave numbers ranging between 4000 and 400 cm^{-1}. For this the samples were pressed as KBr pellets, and the measurements were obtained in FTIR spectroscopy (Model: NEXUS 470, Make: Bruker, Germany). The surface morphology of CC samples was explored by Scanning Electron Microscopy (SEM) (Model: EVO, Make: Casrl Zeiss Microscopy GmbH, Germany), and the elemental composition was analyzed in the same instrument coupled with EDX.

Optimization of Carbonized compound

For the optimization of the dye removal rate of CC from aqueous MG solutions, the Box–Behnken (BBD) experiments were designed at the three different levels (−1, 0, + 1) of 3 independent factors namely CC dosage, the concentration of dye, and adsorption time. The BBD produced total 17 experimental runs with different experimental conditions. The experimental design, model development and statistical analyses were performed using Design Expert software (Version: 12.0.12.0 64-bit) inbuilt mathematical algorithms.

Results and Discussion

Preparation, and Characterization of Carbonized compound

Through the pyrolysis process, about 17.5 g carbonized compound (CC) was obtained from 500 g of raw oven-dried facemasks. FTIR shows the functional groups on the surface of CC before and after adsorption (Figure 1a). 2923–2925 cm^{-1} peak, due to alcohol CH_2 stretch. C=O stretches cause a mild transmittance peak at 1743–1745 cm^{-1}. Carboxyl group C=C stretches cause transmittance peaks at 1429 cm^{-1} and 1431 cm^{-1}. The significant peaks at 1041 cm^{-1} and 1043 cm^{-1} in CC(MG) and CC indicate C–N stretching. Both samples show a C–H bent band at 875 cm^{-1}.The IR spectra of CC (MG) has higher-intensity transmitted peaks than raw CC. This displays CC-MG interaction [6]. Methylene blue adsorbed activated carbon from *Crataegus oxyacantha* plant core showed comparable results [7]. X-ray diffraction pattern for CC before adsorption (Figure 1b) shows the appearance of sharp peaks at 2θ=26.629, 27.488, 27.810, and 29.404 those correspond to disordered graphitic plane. Crystalline carbon samples provide diffractograms with well-defined peaks [8]. The diffraction pattern of CC(MG) following dye adsorption exhibited a decreasing peak, indicating that dye molecules on the surface of CC changed the structure to amorphous [2]. SEM photograph (Figure 1 c & d) of CC after adsorption of MG showed a relatively low porous surface with clumsy aggregates. It has appeared due to the adsorption of MG on CC surfaces [3].

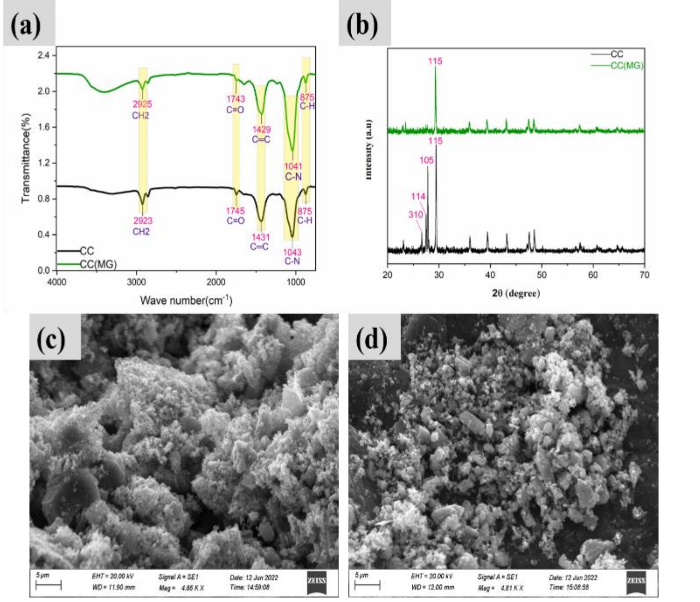

Figure 1. CC and CC(MG) analysis (a) FTIR (b) XRD. SEM characterization, (c) surface of CC, (d) surface of after MG adsorption CC(MG)

Optimization of Carbonized compound

RSM is a useful statistical tool for factorial dye removal process design. RSM optimisation investigations often use BBD [9]. The Design Expert Software's in-built mathematical modelling verified the model adequacy with fit summery, sequential model sum of squares, and lack of fit tests. The quadratic model had the highest predicted (0.7794) and modified R^2 values (0.9608) in the fit summery test. The sequential sum of squares test selected a non-aliased, highest-order polynomial model with significant additional terms. The software suggested quadratic vs 2FI model due to its lower p value (<0.0002), The quadratic model indicated no significant lack of fit with the highest p-value (0.0823) [10]. F test assessed this model's attributes and reaction. Table 1 presents F test ANOVA findings. The model was highly significant with a low p-value (<0.0001) and high F value (44.54). At 95% confidence ($p<0.05$), model terms A, B, C, AB, AC, B2, C2 were very significant. Lack of fit has a greater p-value (0.0823) than $p<0.05$, indicating non-significance. The F-value 4.78 indicates 8.23% risk of model misfit. 3D surface graphs predicted the three separate factor-response interaction. The response is inversely proportional to the interaction between CC and Dye concentrations (AB) (Figure 2a). Rapid adsorption requires more CC (Figure 2b). Concentrated MG solutions affect removal rate while adsorption period is limited (Figure 2c). Numerical optimisation with a desire function determined the ideal settings for three BBD variables [11]. 37 solutions were recommended, and solution 1 demonstrated the highest attractiveness (0.551) and dye adsorption efficiency (99.06%) at the input variables, CC 1000 mg/L, dye concentration 212 mg/L, and Time 180 mins.

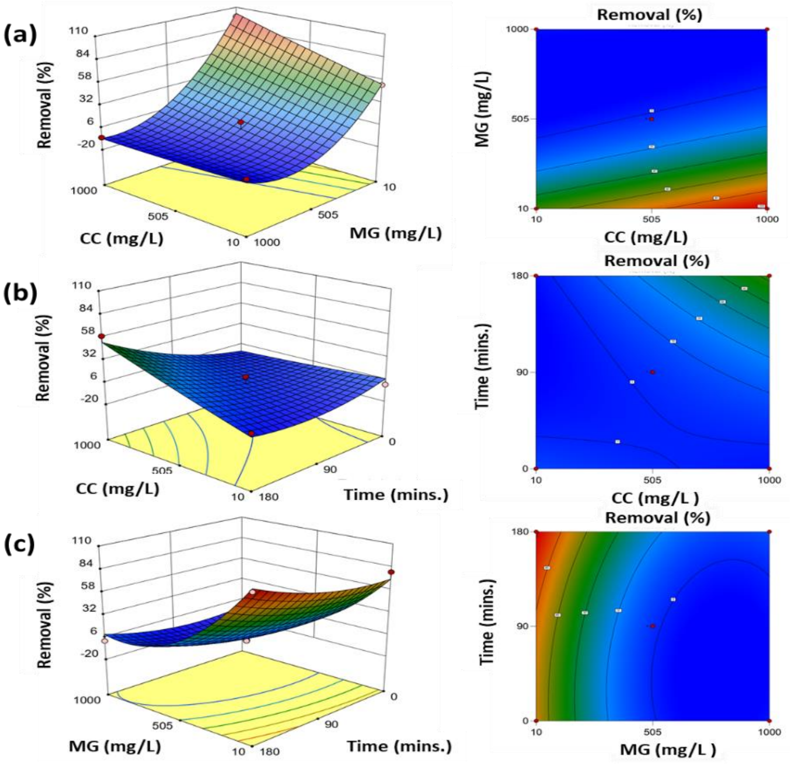

Figure 2. 3D surface graphs (right) and contour plots (left) revealed interaction between factors – CC & MG (a), CC & Time (b), MG & Time (c)

Table 1. Analysis of MG Dye adsorption model variances

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	22799.30	9	2533.26	44.54	< 0.0001	**significant**
A-CC	1072.05	1	1072.05	18.85	0.0034	
B-MG	13825.33	1	13825.33	243.05	< 0.0001	
C-time	1003.15	1	1003.15	17.64	0.0040	
AB	668.81	1	668.81	11.76	0.0110	
AC	1093.17	1	1093.17	19.22	0.0032	
BC	87.27	1	87.27	1.53	0.2554	
A^2	4.59	1	4.59	0.0806	0.7847	
B^2	4475.50	1	4475.50	78.68	< 0.0001	
C^2	375.37	1	375.37	6.60	0.0371	
Residual	398.17	7	56.88			
Lack of Fit	311.38	3	103.79	4.78	0.0823	**not significant**
Pure Error	86.79	4	21.70			

Cor Total	23197.47	16

Conclusions

This study proposes an environmentally friendly strategy for disposing of dangerous facemasks. Disposable facemasks were controlled-pyrolyzed at 600°C to fix the concerns. Several instrumentation methods showed that the carbonised compound (CC) has good adsorption characteristics. MG adsorbs cationic dyes better than anionic dyes. The Box–Behnken design and RSM findings show that all independent factors significantly affect MG adsorption. CC 1000 mg/L, MG 212 mg/L, and 180 min adsorption were optimal for dye removal. Pseudo second-order kinetics shows that carbonised compound adsorbs MG linearly with R2 = 0.999.

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CO_2 Enrichment Regulates Acid Production and Methane Yield from Anaerobic Digestion of Food Waste

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The strategy of injecting exogenous CO_2 gas into the anaerobic digestion reactor can not only reduce CO_2 emissions but also promote the bioconversion of CO_2 to methane, which has received more and more attention in recent years. However, most of the existing research is in its infancy, and there is a lack of in-depth discussions and calculations on the injection method of exogenous CO_2, the enhancement effect of anaerobic digestion and the utilization efficiency of CO_2. This paper aims to explore the enhancement effect of the injection frequency and injection method of exogenous CO_2 on the methane production pathway, so that the quality of biogas can be improved on the basis of the effective utilization of CO_2. The exogenous CO_2 achieved the best effect under the frequency of once every two days. The concentrations of acetic acid and lactic acid reached 812 mg/L and 495 mg/L, which were 91.71% and 95.65% higher than those of the control group, respectively, while the concentration of propionic acid was significantly lower than that of the control group. At this injection frequency, the average daily production of methane reached 4234 mL, which was 26.50% higher than that of the control group. It indicated that the CO_2 enrichment reinforced acetic acid production pathway and weakened propionic acid pathway, thus the methane yield was enhanced. The continuous injection of exogenous CO_2 can also improve the hydrolysis process, as proved by the higher concentrations of SCOD, protein and polysaccharide. Results of microbial community analysis showed that different exogenous CO_2 gas injection frequencies had a great influence on the methanogenesis pathway. When exogenous CO_2 was injected at a more moderate frequency once every two days, the hydrogenotrophic methanogenesis pathway predominated; whereas the acetoclastic methanogenesis pathway was promoted when exogenous CO_2 is injected more frequently once a day.

Keywords: CO_2 utilization; Anaerobic digestion; Biogas upgrading; Methane production; Acid production pathway.

Decentralized Municipal Solid Waste Composting in Tamil Nadu, India – A Case Study

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Solid Waste management is a major challenge throughout the world, and a poor management can result in environmental deterioration and human health hazards. It is estimated that population of India would be about 1.8 billion by 2051 and about 300 million tons per annum of MSW will be generated that will require around 1,450 km^2 of land to dispose it in a systematic manner, if urban local bodies (ULBs) in India continue to rely on landfill route for MSW management. The major fraction of the MSW is the putrescible (biodegradable) organic waste such as the food waste. With the increase in population, urbanization and industrial development, the cost of handling the diverse nature of wastes is expected to increase 4 to 5 folds in countries like India exerting huge pressure. Thus, a low-cost technology to handle the organic fraction of the MSW is preferable for developing countries. Considering the application, level of scientific expertise required and the demand for the recycled products, composting is considered to be an ideal technology. Decentralized community on-site composting is a potential approach to reduce food waste requiring collection also resulting in significant reduction of monetary requirements. Tirunelveli city, the headquarters of Tirunelveli District in Southern Tamil Nadu, India, is the sixth Municipal Corporation in Tamil Nadu and the city spreads over an area of 108.65 km^2. The Corporation has been divided into 4 Zonal Offices with 55 wards and collectively generates about 181 tonnes of MSW per day. Currently, the Corporation is implementing the door-to-door collection of source segregated wastes and divert the OFMSW using battery operated vehicles into dedicated composting units. Each ward has been setup with one composting unit installed with pits used for composting referred as micro-composting facilities. Each facility is provided with 8 or 16 pits depends on the waste received in those wards. The organic fraction of MSW is placed in pits in a sequential manner. A microbial inoculum prepared using jaggery and curd is sprayed on the composting materials when fresh wastes are placed in the pits. The composting pits are turned once a week until they mature. The composting plants do not produce significant odour and the composts are produced in about 41 days. Composting at decentralized level can have its own characteristics. Although the general process conditions provide the process flow for efficient composting, it must be assessed for the specific conditions.

Keywords: MSW, Putrescible waste, Decentralized composting.

Food Waste Generation in The Grocery Retail Sector

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ABSTRACT. Food waste is one of the major waste streams worldwide, linked to monetary, environmental and social implications. Food waste is generated in each one of the food supply chain stages, including the retailers. Grocery retailers are the intermediate actors among producers and consumers. Therefore, they have a key role in food waste prevention. The objective of this research is the assessment of the food waste and donation generated by a major grocery supplier in Greece. In terms of methodology, the detailed recordings of the quantity and value of each unsold food item were extracted from the grocery supplier database. The results of our assessment indicate that food waste accounted for 1.98% and 1.90% of food handled in 2019 and 2020 respectively. The key outcome is that grocery retailers can - and should - make meaningful changes to help prevent food waste generation.

Keywords: *Retail, Grocery, Supermarkets, Food waste, Food donation, Greece*

Introduction

The United Nations Food and Agriculture Organisation has estimated that one-third of food, i.e. around 1.3 billion tonnes per year, produced all over the world for human consumption is spoiled or wasted. Food loss and waste cost the world about $1 trillion a year [1]. In addition to food waste, water, soil, and energy resources are also wasted. Food loss and waste generate 8% of global GHG emissions and consume 30% of all water used by agriculture, which makes this issue a priority concern for all countries [1]. Tackling food waste is a main priority in the context of circular economy and Sustainable Development. The EU is committed to achieving a 50% reduction in food waste generation by the year 2030 [2].

Grocery retailers operate in a consumer-oriented marketplace, selling produce and packaged food products. Because of their unique position at the heart of the supply chain, they have a lot of power to influence food waste minimisation decisions [3]. Grocery retailers stand between the producers and the consumers. Therefore, retailers face contradictory challenges: at first, customers demand that a variety and quality of food be readily available, adding strain to inventory management. On the other side, high customer standards for freshness lead businesses to dispose of safe, edible food based on a perception that is past its prime.

The main objective of the work reported here is to present the variation and composition of the quantities of unsold food, food waste, and food donations in the operations (stores and warehouses) of the 2nd largest retailer supermarket chain in Greece for the years 2019 and 2020, in the context of developing an efficient waste prevention plan. This is the first research of its kind taking place in Greece and therefore the results of the current study can serve as a baseline for the country. Food waste prevention diverts food waste from landfills (which is the dominating waste management method in Greece), while food donation supplies food to people in need and fights poverty [4].

The retailer is committed to contributing to SDG 12.3, to half food waste in its operations, and to contribute to the reduction of food waste by its suppliers and customers. Moreover, the retailer is committed to food donation. To this purpose, the retailer cooperated with Harokopio University to establish the food waste and food donation baseline for the year 2019, along its whole supply chain, to provide external verification to its yearly food waste assessment for its operations, estimate food waste generation by its suppliers and customers, and set the basis for setting up and/or intensifying a range of food waste prevention activities.

Material and Methods

In terms of methodology, the detailed recordings of the quantity and value of each unsold food (or shrink) item were extracted from the company database into Excel files. Depending on the product type, the quantity was recorded either directly in weight units or in a number of items. In the latter case, it was calculated into weight, based on product information that was included in the product description in the file, or, if not available, using product information files and/or information available in the online store. Net weight (excluding packaging) was used. Where such information was not available, typical unit weights of nutrition and dietetics databases were used. Data were then classified in terms of the food supply chain stage that food waste was generated or donated. Data were also classified in terms of the in-store department that food waste was generated or food donation was realised.

Results and Discussion

The results of our assessment indicate that food waste accounted for 1.98% and 1.90% of food handled in 2019 and 2020 respectively. In addition, food donated accounted for 0.20% & 0.16%, respectively, of food handled. And finally, regarding the composition, fruits, and vegetables accounted for 32% of unsold food followed by dairy and bakery products.

Fig. 1 presents the % w/w contribution of the various supply chain stages to the generation of food waste. More than 70% of the total is food waste generated within the store operations. Warehouse food waste accounts for 4%. Food donation accounts, in total, for approx. 9.5%. Donating food to food banks is socially responsible, as it improves local communities and reduces waste generation. It also diverts food to a secondary, quality-differentiated market.

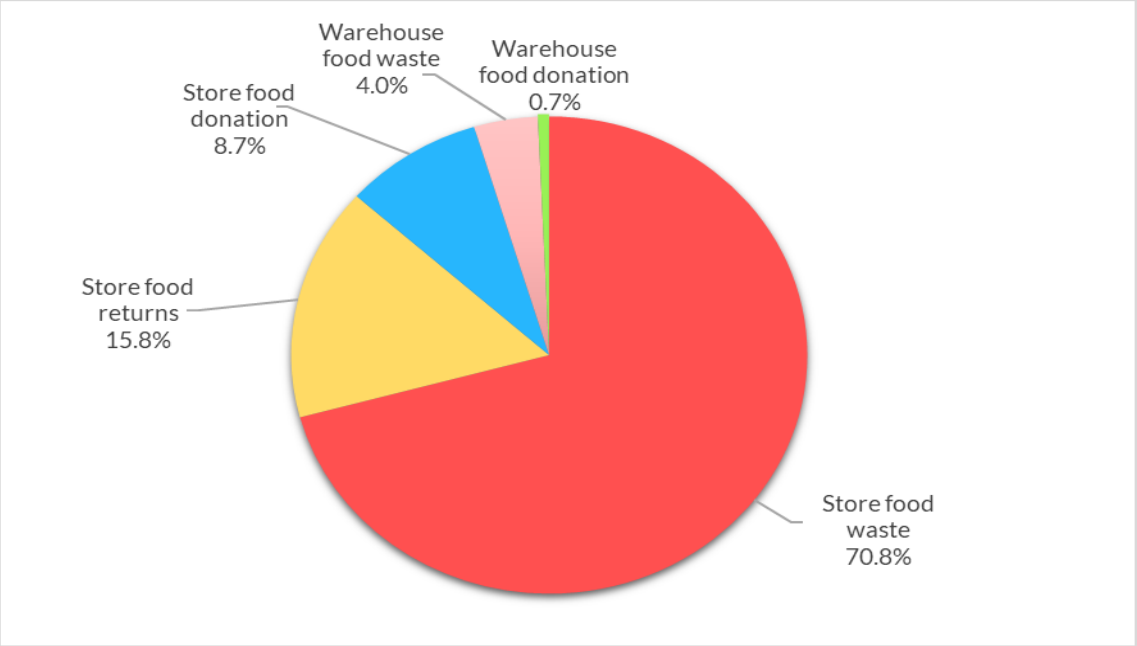

Fig.1. Contribution (% w/w) of the various retail supply chain stages to the food waste generation of the year 2019.

Regarding the % contribution of each one of the in store departments, Fig. 2 indicates that the most food waste is generated by the fresh fruits and vegetables department (32.1%), followed by the dairy products (27.4). Deli and bakery products account for the 18.5% of the total food waste, while meat and fish products, fresh or processed account for 14%.

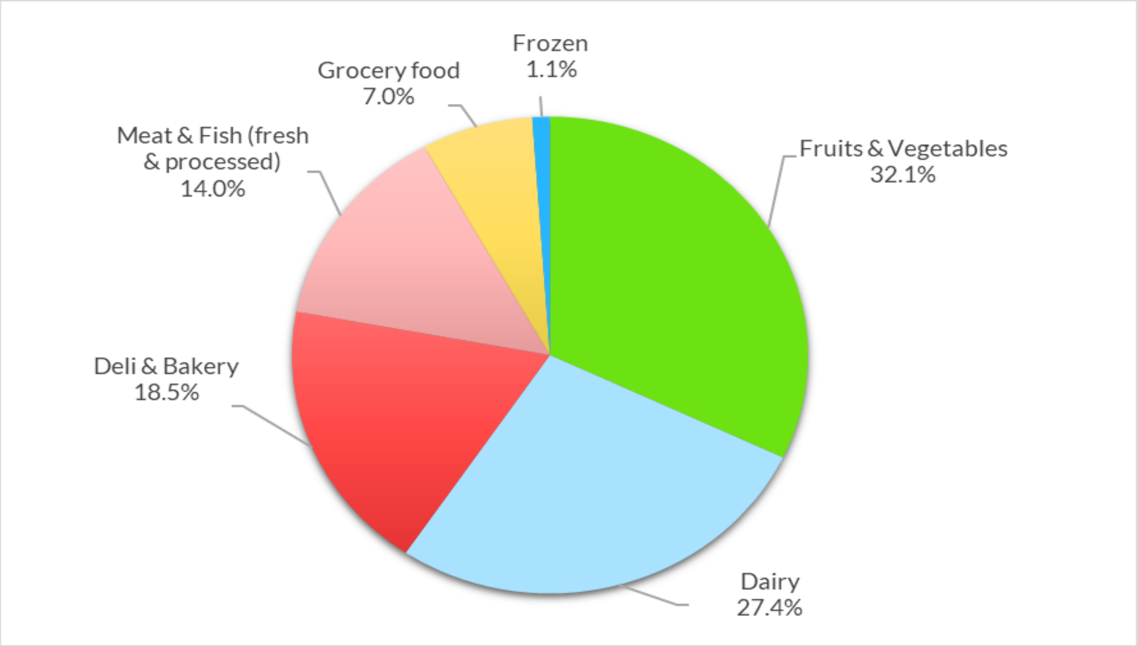

Fig.2. Contribution (% w/w) of the various in-store departments to the food waste generation of the year 2019.

Although the share of the retail sector in food waste generated along the food supply chain is very small, addressing it is important, because of its significant role in influencing food waste generation in the other stages of the supply chain (suppliers / primary production and consumers) and the potential for donation to vulnerable social groups of a large fraction of this waste. For grocery retailers, managing perishable food that is nearing expiry is a major challenge.

Conclusions

For the first time in Greece, the food waste generation data of a major grocery supplier have been quantified for the years 2019 and 2020. Food waste accounted for approximately 2% of the annual sales. Regarding the composition, fruits, and vegetables accounted for 32% of unsold food. Grocery retailers can - and should - make meaningful changes to help limit food waste. Establishing a reliable food waste baseline is the first, labour-consuming but indispensable, step in this direction.

Acknowledgement

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Catalytic Co-Pyrolysis of Sweet Sorghum Stalk and Polypropylene: Simultaneous Waste Reduction and Biofuel Production

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The COVID-19 pandemic has changed the lifestyle of people around the world. E-commerce is one of the major changes; online food delivery is widespread around the world. Therefore, the demand for single-use plastics has increased, worsening the plastic problem. Polypropylene (PP) food packets are widely used to deliver food online. In this study, used PP food packets are used for pyrolyzing with of Sweet Sorghum Stalk (SSS). Sweet sorghum is a perennial crop, can be planted in marginal lands. They had higher tolerance to salt and drought compared to sugarcane and with similar carbohydrate content as sugarcane. Their stalks are considered waste after processing. Intermediate pyrolysis of SSS yielded 42.9 wt% bio-oil and 28.6 wt% biochar as the major products. In the case of intermediate pyrolysis for PP, 52.3% of wax (highly viscous liquid) was resulted as the major product. There was no char as product in SSS pyrolysis. Remaining yield was left as uncondensed gases. Co-pyrolysis of SSS with PP were conducted with and without catalyst. The experiments were carried in a vertical tubular reactor using 30 g of feed at 600 °C and feed ratios of SSS to PP as 1:1. An increase in bio-oil yield and HHV were noticed when SSS was mixed with PP. Al_2O_3, ZSM-5, Ni- Al_2O_3 and Ni-ZSM-5 catalysts were tested for their catalytic activity on bio-oil yield and properties. However, there was no significant change in the yield when catalysts were used. The HHV for bio-oil for catalytic co-pyrolysis were about 41 MJ/ kg.

Keywords: Al_2O_3; Co-Pyrolysis; PP Plastic waste; Sweet Sorghum Stalk; ZSM-5.

Biogas Production from Agro-waste in Nanjing Tech University: Research and Practice

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Anaerobic digestion is becoming more and more attractive for the treatment of organic wastes and have been developing rapidly in the world. The biomethane production from inferior biomass through anaerobic digestion has the triple strategic significance of energy conservation, emission reduction, and resource utilization. China is one of the largest agricultural countries, which has abundant biomass resources, and the two most important types of biomass from organic wastes are the agricultural residues and animal manure. According to a 2020 estimate by the Ministry of Agriculture of the People's Republic of China, approximately 800 million tons of crop straw and 3.8 billion tons of livestock and poultry manure were produced in China. Using biogas processes, it is estimated that (1) in energy sector, 200 bm^3 of biomethane will be generated; (2) in environmental sector, CO_2 emission will be decreased 1 bton; and (3) with additional 30% fertilizer substitutions. Therefore, anaerobic waste treatment — biogas production from manure, straw and municipal wastes, is a tailored option to solve both environmental and energy issues sustainably in China. To develop new technologies and implement them into biogas processes with higher energy efficiency in a sustainable and harmless way is in the focus of research directed to next generations of biogas process. In the last few years, Nanjing Tech University got some projects about the biogas from our governmental. These projects aimed at developing a series of technology to achieve the stable and efficient biogas production and high-value use of bio-methane through the research of pretreatment of raw materails, high efficiency anaerobic reactor, new biogas purification technique, new biogas slurry utilization technology. Meanwhile, A biogas demonstration project (300 m^3 reactor) was built in the campus of Nanjing Tech University, which are combined with raw material pretreatment unit, anaerobic digestion process, biogas purification process, and the biogas slurry treatment unit. Biogas in the campus project is purified to biomethane (methane >97%) which can be used as substitute of natural gas for vehicle fuel or domestic gas, and the biogas slurry was used as fertilizer in the campus. Overall, this study confirmed that converting agro-waste to biomethane is a sustainable way for China.

Keywords: Agrofood wastes, Anaerobic digestion, Biogas, Microbial consortia, Biogas project.

Evaluation of Digestate-Derived Biochar on Humificaton and In-situ Odor Reduction During Food Waste Digestate Composting

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Anaerobic digestion is currently the most commonly used treatment method for food waste (FW) in China, accounting for approximately 80% of all operated FW treatment plants. Due to limited hydraulic retention time, FW cannot be completely converted to biogas during the anaerobic digestion process, resulting in a considerable amount of residue remaining as the byproduct, named digestate from FW (DFW). In general, digestate from food waste anaerobic digestion plants is rich in water, nutrients (e.g., nitrogen and phosphorus), and undegraded organic matter (OM). The degradation of OM contained in digestate could cause health and environmental problems if DFW is not properly managed. As a promising technology, composting can not only transform OM into stable humic substances but also recover nutrients. However, the emission of odorous gases, such as ammonia and reduced sulfur gases, is the main environmental concern associated with DFW composting. In addition, a prolonged duration is usually required for FW composting owing to the refractory OM.

In this study, DFW-derived biochar (BC-DFW) was produced in a furnace with a pyrolysis temperature of 600 ºC. The properties of digestate-derived biochar were analyzed, including pore size, functional group structure, and the speciation of concentration of metals etc. DFW composting was performed using four 100-L cylindrical reactors, with a height and inner diameter of 70 cm and 43 cm, respectively. Different amounts of BC-DFW were added to those reactors to investigate the effects on the emission of odorous gases, including NH_3 and VSCs. Compost samples were taken to analyze for pH, conductivity, germination index (GI), and elemental composition. Moreover, the fluorescence spectra of the dissolved organic matter (DOM) were determined through excitation emission matrix (EEM) fluorescence. The results showed the addition of BC-DFW can effectively enhance FW composting process and decrease the emission of odorous gases. BC-DFW exhibited a highly porous structure and high metal concentrations. The addition of BC-DFW accelerated the degradation rate of OM, which helped increased the temperature and GI. The emission of total VSCs was decreased by 15-20% with the addition of BC-DFW. Results indication the addition of 25% BC-DFW was optimal for promoting the degradation of organic matter and humification and odor emission reduction.

Combined Steam Explosion and Water Leaching Pretreatments to Upgrade the Fuel Properties of Wheat Straw

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ABSTRACT. This paper presents a new approach that involves combined biomass pretreatment techniques using steam explosion and water leaching to upgrade the fuel properties of low-quality lignocellulosic biomass waste such as wheat straw. Results revealed that, when compared to the untreated wheat straw, acid-catalyzed steam explosion of wheat straw followed by water leaching at room temperature (ASL-WS) led to obvious increase in HHV and the fuel ratio, and a substantial increase in the integration combustion index parameter. The final ash content of the treated straw can meet the specifications in the international standard for graded pellets. In addition, it had significantly greater removal efficiencies of ash, Si, and Ca when compared to pretreatment using water leaching alone. By comparison, auto-catalyzed steam explosion followed by water leaching (SL-WS) had less increase in HHV and the fuel ratio; besides, the lower removal efficiencies of ash, Si, and Ca are undesirable.

Keywords: *steam explosion properties; water leaching; physicochemical properties; combustion characteristics*

Introduction

As global demands for wood pellets continue to rise, there has been growing interest in utilizing more varied types of lignocellulosic biomass waste aside from sawmill residues to produce these fuel pellets. The alternative feedstocks include logging residues and non-woody (herbaceous) waste biomass such as cereal grain crop residues - wheat straw, rice straw, and corn stover. A major barrier that hinders the acceptance of straw as the fuel for thermal conversion processes is its low and inconsistent quality. High biomass ash content will lead to reduced fuel heating value; decreased yield, quality, and stability of the various desired products; catalyst poisoning; as well as equipment fouling and corrosion problems. The presence of silica that constitutes a high percentage of ash in straw would aggravate the fouling problem [1-3]. Hence, adequate pretreatment is required to improve the fuel properties of these biomass wastes for utilization as desirable feedstock in different types of biomass conversion systems [4]. The use of various solvents to remove elements from crop residues, forestry and energy crop biomass by leaching (washing) at a range of operating conditions (leaching temperature and duration, mass ratio of solvent-to-biomass) has been widely studied. Leaching using water as the solvent was found to be highly effective for the readily water-soluble elements (typically K and Cl), but not for Si and Ca that are bound in the cell walls, making it more difficult for their extraction. The Si removal efficiency was still substantially lower even under washing conditions with higher temperatures and long duration [5-9]. Reduction in ash content and Si content by 75% and 80% respectively was reported in one study, though mass yield was not determined after steam explosion treatment [10]. This paper presents a new approach that involves combined biomass pretreatment techniques using steam explosion and water leaching, with an aim to upgrade and determine the extent of improvement in the physicochemical and fuel properties of wheat straw.

Material and Methods

Experimental treatments and measurements of physicochemical properties

This study involves six experimental treatments, as listed in Table 1. Wheat straw was harvested and collected from a farm located in Alberta, Canada. The sample was milled by a Retsch grinder with a screen size of 3.2 mm and dried at 105 °C for 24 h in the oven. The straw used for auto-catalyzed steam explosion test was soaked in water with liquid-to-biomass ratio of 5:1 (w/w). As for the acid-catalyzed steam explosion test, 200 g (dry mass) of wheat straw was soaked in 0.5 wt% dilute sulfuric acid (H_2SO_4) with the same liquid-to-biomass ratio. The presoaked biomass was stored in a sealed bucket at room temperature for 12 h prior to steam treatment. The steam explosion test was conducted under operating conditions of (200 °C, 5 min) in a 2 L steam gun. Thereafter, the solid fraction of the steam-exploded biomass was separated from the slurry by vacuum filtration and subject to water leaching. Deionized water was used in the test under (25 °C, 12 h) operating conditions, and 20:1 water-to-biomass (w/w) ratio. After leaching, all samples were dried in the oven at 105 °C for 24 h before they were placed in the sealed bags for further analysis. The physicochemical properties of the biomass samples were measured through ultimate analysis and proximate analysis, X-ray fluorescence (XRF), and Scanning electron microscopy (SEM). Ultimate analysis was conducted using an elemental analyzer. HHV (higher heating value) of the sample was determined using the oxygen bomb calorimeter. The inorganic constituents of biomass were obtained by XRF.

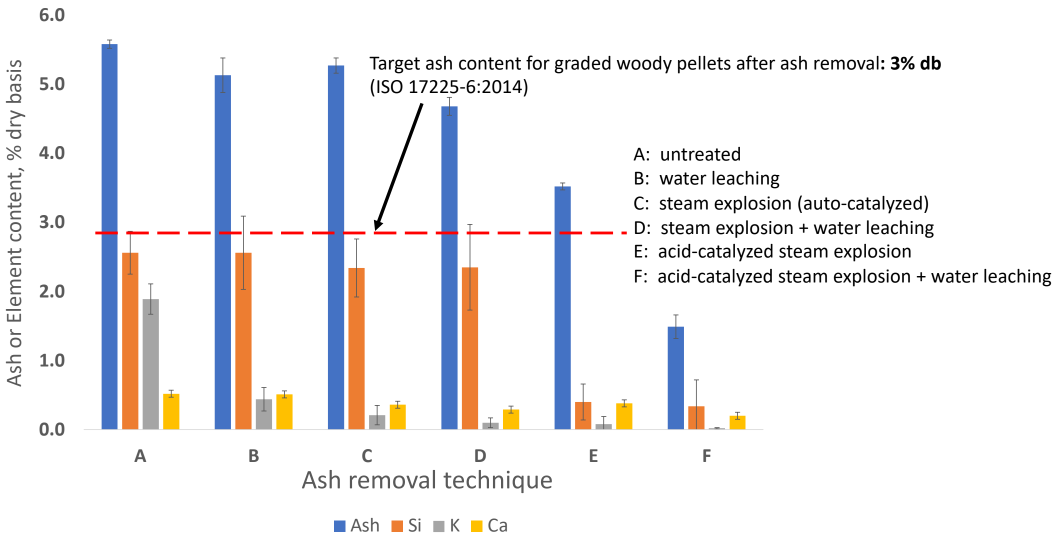

Fig.1. Measurements of ash content and elemental contents for all samples.

Results and Discussion

Physicochemical properties of treated samples

Results (Table 2) showed that acid-catalyzed steam explosion of wheat straw followed by water leaching at room temperature of 25 ºC increased the higher heating value (HHV) from 18 to 22 MJ/kg, and the fuel ratio from 0.19 to 0.34 when compared to the untreated wheat straw. The ash content dropped to 1.49% db, which can meet the specifications in the ISO standard for not only the non-woody but also the woody fuel pellets. Table 3 shows that when mass yield was taken into consideration, the removal efficiencies of ash, and the key inorganic elements Si and Ca were substantially greater at (82.2%, 91.1%, and 74.3%) as compared to (13.1%, 5.6% and 3.5%), respectively when pretreatment was done using water leaching alone. By comparison, wheat straw treated with auto-catalyzed steam explosion and followed by water leaching gave rise to lower ash, Si and Ca removal efficiencies at (40.8%, 35.7% and 60.5%, respectively. It shall be noted that, after steam explosion of the wheat straw, water leaching can be done at room temperature (25 ºC) rather than higher temperatures up to 90 ºC, thus saving energy consumption for water leaching.

Analytical combustion performance analysis

Tests were conducted in a thermogravimetric analyzer (TGA) under air atmosphere (oxidative environment) to obtain the combustion characteristics. Table 4 lists the values associated with the combustion characteristic parameters. S, the integration combustion index parameter, is a function of the heating rate used in the TGA test, the DTG curve at its peak, the ignition temperature T_i, and the burnout temperature T_b.

For the combustion process, positive effects of acid-catalyzed steam explosion (AS-WS) were lower volatile matter content and substantial increase in S at the devolatilization stage. Its values ranged from 0.26×10^{-6} min^{-2} $°\text{C}^{-3}$ for WS, to 0.69×10^{-6} min^{-2} $°\text{C}^{-3}$ for ASL-WS, while S-WS and AS-WS have values in between, suggesting that ASL-WS burned in the most vigorous manner along with the fastest burnout of the char. Besides, the value of S is greater than that obtained for some woody biomass species though not as good as bio-oil (a liquid biofuel) in previous studies. This implies a stronger combustion performance of a power plant boiler in terms of feedstock reactivity, heat transfer efficiency, and more complete combustion.

Conclusions

When compared to the untreated wheat straw, acid-catalyzed steam explosion of wheat straw followed by water leaching at room temperature (ASL-WS) led to obvious increase in HHV and the fuel ratio, and a substantial increase in the integration combustion index parameter. The final ash content of the treated straw can meet the specifications in the international standard for graded pellets. Besides, it had significantly greater removal efficiencies of ash, Si, and Ca when compared to pretreatment using water leaching alone. However, auto-catalyzed steam explosion followed by water leaching (SL-WS) had lower removal efficiencies of ash, Si, and Ca.

Table 1. Experimental treatments

Treatment	Description
A (WS)	Wheat straw without any pretreatment (Control)
B (L – WS)	Water leaching of wheat straw
C (S – WS)	Auto-catalyzed steam explosion of wheat straw
D (SL – WS)	Auto-catalyzed steam explosion of wheat straw followed by water leaching
E (AS – WS)	Acid-catalyzed steam explosion of wheat straw
F (ASL – WS)	Acid-catalyzed steam explosion of wheat straw followed by water leaching

Table 2. Ultimate analysis, proximate analysis and HHV of raw and treated samples (dry basis)

(Numbers in the brackets are the standard deviations)

	Ultimate analysis (% db)				Proximate analysis (% db)			Fuel ratio	HHV (MJ/kg)
	C	H	O	N	VM	Ash	FC		
WS	44.9 (0.07)	5.71 (0.05)	48.8 (0.15)	0.60 (0.14)	79.9 (0.10)	5.58 (0.06)	14.8 (0.09)	0.19 (0.001)	18.0 (0.06)
L-WS	45.1 (0.11)	5.50 (0.07)	48.4 (0.02)	0.38 (0.14)	80.1 (0.13)	5.13 (0.25)	15.0 (0.17)	0.19 (0.001)	18.2 (0.19)
S-WS	47.6 (0.12)	5.51 (0.01)	46.4 (0.02)	0.38 (0.14)	74.9 (0.04)	5.27 (0.11)	19.4 (0.05)	0.26 (0.001)	20.0 (0.13)
SL-WS	48.0 (0.06)	6.07 (0.03)	46.1 (0.04)	0.48 (0.14)	76.3 (0.17)	4.68 (0.13)	19.2 (0.06)	0.25 (0.001)	20.1 (0.17)
AS-WS	48.4 (0.13)	6.01 (0.01)	44.0 (0.10)	0.48 (0.14)	72.3 (0.15)	3.52 (0.05)	24.1 (0.03)	0.34 (0.001)	21.6 (0.06)
ASL-WS	48.7 (0.11)	6.03 (0.07)	44.6 (0.01)	0.58 (0.14)	73.5 (0.08)	1.49 (0.17)	25.0 (0.06)	0.34 (0.001)	21.9 (0.10)

Table 3. Mass yield (Y_m, %), ash removal efficiency (η, %), and elemental removal efficiencies (η_e, %) for Si, Ca and K.

	Y_m	η	??$_{e,Si}$	??$_{e,Ca}$	??$_{e,K}$
L-WS	94.5	13.1	5.6	3.5	78.0
S-WS	73.4	30.7	33.7	46.1	86.2
SL-WS	70.6	40.8	35.7	60.5	96.3
AS-WS	68.2	57.0	89.7	47.4	97.0
ASL-WS	66.6	82.2	91.1	74.3	99.6

Table 4. Combustion characteristic indices of all samples during the devolatilization stage and the combustion stage - ignition index(D_i), burnout index(D_b), and integration combustion index parameter(S).

	R_{max} (wt% min^{-1})	T_{max} (°C)	T_i (°C)	T_b (°C)	? $aUT_{0.5}$ (°C)	D_i×10^{-4} (min^{-1} °C^{-2})	D_b×10^{-6} (min^{-1} °C^{-3})	S×10^{-6} (min^{-2} °C^{-3})
	Devolatization stage							
WS	20.9	261.5	230.8	320.7	58.3	3.46	5.93	0.26
L-WS	19.5	290.3	244.6	324.7	64.3	2.75	4.28	0.24
S-WS	24.8	289.9	263.2	321.0	37.9	3.24	8.56	0.37
SL-WS	27.1	290.8	267.2	320.4	38.2	3.49	9.13	0.43
AS-WS	34.1	294.0	267.5	320.1	35.6	4.34	12.2	0.54
ASL-WS	43.1	293.6	270.0	321.1	33.5	5.44	16.3	0.69
	Combustion stage							
WS	0.6	367.2	349.6	423.3	40.8	1.01	2.47	0.07
L-WS	0.5	395.1	379.7	445.4	43.6	0.58	1.33	0.04
S-WS	0.4	415.1	398.7	470.6	41.8	0.47	1.13	0.03
SL-WS	0.3	427.8	403.3	496.3	74.3	0.34	0.46	0.02
AS-WS	0.5	399.7	385.3	426.4	32.8	0.67	2.03	0.08
ASL-WS	0.2	432.8	398.8	462.1	38.1	0.20	0.53	0.01

Acknowledgement

Special thanks are due to Yan Yu (Biomass and Bioenergy Research Group) and Jie Wu (Forest Product Biotechnology/Bioenergy Group) at the University of British Columbia for conducting the experiments. Fundings by BioFuelNet Canada and Agriculture and Agri-Food Canada's AgriScience program for this research are also gratefully acknowledged.

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Biochar Products, Systems and Processes in North America

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Biochar and carbon removal markets have led to the development of a variety of biochar products and systems in North America. This presentation will describe how organic recycling companies, compost facilities, farms, cities, and wood processing facilities are taking advantage of advances in science, technology, and government incentives to produce biochars suitable for agricultural and environmental markets. Results of a recent survey of the US biochar industry will be presented. Approximately 200 producers supply biochar or biochar enhanced products in North America. Production has grown to 100,000 tpy biochar (450,000 m3). Biochar markets and uses are expanding. Biochars and biochar enhanced products are found in diverse markets such as retail garden, landscaping, and agriculture. They are delivered in packaged and bulk consumer products with composts and biochar-compost blends, with biological inoculants, as biochar enhanced fertilizers, and in soil amendments, which are sold wholesale to specialty crops, horticulture, and landscape turf and tree services. Biochar products are available through major wholesale and retail outlets. Granulated products are made for horticulture, hydro-seeding, and oilfield remediation. Biochars are also used in building products. Producers expect markets to grow in crops, water filtration, odor control, and animal feed. New markets are emerging in environmental remediation, erosion control, mine reclamation, odor control and PFAS reduction in sewage treatment, and in stormwater filtration. A variety of commercial and developmental systems are used to make biochars. They are produced in small-scale systems and as co-products in large industrial gasifiers and renewable energy processes. New technologies are make biochars with biofuels and biomass energy from urban and agricultural residues.

Highly Selective Butyric Acid Production by Coupled Acidogenesis and Ion Substitution Electrodialysis

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Selective production of carboxylic acids (CAs) from mixed culture fermentation remains a difficult task in organic waste valorization. Herein, we developed a facile and sustainable carbon loop strategy to regulate the fermentation micro-environment and steer acidogenesis towards selective butyric acid production. This new ion substitution electrodialysis-anaerobic membrane bioreactor (ISED-AnMBR) integrated system demonstrated a high butyric acid production at 11.19 g/L with a mass fraction of 76.05%. In comparison, only 1.04 g/L with a mass fraction of 30.56% was observed in the uncoupled control reactor. The carbon recovery reached a maximum of 96.09% with the assistance of ISED. Inorganic carbon assimilation was believed to be an important contributor, which was verified by 13C isotopic tracing. Microbial community structure shows the dominance of Clostridia (80.16%) in the unique micro-environment (e.g., pH 4.80–5.50) controlled by ISED, which is believed beneficial to the growth of such fermentative bacteria with main products of butyric acid and acetic acid. In addition, the emergence of chain elongators such as Clostridium sensu stricto 12 was observed to have a great influence on butyric acid production. This work provides a new approach to generate tailored longer chain carboxylic acids from organic waste with high titer thus contributing to a circular economy.

Technological Advancement and Development of Circular Waste-based Biorefinery for Sustainable Production of Chemicals, Materials and Fuels

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There is a growing demand to establish waste-based processes for chemicals, materials and fuels production which can decrease our dependency on dwindling oil reserves and reduce greenhouse gases emission. Furthermore, the increasing production of petroleum derived products has led to concerns related to plastic pollution and its impacts on environment. These novel bioprocesses are incorporated into biorefineries, which are integral units converting different renewable feedstocks into a range of useful products, as diverse as those from petroleum using green and sustainable technologies. At the same time, there are growing concerns over organic waste generation and insufficient resource supply due to the increasing global population and the cradle-to-grave system of material flows in the linear economy.

Therefore, waste-based biorefinery valorisation research conducted in our team aims at valorising organic waste materials through bioconversion processes to recover their inherent nutrients for transformation into value-added products. In this talk, research projects including the bioconversion of food and beverage waste streams, agricultural residues for the nutrient recovery of value-added products, and textile waste recycling will be introduced to illustrate how science and engineering can be applied for organic waste valorisation.

The first part of the talk will illustrate the roles of various bioprocesses in waste transformation, with specific focus on biobased production of polylactic acid (PLA), succinic acid, fructose, biosurfactant, and valorisation of textile waste. State-of-the-art strategies for managing food waste in the context of techno-economic evaluation and the movement towards a circular bioeconomy will be discussed. The second part of the talk will introduce bioconversion of food and textile wastes into value-added products, with special focus on production of lipase, bacterial cellulose, polyurethane foam, personal protective equipment and sustainable aviation fuel will be elucidated.

Valorisation of Cocoa Pod Husks in Cellulose Triacetate and Lactic acid

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Cocoa pod husk (CPH) is a carbohydrate-rich lignocellulosic biomass, and it is abundant and readily available in Côte d'Ivoire to produce cellulose triacetate (CTA) and microbial lactic acid (LA) from this residual biomass. This cocoa belongs to the Amazonian *Forastero* type. The main sub-varieties are Amelonado and Arriba, and the Ivorian cocoa is of the *Amelonado* subgroup. CTA was produced after isolating cellulose from CPH, by alkaline pretreatment with 5% (w/v) NaOH and bleaching with 2 % (v/v) hydrogen peroxide. A yield of 54 % (w/w) of cellulose was obtained. Then, TAC was synthesized by acetylation reaction of the extracted cellulose in the presence of acetic acid and anhydride catalyzed by sulfuric acid. A degree of substitution of 2.87 and an acetylation percentage of 43.75 % were obtained. FTIR results confirmed the formation of cellulose acetate by the appearance of ester group (C=O) and acetyl group (C-O) stretching. XRD gave a cellulose crystallinity index of 38.43 % while indicating the semi-crystalline nature of CTA. Morphology and elemental observation (SEM-EDX) showed small and medium rough and spongy particles within the structure of the TAC and the dominant presence of carbon (C, 87%) and oxygen (O, 13%). Lactic acid was produced after optimization of the processes of delignification by KOH and acid hydrolysis by H_2SO_4. A biomass/solvent ratio of 9.14 % and a temperature of 128 °C, resulting in a degree of delignification of 93.87%. Morphological and elemental analysis (SEM-EDX) revealed several changes within the delignified matrix and the dominant presence of carbon, oxygen and potassium elements. Infrared (TF-IR) analysis confirmed almost complete removal of lignin. Optimal hydrolysis conditions were: 26.95 min, 9.53% (w/v) biomass/solvent ratio in 4.92% (w/v) H_2SO_4, yielding 18.77 g/L of reducing sugars. The hydrolyzate obtained after concentration was used to produce LA using lactobacillus fermentum ATCC 9338 in a biofermentor. A productivity of 1.25 g/L.h at the logarithmic phase after 72 hours of fermentation, a titer of 26.61 g/L and a yield of 0.52 g/g of lactic acid were obtained from 45. 55 g/L of glucose and 12.21 g/L of xyloses.

Keywords: Cocoa Pods Husk, Lactic acid, Cellulose triacetate.

Magnetic Ball-Milled Red Mud@Peanut Seedling Straw Biochar as Hydrogen Peroxide Activator for Degradation of Tetracycline

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Magnetic red mud@peanut seedling straw biochar (BMHRBC) is a composite material made from industrial and agricultural wastes. It is prepared by a two-step process of co-pyrolysis and mechanical ball milling. In this study, we evaluated the performance and complete pathway of tetracycline (TC) degradation in BMHRBC/H_2O_2 systems. Moreover, the toxicity of TC and intermediate was evaluated. TC degradation in the BMHRBC/H_2O_2 system followed pseudo-first-order kinetics, and the removal efficiency of TC reaches 90% in 120 min (TC_0=50 ppm). Some influencing factors such as pH, catalyst dosage, hydrogen peroxide concentration, ionic strength and stirring intensity were comprehensively investigated. The electron spin resonance (ESR) analysis and free radical quenching experiments indicated that both non-radical pathway and direct electron-transfer pathway advanced TC degradation. TC was oxidized by •OH and $•O_2^-$, and •OH was the dominant active species. This work probably can be called "three birds with one stone", which not only makes industrial and agricultural solid waste resources used in the treatment of antibiotic wastewater, but also facilitated understand the reaction mechanism of biochar application of heterogeneous Fenton reaction.

Biodiesel Production from Optimal Food Waste Hydrolysis by Yeast *Rhodosporidium toruloides*

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The potential of biolipid production from the effluents of existing local food waste treatment facilities was evaluated by utilizing the oleaginous yeast *Rhodosporidium toruloides*. In addition, to increase the nutrient recovering efficiency, the conditions for food waste hydrolysis by crude enzymes produced from solid food wastes by *Aspergillus oryzae* were further optimized. The optimized hydrolysis process resulted in reducing sugar (RS) yield of 251.81 ± 8.09 mg/g_{dry} (dry food waste) and free amino nitrogen (FAN) yield of 7.70 ± 0.74 mg/g_{dry} while the waste oil was easily separated. Biomass and biolipid were increased by 41.14 and 25.85%, respectively, when the hydrolysate was diluted/mixed with domestic wastewater to have 20 g/L RS. From biolipid and waste oil, the total biodiesel yield of 229.87 mg/g_{dry} was obtained from food waste, and the properties/qualities of resultant biodiesel met the ASTM D6751 standard.

On the other hand, three different hydrolysis methods (sulfuric acid hydrolysis, industrial enzyme hydrolysis, and fungal mash hydrolysis) were assessed for their effectiveness. Under the optimal hydrolysis conditions, the ratio of reducing sugar (RS) to free amino nitrogen (FAN) obtained was 218.52, 431.89, and 34.60 for each hydrolysis method respectively, and the soluble chemical oxygen demand (SCOD) of each hydrolysate was 93,067, 103,333, and 166,667 mg/L, respectively. For the lipid production by yeast, the resultant hydrolysates were then mixed with local domestic wastewater at different mixing ratios to control the different initial SCOD concentrations (22,000, 28,000, and 34,000 mg/L, respectively). The lipid produced from these three hydrolysis methods was 6.73, 7.76, and 2.33 g per kg food waste, respectively.

Keywords: Biodiesel, Biolipid, Food waste, Food waste hydrolysate, Oleaginous yeast.

Microbial Biotechnology Approaches for Conversion of Fruit Processing Waste in to Emerging Source of Healthy Food for Sustainable Environment

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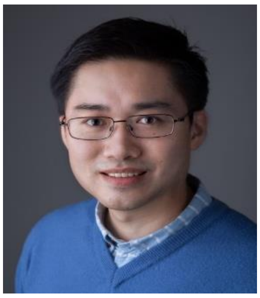
One of the most significant and difficult jobs in food sustainability, is to make use of waste in the vegetable and fruit processing sectors. The discarded fruits along with their waste materials, is anticipated to have potential use for further industrial purposes via extraction of functional ingredients, extraction of bioactive components, fermentation. As a result of its abundant availability, simplicity and safe handling, and biodegradability, fruit waste (FW) is now the subject of extensive research. It is regarded as a resource for economic development. This vast agro-industrial waste is being investigated as a low-cost raw material to produce a variety of high-value-added goods. Researchers have concentrated on the exploitation of FW, particularly for the extraction of prebiotic oligosaccharides as well as bromelain enzyme, and as a low-cost source of fibre, biogas, organic acids, phenolic antioxidants, and ethanol. Thus, this review emphasizes on various kind of FW valorisation approaches, extraction of bioactive and functional ingredients together with the advantages of FW to be used in many areas. From the socioeconomic perspective, FW can be a new raw material source to the industries and may potentially replace the current expensive and non-renewable sources. This review summarises various approaches used for FW processing along with several important value-added products gained which could contribute towards healthy food and a sustainable environment.

Keywords: Fruit waste, Sustainable food, Prebiotics, Bromelain.

Biotechnical Processes for Extraction and Recovery of Metals Value from Electronic Wastes



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Electronic waste (e-waste) refers to all electrical and electronic equipment (EEE) and its parts that have been used and discarded as waste without the intent of re-use. Globally, e-waste generation is rapidly growing at an alarming rate of approximately 2 Mt per year due to high consumption rates of EEE, short life cycles and few repair options. It is the fastest-growing part of municipal solid waste in many countries, and it has been estimated that annual global e-waste generation will reach 74.7 Mt by 2030. Along with the co-existence of various hazardous substances (e.g., heavy metals, flame retardants, persistent organic pollutants), e-waste often contains valuable and critical metals such as gold, silver, copper and other base metals, rare earth elements, lithium, and cobalt. As such, it represents a notable revenue stream, and one worth addressing to minimise the impacts associated with improper handling at the end of life. Also, considering the declining grades of primary minerals resources, developing technologies for sustainable extraction and recovery of metals from e-waste is critical to ensuring sustainable utilisation and management of resources to meet the demands of EEE.

Pyrometallurgy and hydrometallurgy are conventional technology options for recovering metals from e-waste. However, pyrometallurgy is energy intensive and demands high capital investment and supplies of large e-waste feedstock volumes to justify economies of scale. On the other hand, hydrometallurgy relies heavily on the use of strongly corrosive or oxidising chemical agents for metal leaching, rendering the process eco-unfriendly. There has been a growing interest in using biotechnical processes for value recovery from e-waste. Biohydrometallurgy is a subset of hydrometallurgy that harnesses the natural ability of microorganisms, such as bacteria, archaea, and fungi, to facilitate the extraction and recovery of metals from metal-containing solid matrices (e.g., mineral ores, e-waste) in aqueous systems. It has the potential to be a greener alternative to traditional metallurgical processes with lower energy costs and environmental impacts.

This presentation will give an overview of the research conducted at Australia’s national science agency, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), on the development of biotechnical processes for extracting and recovering metals from two types of e-waste, namely spent lithium-ion batteries and printed circuit boards with the view of supporting sustainable resource management and the circular economy. The processes include the extraction of metals into solution with biologically generated leaching reagents (e.g., ferric iron and biogenic acid), as well as the recovery of metals from aqueous solutions by bioprecipitation with biogenic hydrogen sulfide.

Keywords: Batteries, Bioleaching, Bioprecipitation, Circular economy, Printed circuit boards.

Degradation of Emerging Eecalcitrant Contaminants in Wastes and Wastewater Using Electro-technology

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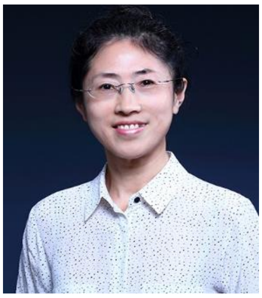
Since 20th Century, higher levels of industrialization were developed in a number of countries around the word (Canada, USA, France, China, etc.) in different sectors of activities: chemical industries, pharmaceuticals, agro-food, cosmetics, petroleum, etc. This industrialization led to the generation of effluents (industrial, municipal and agriculture effluents) more and more complexes and the appearance in environment of emergent recalcitrant contaminants (ERCs). Several ERCs (ex. pesticides, pharmaceuticals, micro-and nano-plastics, per-and poly-fluoroakyl substances, etc.) are included in the category of endocrine disruptors having toxic effects on aquatic organisms and constitute, even at extremely low concentrations, a real risk for human health. The majority of ERCs escape the conventional treatment (ex. activated sludge, bio-filtration, etc.) and can they be accumulated in biological sludge, thereby posing the problem of their valorization (agricultural spreading). To face this challenging problem of ERCs, we propose another approach for the management and decontamination of wastes and wastewater at source (before discharge back to the environment) by means of electro-catalytic processes. Electro-technologies can be considered as «green» technologies, as these techniques allow using non-polluting energy and renewable energy. The electrochemical method takes advantage of coupling chemistry (*in situ* generation of oxidant) with electronic science (electron transfer). Likewise, electrochemical treatment is generally characterized by simple equipment, easy operation, brief retention time and negligible equipment for adding chemicals. The interest of using electrochemical oxidation is based on its capability of reacting on the pollutants (such as ERCs) by using both direct and indirect effect of electrical current. Direct anodic oxidation where the organics can be destroyed at the electrode surface (owing to hydroxyl radical ($HO^•$), and indirect oxidation where a mediator (H_2O_2, $H_2S_2O_8$, and others) is electrochemically generated to carry out the oxidation

Laboratory works dealing with electrochemical treatment of hospital wastewater were carried out. An advanced electro-oxidation (AEO) process was used as tertiary treatment (after biological treatment using membrane bioreactor). The first part of this study involved the treatment of synthetic effluents doped with four pharmaceutical pollutants, namely carbamazepine (CBZ), ibuprofen (IBU), estradiol (EE) at concentrations of 10 $\mu g.L^{-1}$ and 0.2 $\mu g.L^{-1}$ for venlafaxine (VEN). AEO process used as post-treatment allows a high elimination rate (~ 97%) of the four pharmaceutical pollutants after 40 minutes of treatment at a current intensity of 0.5 A (current density 4.4 $mA\ cm^{-2}$) by usend boron doped diamond (used as anode electrode). The scond part of this study was devoted to electrochemical treatment of real hospital effluents at source. A dozen pharmaceutical products have been selected and measured to evaluate the performance of AEO process. The results showed that AEO can be successfully applied for the tertiary treatment of hospital wastewater. Indeed, a complete elimination of ibuprofen, diclofenac, sulfamethoxazole, clarithromycin and metroxazol was obtained. A relatively high reduction rate was recorded for the remaining pollutants (hydromophone, Hydroxy-diclofenac, caffeine, claritromycin, desvenlafaxine and acebutolol), ranging from 72% to 100%, except for carbamazepine (57%) and venlafaxine (41%). The toxicity analysis of the treated effluents shows an increase in the toxicity of the effluents after the electro-oxidant treatment. This increase in toxicity may be due to the by-product generated which could be more toxic than the original compound.

Some works dealing with micro-and nano-plastics (MPs and NPs) degradation in laundry wastewater (LWW) were also carried out. Water pollution by plastics is a contemporary issue which has recently gained lots of attentions. The first part of experiments consisted to make the proof of the concept of the possibility to used electro-oxidation (EO) process for MP and NP degradation. To that end, MP and NP synthetic solutions were separately prepared with distilled water and a commercial polystyrene solution containing a surfactant. Different operating parameters were investigated such as anode material, current intensity, anode surface, electrolyte type, electrolyte concentration and reaction time. The obtained results revealed that the

EO process can degrade 58 ± 21% of MPs in 1 h. Analysis of the operating parameters showed that the current intensity, anode material, electrolyte type, and electrolyte concentration substantially affected the MPs removal efficiency, whereas anode surface area had a negligible effect. In addition, dynamic light scattering analysis was performed to evaluate the size distribution of MPs during the degradation. The combination of dynamic light scattering, scanning electron microscopy, total organic carbon, and Fourier-transform infrared spectroscopy results suggested that the MPs did not break into smaller particles, and they degrade directly into gaseous products. On the other hand, the role of main reactive oxygen species (ROSs) in the electrooxidation (EO), electro-peroxidation (EO-H_2O_2), and photo-electro-peroxidation (EO-H_2O_2/UV) of NPs in water is investigated. In-situ generation of hydroxyl radicals ($^•OH$), persulfates ($S_2O_8^{2-}$), and hydrogen peroxide (H_2O_2) were performed using boron-doped diamond (BDD) as the anode, whereas titanium (in EO process) and carbon felt (CF, in EO-H_2O_2 process) were used as cathode. In the EO process, NPs were mainly oxidized by two types of ROSs on the BDD surface: (i) $^•OH$ from water discharge and (ii) $SO_4^{•-}$ via $S_2O_8^{2-}$ reaction with $^•OH$. In EO-H_2O_2 process, NPs were additionally degraded by $^•OH$ formed from H_2O_2 decomposition as well as $SO_4^{•-}$ generated from direct or indirect reactions with H_2O_2. Analysis of the degradation of NPs showed that EO-H_2O_2 process was around 2.6 times more effective than EO process. The optimum amount of NPs degradation efficiency of 86.8% was obtained using EO-H_2O_2 process at the current density of 36 $mA.cm^{-2}$, 0.03 M Na_2SO_4, pH of 2, and 40 min reaction time. In addition, 3D EEM fluorescence analysis confirmed the degradation of NPs. Advanced electro-oxidation could be the basis of a process able to degrade ERCs from different wastes and wastewater (industrial, municipal and agriculture effluents).

Fermentation of Food Waste for the Production of Clean Energy and Biofertilizer



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Food wastes are generated along the entire food processing, storage and consumption chain. The large amount of food waste from the whole process leads to not only a great economic loss but also an important environmental issue if cannot recycle potentially reusable materials. The study of food waste digestion systems, which promote its enhancement for further conversion and application to different industrial fields such as providing methane production and biofertilizer, was considered. This report discussed the biological approaches used to exploit food waste applications. The physical, chemical, biological operating parameters and factors for the process of methane and biofertilizer production are deliberated. The environmental factors and metabolites that have a major influence on digestion were analyzed. Baseline design information was discussed to develop a suitable food waste digestion system.

Keywords: Food waste; Digestion; Methane; Biofertilizer.

Enzyme Immobilization onto Clay Surface for Waste Conversion

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Enzyme immobilization techniques have been widely used to waste conversion for producing biodiesel from organic waste by biocatalytic transesterification mechanism. As highly efficient biocatalysts with high substrate specificity, selectivity, and mild reaction conditions, enzymes play a pivotal role in multiple industrial areas. However, the drawbacks of free enzymes, including high cost, poor operational stability, and challenges in recovery and reuse, have limited industrial applications of enzymes. Enzyme immobilization is an efficient route for solve these problems and improving the biocatalytic process economics by the reuse of enzyme and the enhancement of enzyme stability, thereby permitting the catalysis under harsh reaction conditions at an industrial scale. To date, a wide range of nanomaterials, including inorganic nanoparticles, nanocomposites, natural nanostructured minerals, and polymers, have been investigated as support matrix for enzyme immobilization. Studies indicate that nanomaterials can improve the efficiency of immobilized enzymes by reducing diffusional limitation as well as by increasing the surface area per mass unit and therefore improving enzyme loading. Montmorillonite (Mt) is an important smectite clay mineral that has been confirmed as a desirable phyllosilicate carrier for immobilization of enzyme due to its natural swelling lamellar nanostructure, exchangeable interlayer cations, high specific surface area, biocompatibility, and easy surface functionalization (rich silanol groups, Si-OH, on the surface, after activation by different functional groups act as attachment sites for bioactive species. In the present study, lipase was immobilized on 3-aminopropyltriethoxysilane (APTES) amphiphilic functionalized montmorillonite (Mt) support via 1-(3-Dimethylaminopropyl)-3-ethyl-carbodiimide hydrochloride (EDC) spacer. The APTES-Mt and APTES-Mt based nanostructured biocatalyst (lipase-Mt) were characterized by XRD, FT-IR, TEM, SEM and contact angle analysis. The results indicated that lipase-Mt activity was 40.65 U/mg, which was nearly 4-fold higher than that of free lipase under optimal conditions. The Michaelis-Menten constant (K_m) were found as 0.357 mM and 3.406 mM for free and lipase-Mt, respectively. The maximum reaction rate (V_{max}) for the free and lipase-Mt were calculated as 63.69 mM/(L·min) and 312.5 mM/(L·min), respectively. Further, the interfacial activation by amphiphilic surface of APTES-Mt and enlarged catalytic interface contributed to the improved activity and storage stability of lipase-Mt. Thus, this work demonstrate an economically viable method for constructing nanostructured biocatalyst for industrial applications based on covalent immobilization of enzyme onto clay minerals.

Keywords: Montmorillonite; Organoclay; Biocatalyst; Enzyme immobilization.

Technological Advances in Bio/Electrochemical Carbon Dioxide Capture & Utilization (CCU)

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Recent years have seen a sharp rise in the share of renewable energy production. This renewable power usually often leads to energy surplus. Storage (batteries, water pumping or hydrogen production) have been proposed to exploit this surplus. One of the novel alternatives is to use excess electricity to convert CO_2 into organic chemicals and fuels. Growing rapidly, currently 25% of the global electricity capacity is now comprised of renewable energy sources, thus providing great opportunity for CO_2 reduction (CO2R). As per International Renewable Energy Agency (IRENA), at the end of 2018, the installed global renewable energy generation across wind, solar, hydroelectric, was near 2351 GW. CO2R pathways have the possibility to directly use electricity in the conversion step or indirectly via other energy carriers (e.g., H_2) in the so called Power-to-X approach. Most common conversion pathways include electrochemical, bioelectrochemical, plasma and thermochemical conversion. Commercially mature non-reductive routes which are such as enhanced oil recovery, food and beverage, and concrete curing also exist. The latter though more mature, provide fewer opportunities for electricity utilization compared to reductive routes. The (bio)electrochemical CO_2 reduction provides a viable option for reducing anthropogenic CO_2 emissions, while at the same time closing the carbon cycle, by selectively converting CO_2 to fuels/chemicals. Currently**,** CO, ethylene, and formate are considered as best possible option as each has been synthesized electrochemically with partial current densities >100 mA cm^2, often considered as commercially relevant current density, at a faradaic efficiency >60%. For the indirect route, methanol and methane are at high current TRL (i.e., low technical barriers to formation) and high achievable rates of formation. In this presentation, along with a general overview of CCU, VITO's research on CO_2 conversion using bioelectrochemical and electrochemical approach will be presented.

Pre- and Co-processing of Tailor-Made Alternative Fuel

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ABSTRACT. A landfill can be reclaimed for environmental reasons (e.g., contamination of groundwater) or for economic reasons (lack of building land). After probing and breaking up the soil, hazardous and non-hazardous wastes may now be found from a variety of sources, and in varying degrees of biodegradation in unknown quantities and composition. In order to use these incompletely bio-degraded materials as alternative fuels for the cement industry, the thermal process must be understood as a manufacturing process, first. Cement is a standardized product and the upstream clinker burning process is not an omnivore! Up to a kiln-specific thermal substitution rate (TSR), the clinker burning process is indeed a well-behaved burning process that forgives fluctuations to a certain extent. However, When the TSR in-creases, the good-natured clinker process is strained and the pyro process becomes uncontrollable. The cement production process is divided into the mechanical raw material extraction in the quarry, homogenization and raw meal grinding. Next comes the feeding of the raw meal into the preheating and calcining process and the feeding to the rotating part of the kiln, the pyro process of the so-called clinker burning process in which the fossil fuels shall continuously be substituted. After cooling down the clinker when leaving the rotary kiln at the end of the kiln, the clinker is blend with additives such as sulphates, slag, calcined clays, fly ashes, etc. and ground to a binder that meets the standards. Consequently, the right waste processing technology now plays a key role in the production of demand-oriented alternative fuels.

Keywords: *waste source, waste composition, thermal process, clinker burning, HCF, RDF, SRF, quality assurance Manuscript; template; conference; Hong Kong*

1. Initial position

Against all odds, the European cement industry was early to point out that alternative fuels (AFs) sufficiently derived from waste can be used without harming its pyro process, the standardized product, and the emissions. As a result, they are now both targeted by national waste management strategies

Now, waste management worldwide is being transformed into a national and sustainable waste management strategy to enforce legal rights and obligations and to comply with the spirit of the Basel Convention, which is committed to a preferred regional approach and the polluter pays principle.

But disposing off in co-processing is not the ultimate solution to eliminate non-recyclable wastes, especially of plastics, which now pollute our entire livelihood from soil to sea. Often, it is overseen that the industry is producing cement for a fluctuating market and can only provide his pyro process as a part of the solution. For example, at a theoretical thermal substitution rate (TSR) of 100%, the German cement industry, with its annual energy demand of about 94 million GJ over the past 10 years, could use only 14% of the total thermal energy provided by the energy content of the entire waste. The waste must either be avoided, used elsewhere or materially recycled.

So, when a virgin cement plant starts co-processing of AFs, the clinker burning process offers a gentle combustion process for trials and errors. This, with a few exceptions, forgives many of the operational and technical mistakes, and lousy AF qualities because of its low feeding rate, the high temperatures and lime surplus. Therefore, the calciner is also the most popular starting point for the use of low-quality RDF. But, due to the oxygen concentration and the burnout time, it is not quite simple from the point of the pyro process and emission.

In contrast, it is easier to use SRF at the main burner, where trails can be realized very cost-effectively by a simple docking station and a straight pneumatical line with a minimum of bows and knees. However, the SRF must then also have lignite-like properties, burn out shortly, and have good particle trajectories without touching the clinker bed and causing reductive burning conditions.

Table 1: Range of AF qualities processed from high-calorific fraction from municipal solid waste [2].

Parameter	wt.-% DM
Calorific value	16.700 – 25.700 kJ/kg
C	48,2 – 54,1
H	7,3 – 8,5
O	32,5 – 34,1
N	0,76 – 1,35
S	0,1 – 1
volatile matter	n.d.
Ash	13,6 – 46,7
CaO	26 – 32,1
SiO_2	22,6 – 30,5
Al_2O_3	7,82 – 60
Fe_2O_3	4,26 – 6,75
Cl	0,8 – 4,3
F	0,02 – 0,09

Trace elements	ppm DM
As	0,48 – 7,33
Pb	131 – 30.176
Cd	2,1 – 55
Cr	82,73 – 3.029
Ni	14,19 – 3.658
Hg	0,28 – 3,39
Tl	0,18 – 5,90
V	5,19 -135

Table 2: Recalculated input criteria for alternative fuels for co-processing in a dry process with preheater and calciner without affecting the limit emission values according to the directive 2000/76/EC on incineration of waste.

element (glow loss free)	concentration
CaO	Single or total ≥ 50 Gew.-%
SiO_2	
Al_2O_3	
Fe_2O_3	
Mercury (Hg)	≤ 1,5 ppm DM
Cadmium (Cd)	≤ 50 ppm Dm
Thallium (Tl)	≤ 45 ppm DM
Other non-volatile trace elements	≤ 20.000 ppm DM

To ensure the high-temperature process nevertheless, the alternative fuel (SRF) for the sinter zone burner should be based on the properties of lignite with a calorific value of 22± 2 MJ/kg.

Up to a thermal substitution rate (TSR) of approx. 25%, the behaviour of the kiln is tolerant; however, as the TSR increases further, the behaviour and quality of the AF dominates the pyro-process and thus the entire clinker burning process. In other words, the higher the TSR, the more precisely all the respective AFs must be prepared and controlled accordingly.

2. Use of alternative fuels in the calciner

In modern rotary kilns with calciner, only 40 % of the thermal heat requirement is covered by the sinter zone burner at the kiln end, while 60 % is fired from one or more points in the calciner at the beginning of the process. In this case, the required combustion air from the clinker cooler is fed into the calciner via a tertiary air duct to support the deacidification of the limestone of 850 to 900°C.

The general sequence of drying, pyrolysis, ignition, and combustion of the fuel takes much longer here than the calcination of the raw meal, which is therefore the decisive factor for the dimensioning of the calciners.

Typically, RDF lump sizes from 50 up to 100 mm are introduced there, so that the fuel particles can burn out within 5 - 8 sec before their ash ends up in the kiln inlet and will become part of the clinker formation process. Therefore, are now various possibilities to design calciners according to the fuel properties and allows control via the combustion temperature and combustion air, respectively, in order to reduce NOx emissions as well.

3. Use of coarse fuels in the calciner

Since pre-processing can become too expensive for certain reasons (e.g., in the case of glass fibre-reinforced plastics from wind blades, tar paper or the like) or the burnout of the calciner fuels cannot take place completely (e.g., in the case of tree roots, whole truck tyres, etc.), there is the possibility of an additional pre-combustion chamber.

There are currently three chamber systems on the market that enable the use of these difficult HCFs, which only need to be coarsely crushed to 300-500 mm for storage, dosing, and transport reasons.

One system is the so-called Hot Disc from FLSmidth, over its slowly rotating turntable the course HCF enter the hot gas stream of the calciner. The coarse materials are dried, pyrolyzed and, after a dwell time of about 10 minutes, are ejected by a crowbar into the rising gas stream of the calciner. Further burnout takes place in the usual calciner loop. The system works best with fractions, which all have very similar thermal behaviour.

The so-called step combustor from ThyssenKrupp-Resource Technologies also introduces coarse-grained HCF with a low calorific value (high water content) into the calciner. In this process, the fuel is not necessarily cleared, but is only conveyed further towards the calciner loop when it is completely ashed and can be pneumatically conveyed. This system is thus also suitable for inhomogeneous fuels with varying combustion behaviour. The retention time can therefore vary extremely among each other.

The third unit is from KHD and the latest on the market, where a rotary tube is installed between the tertiary air duct and the calciner. Depending on the grain size and combustion behaviour coarsely processed HCF, whole tyres or biomass can be fed. The required retention time is set via the rotation speed. However, as with the HotDisc, a certain knowledge of the burning behaviour of the individual fractions is required to regulate the residence time, properly.

4. Modification

As already mentioned, the clinker burning process is not a disposal process. With increasing TSR, the good nature of the kiln process is increasingly strained.

Therefore, absolute attention must be paid to all the requirements of the pyro process, and the quality of the waste input to produce suitable HCF for the pre-combustion chamber, RDF for the calciner and SRF for the kiln end burner.

Indeed, cement manufactures do not always know exactly how tolerant their kiln is and what happened, e.g., regarding water vapour, gas balance, tendencies of alkaline, chorine and sulphur to form circles, and its energy demand or oxygen content at the point of application. But ultimately it is more effective than worrying about expensive conversions of the pyro-process or using standards and fancy supply specifications, which cannot be controlled due to missing commitments. Later it is important for the accounting basis or the CO_2-neutral content for the need of GHG-allowances.

Before starting the pre- and co-processing, the key data of each kiln must be determined by the sound individual inspection. It makes absolutely no sense to seek in general literature or on the Internet. The technology, chemistry and individual kiln type are decisive for the planning of the waste conditioning pant. Therefore, it is not only imperative to distinguish the different AF types verbally and to know some general specifications, the conditions at each feeding point must be well known and specified, as well.

The pre-processing plant must be designed properly to ensure the production of customized alternative fuels. For example, wet kilns or old kilns equipped only with a preheater are not suitable for co-processing a low-grade RDF with a grain size of 80 - 100 mm. Due to the lack of the calciner, SRF with a size <25 mm, and a calorific value like lignite, free of 3 dimensional particles must be produced. In contrast, modern kilns have the possibility of feeding SRF through the kiln end burner, RDF to the calciner and HCF to the precombustion chamber.

Both, the results are important for the effort and items required, the plant operation and the needed design to produce suitable and quality assured AFs and to determine the viability of the co-processing project.

5. Purpose and design of a conditioning plant

The origin of the raw untreated waste no longer plays such a role, today. Modern and well-equipped AF-conditioners are in the position to produce qualities in line with its demand by means of suitability tests, material flow management and quality assurance to paying attention in terms of several types of qualities regarding:

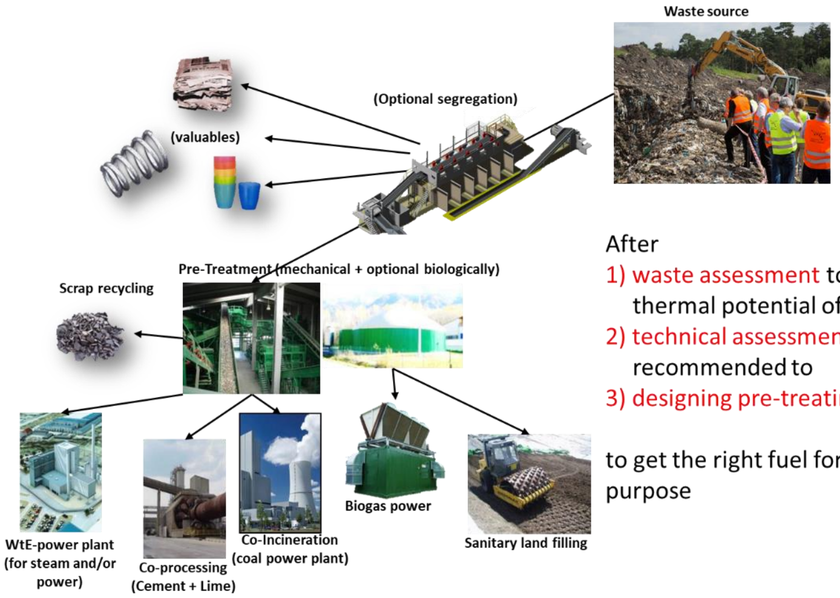
1) emission in accordance to air pollution control,
2) the process of clinker formation with respect to product,
3) and the combustion process incl. disturbances affecting the durability of the brick lining by corrosion, circuit formation, clogging etc.

To match all these requirements the AF production must start with a suitable inspection and reliable acquisition for waste streams.

In countries developed in terms of waste management, commercial and industrial waste (C+IW) can be collected separately at the point of origin. This supports mostly the goal of recycling and avoids contamination from wet organics, minerals, hazardous waste, and other impurities, resulting in a significant reduction in the capital expenditures for sorting and fuel processing. Instead of costly equipment, more effort is put here into a selective acquisition and a reliable chemical analysis in advance.

In contrast, municipal waste (MSW) is usually collected in a "one-ton system" (sometimes already in a separate wet-dry collection - "two-ton system"), but mostly dumped in mixed form at landfill, where a simple conditioning system is already in place. There is no possibility of a qualitative intervention and the (public) plant operator must accept what comes in. A mechanical-biological treatment plant (MBT) - also starting with the biological step before the mechanical treatment - ultimately remains a "splitting plant". If the organic content and thus the main input for moisture is known, the sequence of the process steps can certainly be changed into a bio-drying to take place before a generous segregation by sufficient vibro screening and wind sifting.

It increases the recycling potential according to the determined results of the waste assessment and technical kiln assessment, and shall separate interfering and contaminating substances from recyclable materials, makes compost out of organic matter and produces demand-oriented AFs out of the segregated combustible HCF. It is obvious that the processing depth of each step consequently varies depending on the composition, goal, purposes, and reliability of the installed equipment.



After
1) waste assessment to identify the thermal potential of waste a
2) technical assessment is recommended to
3) designing pre-treating process

to get the right fuel for its right purpose

Fig. 1: The strategy and goal(s) must be defined in advance to determine the solution as well as the financial requirements for a meaningful and sustainable operation.

Thus, MBTs are becoming "servants of several masters" and shall serve an important contribution in the interplay of a governmental waste and climate policy. However, if the conditioning does not fulfil its purposes or the cement works is polluting the environment by poor AF-qualities, the reputation is quickly gone – also with the government, publicity, and banks behind.

In fact, the treatment of solid waste in MBTs has a state-wide $CO_{2eq.}$-reduction potentials, which are the sum of several "avoidance potentials":

- ✓ Avoidance of wild dumping and diffuse emission of methane,
- ✓ Controlled guidance by banning landfilling of untreated waste,
- ✓ The increase in disposal fees and sanctioning should encourage people to reduce their amount of waste,
- ✓ Separate fermentation of organics generates biogas and subsequent composting fertilisers,
- ✓ the recovery of recyclable materials in upstream chains can be shortened or even eliminated,
- ✓ use of alternative fuels inclusive proportions of non-recyclable paper, cardboard, textile, natural rubber etc. will substitute carbon and hydrocarbons from fossil fuels.

Acknowledgement

At this point I would like to mention that everything is based on the international practical experiences of my colleagues and I in my engineering and consulting office WhiteLabel-TandemProjects/ Germany. Therefore, I would like to thank Prof. Klaus Fricke/ TU Braunschweig, Prof. Jonathan Wong/ Hong Kong Baptist University and his team for the invitation and the opportunity to share these practical experiences with the scientifically savvy audience at the ICSWHK 2023.

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and Climate Resilience

Anaerobic Digestion

Factors that Limit Decomposition of Organic Fraction of Non-recyclable Municipal Solid Waste in a High-solids, Leach-bed Anaerobic Digestion Process

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Anaerobic digestion of municipal solid wastes (MSW) involves the biological conversion of organic matter to biogas, a mixture of methane and carbon dioxide. This conversion process is mediated by several groups of prokaryotic microorganisms. It is generally accepted that hydrolysis is the rate limiting step of anaerobic digestion of organic particulate matter. However, when considering the overall conversion of organic particulates of MSW to methane and carbon dioxide in a high solids bioreactor, the hydrolysis process, the availability of appropriate microorganisms, delivery of these microorganisms and the provision of optimal physico-chemical conditions for microbial growth could all affect the rate of degradation. Among the various technologies that are available for anaerobic digestion of organic fraction of municipal solid waste, the high-solids, batch, leach-bed process offers several advantages. The process does not require fine shredding of waste, does not require mixing or agitation of digester contents, and does not require bulky, expensive, high-pressure vessels as it can be operated at low (ambient) pressures. The process can be implemented in bioreactor landfills as well as in-vessel digesters. SEBAC (sequential batch anaerobic composting) is a patented high-solids, batch, leach-bed process that uses a combination of solid-state fermentation and leachate recycle to provide a simple, reliable process that inoculates new batches of waste, removes volatile organic acids and concentrates nutrient and buffer. Methanogenic decomposition is initiated in a fresh bed of waste by flushing it with leachate collected from a methanogenically stabilized MSW bed. It has been widely accepted that this operational strategy provides the fresh bed of waste with inoculum, alkalinity, micro and macro nutrients from the stabilized waste bed, thereby overcoming the limitations to decomposition. The purpose of this research was to identify the critical limiting factor among the many that impedes anaerobic methanogenic decomposition. Both biological (microbial inoculum and extra-cellular enzymes) and physico-chemical (micro and macro nutrients, and pH buffer) factors were investigated. Experiments were carried out in 200 liter insulated, 316-stainless steel vessels. These were fitted with heating tape, thermocouples, automatic temperature control, gas flow meter and leachate pumping equipment. Feedstock used was unsorted, coarsely shredded (average particle size 10 cm) municipal solid waste collected from transfer station. To minimize the effect of feedstock variability in experiments, it was collected in one grab of 1–3-ton batches and stored in a commercial freezer at -20ºC in 120-liter plastic drums. Appropriate quantities of feedstock were removed from the freezer, thawed for a day, and loaded into the anaerobic digesters. Experiments included flushing micro- and ultra-filtered leachate, and nutrient and pH-buffer solutions into the fresh MSW bed. Biogas production, methane composition, pH and concentration of volatile organic acids were monitored. The main findings were inoculation and provision of extra-cellular enzymes are not the major factors limiting start-up; the flushing of pH buffer solution resulted in rapid start up; the start-up of the degradation of a fresh MSW bed could not be initiated without the provision of pH buffer and a fresh bed of MSW was not nutrient and inoculum deficient.

Keywords: Municipal solid waste, Leach-bed, Anaerobic digestion, Biogas, Bioreactor landfills.

Biodegradability Evaluation of Plastics in Organic Solid Waste Using a Novel Volumetric Respirometer

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Knowing the biodegradability of organic matters or biodegradable material under defined conditions is crucial for both operation of biological waste treatment processes and development of environmentally friendly materials with low negative impacts on environment. Traditionally biodegradability assays have been made manually had proven problematic, providing highly variable, unreliable result. These assays are also time-consuming and labor-intensive laboratory work that requires a high skill of the personnel performing the analysis. In order to obtain reliable results, any repeated analysis should be reproducible with good accuracy. In this study, aerobic biodegradability of bioplastics that may present in organic solid waste steam is evaluated using a novel closed respirometer based on volumetric gas measuring technique. The biodegradability of four types of bioplastics sample (PHB, PLA, PLLA, PBS) in both powder, film and granule forms are tested at home composting conditions. The biodegradability assay under home composting condition has been performed over 200 days. All samples including cellulose positive control are tested in triplicate. The tests of plastics were conducted under 23-25 ºC in 1L bottle with 1.5 g of test material and 100 g of compost. The assay was conducted based on oxygen demand measurement using the volumetric respirometer for on-line and continuous measurement of oxygen consumption or depletion caused by aerobic respiration of microorganisms. The test protocol is considered to fulfil the general guideline of AS 5810 for home composting and ISO 17556 for ultimate aerobic biodegradability test in soil. Aerobic biodegradability based on on-line continuous measurement of oxygen consumption or depletion demonstrates multiple benefits against conventional methods replies on off-line manual measurement of evolved carbon dioxide. As demonstrated in the current study, the degradation kinetics of cellulose and PHB powder in the home composting condition showed the fastest initial degradation rate, and PHB powder showed the highest biodegradability. PHB powder (natural origin) shows an easily degradable property, which obtained an over 90% of biodegradation rate after 67 days and without a lag phase, and it reached to 100±10.2% after 200 days. While PHB granule with 5 mm diameter only degraded 9.5±2.0%. PBS powder shows as a difficult degrade plastic, which only degraded 26.5±4.6% after 200 days. 1cm×1cm and 0.05 mm thick PLLA film, and PLA particle with 3-5 mm of diameter can hardly degrade based on the test result. However, there is a sign of starting to degrade with an increase degradation rate after 200 days. They might be degradable if the tests last even longer. The test is considered valid as the degree of biodegradation of microcrystalline cellulose reached more than 60% in less than six months (it was 75.1±1.9% in this study) and all the blanks are within 20% of the mean at the end of the test (i.e., the standard deviation was less than 2% for all blank). As a conclusion, the oxygen demand measurement using automated respirometer demonstrates much higher measurement reliability, accuracy and precision.

Keywords: bioplastics, biodegradability, home composting, aerobic, oxygen demand, respirometer.

Deciphering Molecular Transformation Behaviour and Potential Molecular Markers in Advanced Anaerobic Digestion of Sludge by FT-ICR MS Nontarget Metabolomic Analysis

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Process monitoring is the essential way to ensure stable operation of full-scale biogas plants which often encounter process instability, but selection of an appropriate indicators relating to metabolic status for early-warning is still in its early stage and also a challenge. This study explored the DOM transformation patterns along with advanced anaerobic digestion of sewage sludge, especially, presented a novel strategy to track the potentially molecular markers of metabolic status based on Fourier transform ion cyclotron resonance mass spectrometry (FT-ICR MS) nontarget analysis and subsequent chemoinformatic analysis. Results showed that the molecular compositions of dissolved organic matter (DOM) presented a consistent evolution patterns among different plants, including dramatic release of N-containing molecules (accounting for 69.95%-74.93%, including CHON and CHONS), increased humification of organics with high aromaticity, and high proportion of CRAM-like compounds especially as refractory components ($O/C > 0.3$) along with industry-scale advanced anaerobic digestion. By further data mining with constructed DOM connected network, it was emphasized that sulphur containing transformation perhaps played important roles in metabolism in anaerobic digestion for its appearance with high frequency. According to the nexus of the microbe associated DOM molecules, some metabolites were recognized as potential indicators relating to metabolic status, including the known important metabolites, e.g., L-cystathionine and Coenzyme B. This study suggests that FT-ICR MS measurement coupling with further chemoinformatic analysis can explore “fingerprint” and potential molecular markers to track the DOM transformation and metabolic status in anaerobic digestion, which will assist in finding new indicators for early-warning. To our best knowledge, though the use of FT-ICS MS for characterizing DOM behaviours in biological treatment process of wastewater and biowaste is increasing, still rare works ever explored the DOM transformation especially tracked the keystone molecules and metabolites from the detected thousands of molecules. Overall, this study was the first to present the capacity and feasibility of using FT-ICR MS to explore the behaviour and roles of DOM in biological treatment process from macroscope to deep microscope for a specific molecule. These findings prove that ultrahigh resolution mass spectrometry and further data mining provides a novel way to track the important roles of DOM in biological treatment process, which will not only fill our knowledge gap but also assist in exploring new “fingerprint” and molecular biomarkers for an early-warning of metabolic status.

Keywords: Anaerobic digestion; FT-ICR MS; Chemoinformatics; Transformation; Molecular marker.

Effect of Micro-Nano Zero-Valent Iron on the Metabolic Profiles of Fermentative Bacteria

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This study evaluated the combined impact of micro-nano zero-valent iron (*m/nZVI*) (0-5,000 mg/L) and acid-treated inoculum on fermentative hydrogen production from food waste. Results revealed that *m/nZVI* concentration above and below 500 mg/L decreased H2 production rate and yield. The cumulative H2 production was 2223.4 ± 83.5 mL/L of cultural medium (or 222.34 ± 8.35 mL/g VS) with 500 mg/L of *m/nZVI* compared to 1869.04 ± 42.69 mL H2/L. Acetic and butyric acids were the main organic acids accumulated along with the evolution of H2. The genomic analysis revealed that *Firmicutes*, *Bacteroidota, Actinobactriota*, *Proteobacteria*, and *Thermotoga* were dominant at the phylum level, whereas, *Clostridium_sensu_stricto_1* and *Bacteroides* were dominant at the genus level. Overall, adding m/nZVI improved H_2 yield by 19%, possibly due to the improved electron transfer mechanism, and positively influenced metalloenzymes that catalyze H_2 production via the pyruvate-ferredoxin oxidoreductase (PFOR) pathway.

Keywords: Fermentation, Biowaste, Micro-nano zero-valent iron, Biohydrogen, Acidogens.

Regulation of Acidogenic Fermentation Through Exogenous Additives for Promoting Carbon Conversion of Food Waste in Two-Phase Anaerobic System

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ABSTRACT. The use of internal H_2 from acidogenic phase instead of external H_2 has provided another alternative to improve methane production In two-stage fermentation process, butyrate is identified as the typical H_2-producing pathway, which is produced by the lactate conversion process. As revealed by our previous study, *Megasphaera* was the functioning bacterium enabling lactate-butyrate conversion, where butyryl-CoA: acetate CoA-transferase pathway (*but*) attributed to the major butyrate production. Interestingly, external acetate supply is required to facilitate this pathway for butyrate generation. Therefore, in this study, we introduced exogenous *Megasphaera* inoculum and acetate supplement to acidogenic phase to assess their effects on FW carbon conversion in a Leach Bed Reactor (LBR)-Upflow Anaerobic Sludge Blanket (UASB) AD system. The two additives significantly accelerated organics removal efficiency in solid waste. Subsequently, the FW hydrolysis and acidogenesis in LBR with both additives were individually increased 16% and 35% as compared to those in the control without any additives. As expected, two exogenous additives successfully shortened lactate fermentation and accelerated butyrate fermentation. Under the role of bio-chemical exogenous additives, both hydrogen and butyrate yields increased by over 60%. This desired enhancement resulted in a 25% increase in methane production. Eventually, the overall carbon conversion from FW in two-phase AD system with off-gas diversion significantly increased from 32% to 42% ($p<0.05$) when exogenous additives were applied to regulate acidogenic fermentation. This confirmed the benefit of exogenous functioning additives on FW carbon conversion in two phase AD system. It provides a new insight for the potential of developing approaches for manipulating two phase AD process.

Keywords: acetate supply, Megasphaera, leach bed, fermentation pathway, methane

INTRODUCTION

Food waste (FW) contains large concentrations of volatile solids and oils, and is rapidly degradable in nature, affecting the generation and consumption of organic acids in traditional anaerobic digestion (AD) system. Our previous studies revealed that an increase in partial acidification could significantly stimulate the activity of a methanogenic reactor placed in series with a hydrolysis-acidogenic reactor (Wang et al., 2009). The conditions in the first reactor should be optimized to achieve the maximum acid production rate. In addition, we proposed to transfer acidogenic off-gas to the methanogenic phase to reduce carbon loss via the acceleration of hydrogenotrophic methanogenesis (Yan et al., 2017). Thereafter, maximizing H_2 production accompanied by increasing acidogenic performance becomes the key strategy for improving methane recovery in a two-phase AD with acidogenic off-gas diversion. According to our previous results, there are two fermentation processes that occur in an acidogenic LBR: lactate-type and butyrate-type fermentation pathway (Luo et al., 2021). Lactate accumulation possibly resulted in more acidification and thereby inhibited bacterial growth (Othman et al., 2017) which delayed the occurrence of butyrate fermentation. Further, lactate is not a favorable carbon source for methane production because it can be easily converted to toxic propionate when it is the dominant component in the substrate (Zellner et al., 1994). Compared with that of lactate-type fermentation, improvement of butyrate-type fermentation greatly contributed to increased FW carbon conversion efficiency in an acidogenic LBR (Yan et al., 2017). Most importantly, butyrate-type fermentation is a typical H_2-producing pathway in anaerobic fermentation (Luo et al., 2019). Thus, butyrate fermentation is desired for our acidogenic LBRs. *Megasphaera* has the capability to convert lactate to butyrate, which is the functional bacteria at the second fermentation stage. Ohnishi et al. (2010) successfully applied *M. elsdenii* in anaerobic fermentation to produce butyrate by accelerating lactate conversion and H_2 production. However, studies on the utilization of *M. elsdenii* in promoting solid-state FW fermentation and increasing methane production are lacking. In theory, butyrate can be produced through the butyrate kinase (Buk) and butyryl-CoA (But) pathways (Louis et al., 2004). When butyrate production was attributed to lactate conversion, the pathway from acetyl-CoA to butyryl-

CoA probably served as a major carbon metabolism channel in *M. elsdenii* (Chowdhury et al., 2015). Thus, the key reaction for butyrate synthesis is the formation of butyryl-CoA, which can be obtained from two molecules of acetyl-CoA. Duncan et al. (2002) reported that excess acetate could stimulate the synthesis of But, indicating that acetate can be predicted as the main factor affecting butyrate production. In this study, we hypothesized that the addition of acetate could stimulate But formation in *M. elsdenii* to facilitate lactate-butyrate conversion. Therefore, *M. elsdenii* was first inoculated in acidogenic LBRs to determine its feasibility in improving butyrate and H_2 production and thus promote methane conversion in the present study. The effects of extra acetate in the *M. elsdenii*-inoculated two-phase system on FW hydrolysis and acidogenesis were explicitly revealed. In addition, a carbon balance was performed to further study how *M. elsdenii* inoculation and acetate supply were coordinated in an efficient manner to remarkably promote carbon conversion in two phase AD.

MATERIALS AND METHODS

2.1 Food waste and inoculum

Artificial FW was prepared in this study and included 35% bread, 25% cooked rice, 25% cabbage, and 15% cooked pork (on wet weight basis) (Luo et al., 2021), with 42.9 ± 0.5 wt% total solids (TS) content and 41.9 ± 0.6 wt% volatile solids (VS) content. The seed sludge for LBRs and UASBs in this study was obtained from an anaerobic digestor in the Yuen Long Sewage Treatment Works, Hong Kong. The TS and VS of the anaerobic inoculum were 2.3 ± 0.0 wt% and 1.5 ± 0.0 wt%, respectively.

2.2 Batch experimental operation

Batch studies were carried out in two-phase AD, in duplicate for different conditions. The two-phase process consisted of one LBR with 5.3-L working volume for hydrogen production as hydrolysis-acidogenesis phase and one UASB with 10.0-L working volume for methane production as methanogenic phase. The temperature of LBR-UASB was maintained at 37 ºC. Food waste, 2 kg, was mixed with 20 % (I/S, wet basis) AD sludge and 10 % wood chips (10% w/w, wet basis) which was used as a bulking agent to facilitate the liquid leaching in LBR. Deionized water was added to adjust the total solids (TS) content to 15% in the LBR. During the experiment, leachate was collected daily from the bottom of LBR and its pH and volume was measured immediately after collection. Around 50 mL leachate was sampled for further chemical analysis. 50% of the leachate was fed into the corresponding UASB after adjusting pH to 7.5 ± 0.2. Another 50% of the collected leachate was mixed with the equal volum of deionized water (v/v) and then adjusted pH to 6.0 ± 0.2 using 5 M NaOH and/or 5 M HCl solutions, thereafter, recirculated back to LBRs. Wherein, 1) LBR-C, 40 mL blank culture medium (i.e., 2% v/w of FW) was added as a control treatment; 2) LBR-M, 40 mL *M. elsdenii* inoculation (i.e., 2% v/w of FW) was added to evaluate its role on FW conversion; 3) LBR-AM, after adding 40 mL *M. elsdenii* inoculation, 500 mL of 0.1M sodium acetate instead of 500 mL water replacement was performed to achieve acetate supply so as to investigate the extra acetate impact on FW degradtaion. Correspondingly, the methanogenic UASBs were labeled as UASB-C, UASB-M, and UASB-AM, respectively. All conditions were carried out in duplicate.

2.3 Analyses

The initial food waste, the inoculum at the beginning of batch experiment and the digestate after 16 days of experiment from each LBR were taken out for TS and VS analysis according to the APHA Standard Method 2540. Leachate volume and pH were measured daily by volumetric cylinder and pH electrode (Orion 920, Thermo), respectively. The soluble chemical oxygen demand (sCOD) of daily leachate samples and UASB effluents were analyzed using Standard Method 5520. Leachate sample was first filtered through a 0.45 um cellulose acetate membrane before the analysis of soluble metabolic products (SMPs) in leachate including ethanol and volatile fatty acids (VFAs) using GC (HP 6890) with a flame ionization detector (FID). The acidogenic off-gas and biogas composition were analyzed using GC (HP7890) equipped with thermal conductivity detector (TCD) (Luo et al., 2021).

RESULTS AND DISCUSSION

3.1 Impacts of exogenous additives on food waste conversion in acidogenic LBRs

The overall food waste degradation performance in the integrated two-phase AD system is presented in Table 1. The net cumulative sCOD production in LBR-M and LBR-AM were 728.1 ± 6.2, and 780.3 ± 3.5 gCOD/kg VS_{added}, respectively, with an increase of 8.7% and 16.4% compared to the control. Considering that polysaccharide and protein are the major components in FW, changes of their concentrations can be used to reveal the degradation of particulate FW. At the end of the experiment, the TOC removal efficiencies were 67.7 ± 0.7%,75.4 ± 1.5% and 77.3 ± 0.5% for LBR-C, LBR-M, and LBR-AM, respectively, indicating that carbohydrates degradation could be promoted by exogenous *M. elsdenii* inoculation (p = 0.016 and 0.020, <0.05). In addition, the highest TKN removal efficiency of 62.5 ± 1.3% was obtained in LBR-AM, followed by 58.2 ± 1.4%, and 51.0 ± 1.9% in LBR-M and L-C, respectively, which was in accordance with the soluble protein concentration. Therein, *M. elsdenii* could not directly contribute to carbohydrates degradation. The promoted carbohydrates degradation might be derived by the increase in protein degradation, because N-components increased with protein degradation and thus required more carbon dissolved to maintain a suitable C/N ratio for anaerobic fermentation (Feng et al., 2009). In addition, the highest organics removal efficiency, in terms of VS removal efficiency, was obtained in LBR-AM, which was 11.2% and 20% higher than that in LBR-M, and LBR-C, respectively. Thus, synergistic effect of exogenous *M. elsdenii* inoculation and acetate supply can simultaneously improve the carbohydrates and proteins degradation, and thus facilitated FW hydrolysis in acidogenic LBR. As for FW acidogenesis, at the first lactate fermentation stage, acetate supplement effectively increased the lactate production, while the exogenous inoculum did not have significant impact on lactate production. Although *M. elsdenii* was not a lactate-producing bacterium, it is interesting that around 20-50% improvement on lactate concentration was obtain in LBR-M and LBR-AM. This might be resulted from the need for *M. elsdenii* growth. *M. elsdenii* is a typical lactate-consuming bacterium. When *M. elsdenii* was inoculated in acidogenic LBR to enrich a selective fermentation pathway, more substrate i.e., lactate was probably required to stimulate the intrinsic pathway regarding converting lactate to VFAs. For the second fermentation stage, butyrate was the dominant SMPs, accounting for over 50% of total SMPs. As expected, introducing exogenous *M. elsdenii* inoculation effectively improved the butyrate production. The highest butyrate concentration in LBR-M and LBR-AM were nearly 12.6 g/L which was approximately 45% higher than that in control (LBR-C). When compared to LBR-M, butyrate production in LBR-AM was further increased by 60%, indicating that acetate supply successfully increased lactate-butyrate conversion process. Meanwhile, the production of by-products such as propionate and valerate from lactate conversion reactions contributed by *M. elsdenii* was lower in LBR-AM as compared to LBR-M. Accordingly, the addition of extra acetate potentially promoted butyryl-CoA activity with butyrate-producing bacteria such as *M. elsdenii* even under complex acidogenic environment with mixture inoculation so that it increased butyrate generation and reduced the occurrence of other side reactions (Vital et al., 2014). In addition to SMPs, H_2 is important by-product during acidogenesis. The highest hydrogen production rates in LBR-M and LBR-AM were 2.7 and 3.2 L/day, which was 35.4% and 57.6% higher than that in control (p = 0.02 and 0.009, <0.05). Finally, the highest hydrogen production of 2.90 mol H_2/kg VS_{added}FW was observed in LBR-AM, followed by LBR-M (2.49 mol H_2/kg VS_{added}FW), and LBR-C (2.04 mol H_2/kg VS_{added}FW).

Table 1. Food waste degradation performance in two-phase AD process

	Without exogenous additives	**Added *M. elsdenii***	**Added *M. elsdenii* and acetate**
Hydrolysis yield by sCOD concentration (g COD/kg VS_{added})	670.3 ± 8.0	728.1 ± 6.2	780.3 ± 3.5
TOC removal efficiency (%)	67.7 ± 0.7%	75.4 ± 1.5%	77.3 ± 0.5%
TKN removal efficiency (%)	51.0 ± 1.9%	58.2 ± 1.4%	62.5 ± 1.3%
VS removal efficiency (%)	60.4 ± 0.4%	65.5 ± 0.8%	72.1 ± 0.6%
Acidogenesis yield (g COD/kg VS_{added})	471.5 ± 8.6	529.3 ± 9.1	692.7 ± 3.8
Lactate production (g COD/kg VS_{added})	81.2 ± 0.7	113.6 ± 0.8	122.7 ± 0.4
Butyrate production (g COD/kg VSadded)	169.6 ± 13.1	200.5 ± 1.7	279.7 ± 4.0
Hydrogen production (mol H_2/kg VS_{added}FW)	2.04	2.49	2.90
Methane yield (L/kg VSadded)	188.9 ± 8.7	207.9 ± 5.6	236.6 ± 7.1

3.2 Impacts of exogenous additives on methane production in methanogenic UASBs

In the second methanogenic phase, the highest methane production was achieved in UASB-AM, in which the incrment was 13.8–25.3% compared to UASB-C and UASB-M ($p < 0.05$). The cumulative methane production rates among different conditions were simulated using the modified Gompertz model. The high correlation coefficient (R^2) of 0.994–0.997 indicated that the measured results fitted well with the modified Gompertz model. The lag phase increased in UASB-M (1.95) and UASB-AM (2.03) with exogenous additives compared with that in the control (1.06). The highest methane production rate was obtained in UASB-AM, followed by that in UASB-M and UASB-C; the maximum methane production rate was 12.7, 14.4, and 16.8 L/kg VS_{added}·day, respectively. The contribution of gas diversion to methane production increased from 5.48 ± 0.13% in UASB-C to 6.63 ± 0.36% in UASM-M ($p = 0.039$) and 7.01 ± 0.48% in UASB-AM ($p = 0.041$) owing to the improvement in H_2 production in the corresponding acidogenic phase. The increment in H_2 production mediated by *M. elsdenii* inoculation led to a >20% enhancement in methane production via hydrogenotrophic methanogenesis. However, >90% of the total methane produced was sourced from leachate conversion. The contribution of extra acetate supplement to methane production in UASB-AM was estimated to be 4.48%. When the acetate supply was reduced, the net methane production in UASB-AM was 190.7 L and was 9.0% and 19.5% higher than that in UASB-M and UASB-C, respectively (p = 0.045 and 0.020). This indicated that the contribution of acetate supply to methane improvement could be negligible. The increase in methane production relied on regulation of the leachate components after the addition of exogenous additives.

CONCLUSIONS

This study investigated the effects of exogenous additives including *M. elsdenii* inoculation and acetate supply on FW degradation in two-phase AD system. *M. elsdenii* inoculation could improve the FW hydrolysis, but additional acetate supply had better degradation performance converting more organics into leachate and off-gas for subsequent utilization. As for acidogenesis, expectedly, exogenous *M. elsdenii* inoculation effectively improved butyrate production. Additionally, acetate supplementation successfully enhanced lactate–butyrate conversion. The combined addition of these two additives could improve methane production from 188.9 L/kg VS_{added} to 236.6 L/kg VS_{added}.

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Effect of Microaeration on Anaerobic Co-digestion of Food Waste and Sewage Sludge

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Sustainable management of food waste (FW) and sewage sludge (SS) has been a major environmental challenge in urban areas. Anaerobic digestion (AD) has long been widely adopted for the valorization of diverse organic wastes into bioenergy (methane-rich biogas) and organic fertilizer (residue following AD, also called digestate). In recent years, co-digestion of FW and SS has attracted significant research and development efforts due to their inherent merits, such as availability in proximity, proper carbon-to-nitrogen ratio, nutrients and alkalinity supplementation, and dilution of any inhibitory compounds, resulting in improved bioenergy production and digestate quality for land application. Oxidation-reduction potential (ORP)-based microaeration has emerged as a novel strategy to improve the performance of AD process, including enhanced hydrolysis of complex substrates, mitigation of volatile fatty acids accumulation through improved hydrogenotrophic methanogenesis, prevention of digestor toxicity (e.g., oxidation of hydrogen sulfide). In this study, we evaluated the effect of microaeration on methane yield and volatile solids (VS) removal during FW and SS co-digestion at different mixing ratios. Two 6-L continuous stirred-tank reactors were operated in a semi-continuous mode under mesophilic conditions at a hydraulic retention time of 20 days. Initially, mono-digestion of SS and FW was examined. SS mono-digestion reached the maximum organic loading rate (OLR) of 2.25 g VS/L·d with the methane yield of 183 NmL/g VSadded, while FW mono-digestion failed at OLR of 1.0 g VS/L·d due to VFAs accumulation. During co-digestions of FW and SS with ORP-based microaeration (ORP was maintained 25 mv above the reference ORP), microaeration resulted in significant ($p \leq 0.05$) improvement in methane yield at the mixing ratio of 60:40 (on VS basis). This could be due to the synergistic effects of the co-substrates. Higher SS (FW:SS = 40:60) could inhibit the effect of microaeration due to slow hydrolysis of SS. Furthermore, higher alkalinity level could enhance biogas production through improved digester stability. Similarly, at higher FW content (i.e., FW:SS = 80:20) microaeration did not result in significant improvement in digester performance, likely due to the rapid degradation of organic matter. Therefore, the effect of microaeration during co-digestion of FW and SS is specific to co-substrates mixing ratios.

Keywords: Co-digestion, Microaeration, Food waste, Sewage sludge, Oxidation-reduction potential (ORP).

Precise pH Control of Food Waste Biomethanation Using Granulated Activated Carbon

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ABSTRACT: During the food waste biomethanation, volatile fatty acids (VFAs) produced by acidogens accumulate rapidly and lower the pH, negatively impacting the process and methanogens. However, maintaining the optimal VFA concentration in the anaerobic digester that enables methane generation is imperative. Hence, this study aims to provide the ambient environment for methanogens to consume VFAs by adding granular activated carbon (GAC) which kinetically favors the forward reaction of VFAs conversion to methane due to its large surface area providing a porous environment. Due to their high electrical conductivity, GAC accelerates direct interspecies electron transfer (DIET) between acetogens and methanogens and improves pH buffering. The experiments were conducted under mesophilic conditions, and the biogas was collected in a syringe attached to serum bottles via a rubber septum. The results indicated high methane generation, which proves GAC reduces acidification by utilizing VFAs during the methanogenic phase.

***Keywords**: Biomethanation, Biogas, Food waste, Volatile fatty acids.*

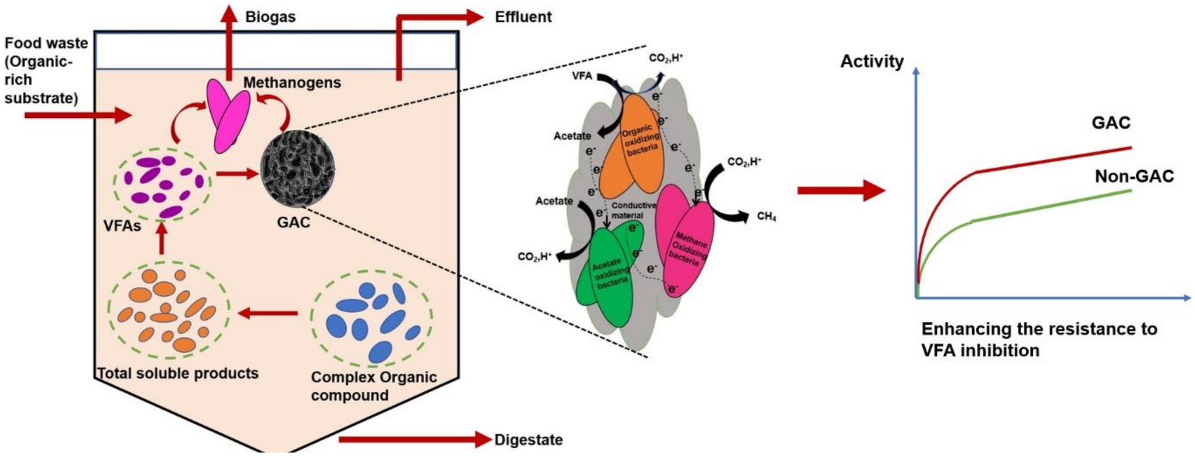

Fig. 1. Role of GAC in enhancement of food waste biomethanation

Introduction

Food waste can be generated at every level along the supply chain and it is reported worldwide that over 1.3 billion tons of food are wasted annually [1]. Biomethanation is a sequential process that involves four stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis which can be performed in a single anaerobic digester [2]. Biomethanation of highly concentrated substrates food waste which is mostly comprised of easily biodegradable organic substances leads to faster production of VFAs. The accumulation of VFAs results in a sharp pH drop inhibiting the final (methanogenesis) phase of biomethanation where the methane-rich end product is produced. To encourage VFA consumption by sensitive methanogens, carbon-based conductive materials are currently exploited. These materials enhance the syntropic interactions between microorganisms by encouraging the growth of biofilms on their surface [3]. Activated carbon (granular and powdered) has been extensively developed in favor of reactor performance by utilizing VFA at a faster rate which leads to quicker methane production [4]. The potent benefit of activated carbon is the high-surface-area and porous structure. In DIET (direct interspecies electron transfer) there will be a free flow of electrons without being carried by reduced molecules unlike MIET (mediated interspecies electron transfer) [5]. The electrons are transferred with the aid of conductive materials between electron-donating and accepting partners (Gabriel Capson-Tojo et al., 2018). DIET is anticipated to be a more rapid and efficient electron transfer mechanism than MIET. Thus, the application of activated carbon materials favors DIET and avoids VFA accumulation during the anaerobic digestion process [6].

Materials and methods

Substrate and inoculum collection and preparation

The substrate used in this experimental study was food waste. It was collected from the BITS Pilani Hyderabad campus hostel mess and ground into a fine paste using a blender to maintain the homogenous nature of the substrate. The inoculum was collected from a full-scale anaerobic plant, treating food waste. The inoculum and substrate were fed in a 1:1 ratio into the reactors. To improve the efficiency of biogas production 0.05g/TSS of GAC was added and monitored for 16 days.

Experimental setup and operating condition

GAC experiences abrasions when being in direct contact with the reactor's agitator. Thus, the experimental setup consists of a hybrid reactor design to introduce GAC into the contents of the reactor as shown in Figure 2. Experiments were carried out in 132ml serum bottle reactors. Each reactor consists of non-diluted inoculum and food waste. Reactors were operated in batch feeding mode under mesophilic conditions (35+ 2 °C) and monitored for 16 days. A syringe was inserted into the serum bottle via rubber septum, to study the biogas production level.

Analytical methods

Biogas is measured using a syringe. pH was measured using Oakton PC2700 pH meter. COD (chemical oxygen demand) and BOD (biological oxygen demand) were determined by the calorimetric method, according to Standard Methods (APHA)

Results and discussion

In favorable environmental conditions during the biomethanation of organic wastes in the presence of microbial cultures results in VFA production along with other soluble intermediates and interconversion to other products. The optimization of operational parameters, particular to each kind, is a significant problem in VFA production. of waste and its individual constituents, as in food waste where the constituents are majorly carbohydrates and it is easily hydrolyzable. The production of various intermediate products during the biomethantion process is the result of interconnected series of chemical reactions. These pathways are the basic unit of measuring the digester's performance.

(a)

(b)

Fig. 2. (a) GAC filled column, (b) lab-scale serum bottle reactor

COD is a measure of available organic matter and a key parameter used in anaerobic digestion. COD determines the amount of oxygen required for the chemical oxidation of organic matter whereas, BOD is used to determine the amount of oxygen required by microorganisms to break down organic materials [7]. These tests are widely done to determine the efficiency of treatment plants. The COD of anaerobic digestion of food waste ranges from 9,000 mg/l to 88,000 mg/l and the COD reduction percentage were documented effectively up to 60% as shown in the Figure 3. Also, the BOD of the food waste biomethanation ranges from 9600 mg/l to 38400 mg/l, and the reduction percentage was found to be around 35%. The overall COD and BOD reduction percentage with the addition of GAC is 55.5% and 35.3% respectively. When compared to traditional food waste biomethanation, there is an enhanced reduction in COD and BOD of 5% and 3%, respectively. pH is one of the most influential parameters due to different levels of sensitivity towards pH for different groups of organisms. The pH range of the reactor's content is 6.8 to 4.4, initially when the new substrate is added the pH is recorded as 6.8 and it gradually decreases over the following days [8]. The variation in pH value over 16 days is recorded and illustrated in Figure 3. The variation is due to the formation of acids during the acetogenesis and acidogenesis process. Among the different groups, the pH tolerance of acidogens ranges from 4.0 to 8.5 however, most methanogens require a narrow window with a pH value between 6.5 to 7.2, beyond which methanogens fails, which is the main group of microorganisms that produces the desired methane-rich biogas product. The daily biogas production ranges from 0.29 m3/Kg VS – 0.03 m3/Kg VS. Anaerobic digestion of highly concentrated substrates such as food wastes is a complex biological process prone to failure if it is not properly managed. The reactor can readily get overloaded due to the easily digestible carbohydrates that make up most of the food waste, leading to the accumulation of VFAs due to unbalance of the acidogenesis, acetogenesis, and methanogenesis steps. The increased consumption rate of VFA during anaerobic digestion of food waste provides steady maintenance of pH while GAC is present, establishing conditions that are favorable to methanogens and enhancing the uptake of VFA and the production of biogas.

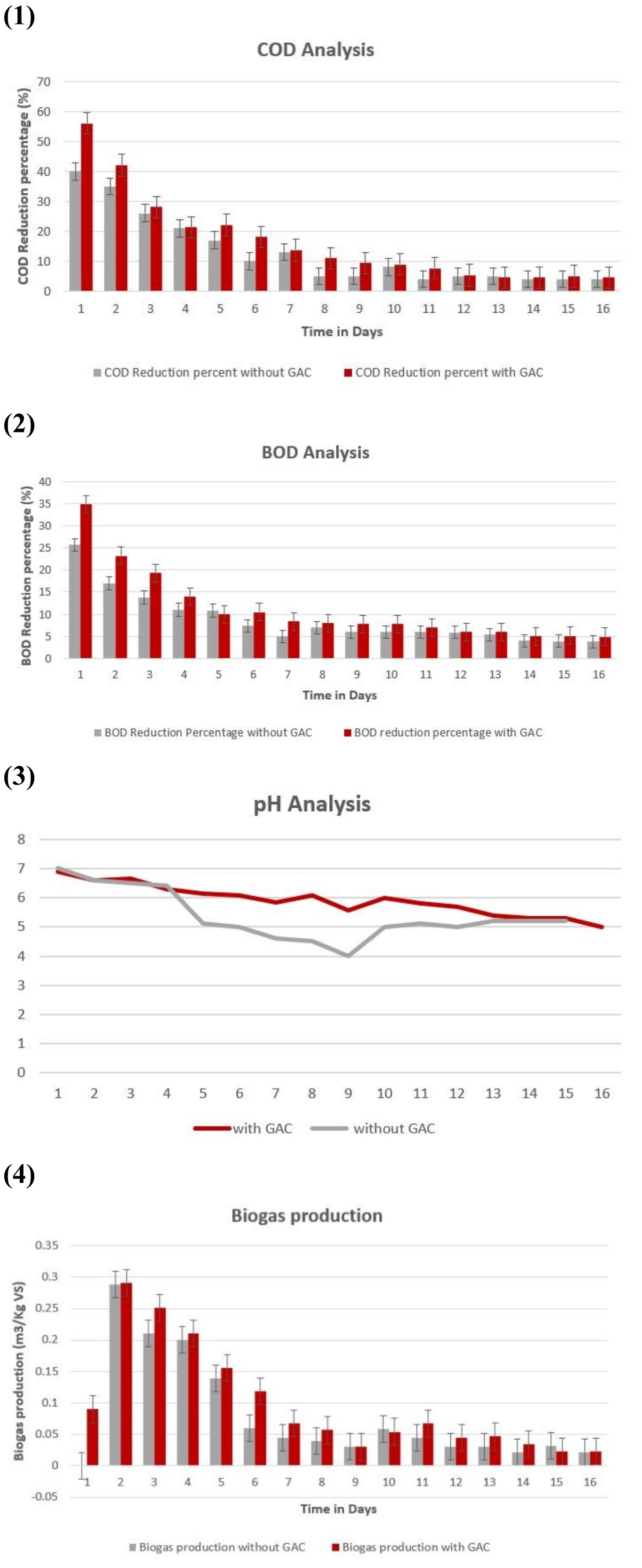

Fig. 3. (1) COD reduction percentage, (2) BOD reduction percentage, (3) pH analysis (4) Biogas production analysis

Conclusion

Food waste is considered a significant substrate for biomethanation while there is potential to generate large economic energy yield, food waste application can also be a hindrance because of the threshold limit of VFA inhibition. There are several ways to overcome VFA acidification but the addition of GAC is the most economical method to increase the rate of VFA consumption by the sensitive methanogens. GAC addition showed promising effects by enriching syntropic bacteria and benefits as there was less pH variation observed and minimal lag phase in the production of biogas, increasing the biogas productivity and overall COD and BOD reduction percentage was increased compared to the conventional method of food waste digestion.

Acknowledgment

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Co-Digestion of Swine-Manure and Carcass at Low Temperature: A Long Term Operation and Stability Monitoring

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Anaerobic co-digestion of agricultural residues including animal wastes for energy recovery and manure productions were considered as promising approaches to promote circular bio-economy concepts in Canada. However, co-digestion of animal wastes such as manure and carcass required special attention owing to their unique characteristics, such as high-biodegradability, pathogen distributions and nitrogen contents. In this research, we have used a lab-scale anaerobic bioreactor (~24L total volume and 20L working volume; Fig 1.) to co-digest swine-manure and -carcass under sequential batch mode under 25oC for more than 3 years. The specific organic loading rate (OLR) was 3 g.L-1.d-1 for first one year and changed it to 1.5 g.L-1.d-1 for rest of the operations. The study used 6 identical reactors and operated as duplicates under three different co-digestion conditions i.e., by keeping OLR constant but varied the ratio of manure to carcass addition. Based on the carcass loading, the systems were marked as Low, Medium and High-carcass reactors (LC, MC and HC). Each condition was tested and validated for 3 repeated cycles and mixing was done twice a week for 5 min (sampling purpose only). Biogas production, volatile fatty acids and ammonia-N accumulations were monitored from the leachate samples collected once in 7 days and compared between the treatment conditions. Acetic and propionic acids were dominant during co-digestion indicated that the three system were dominated by the microbial hydrogen consuming pathways. The pH was near neutral to alkaline in range throughout the operation for all the 6 reactors, while the total kjeldhal nitrogen (TKN) concentrations were between 5,000 and 9,000 mg/L. The cumulative biogas production was comparatively lower with the LC than in MC and HC. Overall, the total solids and volatile solids reductions were achieved between 70-85% in all the three test conditions with the high-methane recovery rate even at high TKN concentration was observed.

Keywords: Low-temperature, Swine manure, Swine carcass, Co-digestion, Sequencing mode.

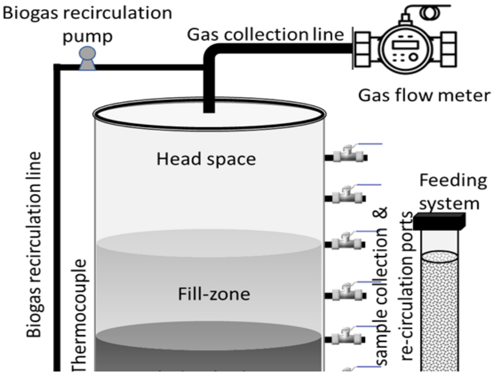

Fig 1. Lab-scale anaerobic co-digestion system for swine manure and carcass treatment

Design and Implementation of a Pilot Carbon Capture Technology to obtain Compressed Biogas (green fuel) & Compressed CO_2 from Biogas plant at NIE-CREST, Mysuru, India

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As there is an increase in air pollution by the emission of gases (such as carbon dioxide) due to burning of fossil fuels, it is instrumental for the engineering world to adopt new technologies to cope with the ever-increasing pollution aiding to the climatic crisis, where carbon capture technology is emerging as a new face of this field. To decrease the carbon footprint, capturing the CO_2 at the source is an economical option. One such source is a BIO-GAS plant. The separation of CO_2 from the BIO-GAS also increases the calorific value of BIOGAS and separated carbon dioxide can be used to produce useful products such as Clean fuel, methanol etc. A prototype is designed and developed at NIE-CREST, Centre for Renewable Energy & sustainable Technologies at the National Institute of Engineering, Mysuru India , where in a pilot plant kitchen waste is converted into Biogas by anaerobic digestion by a portable floating drum biogas plant and later the biogas generated is scrubbed to remove impurities in a Portable scrubber unit and finally the pure methane and co2 are captured separately. Working of the pilot plant: The BIOGAS which is produced in floating drum biogas plant is passed through the scrubbers. The H_2S is removed using iron filings and moisture is removed by CaCl2. The gas is compressed and then passes through the adsorption column containing adsorbent zeolite 13X/activated charcoal in a PSA scrubber. The switching operation of valves are done to capture CH4 and Co2 separately. The captured CH4 and CO2 in the cylinder is ready to be used for applications.

Keywords: Alternative fuels, Carbon capture, Biogas, Green fuel, PSA scrubber, clean fuel, Waste to wealth.

Effect of Biogas Residue Biochar on Anaerobic Digestion of Food Waste with Different Organic Loading

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To improve the methane production of anaerobic digestion (AD) of food waste (FW) with high organic loading and realize the resource utilization of biogas residue. Different organic loading gradients (0.5:1, 1:1, 2:1, 3:1, based on the VS ratio of substrate and inoculum) were set to study the effect of biogas residue biochar (BRB) on AD performance of FW. The results showed that cumulative methane production was the highest (375.5 ± 8.4 mL/g-VS) when the VS ratio was 1:1 without addition of BRB. When the VS ratio was greater than 1:1, the accumulation of volatile fatty acids (VFAs) led to systematic acidification, and the methanogenesis was inhibited. The cumulative methane production decreased with the increase of organic loading, and the lag period of methanogenesis continued to extend. BRB did not increase methane production under low organic loading (VS ratio: 0.5:1). With the increase of organic loading, appropriate addition of BRB could promote the degradation of organic matters and increase the VFAs content in the early stage of AD. In the middle and late stages of AD, it can accelerate the consumption of VFAs and promote the methane production. Also, BRB has a more significant effect on the promotion of methane production with the increase of organic loading. When the VS ratio was 3:1, the addition of 5 g/L BRB (318.5 ± 38.2 mL/g-VS) could increase the methane production by 21.37% ($p<0.05$) compared with the blank group (262.3 ± 34.9 mL/g-VS). Microbial community analysis showed that the enrichment of Clostridium_ sensu_ stricto_ 1 and Syntrophomonas may be important factor for the rapid consumption of VFAs, while the increase of methane production is mainly related to the enrichment of methanogens such as Methanosarcina.

Keywords: Food waste, Anaerobic digestion, Biogas residue biochar; Organic loading, Microbial community.

Enhanced Anaerobic Digestion of Waste Activated Sludge with Periodate-Based Pretreatment

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The potential of periodate (PI) in sludge anaerobic digestion is not tapped, although it has recently attracted great research interest in organic contaminants removal and pathogens inactivation in wastewater treatment. This is the first work to demonstrate significant improvement in methane generation from waste activated sludge (WAS) with PI pretreatment and to provide underlying mechanisms. Biochemical methane potential tests indicated that methane yield enhanced from 100.2 to 146.3 L per kg VS (VS, volatile solids) with PI dosages from 0 to 100 mg per g TS (TS, total solids). Electron spin resonance showed PI could be activated without extra activator addition, which might be attributed to the native transition metals (e.g., Fe2+) in WAS, thereby generating hydroxyl radical (•OH), superoxide radicals (•O2−), and singlet oxygen (1O2). Further scavenging tests demonstrated all of them synergistically promoted WAS disintegration, and their contributions were in the order of •O2− > •OH > 1O2, leading to the release of substantial biodegradable substances (i.e., proteins and polysaccharides) into the liquid phase for subsequent biotransformation. Moreover, fluorescence and ultraviolet spectroscopy analyses indicated the recalcitrant organics (especially lignocellulose and humus) could be degraded by reducing their aromaticity under oxidative stress of PI, thus readily for methanogenesis. Microbial community analysis revealed some microorganisms participating in hydrolysis, acidogenesis, and acetoclastic methanogenesis were enriched after PI pretreatment. The improved key enzyme activities and up-regulated metabolic pathways further provided direct evidence for enhanced methane production. This research was expected to broaden the application scope of PI and provide more diverse pretreatment choices for energy recovery through anaerobic digestion.

Keywords: Energy recovery, Anaerobic digestion, Recalcitrant organics, Free radicals.

Enhancement strategies and mechanisms of high-value medium-chain fatty acids production from waste activated sludge through anaerobic fermentation

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Medium chain fatty acids (MCFAs) production from waste activated sludge (WAS) is restricted by poor biodegradability of WAS, competitive inhibition of methanogens and low electron transfer efficiency. Therefore, the first work proposes a promising ferrate (Fe (VI))-based technique to enhance MCFAs production from WAS through accelerating WAS disintegration and substrates transformation, and eliminating competitive inhibition of methanogens, simultaneously. Results shows that the maximal MCFAs production attains 8106.3 mg COD/L under 85 mg Fe/g TSS, being 58.6 times that of without Fe (VI) pretreatment. Mechanism exploration reveals that Fe (VI) effectively destroys EPS and cytoderm through electron transfer, reactive oxygen species generation (i.e., ·OH, ·O2- and 1O2) and elevated alkalinity, resulting in the transfer of organics from solid to soluble phase and from macromolecules to intermediates. Generation and transformation of intermediates analyses illustrate that Fe (VI) facilitates hydrolysis, acidification and chain elongation (CE) but suppresses methanogenesis, promoting the targeted conversion of intermediates to MCFAs. Also, Fe (VI) pretreatment provides potential electron shuttles for chain elongation. Microbial community and functional genes encoding key enzymes analysis indicates that Fe (VI) screens key microorganisms and up-regulates functional genes expression involved in CE pathways. Overall, this technology avoids methanogens inhibitor addition and stimulates vivianite synthesis during MCFAs production from WAS. Then, a novel ferroferric oxide (Fe3O4) technique was proposed to accelerate electron transfer efficiency from substrates to MCFAs production during anaerobic fermentation of WAS. Results indicated that the MCFAs yield, and selectivity were respectively enhanced by 155.4% and 66.7% in the Fe3O4-mediated WAS. Mechanistic studies disclosed that Fe3O4 promoted substrates degradation through conducting dissimilatory iron reduction (DIR) and stimulating hydrolase activity, providing precursors for chain elongation (CE). Generally, Fe3O4 improved the key processes for MCFA production at different degrees, i.e., hydrolysis, acidification and CE. Interestingly, MCFAs yield enhancement was primarily ascribed to facilitated electron transfer rather than DIR or produced ferrous iron, which could be supported by the analyses of electrochemical properties, electron transfer system activity and morphology. Further, Fe3O4 shifted the key microorganisms in favor of MCFAs production. Overall, this strategy could improve MCFAs production, sludge dewatering and phosphorus removal, concurrently.

Keywords: Medium-chain fatty acids (MCFAs); Chain elongation (CE); Waste activated sludge (WAS); Anaerobic fermentation; Extracellular polymeric substances (EPS); Ferrate (Fe (VI)).

Sludge Source-redox Mediators Obtainment and Availability for Enhancing Bioelectrogenesis and Acidogenesis: Deciphering Characteristics and Mechanisms

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Anaerobic biological treatment was regarded as one of promising options for realizing concurrent WAS reduction, stabilization and bioenergy/bioresource recycle. But the relatively low treatment efficiency and long retention time limited its spreading application toward larger scale considerably in China. Aimed at such barrier, this study offered a novel enhancing strategy for achieving high-efficiency of bioenergy/bioresource recycle from WAS anaerobic treatment via improving bioelectrogenesis/acidogenesis using sludge source-redox mediators (SSRMs). SSRMs not only facilitated bioeletrogenesis with an increasing efficiency of 36% for voltage output and 39% for bioelectricity production efficiency, but also enhanced acidogenesis of WAS with a mean elevating efficiency of 37.5% of volatile fatty acids (VFAs) production within 5 d. Mechanistic investigations indicated that SSRMs were capable to have a potential influence on improving the protein and carbohydrate metabolisms-related genes' expression for enhancing bioelectrogenesis and acidogenesis. On the other hand, SSRMs exerted roles of electrochemical "catalysts" or as terminal electron acceptors with affecting functional proteins of complexes of I and IV in electron transfer chains for improving electron transfer efficiency. Meanwhile, the microbial community evolutions with enriching core microbes' abundance, increasing microbial diversity and community distributive evenness were triggered concurrently for carrying out superior bioelectrogenesis and acidogenesis successfully. Besides, a schematic illustration was established for demonstrating the mechanisms of SSRMs for enhancing bioelectrogenesis and acidogenesis via changing microbial metabolism functions, enhancing electron transfer efficiency, and regulating functional genes' expression of functional proteins (up-regulating cytochrome c oxidase and down-regulating-NADH dehydrogenase). This study provided an effective enhancing strategy for facilitating WAS bioconversion to bioenergy/bioresource with well-process sustainability.

Keywords: Waste activated sludge (WAS), Sludge source-redox mediators (SSRMs), Bioelectrogenesis, Electron transfer efficiency, Microbial mechanisms.

Direct Carbon Recovery from Raw Wastewater for Bioenergy Production by Anaerobic Digestion

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Wastewater is rich in carbon and normally expressed as chemical oxygen demand (COD). However, traditional wastewater treatment is aimed to remove COD mainly by biological treatment. In biological treatment, the biodegradable COD is converted to CO_2 by inputting large amount of energy (aeration) which is in fact a great wasting of resource. Recovering carbon from wastewater for biogas production would produce energy instead of spending energy. In this study, carbon was recovered from raw wastewater by flocculant and then converted to biogas by anaerobic digestion. In order to avoid inorganic flocculation impact on anaerobic digestion, bio-flocculants Chitosan was employed. It was found that chitosan quaternary ammonium salt (HACC) can remove 66.11% of total chemical oxygen demand (COD_t), 31.15% of total phosphorus in the wastewater. The trapped carbon-rich sludge was undergone anaerobic digestion. The anaerobic digestion was carried out for 45 days at temperature of 35°C. The sludge volume reduction was approximately 40% and the methane yield was 167.84 mL CH_4 per gVSS of carbon-rich sludge. It shows that the process is simple, requires low energy input, and can significantly recover energy from wastewater. It indicates that this system could be used as a novel domestic wastewater treatment model for developing countries combined with new nitrogen and phosphorus removal technology.

Iron-Rich Digestate Biochar Toward Sustainable Peroxymonosulfate Activation for Efficient Anaerobic Digestate Dewaterability

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Large amount of hazardous Fe-rich dewatered digestate from Fenton/Fenton-like treatments are becoming a reservoir of pathogens/viruses, heavy metals, and emerging pollutants, which would pose serious secondary pollution in the worldwide environment. Converting Fe-rich dewatered digestate into Fe-rich biochar (Fe-BC) for anaerobic digestate dewatering could achieve the dual purpose of waste reutilization and pollution elimination. In this study, a suite of Fe-rich biochars derived from Fe-BC were fabricated under different pyrolysis temperatures (300, 500, and 800 °C), which were firstly utilized as peroxymonosulfate (PMS) activators for promoting digestate dewaterability with wide applicability. Results showed that compared to the Fe-BC$_{300}$/Fe-BC$_{500}$ + PMS treatments, Fe-BC$_{800}$ + PMS process performed superior digestate dewaterability in which specific resistance to filtration reduction and water content reduction improved by > 12.5% and > 130%, respectively, under the optimal conditions. Mechanistic results demonstrated that in Fe-BC$_{800}$ + PMS system, HO• and $SO_4^{\bullet-}$ oxidation played a pivotal role on promoted digestate dewaterability, while HO• and $^1O_2$ oxidation was dominated in Fe-BC$_{300}$/Fe-BC$_{500}$ + PMS treatments. Fe-BC$_{800}$ containing higher Fe and C=O contents could efficiently interact with PMS to generate numerous HO• and $SO_4^{\bullet-}$ via iron cycle. These highly reactive oxygen species proficiently reduced the hydrophilic biopolymers, protein molecules, and amino acids in extracellular polymeric substances, leading to remarkable decrease in particle size, hydrophilicity, adhesion, network strength, and bound water of digestate. Consequently, the flowability and dewaterability of digestate could be significantly enhanced. The cost-benefit result indicated the Fe-BC + PMS treatment possessed desirable reusability, applicability, and economic viability. Collectively, the Fe-BC + PMS is a high-performance and eco-friendly technique for digestate dewatering, which opens a new horizon towards a closed-loop of digestate reutilization.

Keywords: Anaerobic digestate dewaterability; Fe-rich digestate biochar + peroxymonosulfate; Hydrophilic amino acids destruction; Iron redox cycle; Digestate recycling system.

Impact of salinity on hydrogen production and acidogenic bacteria for food waste fermentation

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In recent years, fossil fuel utilization has caused a significant increase in greenhouse gas emissions and global warming, threatening human health by affecting water, food, and other energy security. Hydrogen (H_2) is a carbon-neutral fuel and is considered an alternative to fossil fuels. Biological methods for H_2 production, especially via dark fermentation (DF), have multiple benefits compared to the physico-chemical processes, as simultaneous bioconversion and energy generation are possible. However, the H_2 yield under DF is lower due to thermodynamic constraints and is further affected by H_2-consuming microorganisms in a mixed culture system. For example, hydrogenotrophic methanogens, homoacetogenic bacteria, and sulfate-reducing bacteria uptake H_2 for their metabolic processes. In addition, the H_2 production rate is affected by operating environmental conditions, i.e., temperature, salinity, pH, etc. Among all the parameters, salinity affects the microorganism as it causes osmotic stress on the microbial cells, leading to drop-in process performance and plasmolysis. In this study, we evaluated the impact of salinity (i.e., 2 to 20 g NaCl/L) on the microbial community dynamics and metabolic pattern using food waste as substrate. Genomic analysis and metabolic pattern revealed that the H_2 production was mainly through Clostridial-type fermentation under medium to high salinity levels, whereas Enterococcus-type fermentation was under low salinity levels.

Keywords: Dark fermentation, Acidogenic bacteria, Hydrogen, Salinity, Food waste.

Investigation of Microbial-substrate Interaction using Mixed Microbial Consortia for Enhancement of Biogas Production from Food Waste

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Annually, ~2 billion tonnes of municipal solid waste (MSW) are generated all over the world and 0.15 million tonnes of MSW are wasted per day in urban India, among which 34–53% is organic biodegradable waste which comprises of food waste generated from restaurants, household food waste (cooked and uncooked), animal feed waste, food industry waste, vegetable market waste, etc. The treatment of such huge amounts of waste increases the economic load on the government, which is very difficult for a developing country. Hence, only 70–75% is collected and around 20–25% is treated. Therefore, a major portion of MSW is dumped in landfill areas where it degrades naturally, causing greenhouse gas emissions (methane and CO2) and toxic leachate to mix in groundwater and make it toxic. Food waste, which constitutes a major portion of municipal solid waste, is rich in nutrients and can be used for anaerobic digestion for biogas production. Biogas production is the sequential biodegradation of organic waste routed through four steps of anaerobic digestion, such as hydrolytic, acidogenic, acetogenic, and methanogenic. Each step is governed by different microbial community groups. Most of the inoculum used for the anaerobic digestion process experiences desired and undesired microbial-microbial interaction. An efficient inoculum leads the anaerobic digestion process smoothly by following positive microbial-microbial interaction. In the present studies, a mixed inoculum for biogas production was developed by combing two inoculums (mixing sewage sludge and cow dung). The result shows that 62% soluble chemical oxygen demand (sCOD) is released in a reactor with 5g/L total solid (TS), i.e., higher than in a reactor inoculated with a single inoculum. After the screening of the inoculum, the assessment of biogas production at different organic loads was carried out. These organic loadings are 5 g/L in reactor 1, 10 g/L in reactor 2, and 15 g/L of TS in reactor 3. Total biogas production observed was 400 mL, 1100 mL, and 420 mL in reactor 1, reactor 2, and reactor 3. Lower biogas production in reactor 3 due to high organic loading leads to high volatile fatty acid production (VFAs), i.e., 9000 mg/L higher than both reactor 1 and reactor 2. High VFAs inhibit both methanogenic and syntropic bacteria. Methanogen inhibition and the breakdown of the syntropic relationship between syntropic bacteria and methanogens A decrease in the methanogenic population eventually decreases biogas production. Results suggest that an organic load with 10 g/L of total solid concentration gives higher biogas with 60-70% sCOD degradation. Further studies will be done to explore the microbial-substrate interaction in the anaerobic digestion process and its role in the enhancement of biogas production. In this study, the microbial biofilm will be developed for the enhancement of microbial-substrate interaction. Extrapolymeric substances (EPS) estimation was used as a biochemical analytical parameter for the development of healthy biofilm. In addition, activities for hydrolytic enzymes was estimated at a fixed duration to confirm the interaction between the microbial-substrate. The correlation between the enhancement of biogas production and microbial-substrate interaction were analyzed.

Keywords: Municipal solid waste, Food waste, Biogas, Microbial-substrate interaction.

Cascading Fermentation of Oleaginous Yeast Using Organic Waste for Lipid Production

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The high operating cost is currently a limitation to industrialize microbial lipids production by the oleaginous yeasts. To explore economic fermentation technology, cascading fermentation of *Lipomyces starkeyi* using yeast extract peptone dextrose (YPD) medium, orange peel (OP) hydrolysate medium, and their mixed medium were investigated for 7 days by monitoring OD_{600} values, pH values, cell growth status, C/N ratios, total carbon concentration, total nitrogen concentration, residual sugar concentration, lipid content, lipid titer, and fatty acids profiles of lipids. Results showed that two-stage fermentation with YPD and 50%YPD+50%OP medium contributed to lipid accumulation, leading to larger internal lipid droplets in the yeast cells. However, the cells in pure OP hydrolysate grew abnormally, showing skinny and angular shapes. Compared to one-stage fermentation, the two-stage fermentation enhanced lipid contents by 18.5%, 27.1%, and 21.4% in the flasks with YPD medium, OP medium, and 50%YPD+50%OP medium, and enhanced the lipid titer by 77.8%, 13.6%, and 63.0%, respectively. The microbial lipids obtained from both one-stage and two-stage fermentation showed no significant difference in fatty acid compositions, which were mainly dominated by palmitic acid (33.36-38.43%) and oleic acid (46.6-48.12%). Hence, a mixture of commercial medium and lignocellulosic biomass hydrolysate could be a promising option to balance the operating cost and lipid production. In this talk, I will cover the following several points, research background, technical route, why two-stage cascading fermentation, strategies for higher yield and productivity, and finally summary and suggestions for future studies.

Keywords: Cascading fermentation; Microbial lipids; Oleaginous yeast; Waste-to-resource.

Physicochemical and Biological Pretreatment of Municipal Wastewater against Antimicrobial Resistance for Enhanced Anaerobic Digestion

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The biopharmaceutical industry includes various unit processes, and fermentation engineering is the most popular. However, as the pharmaceutical industry grows, so does the severity of environmental contamination. High-concentrated antibiotic wastewater, which has strong quantity fluctuation, low C/N, high suspended solids and sulphate concentrations, complex composition, biological toxicity, and high chroma, is the primary source of biopharmaceutical wastewater. The high concentrations of antibiotics in the biopharmaceutical fermentation wastewater will lead to antimicrobial resistance. When bacteria, viruses, fungi, and parasites, among other microbes, can adapt and flourish in the presence of drugs negatively impacting them, antimicrobial resistance is generated. Antimicrobial Resistance has emerged as one of the most pressing risks to public health, seriously compromising the ability to prevent and cure chronic illnesses. Most pathogens are thought to be killed or rendered inactive by disinfection procedures used in wastewater treatment, and prior research has shown that disinfection efficiently renders antibiotic-resistant bacteria inactive. Even if antibiotic-resistant bacteria are completely inactive, the intact DNA may persist. Antibiotic resistance genes are often carried on genetic material that is highly transmissible, such as plasmids, integrons, and extracellular DNA. These genetic components can continue operating and pass antimicrobial resistance genes to downstream bacteria through horizontal gene transfer. Antimicrobial resistance genes are thought of being major pollutants since they have the potential to outlast their bacterial hosts. In order to address the major issues brought on by these genes, their removal or trapping should occur before disinfection or the release of wastewater treatment plant effluent into the environment. Various pretreatment techniques can be applied to increase the biodegradability of the biopharmaceutical fermentation wastewater produced. These include chemical addition, heat treatment, mechanical or ultrasonic disintegration, and oxidative, enzymatic, or microbiological pretreatment. An effective pretreatment can improve the substrate's accessibility to the anaerobic bacteria, maximising the waste's methanogenic potential and enhancing the pace and degree of degradation. Hence, this study focused on various pretreatment techniques, including physicochemical and biological methods. Thermal and pulsed electric field methods were studied under the physical methods. Poly-aluminium chloride and polyelectrolytes were used under chemical methods. The biological method involved using a Bacta-Cult powder, a specially formulated microorganism used to treat and remove BOD and COD. Kirby-Bauer's disc diffusion method confirmed these different methods' effects on antimicrobial resistance.

Keywords: Biopharmaceutical fermentation wastewater, Antibiotic resistance, Pretreatment, Anaerobic digestion, Pulsed electric field.

Evaluation of Substrate Competition for *Thermotoga Neapolitana* Fermentation

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Using fossil fuels causes climate change because of the high emission of greenhouse gases, especially carbon dioxide. Hydrogen (H_2) is considered an alternative to fossil fuels due to its low-carbon footprint. However, current H_2 production from fossil resources is cheaper but not environmentally friendly due to carbon emissions. Thus, applying biological routes to produce H_2 from organic waste can simultaneously help manage waste management issues and recover resources in terms of energy and valuable organic chemicals. In this study, we intend to understand the substrate uptake kinetics and mechanism. In this research, we used a marine hyperthermophilic strain (i.e., Thermotoga neapolitana) to evaluate its potential for H_2 and valuable organic acid production from different sugars and combinations of sugars. The experiments were carried out in 600 mL batch reactors with a working volume of 450 mL. Further, gaseous and aqueous metabolic profiles were studied by varying salinity levels and sparging gas (i.e., N_2 and CO_2). It was also observed that acetic acid was the only pathway for hydrogen production. The substrate competition studies in the batch reactors showed that glucose and xylose had similar sugar consumption patterns, and fructose and arabinose had similar consumption profiles. After analyzing the rate kinetics, the preferred sugars for T. neapolitana fermentation were glucose > xylose > fructose > arabinose under both CO_2 and N_2 sparging atmosphere.

Keywords: *Thermotoga neapolitana*, Dark fermentation, Substrate competition, Hydrogen production, Acetic acid.

Rhamnolipid Pre-Treatment of Primary Sludge Effectively Improves Short-Chain Fatty Acids Production from Anaerobic Fermentation

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Resource recovery in form of short-chain fatty acids (SCFAs) from primary sludge is restricted by the deficient sludge degradation degree and the rapid consumption of methanogens. This work reported a new rhamnolipid (RL) pretreatment method to improve SCFAs production from anaerobic fermentation of primary sludge for the first time. Experimental results showed RL pretreatment significantly improved the SCFAs production from primary sludge, and the maximum SCFAs production of 206.12 mg chemical oxygen demand (COD)/g VSS was obtained by 0.08 g/g TSS of RL, which was around 3.8-fold that of blank without RL addition (i.e., 54.14 mg COD/g VSS). Mechanism investigations revealed that RL significantly promoted the disintegration of primary sludge, under which the released protein and carbohydrate was >4 times higher than that without RL addition, thus providing more organics for subsequent SCFAs production. It was also found that the high dose of RL significantly suppressed the methane production during fermentation, leading to the accumulation of more SCFAs. Considering that studies have demonstrated that RL could be produced in situ by fermentation of sludge or digestate, this can promote the transformation of the sludge resource treatment mode from a linear mode to a circular mode, forming a “closed-loop”. But this study has not been technically optimized. This is because the purpose of this study was to evaluate the feasibility of using RL pretreatment to enhance SCFAs production from anaerobic fermentation of primary sludge. A comprehensive technical optimization and economic analysis will be required in the future.

Keywords: Rhamnolipid, Primary sludge, Anaerobic fermentation, Degradability, Short-chain fatty acids.

Role of Quorum Sensing and Quenching in Anaerobic Digestion: A Mini Review

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ABSTRACT. Anaerobic digestion (AD) is a bioprocess that utilizes anaerobic microorganisms to break down organic material in an oxygen-free environment, controlled by temperature, to produce biogas and biofertilizer. The investigation of quorum sensing (QS) and quorum quenching (QQ) technology has provided valuable insight into the behavior and functionality of microbial communities in mixed bacterial systems. In this review, the role of QS in anaerobic digestion is investigated, which includes the microbial community shift and the enhancement of methane production by various types of N-acyl homoserine lactones (AHLs). Short-chain AHLs, for instance, improve treatment efficiency by stimulating the hydrolytic bacterial community, while long-chain AHLs increase the rate of methane production by methanogenic bacteria or archaea. Furthermore, the impact of QQ on AD processes has also been investigated. While QQ has been shown to effectively control membrane fouling in anaerobic membrane bioreactors, its impact on methane production and treatment efficiency remains unclear. While this study contributes to shedding some light on the role of QS and QQ in AD, further researches are necessary to address the remaining enigmas and comprehend the underlying mechanism.

Keywords: *Anaerobic digestion, Bacterial signalling, Quorum sensing, Quorum quenching*

Introduction

The rapid growth of the human population and industrial development poses a significant environmental threat due to greenhouse gas (GHG) emissions and global warming. Food waste (FW) and waste-activated sludge (WAS) are major contributors to GHG emissions. To address this issue, various physical, chemical, and biological strategies have been employed. Anaerobic digestion (AD) and dark fermentation (DF) are effective biological techniques that convert organic waste into valuable products like bioenergy and organic acids. Microbial populations in AD and DF play a crucial role in different stages, and maintaining a balance between bacterial growth and metabolism is essential for stable production.

Anaerobic digestion involves the breakdown of complex organic molecules into biogas and digestate by anaerobic microorganisms. It consists of four phases: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. The interaction between microorganisms in these phases is crucial. Hydrolytic bacteria release enzymes that break down carbohydrates, lipids, and proteins into smaller intermediates (Meegoda et al., 2018). Enhancing AD hydrolysis has been addressed through various pretreatment strategies, although some methods are impractical due to energy and chemical requirements.

Quorum sensing involves the secretion of autoinducers, primarily N-acylated homoserine lactone (AHL), in gram-negative bacteria (Anburajan et al., 2021; Yeon et al., 2009). AHLs have short and long chain forms that play different roles in diffusion and transport within cells. AHLs increase cell density, and when a threshold is reached, the LuxR receptor protein is activated (Jiang and Liu, 2012; Li et al., 2019). AHLs exhibit heterogeneity, with a bacterium producing multiple AHLs and other bacteria recognizing identical AHLs in complex environments. QS-based technologies have been used to enhance bioenergy production and improve pollutant removal in wastewater treatment systems. However, further research is needed to optimize their application in these fields and explore other environmental applications.

Role of QS in anaerobic digestion

Anaerobic digestion (AD) is a highly effective process for producing biogas, relying on the symbiotic interaction of diverse microbial populations. The formation of biofilms and granules is crucial in enhancing microbial stability and biogas production. Researchers are studying the role of quorum sensing (QS) signals in AD (Fig. 1), as they have been found to induce biofilm formation, bacterial aggregation, promote the release of extracellular polymeric substances (EPS), and enhance the degradation of organic matter. Different AHL signal molecules, both endogenous and exogenous, serve various functions in the bacterial system. Exploring communication systems between different bacterial community components can provide insights for future advancements in AD monitoring. The use of QS can alter the microbial community in anaerobic digestion, including Firmicutes, Proteobacteria, Chloroflexi, Geobacter, and Desulfovibrio. Adding AHL signal molecules to a batch reactor increases the abundance of Proteobacteria and Synergistetes involved in hydrolytic acidification (Li et al., 2021).. QS signals can improve the breakdown of refractory organics, enhancing the hydrolysis and acidogenesis of difficult-to-degrade compounds. Additionally, QS systems enhance the activity of acetogens and methanogens in AD systems, with specific AHLs being utilized to enhance COD removal. Increasing the content of endogenous AHLs in the anaerobic community improves synergy between methanogens and acetogens. AHL addition to AD reactors can increase granule size and EPS concentration. Short-chain AHLs enhance treatment efficiency by promoting the hydrolytic bacterial community, while long-chain AHLs improve methane production rates by increasing methanogenic bacteria or archaea. QS plays a vital role in particle formation, EPS secretion, microbial communication, and overall treatment capacity improvement in AD. In brief, the use of QS signals holds potential for enhancing the stability and performance of AD. Future research can delve into the mechanisms of QS involvement in AD and identify novel strategies to improve biogas production efficiency.

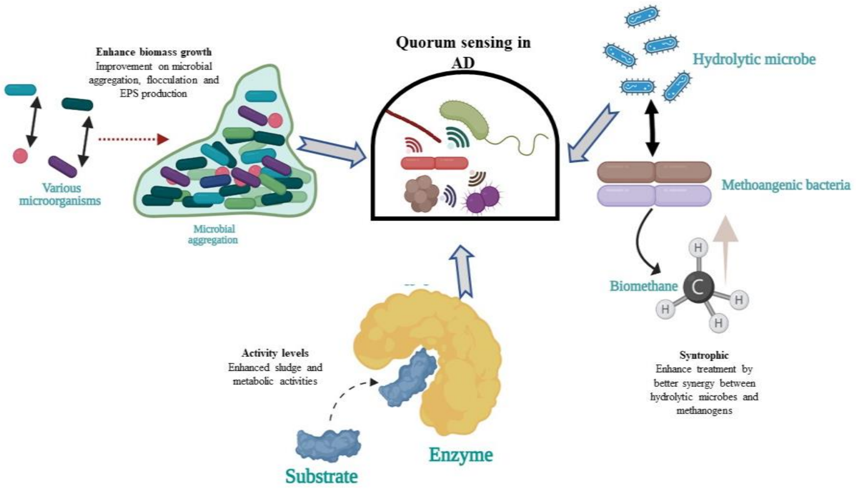

Figure 1 Advantages of QS in Anaerobic Digestion

Quorum quenching (QQ) in anaerobic digestion

Quorum quenching (QQ) is a process that inhibits bacterial quorum sensing (QS) activities by disrupting QS signal molecules. QQ has been proven effective in mitigating biofouling in membrane modules during wastewater treatment (Anburajan et al., 2021; Lee et al., 2018; Oh and Lee, 2018). It can be achieved through mechanisms such as competition, inhibition, degradation, and blocking the AI receptor of signal molecules. Enzymes like lactonase, acylase, and oxidoreductase are commonly used in QQ schemes to hydrolyze lactone rings, destroy amide bonds, and modify acyl chains in AHL signaling molecules.Quorum-sensing inhibitors (QSIs) secreted by microorganisms and plants can also inhibit QS. However, QQ bacteria offer a more efficient and sustainable approach compared to the addition of QSIs. The promotion of QQ activity in membrane bioreactors (MBRs) has shown promise in controlling biofouling. The Rhodococcus sp. BH4 strain is being developed as a bacterial QQ approach to mitigate MBR biofouling.

In anaerobic digestion (AD), the lactonase effects of AiiM have been observed to enhance methane production. QQ through AHL lactonase inactivates QS in Gram-negative bacteria, leading to the release of antibacterial compounds and a shift from Gram-negative to Gram-positive bacterial communities, thereby promoting the growth of fermentative and acidogenic bacteria. Recent studies have demonstrated that QQ bacterial strains enhance methane production in AD by influencing microbial community changes and promoting the growth of fermentative and acidogenic bacteria. QQ can also control biofilm formation by inhibiting extracellular polymeric substance (EPS) production, an important factor in preventing biocake layer formation. Overall, QQ is an effective approach to control biofouling and improve microbial community changes in AD. The use of QQ bacteria is more efficient and sustainable than the addition of QSIs. Further research is needed to optimize the application of QQ in wastewater treatment and AD processes.

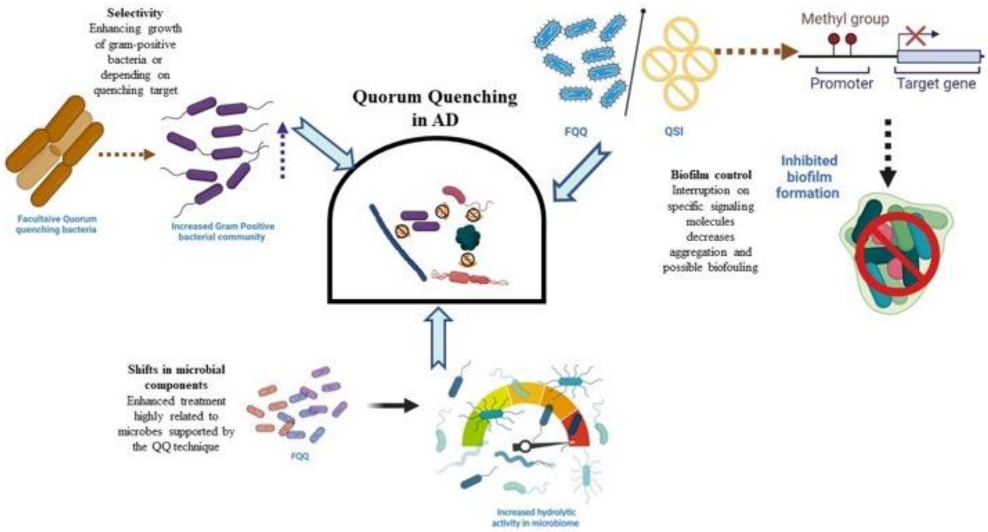

Figure 2 Advantages of QQ in Anaerobic digestion

Conclusion and future recommendations

AD and its microbial communication have become an increasingly fascinating research area. The use of QS has helped to understand the complexity behind the behavior of the mixed bacterial community in AD. This review explains the role of QS in anaerobic digestion, showing that different types of AHLs can improve the microbial community and increase methane production. Short-chain AHLs are particularly effective in enhancing the hydrolytic bacterial community, thereby improving treatment efficiency, while long-chain AHLs improve methane production rates by increasing the abundance of methanogenic bacteria or archaea. QQ has also been useful in waste management, especially in anaerobic MBRs, as it controls membrane fouling. Moreover, QQ plays a significant role in improving methane production. Despite the promising results, there are still challenges to fully understanding the mechanisms of QS and QQ in the mixed bacterial community. Overcoming these obstacles will require studies in areas such as metabolic engineering and genomics to elucidate the exact function of QS and QQ.

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Effects of Hydrothermal Pretreatment and the Activated Sludge on Anaerobic Digestion of Food Waste

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Abstract. Food waste (FW) was pretreated using a hydrothermal pretreatment (HTP) method, and the effects on physicochemical properties and methane yield improvement were investigated. These results illustrate that the hydrolysis of food waste improved with increasing temperature. It is noted that after pretreatment at 120°C, food waste digestion obtained the cumulative methane yield of 324.39±4.5 mL/gVS_{add}, which was significantly increased by 41.75% higher than untreated food waste 228.83±1.13 mL/gVS_{add} due to the inhibition by by-products (Humic acid) formed at high temperatures. HTP significantly changed the electron transfer rate during anaerobic co-digestion. Increased relative abundances of *Methanosarcina, Methanobacterium, Syntrophomonadaceae*, and *Synergistota* were observed in pre-treated FW. In addition, the co-digestion of food waste pre-treated at 120°C obtained the maximum energy production of 11.48 MJ/t, 49% promotion compared to the co-digestion without pre-treatment. These results suggest that co-digestion of FW and SS can achieve the highest methane production and energy conversion efficiency.

Keywords; Food waste, sewage sludge, co-digestion, Hydrothermal pretreatment, Energy conversion efficiency.

Introduction

Nowadays worldwide, the rapid growth of population and economic activities are producing an increasing amount of municipal solid waste (MSW), which leads to serious environmental threats [1]. Hong Kong is a highly dense city, where per capita food waste (FW) generation is 0.30 kg/day and sewage sludge (SS) rate is comparatively >0.16 kg/day [2]. Therefore, significant efforts are necessary to handle FW and SS to avoid detrimental environmental and social impacts. Anaerobic digestion (AD) is well recognized as a promising method for simultaneous waste stabilization and energy recovery in the form of methane-rich biogas [3]. In addition, FW contains complex organic compounds, such as animal fats, vegetable oils, and large molecular weight carbohydrates, which make hydrolysis a limiting step in AD. Various pretreatment techniques have been developed to improve the biodegradability of the AD process and the production of methane, including biological, mechanical, thermal, and chemical treatments. These techniques increase the solubilization of organic matter and refractory compounds, leading to a reduction in organic matter, which increases biogas production [4]. Among these methods, hydrothermal treatment (HTP) is the most efficient and environmentally friendly because it does not involve the addition of chemicals. The HTP process involves increasing the ionized products of water at elevated temperatures and pressures. Macromolecular materials can be hydrolyzed by these ionized products, along with organic dissolution [4]. Generally, most studies have reported that the optimal temperature for HTP is in the range of 90-180 °C and the treatment time is 20–60 min [5, 6]. Wang et al. (2018) [7] reported the AD of pretreated straw by HTP at four temperature gradients (90, 150, 180, and 210°C). The results showed that increased pretreatment temperature could significantly improve the hydrolysis performance of straw and promote the conversion of insoluble components to soluble ones. Pretreatment temperatures and durations are difficult to determine; they depend on the type of substrate and the conditions of anaerobic co-digestion. This study aimed to investigate the effects of hydrothermal pretreatment (HTP) on the anaerobic digestion of food waste. To estimate the digestive performance, energy conversion efficiency, and economic feasibility of food waste co-digestion with food waste by HTP at different temperature gradients (90, 120, and 140°C). The HTP treatment was applied prior to the FW of organic solid wastes originating from FW and sewage sludge (SS) to increase the biogas production and digestion ratio. We investigated the effect of pretreatment temperature on the characteristics of organic matter and evaluated the efficiency of biogas production based on the potential methane yield.

2. Materials and methods

Substrates and inoculum

Food waste and anaerobic digestate (non-saline) sludge were used as the inoculum, while primary and secondary (biologically activated) sludges were used as co-substrates with FW in the co-digestion experiments [3]. The sludge and FW substrates were individually characterized for various physicochemical parameters before addition to the co-digestion systems.

Hydrothermal pretreatment

Food waste was hydrothermally pretreated in 100 mL air-tight pressure digestion vessels (adjusting the moisture content to 80%). Reactors were operated at 90°C, 120°C, and 140°C for 60 minutes in an air-dry oven with no chemicals added. After 60 minutes of pretreatment, the reactors were cooled to ambient temperature. Batch anaerobic digestion tests were performed using a (Bioprocess AMPTS-II; Sweden). Biogas production was estimated using a control without pre-treatment FW. The mixed FW was pre-treated at three different temperatures (90°C FW+WAS, 120°C FW+WAS, 140°C FW+WAS, and untreated FW control). The working volume of each reactor was 400 mL. According to Johnravindar et al. (2023) [8], the inoculum/substrate ratio was set to 0.6, and the FW/WAS mixture ratio was 1:7 (TS basis). All reactors were operated at 35 °C for 20 days with continuous stirring (80 rpm).

Analytical methods

During the HTP, soluble and solid indices were measured, volatile fatty acids (VFAs) using gas chromatography (Agilent CP7675) coupled with flame ionization detector (FID), soluble and total COD using the standard protocols (APHA, 2005) [9] and methods as detailed in Johnravindar et al. (2021). Soluble protein, carbohydrates, ammoniacal nitrogen (NH_4^+-N), phosphate (PO_4^+-P), total solids (TS), and volatile solids (VS) were determined as previously described [9,10]. The soluble and solid index determinations were performed as described above. The final experimental data were the averages of triplicate reactor tests. energy consumption is calculated according to the average energy consumption of large-scale implementation. The populations of methane-producing microorganisms in the digester bulk sludge/food waste and sludge were analyzed [11].

Results and Discussion

Effect of hydrothermal pretreatment on FW

Food waste was pre-treated under hydrothermal pressure for 60 min at 90°C, 120°C, and 140°C. The characteristics of the pre-treated food waste are listed in **Table 1**. The pre-treated solid had a darker brown color than untreated food waste. In addition, the color darkened with increasing pre-treatment temperature. The total solid content of the pre-treated food waste was nearly constant below 140 °C. The soluble COD of different HTP 90, 120, and 140°C pre-treated food waste reached 41.43±0.81, 67.6±1.7, and 72.0±0.2 g of COD/L, respectively. While that of untreated food waste was only 37.83±0.04 g of COD/L. After HTP, the sCOD of the treated FW was higher than that of the untreated food waste, indicating that HTP promoted the solubilization of solid organics in the FW. As the hydrothermal temperature increased from 90 °C to 140 °C, the COD solubilization yield increased from 52.74% to 88.846%. This phenomenon occurs because high temperatures increase the breakdown of chemical bonds, such as the breakdown of proteins and polysaccharides contained in FW, resulting in the release of organic compounds in the liquid phase [12].

Table 1. Impact of different hydrothermal pretreatment temperatures on food waste characteristics

Parameter	**Unit**	**90°C FW**	**120°C FW**	**140°C FW**	**Untreated FW (control)**
pH	--	4.57± 0.02	4.51± 0.16	4.29± 0.01	4.5± 0.01
TS	%	20.16± 0.21	20.91± 0.61	21.98± 0.29	20.96± 0.11
Total soluble polysaccharides	g/L	45.31± 3.3	71.18± 6.12	81.80± 0.8	35.74± 0.8
Total soluble protein	mg/L	278.74± 1.31	336.7± 0.32	526.45± 4.5	215.2± 1.6
sCOD	g/L	41.43± 0.81	67.6± 1.7	72.0± 0.2	37.83±0.04
tVFA	g/L	2.427± 0.03	2.53± 0.62	3.437± 0.05	2.0918±

Increasing the hydrothermal temperature significantly affected the total and soluble carbohydrate content. **Table 1** shows in maximum content of soluble carbohydrates 45.31±3.3, 71.18±6.12 and 81.80± 0.8 g/L was observed at 90, 120, and 140°C, respectively. The increase in soluble carbohydrates at the temperature 90-140°C could be explained by the following reason: when FW was subjected to HTP, the large molecular-weight carbohydrate polymers (e.g., starch, cellulose, and hemicellulose) were hydrolyzed into small molecular weight oligosaccharides and monosaccharides (e.g., glucose, fructose, and xylose) [13], leading to the release of soluble sugars from the solid carbohydrates in FW. However, some soluble sugars, such as hemicellulose derivatives, were further degraded into short-chain VFAs, such as acetic acid, thus decreasing the total carbohydrate content. In addition, the improvement of CODs has demonstrated that the HTP has a beneficial effect that can enhance methane generation since the release of organic in a liquid phase increases its accessibility for bacteria. Therefore, the HTP at 120°C for 60 mins was chosen for co-digestion optimal performances.

Fig 1. shows the effect of various HTP temperatures 90°C, 120°C and 140°C on total VFA production. Generally, after HTP the amount of pretreated tVFA was much higher than the unpretreated FW. The concentrations of tVFA in 90°C, 120°C and 140°C HTP food waste increased to 2.427± 0.03, 2.53± 0.62, and 3.437± 0.05 g/L respectively, ~ 1.16, ~1.20, and 1.64- fold greater than that of the control, respectively. It was reported that different VFA compositions could lead to different methane yields, and acetic acid was the main source of methane production [13]. The concentrations of acetic acid were the highest among those of the VFA components in all the groups, followed by the lactic, propionic acid, ethanol and butyric acid. Acetic acid in VFAs of 90°C, 120°C and 140°C HTP accounted for 40%, 44.6%, and 43.1% respectively. Acetic acid, as the dominant substrate of the metabolism of methanogens, could be an important factor for the selection of pretreatment methods during anaerobic digestion.

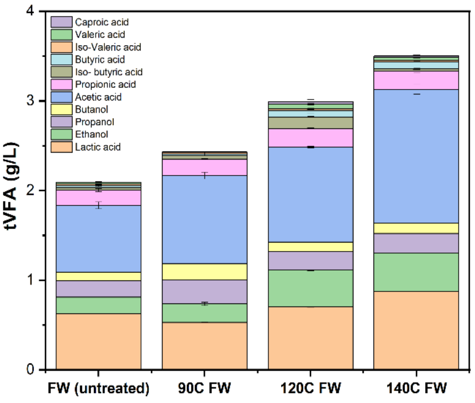

Figure 1. Variations in the temperature of hydrothermal pre-treatment have an impact on the properties of food waste.

The HTP process may enhance the solubilization and anaerobic biodegradability of the FW/WAS co-digestion mixture, and anaerobic digestion of FW is thought to disrupt the physical structure of the organic solid; therefore, methane production and rates can be increased by anaerobic co-digestion. The specific cumulative methane production (**Fig. 2a**) showed a threshold value for increased methane production. Indeed, it increased with the HTP temperature until 120°C, from 324.39± 4.5 mL CH_4/gVS_{add} for the unpretreated FW/WAS to 228.83± 1.13 mL CH_4/gVS_{add} for the FW pretreated 120°C.

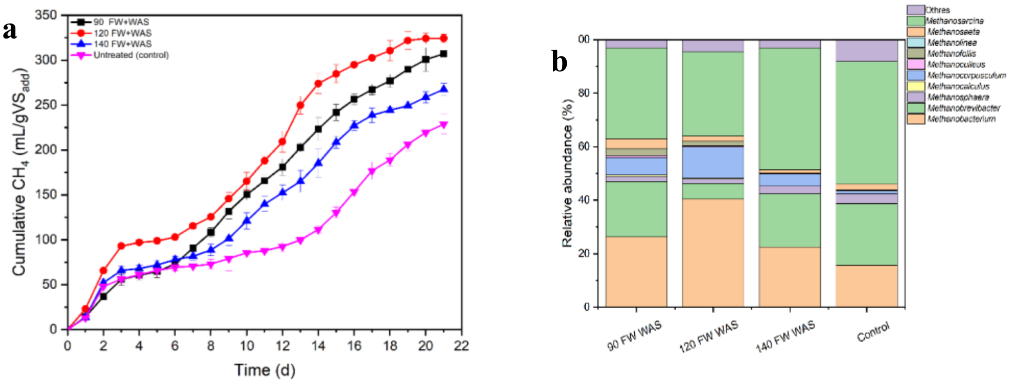

Figure 2. Cumulative methane and Microbial community structure in different food waste HTP anaerobic co-digestion systems along with sewage sludge addition: (a) Cumulative methane and (b) Archaea at the genus level.

Furthermore, the cumulative methane production increased FW pretreated 120°C by 41.75% compared to that of untreated FW. These findings show that HTP increases methane yield due to the deflocculation of macromolecules, which increases surface area and encourages interaction between the substrate and microorganisms [4]. Moreover, at 140°C, large solubilization of particulate organic matter occurred, and the food waste biodegradability was inhibited as the food waste/WAS biodegradability (324.39± 4.5 and 267.43± 1.46 CH_4 mL/gVS_{add}). At 140°C, the carbohydrate in the soluble phase reacts with the other components to form the product slowly or to make it hardly biodegradable [4, 14]. Kim et al. (2014) [14] suggested the presence of a changed chemical structure due to the “burn sugar” reaction and the Maillard reactions for a high pre-treatment temperature. Methanogens are strictly anaerobic microorganisms that are more vulnerable than hydrolytic and acidogenic microorganisms. The genera and abundance of methanogens are important for FW/sludge co-digestion. The relative abundances of methanogens in the control and pretreatment groups were 92.9 and 97.3%, respectively, but the distribution of methanogens was quite different (**Fig 2b**). *Methanobacterium* was the dominant methanogen in both systems, and the relative abundance of *Methanosarcina* in the control group was 61.15%, whereas that in the pretreatment group reached 71.5%. *Methanosarcina* was an acetotrophic methanogen and used acetate as the only substrate for methanogenesis.

Conclusions

This study demonstrates that HTP is a suitable approach for the pretreatment of FW to promote co-digestion performance. The solubilization of sCOD, VFAs, and solubilization of organic components (i.e. carbohydrates and proteins), increased with temperature increase reaching the maximum value of 87.94%, 64.45, 64.54 and 34.64% at treatment temperature of 90, 120, 40°C for 60 mins. Hydrothermal pre-treatment at 120°C for 60 mins facilitates the solubilization of organic components and thus could significantly increase the methane generation of the co-digestion of food waste/sludge. Microbial community analysis revealed that 120°C HTP of FW significantly increased the relative abundances of acetogenesis and methanogens. The energy conversion efficiency (ECF) output of the HTP 120°C FW was the highest (11.48 MJ/ t Fed VS), which was 49% higher than that of the control.

Acknowledgment

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Enhancing Bio-Hydrogen Production in Anaerobic Reactor Through Exogenous Addition of Quorum Sensing Signals

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ABSTRACT. Quorum sensing (QS) is a cell-to-cell communication process based on population density, which is used to regulate group behaviors via signaling molecules known as auto-inducers. In this study, we examined the effect of QS molecules on bio-hydrogen production in a continuous stirred tank reactor. The exogenous addition of N-acyl homoserine lactones (AHLs), a QS molecule, altered the structure of the microbial community during dark fermentation while increasing the hydrogen production rate and hydrogen yield. The addition of AHLs showed a positive effect with a 61% increase in hydrogen production rate and enhance the abundance of the genus *Clostridium* known as hydrogen-producing bacteria. This study suggests that QS signaling plays an important role in biological hydrogen production and confirms that increased hydrogen production can be achieved through its regulation.

Keywords: *Bio-hydrogen; Dark fermentation; Quorum sensing; N-acyl homoserine lactone (AHL); Microbial community*

Introduction

Bio-hydrogen (H_2) is one of the most promising green energy sources, with several advantages over other biofuels [1]. Dark fermentation is one of the most effective pathways for bio-hydrogen production compared to other processes such as photolysis and photo fermentation. A mixture of various microorganisms present in the anaerobic sludge of a wastewater treatment plant is used in this process to break down different types of organic substances and convert them to hydrogen in the absence of light and oxygen [2]. Quorum sensing (QS) is a cell-to-cell communication process based on population density to regulate group behaviors such as biofilm formation, luminescence, and virulence using signaling molecules known as auto-inducers, which are produced and recognized by microorganisms [3]. N-acyl homoserine lactones (AHLs), a type of auto-inducers, are small diffusible chemical signals mostly synthesized by gram-negative bacteria. This is the first study aimed to investigate the effect of AHLs on the production of bio-hydrogen through dark fermentation. The effect of adding AHL molecules in a lab-scale continuous stirred tank reactor (CSTR) was examined by evaluating the production of biogas and hydrogen, as well as observing the changes in the microbial community and the metabolic pathways.

Material and Methods

Inoculum and substrate

The anaerobic digester sludge was heat treated and followed by immobilized alginate beads were used as an inoculum and a modified endo medium with 15g/L glucose as a sole carbon source was used as a media [4].

Experimental setup and exogenous AHL addition

A lab-scale CSTR was used with a working volume of 2.9 L and a total volume of 5 L. The reactor was maintained at 35 ± 1 °C and 5.5-6.5 pH, with continuous stirring at 50 rpm. After an acclimation period of 38 days, on the hydrogen production with 6h HRT, a cocktail of AHLs was added to the reactor twice, with a concentration of 5 µM for each AHL. The AHL cocktail stock solution was prepared by dissolving C4-HSL, C6-HSL, C8-HSL, and C10-HSL into DMSO to reach a final concentration of 12500 µM each, and then diluted using 50 mM Tris-HCl buffer (pH 7.0).

Analytical methods

The biogas production and composition were analyzed by gas chromatography using a thermal conductivity detector. Volatile fatty acids (VFAs) were analyzed using high-performance liquid chromatography. The AHL was extracted from mixed liquor samples by liquid-liquid extraction and quantified by using a high-performance liquid chromatograph equipped with a tandem mass spectrometer with a C18 column (3.5 µm, 4.6 mm ×50 mm, Agilent, USA) at a flow rate of 0.3 mL/min [5]. The extracted DNA from mixed liquor was prepared to build a sequencing library that was sequenced on an Illumina MiSeq 100 system. Bar-coded primers were used to amplify the 16S rRNA gene segments and the sequencing reads were processed using QIIME2 and Ezbiocloud. PICRUSt2 was used to predict the functional potential of the microbial community using marker gene sequencing profiles, and KEGG Orthologs were used to support functional gene profiling.

Results and Discussion

Bio-hydrogen production performance in CSTR with exogenous AHL addition

According to the results (Table 1), hydrogen production increased by 60.9% and 53.9% following the first and second doses, respectively. After the first dosage of AHL, the maximum hydrogen yield was 2.64 0.34 mol H_2/mol $glucose_{added}$. The two repeated AHL dosages confirmed that the addition of exogenous AHL in the dark fermentation process could have a positive effect on bio-hydrogen production.

Table 1: Pseudo-steady state hydrogen production performance before and after AHL dosages into the system

	Biogas production rate (L/L-d)	Hydrogen production rate (LH_2/L-d)	Hydrogen yield (HY) (mol H_2/mol $glucose_{added}$)
Before first AHL dosage (day 38-day 42)	22.56 ± 1.30	13.81 ± 1.89	1.64 ± 0.22
After first AHL dosage (day 43-day 46)	28.97 ± 2.58	22.22 ± 2.89	2.64 ± 0.34
Before second AHL dosage (day 51-day 55)	22.99 ± 1.44	12.01 ± 3.62	1.43 ± 0.43
After second AHL dosage (day 56-day 65)	24.92 ± 0.69	18.48 ± 1.01	2.19 ± 0.06

Variations in organic acids formation during bio-hydrogen production

The organic acid formation is an important indicator to show the impact of AHL addition on hydrogen production during dark fermentation. Following the exogenous addition of AHLs to the CSTR, alterations in the synthesis of organic acids are shown in Fig. 1. The concentration of butyric acid increased by 7.49% after the initial AHL dosage (from 4.52 ± 0.32 to 4.85 ± 0.16 g/L). The study by Wu et al.,[6] found a favourable correlation between the system's butyric acid production and the substrate metabolism of the hydrogen-producing microbial population. After the second AHL dosage, the acetic acid concentration decreased to the previous level, whereas the butyric acid concentration increased by 23.1% (from 4.15 0.51 to 5.11 0.13 g/L). Butyric acid is thermodynamically more favourable than acetic acid for bio-hydrogen generation, resulting in efficient bio-hydrogen production. According to the VFA results, the addition of exogenous AHLs enhances hydrogen generation via the butyrate pathway. However, the mechanism by which AHL-type QS affects the microbial community in the dark fermentation systems is not yet clear, and further studies are needed to understand how operating factors influence AHL-type QS and, as a result, hydrogen production.

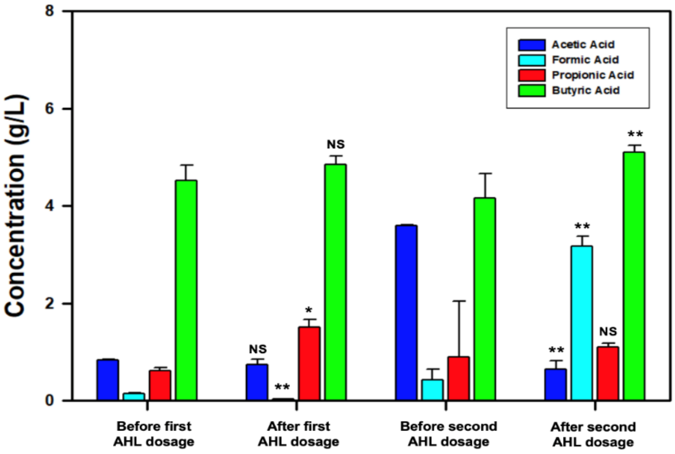

Figure 1. Variation of VFA production upon exogenous AHL addition in CSTR with immobilized

Microbial community changes

The microbial community analysis (Fig 2.) showed that *Clostridium*, *Sporolactobacillus*, and *Enterobacter* were the major genera present in the system. The addition of AHLs favoured the growth of

Clostridium, a major hydrogen-producing bacteria group, leading to an increase in hydrogen production efficiency and butyric acid release. The proportion of hydrogen-consuming microorganisms such as *Sporolactobacillus* and *Enterobacter* decreased after AHL addition. However, an increase in some undesirable microorganisms was observed before the second AHL dosage due to operational issues.

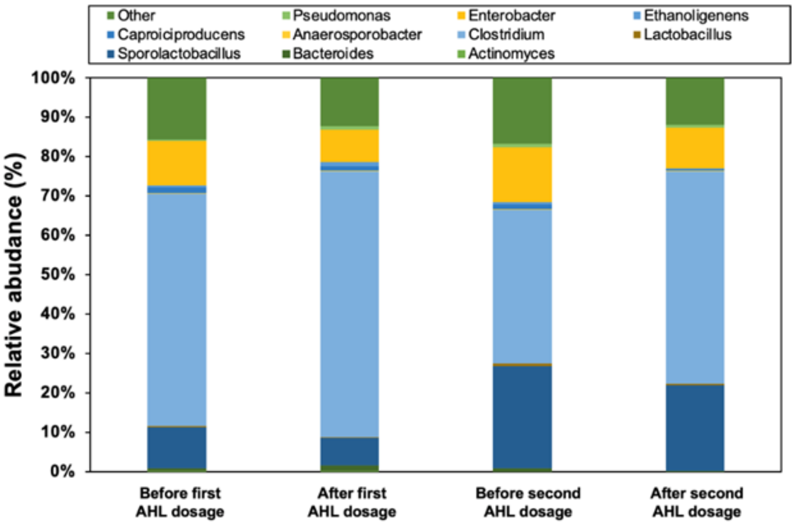

Figure 2. Taxonomic distribution of microbial community at the genus level, as revealed by Illumina MiSeq of 16S rRNA analysis.

Variation of AHL concentration

Fig. 3 shows the distribution of various AHLs before and after their dosage during the operation of the CSTR. The analysis aimed to provide additional information on the AHL signals produced by the existing microbial community and to investigate the relationship between AHLs and system productivity. Various types of AHLs were detected in the concentration range of 0.03 ng/L–1.15 µg/L before adding any exogenous AHLs. C4-HSL was the main AHL produced during the operation of the CSTR, in agreement with previous studies employing anaerobic fermentation reactors. Interestingly, the concentration of most AHL species increased after the first and second dosage of AHL cocktails, but the concentration of C4- and C6-HSL (after the first and second dosage) and C10-HSL (after the second dosage) were considerably reduced. Increased concentrations of C8- and C12-HSL after the first and second AHL dosages and of C10-HSL after the first AHL dosage suggest that they may affect anaerobic granulation in the system, which could be crucial during bio-hydrogen production via the dark fermentation pathway.

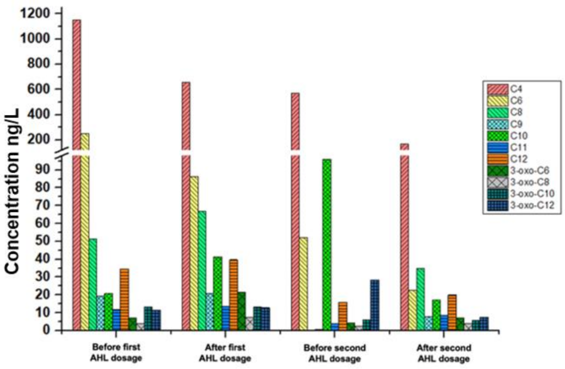

Figure 3. Distribution of various AHLs in mixed liquor of CSTR.

Conclusion

This study showed that the exogenous addition of AHL had positive effects on the hydrogen-producing microbial community in a dark fermentation system, with a 61% increase in hydrogen production rate and a maximum HY of 2.64 mol H_2/mol glucose$_{added}$ after adding AHL to the system. The results also showed an increase in *Clostridium* abundance in the microbial community, leading to increased concentrations of produced butyric acid, with corresponding increased hydrogen production. However, the variation as well as the impact of AHLs on the EPS and biofilm formation in the present system remain to be investigated.

Acknowledgments

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Biochar Mediated Methanogenesis from Acetic Acid and Ethanol and its Correlation with the Electron Exchange Capacity

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In order to explore the effect of straw biochar on anaerobic digestion process and whether it can promote anaerobic digestion methane production through DIET. Biochars derived from straws with different electron exchange capacities (EEC) were added to the anaerobic digestion system with acetic acid and ethanol as substrates to explore the effects of biochar on the methane production, substrate degradation and microbial community structure. The roles of direct interspecific electron transfer (DIET) in the process were explored. When the substrate was acetic and alcohol, the biogas yield of biochar experimental group was higher than that of the blank group. The performance of hydrochar group was the best, which cumulative methane production and the biodegradability were increased by 45.4% and 95.1%, and the anaerobic digestion lag period was 0.26 d, which was 45.8% shorter than that of the blank group. The percentage of hydrogen in the biogas from biochar experimental group was lower than that of the blank group. The gas production performance of the old biochar experimental group is generally higher than that of the corresponding new biochar experimental group. In the aspect of microbial community change, the dominant bacteria in the original inoculum changed, and the most important change was *Geobacter*, which could participate in DIET, and the relative abundance increased from 4.5% to 8.8%–14.8%.

Keywords: Straw biochar; Anaerobic digestion; Direct interspecific electron transfer.

Nitrogen-Iron Doped Hydrochar Facilitating Methane Production in Co-Anaerobic Digestion of Cow Manure and Corn Straw

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ABSTRACT. This study assessed the impact of hydrochar addition on methane production during co-anaerobic digestion of cow manure and corn straw. Nitrogen-doped hydrochar showed the highest methane production (345.3 m^3/t), a 45.93% increase compared to the control. Microbial analysis revealed changes in bacterial flora and increased microbial richness with hydrochar addition. Methanobacterium abundance increased with hydrochar addition, reaching a peak of 64.62% in the hydrochar group. Iron doping also influenced Methanobacterium abundance. Nitrogen addition during the hydrothermal carbonization process showed varying Methanobacterium abundance. Overall, hydrochar addition enhanced methane production and influenced the microbial community structure.

Keywords: DIET, Cow manure, Corn straw, Hydrochar, Biogas slurry.

1. Introduction

DIET facilitates electron transport between bacteria and archaea during anaerobic digestion, promoting the rapid conversion of organic matter into biomethane. Studies have shown that the addition of conductive materials in anaerobic digestion systems increases the abundance of key DIET indicator microorganisms such as Geobacter, *Methanosarcina*, and *Mathanosaeta* (Pan et al., 2020; Tian et al., 2017; Xu et al., 2015). *Methanosarcina*, in particular, is capable of methane production through DIET (Rotaru et al., 2014b). The addition of granular activated carbon (GAC) in anaerobic digestion systems has demonstrated a decrease in the relative abundance of pilA and omcS genes, while GAC addition in continuous UASB treatment has increased the copy numbers of these genes in the Geobacter anaerobic digestion system (Park et al., 2018). Hydrochar addition in anaerobic digestion systems has been shown to improve biogas and methane efficiency (Igarashi et al., 2020). Furthermore, the addition of hydrochar as a conductive material enhances electron transfer rates, promotes DIET between microorganisms, strengthens anaerobic reaction stability, improves reaction efficiency, and mitigates inhibitory effects (Si et al., 2020).

2. Materials and Methods

2.1 Experimental reagents and equipment

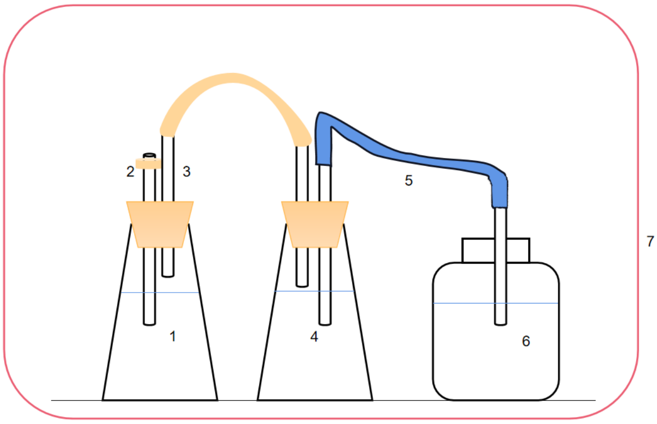
Table 1. experimental reagents

Reagent	Specifications	Vender
Urea	AR	Sinophenol Chemical Reagent Co., LTD
Caustic soda	AR	Sinophenol Chemical Reagent Co., LTD
Iron trichloride	AR	Sinophenol Chemical Reagent Co., LTD
Hydrochloric acid	AR	Shanghai Runjie Chemical Reagent Co., LTD
Absolute ethyl alcohol	AR	Beijing Kangpu Xiwei Technology Co., LTD
LH-D reagent	AR	Lanzhou Lianhua Environmental Protection
LH-E	AR	Technology Co., LTD
LH-N3	AR	Lanzhou Lianhua Environmental Protection
LH-N2	AR	Technology Co., LTD
DNA extraction kit	PowerSoil® Total DNA Isolation Kit	Mo Bio

2.2 Materials

Cattle dung straw biogas residue was filtered and different types of HTC were prepared in a high-temperature and high-pressure reactor. For HTC, the reaction conditions were 220°C, 200 rpm, and pH 5±0.1 for 4 hours. The mixture was then removed, washed, and dried. For HTCFe, the reaction conditions were 180°C, 200 rpm, and pH 5 ± 0.1. The hydrochar was soaked in 2 mol/L $FeCl_3$(aq) for 24 hours, followed by pyrolysis at 700°C for 2 hours with N_2. For HTCN, the reaction conditions were 180°C, 200 rpm, and pH 5±0.1. After washing and drying the hydrochar, it was mixed with dicyanamide and water and stirred at 80°C until dry. The mixture was then soaked in 2 mol/L $FeCl_3$ for 24 hours, followed by pyrolysis at 700°C with N_2 for 2 hours.

2.3 Experimental device



Note:1. anaerobic digestion reactor; 2. sampling mouth; 3. gas collection pipe; 4. drainage collecting pipe; 5. drainage pipe; 6. liquid collection bottle; 7. constant temperature incubator

Figure 1. Anaerobic digestion device.

2.4 Experimental Methods

1) Conventional Analysis:

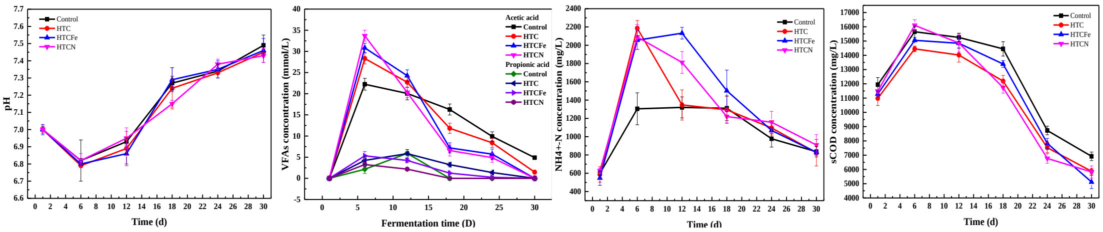
Daily biogas yield was measured using gas collection. CH_4 content was analyzed using gas chromatography. TS, VS, pH, carbon and nitrogen contents were determined using weighing and titration methods. sCOD, NH_4±N, and coenzyme F_{420} contents were measured with rapid testers. VFAs were analyzed using gas chromatography. Specific surface area was determined using physical sorption. Adsorption isotherms of hydrochar were obtained at 77K, and specific surface area was calculated using the BET method.

2) DNA extraction and PCR amplification

DNA samples were extracted using a kit following the instructions. Primers 515F and 909R were used for PCR amplification of the 16S rRNA gene. PCR products were purified and processed using the QIIME Pipeline. Quality control steps included removing sequences shorter than 300bp, those with ambiguous bases, and sequences with an average base quality score lower than 30. OTUs were formed by clustering sequences with 97% similarity, and species diversity was analyzed on the Meiji biological test platform.

3. Results and Discussion

Characterization of modified hydrochar



a b c d

Figure 2. Changes in anaerobic digestion after addition of modified hydrochars:(a)Changes in pH (b) Changes in VFAs (c) Changes in Ammonia nitrogen content (d) Changes in sCOD content.

Effect of adding modified hydrochar on methanogenesis in the anaerobic digestive system

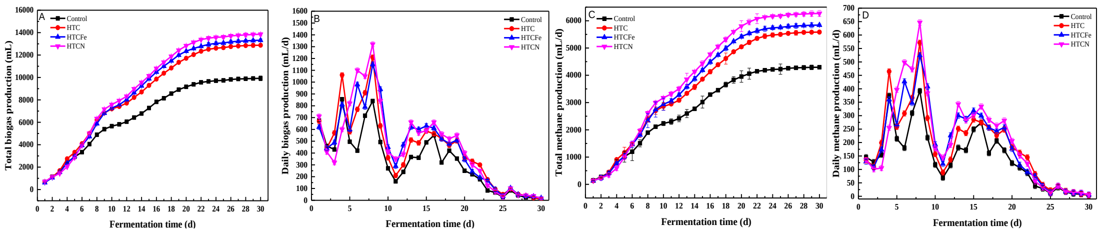
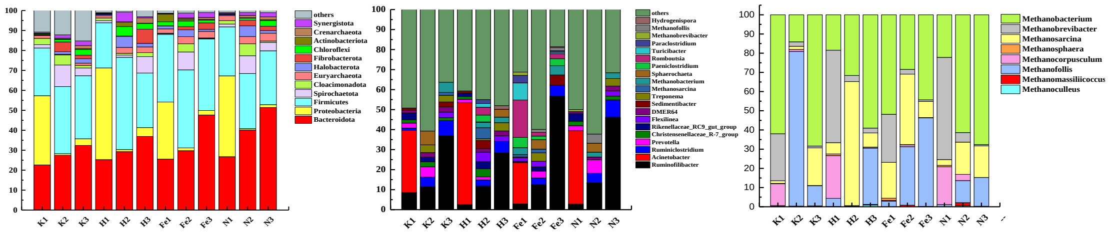


Figure 3. Results of anaerobic digestion between different treatments: (a) total biogas production, (b) daily biogas production, (c) total methane production, (d) methane daily production

Effect of the addition of modified hydrochar on the microbial diversity in the mixed anaerobic digestion system



a b c

Figure 4. Composition of microbial community:(a) phylum level of system after adding modified hydrochars, (b) genus level of system after adding modified modified hydrochars, (c) genus level of system after adding modified hydrochars.

Table 2. Microbial community diversity index in the mixed anaerobic digestion system of different modified hydrochar

Samples	Ace	Chao	Shannon	Coverage
K1	1178.826	1197.038	3.327	0.993
K2	1301.346	1318.833	4.154	0.993
K3	981.945	846.842	3.111	0.996
H1	1338.023	1319.883	3.854	0.993
H2	1420.734	1438.350	4.154	0.994
H3	1074.351	1095.767	3.813	0.995
Fe1	1400.960	1384.155	4.271	0.995
Fe2	1510.583	1475.428	4.236	0.992
Fe3	1143.528	1005.638	3.555	0.995
N1	1354.458	1227.151	4.632	0.995
N2	1552.98	1524.522	4.763	0.996
N3	1159.943	987.794	4.425	0.993

4. Conclusion

This manuscript discusses the preparation of modified hydrochar with increased surface area and electrical conductivity, and its effects on biogas production, microbial community, and microbiological processes. Key findings include:

(1) Successful synthesis of nitrogen-iron doped hydrochar, which exhibited increased pyridine nitrogen content, indicating its potential for anaerobic redox processes. The HTCN group achieved the highest CH_4 yield of 13,851 mL, 45.93% higher than the control group, during the anaerobic digestion of

cow dung and straw.

(2) Addition of nitrogen-iron doped hydrochar significantly increased microbial abundance in the anaerobic digestion system, with the order of abundance: control < hydrochar < iron-doped hydrochar < nitrogen-doped hydrochar. However, minimal changes were observed in microbial species.

(3) *Methanobacterium* was the dominant archaeal group in all digestion systems. The abundance of Methanobacterium ranged from 14.08% (control group) to 61.61% (nitrogen-doped hydrochar group). *Methanosarcina*, another significant archaeal group, had varying abundances across systems.In summary, different modified hydrochar had minimal impact on archaeal species but influenced the abundance of specific archaeal groups, particularly enhancing the relative abundance of hydrogen-utilizing methanogens.

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Zero Valent Iron Application in Anaerobic Co-digestion of Sewage Sludge and Food Waste

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ABSTRACT. Food waste management has garnered increasing concern owing to its potential social large production scale and environmental impacts. Anaerobic conversion to methane is an attractive treatment method for food waste management as it can reduce the environmental impact while recovering bioenergy simultaneously. Anaerobic co-digestion is considered to be one of the most important approaches to solving the problem of food waste recycling. Supplemented with ZVI in the co-AD system is proved to be of great improvement. Most studies demonstrated that the proper dosage of ZVI has a good effect on microbial abundance, that is, the control of the optimum dosage of ZVI has an affirmative effect, such as greater substrate degradation, lower volatile fatty acids concentration, and methane production. Because of the great difference between digestion substrates and AD operation, there are still many problems when designing an efficient AD system for practical food waste recycling. Therefore, further research is acquired for better utilize ZVI to improve AD performances according to various conditions.

Keywords*: Anaerobic co-digestion, Solid waste, Zero-valent iron*

Introduction

Food waste management has garnered increasing concern due to its large generation scale and potential environmental impacts [1]. Food waste, a typical solid waste such as sewage sludge, municipal solid waste, food waste, fecal sludge, livestock manures and so on that includes high levels of organic solids, has not been well disposed of in developing countries [2].

Anaerobic conversion to the gas of methane (CH_4) is an attractive treatment approach for food waste management as it can decrease the environmental impact while recovering bioenergy at the same time [3]. Anaerobic digestion (AD) is a widely used method to convert organic wastes to bioenergy and meantime decrease waste bulk. AD is a biological process, which includes several microbial steps (hydrolysis, acidogenesis, acetogenesis, and methanogenesis) and depends on several synergisms by various microorganisms, thus the efficiency of microbial metabolism is critical for AD [4]. The AD efficiency has to be improved to make the procedure more cost-effective. On the other and, Sewage sludge is one of the most favorable substrates in methane production via AD [5, 6]. It has been demonstrated that with the combination with other waste, that balances them, better results of biogas production are achieved during the AD. This process is called anaerobic co-digestion, and with it, many benefits can be achieved in comparison with anaerobic mono-digestion. Some of these benefits would be improved methane production, reduction of volatile solids higher biodegradability of waste, improved dilution of toxins compounds, and therefore a suitable carbon-to-nitrogen ratio [7].

Optimizations of this procedure control variables have to efficiently minimize the consumption of energy and raise biogas generation.

In recent years, researchers found that methane generation by anaerobic co-digestion of organic waste could be accelerated by adding reductive additives such as trace metals, zerovalent iron (ZVI), and Fe_3O_4 [8]. Among them, ZVI as a cost-effective and readily available substance has gained growing attention. ZVI possibly plays multiple roles during the whole enhanced process. Firstly, ZVI stimulates the activities of key enzymes, including acetate kinase, pyruvateferredoxin oxidoreductase, phosphotransacetylase, phosphotransbutyrylase, and dehydrogenase in acidogenic phase as well as F420-reducing hydrogenase enzyme in methanogenic phase [9]. Furthermore, alleviates acidic accumulation and reduces the oxidation–reduction potential of the AD process, creating a more favorable living condition for methanogens [10]. Baniamerian et al., 2019 [11] found to ZVI have positive effects on AD, such as the removal of H_2S, promotion of key enzymes in the methanogenesis process, and reduction of oxidation-reduction potential. Low oxidation-reduction potential (ORP) can supply a better environment condition for AD. In the CO-AD process of waste, because of the high hydrolysis rate and amount of organic matter excessive volatile fatty acids will be generated, thereby lowering the pH value of the digestive system, cause to a reduction in the stability of the digestive process and a reduction in biogas performance. addition of ZVI, the formation of volatile fatty acids and methane in the system can be improved.

During the co-AD process, ammonia nitrogen supplies a nitrogen source for microbial metabolism. It can neutralize volatile fatty acids in the reaction and adjust the pH of the digestive system. If the concentration of ammonia is too high, it will influence the activity of microorganisms. For high-nitrogen organic matter such as food waste, reducing the inhibition of high amounts of ammonia on microorganisms' activity will improve digestion efficiency.

Yan et al. 2020 [12] reported that ZVI is beneficial to improve the ability of microorganisms to resist high-amount ammonia nitrogen. Wang et al. (2019) [13] reported that the addition of ZVI (0–20 g/L), had no significant reduction effect on ammonia. It was demonstrated that the additional concentration of ZVI was not sufficient to affect the amount of ammonia due to the organic load was too high.

In addition, overly high dosages of additives can hinder methanogenesis because of varied complex factors, such as substrate competition, cell membrane damage, transfer limitation, and direct inhibition [14]. In addition, the adsorption of particles with the assistance of microbial activity will shift the increased activity of biogas production or inhibition level that depend on the dosage of metal in the AD process. Thus, maintaining the optimal dosage of ZVI in an AD is a critical step to boost biogas production.

Feng et al. (2014) [15] added different concentrations of ZVI (0, 1, 4, and 20 g/L) to the process of AD, and the results showed that ZVI effectively increased the decomposition of cellulose and protein. Wei et al. (2018) [16] reported that the addition of ZVI at the three concentrations (1, 4, and 20 g/L) remarkably improved biogas production by 12–27%. Suanon et al. (2015) [17] showed that the addition of ZVI in the nanoscale also increased biogas production. However, a high level of iron nanoparticles has a toxic influence on AD and prevents biogas production.

Conclusion

Using ZVI as an additive supply is an effective approach for the efficient treatment of co-digestion of sewage sludge and food waste. ZVI’s feasibility in food waste AD has been extensively investigated and demonstrated, which also indicated great performance and technical restrictions. ZVI mainly improves the yield of methane production by affecting enzyme activity and microbial metabolism. Due to various operating conditions, the same concentrations of ZVI indicated various effects on AD of the same kinds of food waste. Knowledge gaps regarding the evaluation of ZVI in sewage sludge and food waste are needed for further studies application of ZVI-based biological technology.

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Bioenergy and Bioproducts

Bio-hydrogen Generation from Food waste: Effects of Microwave Pre-Treatment and Inoculum Source

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ABSTRACT. Global food waste generation accounts for about 1.3 billion tons annually. Bio-hydrogen produced from food waste could be an ideal energy that is much superior to methane in terms of energy density, carbon footprint etc., that can address all the shortcomings of methane. However, the presence of competitive microbes in the seed sludge used for fermentation (methanogens majorly, lactic acid bacteria, etc.) and the amount of soluble portion of the organics in the food waste (varying between 10-30%) readily available for conversion to bio-hydrogen production are the areas of concerns that need to be addressed. Experiments were carried out with food waste as substrate and microwave pre-treatment to the raw food waste. The microwave pre-treatment promoted bio-hydrogen and yielded 2.96 times more hydrogen than raw food waste. Thus, MW pre-treatment could be an alternative and feasible option to the conventional-heating pre-treatment technique.

Keywords: Bio-hydrogen, Pre-treatment, Microwave.

Introduction

Bio-hydrogen is one of the intermediate products of anaerobic digestion. It has an energy potential of 122 kJ/kg, which is higher than that of methane. The process of bio-hydrogen production involves the prevention of methanogenesis, which is formed as a result of consumption of the hydrogen produced during the methanogenic phase. The prevention of methanogenesis can be done by altering the operating conditions of the reactor like temperature, and pH, increasing the substrate concentration, and exposing the substrate and inoculum to the radiations such as gamma rays, microwaves, etc [1]. Besides eliminating the hydrogen-consuming organisms, the pre-treatment also helps in solubilizing the complex substrate used in the process. This study aims at studying the effect of microwave power on the solubilization of food waste and its effect on bio-hydrogen production from food waste. Apart from the above mentioned pupose this study also explores the possiblity of using mix of aerobic and anaerobic sludge as seed for the dark fermentation process.

Material and Methods

Food Waste and seed sludge Collection

Aerobic seed sludge was collected from an aeration tank in a sewage treatment plant and food waste was collected from one of the dormitories at IIT Madras campus, Chennai, India. Anaerobic seed sludge was collected from an anaerobic digester in common STP located at Nesapakkam in Chennai, Tamil Nadu, India.

Experimental setup

A batch reactor of 200 mL working volume was used for the experiments using food waste as a substrate. Nearly 125 mL headspace was left for gas-holding which would be generated during the process. The reactor was filled with 20 mL of the sludge solution, 7.5 mL of nutrient solution, and 10 mL of 1 M phosphate buffer solution. The microwave reactor used in this study has a frequency of 2450 MHz and adjustable power range and temperature. The volume of food waste used for the present study was 30 mL. The seed sludge, substrate, media, and phosphate buffer were added to the reactor and the pH of the reactor was adjusted in the range of 6.2 to 6.5.

Analytical techniques

The composition of biogas was analyzed using a gas chromatography (GC, Agilent model 7890A), equipped with a thermal conductivity detector (TCD) and PORAPAK (70/100) column. The conditions used for the gas analysis are as follows: Carrier gas flow-7 mL/min, Front inlet temperature-100 ℃, and the detector temperature-250 ℃. The runtime was fixed as 5 min. The carrier gas used was nitrogen. All the other sample analysis were carried out according to The Standard Methods, APHA, 2017 [2].

Results and Discussion

Characteristics of food waste and seed sludge

Table 1. Characteristics of food waste and seed sludge samples used for the study.

PARAMETERS	FOOD WASTE	ANAEROBIC SLUDGE	AEROBIC SLUDGE
Moisture content (%)	91.82	93.29	96.84
Total solids (mg/l)	79845	87950	43654
Volatile solids (mg/l)	75596	37000	23176
Fixed solids (mg/l)	4246	50950	20476
VS/TS (%)	0.95	0.42	0.53
Total COD (mg/l)	88000	121200	16800
Soluble COD (mg/l)	11440	-	-
Carbon/Nitrogen (C/N) ratio	23.3	9.5	16.5

Effect of inoculum source on bio-hydrogen production from glucose

A synergistic effect was observed when the combination of aerobic (C1), anaerobic (C2) and the mixture of aerobic and anaerobic (C3) sludges was used as an inoculum with glucose as a substrate (3 g/L). Figure 1 shows the percentage of bio-hydrogen and volume of bio-hydrogen.

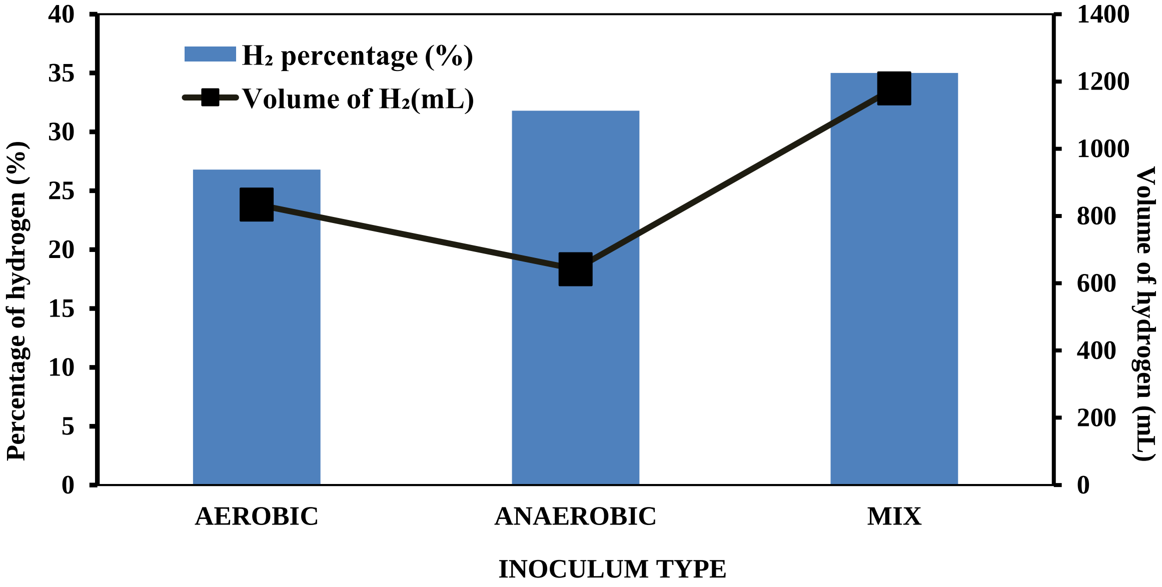

Fig.1 Percentage of bio-hydrogen and volume of bio-hydrogen from C1, C2 and C3.

It can be inferred from Fig.1 that the percentage of hydrogen in combination 3 was better when compared to the other 2 combinations. A similar set of experiments were carried out by varying the pre-treatment method adopted for the study. The seed sludge mix was microwaved at 3 different power levels (100, 200 and 300W) to study the effect of microwave power on seed sludge treatment. The volume of hydrogen produced from the reactors having seed sludge treated at a lower power level was higher when compared to that of the reactors having seed sludge treated at a higher power level. It might be due to the uniform heating of the microwave that might have affected the microbes responsible for producing hydrogen [3].

Effect of microwave pre-treatment on bio-hydrogen production from food waste

Figure 2 shows the percentage and volume of bio-hydrogen produced from raw and pre-treated food waste. The volume and percentage of hydrogen from raw food waste were found to be less when compared with that of the pre-treated food waste. This might be due to the presence of competitive/hydrogen-consuming microbes present in the raw food waste. Similar results were obtained in the study carried out by Joana et al., (2019) and Ortigueira et al., 2019, where microwave pre-treatment was adopted to eliminate the hydrogen-consuming bacteria and there was an increase in the hydrogen yield after pre-treatment [4,5]. However, a study carried out by Bundhoo, 2017 has resulted in the reduction of hydrogen yield when compared to that of the control [6]. This might be due to the exposure time of the substrate and the nature of the inoculum used for the study.

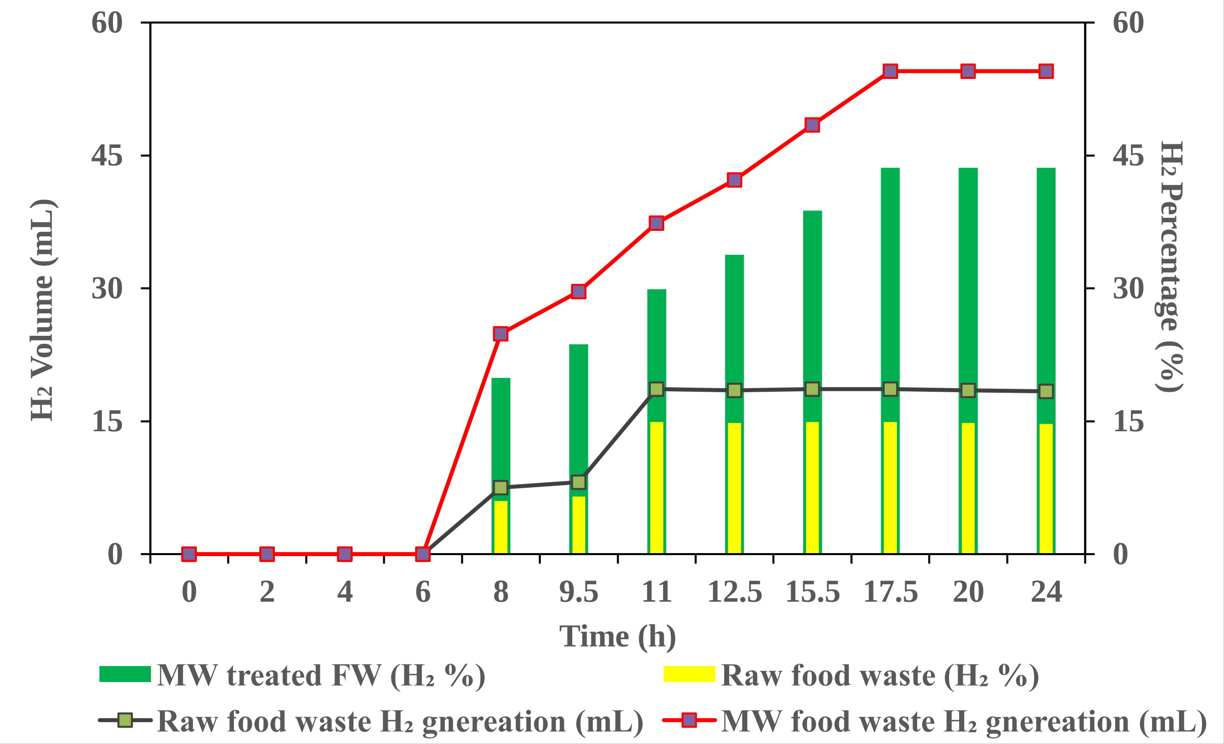

Fig.2 Percentage and volume of bio-hydrogen produced from raw and pre-treated food waste.

Effect of microwave power on bio-hydrogen production

In addition to the elimination of competitive microbes, microwaving also increases the soluble COD of the food waste that is available to the microbes for bio-hydrogen production. The power of microwave on bio-hydrogen production was evaluated by treating the food waste at 2 different power levels of 200 W and 490 W respectively. The soluble COD of the food waste had a positive correlation with the power level of the microwave [6].

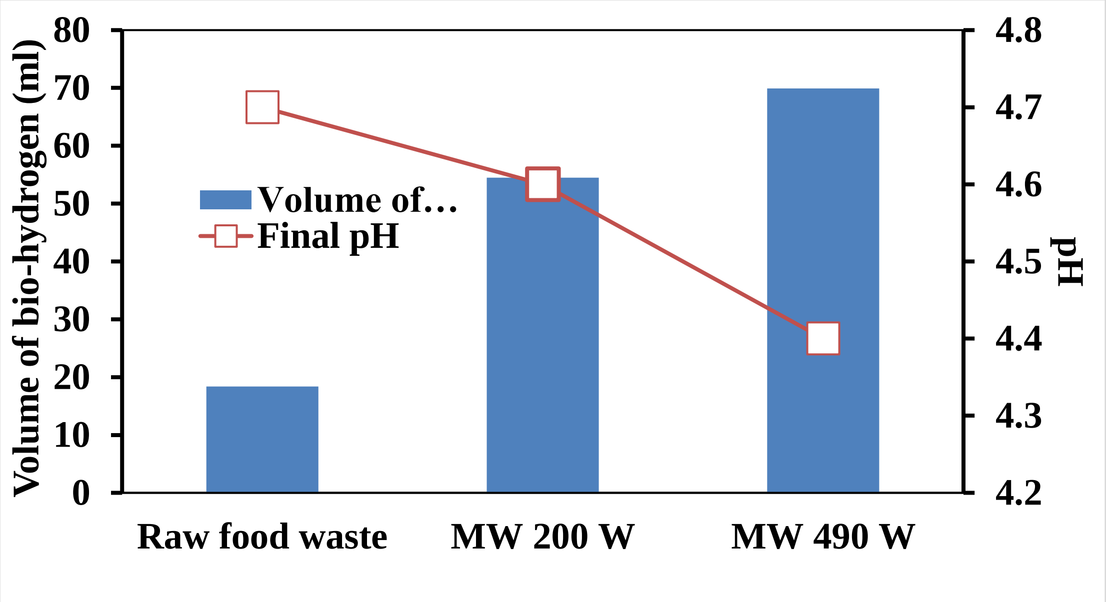

Fig. 3 Volume of hydrogen and pH of the reactors with raw and pre-treated waste.

The soluble COD after microwaving was 0.45 and 1.2 times more than the initial COD of the raw food waste. The volume of hydrogen and pH in different types of substrates used for the study is shown in Fig.3. The volume of hydrogen for the food waste pretreated at 490 W is higher when compared to the others. This shows that the power range chosen for the study does not divert the pathway of bio-hydrogen production but enhances it when compared to raw food waste. The final pH of the reactors confirms that there was a reduction of pH in all the reactors, which might be due to the acid production in the reactors. The acids produced in the reactor containing raw food waste might be due to the production of acids that might divert the entire system from hydrogen production. However, in the reactors with pre-treated waste, the pH reduction might be due to the production of acids that will yield bio-hydrogen. The microwave pre-treatment might have eliminated the hydrogen-consuming microbes in the raw food waste and increased the solubilization of food waste that might have increased the hydrogen yield.

Conclusions

The mix of sludge (aerobic and anaerobic sludge) can be used as an inoculum source for the production of bio-hydrogen from food waste. The microwave pre-treatment had a positive impact on the bio-hydrogen yield from the food waste by eliminating the competitive microbes and increasing the solubilization of particulate matter in the food waste.

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Solid Waste Biorefinery: Integrated Process Development via Hydrothermal Liquefaction and Dark Fermentation

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Municipal solid waste (MSW), an inevitable by-product of anthropogenic activities and its management has been a challenging problem. Herein, we report the catalytic hydrothermal liquefaction (HTL) of the organic fraction of MSW to facilitate thermal depolymerization to yield biocrude by employing various alkali and metal-based catalysts at 150-250^{0}C and 100 bar pressure under inert (N_2) and reducing (H_2) atmospheres with twenty-four designed experiments. The specific influence of catalyst and N_2 and H_2 conditions on bio-oil yields as well as the composition, energy recovery and by-products were explored. Catalysts with an H_2 atmosphere resulted in bio-oil with higher heating ratios (HHV) and yields by hydrodeoxygenation (H/C and O/C ratios). Among all the catalytic conditions, Pt/C under H_2 afforded more bio-oil with saturated hydrocarbon (biodiesel) content having high HHV. Further, the HTL aqueous fraction was valorised by employing dark fermentation to produce biohydrogen and bio-methane, wherein maximum biogas yield and substrate conversions were noticed under alkali-catalyzed conditions. Standalone HTL and integrated biorefinery processes were compared for sustainability by employing the lifecycle impact assessment (LCA). The biorefinery scenario depicted lesser environmental impacts and CO_2 emissions (GWP).

Keywords: Municipal Solid Waste, Catalytic Hydrogenation, Sub-critical temperature, Bio-Oil, Energy recovery, Bio-Hydrogen, Zero liquid discharge (ZLD), Circular Chemistry.

Elucidate Biorefinery Inhibition Effect on Commercially Collected Food Waste and Greener Pre-Treatment for Sophorolipids Production

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Secondary or waste organic streams have been used to produce sophorolipids (SLs) in the prospective of circular economy, and food waste (FW) is recognized as a promising feedstock. However, the quality of FW varies according to the location and seasonal changes, thereby resulting in different inhibitor's composition and interfere with the sustainable sophorolipids production. This study aimed to characterize the presence of inhibitors in a commercially collected FW, followed by designing a FW pre-treatment strategy to remove the inhibitors for sustainable sophorolipids (SLs) production. Key findings: Compare with the fresh canteen FW, the commercial FW hydrolysate had a low glucose concentration (29.40 ± 8.65 g L−1 versus 49.60 ± 2.97 g L−1), high fructose (9.73 ± 8.46 g L−1 versus 3.10 ± 0.14 g L−1), ethanol concentration (3.00 ± 2.62 g L−1 versus 2.55 ± 0.07 g L−1), lower pH (3.55 ± 0.10 versus 4.62 ± 0.12), and extra lactic acid and acetic acid of 32.10 ± 3.84 and 5.77 ± 0.21 g L−1, respectively. This was due to the facts that commercial FW was mixed and naturally fermented during collection and processing. SL bioprocess of the untreated commercial FW hydrolysate resulted in lower SL production was ascribed by low C/N ratio and inhibitory effect of lactic acid. A single factor inhibition experiment has proven a dose dependent inhibitory effect of lactic acid, at concentration relevant to the commercial FW hydrolysate (i.e., 40 g L-1), and a 98.7% and 46.7% drop in SLs and CDW observed. Further experiments indicated that increase in nitrogen concentration increased the CDW and partly improved SLs production regardless of the lactic acid concentration in the medium. To further reduce the inhibitory effect of commercially collected FW on SLs production, a washing step using deionized water was included in the pre-treatment. Although, the washing of the FW resulted in a complete removal of lactic acid and partly reduced of acetic acid and ethanol, however the washing also led to the loss of 62% ± 1.72% free amino nitrogen (FAN), despite the residual FAN was still high enough to support for SLs bioprocess. Further SLs bioprocess of the pre-treated commercial FW hydrolysate increased the SLs titre to 115.3 ± 9.3 g L-1 which is 8.5-fold higher than that of the untreated counterpart (i.e.,13.5 ± 3.2 g L-1). Conclusions: This study identified lactic acid as the major inhibitor of commercially collected FW, and a cost-effective pre-treatment method. A high FAN containing fermentation method was also provided to overcome the inhibition issue. This work strongly enhanced the actual operability of FW-based biorefinery and significantly accelerated the establishment of a circular bioeconomy.

Keywords: Food waste inhibitor, Lactic acid, Sophorolipids, Starmerella bombicola, Sustainability.

High Solid Anaerobic Fermentation of Vegetable Wastes for Propionic Acid Recovery

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Propionic acid is an important short-chain fatty acid with wide industrial applications, especially in the food industry. Currently, it is produced from petroleum-based chemicals via chemical routes. Increasing concerns about greenhouse gas emissions from fossil fuels and a growing consumer preference for bio-based products have led to interest in fermentative production of propionic acid, but it is not yet competitive with chemical production. In this study, high solid anaerobic fermentation of typical vegetable wastes, cabbage and Chinese cabbage were carried out in leach bed reactor. Results showed that the maximum yields of propionic acid in single fermentation with cabbage, single fermentation with Chinese cabbage and mixed one reached 12.50, 8.18 and 15.51 g COD/L, corresponding to 35.46%, 31.22% and 32.50% proportions of propionic acid in the total soluble products, respectively. Lactic acid was another large component in the soluble products with maximum productions of 12.47 g COD/L, 10.72 g COD/L and 16.21 g COD/L, suggesting lactic -propionic type fermentation was achieved. The operation was performed well with the volatile solid removal rate of 62.5%-73.2%. Microbial community analysis showed that *Lactobacillus* was the dominant genus in the fermentation broth. Propionic acid was mainly mediated by *Lactobacillus plantarum* using lactic acid as temporary substate. The result may pose an insight for propionic acid recovery from high solid anaerobic fermentation of vegetable wastes.

Keywords: Fermentation, Waste vegetable, Propionic acid, Leach bed reactor.

Biodiesel Production from Rice Straw using Ascomycetous Yeast *Yarrowia Lipolytica*

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Finding alternate resources is necessary to address the energy needs of the expanding population due to hydrocarbon resource depletion. As a fuel, microbial biodiesel has the potential to replace fossil fuels more affordably and sustainably. Utilizing oleaginous media, single-cell oil made of carbon, hydrogen, and oxygen is developed over lignocellulosic biomass. Triacylglycerols produced by microorganisms can be turned into biodiesel, which has qualities that are comparable to those of regular diesel. However, using lignocellulosic biomasses requires a number of low-cost pretreatment techniques. In the current study, different pretreatment methods are used to increase the biooil in the microbial production (and biodiesel properties) of rice straw hydrolysate. Based on the concentration of glucose, the pretreatment with 3 % v/v H_2SO_4 at 30 min of ultrasonication produced the best depolymerization results. The hydrolysates were injected with *Yarrowia lipolytica*. The biomass produced after six days of growth at 30 °C, 6.5 pH, and quick mixing was 14.46 g/l. The biomass was transesterified both in-situ and ex-situ to produce biodiesel. 82% of the biodiesel produced by in-situ transesterification using the magnesium zirconate catalyst. In contrast, 61% were attained with ex-situ transesterification, which involved first performing lipid extraction and then transesterifying further while using the same catalyst to produce biodiesel. When the resulting fatty acid methyl esters were exposed to FTIR analysis, the physical and chemical characteristics that were discovered were in compliance with international standards.

Keywords: Biodiesel; Transesterification; Ultrasonication; *Yarrowia lipolytica;* Rice Straw.

Cocoa Pod Husk Valorization: Acid-Alkaline Pretreatment for Microbial Lactic Acid Production

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ABSTRACT. Lignocellulose contains high levels of carbohydrates, which are contained in a network consolidated by lignin, and hydrolysis of the substrate is necessary to access them. Cocoa pod husk is rich in carbohydrates. It is very abundant and readily available in Côte d'Ivoire. The objective of this study was to produce lactic acid from cocoa pod husk, after alkaline delignification and then acid hydrolysis. Lactic acid was produced by fermentation of acid hydrolyzate obtained, using *Lactobacillus fermentum* ATCC 9338 inoculated in a Lamda Minifor biofermentor. After alkaline delignification and acid hydrolysis, 18.77 g/L of reducing sugars are obtained. After concentration then fermentation, a productivity of 1.25 g/L.h after 72 hours, a title of 26.61 g/L and a yield of 0.52 g/g of lactic acid from 45.55 g /L of glucose and 12.21 g/L of xylose. *Lactobacillus fermentum* has 74.99 % furfural detoxification. it was used to ferment lignocellulose hydrolyzate, without detoxification.

Keywords: *Cocoa pod husk; delignification; acid hydrolysis; lactic acid.*

Introduction

Lactic acid or 2-hydoxypropanoic acid is a monocarboxylic acid which is widely used in the production of food, medicine, cosmetics. It is used as an acidulant, preservative, flavoring agent, emulsifier and pH regulator in many products [1]. Also, it is polymerizable into poly lactic acid (PLA), which is a biopolymer, biocompatible and biodegradable. An estimated annual demand of 1960.1 tons is expected en 2025 [2].

The scientific interest in the use of cocoa residual biomass for the production of lactic acid lies in the need to increase the circularity of this crop, to develop biobased value chains to achieve sustainability in the cocoa industry. cocoa, to increase the economic profitability of the crop for producers and to reduce the environmental impact of the residues produced.

Nevertheless, reports of this biomass being delignified with potassium hydroxide (KOH), then hydrolyzed with sulfuric acid, for the biotechnological production of lactic acid, are rare. However, it has been reported that KOH is potentially effective in pretreating lignocellulosic biomass [3]. The general objective of this study is to produce lactic acid from cocoa pod husk.

Materials and methods

Plant material

The plant material and the resulting powder (Figure 1) consist of cocoa pod husk (CPH) from the cocoa harvest in the region of Soubré (south-west of Côte d'Ivoire).

Fig. 1. Fresh cocoa pods and powder.

This cocoa belongs to the Amazonian *Forastero* type, which originates from the southern region of Panama.The main sub-varieties are *Amelonado* and Arriba, and the Ivorian cocoa is from the *Amelonado* sub-group. The cocoa pod husks were harvested from September 26, 2022, to October 2, 2022, in a high-productivity plantation, and then pre-treated mechanically.

Methods

Bacterial strain and culture method

Lactobacillus fermentum ATCC 9338 is a heterofermentative lactic acid bacterium. It was purchased from Industrial Analytical (PTY, South Africa). It is cultured and stored in Man Rogosa and Sharpe (MRS) agar at 4°C. After two successive transfers of the organisms tested in MRS broth at 37°C for 12 hours than 15 hours, five well-isolated colonies were reinoculated in 5 mL of MRS broth and incubated for 16 h at 37 °C.

Preparation of the acid hydrolyzate

The CPH powder, devoid of extractables, is delignified under the optimal conditions obtained in our previous study [4] (KOH 1% (Merck KGaA, Germany) for 4 hours at room temperature and 15 min in the autoclave (Digital vertical, LX-C autoclave, HEFEI Huatai) at 128 °C under a biomass/solvent ratio of 9.143 %). The delignified substrate is hydrolyzed in 250 mL SCOTT flasks, using sulfuric acid (H_2SO_4) (95-98 %, Scharlab S.L, Spain), in 26.95 min in the autoclave, a biomass to solvent ratio of 9.53 % (w/v), in 4.92 % (w/v) H_2SO_4. Chemicals and solvents were of analytical grade and were used in this state.

Adjusting the pH of the hydrolyzate

The concentrated acid hydrolyzate was made alkaline to pH 11, with NaOH crystals (Merck KGaA, made in Germany), and maintained at this pH for 1 hour. It is centrifuged then filtered on Whatman paper. The pH of the solution is then adjusted to 5.5 using concentrated sulfuric acid (H_2SO_4), then maintained for 1 hour, then filtered. The hydrolyzate is stored in a cold room at 4°C for 24 hours, then filtration.

Lactic fermentation of acid hydrolyzate

LAMDA Minifor biofermentor (Figure 2) was used for lactic fermentation of CPH hydrolysate, with temperature control and automatic pH adjustment, with a 5N NaOH solution.

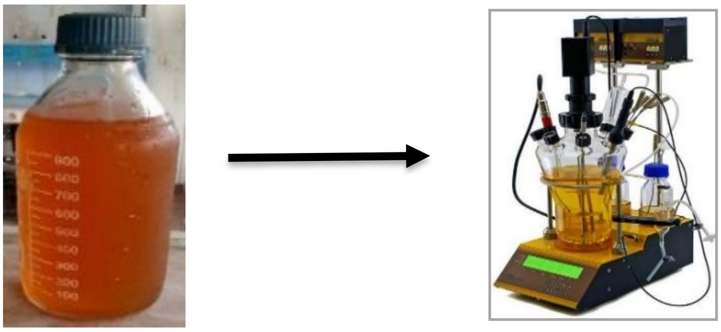

Fig. 2. Cocoa pod husk hydrolysate and biofermentateur LAMDA Minifor.

Analytical methods

Glucose, xylose, furfural and lactic acid are assayed by high performance liquid chromatography (HPLC) (Shimadzu Corporation, Japan) equipped with a 10 µL loop injector, a thermostating device (Meta ThermTM (Interchrom, France), a detector (Shimadzu SPD-20A UV Spectrophotometric detector) and a recorder with an ion exclusion column ICSep ICE ORH-801 (40 cm x 5 µm, Interchom, France), a mobile phase : H_2SO_4, 0.0125 M, at a flow rate of 0.6 mL/min at a temperature between 60 and 65°C. phenolic compounds were estimated by the Folin-Ciocalteu method [5].The amount of H_2SO_4 insoluble lignins was determined, following the Laboratory analysis procedure from National Renewable Energy Laboratory (NREL) [6]. Cellulose is isolated from holocellulose after dissolving the hemicelluloses in a dilute alkaline solution. The hemicellulose is obtained by differentiating between the cellulose and the holocellulose.

Results and Discussion

Chemical composition of raw cocoa pod husk

The chemical composition of the studied cocoa pod husk can be found in Table 1.

Table 1. Chemical composition of cocoa pod husk.

Parameters	Proportion (%)
Carbohydrates	67.07 ± 2.20
Extractables	13.26 ± 0.84
Lignin	28.54 ± 3.07
Cellulose	31.68 ± 2.07
Hemicelluloses	16.97 ± 2.07

The high values of carbohydrates (67.07 ± 2.20 %) are obtained, showing strong consistency with those reported in the literature [7]. However, a study [8] suggested levels close to 45 % for the cellulose content. This rich composition could help to amplify the range of applications of this agro resource, while increasing its importance on the world market. Its hydrolyzate could serve as an input for the fermentative production of bioactive compounds that can be used in various fields of industry. However, it contains high levels of lignins and extractables, whose reduction is crucial to release carbohydrates.

Production profile of organic acids (lactic and acetic acids) by Lactobacillus fermentum ATCC 9338 and effect of fermentation inhibitors (phenolic and furfural compounds) on cell presence

The fermentation study was conducted with an initial pH of 5.5 under mesophilic conditions at 37 °C in a biofermentor without any mineral or nitrogen compound supplementation. Figure 3A shows the production of organic acids (lactic and acetic acids) by *Lactobacillus fermentum* ATCC 9338.

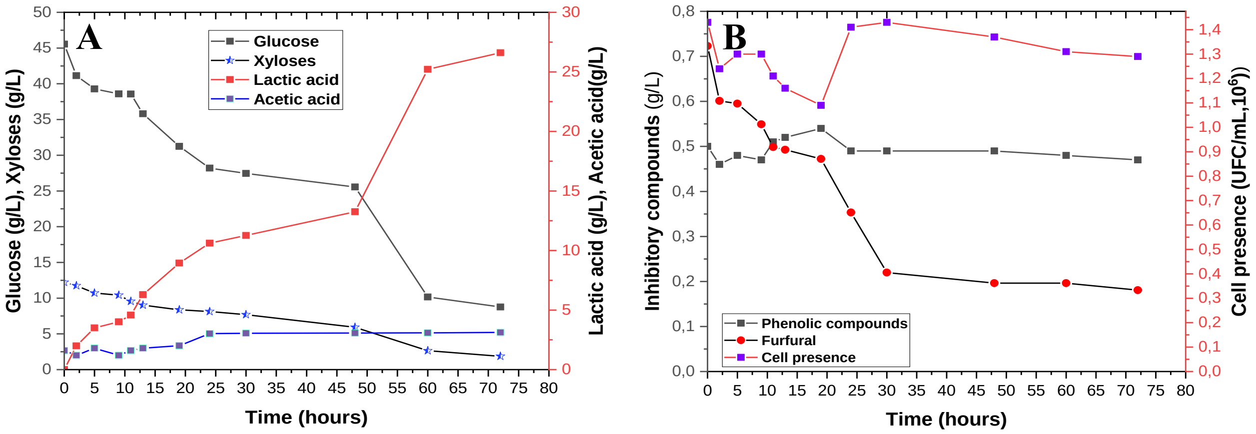

Fig.3. Production profile of organic acids (lactic and acetic) (A) and effect of fermentation inhibitors (phenolic and furfural compounds) (B) on the number of viable cells

The hydrolyzate contained 45.55 g/L initial concentrations of glucose and 12.21 g/L of xylose, after concentration. Simultaneous consumption of glucose and xylose and low production of acetic acid are observed. Indeed, this bacterium is obligate heterofermentative [9]. A low lag phase is observed at the start of fermentation, by *Lactobacillus fermentum* ATCC 9338. This is probably due to the ease of adaptation of the bacterial strain to the medium. After 72 hours, almost all of the glucose and xylose had been consumed. This resulted in the production of 26.61 g/L of lactic acid and 3.12 g/L of acetic acid when the fermentation stopped. The results obtained during the present study are consistent with those reported with a protein hydrolyzate from the organic fraction of municipal solid waste compost as a nitrogen source [9]. Phenolic compounds produced during the breakdown of lignin, can interfere with microbial fermentation. They can even cause changes in the metabolic pathways of cells of microorganisms [10]. Figure 3B presents, as a function of time, the diagram of the number of cells in the presence of furfural and phenolic compounds in the hydrolyzate. This figure shows low levels of phenolic compounds and a significant decrease in furfural content up to 74.99 %, from 0.72 g/L to 0.18 g/L. This value is close to that obtained with Bacillus coagulans during the fermentation of the hemicellulose hydrolyzate of sugar cane bagasse. [10]. This could be due to the biodetoxification effect of furfural by *Lactobacillus fermentum*. Also, it could be that this inhibitor is used as a carbon or energy source. The decrease in furfural content may also be due to the conversion of this compound into another less inhibitory compound. Thus, the use of *Lactobacillus fermentum* as a lactic acid-producing bacterium in dilute acid hydrolyzed hemicellulosic hydrolyzate would avoid the need for excessive detoxification prior to fermentation. Furthermore, this figure shows that *Lactobacillus fermentum* ATCC 9338 is more sensitive to phenolic compounds than to furfural.

Conclusions

This study explored the bioconversion of cocoa pod huks into lactic acid. It has shown that *Lactobacillus fermentum* has the ability to simultaneously ferment glucose and xylose while detoxifying the hydrolyzate. A strong tolerance to furfural was observed, with 74.99 % reduction. This helps reduce the need for detoxification before the fermentation process. In addition, despite the heterofermentative character of this bacterium, a significant productivity of lactic acid was observed. A titre of 26.61 g/L of lactic acid, a yield of 0.52 g.g^{-1} and a productivity of 1.245 g/L.h at the logarithmic phase, after 72 hours were obtained.

Acknowledgement

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Deep Eutectic Solvents for the Pretreatment of Lignocellulosic Biomass to Enhance the Sugar Recovery

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In recent years lignocellulosic biomass has received a lot of attention in the hunt for renewable and sustainable energy. However, a pre-treatment stage is usually necessary to overcome the stubborn structure of the biomass which is mostly composed of cellulose, hemicellulose, and lignin. The conversion of lignocellulosic biomass to biofuels and chemicals has resulted in substantial research and development around the world. Deep eutectic solvents (DESs) are newly created green solvent that is inexpensive and easy to prepare. DES has the potential to selectively remove lignin from the lignocellulosic complex, resulting in a new and ecologically sustainable approach for biomass pre-treatment under mild reaction conditions. Rice husk was processed with a DES mixture of choline chloride: urea in a 1:2 molar ratio in this investigation. The influence of temperature and residence period for the most effective pre-treatment condition was also investigated. Scanning Electron Microscopy (SEM) is then used to examine the morphology of the surface of rice husk. To assess the effect of the pre-treatment on the biomass, the treated biomass is examined for crystallinity using XRD, and the functional group was analysed by using FTIR, and then the results are compared to the raw biomass. However, pre-treatment at 80 °C for 6 hours yielded the highest amount of total reducing sugar i.e., 0.694 mg/ml. The facile process used in this study has the potential to be used on a massive scale to produce fermentable sugars and other compounds.

Keywords: Deep eutectic solvent, Pre-treatment, Rice husk, Lignocellulose.

Exploration of Organic Waste for its Bioactive Pigments

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ABSTRACT. Pomegranate, beetroot, and their peels were taken from kitchen waste in Kanchipuram, Tamil Nadu, India, for this study. Using ethanol and water as the solvent, the colour was recovered from residual pomegranate and beetroot products. This study included a variety of uses as well as antibacterial and synergistic effects. Against clinical infections such Staphylococcus aureus, beetroot and pomegranate peel ethanol extracts were shown to be the most effective. We've used colour to paint and then applied it on paper. The development of the plants (black gramme) was then closely watched, and the leftover pomegranate and beetroot were used as biofertilizers (after extraction). Therefore, the synthesis of pigments using renewable bioresources must be sustainable.

Keywords: Organic waste, natural pigments, Beet Root, Pomegranate and Antimicrobial activity

Introduction

Natural pigments and other bioactive substances can be found in waste or byproducts created during food preparation. While synthetic colourants have many detrimental consequences on human health, natural pigments and colourants provide a variety of health benefits. Thus, the extraction of pigments from natural sources is of great importance on a global scale. Fruit and vegetable waste is produced in large quantities by the agro-food sectors, which makes it possible to manage this waste effectively. But despite the fact that these wastes include nutrients that are good for you like dietary fibre, an antioxidant, and colour, they are still not being used. (Čanadanović-Brunet et al., 2011).

Material and Methods

Sample Collection and Extraction

In Kanchiuram, Tamil Nadu, India, *Beta vulgaris* (beetroot) and *Punica granatum* (pomegranate) were taken from kitchen waste and taken to the lab for further examination. The pomegranate and beetroot were chopped into little pieces after being peeled off. To create a pulp, the peels were then mixed in a mixer for 2 minutes (Zin, Marki, and Banvolgyi, 2020). Different peel-to-solvent ratios (0.2, 0.6, and 1.0 w/v) of aqueous and (15%) ethanol were combined with the beetroot and pomegranate pulps (50 g). Separate ethanol and aqueous extractions were carried out. The extraction procedures were carried out in a thermostated water bath with stirring at a speed of 215 rpm, maintaining temperatures of 20ºC, 35ºC, and 50ºC for three distinct operation times (1 h, 3 h, and 5 h).

Antimicrobial and Synergistic activity of pigments using disc diffusion method.

Using a disc diffusion technique, the antimicrobial effects of beetroot root pulp and peel extracts were evaluated against *Staphylococcus aureus 29213, Staphylococcus aureus 252923, Escherichia coli 25922, Pseudomonas aeruginosa 27853* and *Klebsiella pneumoniae 13439*. The strains were purity tested after being cultivated on Mueller-Hinton agar slants at 37°C for 24 hours. The cells were removed from the agar surface after the incubation and suspended in sterile physiological solution. Using the McFarland standard, the number of cells in 1 ml of suspension was calculated. The Mueller-Hinton agar was warmed (45°C) and mixed with 1 ml of this suspension before being placed onto Petri dishes. In order to detect halo zones of inhibition around the well, 6 mm diameter paper discs were put to the surface of the agar and impregnated with 15 l of ethanol and aqueous extracts. Plates were then incubated for 18 to 24 hours at 37 °C. Triplicate analyses of each sample were performed (Anadanovi-Brunet et al., 2011). Combining two distinct chemicals has a synergistic effect, which increases the potency of antimicrobial drugs. Different combinations of substances (pomegranate aqueous + beetroot ethanol; pomegranate beetroot ethanol + citric acid + pomegranate beetroot aqueous + honey; pomegranate beetroot aqueous + pomegranate beetroot aqueous + pomegranate beetroot aqueous + pomegranate beetroot aqueous + honey) were assessed. For this test, a modified procedure was employed. Triplicates of the experiment were run (Diaz et al., 2019).

In-Vitro Antioxidant Assay

Add 100µl of 0.1 mM DPPH solution to 100µl of sample and 100 microl of standards that have been generated at various concentrations (100, 200, 300, 400, 500 g/ml) to a 96 well plate.As a control for the antioxidant experiment, 100µl of DPPH solution and 100µl of methanol are added. After mixing, the reaction mixture was left to react for around 30 minutes in a dark, room-temperature environment. Using a UV spectrophotometer, the sample's absorbance value was measured at 517 nm (Čanadanović-Brunet et al., 2011). The inhibition of radical scavenging activity percentage is determined by using the equation:

$$\text{Radical scavenging activity (\%)} = A0 - A1 / A0 \times 100$$

AO - Absorbance of DPPH radicals with methanol

A1 – Absorbance of DPPH radicals with sample extract or standard

Applications of pigments and its waste

The coloured paper samples were made by drawing papers through various temperature colourant dyes, which were held at 40–50 °C and 50–60 °C when using beetroot and pomegranate dyes, respectively. At 20 to 25 °C for 48 hours, the treated papers were suspended on glass rods (Luo and Zhang, 2021). In plastic pots (12 cm height 10 cm in diameter) filled with sterilised soil, seeds of beetroot root and pomegranate extract waste were sown at a depth of 1 cm and treated with eight Vigna mungo (black gramme). Standard procedures were used in an experiment on plant growth (Shah et al., 2014).

Results and Discussion

Extraction

Waste from beetroot roots and pomegranates was correctly treated using the right techniques. Pigments were extracted more effectively using aqueous and ethanol solvents.150 ml of pigment extraction from 50 gms yields 15 gms of pigments (Figure 1).

Fig. 1 Extraction with aqueous and ethanol solvent

Antimicrobial activity of pigments using disc diffusion method.

Beetroot, Pomegranate aqueous and ethanol extract showed antimicrobial against *Staphylococcus aureus* 29213 (11mm) (Čanadanović-Brunet et al., 2011).

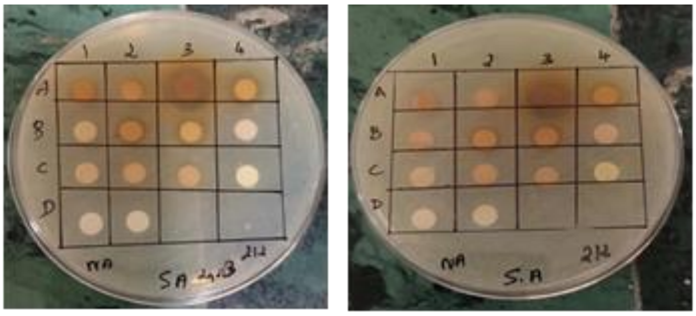

Fig. 2 Antimicrobial activity of Beetroot, Pomegranate aqueous and ethanol extract against *Staphylococcus aureus* 29213

Evaluation of synergistic effect

In synergistic effect, pomegranate beetroot ethanol + Citric acid + Pomegranate beetroot aqueous+ honey combination showed promising antimicrobial activity (15mm) (Figure 3) (Diaz et al., 2019).

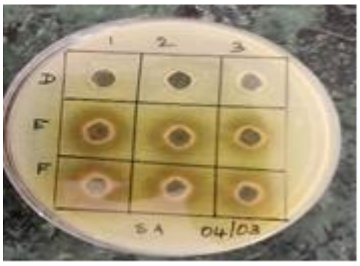

Fig.3 Synergistic activity of extract

In-Vitro Antioxidant Assay

The extract was showed good antioxidant activity. The reduction capability of DPPH radicals was determined by the decrease in its absorbance at 517 nm induced by antioxidants. The absorption maximum of a stable DPPH radical in methanol was at 517 nm (Figure 4).

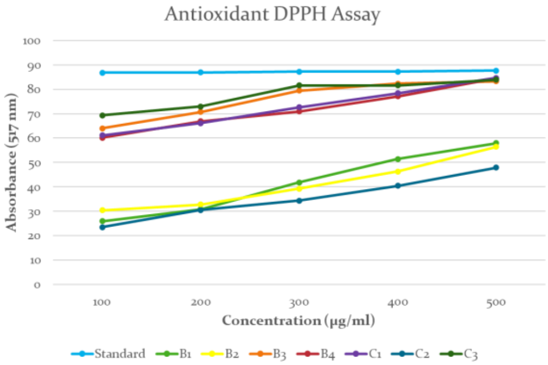

Fig 4 : Antioxidant activity of extracts

Applications of pigments and its waste

Our pigment gave good color to the paper and adherence property of the pigment was improved by using alum, vinegar and honey (Figure 5). Inoculation of black gram with extract waste has stimulated the o plant growth (Figure 6).

Fig .5 colored paper

Fig .5 Plant growth stimulation by extract waste

Earlier research on these works was less extensive. Our findings indicated that beetroot root and pomegranate waste, an inedible environmental waste product, may be a rich source of antioxidants and may have potential as value-added pigments for enterprises.

Conclusions

Natural colours such anthocyanins, betalains, carotenoids, and chlorophyll are abundant in these wastes/byproducts. These natural pigments are expected to have a substantial impact on both the industrial and agricultural sectors.

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Construction of A Multi-Parameter-Based Model to Simulate Lignin Fractionation Kinetics in Biorefinery Processes for Urban Waste Valorization

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Developing urban biorefinery to harvest renewable biofuels and chemicals is an environmentally attractive approach toward sustainable development. To achieve a circular bio-economy, whole biomass valorization for both sugars and lignin conversion is of a key importance, leading to both functional fermentation products to renewable aromatic chemicals at high yield. Lignin separation in the design phase is the key to tackle the goal of whole biomass valorization. Within different pretreatment approaches, diols organosolv has showed its potential in our previous studies which could induce the benzyl carbocation intermediate quenching for reducing the negative effects of lignin condensation. In this study, a series of biorefinery experiments were conducted and a novel universal severity factor: Organosolv Pretreatment Factor (OPF) was introduced. This index was developed based 1,4-butandiol fractionation of a Camellia's shell whole biomass, which covers an extreme lignin/cellulose ratio (3/1) and the unclarified lignin structure for broadening the simulation boundary. The OPF index successfully simulated the performance of hydrolysis (R2 =0.9014), lignin separation and the subsequently the degree of lignin condensation under various operational conditions (i.e., temperatures, time, types, and concentrations of acid catalysts). OPF is the first mathematical function considering and proving the relationship between polysaccharides structures and the aromatic condensation. Moreover, the model also supported that lignin separation is a stepwise process as the following order: (1) hemicellulose hydrolysis; (2) lignin is segregated from hemicellulose; (3) lignin is solvated and removed by solvent. Accurate prediction of native lignin preservation and the mechanism of lignin condensation was further revealed by combining OPF with various advanced characterizations methodologies (2D-HSQC NMR, XRD and chemical composition analysis). The model also implied that the loss of hydroxyl groups at C and Cγ positions in lignin polymer could be the key reason for lignin reprecipitation in alcohol based organosolv. In the establishing of continuous flow pretreatment process, OPF could help achieve high quality lignin separation with the efficiency which more than 95%. OPF may serve as an universal optimization factor in lignin-first biorefinery using municipal woody waste as biomass feedstock.

Keywords: Biorefinery, Model, Polysaccharides structures, Organosolv, Lignin.

The Role of Novel Biocarbon on The Treatment of Industrial Wastewater – A Green Concept

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ABSTRACT: The contamination of water by potentially toxic elements is considered a global problem. It calls for a safe, economic and technological approach in order to curb and prevent the devastating effect of the menace on both human and the aquatic life. This study presents the preparation of Lawsonia inermis biocarbon collected from the plant leaves of Henna and the biocarbon is doping with alumina particles to enhance the adsorption capacity. Chromium is one of the most dangerous toxic heavy metals in the environment and is discharged from many industrial activities. The leather industry is one which uses chromium chemicals in its process operations. The biocarbon was applied as an adsorbent for the removal of Chromium (Cr) from synthetic wastewater (98.65%) and then applied in the treatment of leather industry wastewater as an economical water cleaning technology. Significantly, in leather industry wastewater, most of the heavy metals are significantly removed (Cu (II) was 81.12%, Cd (II) was 92.20%, Pb (II) was 90.74%, Ni (II) was 82.81% and Cr (VI) was 84.95% respectively. This study revealed that biocarbon was an efficient adsorbent material for the removal of heavy metals from wastewater.

Keywords: Leather industry, wastewater, heavy metal ion removal; chromium, green adsorbent

Introduction

The pollution of water by the presence of toxic heavy metals has been a topic of global concern among environmental experts. Heavy metals are the most hazardous contaminants among all the pollutants found in water and are of major concern because they are non-biodegradable in nature having serious effects on both human and environmental health. The spontaneous increase in the pollution of water by toxic heavy metal has been attributed to the breakthrough in the advancement of technologies for industrial expansions [1]. Lead and chromium are among the priority toxic pollutants present in wastewaters which are released to the environment through various industrial operations.

The presence of heavy metals in wastewater has been increasing with the growth of industry and human activities, e.g., plating and electroplating industry, batteries, pesticides, mining industry, rayon industry, metal rinse processes, tanning industry, fluidized bed bioreactors, textile industry, metal smelting, petrochemicals, paper manufacturing, and electrolysis applications. The heavy metal contaminated wastewater finds its way into the environment, threatening human health and the ecosystem.

The heavy metals are non-biodegradable and could be carcinogenic [2-4]. Heavy metal ions are generated, in large amounts, throughout the industrial activities which then contaminate the environment and the living organisms. Presence of these metals in water by undesirable amounts could result in critical health issues to living organisms. Metal ions are non-biodegradable and may cause disorders in plants and animals [5-7]. The most popular heavy metals are lead (Pb), zinc (Zn), mercury (Hg), nickel (Ni), cadmium (Cd), copper (Cu), chromium (Cr), and arsenic (As). Though these heavy metals can be detected in traces; however, they are still hazardous and all of which pose a major threat to the ecosystem [8,9].

Lead and chromium are considered among the top sixteen toxic pollutants whose exposure is carcinogenic to both humans and aquatic animals [10]. They have adversely affected the human health and cause many diseases and allergies. Treatment technologies for both drinking water and wastewater are one of the most important key concerns for sustaining human well-being. Thus, removing them from aqueous solutions is both important and challenging. There are several methods of heavy metal ion removal from contaminated water but the best is adsorption using a suitable sorbent [11, 12].

Materials and Methods

Preparation of biocarbon

The *Lawsonia inermis* medicinal plant leaves have been collected and air-dried for 48 hours. Biocarbon was produced by the treatment of leaves with concentrated analytical grade sulphuric acid. The resulting black product was kept in hot air oven at 160 ± 2 °C for 6 hours, then washed with distilled water and then dried at 105 ± 2 °C. Biocarbon particle sizes between 85 and 130 µm have been used. In a 500 mL beaker, pure alumina and biocarbon were taken at a ratio of 2:1 and double distilled water was added and heated at 60 °C for 30 min and the resulting product was filtered and dried at 200 ± 2 °C for 3 hours. The hot air-dried material is finely ground in a range of 100 to 120 microns and maintained in a separate glass container for further use. The biocarbon material is known as alumina interfaced biocarbon (AIBC) [13]. The scheme of preparation of biocarbon was presented in the Figure 1.

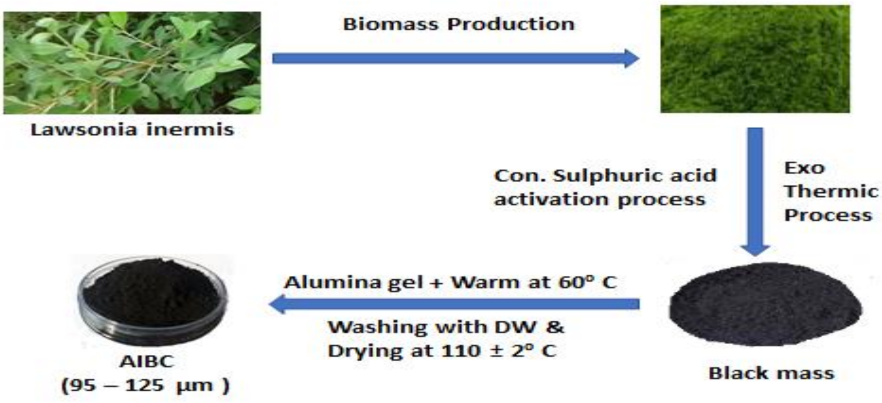

Fig. 1. Preparation of alumina interfaced biocarbon (AIBC).

Adsorption Process

Percent removal of hexavalent chromium ions and the quantity of metal ions adsorbed from the wastewater system was calculated using the equations described by Dada et al., [14]:

$$q_e = \left(\frac{C_o - C_e}{w}\right) \times V \qquad (1)$$

$$\%\ \text{Removal} = \left(\frac{C_o - C_e}{C_o}\right) \times 100 \qquad (2)$$

Where C_o and C_e are the initial and equilibrium concentrations of the metal ions (mg/L), w is mass of biocarbon (g) and V is the volume of the metal containing wastewater (mL) respectively.

Results and Discussion

The synthetic wastewater sample containing Cr (VI) ions was prepared using 1.4143g of analytical grade potassium dichromate ($K_2Cr_2O_7$) substance in deionized water and diluted to 500mL This aqueous solution was used as model pollutant for the removal of heavy metal ions and also for the evaluation of adsorption capacity of the produced biocarbon. In this research, the operational parameters involved in the removal of Cr (VI) ion was adjusted as pH 4.5, biocarbon dose (BCD) 3.0g/100mL, contact time (CT) 180 min, agitation speed 250 rpm and temperature of 30 ± 2°C.

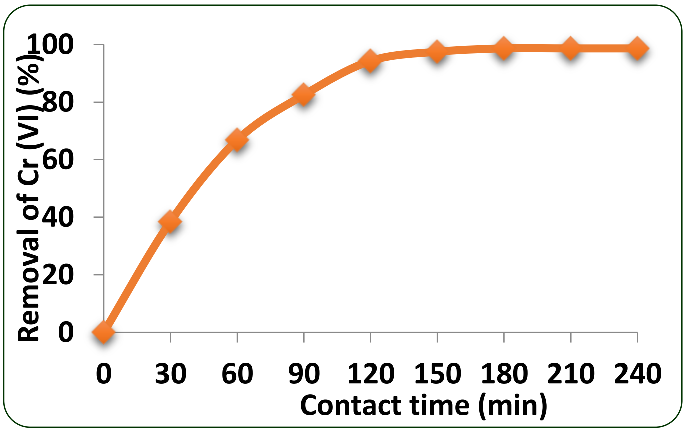

Figure 2. Removal of Cr (VI) in synthetic wastewater

The results were presented in the Figure 2. It is observed that, 98.65 % of Cr (VI) was removed under the established experimental conditions. It indicates that, the produced biocarbon has excellent adsorption capacity for the removal of metal ions in aqueous solution under mainly acidic condition. Based on this supportive analysis, it is applied in the real wastewater sample analysis.

Treatment of leather industry wastewater

The outlet leather industry wastewater was collected from the industrial complex in the catchment area in Northern district of Tamil Nadu, India and analysed the essential physico-chemical parameters and selected heavy metals and the analytical results are reported in table 1.

Table 1. Treatment of leather industry wastewater

Sl. No	Characteristics of leather industry wastewater	Quality leather industry wastewater (mg/L)		Removal result (%)
		Before Treatment	After Treatment	
1.	pH	5.37	4.20	21.78
2.	EC (µmhos/cm)	23372	1460	93.75
3.	TDS	25756	1010	96.07
4.	TSS	1824	120	93.42
5.	TH	2524	485	80.78
6.	BOD	2850	35	98.77
7.	COD	11489	185	98.38
8.	Calcium	457	62	86.43
9.	Magnesium	331	55	83.38
10.	Chloride	250	40	84.00
11.	Sulphate	10441	190	98.18
12.	Nitrate	184	14	92.39

The analytical results clearly indicate that, in leather industry wastewaters all the waste water quality parameters. Particularly, BOD and COD level is reduced to 98.77% and 98.38% respectively. Since, BOD and COD are the main pollution parameters and includes the biodegradable and non-biodegradable organic matter in the wastewater. Similarly, chloride, sulphate and nitrate also well reduced in all the wastewater.

Presence of heavy metals in wastewater is very much dangerous and may create health hazardous to human beings as well as to aquatic animals [15]. Hence, proper treatment and removal of toxic heavy metals are necessary. In the present research work, the wastewater sample was subjected to treatment process involving various steps and finally with adsorption process. The removal of various heavy metals present in the leather industry wastewater was presented in the Figure 3.

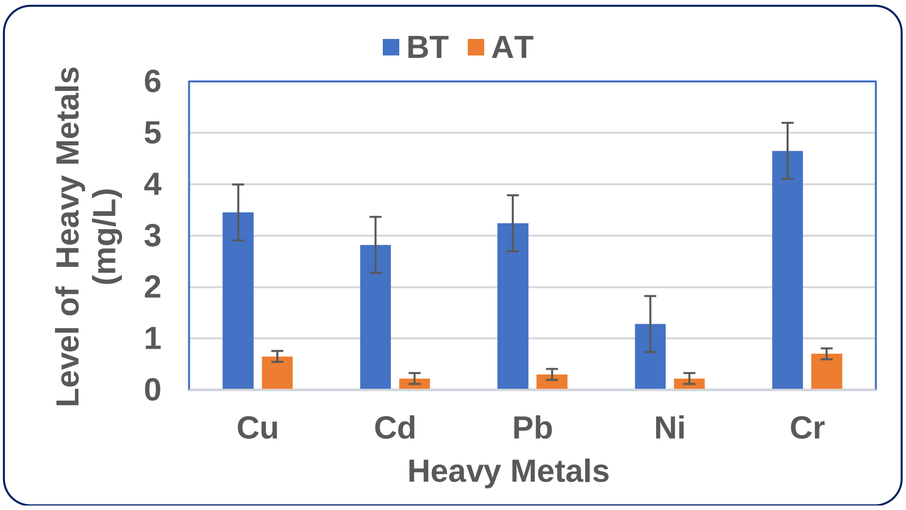

Figure 3. Removal of heavy metals in the leather industry wastewater.

In the heavy metals removal process AIBC is used as adsorbent and the results indicates that, in leather industry wastewater, the percent removal of Cu is 81.12, Cd is 92.20, Pb is 90.74, Ni is 82.81 and Cr is 84.95 respectively. It is well noted that, all other inorganic pollutants present in the wastewaters are also significantly reduced. It is a promising result. It also well supported that *Lawsonia inermis* plant leaves based biocarbon and interfaced with aluminium is a good and cheap adsorbent and cab be used for the removal of all inorganic and organic pollutants in wastewater system.

Conclusions

The following conclusions are derived from this research work.

- ✓ The biocarbon prepared using *Lawsonia inermis* plant leaves are an having higher potential for removal of Cr (VI) and other inorganic and organic pollutants in leather industry wastewater.
- ✓ The process of adsorption employed in this research work is cost effective, simple and highly efficient. The maximum uptake of Cr (VI) was observed at the pH of 4.5 with optimum biocarbon dose rate of 3.0g/100mL at 180 minutes equilibrium time.
- ✓ The percentage of the removal of Cr (VI) in synthetic wastewater is 98.65% and the removal process was progressively increased with the increase of contact time. This results supports that, the biocarbon can be used for the treatment of any industrial wastewater.
- ✓ As an application part, leather industry wastewater was used for the batch adsorption process. It is observed that, BOD (98.77%) and COD (98.38%) is well reduced in the wastewater.
- ✓ Similarly, most of the heavy metals are significantly removed (Cu (II) was 81.12%, Cd (II) was 92.20%, Pb (II) was 90.74%, Ni (II) was 82.81% and Cr (VI) was 84.95%.

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Study on the Effect and Potential Mechanism of Suppression on Cucumber Fusarium Wilt from Different Biogas Slurry

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Biogas slurry, the main by-product of anaerobic fermentation, can promote crop growth, inhibit soil-borne diseases, partially replace chemical fertilizers and chemical pesticides, and improve food yield and food safety. In this study, pig manure biogas slurry, chicken manure biogas slurry, distiller's grains biogas slurry and kitchen waste biogas slurry were used to investigate their effects on Cucumber Fusarium wilt caused by *Fusarium oxysporum* f.sp. *Cucumerinum* (FOC). Pot experiment, gradient sterilization experiment and biofilm experiment were carried out with the aim to find out the suitable adding ratio for different sources biogas slurry and to illustrate the relationship between the biological and non-biological composition of biogas slurry and its suppression. The results were shown below:

The biochemical properties of the four biogas slurry samples were significantly different, but they had the same influence on soil physical and chemical properties, cucumber plant dry weight, fusarium wilt incidence and FOC. They significantly increased soil pH, available phosphorus and potassium contents, but not significant influenced soil organic carbon. When the application rate was 10% and 20%, it could significantly increase soil EC value and alkali-hydrolyzed nitrogen. With the increase of application rate, the dry weight of cucumber plants increased first and then decreased, while the incidence and disease index of cucumber fusarium wilt decreased first and then increased. The abundance of cucumber rhizosphere soil FOC was significantly decreased in all treatments.

The four types of biogas slurry increased the abundance of *Bacillus*, *Sphingomonas*, *Pseudomonas*, *Chaetomium* and *unclassified_Chaetomiaceae*, while reduced the abundance of Fusarium. Application of sterilized biogas slurry significantly increased the abundances of *Bacillus* and *Pseudomonas* in the rhizosphere, and reduced the abundances of FOC and the incidence and disease index of cucumber fusarium wilt, but the inhibitory effect was significantly lower than that of non-sterilized biogas slurry. With the deepening of sterilization degree, the dry weight of cucumber plants decreased significantly, which gradually increased the incidence of Fusarium wilt (from 41.44%-46.67% to 70.34%-72.94%) and disease index (from 39.67%-43.33% to 64.00%-68.01%).

Soil bacterial community, total bacterial abundance, Bacillus abundance and Pseudomonas abundance were significantly negatively correlated with fungal community, total fungal abundance and FOC abundance. Soil pH was positively correlated with bacterial community, the abundance of total bacterial, *Bacillus*, *Pseudomonas*, and negatively correlated with total fungal abundance and FOC abundance. The fungal community composition and FOC abundance determines the degree of cucumber fusarium wilt disease, while the rhizosphere bacterial community composition of blight morbidity rate and rhizosphere FOC abundance had an adverse effect. In conclusion, application rate of 3% was the appropriate one for all biogas slurry, for they contain common biocontrol strains, which will have similar effect on soil microbial population changes and regulating soil microorganisms. Their abiotic components contribute to microbial colonization in the rhizosphere, which will help to improve the inhibitory effect on cucumber fusarium wilt.

Keywords: Diseased vegetable waste, Aerobic compost, Pathogens.

Fabrication of Food Waste-derived Biodegradable Medical Textiles via Electrospinning and Electrospraying for Healthcare Apparel and Personal Protective Equipment

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ABSTRACT. Development of sustainable and biodegradable non-woven textiles is essential to produce environmentally friendly personal protective equipment (PPE). This paper will demonstrate fabrication of medical textile for surgical mask from a substitute of food waste derived polymers PLA and PHBV via electrospinning process. Polymer concentration of 12.5% and PLA/PHBV ratio of 1:1 in formic acid resulted in stable electrospinning and defect-free nanofibers with mean diameter of 323 ± 76nm. Presence of PLA/PHBV nanofiber was confirmed by NMR. Blending of PHBV in PLA enabled higher resistance to moisture and temperature degradation of the nanofiber. A dual-layer nanofiber non-woven was able to achieve filtration efficiencies of over 99.5% and over 96.2% for 1-5µm and 0.3µm particulates respectively, while maintaining high breathability with differential pressure less than 5mmH_2O. These characteristics fulfilled medical mask standard ASTM-F2100.

Keywords: *Biowaste utilization, Electrospinning, Polylactic acid, Poly(3-hydroxybutyrate-co-3-hydroxyvalerate)*

Introduction

Personal protective equipment (PPE) and healthcare apparel are instrumental in the reduction of risk of viral transmission and infection of COVID-19. Most PPE are single use items made with non-biodegradable polymers such as polypropylene and is a significant environmental issue since these materials do not readily break down and accumulate in landfills and marine environments. There has been growing interest in the development and use of biodegradable polymers as a more sustainable alternative. Biodegradable polymers polylactic acid (PLA) and poly(3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV) are attractive alternatives. PLA is made from renewable resources such as corn starch and sugarcane is fully compostable [1], while PHBV is produced by bacteria through fermentation, with additional benefits of being fully marine biodegradable and more resistant to moisture and UV light than PLA [2]. In addition, both polymers can be derived from non-edible feedstocks from the valorization of food waste through a biorefinery process [3,4]. This paper will demonstrate fabrication of PPE such as surgical mask from PLA/PHBV via electrospinning process to produce nanofibers, and achieved levels of filtration efficiency and breathability that fulfilled medical mask standard ASTM-F2100 level 1, which is suitable for application in a highly aggressive medical environment.

Material and Methods

Materials

PLA 4060D (Mw: 119,000) were obtained from Nature Works LLC. PHBV ENMAT Y1000 (Mw: 231,000) were obtained from Tianan Biologic. The solvent studied were ethanol (ETOH), chloroform (CHL), dichloromethane (DCM), dimethylformamide (DMF), acetic acid and formic acid. PLA spunbond non-woven with base weight of 30 g/m^2 was used as the substrate for nanofiber deposition during electrospinning.

Electrospinning process

Electrospinning solution were prepared by heating to 80 °C and stirred for 30 mins until all PHBV powder has dissolved. Then, the solution was stirred for 12 hours at 40 °C until all PLA pellet has dissolved. Electrospinning machine (MECC NF-500) was used to carry out the electrospinning process with a triple 25G needle spinneret. Voltage was varied from 30-45KV, solution flow rate 1-3mL/min and distance to collector of 200-230mm.

Characterization

Morphology of nanofibers was characterized by scanning electron microscopy (SEM) (Hitachi TM3030PLUS). Images were taken at magnifications between 1,000 and 5,000x and analyzed with imaging software (ImageJ version 1.53e). The shear viscosity of polymeric solution was measured using a rotating viscometer (Brookfield Viscosity Meter DV-I Prime). Qualitative analysis of ^{1}H NMR of nanofiber was carried out by Spinsolve 60, where PLA/PHBV nanofiber was dissolved in chloroform ($CDCl_3$).

Filtration and breathability performance

Filtration efficiency of the nanofiber non-woven was measured by TSI automated Filter Tester 8130A and TSI Optical Particle Sizer 3330. Sub-micron particulate filtration efficiency (PFE) was evaluated using ASTM F2299 standard method. Differential pressure (ΔP) was evaluated using EN 14683 Annex C or Military Standard MIL-M-36954C to determine the breathability. Quality factor is the representation of the ratio between the filtration efficiency measure and the pressure drop and is defined according to equation: Quality factor (QF) = $-(\ln(1\text{-PFE}))/\Delta P$. Stress test was performed in accordance to ISTA 2A to simulate the temperature and humidity of international transportation.

Results and Discussion

Solvent selection

Homogeneous polymer solution is necessary for stable electrospinning. 10% of PLA and PHBV was dissolved into each of the shortlist solvents above. PLA was soluble in all the solvents except of ETOH while PHBV was only soluble in chloroform and formic acid. Highly polar nature of these solvents were found to be effective to stabilize PHBV for dissolution [5]. 10% (w/v) of 1:1 ratio of PLA and PHBV polymer blend was dissolved in single and binary solvents systems and electrospun. Results are shown in Table 1. Chloroform has high vapour pressure and low conductivity and did not result in stable electrospinning. Electrospinning with formic acid as solvent has high conductivity but low viscosity leading to defect-free nanofibers but dripping of solution. Blending of formic acid with acetic acid did not improve the viscosity and conductivity of the solution. Pure formic acid was an appropriate solvent for the PLA/PHBV polymer system.

Table 1: Electrospinning conditions and morphology of single and binary solvent system for PLA/PHBV (5:5 ratio)

Solvents	Viscosity (mPa.S)	Conductivity (µS)	Electrospinning Stability	Morphology	Nanofiber diameter (nm)
CHL	382.2	~0	Drying at needle tip	No nanofiber	N/A
CHL/DMF (8:2)	172	1.21	Drying at needle tip	Beaded nanofiber	642 ± 211
Formic acid	28.1	114.2	Stable but dripping	Defect-free nanofiber	287 ± 70
Formic acid /acetic acid (8:2)	27.5	61	Stable but dripping	Defect-free nanofiber	240 ± 71

Polymer concentration and ratio

PHBV/PLA solutions (7.5-15%) were completely dissolved and electrospun at 35KV at a collector distance of 200mm, and resulted in defect-free nanofibers as shown in Table 2. Viscosity increased with polymer concentration from 28 to 270 mPa.s.. PLA/PHBV solutions with concentration above 12.5%. solution is viscous enough for stable electrospinning with no dripping. Increasing polymer concentration from 10% to 30% w/v, nanofiber diameter also increased slightly from 287nm to 323nm. This is attributed to increased viscosity and more chain entanglements, hence increased in viscoelastic forces therefore resulting in nanofibers has higher diameter.

Subsequently, the PLA to PHBV polymer ratio has been investigated and results are shown in Table 3. At high PLA ratios, the solution viscosity was low, and from the observations from previous chapter, bead formation indicated insufficient chain entanglement. As PHBV ratio increased, the viscosity of the solution also increased, which improved the electrospinnability of the polymer solution, and increased the viscoelastic forces which counterbalances the coulombic stretching forces [6], leading to nanofiber with fewer beads and defect free nanofiber as shown in Figure 3. The fiber diameter first decreased from PLA/PHBV ratio of 7:3 to 5:5 due to better control in electrospinnability but decreased when PLA/PHBV ratio changed from 5:5 to 1:9, due to rapid increase in viscosity and viscoelastic forces.

Table 2: Electrospinning conditions, morphology physical properties, and mean fiber diameter of different polymer concentrations for PLA /PHBV (5:5) in formic acid.

Polymer Concentration (w/v)	Viscosity (mPa.s)	Electro-spinnability	Morphology	Mean fiber diameter (nm)
7.5%	50	Slight dripping	Defect-free nanofiber	286 ± 42
10%	95	Slight dripping	Defect-free nanofiber	278 ± 65
12.5%	139	Stable	Defect-free nanofiber	299 ± 79
15%	270	Stable	Defect-free nanofiber	323 ± 76

Table 3: Electrospinning conditions, morphology physical properties, and mean fiber diameter of different PLA and PHBV ratios for 15% (w/v) PLA /PHBV in formic acid.

PLA/PHBV (w/w)	Viscosity (mPa.s)	Electro-spinnability	Morphology	Mean fiber diameter (nm)
9:1	36.5	Dripping	Mostly beads	N/A
7:3	96.7	Slight Dripping	Defect-free nanofiber	359 ± 169
5:5	270	Stable	Defect-free nanofiber	323 ± 76
3:7	320	Slight Dripping	Thickened nanofiber	447 ± 156
1:9	825	Slight Dripping	Beaded nanofiber	410 ± 88

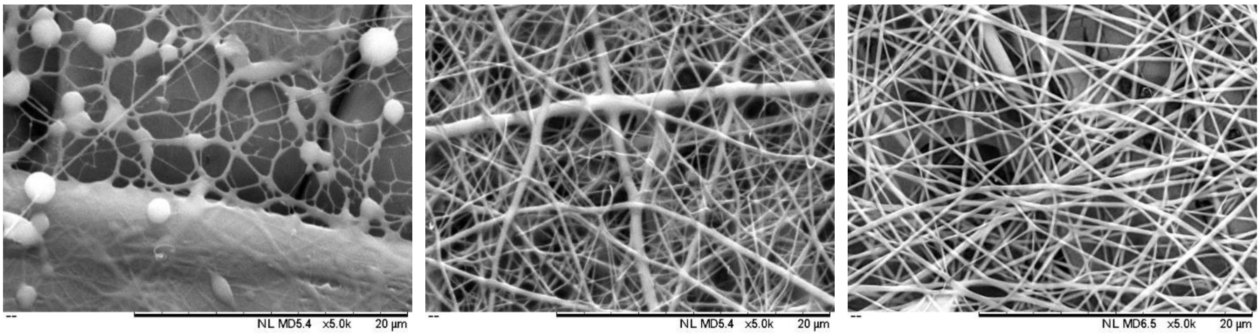

Fig. 1. Polymer ratio on nanofiber morphology: PLA/PHBV ratio 9:1, 7:3 and 5:5 (left to right)

^{1}H-NMR analysis of nanofiber

The spectrum of PLA/PHBV 5:5 nanofibers was compared to the spectrum of pure PLA and pure PHBV reference material in Fig. 2. Downfield chemical shift of quartet around 5.3ppm was common to both PLA and PHBV. But upfield shift around 1.6ppm showed a doublet signal unique to PLA, while downfield shift around 2.6ppm and upfield shift around 1.4ppm showed doublet and quartet signal similar to PHBV. This provided qualitative confirmation of presence of both PLA and PHBV in the electrospun nanofiber.

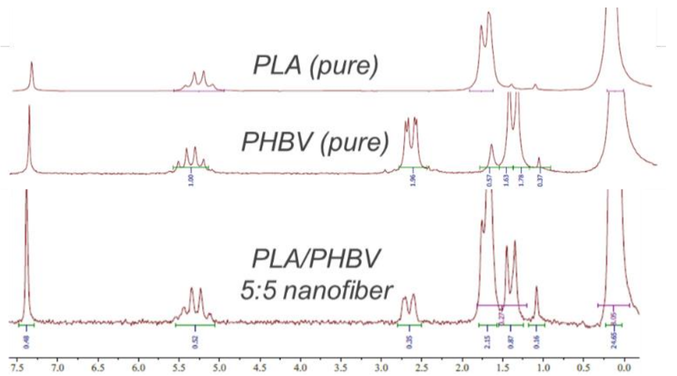

Fig.2. Comparion of ^{1}H-NMR spectrum of pure PLA, pure PHBV and PLA/PHBV 5:5 nanofiber

Filtration efficiency and breathability performance

A dual layer PLA/PHBV nanofiber was prepared for testing of filtration efficiency and breathability by selection of suitable electrospinning speed of 60mm/min. Dual layer design was employed for optimization of productivity and test performance, since thinner nanofiber layers have higher porosity and thus better quality factor. Results of filtration efficiency and breathability are shown in Fig. 2. For nanofiber of

PLA/PHBV of different ratios, the filtration efficiency increased with PHBV ratio since fiber diameter decreased as shown in Table 3, which generate smaller pore size and beadless nanofiber. Both PLA/PHBV ratio of 7:3 and 5:5 achieved over 95% efficiency for 0.3µm and over 99.5% for 1-5µm particulates respectively. Increased fiber diameter also lead to lower pressure drop experienced in PLA/PHBV 7:3 ratio than 5:5 ratio, but 9:1 ratio resulted in beaded nanofiber and hence reduced pore size. A quality factor requirement of >0.6 is required for ASTM-F2100 standard level 1 (based on filtration efficiency >95% and pressure drop less than $5mmH_2O$), which both PLA/PHBV 7:3 and 5:5 nanofiber was able to achieve.

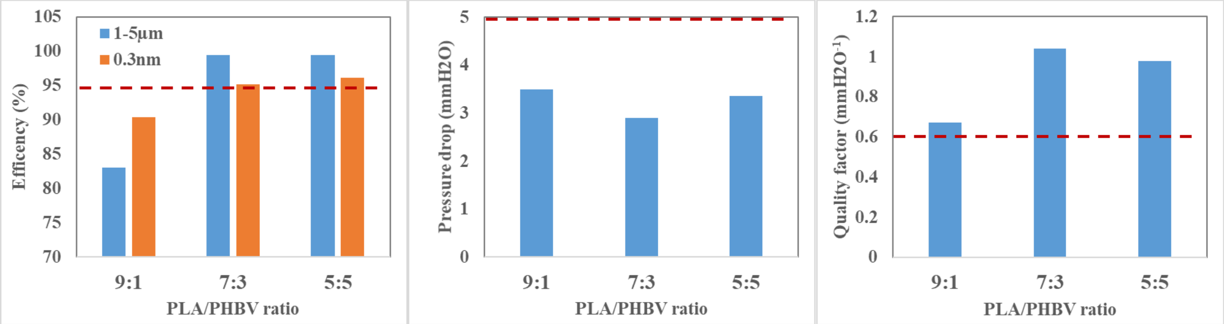

Fig. 2. Comparison of filtration efficiency (1-5µm, 0.3µm), pressure drop and quality factor for nanofiber non-woven of PLA/PHBV with ratio 9:1, 7:3 and 5:5 (red dotted line: ASTM-F2100 standard)

Stress test for the nanofiber non-woven was carried out in temperature of 60°C and humidity of 85% for 6 hours. Filtration efficiency of PLA/PHBV blend of 7:3 and 5:5 decreased by 19% and 20% respectively, with no significant difference in pressure drop. While for PLA/PHBV blend of 9:1, filtration efficiency reduced by 30% and pressure drop reduced by 62%. This shows the morphology nanofiber was better preserved with higher ratio of PHBV in the blend when subject to temperature and humidity stress.

Conclusions

Biopolymers PLA and PHBV were successfully blended at a 1:1 ratio and electrospun at concentration of 12.5% with formic acid as solvent. Blending of PHBV into PLA improved filtration efficiency and quality factor of nanofiber non-woven, and increased resistance to temperature and moisture degradation. PHBV also has the advantage over PLA of being marine biodegradable. The dual layer PLA/PHBV nanofiber achieved sub-micron filtration efficiency of over 96.2% with low differential pressure of $3.35mmH_2O$, which fulfilled medical mask standard ASTM-F2100 level 1.

Acknowledgement

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Separation and Purification of Glabridin from A Deep Eutectic Solvents (DES) Extract of Glycyrrhiza Glabra Residue by Macroporous Resin

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Glabridin can effectively inhibit antioxidant, anti-inflammatory, and tyrosinase activity. It is mainly used in the pharmaceutical and cosmetic industries. The residue of Glycyrrhiza glabra after glycyrrhizic acid extraction in industrialization still contains glabridin. Given the disadvantages of traditional extraction solvents, such as strong volatility, high toxicity, nondegradation, and low extraction rate, deep eutectic solvent (DES), an environmentally friendly, sustainable, nontoxic solvent with a high extraction rate, has been gradually developed and applied to the research of traditional Chinese medicine extraction. However, DES cannot easily achieve the separation and purification of target substances because of its high viscosity, low pH, and low volatility. In this study, DES was used to extract the glabridin from the residue of G. glabra. The extract was extracted with ethyl acetate and concentrated under reduced pressure to obtain the crude extract of glabridin. Subsequently, the macroporous resin was used for further separation and purification of glabridin. The Langmuir model, Freundlich model, intraparticle diffusion model, and kinetic model were used to study the adsorption mechanism of the resin. The adsorption and desorption conditions of the resin were also optimized. Results showed that compared with the extraction rates of 15.34, 34.44, and 194.80 μg/gwith the traditional extraction solvents of water, NaOH aqueous solution, and ethanol, the extraction rate of 317.10 μg/g with DES was the highest. The DES extract of G. glabra residue was extracted with two times the volume of DES extract by using ethyl acetate to obtain the crude extract of glabridin. The glabridin extraction rate was 91.63%. The application of 12 different resins in the separation and purification of glabridin from the crude extract of glycyrrhrizae radix was studied. LSA-21 was found to be the optimal resin. The study of the adsorption mechanism showed that the adsorption process of LSA-21 resin on glabridin conformed to the second-order kinetic model and Langmuir model, the thermodynamic parameters ΔH (enthalpy change) and ΔG (Gibbs free energy) were both negative, ΔS (entropy change) was positive, indicating that LSA-21 resin spontaneously and exothermically adsorbs glabridin to form a monolayer. The separation and purification conditions of glabridin by LSA-21 resin were optimized. The optimal adsorption conditions were a glabridin concentration of 56.90 μg/mL, 16.5 bed volume (BV) sample volume, and 2 BV/h adsorption flow rate. The desorption condition was 4 BV of ethanol, the elution flow rate was 2 BV/h, and the recovery rate of glabridin was 97.80%. The recovery rate of glabridin was still higher than 90% after the resin was reused four times. Finally, the total recovery of glabridin is 89.61%. This study confirmed that macroporous resin is an effective method for separating and purifying glabridin from the DES extract of G. glabra residue.

Keywords: Glabridin, DES, Macroporous resin, Separation, Purification, Mechanism.

One-Pot Fractionation of Endocarp Waste for Sustainable High Value-added Products

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ABSTRACT. Endocarp waste, the recalcitrant and inedible part of nuts and stone fruit, is a lignin rich, promising energy-dense feedstock for aromatic commodity chemicals in sustainable biorefineries. In this study, we tested the monomer production potential of phylogenetically diverse endocarp species through reductive catalytic fractionation (RCF) (Ru/C, THF, 5h, 250 °C, 40 bar H_2) and reported their aromatic monomer yield can surpass those obtained using wood up to 25-30% by dry biomass basis. We provide detailed chemical analysis of phylogenetically diverse species for better understanding of the linkages within various endocarps. Extractive analysis conducted by LC-MS suggested that the endocarp biomass is rich in extractives which further boost the economic and overall benefit of biorefinery. High S-lignin contents was related to high monomer yield with more B-O-4 linkages. Endocarp waste deconstructed with RCF prove to be an attractive lignin first biorefinery scheme and the detailed sustainability analysis could strengthen the shift of lignin aromatics into current petroleum dominated infrastructure to further enhance the circular economy.

Keywords: *Endocarp waste, Reductive catalytic fractionation, Circular economy.*

Introduction

The climate impacts due to fossil fuels utilization is undeniable today, demanding a dire need to shift our dependence and focus on renewable and sustainable materials. Being an abundant and sustainable carbon feedstock, lignocellulosic biomass is a promising alternative to petroleum and has great potential in carbon sequestration [1]. While most of the studies are focusing on lignocellulosic biomass, lignin being crucial and one of the three major components of lignocellulosic biomass (15-30%), is often treated as a waste and is usually degraded or left in condensed form [2]. The incumbent need for more efficient strategies shifted the focus on the “lignin-first” technologies aiming to extract and stabilize lignin and its derivatives without condensation [3]. Among various methods, reductive catalytic fractionation (RCF) has been considered one of the most efficient strategies which produce near theoretical yield of the phenolic monomers [4]. The conceptual diagram of the RCF biorefinery has been shown in Fig.1. In RCF, lignin is first solubilized and solvolysis with targeted interunit bonds properly cleaved [5]. The redox catalyst then stabilizes the resulting lignin moieties, promoting the hydrogenation of C-C bonds [6].

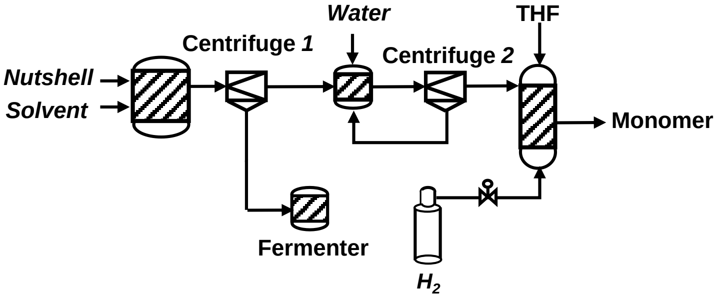

Fig.1. Schematic presentation of One Pot batch pretreatment of endocarp waste

Endocarp waste is the inedible part of fruits and nuts estimated at 24-31 million tons annually worldwide [7]. The lignin structure among different plant species, such as G/S ratio have not been widely studied, as the endocarp waste usually ends up in landfills. This waste could provide much more potential to contribute to lignin biorefinery. Meanwhile, endocarp waste is easily available everywhere and some of them are with high lignin content (50 wt%), making it an attractive source of monomer production. The nut-processing industry is already well-established globally, and thus the endocarp feedstock procurement for the purpose of lignin valorization practices is both stable and logistically efficient [8]. However, significant uncertainty of monomer yields over different endocarps were also found with lack of systematic understanding of the lignin-hemicellulose and lignin-lignin structures over different plant species and parts.

The purpose of this study is to determine the potential monomer production of endocarp waste and to test for unique lignin structures that are often found in common fruit remains and nutshells. Five different phylogenetically diverse endocarp species have been selected to analyze their potential for monomer production and to search for any unique lignin structure/monomer unit that has been missing in other kind of biomass studies. Besides we also check the biomass extractives qualitatively to further emphasize on the importance of the corresponding waste valorisation practice.

Material and Methods

Biomass feedstock and chemicals

All the fruits and whole nuts (i.e., Peach, Cherry, Pistachio, Peanut, and Walnut) were purchased from the local grocery shops in Hong Kong. The nuts were dried and removed from the shells. The shells were washed, dried and were grounded in the shaker mill and kept in airtight container for further analysis. All the reagents and chemicals used in this study were of analytical grade.

Biomass compositional analysis

The compositional analysis of the endocarp wastes was performed according to the National Renewable Energy Laboratory (NREL) protocol [9]. Briefly, the extractive free biomass (150 mg) was taken in 50ml falcon tubes and treated with 1.5 ml of 72% sulfuric acid in the water bath at 30 °C. The suspension was stirred every 10 min for 1 hour and afterwards 42 ml of distilled water was added to dilute the suspension and was autoclaved at 121°C for 1 hour. The solutions were kept at room temperature to cool down and then around 5-7 ml of the supernatant was transferred to 15ml tubes and were neutralized with barium carbonate before determining the sugar composition of the samples by high-performance liquid chromatography (HPLC), equipped with CHO-782 column. The remaining solution was passed through pre-weighed glass crucibles. The filtrate was washed by distilled water and dried in the oven overnight at 105 oC and weighed again to determine the Klason lignin content in the samples. Ash content was determined by placing the crucibles in the furnace at 575 C for 6-8 hours.

Reductive Catalytic fractionation

The labs-scale RCF experiments were performed in 50ml batch reactor (Parr Instruments & Co.). 500 mg of biomass was used together with catalyst Ru/C (150mg) and 20ml of the solvent tetrahydraflouran (THF). The reactor was sealed and pressurized with H_2 gas (40 bar). The reaction mixture was stirred and heated to 230 C during 30 mins and when the reaction temperature reached 230, it was kept constant for 5 hours. After the experiment, the mixture was passed through filter to separate the solid residual from the solvent. The solvent residues were washed and dried at room temperature, which were later used for carbohydrate analysis. The lignin oil containing monomers and some sugars were kept at 4 C for further analysis.

Lignin and monomer characterization

The monomer identification and quantification were performed by gas chromatography using Agilent Technologies 7890B equipped with FID detector. The lignin structure and the detailed linkages were determined by two-dimensional heteronuclear single quantum coherence nuclear magnetic resonance (2D HSQC NMR). JEOL ECZR 500 MHz spectrometer equipped with a 5 mm ROYAL probe was used to measure the HSQC spectra.

Results and Discussion

Chemical composition analysis of endocarp wastes

The results of chemical compositional analysis on the endocarp waste samples in duplicates are shown in Fig.2, and high lignin contents were found in four of the nutshells. The walnut, cherry, peach, and peanut from Fabids have lignin content in the range 30-40 %, while the pistachio nutshell has lignin below 20%. The high lignin contents in these samples proves it to be an ideal biomass for further valorization. Endocarp waste with high lignin content can be utilized for monomer production while those rich in carbohydrate can be used for the bioconversion in addition to monolignol production.

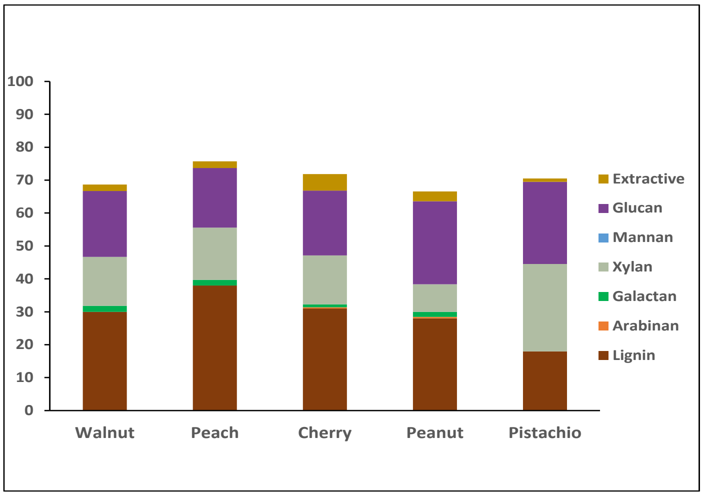

Fig.2. Chemical compositions of five endocarp wastes

Monomer yield potential of endocarp waste

The potential of the endocarp waste for monomer yield was tested by RCF. The significant differences in the abundance of G- (guaiacyl) and S- (syringyl) lignin along with variation in the monomer yield as shown in Fig.3. Walnut had the highest monomer yield (>70 mg monomers /g dry biomass) as compared to the other biomass. The monomer yield of peach, cherry, and pistachio were more than 50 mg monomer/ g dry biomass. While peanut have monomers in the range of 20-30 mg/ g dry biomass. There was variation in abundance of S- and G- monomers in all the species. The walnut belongs to different clades of eudicots and was rich in S- type monomers along with pistachio. While peach, cherry, and peanut were rich in G-type monomer. The species that are rich in G-type monomers have lesser yield as compared to the species rich in S-type monomers. One reason may be that the species that are rich in G-type monomers have more C-C bonds and can cause recalcitrance which can affect the monomer yield of that species. Besides this, the abundance of different type of monomer also enhances the selectivity of the monomers among these species. The biomass can be selected on the basis of desired monomer rich species. These results were further validated by 2D-HSQC NMR spectroscopy analysis.

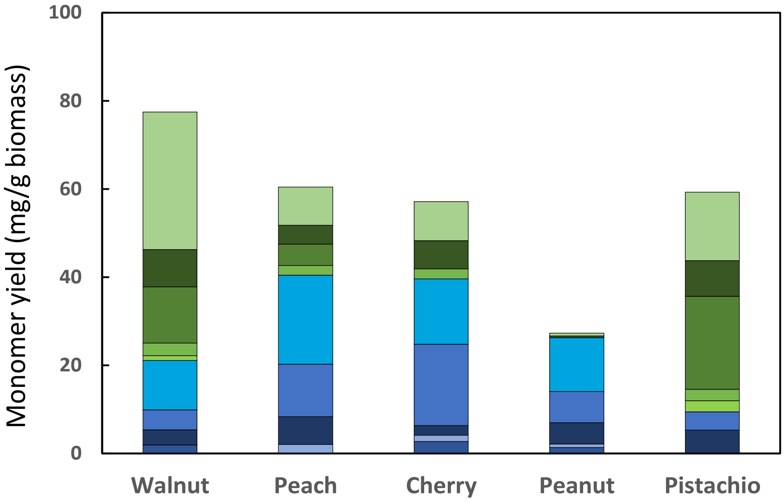

Fig.3. Monomer yield of endocarp waste as a result of RCF

The NMR spectra gave detailed information about the quantification of different components of polymeric chain such as S, G, C units and also helps in the estimation of the interunit linkages such as β-O-4, β- β, and β-5 as shown in figure 4. The NMR spectra of walnut revealed that it is rich in S lignin (>70 %) and high β-O-4 content (40%) resulting in high monomer yield and less condensation as the S-unit at 3 and 5 position of the ring don’t help in the formation of extra C-C bonds which ultimately increases the cleavable β-O-4 linkages and decreases the condensation in the depolymerization experiments.

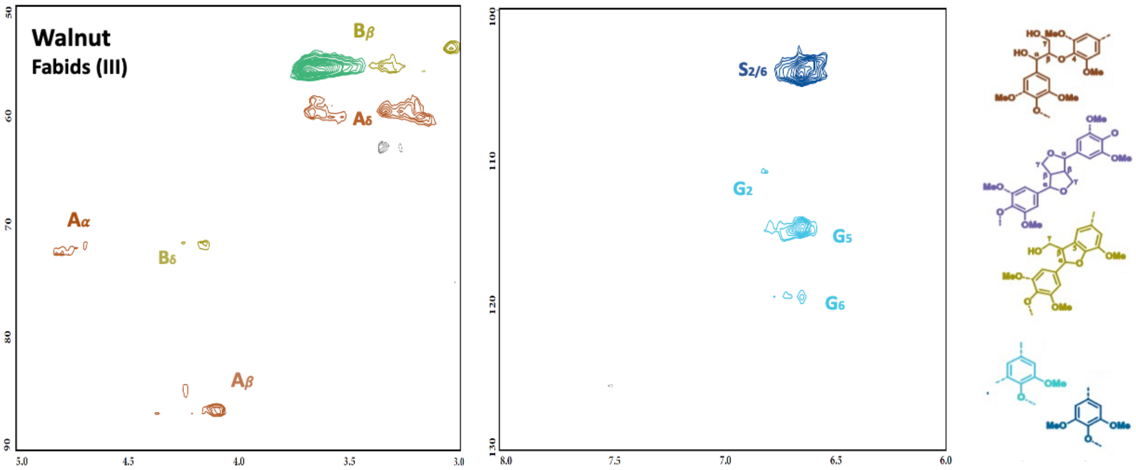

Fig.4. 2D HSQC analysis of walnut lignin

Conclusions

In this study, the potential of endocarp waste being an abundant and lignin rich waste was investigated for sustainable biorefinery. The lignin first strategy, reductive catalytic fractionation (RCF) was used on all the selected diverse phylogenetic endocarp species and resulted in different types of monomers with walnut and pistachio having the highest yield and demonstrated that β-O-4 was the most critical factor that greatly impact the monomer yield. Overall, the study provides profound knowledge on the crucial lignin properties that highlights the importance of endocarp biomass for the sustainable production of value-added chemicals.

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Conversion of Food Waste into Lipid by Oleaginous Fungi

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ABSTRACT. A batch experiment was conducted in culture flasks to evaluate the growth and lipid accumulation of *Cryptococcus curvatus* 2698 on food waste medium aiming at optimizing the growth conditions, preparation of food waste medium with different pre-treatment for the growth and lipid accumulation of the yeast strain. The food waste (FW) was pre-treated by different hydrolysis (acid, thermal and acid thermal) methods to increase the availability of carbon in food waste medium. FW medium without pre-treatment (FW-C) and Yeast Peptone Dextrose (YPD-C) broth medium were set as controls. The experiment was conducted for 8 days. The biomass obtained from different pre-treated food waste medium was higher compared to FW-C and YPD broth medium. But comparing lipid content (%), it was higher in YPD-C medium, followed by acid treated food waste (FW-A) and FW-C media. Thus, different pre-treatment methods increased the carbon content of FW medium than untreated medium, also supported the growth of *C. curvatus* and FW-A medium showed higher lipid accumulation compared to FW-T and acid-thermal treated FW medium(FW-AT).

Keywords: *Cryptococcus curvatus* 2698; Food waste; pre-treatment; lipid

Introduction

The demand for fossil fuels is increasing with increasing population and industrialization. To reduce this dependency and to mitigate the fossil-fuel based environmental pollution, development of alternative renewable fuels from renewable feedstock has received high priority in the past two decades. Biofuel production using oleaginous organisms is one the most important alternative methods. Oleaginous fungi, that can accumulate >20% lipid of their dry cell biomass, can be exploited to produce the biodiesel. Potential oleaginous filamentous fungi include (maximum oil accumulation in parenthesis) *Aspergillus oryzae* (57%), *Mortierella isabellina* (87%), *M. vinacea* (66%), and *Humicola lanuginose* (75%) while yeasts include *Candida curvata* (58%), *Cryptococcus albidus* (65%), *Lipomyces starkeyi* (64%) and *Rhodotorula glutinis* (72%) [1]. In India, many studies demonstrated the possibility of growing the oleaginous fungi on an array of substrates: cheese whey, sugarcane bagasse, grape stalk, banana peel, corn cob and groundnut [2]; vegetable waste [3]. Compared to other substrates, food waste (FW) is receiving greater attention recently [4-7] due to the greater availability, and to eliminate the need to dispose these wastes. Food waste contains a number of organics (protein, starch, amino acids and sugar) and inorganics (sodium, magnesium, iron, calcium, phosphorus and nitrogen) that can be utilized for the growth of oil accumulating yeast. In this study, food waste material was treated by different hydrolysis methods like acid, thermal and acid-thermal pre-treatment. Filtrate from different treatment was used as culture medium for growth and lipid production of the oleaginous yeast strain *Cryptococcus curvatus* 2698.

Materials and methods

Yeast strain

The oleaginous yeast strain *Cryptococcus curvatus* -2698 used for the study was procured from Microbial type culture collection centre and gene bank (MTCC), Chandigarh, India. The culture was maintained on YPD (dextrose- 20 g/L, yeast extract-10 g/L, peptone- 20 g/L and agar- 1.5 g/L, pH- 6.5) agar medium and sub cultured at regular intervals. the oleaginous strain *Cryptococcus curvatus* 2698

Collection of food waste material

Food waste material was collected from canteen at Manonmaniam Sundaranar University, Tirunelveli, India. The collected food waste material was analysed for selected physico-chemical properties like moisture content, pH, Electrical conductivity (EC), Total organic carbon (TOC), Total Kjeldahl nitrogen (TKN).

Pretreatment of food waste material

The food waste material was then ground well with the addition of water in 1:4 ratio using a blender. After that, the food waste slurry was pre-treated by acid, thermal and acid-thermal hydrolysis pre-treatment using the methods followed previously [7].Then the FW hydrolysate from each were filtered through a fine cheese cloth followed by centrifugation. Prior to sterilization of the FW filtrate media, the pH of each medium were set as 6.5 using 1N NaOH. FW medium without pre-treatment and YPD broth medium were set as control.

Culture of *Cryptococcus curvatus* 2698 on FW medium

0.1 ml of pre inoculum culture from 24 hr old culture of *C.curvatus* 2698 on YPD broth medium was inoculated into each 250 ml conical flasks containing 100 ml of FW medium pre-treated by different hydrolysis methods and incubated in an orbital shaker for 192 hr at 120 rpm at room temperature. Selected physico-chemical properties like pH, EC, TOC and TKN of culture media were determined at regular intervals to monitor the growth conditions for *C.curvatus* on different treatments. After 192 hr of cultivation, the cells from each treatment were harvested by centrifugation and lipids from dried biomass were extracted.

Analytical methods

The growth of the yeast strain on different food waste medium was monitored at regular intervals using spectroscopic method (OD 600 nm). Total organic carbon (TOC) content was analysed by using modified Walkley Black titration method. Total Kjeldahl nitrogen (TKN) content of the samples from each treatment were analysed by Kjeldahl digestion method. pH was measured by using standard methods. Biomass from each treatment was calculated by gravimetric method. Lipids from the dried biomass was extracted according to [8] with some modifications. Briefly 0.1g of dried biomass was digested with 4M HCl for 2 hours at 70˚C. After digestion the mixture was centrifuged at 2500 rpm for 15 min. The pellet was extracted twice with methanol/chloroform (1:1), then washed with 0.1% NaCl solution. After evaporation the sample was dried at oven. After drying of the sample, the total lipid content was calculated.

Results and Discussion

Properties of food waste material

The pH value of collected food waste material from the table.1 indicates that it was slightly acidic in nature. Moisture content, EC and TS content of FW material was similar to reported values [9] and TOC and TKN values are low.

Table 1. Selected properties of food waste material

Sample	pH	Electrical conductivity (mS/cm)	Moisture content (%)	Total solid (%)	Total organic carbon (%) on wet basis	Total Kjeldahl nitrogen (%) on wet basis
Food waste	4.46	3.39	70.76	29.24	1.066	1.6807

Effect of pH on the growth of *C.curvatus* 2698

It was stated that the pH of the culture medium is an essential parameter in the assimilation of the carbon source by the yeast and the accumulation of lipid. The ideal pH value varies from one strain to another and is also dependent on the carbon sources [10]. Initially, pH values of each culture media were set as 6.5 to support the growth of the yeast strain. Then the pH values of each culture media were started decreasing it may be due to the accumulation of some organic acids formation. Then the pH of culture media were gradually increased after 48 h. Compared with neutral pH 7.0 in alkaline pH (8-10) *C.curvatus* ATCC 20509 in acetic acid medium showed higher lipid production [11]. It was reported that the growth of *C.curvatus* 2698 in acid pre-treated vegetable waste hydrolysate medium pH values decreased with due course of time [3].

Growth of *C.curvatus* 2698 on food waste medium

In all the treatments, from day 0 to day 2 gradual increase in cell growth was observed and maximum growth was observed at day 4. Compared to all the treatments, in acid treated FW medium the cell growth was high. Due to unavailability of carbon content the growth started gradually declining after day 4 as indicated in figure 2. Growth pattern of *C.curvatus* varies slightly from one to another medium.

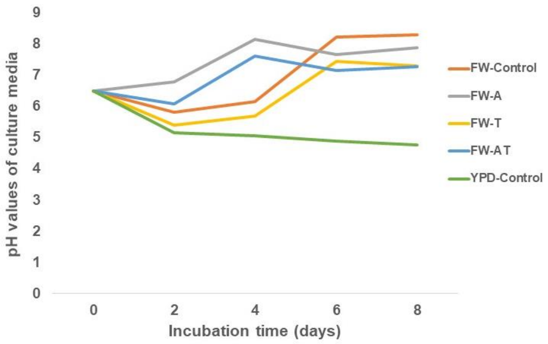

Fig .1. Changes in pH values of different culture media,(FW-control, FW-A- acid treated food waste medium, FW-T-thermal treated food waste medium, FW-AT- acid- thermal treated food waste medium)

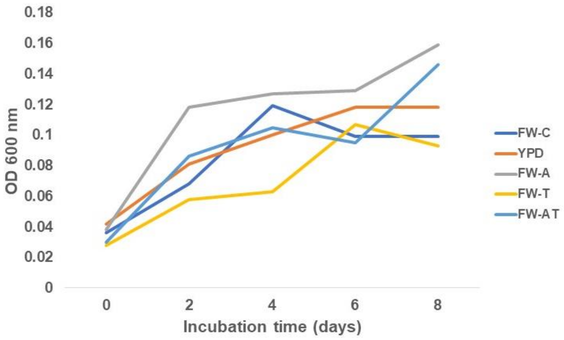

Fig .2. Growth of *C.curvatus*-2698 cells from different culture media

Carbon and nitrogen content of different culture medium

Initially, FW-T medium and FW-A medium consists of high amount of TOC compared to the two control medium. Figure 3a and 3b indicated that in all the treatments from day 0 to day 2 maximum consumption of both nitrogen and TOC content take place due to the active growth of *C.curvatus*-2698. After day 2 gradual declining of TOC and TKN content from the culture media was observed. Consumption of TOC and TKN content from culture media were indirectly proportional to the growth of the yeast strain.

Biomass and lipid content of *C.curvatus* 2698

Biomass and lipid content of *C.curvatus* 2698 from different culture media were listed in table 2. After 192 h of cultivation, maximum biomass was harvested from FW-T medium. Although low biomass was produced from YPD control medium, high amount of lipid content was extracted compared to other medium. Next to YPD control medium acid treated FW medium produced high amount of lipid content. Lowest amount of lipid content was obtained from FW-AT medium. It was reported that *Cryptococcus curvatus* MTCC 2698 produced 9.46 ± 0.1 g/l of biomass and 28.3 ± 0.5% of lipid content from 1.5% H2SO4 pre-treated-Vegetable Waste Hydrolysate medium as carbon source and also supplemented with 0.25% of yeast extract and 0.25% of peptone as a nitrogen source [3]. It was also reported that *Cryptococcus curvatus* produced 9.23 ± 0.33 g/L biomass from food waste leachate medium [6].

Conclusions

Pre- treatment of food waste material increased TOC content of FW medium. *C.curvatus* 2698 cultured on FW medium pretreated by acid, thermal and acid-thermal hydrolysis method resulted in higher biomass compared to FW medium without any pre-treatment. Lipid content was higher in YPD-C medium (8.5842 %) followed by FW-A (8.3028 %) and FW-C media (7.1573%). Further studies are needed to increase the lipid accumulation potential of *C.curvatus* from food waste medium.

Acknowledgement

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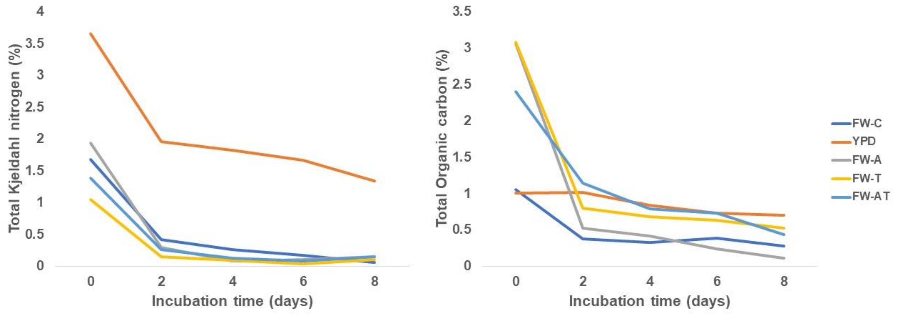

Fig .3. Changes in Total Kjeldahl nitrogen and Total organic carbon content (%) of different culture media collected at regular intervals.

Table 2. Biomass and lipid content of *C.curvatus* 2698 from different culture media

S.no	**Treatment**	**Biomass on dry basis (g/L)**	**Lipid concentration (g/L)**	**Lipid content (%)**
1	FW-C	3.8111	0.1955	7.1573
2	YPD-C	3.3755	0.2344	8.5842
3	FW-A	6.3933	0.2777	8.3028
4	FW-T	9.256	0.2106	5.9198
5	FW-AT	6.4744	0.1311	3.0381

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Development of Low-Cost Proton Exchange Membrane (PEM) For Microbial Fuel Cells (MFC)

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Microbial Fuel Cells (MFCs) are a well-known alternative to fossil-fuel-based electricity generation and one of the most innovative bioelectrochemical approaches for the direct conversion of organic waste into electrical energy using biocatalysts. Despite its best efforts, MFC faces numerous commercialization challenges, one of which is the use of expensive membranes, which makes them unaffordable. The goal of this research is to create performance-driven, cost-effective, and environmentally friendly separators that will make MFC technology a viable option. Three different types of low-cost materials were used in MFC, i.e., clay as the nonconductive material in the single (S) chamber with a cement/sodium chloride coat as the conductive agent to replace costly carbon cloth; agar and cement as the membrane in the dual (D) chamber along with sodium chloride as the proton mobilizer to replace the costly commercial Proton Exchange Membrane (PEM) For comparison, carbon cloth in SMFC and Nafion in DMFC were used. With different combinations of low-cost materials and proton mobilizers, the simultaneous bioelectricity production and bioremediation of septic tank wastewater (STWW) in SMFC and DMFC with native microflora as a biocatalyst; sterile STWW with *Serratia marcescens* (AATB1) as a biocatalyst, and sterile STWW as a control were analyzed. In DMFCs with Nafion 117, an agar bridge with 10% sodium chloride, and a cement bridge with 10% sodium chloride, current densities of 728±10 mA/m^2,442±21 mA/m^2 and 376±16 mA/m^2, while power densities of 341±8 mW/m^2, 180±10 mW/m^2 and 148±14 mW/m^2 were obtained. Our study shows a cost reduction in terms of USD of 4.67, 0.376, and 0.0044 and power generation performance of 100%, 61%, and 52% for DMFCs with Nafion 117 (9 cm^2), an agar bridge with 10% sodium chloride (108 cm^2), and a cement bridge with 10% sodium chloride (108 cm^2), respectively. Compared to Nafion 117 in DMFC (considered at 100% cost), agar bridges and cement bridges with 10% sodium chloride used in DMFC showed reduced costs of 88% and 99%, respectively.

Keywords: Bioenergy, Bioremediation, Low cost, MFC, PEM, SMFC.

Deciphering Chloramphenicol Biotransformation Mechanisms and Microbial Interactions via Integrated Multi-Omics and Cultivation-Dependent Approaches

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As a widely used broad-spectrum antibiotic, chloramphenicol is prone to be released into environments, thus resulting in the disturbance of ecosystem stability as well as the emergence of antibiotic resistance genes. Microbes play a vital role in the decomposition of chloramphenicol in the environment, and the biotransformation processes are especially dependent on synergistic interactions and metabolite exchanges among microbes. Herein, the comprehensive chloramphenicol biotransformation pathway, key metabolic enzymes, and interspecies interactions in an activated sludge enriched consortium were elucidated using integrated multi-omics and cultivation-based approaches. The initial biotransformation steps were the oxidization at the C_1-OH and C_3-OH groups, the isomerization at C_2, and the acetylation at C_3-OH of chloramphenicol. Among them, the isomerization at the C_3-OH is an entirely new biotransformation pathway of chloramphenicol discovered for the first time. Further, we identified a novel glucose-methanol-choline oxidoreductase responsible for the oxidization of the C_3-OH group in *Sphingomonas* sp. and *Caballeronia* sp. Moreover, the subsequent biotransformation steps, corresponding catalyzing enzymes, and the microbial players responsible for each step were deciphered. Synergistic interactions between *Sphingomonas* sp. and *Caballeronia* sp. or *Cupriavidus* sp. significantly promoted chloramphenicol mineralization, and the substrate exchange interaction network occurred actively among key microbes. This study provides desirable strain and enzyme resources for enhanced bioremediation of chloramphenicol-contaminated hotspot sites such as pharmaceutical wastewater, livestock and poultry wastewater. The in-depth understanding of the chloramphenicol biotransformation mechanisms and microbial interactions will not only guide the bioremediation of organic pollutants but also provide valuable knowledge for environmental microbiology and biotechnological exploitation.

Keywords: Chloramphenicol biotransformation, Multi-omics, Interspecies interaction.

Characterization and Valorization of Marine Sediment

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Large volumes of marine sediments are dredged annually in ports, but changes in regulations will tend to restrict their disposal at sea. The recovery of part of these sediments as raw materials in the field of construction help to limit their storage and give them added value. Our study is then oriented towards the characterization and the valorization of marine sediment. This work focuses on the feasibility of using dredged marine sediment from TENES port as partial replacement of sand in mortar. Physical, chemical, mineralogy, and rheology characterization were carried out. This study revealed that the substitution of sand by sediments can be considered as a suitable option of their valorization. This solution should have a great economic and environmental interest.

Keywords: Marine sediment, Caracterization, Valorization, Mortar.

Valorization of Biowastes from Wastewater Phytoremediation Process : A Model for Constructed Wetlands Integrated Management in a South-Mediterranean Region

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Constructed wetlands (CWs) are increasingly used for effluents treatment in south Mediterranean countries, as in Tunisia. The CW treatment plant of Jougar in northern Tunisia generates considerable amounts of macrophyte biomass and sewage sludge (SS) as biowastes. Integrated management of these wastes is of great importance to CW plant sustainable functioning. Firstly, SS production by the primary treatment pond (PTP) was studied to optimize it and then to ensure downstream CWs maintenance. Dysfunction of PTP generated excessive SS amounts that could cause wetlands clogging. The GPS-X simulation software was used to perform modeling of the PTP operation. Likewise, impacts of wastewater physicochemical parameters and pumping rate on the sludge settling operation were studied, leading to different simulation scenarios. Analysis of influent physicochemical parameters database over the period 2004-2009 defined three cases: minimum, mean, and maximum. Each case could be associated to one of the year seasons. During winter and autumn, several solutions corresponding to the mean case were possible. In the summer, best alternative would be adoption of a pumping rate of 21 $m^3.d^{-1}$ over a 36-day period (minimum case). For the spring season, influent characteristics were close to those of the maximum case. Accordingly, this study recommended integration of a second PTP to enhance the primary treatment efficiency, and then to achieve a better performance of the CW system of Jougar. After PTP emptying operation, the routinely removed SS was used to reactivate macrophytes biomass composting process at the beginning step. Indeed, significant amounts of reeds and cattails' biomasses were collected from the vertical and horizontal CWs of Jougar treatment plant after harvesting operation at the end of the macrophytes' life cycle. Then, aerobic composting pile of macrophyte residues mixed with SS fraction was controlled over a four-month period through the monitoring of different key physicochemical and biological parameters. Compost maturity was assessed by C/N ratio of about 9 and germination index reaching approximately 96%. Compost application to soil with 1/3 volume proportion likely appeared to be beneficial and sufficient for soil fertilization and plant growth improvement after nutrients input. Then, valorization of CW biowastes by composting could contribute to a better management of such systems and to the fertilization of Tunisian agricultural soils continuously getting poorer in organic matter. Another way of phytomass recycling was to use it as a filter substrate to enhance wastewater treatment efficiency by the filtration technique. Annually harvested aboveground macrophyte parts composed of leaves, stems and inflorescences of reeds and cattails were crushed and dried. Then, phytofiltration assays using poly-substrate filters made with mixtures of macrophyte dead biomass and conventional inert media (gravel or brick wastes) showed a significant organic and inorganic contaminants reduction. When added to inert filter media, the new substrates of macrophyte biomass have proved to be able of improving CWs treatment performance. In conclusion, the presented integrated management model would be successfully applied to CW systems in south Mediterranean regions, as in Tunisia to ensure their sustainable efficacy and protect environment and natural resources after biowastes recycling and valorization.

Keywords: Biowastes recycling, Constructed wetlands management, Macrophytes biomass, Sewage sludge, Valorization.

Factors Influence on *Citrobacter Amalonaticus* Metabolism Towards Succinic Acid Production Through CO_2 Utilization

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Increased usage of fossil fuels has resulted in fuel shortages and higher energy prices. In order to compensate for decades of energy use, research has focused on the use of renewable energy sources towards the production of platform chemicals, with a particular emphasis on employing inorganic carbon as a substrate, such as CO_2. Succinic acid, a well-known industrial chemical, is a precursor of many important industrial compounds and consumer products. Exploiting the capabilities of microbes in enabling CO_2 biotransformation to yield succinic acid is of commercial interest and gaining prominence. Fermentative succinic acid production system, an alternative to the fossil-based production process, is well known however, little is understood regarding the specific requirement of their critical concentrations under different operating conditions such as substrate, buffer, organic loading rate (OLR), pH and temperature. This study explored the metabolism shift of isolated *Citrobacter amalonaticus* (SVMIICTSA1) towards succinic acid with eight selected parameters by employing the Taguchi design of experiment (DOE) approach. Factors such as CO_2 utilisation, pH, temperature, organic substrate, cofactors, buffer, OLR and influence of external potential/electron donor were taken into consideration. The influence of all the critical parameters driving the metabolism of *C. amalonaticus* was assessed/evaluated with bioprocess analysis, electrochemical parameters and gene expression studies. Further to evaluate the importance of $NADH/NAD^+$ ratio towards succinic acid production (rTCA cycle), cyclic voltammetry analysis and enzyme assay were performed. Overall, the eight parameters considerably influenced the metabolism of the bacteria with diverse productivity of succinic acid. Thus, the transition from fossil fuels to renewable raw materials such as CO_2 for the production of value-added products opens up great prospects for applying industrial biotechnology to create long-term CO_2 biorefineries.

Keywords: Reverse Krebs cycle, KEGG annotation, primers, hybrid fermentation, metabolic flux, CO_2 sequestration.

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Composting

Lignite Affects Active Nitrogen Gas Emissions during Poultry Wastes Composting: Insight Into the Microbial Mechanism

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ABSTRACT. Ammonia (NH_3) and nitrous oxide (N_2O) emissions are substantial contributor to nitrogen (N) loss in composting. Lignite addition can increase N retention by absorbing NH_4^+ and NH_3, and lignite dewatering could enhance NH_4^+ adsorption capacity in pure solution system. However, the results on the impacts of lignite on N_2O emissions during composting are controversial because of the lack of the study on the inner microbial mechanisms. Results showed that the cumulative NH_3 emission in lignite and dewatered lignite treatments were reduced by 39.3% and 50.2%, while N_2O emissions were increased by 7.5 and 15.6 times, relative to non-lignite control. Lignite addition increased abundances of *amoA*, *amoB*, *nirK* and *nirS* in the cooling and maturity stage of composting. Structural equation models revealed that lignite and dewatered lignite may reduce NH_3 emission by increasing cation exchange capacity, promoting the growth of ammonia-oxidizers and by reducing compost pH.

Keywords: Lignite amendment; Surface modification; Manure composting

Introduction

Aerobic composting is an effective and environment friendly technology that can transform organic wastes into organic fertilizer under the action of microbial activity. The high temperature in the thermophilic stage of composting could eliminate pathogens and enhance degradation of various hazardous substances. However, approximately 10%−46% of N in animal manures is lost in the form of ammonia (NH_3), and 1%~9% of N is lost in the form of nitrous oxide (N_2O). NH_3 and N_2O emissions not only lower the compost quality but also cause serious pollution to the atmosphere and environment.

Lignite has been widely used as an amendment to the bedding of animal feedlots [1] or commercial scale animal manure composting to reduce at least 35%−54% NH_3 emission from lignite amended composting systems [2,3]. However, contradictory effects of lignite amendment on the N_2O emissions during cattle manure composting have been reported previously [4]. It is necessary to understand the variations of N transformation functional genes under the amendment of lignite during composting. Lignite dewatering decreased moisture content from 61.6% to 4.2% and significantly increased adsorptions of NH_4^+ and NH_3 by 65.8% and 28.8% [5]. However, the effects of dewatered lignite on NH_3 and N_2O emissions during composting are still unclear.

The aims of the study were to: 1) explore the effects of dewatered lignite amendment on NH_3 and N_2O emissions during aerobic poultry litter composting; 2) understand the bacterial community structure succession and N transformation functional genes under lignite addition; 3) determine the contributions of environmental and microbial factors to NH_3 and N_2O emissions. The results of this study will provide a theoretical basis and strategy for the using of lignite to reduce NH_3 and N_2O emissions in aerobic composting.

Material and Methods

Composting experiment design and sample collection

Three treatments were set up in the experiment. Poultry litter was thoroughly mixed with 15% (dry weight) lignite (T1), 15% (dry weight) dewatered lignite (T2), while the non-lignite control (CK) contained poultry litter only. Each composting vessel contained 7 kg (dry weight) of raw materials and the initial moisture content was adjusted to 55%−60% and composted for 52 days. The composting mixture was mixed thoroughly and approximately 200 g fresh subsample was collected from each vessel once a week on days 0, 7, 14, 21, 28, 35, 42, and 52 and subjected to pH, EC, DOC, CEC, NH_4^+ and NO_3^- analysis.

Gas emission measurements in composting experiment

Real-time gas concentrations of CO_2 and N_2O from gas samples taken from the headspace of each vessel were simultaneously analysed by the Spectronus FTIR analyser. NH_3 concentration was measured separately using an acid trap supplied with an aeration system at a rate of 0.5 L/min.

Microbial analysis of composting samples

The DNA was extracted in triplicate from 0.25 g of each sample collected at 0, 1, 7, 28, and 52 days with a Fast DNA Kit for Soil (MP Biomedicals, Irvine, California, USA). The target genes quantified by qPCR comprised bacterial 16S rRNA and five nitrogen cycle genes, i.e., bacterial ammonia monooxygenase (amoB), archaeal ammonia monooxygenase (amoA), nitrite reductase (nirK, nirS), and nitrous oxide reductase (nosZ).

The total DNA from each sample was subjected to 16S rRNA gene amplification and microbial community analysis on the Illumina 2500 platform. The V4-V5 regions of 16S rRNA gene were amplified with the primers 515F (5′-GTGCCAGCMGCCGCGGTAA-3′) and 907R (5′-CCGTCAATTCMTTTRAGTTT-3′).

Data analysis

Redundancy analysis (RDA) was used to analyze the relationships between environmental factors and microorganisms using CANOCO (Version 4.5). Structural equation modelling (SEM) was applied to identify the key driving factors to NH_3 and N_2O emissions in different composting treatments by IBM SPSS AMOS 24.0 software.

Results and Discussion

Evolution of temperature and chemical properties during composting

Lignite addition increased the temperature of composting. The thermophilic phase (>50°C) for CK, T1, and T2 were 5, 10, and 7 days, respectively. The moisture content increased dramatically during thermophilic stage and declined slightly in the cooling and maturity stage. Due to great water retention capacity, the moisture content in the final products of T2 was 7.2% higher than that in CK. The pH values of T1 and T2 were clearly lower than that of CK because of the low pH of lignite and dewatered lignite. The CEC increased significantly during composting with significantly higher CEC in T1, T2 than CK due to high CEC capacity of lignite. The compost DOC results generally showed a decreasing trend during composting. The addition of lignite increased OM degradation rate and the TN content. Addition of (dewatered) lignite enhanced the ammonification and retained NH_4^+ in the compost [1,2,4,5]. The nitrate (NO_3^-) content was quite low during the first three weeks and then increased gradually until the maturity stage, suggesting lignite addition promoted the nitrification process during composting.

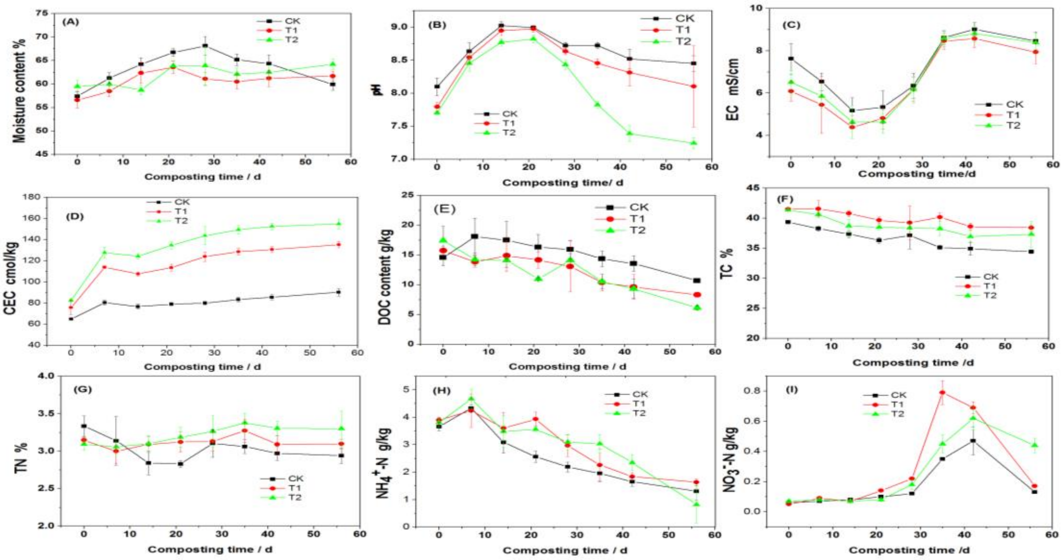


Fig.1 Variations in physiochemical properties during poultry litter composting

Gaseous emission patterns in composting

The cumulative NH_3 emissions were reduced by 39.3 % in T1 (4.64 g/kg) and 50.2% in T2 (3.81 g/kg) compared to CK (7.66 g/kg) over the composting period (Fig. 2A). The mitigation of NH3 emission from composting by adding lignite could be related to adsorption of NH_4^+ and NH_3 by oxygen-containing functional groups in the surface of lignite, as well as the lowered pH of composting mixtures [3]. The enhanced adsorption of NH_3 by dewatered lignite was in an agreement with previous studies [5]. The N_2O emissions were consistent with the changes of NO_3^-, suggesting N_2O emissions were generated through nitrification of ammonium and denitrification of nitrate. The N_2O emission rate in T2 was 50% lower than that in T1 which suggested that the promotion effect on N_2O emission was weakened by lignite dewatering. The cumulative N_2O emissions of T1 and T2 were increased by 15.6-fold and 7.5-fold, respectively, compared to CK (Fig. 2E). The CO_2 emission rates in T1 and T2 were 12.4% and 25.6% higher than that of CK in the first 14 days. However, with the composting process progressed, CO_2 emission rates in T1 and T2 were significantly reduced compared with CK. The accumulative emission of CO2 in T1 (476.2 g/kg) and T2 465.8 g/kg was 25.5% and 27.1% lower than that in CK (638.9 g/kg) (Fig.2C), indicating the lower microbial activity in the cooling and maturity stage of composting in both T1 and T2 treatments. This finding is supported by Impraim et al. (2020), who observed that lignite reduced CO_2 emission by 12%–23% from cattle manure composting [4].

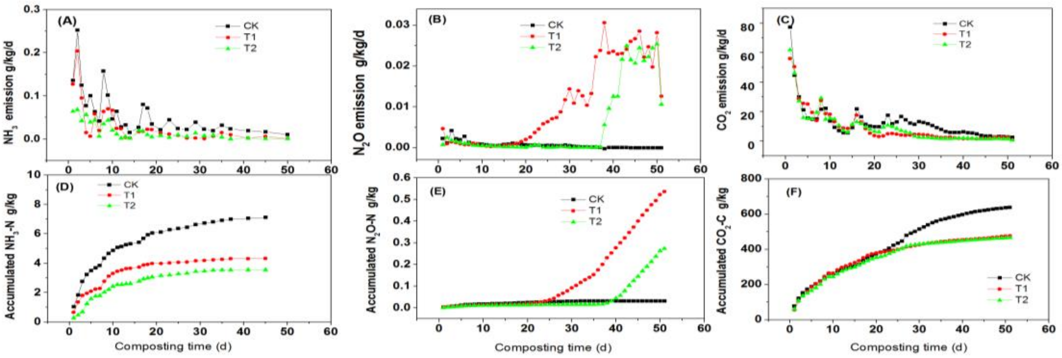


Fig. 2 Fluxes and cumulative emissions of NH_3, N_2O, CO_2 and CH_4 during poultry litter composting

Quantification of nitrification and denitrification genes in composts

The archaeal amoA gene and bacterial amoB gene were abundant throughout the composting process (Fig.3). However, the archaeal amoA gene abundance showed more variation than bacterial amoB gene, suggesting bacterial oxidizers were tolerant to high NH3 contents and thus became dominant in the thermophilic stage of composting. Lignite significantly decreased the abundance of amoB genes in the early stages but increased the abundances of amoA genes in the cooling and maturity stages.

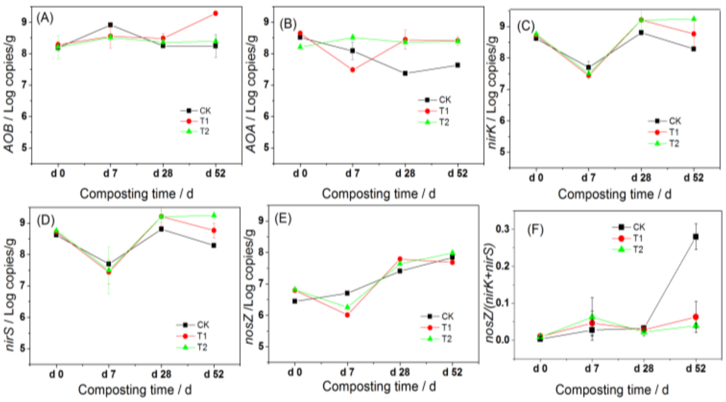


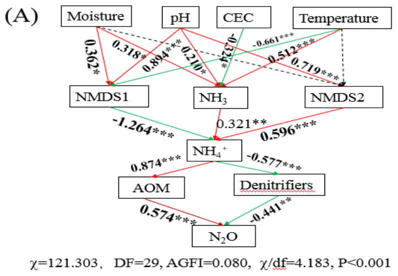
Fig.3 Abundacnes of nitrifying and denitrifying functional genes during poultry litter composting.

The abundances of nirS and nosZ genes were decreased by 99% and 92%, 79% and 64% in T1 and T2 than that in CK on day 7. Changes in the abundances of genes (amoA, nirS, and nosZ) could affect the emission of N_2O during lignite amendment composting, where an increased in the abundance of AOA promoted the generation of N_2O through nitrification during the maturity stage, and the reduction in the abundance of the nirS and nosZ gene was another factor that affected the generation and consumption of N_2O through denitrification.

Key factors affecting NH_3 and N_2O emissions in composts

Temperature, moisture and pH were significantly positively related to NH_3 emissions.Temperature may also affect NH_3 emissions by DOC indirectly (Fig.4A). An increase in temperature may increase the degradation of OM and ammonification rate, which would provide substrate for NH_3 emissions. CEC was significantly negatively correlated to NH_3 emissions. Core bacterial communities such ammonia-oxidizing microorganisms (AOM) reduce NH_3 emissions by assimilating NH_4^+ in composts. Lignite or dewatered lignite may reduce NH_3 emissions by (1) decreasing the pH of composts; (2) increasing CEC for adsorption of NH_3 and NH_4^+; (3) increasing DOC for the growth of microorganisms in the composts to immobilize the manure ammoniacal N into organic N.

The pH value was negatively correlated with N_2O emissions, while moisture had positively effects on N_2O emissions (Fig. 4B). Both NH_4^+ and NO_3- were significantly correlated with N_2O emissions, suggesting that moisture might affect N_2O emissions by affecting nitrification and denitrification during composting. Significantly positive relationship were observed between ammonia-oxidizing microorganism (AOM) and N_2O emission. Denitrifiers were significantly positively correlated to N_2O emission in T2 and T3, while they were significantly negatively correlated to N_2O emission in CK. The above results suggested that N_2O may be primarily produced from oxidation of hydroxylamine to nitrite by AOMs in CK, while both nitrification and denitrification contributed significantly to N_2O emission in T1 and T2.



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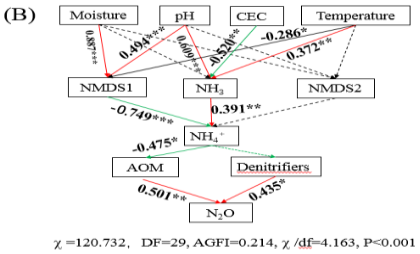

With lignite

Fig.4 Multi-variable interaction of various factors in NH_3 and N_2O emissions during composting.

Conclusions

Lignite and dewatered lignite reduced NH_3 and CO_2 emissions by 39.3%−50.2% and 25.5%-27.1%, respectively, but increased N_2O emissions by 7.5-15.6 folds during poultry litter composting than unamended. The structural equation model indicated pH, CEC, and temperature significantly influenced NH_3 emission, while N_2O emissions were mainly affected by pH and moisture.

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Synergistic Abatement of NH_3 and N_2O Emission from Composting Process

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Reducing reactive nitrogen (N) leakage from livestock manure management is of global concern. Aerobic composting of organic waste is an important anthropogenic source of ammonia (NH_3) and nitrous oxide (N_2O). The increasing implementation of ammonia (NH_3) mitigation measures in livestock production inevitably results in ammonium (NH_4^+) enrichment in the manure, but there is a lack of mechanistic understanding of such enrichment on N cycling and gaseous N emissions from subsequent manure management. Moreover, it is difficult to implement targeted options to mitigate emissions from this source because the dominant N_2O production pathway remains unclear. Here, combined approaches of N-form analysis, isotopocule mapping, qPCR, and Illumina MiSeq sequencing were used to differentiate N_2O production pathways and decipher the underlying microbial mechanisms during composting. Results indicated that bacterial denitrification dominated the N_2O production overall, but the major N_2O production pathway varied at different composting stages, with heterotrophic denitrification (HD) being most important at the early stage and nitrifier denitrification (ND) at the latter stage. Most N_2O was produced at the latter stage, where the production of nitrite through ammonia oxidation provides substrate for nitrifier denitrification. Quantification of the functional genes involved in nitrification and denitrification revealed that the N_2O emission rates correlated with the abundance of the amoA gene in ammonia-oxidizing bacteria (bac-amoA). The application of an electric field during composting reduced N_2O emission by 28.5-75.5%. The underlying mitigation mechanism of the electric field was attributed to ammonia oxidation inhibition, as evidenced by the observed reduction in nitrite accumulation and the abundance of bac-amoA. Sequencing of the bac-amoA gene suggested that the amoA-containing family Nitrosomonadaceae was responsible for ammonia oxidation and N_2O production, and the application of an electric field could reduce the proportion of Nitrosomonadaceae from 99% to 83% at the lower voltage and to a negligible level at the higher voltage assessed, which was attributed to their depressed competitiveness for oxygen (O_2) with heterotrophs. The application of an electric field promoted the degradation of organic matter while reducing the O_2 availability, as evidenced by the decreased free air space and O_2 concentration. The findings of this study provide evidence that an electric field could be used as an innovative nitrification inhibitor to reduce compost derived N_2O emissions.

Keywords: Composting, Ammonia mitigation, Nitrifier denitrification, Nitrification inhibitor, N_2O mitigation.

Nutrient Recovery and Treatment of Organic Waste by Vermitechnology

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Solid waste disposal and management is a challenge in developed as well as developing nations. A number of destructive methods have been proposed and practiced for the disposal of solid wastes. Scientific community is in search of non-destructive methods by which nutrients can be recovered from the solid wastes. Among various biological methods of solid waste management, vermitechnology has attracted attention of scientific community, policy makers and municipalities. It is one of the ecologically and economically sound technologies for handling biodegradable organic fraction of solid wastes. The process vermicomposting is conducted in a narrow range of temperature (25-40ºC), near neutral pH (6.5-8.5) and high humidity (60-70%) in order to sustain a large population of earthworms. It degrades the organic waste in about 2 to 4 months and the end product is odourless, disinfected and highly nutritive vermicompost which is suitable for organic manuring of agricultural soil. Moreover, it is known that the earthworms release coelomic fluids in which mucocytes, vacuolocytes, granulocytes and lymphocytes are present which kill the bacteria and parasites present in the waste, thus, making the vermicompost odour and pathogen free. Significantly, the vermicompost is considered an excellent product of homogeneous and odour-less nature, rich in microflora, and tends to hold more plant nutrients over a longer period. Vermicomposting is one such technology which can be used at small (household level) to very large (several households, village or an entire city) scale. A large variety of wastes of plant and animal origins have gainfully been vermicomposted and used as used at laboratory as well field scale.

Keywords: Vermitechnology, Earthworm, Solid waste, Organic waste.

Responds of Physiological Inheritance Mechanism on Seed Germination Under Phytotoxicity During Chicken Manure Composting

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Composting is a biotransformation environmentally friendly and potential sustainable way to convert organic waste into a fertilizer in farmland. Nevertheless, salts, ions, small organic acids and inorganic nitrogen condensation and production in composting make it a threaten for seed germination. Germination index (GI) is considered the most authoritative index for maturity evaluation of compost. Thus, seed responds to different periods of composting stress were detected during metabolism activities, such as producing certain endogenous phytohormones, invoking activities of antioxidant enzymes. Co-composting of livestock manure and straw for 42 days and the maturity and phytotoxicity were analyzed during the process. Five periods of mesophilic, thermophilic, cooling, first mature and second mature phases were clearly divided. GI increased to above 90%, other characteristics (pH, EC, C/N and so on) indicated the higher maturity of the final compost. The transcriptome and proteome are also necessary to build an available genomic resource to investigate the molecular mechanisms underlying different composting stress in seed. Comparative omics analysis showed that 14679 genes and 1091 proteins were differentially expressed in seed under initial compost stress, which were enriched in the following processes: catalysis and metabolic process. The reprogramming of transcript and protein works suggested that the induced activity of ribosome and carbon metabolism may endue seed with compost phytotoxicity tolerance, and >70% proteins in these two significant pathways were reversible with composting proceeding. With high-quality sequencing and annotation, the obtained transcriptomics and proteomics provide a robust genomic resource for higher quality and safety application of manure composts in agriculture.

Keywords: Composting, Seed, Phytotoxicity, Transcriptomics, Proteomics.

Deciphering the Dynamics of Antibiotic Resistance Genes and the Driving Mechanisms during Pig Manure, Kitchen Waste, Sewage Sludge Composting

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The organic solid wastes (OSWs) are the important hotspots of antibiotic resistance genes (ARGs), mainly including livestock manure, kitchen waste (KC) and sewage sludge (SG). Aerobic composting is a harmless recycling treatment method for transforming OSWs into organic fertilizers. However, the effects of aerobic composting on ARGs are controversial. In this study, we adopted the high-throughput quantitative polymerase chain reaction (HT-qPCR) to quantify and compare the ARGs and MGEs abundances in three raw materials composting, including pig manure (PM), KC and SG. The corresponding driving mechanisms were explored using structural equation models (SEMs). We found the dominant types of ARGs in initial materials are different, mainly including the genes resistant to tetracyclines, aminoglycosides, macrolides in PM, tetracyclines and aminoglycosides in KC, sulfonamides in SG, respectively. Interestingly, the abundance of ARGs tended to be similarity in final composts of three raw materials ($P \geq 0.05$), although there were significant differences in initial raw materials (PM > SG > KC, $P \leq 0.001$). More importantly, at the end of composting, the abundance of ARGs decreased in PM treatment (removal rate of 71%), while increased in KC (5.9-fold) and SG (1.3-fold) treatments. In addition, the rebound of ARGs abundance in maturation period happened in all treatments, which should be taken seriously owing to the increasing resistance risk of compost products. The network analysis indicated Firmicutes, Proteobacteria and Actinobacteria were the important potential hosts of ARGs. Notably, several genes should be taken seriously, including tetW, aadA, aadE, tetX, strB, tetA, mefA and intl1, intl2 in final products. Finally, according to the SEMs, we concluded the different driving mechanisms of ARGs variations in three treatments, including "microenvironment-ARGs" in SG compost, "microenvironment-ARGs" and "microenvironment-microorganisms-ARGs" in PM compost, "microenvironment-microorganisms-ARGs" and "microorganisms-HGT-ARGs" in KC compost, respectively. This study provided a systematic and deep insight of ARGs dynamics during PM, KC and SG composting.

Keywords: Antibiotic resistance genes, Dynamics, Driving mechanisms, Different raw materials, composting.

Effects of Reflux of Mature Compost During Perishable Waste Composting

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ABSTRACT. Aiming at the problems of low bioconversion efficiency and serious secondary pollution of urban perishable waste, mixing or covering &mixing reflux were applied in kitchen waste composting to investigate the effects of reflux modes on composting process and emission of NH_3, CH_4 and N_2O. 20% was determined to be the optimal ratio of reflux and used in the current experiment. Mixing with 15% and covering with 5% mature compost had a better reduction effect on NH_3 and CH_4 emission. Mixing with 15% thermophilic compost and covering with 5% mature compost had a better reduction effect on N_2O emission. In conclusion, reflux compost can accelerate the compost fermentation process, while covering &mixing was conducive to the reduction of polluted gases, which can provide theoretical and technical support for rapid composting of urban perishable waste in the future.

Keywords: *Compost, Foul odor gas, Perishable garbage, Clinker reflux*

Introduction

Perishable food waste is an organic solid waste with high water content, low calorific value, and highly putrescible [1]. According to the Food and Agriculture Organization, there is about 1.3 billion tons of food waste disposed to landfill every year, resulting in many environmental problems [2]. Composting is an effective way to solve the problem. However, the composting process would produce considerable emissions of NH_3, CH_4 and N_2O, which may lead to secondary pollution such as greenhouse effect. Compost clinker is favored as its large specific surface area, good structural properties, and a large number of indigenous microorganisms, which facilitate the fermentation process [3]. However, as an important technological measure in the optimization of compost fermentation process, clinker reflux is still in the exploration stage, and there is a lack of systematic research on the clinker reflux process, which affects the power and efficiency of composting enterprises to reduce emissions to a certain extent. Therefore, the objective of this study is to evaluate the influence of different clinker reflux modes on the emission reduction of foul odor gas. Before that, the optimal reflux ratio was determined to be 20% in advance.

Materials and Methods

Composting materials and setup

The kitchen waste (food and vegetable waste) used in the composting experiment was taken from the canteen of West Campus of China Agricultural University; rape straw and sawdust were obtained from Shangzhuang Experimental Station, China Agricultural University. Microbial agent (VF20F0020) was obtained from Beijing VOTO Biotech Co., Ltd.

A series of 8L composting vessels were used in this study to simulate the forced-draft aeration system, which is equipped with temperature sensor and automatic data recorder. Ventilation oxygen supply was controlled to 0.2L min^{-1} kg^{-1} DM, and the automatic temperature control box was set to 50°C.

Experimental design and sampling

The raw material was a thorough mixture of kitchen waste (food waste and vegetable waste mixed at a ratio of 1:1, wet weight), rape straw and sawdust at a ratio of 3:1:1 (dry weight). The experiment of different compost reflux modes was carried out, of which the reflux ratio is 20%. Five treatments including CK (control, no-reflux), T1 (mature compost, completely mixed with the initial material), T2 (mature compost, 15% was used for the initial material mixing, 5% was used for surface covering), T3 (mature compost, 10% was used for the initial material mixing, 10% was used for surface covering) and T4(thermophilic and mature compost, 15% thermophilic compost was used for the initial material mixing, and 5% mature compost was used for surface covering). In all treatments, 3‰ (dry weight) VF20F0020 microbial inoculum and 3% (wet weight) pH regulator were added. The water content of mixed materials was adjusted to 75%, and the filling bulk density of materials was set to 0.35 kg L^{-1}.

The composting was carried out for a total of 28 days, and at days 0, 3, 7, 14, 21 and 28, the heap was turned and samples were collected. NH_3 was measured via washing bottle with boric acid and titrated against H_2SO_4. Greenhouse gases (GHG, CH_4 and N_2O) were determined by gas chromatography. Germination index (GI) was measured and calculated according to [4].

Analyses

Microsoft's Office Excel software was used to process the data.

Results and Discussion

Composting fermentation process

Changes in temperature during composting are shown in Figure 1(a). Except CK, all treatments entered the thermophilic stage on the second day and the peak temperature in T4 was the highest, while the duration in T1 was the longest. When the total amount and type of reflux compost are the same, the thermophilic stage will be longer with the increase of the mixing ratio. GI values of all treatments are shown in Figure 1(b). At the end of composting, GI values of TI to T4 could reach more than 80%, conforming to the standards of compost maturation, while GI value of CK was only 69.7%. Covering &mixing reflux can accelerate the composting fermentation process, and mixing with thermophilic compost is more conductive than the mature compost to raise the composting temperature.

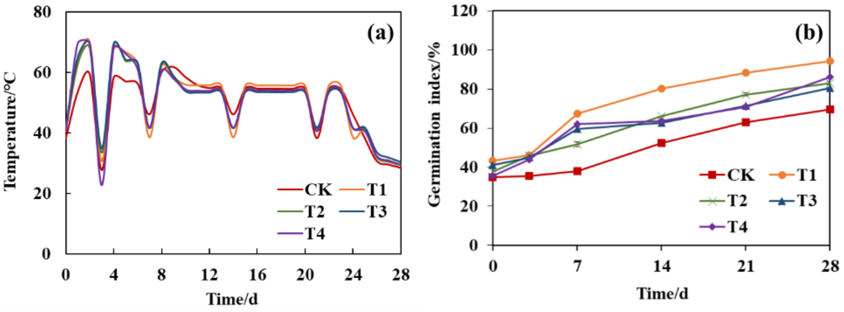

Fig.1. Different reflux mode on the variations of Germination index (a) and Temperature (b)

Ammonia emission rate and cumulative emission amount

The emission rate and cumulative emission amount of NH_3 in all runs are shown in Figure 2(a) and (b). The NH_3 emissions of T1 to T4 were all less than CK. During the first 8 days, mixing &covering with compost can adsorb NH_3 to a certain extent, making the emission rate of NH_3 in each treatment be at a low level. NH_3 emitted intensively during the 7th to 14th day. When the total amount and type of the reflux compost were constant, NH_3 accumulative emission dropped and then rose with the increase of covering ratio, possibly due to the conversion of NH_4^+ into NH_3 in the covered mature compost and the increase of mixing ratio [5]. Although the treatment of purely mixing with mature compost adsorbed part of NH_3 due to its soft texture and large specific surface area, the emission reduction was still insufficient compared with the mixing &covering treatment. T2 had the best reduction effect on NH_3 emission. It could be a result of process that NH_4^+, urea and uric acid onto mature compost were physiochemically absorbed [6,7].

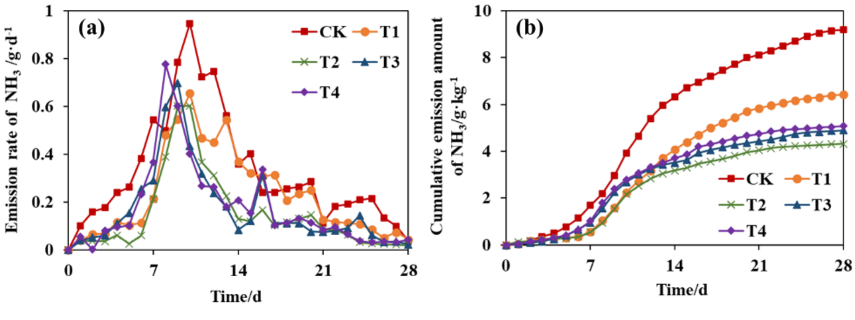

Fig.2. Different reflux mode on the variations of (a) Emission rate of NH_3 (b) Cumulative emission amount of NH_3

Greenhouse effect analysis

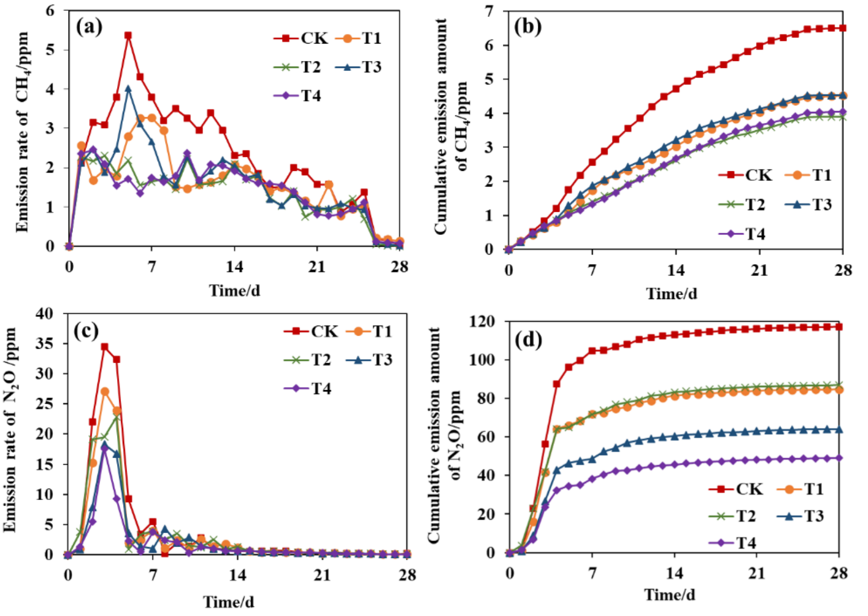

Fig.3. Different reflux mode on the variations of (a) Emission rate of CH_4 (b) Cumulative emission amount of CH_4 (c) Emission rate of N_2O (d) Cumulative emission amount of N_2O

The emission rate and cumulative emission amount of CH_4 in all runs are shown in Figure 1(a) and (b), as well as N_2O in (c) and (d). CH_4 emitted intensively in the first two weeks of composting, and most of the N_2O emitted in the first five days, which was consistent with previous studies [8,9]. During this period, organic matter degraded rapidly leading to an anaerobic environment, so methanogens produced a large amount of CH_4 and nitrate nitrogen also generated N_2O through denitrification. When composting entered the cooling phase, CH_4 emission decreased as a result of process that the content of O_2 increased and the local anaerobic environment got improved. It indicates that when the total amount and type of reflux compost is constant, the emission intensity of CH_4 tends to drop firstly and then rise with the increase of covering ratio, which is consistent with the emission pattern of NH_3. While N_2O emission would decrease with the increase of the covering ratio. The reduction effect of mixing with mature compost on CH_4 emission is better than that of thermophilic compost, however, the effect is not significant. On the contrary, T4 has a better reduction effect on N_2O emission.

GHG emission equivalents are given in Table 1. Table 1 indicates that compost reflux has a significant effect on the reduction of GHG emission in the composting process, which ties well with previous study [10]. Compared with the pure mixing, mixing &covering is more conductive to the emission reduction because it increases the porosity of the heap and improves the hindering effect on gas escape.

Table 1. Total GHG emission

treatments	Greenhouse gas emissions equivalent (kg CO_2-eq t^{-1})		
	CH_4	**N_2O**	**Total GHG**
CK	0.02	3.46	3.48
T1	0.01	2.50	2.51
T2	0.01	2.46	2.47
T3	0.01	1.89	1.90
T4	0.01	1.45	1.46

Conclusions

Compost reflux can shorten the mesophilic stage, prolong the thermophilic stage and accelerate the fermentation process. Reflux ratio at 20% is conducive to the compost fermentation process and reduces the emission of NH_3, CH_4 and N_2O. From the point of foul odor gas emission reduction, mixing &covering is the greatest. Mixing with 15% thermophilic compost has the best reduction effect on N_2O, while mixing with 15% mature compost is more conducive to NH_3 and CH_4. As a compound agent, clinker can effectively reduce polluted gas emission, which is valuable for reducing gas pollution during urban perishable garbage composting.

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Examination of Feasibility and Effectiveness of Earthworm in Degradation of Kitchen Refuse

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Earthworms pledge to provide incredible solutions to several social, economic, and environmental problems plaguing the human society. Earthworms can safely manage all municipal and industrial organic wastes including sewage sludge and divert them from ending up in the landfills. Since past many years earthworms and species of it are used in degradation of different types of waste. The study examined the ability of the earthworm species *Eisenia foetida,* in the vermicomposting of Kitchen refuse. In these treatments, the vermicompost materials were analysed the micro and macronutrients to understand the impact on the bioconversion of waste into compost. Experiments were conducted for 60 days, after 15 days of pre-composting, Pre decomposition of 15 days and subsequent vermicomposting of 60 days indicates the role of this species in vermitechnology. The efficiency of kitchen waste degradation with earthworm was evaluated after mixing in different ratio with the help of saw dust and cow dung in compost trial pits in various proportions. The sampling was done once in 5 days. Analysis of physical and biochemical parameters was done during period of 60 days. After the completion of maturation period the compost and earthworms will be recovered from each trial pits. Samples were dried and sieved through 2.5mm sieve and then analysed for the final characteristics. The protein rich earthworm biomass is being used for various application like 'nutritive feed materials' for fishery, dairy & poultry industries. The study is aimed at scientifically monitoring vermicomposting process and to understand the optimum management requirements to improve the operation of an institutional scale worm farm. The investigation of earthworm species with waste helped to improve the knowledge base to influence and support urgently needed solutions aimed at improving waste management system.

Keywords: Kitchen Refuse, Potential Earthworm species, Vermicomposting, Waste degradation.

The Role of Different Types of Biochar in Food Waste Digestate Composting

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ABSTRACT. Anaerobic digestion (AD) is increasingly recognized as a green technology to tackle the persistent issue of food waste due to limited landfill space, climate mitigation policies, and growing environmental awareness. This has led to a surge in food waste digestate (FWD) production, estimated at 180 million tons annually, prompting the need for effective management to close the circular economy loop [1]. Despite challenges like high NH_4^+-N levels, moisture content, and low C/N ratio, FWD is acknowledged as a valuable resource for agriculture utilization after treated by composting process. The integration of biochar into FWD composting offers a sustainable solution. Biochar, a porous carbon-rich material, enhances nutrient retention, microbial activity, and mixture structure. Combining FWD composting with biochar addresses challenges and results in nutrient-dense soil amendments. This paper explores the synergistic benefits of biochar integration in FWD composting, enhancing the composting process and end-product quality. The study's key findings underscore the significant role of biochar in enhancing FWD composting processes. Biochar's remarkable adsorption capacity serves as a powerful tool in mitigating the inhibitory effects of elevated NH_4^+-N content, resulting in substantial reductions in NH_3 emissions. Furthermore, the integration of biochar into composting practices proves effective in preserving valuable nitrogen resources within the compost matrix. This presents the potential for a controlled, gradual release of nutrients, positioning the amended compost as a beneficial biofertilizer for agricultural applications. The research highlights that the efficacy of biochar varies based on factors such as pyrolytic temperature and feedstock origin. Importantly, the study confirms that the presence of biochar significantly impacts nitrogen transformation during FWD composting, with specific effects contingent on the type of biochar employed.

Keywords: Food waste digestate, Composting, Biochar, Compost quality, nitrogenous gas emission

Introduction

Anaerobic digestion (AD) is increasingly recognized as a green technology to address the persistent issue of food waste, driven by the constraints of limited landfill space, the implementation of climate mitigation policies, and growing environmental consciousness. As a consequence of the proliferation of anaerobic digestion plants, the production of food waste digestate (FWD) has surged globally, estimated at approximately 180 million tons annually. However, without effective management of this burgeoning FWD output, the circular economy loop remains open-ended. Notably, FWD is characterized by elevated NH_4^+-N levels (ranging from 10000 to 12000 mg/kg dm), high moisture content (75-80%), and a low C/N ratio (5-7). Despite these challenges, it is recognized as a valuable recycling resource [1][2]. A cutting-edge approach is imperative to realize the valorization of FWD, potentially replacing inorganic fertilizers on a global scale, thereby aligning with principles of green recovery and a circular economy. Among the array of prospective strategies, composting emerges as a viable means to actualize the principles of a circular economy, enabling the transformation of FWD into a valuable biofertilizer. Nevertheless, when subjected to conventional composting conditions, a noteworthy challenge arises due to the characteristic inherent in FWD, rustling in nitrogen loss via NH_3 and N_2O emission as well as long maturation periods. The cumulative impact of these factors ultimately yields compost of diminished agronomic value[3][4].

Food waste digestate composting, combined with biochar amendment, represents an innovative and sustainable approach to addressing food waste management challenges while enhancing soil health and agricultural productivity[5]. Biochar, a porous carbon-rich material produced through the pyrolysis of organic matter, has the potential to sequester carbon in the soil for prolonged periods, contributing to climate change mitigation. In terms of the agriculture utilization, the published papers have reviewed the advantages of biochar amendments on the land application. Biochar's high surface area and porosity enable it to retain nutrients, preventing their leaching into groundwater and enhancing their availability to plants over time. Biochar provides a habitat for beneficial microorganisms, fostering soil microbial activity and promoting nutrient cycling. The addition of biochar enhances soil aggregation, water infiltration, and aeration, thereby improving overall soil structure [6]. Nowadays, the researcher applied the biochar on the composting process[6]. The integration of biochar amendment into composting processes offers a host of synergistic advantages that enhance the overall quality and effectiveness of the resulting compost. Its exceptional surface area and porosity enhance microbial activity and nutrient retention, promoting nutrient cycling and reducing the risk of nutrient leaching. Furthermore, biochar's carbon sequestration potential contributes to long-term carbon storage in soils. By partnering biochar with composting, the compost's nutrient-rich matrix is fortified, leading to the creation of a high-value soil amendment that addresses the limitations posed by traditional composting methods [7].

Thus, it is speculated that biochar, with its porous and stable structure, acts as a dual-purpose amendment, facilitating improved and accelerated decomposition while mitigating the challenges associated with high NH_4^+-N content in food waste digestate. Combining food waste digestate composting with biochar amendment capitalizes on the nutrient-rich compost matrix and the sorptive properties of biochar, creating a balanced and nutrient-dense soil amendment, resulting in a compost product with improved nutrient content and longer-lasting benefits for crops.

This paper explores the synergistic advantages achieved through the incorporation of biochar amendment into the food waste digestate composting process. It delves into the benefits that biochar imparts to both the composting process itself and the resulting end products.

Material and Methods

The dewatered FWD generated through anaerobic digestion and mature compost were collected from organic Resources Recovery Centre Phase 1, while locally purchased sawdust served as the bulking agent. According to the characteristics of the FWD, it is recommended a mixture of FWD, sawdust, and mature compost in a 1:3:1.3 (dry weight ratio) combination to achieve optimal composting conditions, including a moisture content of roughly 55% and a C/N ratio of 30 [2], [3], [7], [8].

For the experimentation, three types of biochar—tobacco biochar, bamboo biochar, and coconut biochar—generated at pyrolytic temperatures of 450 °C, 600 °C, and 900 °C respectively, were employed. The present study comprised four treatment groups, comparing the effects of adding the three types of biochar to a control group. The first treatment, denoted as R1, was the control without any biochar amendment, consisting of FWD, sawdust, and mature compost. The subsequent treatments, named R2, R3, and R4, incorporated 10% of tobacco, bamboo, and coconut biochar by weight into the composting mixture, respectively [7].

Composting procedures were meticulously managed through an interconnected computer-controlled system linked to 20-L bench-scale composters. Each composter was enveloped by a heating coil and insulation layers to curtail heat dissipation, with thermocouples strategically positioned at the core of the composter and along its external wall, shielded by insulation. The integrated composting system was orchestrated through a feedback-based computerized control mechanism, in conjunction with continuous temperature measurements facilitated by thermocouple. When the temperature variance between the inner (within the reactor) and outer (reference) sensors was less than 3°C, the heating mechanism was activated to uphold the desired conditions. The aeration system, meticulously assembled, was also managed by the programmed control system, ensuring a consistent air supply at a rate of 0.25 $L/kg\ min^{-1}$. During the thermophilic phase, the risk of excessive heating was averted by engaging the supplementary aeration pump when temperatures exceeded 65 °C. Additionally, arrangements were implemented for the capture of gaseous emissions at the composter's outlet. Over a span of 42 days, the composting investigation transpired, during which intervals of approximately 300 g of uniform samples were collected on days 0, 3, 7, 10, 14, 21, 28, and 42. These samples facilitated the assessment of alterations in composting parameters throughout the study [2], [7].

Moisture content, pH, electrical conductivity (EC), extractable ammonium (NH_4^+-N), nitrate (NO_3^--N), nitrite (NO_2^--N), seed germination index (SGI), total nitrogen (TN), and total carbon (TC) underwent analysis, adhering to the methodologies outlined in [2], [7].

The assessment of gaseous emissions, including ammonia (NH_3), and nitrous oxide (N_2O), was performed on a daily basis throughout the composting process using gas analyzers. The gas sampling protocol was conducted in accordance with the procedure detailed by [4], [9]. In brief, the emitted gas was captured at the composters' outlet within gas bags, subsequently subject to detection through gas analyzers using the syringe sampling technique.

Results and Discussion

The thermophilic phase lasted 13 days for the control, tobacco biochar, and bamboo biochar treatments, while the coconut biochar treatment experienced an extended thermophilic phase (17 days), possibly due to the larger surface area of coconut biochar enhancing microbial activity. All treatments met the hygienic requirements of the Environment Protection Agency (USEPA) guidelines. Biochar amendment expedited the thermophilic phase by improving oxygen diffusion, promoting faster microbial proliferation than the control.

pH stability during cooling phases was observed in all treatments due to humic substance production, maintaining a range of 7.0 to 7.6 in accordance with the HKORC standard[10]. Coconut biochar exhibited lower values, likely due to nutrient absorption.

At composting's end, TC decreased to ~26% in control, with a significant decrease in R3 (coconut biochar) to ~20%. Nitrogen content reduction correlated with substrate degradation, microbial growth, and metabolism, resulting in 1.2% to 1.8% decreases. Bamboo, tobacco, and coconut biochar treatments achieved the 700 mg/kg dm standard within 21 days, compared to 28 days in the control [10]. Biochar-amended composts could act as slow-releasing nitrogen sources for enhanced plant growth. Nitrogen loss via gaseous emissions was mitigated by tobacco, bamboo, and coconut biochar, reducing it to 9.23%, 6.85%, and 5.18% respectively, compared to 13.31% in the control. Coconut biochar reduced NH_3 emissions by 62%. Taking into account the reduction in nitrogen loss by 61%, NH_3 loss by 55%, and N_2O emission by 24%, it can be concluded that coconut biochar demonstrated its efficacy as a potent agent for nitrogen conservation during FWD composting.

Seed germination index (SGI) testing assessed compost maturity. While no significant difference in final SGI existed among treatments, the time to reach the standard varied, indicating the effectiveness of biochar. Bamboo biochar achieved 50% SGI in 21 days, while tobacco and coconut biochar treatments took 28 days and 42 days for the control treatment. Effective conversion of phytotoxic FWD into mature compost was achieved with 10% biochar amendments.

From the results obtained, it is well noted that optimizing the production of biochar from diverse feedstocks and under varying pyrolysis conditions is crucial to ensuring consistent quality and benefits. Further research is needed to understand the complex interactions between biochar, compost, and soil microbiota to maximize the positive effects of the combined amendment. Long-term field trials are necessary to assess the effectiveness and sustainability of food waste digestate composts amended with biochar across different soil types and crop systems. Nevertheless, evaluating the economic feasibility of large-scale biochar production and integration into composting processes is essential for widespread adoption.

Table 1. Compost Maturation and Process Parameters in Food Waste Digestate Composting with Biochar Amendment

Parameters	Treatments			
	R1 (Control)	R2 (Tobacco BC)	R3 (Bamboo BC)	R4 (Coconut BC)
The periods of thermophilic phase, days	13	13	13	17
pH	7.1±0.01	8±0.4	7.5±0.24	7.5±0
EC, mS/cm	7.1±0.56	11.15±0.13	8.33±0.08	6.48±0.25
TC, %	24.4±0.95	23.1±0.02	22.3±0.14	19.4±0.42
TN, %	1.95±0.01	1.92±0.02	1.89±0.03	1.87±0.02
NH_4^+-N, mg/kg dm	626.59±66.73	45.88±6.83	393.95±7.76	461.99±13.97
nitrogen loss, %	13.31	9.23	6.85	5.18
nitrogen loss as ammonia, %	8.43	2.61	4.36	2.99
nitrogen loss as nitrous oxide, %	3.51	4.55	2.4	1.83
SGI, %	61.03±3.26	45.89±6.8	94.87±5.08	74.36±7.98

Conclusions

In conclusion, the integration of biochar amendment into food waste digestate composting holds the potential to accelerate the process and mitigate nitrogen loss. It is evident that coconut biochar stands out as a reliable agent for both nitrogen preservation and decomposition during FWD composting, resulting in the production of higher-quality compost. Further investigations should delve into the intricate interplay between biochar and microbes, as well as assess the agricultural value and economic viability of its widespread application.

Acknowledgment

I would like to take this opportunity to express my immense gratitude to all those persons who have given their invaluable support and assistance. In particular, I am profoundly indebted to my supervisor, PROF. WONG, Jonathan Woon Chung, who was very generous with his time and knowledge and assisted me in each step to complete the experiment.

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Different Composting Technologies and Raw Materials Induced Microbial Dynamics and Core Microbiomes

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Composting technologies is the best way to recycle the organic wastes and make them into organic fertilizers or composts, to increase the rate of recycling. However, which process or raw material was the best choice unclear. For evaluating which was the preferable method for recycling, the research was choosing three main composting process, pile, bed and reactor, and three livestock manures, swine, cow and chicken manure through analysing by physicochemical indices and bacterial 16S rRNA gene amplicons. Compared to pile and bed, reactor process was better to reduce moisture content, especially swine manure, this process could reduce moisture content 9.15% per day. For reactor process, the moisture content of swine, chicken and cow manure reduced to 25.97%, 21.13% and 23.09%, respectively. For ammonia emission, bed process was the best, there was 18.61 g/m3, 17.38 g/m3 and 34.90 g/m3 in swine, cow and chicken manure, respectively. On the contrary, the average of ammonia emission content was above 200 g/m3. The germination index of three processes were above 70%, and followed the Chinese standard, it means that all these three processes were good for recycling livestock manure. This study also revealed that microbial dynamics among different processes and raw materials had significance difference, the variance was 7.38% and 8.15%. The relative abundance of phylumn during these treatments were different, for all composting processes, the main phylumn was Firmicutes. Nevertheless, there were difference among three composting processes, for reactor, the second was Actinobacteria, while for pile and bed, when the raw materials were chicken or swine manure, the second was similar like reactor progress. While when the raw materials were cow manure, the second was Bacteroidetes in bed progress and was Deinococcus-Thermus in pile process. Core microbiomes with these processes and raw materials were distinct. Bacillus and Actinobacteria were higher in reactor progress, Thermomicrobia and Thermotogae were important in pile progress, while Deinococci, Sphingobacteriia and Methanomicrobia were predominant in bed process. In conclusion, this study provides basic assessments of these processes and raw materials in compost.

Keywords: Composting process, Raw materials, Physicochemical indices, Microbial dynamics, Core microbiomes.

Mature Compost Promotes Biodegradable Plastic Degradation and Reduces Greenhouse Gas emissions during Kitchen Waste Composting

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ABSTRACT. This study investigated the impact of mature compost on biodegradable plastics (BP) degradation and greenhouse gas emission during composting by adding mature compost (MC) and no addition (CK). In MC, the time of plastic obvious cracking advanced for 4 days and the degree of plastic cracking deeper at the end of composting, these results may be related to the extension of high temperature period of compost. Thermobifida and Ureibacillus were more abundant in MC, which played an important role in organic matter degradation to generated more heat. Mature compost decreased the total GHG emissions (kg CO2-eq t-1 DM) by 23.5% mainly due to inhibiting the activity of bacteria related to the production of CH4 and N2O (Caldibacillus, Aeribacillus and unclassified_f_Bacillaceae). Overall, mixing mature compost is expected to serve as an effective measure for promoting BP degradation and reduces GHG emissions during kitchen waste composting.

Keywords: biodegradable plastic; kitchen waste composting; mature compost; greenhouse gases; microbial community

Introduction

The heavy usage and difficult degradation of conventional plastic materials cause the "white pollution" in globe. This problem can be solved effectively by using biodegradable plastics (BP), a polymer that degrade in nature by the action of microorganisms without harming the environment. Studies have shown that it is difficult for BP to achieve complete degradation in the short term in soils, the biodegradation rate of PBAT was only 7% in 100-days soil incubation [1]. Composting can create more appropriate environment for BP degradation compared with natural soil to increase the degradation efficiency [2]. It is reported that mature compost contains abundant microorganisms which could shortened the composting period and reduced the greenhouse gas (GHG) emissions [3]. However, the BP degradation and GHG emissions during composting with mature compost addition is not clear. The goals of this study were to: 1) assess the enhancement of bioplastic degradation in composting by mature compost addition; 2) investigate the influences of mature compost on GHG emissions during BP composting process; 3) determine the role of mature compost to drive bacterial community succession, identify the dominant bacteria and discuss their relationship with environmental parameters.

Material and Methods

Composting materials

In this study, Cornstalks and sawdust were used as bulking agents during co-composting of kitchen waste and polybutylene adipate terephthalate (PBAT). Kitchen waste was from a school canteen (Beijing, China), PBAT film bags were bought online and cut into same size(8cm×8cm). Mature compost produced from the composting of kitchen waste and cornstalk for 7th days. All these materials were mechanically shredded to a length below 2 cm.

Composting methods and experimental design

Kitchen waste, cornstalks and sawdust were mixed at a 5:1:1(wet weight basis) ratio before added 5% PBAT (wet weight basis). Several cylindrical composting reactors with 8L working volume were used in this study. Each reactor bottom was connected to an automatically controlled aeration system to provide continuous aeration with an intensity of 0.2 L·min-1·kg-1DM. “CK” is the control treatment without mature compost, mature compost was added to the composting materials on wet weight basis at 20% corresponding to “MC”. The composting experiment was conducted continuously for 21 days. Manual turning and collecting samples on days 3, 6, 10, 14 and 21. Each sampling event used the 5-point sampling method.

Analytic methods

Scanning electron microscopy (SEM, Hitachi S4800, Japan) was used to characterize the morphologies and physical dimensions of PBAT. Methane (CH4) and nitrous oxide (N2O) were collected daily from the lid outlet based on the syringe sampling method and then determined by a gas chromatograph (GC) (Beifen, China). Genomic DNA materials were extracted from compost samples for microbial community analysis [4]. Raw sequencing data were processed by Quantitative Insights into Microbial Ecology (QIIME 1.9.1). All raw sequencing data were submitted to the Sequence Read Archive of the National Center for Biotechnology Information (NCBI) with the accession number PRJNA876397.

Results and Discussion

Temperature and visual inspection of plastic degradation during the composting process. The composting temperature of CK and MC reached peak of 72.02 °C and 74.17 °C on the 7th day, and then gradually decreased to the ambient level (Fig.1a). From the perspective of composting heat accumulation, the duration of composting temperature exceeding 60 °C in CK and MC was 6 days and 11 days, respectively (Fig.1a). The significant difference in composting temperature of two treatments indicating that mature compost promoted the organic matter degradation and generated more heat. Macroscopic changes for the PBAT samples were shown in Fig.1b, obvious cracking of samples was noticed on day 10 in MC treatment, while cracking occurred on the 14th day in CK. SEM clearly showed more details on PBAT decomposition (Fig. 1c). The untreated sample revealed a smooth and regular surface. After 21 days of composting, the samples formed numerous cracks and cabinet slots and the cracks of MC treatment were deeper. These results might be attributed to thermophilic temperatures and high microbial activity caused by mature compost addition. On the one hand, the degradation extent of BP produced thermally is affected by the temperature value and the time of exposure, sustained thermal aging at high temperature promotes abiotic degradation of BP [5]. On the other hand, the biological degradation of thermophilic microorganisms promoted the break in the polymer chains to form monomers and oligomers [6].

Greenhouse gases emissions

The CH4 and N2O emissions of two treatments exhibited similar trends during composting (Fig. 2a). High levels of CH4 emissions occurred in all treatments within the first 8 days. It is because the rapid oxygen consumption with organic matter degradation, forms anaerobic conditions for methanogenic activities. Adding mature compost reduced CH4 emission (16.20%) by alleviating anaerobic conditions. The peak values of N2O emissions in the CK and MC were observed on day 2 (14.38 g·kg-1DM·d-1) and day 3 (10.4g·kg-1DM·d-1), respectively. The N2O emission in the initial phase could be ascribed to denitrification under nitrate accumulation and oxygen scarcity. The N2O emission reduced by 23.47% in MC treatment, since mature compost created better air permeability of composting pile and restrained denitrification. In addition, compost promoted plastic degradation to produce more microplastics, which reduced nitrite production by reducing ammonia oxidation, and then reducing N2O emissions [7]. GHG emissions of the all treatments were expressed as CO2-C equivalents (Fig. 2b) [8]. In sum, the total GHG emissions reduced by 23.50% in MC as the reduction of CH4 and N2O emissions, of which N2O emissions contributed more than 90% to GHG emissions reduction.

Successional changes in the bacterial community during composting

The microbial community succession from the beginning to mature phase of composting were deciphered at the phylum level (Fig. 3a). The addition of mature compost advanced the time of Firmicutes becoming the dominant phyla from day 3 (CK, 22.82 %) to day 0 (MC, 70.68 %), resulting in massive organic biodegradation and corresponds to the composting temperature increasing. The linear discriminant analysis for effect size (LEfSe) algorithm was used between CK and MC groups on genus level (Fig. 3b). the significant difference appeared earlier in MC than in CK, which was consistent with the results of phylum level change. In CK, Caldibacillus, Aeribacillus and unclassified_f_Bacillaceae were indicator species, which significantly positively correlated with CH4 and N2O emission to lead CK treatment show higher total GHG emissions. After adding mature compost, Thermobifida, Ureibacillus and Bacillus were found an enrichment in MC treatment. Thermobifida and Ureibacillus are the main thermophilic bacteria that degrade organic matter [9], which might be the reason for prolonging the high temperature period of composting and accelerating the decomposition of PBAT. Additionally, Bacillus as ammonifying bacteria to decrease nitrogen loss and were positively correlated with temperature in correlation analyses (Fig. 3c).

Conclusions

During co-composting of PBAT and kitchen waste process, the addition of mature compost results more serious disintegration on PBAT from microscopic level to macroscopic level. The total GHG emissions in MC decreased by 23.5% due to the reduction of CH4 and N2O emissions. The addition of mature compost promoted PBAT degradation and reduced GHG emissions by increasing the abundance of organic matter-degrading microorganisms (Thermobifida, Ureibacillus) and reducing the abundance of GHG-producing microorganisms (Caldibacillus, Aeribacillus and unclassified_f_Bacillaceae), respectively.

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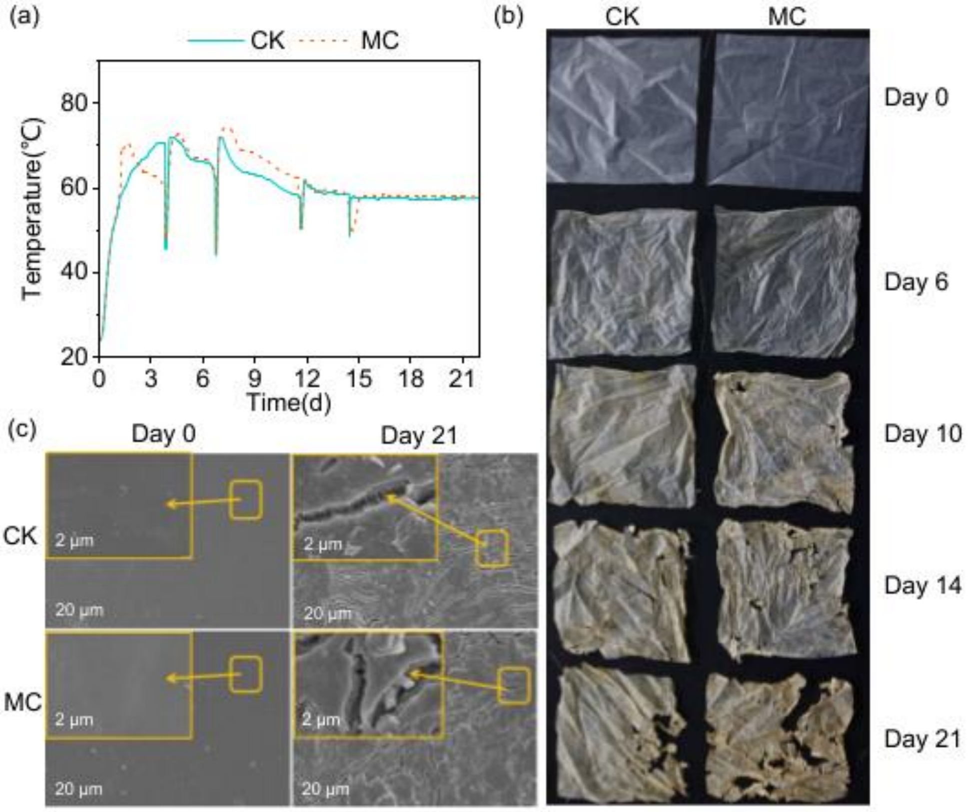

Fig 1. Temperature (a), representative pictures (b) and SEM images (c) of PBAT samples during composting.

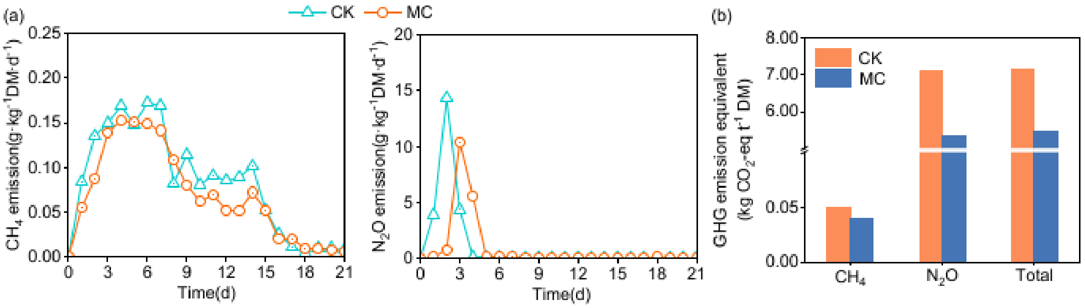

Fig 2. Variations in the daily CH4 and N2O emissions (a) and GHG emission equivalent (b).

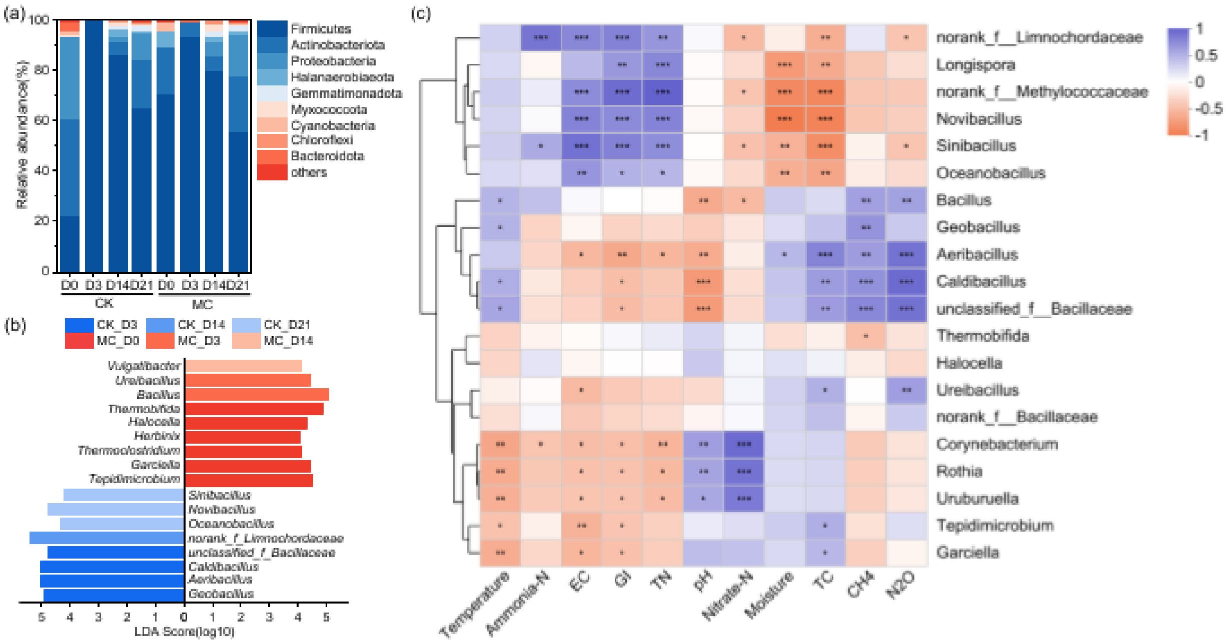

Fig 3. Relative abundances of the bacterial community at phylum (relative abundance>1%) (a), LEfSe at genus level (LDA value>4.0) between two treatments (b) and heatmap analysis of Spearman correlation between the genera-level of bacterial community (top 20) and physicochemical parameters (c).

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Effect of Mature Compost as Additive During Municipal Solid Waste Composting

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ABSTRACT. Tirunelveli City corporation is operating micro-composting facilities in which dry leaves collected from the streets become the major bulking agent. However, the quantity of dry leaves is not adequate resulting in inadequate thermophilic temperature or very short thermophilic periods which eventually affect the compost product. Therefore, this study aimed at investigating the effectiveness of mature compost (MC) from the micro-composting facilities as additional bulking agent along with dry leaves. Mature compost (MC) is an inexpensive bulking agent that aids in the composting process. By combining mature compost with raw materials, it can improve inter-particle voids in a composing pile and increase air permeability. It could be used as a different source of microbial inoculants. Mature compost was collected from a micro-composting facility operated by the Corporation. MSW was mixed with mature compost (MC) along with dry leaves (DL) or sawdust (SD) as follows: Treatment 1 - MSW+SD+20%MC, Treatment 2 -MSW+DL+20%MC, Treatment 3 -MSW+DL+30%MC (w/w, dry weight basis). The mixtures were composted for 42 days in 25-L homemade composters. The results revealed that in all treatments, the thermophilic phase was maintained for three weeks. At the end of the composting process, the pH of treatments was slightly alkaline and ranged from 7.62 to 8.07 while the EC was less than 3 mS/cm in all treatments. Total organic carbon contents ranged 35.6-38.0% while the TKN content ranged 1.77-1.89%. The treatment with 30% MC+DL had the highest TKN concentration. The C/N ratio was 21.51, 20.06 and 18.95 in treatments 1,2 and 3 respectively. Treatment 3 showed the highest seed germination index (122.58%), followed by Treatment 2 (117.60%) and Treatment 1 had the lowest SGI (105.42%). Mature compost addition, particularly 30% mature compost addition treatment MSW+DL+30% had a long thermophilic period, a high nutrient content, a high degradation rate, and high seed germination index compare to other treatments. Therefore, MSW+DL with 30% mature compost addition is an optimal mixing ratio for improving the MSW composting process and increasing the quality of the finished compost.

Keywords: MSW, Dry leaves, Mature compost.

1.Introduction

Municipal solid waste is one of the most serious issues in developing countries. As reported by World Bank, 2.01 billion tonnes of MSW were generated in 2016, and up to 3.40 billion tonnes will be generated in 2050 (Kaza et al., 2018). In India, 1, 52,076 tonnes per day MSW generated (Central pollution control board annual report 2018-2019). In Tamil Nadu, 13,968 tonnes per day of MSW were generated (Central pollution control board annual report 2018 - 2019). Generated waste is most of part disposed of mainly land filled, dumped, incineration and composting (Ghosh et al., 2015). The causes of greenhouse gas emissions, such as CH_4, CO_2, N_2O, and odour compounds, cause human health problems and groundwater pollution from leachate (Castaldi et al., 2008).

Mature compost (MC) is an inexpensive bulking agent that aids in the composting process. By combining mature compost with raw materials, it can improve inter-particle voids in a composing pile and increase air permeability. It could be used as a different source of microbial inoculants (Iqbal et al., 2010, Liu et al., 2020). Total greenhouse gas emissions (including CH_4 and N_2O) during kitchen waste composting were reduced by 69.2% when mature compost was added (Yang et al., 2019). Previous research has also discovered that adding mature compost speeds up the composting process (Kato & Miura, 2008). Various types of mature compost were used, including food waste compost, green waste compost, cattle manure compost, sewage sludge compost, and kitchen waste compost, each with a different organic substrate (Wang et al., 2022, Yang et al., 2022, Kato and Muira (2008), Ma et al., 2019 Luo et al., 2014, Yang et al., 2019). Sewage slude compost was combined with MSW composting to reduce N_2O emissions (Bian et al., 2017). However, the impact of MSW compost on municipal solid waste has not been determined. There is especially little research on how MSW mature compost inoculation speeds up and improves the composting process. The aim of the study was 1) to investigate the influence of mature compost on the MSW composting process. 2) To determine the optimal mature compost addition percentage for MSW composting.

2.Materials and method

2.1. Sample collection

Artificial solid waste as MSW was prepared for this experiment such as food waste, vegetable waste and flower waste in the ratio of 26:7:2 (wet weight basis) which were homogenized by cutting the material into approximately 1– 2 cm lengths. Food waste was collected from nearby hotels in Tirunelveli district, Tamil Nadu. Sawdust was purchased from the nearby sawmill. Dry leaves were used for this experiment were collected from the university campus. The dried leaves were crushed and used as bulking agents in the experiment. Mature compost was collected from nearby micro composting centre. Municipal solid waste was mixed with bulking agent's ratio (3:2) dry weight basis to adjust the C/N ratio and moisture. The municipal solid waste was thoroughly mixed before being used for the experiment. Selected physicochemical properties of municipal solid waste and bulking agents are presented in Table 1.

Table 1. Initial Physicochemical parameter of substrate and bulking agents

Parameters	Substrate	Bulking agents		
	MSW	Sawdust	Dry leaves	MSW mature compost
pH	4.29 ± 0.07	6.1 ± 0.17	6.18 ± 0.08	7.09 ± 0.05
EC (mS/cm)	3.38 ± 0.05	1.59 ±0.08	2.25 ± 0.03	3.386 ± 0.08
Moisture (%)	64.74 ±1.86	8.73 ± 2.70	9.17 ± 1.97	23.41 ± 1.95
Total organic carbon (%)	46.02 ± 0.78	49.04 ± 0.98	48.62 ± 0.81	35.01 ± 1.40
Total Kjeldahl nitrogen (%)	2.4 ± 2.06	0.45 ± 0.11	0.63 ± 0.3	1.69 ± 1.88

Note: Values are mean ± standard deviation (n = 3).

2.2. Experiment and analyses

The experiments were carried out in a 25 - L homemade composter. The temperature was monitored every day by a digital sensor thermometer inserted into the middle of the composting materials. Samples were collected after totally mixing the materials during the turning day on 0, 3, 7, 14, 21 28, 35 and 42 for the analysis of physic-chemical properties. A 1:5 aqueous extract (w/v) of the fresh sample with deionized water was used for the analysis pH, electrical conductivity (EC), extractable ammonium (NH_4^+ -N). Total organic carbon (TOC) was measured by $K_2Cr_2O_7$ and H_2SO_4 using a modified Walkey - Black method. The seed germination test is one common method used to evaluate compost maturity and was tested using the method of Zucconi et al., 1981.

3. Results and Disucssion

Temperature changes were similar across the three treatments, with temperatures rising to a peak before gradually falling to the ambient temperature shown in fig.1. The temperatures of three treatments exceeded 50 °C on day 3, indicating that the composts had entered the thermophilic period (Cao et al., 2019). MSW+SD+ 20% MC, MSW+DL+20% MC and MSW+DL+30% MC treatments reached maximum peak temperature on day 3 (51.6 °C), day 12 (63.4 °C), day 10 (67.60 °C) respectively. In comparison to the other treatments, MSW+DL+ 30% MC had a higher average composting temperature. The thermophilic phase was maintained for three weeks in all treatments. The statistical analysis results show that there were not significant differences between the three treatments in temperature (P = 0.33).

Changes in pH and EC

During the first week of composting initial pH range was 4.79 to 5.19 in all treatments. The pH of all treatments slowly rose in all treatments until end of the composting, which was due to the ammonification and degradation of organic acids (Wang et al., 2021b). On day 21, the pH of MSW+ DL+20% MC and MSW+ DL+30% MC peaked between 8.51 and 8.62 shown in fig 1. The high pH may cause NH_3 volatilization, resulting in increased nitrogen loss (Guo et al., 2012). After 21 days, the pH gradually decreased. SD+20% MC (7.62), DL+20% MC (7.89), and DL+30% MC (8.07) treatments had alkaline pH at the end of the composting process. The statistical analysis results show that there were not significant differences between the three treatments in temperature (P = 0.68). During the composting changes of EC in all treatments shows in (Fig. 1). The initial stage of composting EC value was observed in DL+30 % MC had a high EC value (3.28 mS cm $^{-1}$), DL+20% MC (2.84 mS cm $^{-1}$) and SD + 20% MC (2.37 mS cm $^{-1}$) had a low value respectively. After four weeks the EC was increased in all treatments. The EC was detected during the final stage of composting MSW+SD+20% MC (1.45 mS cm^{-1}), MSW+DL+20% MC (2.56 mS cm^{-1}), MSW+DL+30% MC (2.08 mS cm^{-1}), respectively shown in fig.4. The other treatments had lower EC values than DL+30% MC because they did not enhance the compost's physical structure as much as DL+30% MC did. The statistical analysis results show that there were not significant differences between the three treatments in temperature (P=0.0002). As a result, they had weaker capacities to adsorb mineral ions. The final EC of the three treatments (1.45, 2.56 and 2.08 mS/cm) was less than the advised threshold value (3 mS/cm), demonstrating the lack of phytotoxicity in the final products (Wang et al., 2021a).

3.4. Changes in extractable ammonium

The initial stage of composting extractable ammonium content in all treatments MSW+SD +20% MC (648 mg/kg), MSW +DL+20% MC (688 mg/kg) and MSW+DL+30% MC had (713 mg/kg) shown in fig.2. The NH_4^+-N content increased during the first week, then decreased for all treatments until the composting process was completed. Ammonification with the biodegradation of nitrogenous organic compounds and low nitrification at the thermophilic phase (>50 °C) were the main contributors to the increased NH_4^+-N content (Li et al., 2012) . In the final stage of composting, DL+30% MC had the highest extractable ammonium value (524 mg/kg), followed by DL+20% MC (513 mg/kg), and SD+20% MC had the lowest value (450 mg/kg).

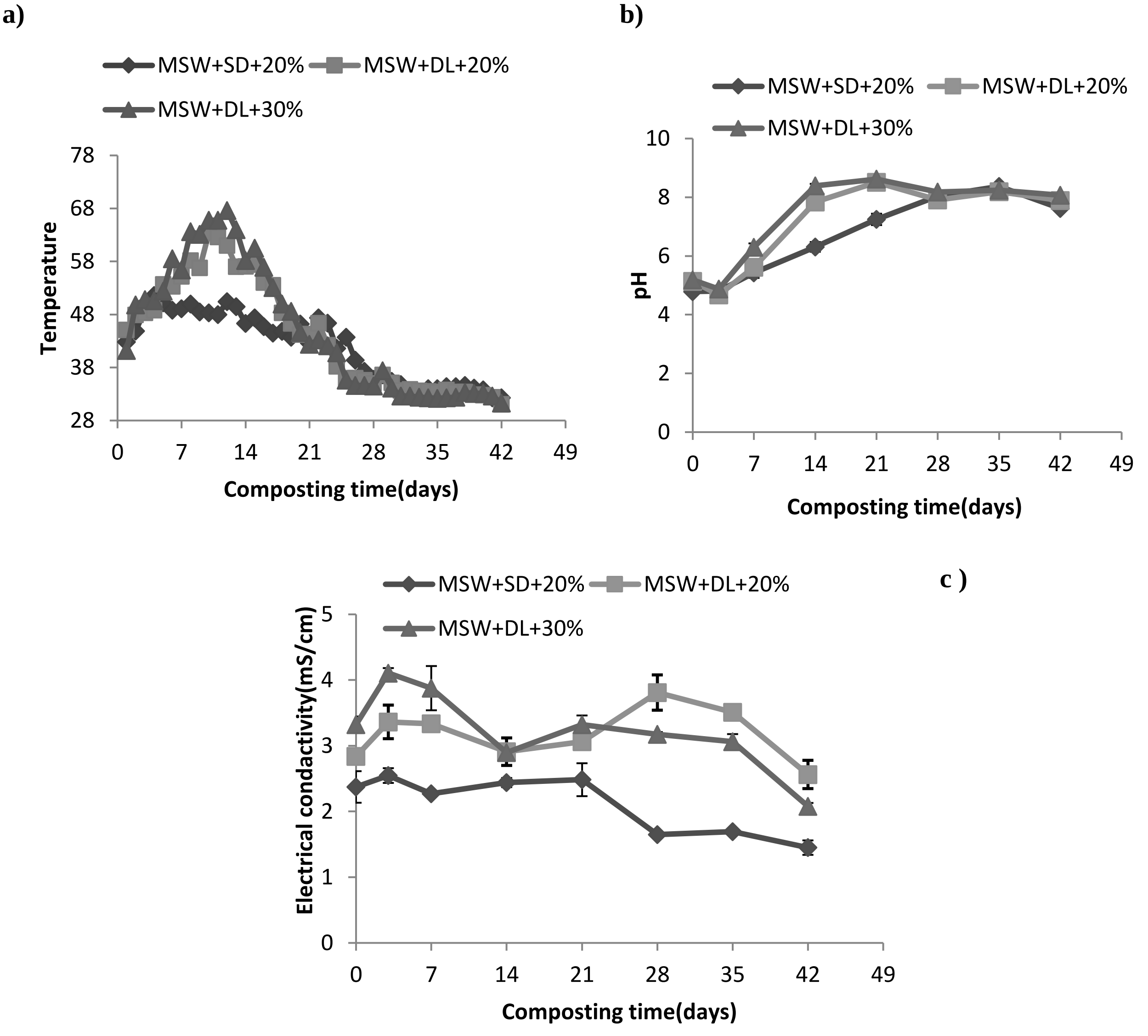
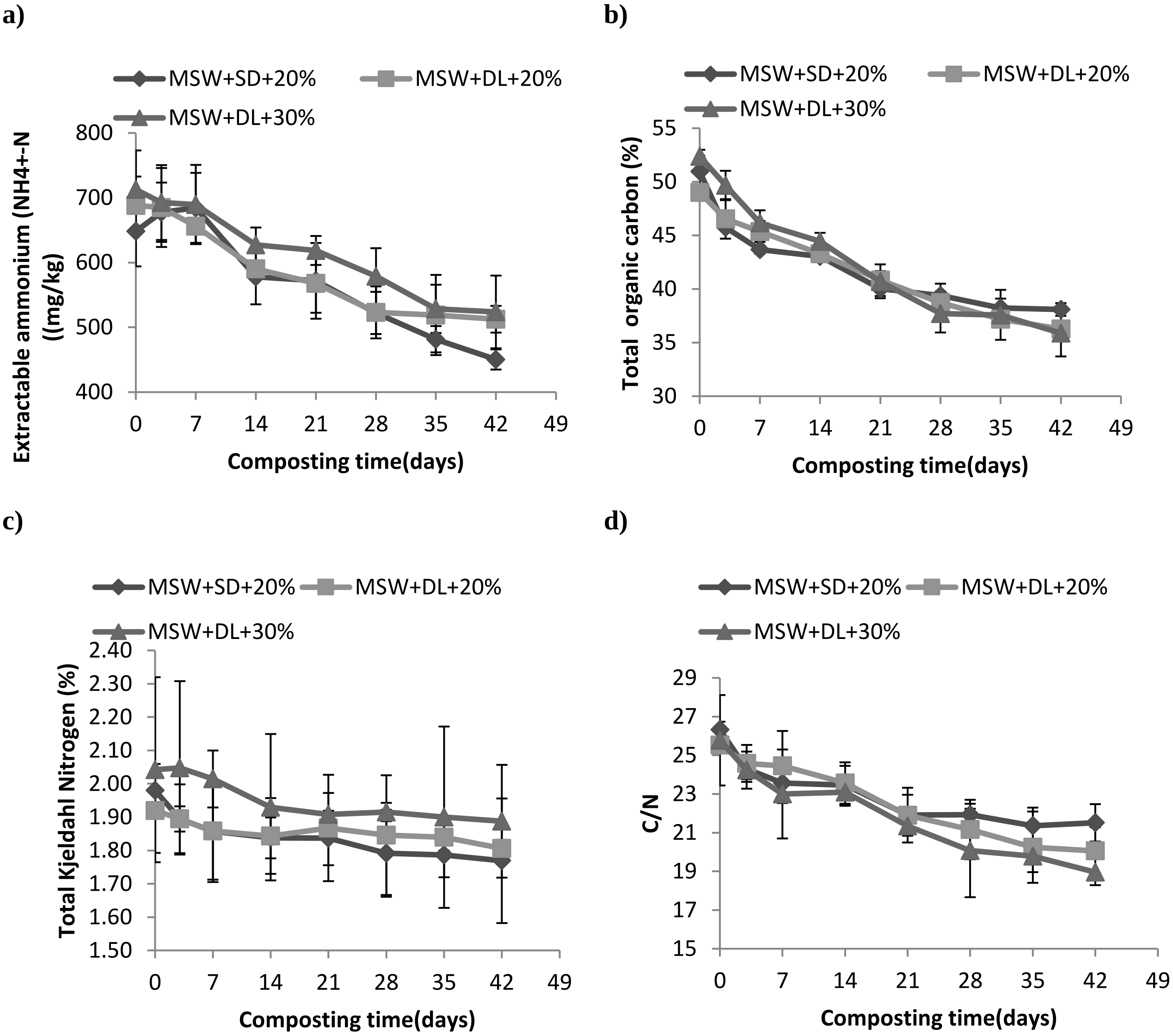


Figure 1. Changes of a) temperature b) pH c) electrical conductivity during the composting. Data represent the mean of three replicates and the error bars are standard deviation.

Changes in total organic carbon, TKN and C/N ratio

The MSW+SD+20% MC, MSW+DL+20% MC, and MSW+DL+30% MC treatment had initial TOC contents that ranged from 50.96%, 49.1%, and 53.39%, respectively. With composting time, the TOC contents of the mass in different treatments gradually decreased shown in fig.2. At the conclusion of the composting process, the highest value for each treatment was MSW + SD+30% (38.0%), followed by MSW + DL+20% (36.27%), and the lowest value was MSW + DL+30% (35.88 %).



a) **b)** **c)** **d)**

Figure 2. Changes of a) temperature b) pH c) electrical during the composting. Data represent the mean of three replicates and the error bars are standard deviation.

The TKN content of the MSW composting materials in the three treatments ranged from (2.04 to 1.98%), with SD+20% MC having the lowest content and DL+30% MC having the highest. As a result, the TKN content gradually declined until the composting process was completed because of the high temperature and pH, which promotes NH_3 volatilization, NH_3 emission occurred primarily during the thermophilic phase (Wang et al., 2016). The loss of N during composting is a major cause of a compost product's low N content (Karak et al., 2013). At the end of the composting process The highest TKN content was found in DL+ 30% MC (1.89%), followed by DL+20% MC (1.81%), and the lowest TKN content was found in SD + 20% MC (1.77%) shown in fig.5. In all treatments, the initial C/N ratio was fixed at 26 which gradually decreased until the end of composting reached 21.51, 20.06, and 18.96. The C/N ratio fell during the three experiments composting process because organic matter mineralized. In comparison to MSW+SD+20% MC, the reduction was greater in MSW+DL+30% MC and MSW+DL+20% MC. In the composting process's final stage, the C/N ratio was SD + 20% (21.51), DL+20% (20.06) and DL+30% (18.95), respectively shown (fig.2).

Changes in seed germination index

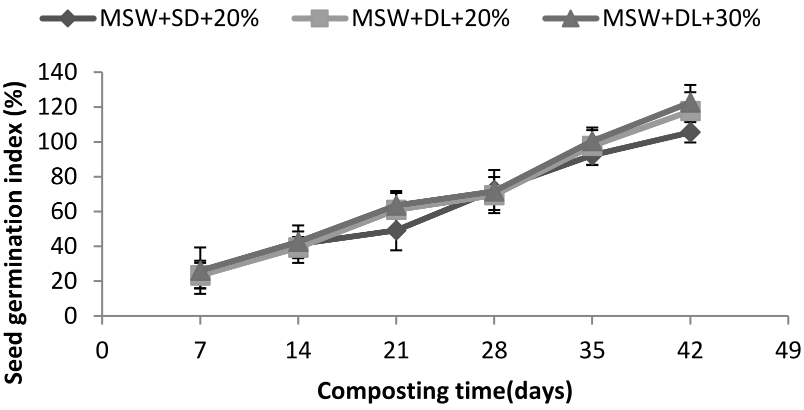


Figure 3. Change of SGI during the composting. Data represent the mean of three replicates and the error bars are standard deviation.

The germination indices were initially very low. Due to active decomposition, which produced high concentrations of NH_4^+ and volatile fatty acids, both of which are toxic and reduce seed germination (Wang et al., 2013). From day 7 until the conclusion of the composting process for all treatments shown in fig 3.The germination Index values increased gradually. The MSW+DL+30% MC and MSW+DL+20% MC treatments had the highest SGI (122.58% and 117.60 %) at the end of composting, while MSW+SD+20% MC had the lowest (105.42 %). The final SGI results showed that all treatment composts were well matured within 42 days, were free of phytotoxins, and would not have a toxic effect on plant growth.

4. Conclusion

This study found that adding mature MSW compost accelerated MSW composting and improved its quality. MC addition, particularly 30% mature compost addition treatment MSW+DL+30% MC had a long thermophilic period, a high nutrient content, a high degradation rate, and high seed germination index compare to other treatments. According to physicochemical parameters and maturity index, MSW+DL with 30% mature compost addition were the optimal percentage for improving the composting process and increasing the quality of the finished compost. This finding also implies that using mature compost can speed up the composting process. Mature compost can be used instead of inoculums in MSW composting.

Table 2. Physico-chemical parameters of MSW final compost

Parameters	Treatments		
	MSW+SD+20% MC	MSW+DL+20%	MSW+ DL+30%
pH	7.62 ± 0.08	7.89 ± 0.03	8.07 ± 0.03
Electrical conductivity (mS cm^{-1})	1.45 ± 0.11	2.56 ± 0.22	2.08 ± 0.05
Extractable ammonium (mg/kg)	450 ± 15.54	513 ± 20.62	524 ± 56.10
Total organic carbon (%)	38.09 ± 0.60	36.27 ± 0.39	35.88 ± 2.17
Total Kjeldahl nitrogen (%)	1.77 ± 0.19	1.81 ± 0.03	1.89 ± 0.17
C:N ratio	21.51 ± 1.14	20.06 ± 0.56	18.95 ± 0.57
Seed germination index (%)	105.42 ± 5.82	117.10 ± 10.85	122.58 ± 10.12

Note: Values are mean ± standard deviation (n = 3).Statistically, there are not significantly different between the three treatments ($p < 0.05$).

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Controllability Improvement of Food Waste Composting Quality: A Comparative Study of Control Strategies

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Composting of food waste to produce organic fertilizer is considered an effective strategy for clean organic waste treatment and its conversion into high value-added products in developing countries. In this study, the effect of regulating key parameters (temperature, agitation frequency and aeration frequency) in the composting process using different intelligent regulation strategies on enhancing the controllable level of fertilizer output quality was investigated through a comparative validation experiment. To improve the reproducibility of the experiment, a 7-day rapid composting control strategy meritocratic experiment was conducted using food waste standard samples (high oil and high salt samples (HOAS)). The results showed that there were differences in seed germination index, maximum fermentation pile temperature, and the number of days with fermentation pile temperature ≥ 50°C for the fertilizers produced using different intelligent control strategies for composting process. This study helps to improve the controllability of the quality of kitchen waste composting, thus improving the standardization of composting products, as well as to select an intelligent control strategy for composting process with low energy consumption and excellent reaction rate. It provides a reference for further development of clean treatment technology and waste resource utilization.

Keywords: Food waste, Composting, Composting control strategy, Seed germination index

Study of the Three Common Vermicomposting Species on Cyclical Utilization of Swine Manure in Organic Farmland

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The pig industry is the largest livestock industry in Taiwan, however, it derived much pig manure to be treated. Many studies indicate that the livestock's manure can be effectively treated and turned it into a high added-value compost in an environmentally friendly pathway particularly by vermicomposting, and earthworm can also be used as a raw material feeding other animals. Although the vermicomposting species are commonly known as #2 Tai-pin (red earthworm), they are actually three common species as Eisenia andrei and Perionyx excavates and Eudrilus eugeniae. The present study aims to explore the utilization and substitution of feed material by vermicomposting to achieve a cyclical resource use in Taiwan. The three main vermicomposting species in Taiwan were reared them respectively in spent mushroom substrate (SMS) which was commonly used and field soil from an eco-farm nearby in which the latter for evaluating the possibility of alien species invasion. A total of nine earthworm farms were investigated in this trial and confirmed the main three vermicomposting worms, however only one farm with all three species. Furthermore, we found the body sizes($P<0.001$) and cocoon number of three species ($P<0.01$) were significantly different. No significant differences were found with the survival rate between those cultured in field soil and spent mushroom substrate. Eisenia andrei with a lower survival rate reared in SMS than that of field soil, confirmed that the common vermicomposting species may have the opportunity to survive in the wild. The vermicomposting earthworms used as a feed raw material by proximate analysis of the three earthworms species. The results showed after vermicomposting with pig manure, the nutrition composition of three earthworm species all with high nutrient, hence they all have opportunities as feed material. Particularly Perionyx excavates is the best among the three species with a crude protein 69% and crude lipid 16%. However, the body size of Perionyx excavates being too small to be a good candidate ready for fresh fed living organisms. We recommend the other two species also with high nutrient can be used together with Perionyx excavates on replacing fish meal. Overall, the three vermicomposting species in the present study have good opportunities treating pig manure in Taiwan, they all possess high nutrient and good potential to replace feed material after vermicomposting pig manure. Therefore, the cyclical use of the waste into resource by vermicomposting has feasibility for further development.

Keywords: Vermicomposting, Eisenia andrei, Perionyx excavates, Eudrilus eugeniae, feed substitution.

Preliminary Risk Assessment of Decentralized Composting Systems for Source Separated Biodegradable Wet Waste from Households

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Decentralized composting is recommended as a potential treatment method for source separated biodegradable organic waste from households to reduce waste transport and processing costs at the centralized location. Composting is an aerobic microbial activity which results in air-borne emissions to the surrounding environment. Hence, it is prudent to assess human health risks associated with the activity in decentralized mode. Further, suitable measures should be taken to avoid any such risks. Hence, the present study is an attempt to identify and compare the risks involved with the operation of decentralized composting systems in India and the UK. To achieve the objectives, three types of decentralized composting systems, i.e., rotary drum (RD), plastic drum (PD) and basket (BT) with capacity ~160 L, 140 L and 4.5 L, respectively, were operated for the treatment of household wet biodegradable waste (HWBW) at Mumbai, India for 50 days. The HWBW added to the three systems was 100 kg, 25 kg and 2-2.5 kg, respectively. The RD and PD systems were operated in continuous mode with daily addition of 2.5 kg/day for 10 days while the waste was added only once to the BT system. Several important attributes such as air emissions, leachate generation, exposure to operators and nearby residents were considered qualitatively to evaluate the severity of risk. Subsequently, risk ranking was assigned to each attribute based on the local conditions. The seasonal variations and meteorological conditions have significant impact on the nature of risk. Gaseous emissions such as odour, methane and ammonia are expected from the systems though these may pose low risk to the surrounding residents. However, the risk to systems operators may be higher. In monsoon season, the emissions may be considered much higher compared to those in summer and winter seasons in India. Due to the low moisture content in the HWBW and setting up the composting facility away from receptors, the risks involved were considered relatively lower in the UK as compared to the Indian conditions. One of the recommendations may be the selection of proper location for the decentralized systems. A secluded confined location with proper ventilation may be found for such systems. Further, proper guidelines to place and operate the decentralized systems in developing nations should be formulated. The findings from the presented initial study can be useful for the policy makers to formulate a guidance document on immediate need basis. Whereas the interested researchers can perform rigorous risk assessment study to obtain more detailed and quantitative information.

Keywords: Decentralized composting, Household biodegradable waste, Risk identification and assessment.

Patterns of Heavy Metal Resistant Bacterial Community Succession Influenced by Biochar Amendment During Poultry Manure Composting

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The purpose of this study was to investigate the heavy metal resistant bacteria (HMRB) community succession and bacterial activity in poultry manure composting. Five different concentration of chicken manure biochar (CMB) at 0 %, 2 %, 4 %, 6 %, and 10 % on a dry weight basis was applied with initial feed stock (poultry manure + wheat straw) and indicated with T1, T2, T3, T4 and T5. In addition, high-throughput sequencing, principal coordinate analysis, and correlation analysis were used to analyze the evolution of HMRB communities during composting. The study indicated that crucial phyla were *Proteobacteria, Actinobacteria, Bacteroidetes* and *Firmicutes*. The bacterial diversity in the CMB amendment treatment was higher than in the control treatment, and T4 treatment was the highest in all CMB treatments. Moreover, results from CCA indicated that T4 and T5 treatments quickly enters the high temperature period, which is maintained for 5 days, and is significantly positively correlated with *Proteobacteria*, and *Actinobacteria*. These findings offer insight into potential strategies to understand the succession of HMRBs during poultry manure reuse. Overall, above results show the addition of 6% biochar (T4) was potentially beneficial to enrich the abundance of bacterial community to improve composting environment quality and composting efficiency. In addition, effective to immobilize the heavy metals and HMRB in end product.

Keywords: Heavy metal resistant bacteria, Chicken manure biochar, Poultry manure, Community succession.

Effects of Fungal Pathogen and Assistant Materials on Composting Process of Infected Vegetable Wastes

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ABSTRACT. Improper handling of diseased plants may result in the risk of plant disease spreading. Composting can effectively inactivate pathogens, whose product could be applied in soil to suppress soil-borne diseases. We hypothesis that the composting product with inactivated pathogen could suppress the pathogens by microorganism competition. In this study, cucumber wastes contaminated by *F. oxysporum* were composted as the main material, during which sawdust, bagasse and Chinese medicinal residue were used as auxiliary materials, to investigate whether the pathogens in cucumber wastes may inhibit the composting, and the effects of auxiliary materials on pathogen removal and products suppressive effect. The results showed that pathogens in material did not significantly affect the composting process, through which sawdust had the best effect on the removal of pathogens, with a removal rate of 80.3%. The product of diseased plants had a suppressive effect on *F. oxysporum*, which was more stable when composted 18 days. The suppressiveness was related with the increased diversity of bacteria and fungi, such as *Bacillus*, *Aspergillus* and *Penicillium*. In conclusion, pathogens in diseased plants did not have a large effect on the composting process, but it can affect the microbial community and also has a suppression effect.

Keywords: pathogens, aerobic composting, microbial community, disease suppression

Introduction

Vegetable waste has a large proportion of diseased plants, and there are risks of pathogen transmission and environmental pollution. The composting process can efficiently reduce the number of pathogens in it, and has also demonstrated a potential inhibitory effect on soil-borne pathogens[1].Microorganisms play a key role in the whole composting process, while microorganisms in compost are able to suppress soil-borne diseases through competition and antibiotics[2], and it has also been demonstrated that sterilized pathogens can suppress plant diseases[3].In this study, we intend to clarify the effects of pathogens and different auxiliary materials on the composting process and microbial community, and also to investigate the changes in the number of pathogens and the inhibition effect during the composting process.

Material and Methods

Composting procedure and sampling

The concentration of pathogens in cucumber seedlings was 10^4 CFUs/g. Four treatments were set up in the experiment, in which CK mixed cucumber seedlings without pathogens with sawdust as the control, and J1, J2 and J3 mixed diseased cucumber seedlings with sawdust, sugarcane bagasse and Chinese medicine residue. Composting was carried out in a closed composting reaction device with a composting fermentation cycle of 23 days. After the start of composting, turning operations were carried out on days 0, 3, 5, 8, 13, 18 and 23, while samples were collected.

Experimental method

The seed germination test reflected the method described in the Chinese Organic fertilizer (NY/T 525–2012)； The suppressive effect of the compost against the pathogens was examined with the growth rate method[4]. The number of pathogens was determined by Quantitative Real-time PCR, 16sRNA/ITS high-throughput sequencing technology was used to determine microbial communities. *Microsoft Excel 2019 、SPSS 24.0 and Majorbio Cloud Platform were used for statistical analysis .*

Table 1 Physical and chemical properties of tested materials.

	TC(%)	TN(%)	C/N	pH	EC	Moisture（%)
cucumber seedlings	28.29	2.69	10.74	7.85	1.81	53.8
sawdust	42.84	0.26	167.01	6.92	0.44	11.20
bagasse	46.72	0.59	79.59	5.62	0.18	56.30
Chinese medicinal residue	49.14	3.10	15.85	5.69	0.81	21.21

Results and Discussion

Composting process

With the increase of composting time, the temperature of the pile in all treatments showed a trend of first increasing and then decreasing, and finally tending to stabilize (Fig. 1a). The maximum temperature of the pile in the JI treatment was higher and the rate of temperature increase was lower than that in the CK treatment. The pathogens may have inhibited the degradation of organic matter. In comparison with the three different auxiliary materials treatments, the high temperature duration was longer in the J3 treatment and shorter in the J2 treatment. Temperature will affect the microbial community, and then affect the pathogen suppression rate[5] and the extermination of pathogens. The GI of each treatment showed an overall increasing trend, and all treatments reached the basic decay standard (Fig. 1b). Except CK, GI of all treatments was the highest on the 18th day. while the GI of J2 treatment was the lowest, probably due to the short duration of its high temperature during composting, which had a certain toxic effect on the germination of seeds.

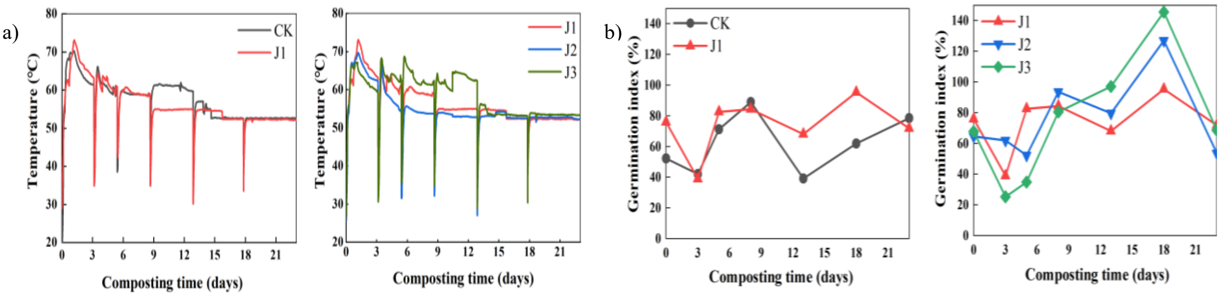

Fig.1. Temperature（a） and GI（b） changes during the composting process

Number of pathogens and suppression rate

The initial values of the number of colony-forming units (CFU) of pathogens were more consistent among the treatments, and the number of CFU decreased slightly in both the J1 and J3 treatments in the first 3 days, probably because of the inhibitory effect of the persistently higher temperature at the beginning of composting, while the number of CFU increased significantly in all treatments from day 3 to day 18. which is consistent with the trend of rising and then decreasing in the results of Chorolque et al[6]. At the end of composting, J1 treatment and J3 treatment showed some removal effect on pathogens during composting, with the removal rate of 80.3% and 35.6% compared to the initial value.

The suppression effect of each treatment was calculated separately for different composting periods, and it was obtained that the compost had a general suppression effect on *F.oxysporum*,and the highest suppression rate was up to 65%, which appeared on the fifth day of J3 treatment, probably because the Chinese medicine residue in J3 had a better suppression effect, and the three treatments of CK, J1 and J2 showed an overall decreasing trend of suppression rate in the first period, probably because the compost entered the high temperature period and the microbial species were reduced, which led to a decrease in the inhibition effect, and the suppression rate increased again in the late composting period, and the suppression rate of each treatment on the 18th day was higher than that on the 23rd day, which was consistent with the results of GI.

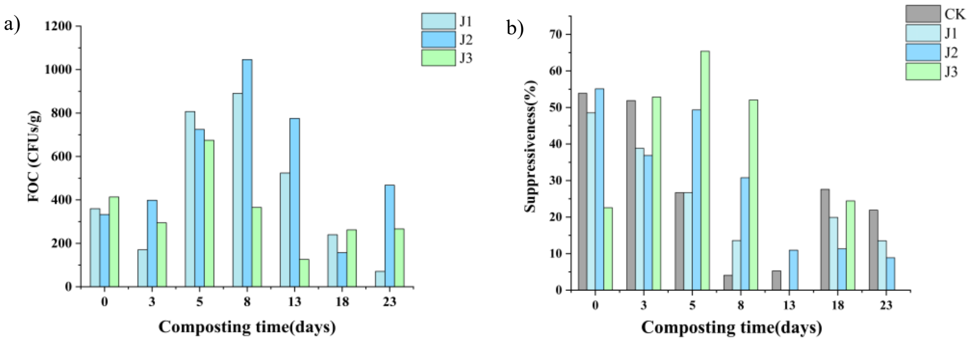

Fig.2 Changes in the number of pathogens(a) and composts suppression rate (%) against FOC during composting(b).

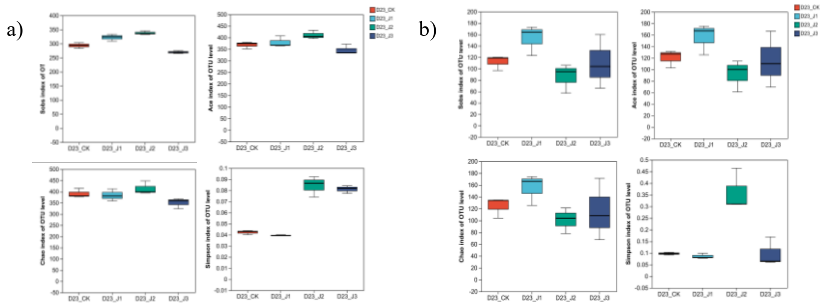

Fig.3. α-diversity of the bacteria (a) and fungi (b) in the samples at the end of composting.

The bacterial diversity index (a) and fungal diversity index (b) of each treatment are shown in Fig.3. Compared with CK, J1 treatment increased the sobs and ace indices of bacterial populations and increased the sobs, ace and chao indices of fungal populations, pathogens was able to increase the species diversity of bacteria and fungi.Auxiliary materials also affected species diversity, where J2 treatment increased bacterial species diversity and decreased fungal species diversity.

Microbial community composition

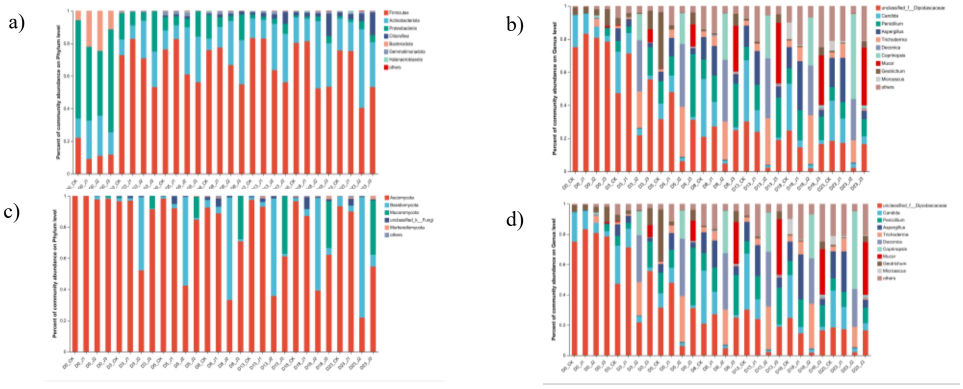

Fig.4. Relative abundance of bacterial and fungal community at the phylum (a、c) and genus (b、d) levels.

At the phylum level, the bacterial community contained seven main phyla; among them, the phylum Actinobacteriota, the phylum Bacteroidota and the phylum Proteobacteria, all of which have been well documented to be associated with the suppression of soil-borne pathogens[7];The fungal community mainly contained five phyla. Except for the J2 treatment, Ascomycota dominated the whole composting process, and after the start of composting, the abundance of Ascomycota decreased rapidly in J2 treatment, Basidiomycota became the dominant population, Mucoromycota appeared in J3 treatment, and the abundance of Mucoromycota gradually increased with the composting process. At the genus level, the microbial community mainly includes 13 genera of bacterial community and 10 genera of fungal community.The higher abundance of *Bacillus* may be the reason for some suppressive effect of J1. The abundance of *Aspergillus* in J1 and the abundance of *Penicillium* in J3 were higher than those in CK, which could contribute to the inhibition of pathogens[8].

Differences in microbial populations

Principal component analysis (PCA) and LDA Effect Size (Lefse) analyses were performed according to the OTUs of bacteria in compost samples. In the PCA analysis, the differences between microbial populations in the pre- and post-composting stages of each treatment were large. J3 showed greater microbial differences, which may be influenced by the specific components in the Chinese medicine residue and the degree of fermentation. In the Lefse analysis, J1 had more characteristic genera and contains a variety of Bacillus.It further indicated that pathogens could affect the microbial community in compost, which might lead to the difference of suppression effect.

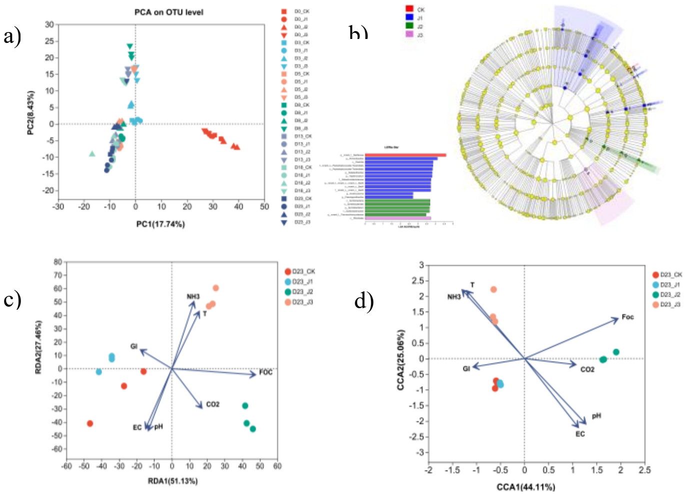

Fig.4. Principal component analysis (PCA) of amplified 16 S rRNA gene fragments from bacterial community (a)； Effect of pathogens and auxiliary materials on the microbial community in compost(b); Redundancy analysis (RDA) of bacteria (a) and fungi (b) community at the end of composting.

Redundancy Analysis

The relationship between chemical properties of compost and bacterial and fungal communities in different composting stages was further analyzed by redundancy analysis (RDA).The bacterial communities of J2 and J3 treatments were significantly correlated with temperature and the number of FOC, and the bacterial communities of CK and J1 treatments were significantly correlated with EC and GI; the fungal communities of J3 treatments were significantly correlated with the number of CO_2 and FOC, It shows that the type of auxiliary materials can have a greater impact on the microbial community, and the pathogens has a greater impact on the bacterial community.

Conclusions

Vegetable wastes containing pathogens did not have a negative effect on composting process, while the auxiliary material significantly influenced the process. The composting product of diseased plants had the suppression effect on plant pathogens. Therefore, composting of diseased plants can achieve safe product and soil-borne pathogen suppressive amendment.

Acknowledgement

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Bacterial Dynamics and Functions Driven by Fermentation Material Backflow to Reduce Environmental Burden During Food Waste Composting

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ABSTRACT. This study investigated the addition of composting materials from thermophilic, cooling and mature stage to mitigate gaseous emissions, such as ammonia, methane, and nitrous oxide, during kitchen waste composting. Results show that, gaseous emissions during kitchen waste composting were considerably reduced with the addition of composting materials. Mixing thermophilic compost with raw composting materials reduced N_2O emissions by 20.7%. The addition of mature compost significant decreased NH_3 and CH_4 emissions by 21.54% and 24.03%, respectively. These results provide guidance for optimizing the composting process when different compost phase materials as bulking agent.

Keywords*: *Composting, Kitchen waste, Fermentation material backflow, Gaseous emission

Introduction

Aerobic composting has been considered as an effective and environmentally friendly processing technology to recycle kitchen waste (KW) by convert it into organic fertilizer through biodegradation. However, kitchen waste composting is impeded by several technical challenges, such as gaseous emission, like ammonia (NH_3), hydrogen sulfide (H_2S), methane (CH_4), and nitrous oxygen (N_2O), which not only pose severe atmosphere contamination, but also give rise to nitrogen loss and reduce the availability of produced biofertilizer (Onwosi *et al.*, 2017). Mature compost has been proposed to control gaseous emissions during composting, since it is an easily obtained material with porous, microbial, and cost-efficient features. Previous study reported that significant discrepancy in physicochemical properties and microbial community structure between different composting stages, which closely related to gaseous emission (Maeda *et al.*, 2010). Therefore, the objective of this study is to evaluate the influence of compost materials from different phase on the emission reduction of greenhouse gas and odor gas.

Materials and methods

Composting materials

Kitchen waste and compost materials from different stages were obtained from a local solid waste collection station and lab-scale composting process. Sawdust obtained from a crop planting experimental station (Beijing, China) was air-dried and then passed through a cutting mill to ensure its length < 5 mm.

Composting system and Experimental design

A bench-scale composting system with four experimental reactors were used in this study for composting. All components and their functions of the system were detailed elsewhere (Chang *et al.*, 2019). The automatic aeration device was used to provide a continuous aeration of 0.2 L kg $^{-1}$ dry mass min $^{-1}$ from the composter bottom.

Four treatments were conducted in parallel to investigate the effects of compost materials from different stages on bacterial dynamics for gaseous emissions in kitchen waste composting. In addition to the control treatment without compost material assistance, other three treatments were blended with compost materials from thermophilic, cooling and mature stage and thus defined as TS, CS, and MS, respectively. All treatments were composted for 4 weeks, where manual turning and then sampling was performed at day 0, 3, 7, 14, 21, and 28.

Analytical methods

The GI was measured following the method described by (Guo *et al.*, 2012). Released gases from the composter outlet were captured daily for measurement of NH_3, N_2O and CH_4. NH_3 was determined by boric acid (2%) adsorption and then titrating against 0.01 M sulfuric acid for quantification. N_2O and CH_4 were collected using the syringe sampling method and then determined by a gas chromatograph (Trace 1300, Thermo Scientific, USA). All data were calculated by Excel 2013 (Microsoft, USA) and were expressed as the means and standard deviations. Tukey's t test was used to assess the possibility of significant difference and any difference ($P<0.05$).

Results and discussion

Physiochemical and phytotoxic characteristics

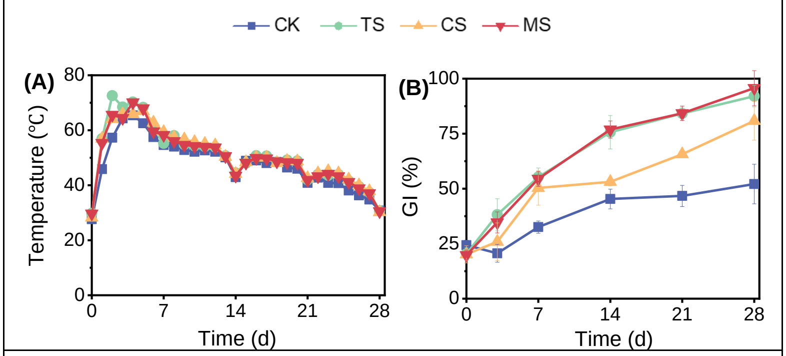

Fig. 1: Temperature (A) and GI (B) in composting of kitchen waste with different fermentation material backflow.

All treatments displayed a similar and typical composting process as indicated by composting temperature, including mesophilic, thermophilic, cooling, and mature phase (Fig. 1A). Since KW contained considerable readily biodegradable organic matter, the temperature in all treatments sharply increased to enter into the thermophilic stage within the first 2 days. Addition of compost materials facilitated temperature increase to shorten the mesophilic stage given the improved physicochemical properties and microbial composition of composting feedstocks. In particular, the TS treatment exhibited the most rapid temperature increase to achieve the highest peaks (> 70 °C) around day 2, possibly due to its more presence of functional microorganisms and easily biodegradable substances introduced from compost materials of thermophilic stage to promote organic metabolisms and thus thermal release.

Similar GI values profiles was observed for the four treatments (Fig. 1B). All treatments increased continuously to above 70% but in CK, possibly due to phytotoxic substances, such as long-chain organic acids, alkaloids and phenols could be biodegraded and/or released, which promoted by the addition of compost materials (Gou *et al*., 2017). Mixing compost materials, above all incorporating matured compost, did have a significant impact on GI of the final compost ($P<0.05$).

Gaseous emissions

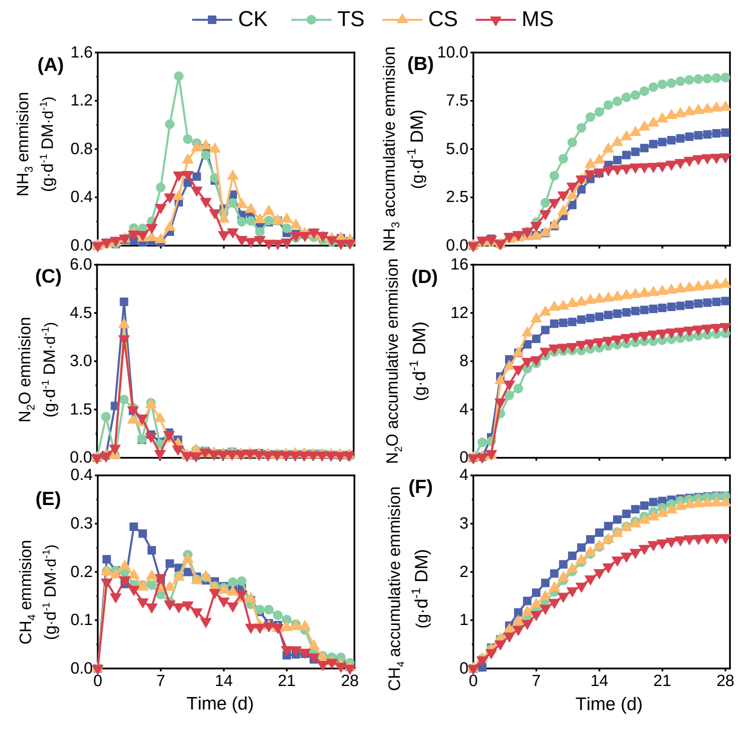

Fig. 2: NH_3 daily (A) and accumulative (B) emissions, N_2O daily (C) and accumulative (D) emissions, CH_4 daily (E) and accumulative (F) emissions in composting of kitchen waste with different fermentation material backflow.

The NH_3 emission increased significantly in the thermophilic phase (7-14 d) then decreased gradually (Fig. 2A). Compared to the CK group, mixing mature compost could significantly reduce NH_3 emission over 28 days of composting (Fig. 2B). The addition of thermophilic period compost materials accelerated it conversely. NH_3 emission was undetectable at the beginning of composting for four groups, possibly due to weak acid condition and lower temperature against the released of ammonia. It is noteworthy that NH_3 emission was notable in TS, which had the highest content of NH_4^+-N within the 7 to 10 days, could due to the conversion of NH_4^+ into NH_3 during the thermophilic phase (Luo *et al*., 2014). Xiong et al also reported that the application of mature compost could reduce NH_3 emission by bring down the pH value.

The N_2O emission mainly occurred in the initial stage of composting (0-7 d) and peaked at 3 days, then decreased to an undetectable level for all treatment by degrees (Fig. 2C). Backflow of cooling stage composting enhanced N_2O accumulative emission ultimately. Thermophilic phase materials made a considerable effect on reduce N_2O emission (Fig. 2D). This result could be attributed to favourable conditions (e.g., the low temperature) for activity and growth of denitrifying bacteria during the storage of composting materials (Wu *et al.*, 2020). Compared to the control treatment, a higher N_2O emission was observed for the CS group, possibly due to the addition of cooling stage compost material enhanced NH_4^+-N content and contained high abundance of denitrifying bacteria and thus facilitate denitrification for N_2O emission. Since the activity and growth of nitrifying and denitrifying bacteria could be inhibited at the thermophilic stage, N_2O emission was comparatively low in TS treatment.

Four treatments had intensive CH_4 emission within the first two weeks (Fig. 2E) and the accumulative emission was reduced by mixing compost materials, particularly in MS group (Fig. 2F). Since the storage of KW could contribute to acid and anerobic condition, possibly facilitated the high abundance of methanogens, which efficiently promoted the release of CH_4 at the beginning of composting. With the biodegradation of organic matters, all treatments experienced a gradual decline in CH_4 emission. Mature compost had a low moisture content. When the mature compost was incorporated into composting pile, the construction had loosened and was conducive to oxygen diffuses across in composting pile. Similar results have also been reported by (Luo *et al.*, 2014) high abundance of methane-oxidizing bacteria in mature compost could remarkable reduced CH_4 emission during KW compost.

Conclusions

Results reported here show that mix different compost phase materials could effectively optimize the physicochemical characteristics, and alleviate greenhouse gas and odour gaseous emission during kitchen waste composting. Adding compost materials facilitated temperature increase to shorten the mesophilic stage. Mixing thermophilic compost and mature compost materials with raw composting materials reduced N_2O, NH_3 and CH_4 emissions by 20.7% 21.54% and 24.03%, respectively.

Acknowledgement

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Effects of Biochar, Superphosphate and Magnesium Sulfate as Additives on Gaseous Emissions during Chicken Manure Composting

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Abstract: This study investigated the effects of biochar (BC), superphosphate (SP) and magnesium sulfate (MS) on odor emission and bacterial community succession during chicken manure composting. The main sulfur odor was hydrogen sulfide (H2S), methyl sulfide (Me2S) and dimethyl disulfide (Me2SS). SP or BC addition just reduced sulfur odor by 51.3% or 62.3%, respectively. The combination of SP and MS reduced 60.0% sulfur odor and 47.9% NH3 emissions. The Ca2+ was the main reason for fixing sulfur, and the existence of phosphoric acid and Mg2+ plays a role in reducing NH3 emission. And the comprehensive amendment of SP, MS and BC reduced the sulfur odor and NH3 emissions by 72.5% and 38.8%, respectively. SP and MS decreased NH3 emission by reducing the ammonifying bacteria Bacillus, or increasing the N-fixing bacteria Thermoactinomyces. Biochar reduced the generation of sulfur odor by reducing the Caldicoprobacter, Hydrogenispora and Desulfitibacter and increasing the Planifilum.

Keywords: Composting; sulfur odors; superphosphate; magnesium sulfate; biochar.

Introduction

the “odor nuisane” is widespread and has become the main reasons restricting the composting technology application. Studies have shown that ammonia (NH_3) and volatile sulfur compounds (VSCs) contribute the most to odor during aerobic composting [1]. In situ control is an effective method to reduce the release of odorous gases during composting. Acidic substances can effectively reduce nitrogen loss caused by organic nitrogen mineralization during composting. biochar can reduce 20% - 40% of NH_3 and 30% of VSCs emission due to its large porosity and specific surface area [2]. Phosphogypsum and superphosphate can also reduce NH_3 emissions by 16.5–38.1% due to their lower pH and the introduction of Mg^{2+} into the pile [3]. The combined application of related physical and chemical additives may be an effective way to reduce various odors emission. However, few studies were able to achieve and strengthen the effect of synergistic emission reductions. Therefore, this study explored the effects of biochar (BC), superphosphate (SP) and magnesium sulfate (MS) addition alone or in combination on the NH_3 and VSCs emission during chicken manure composting.

Material and Methods

Experiment design and sample collection

The application rates of superphosphate and magnesium sulfate were selected based on the previous results. The experimental design is shown in Table S1.

Table S1 Design of experiment.

No.	Abbreviation	Additives (%)		
		Biochar (BC)	Superphosphate (SP)	Magnesium Sulfate (MS)
1	CK	—	—	—
2	BC	10 [a]	—	—
3	SP	—	15 [b]	—
4	SP+MS	—	15 [b]	15 [b]
5	BC+SP+MS	10 [a]	15 [b]	15 [b]

[a]-Dry weight basis.
[b]-Based on the mole ratio of initial total nitrogen

Analytical methods and calculations

The NH_3 was trapped in boric acid in a wash bottle and titrated against 0.1 N H_2SO_4. A Tedlar bag was connected to the exhaust port, flushed three times, and then filled with gas for 10 min, then the sample bag was connected to a gas chromatograph (GC-A90, Echrom, China) to determine the sulfur-containing odorous compounds. The gas chromatograph had been calibrated and met the analysis requirements for sulfur compounds. Bacterial community was determined based on the method previously reported.

Statistical analysis

Redundancy analysis, which combines the regression analysis and principal component analysis, was performed using Canoco 5 to qualify the effects of substrate physiochemical characteristics on gaseous emissions during composting. Furthermore, correlation heatmap based on the Pearson correlation coefficients was pictured using Origin 2020 to identify the relationship between substrate physiochemical characteristics and gaseous emission. The SAS 8.2 for Windows (SAS Institute, Cary, NC, USA) was used for statistical analyses.

Results and Discussion

temperature and maturity index

The temperature of SP, SP+MS and BC+SP+MS treated with superphosphate was significantly lower than that of CK (p=0.034, p=0.048, p=0.001). The lower pH values and higher $H_2PO_4^-$ and PO_4^{3-} contents of superphosphate inhibited microbial activity. And the low pH value further affect organic matter degradation due to the increased content of VFAs and NH_4^+. The pH values of superphosphate amendment treatment (SP, SP+MS and BC+SP+MS) were significantly lower than CK and BC (p<0.001), but there was no significant difference between CK and BC (p=0.076). The final EC value (5.51–7.62 mS·cm^{-1}) was higher than the 4 mS·cm^{-1}. And the EC values of SP, SP+MS and BC+SP+MS treatments were significantly higher than those of CK and BC treatments (p<0.001) due to increase the content of ions (mainly Ca^{2+}, Mg^{2+} and SO_4^{2-}). All the final GI values reached to 99 - 122.8%, while CK and BC treatments were significantly higher than those of SP, SP+MS and BC+SP+MS treatments with superphosphate added (p<0.040).

Nitrogen transformation and nitrogen losses

The BC treatment increased the cumulative NH_3 emissions by 16.2%. The SP treatment promoted the nitrification and denitrification, while NH_3 emissions were not significantly affected. Furthermore, the combination of superphosphate and magnesium salts promoted the formation of struvite crystals ($Mg(NH_4)PO_4 \cdot 6H_2O$), making free NH_4^+ difficult to volatilize in the form of NH_3. Therefore, the NH_4^+-N content of SP+MS treatment was significantly higher than that of other treatments (p<0.015). Compared with CK, the cumulative NH_3-N emissions of SP+MS and BC+SP+MS treatments were reduced by 47.9% and 38.8%, respectively.

Sulfur odor emission

A total of 8 volatile sulfides compounds (VSCs) were detected. Among them, H_2S, Me_2S and Me_2SS) were the main sulfur odor. All additive treatments reduced H_2S emissions by 22.0–35.3%, and the BC+SP+MS and SP+MS treatments had better performance. Since H_2S was an important precursor of Me_2S and Me_2SS, all additive amendment treatments significantly reduced Me_2S and Me_2SS emissions. In terms of reducing of the total sulfur odor, BC+SP+MS (72.0%) > BC (65.3%) > SP+MS (60.0%) > SP (51.3%), the combination of physical and chemical additives had the best performance.

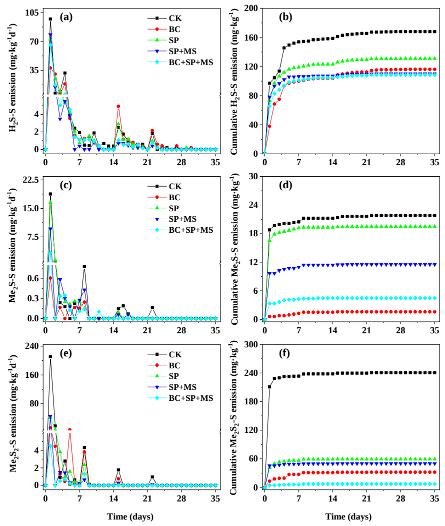

Fig.1 Evolution of H_2S (a), Me_2S (c) and Me_2SS (e), and cumulative H_2S (b), Me_2S (d) and Me_2SS (f) emission during chicken manure composting.

Relationship between physiochemical characteristics and gaseous emissions

Redundancy analysis (RDA) and Pearson correlation heatmaps were used to evaluate the influence of physicochemical properties on malodorous gas emissions during composting. Temperature, NH_4^+ and NO_3^- were significantly positively correlated with NH_3, H_2S, Me_2S and Me_2SS, while O_2 content and GI value were significantly negatively correlated with them. Moisture content was also an important factor.

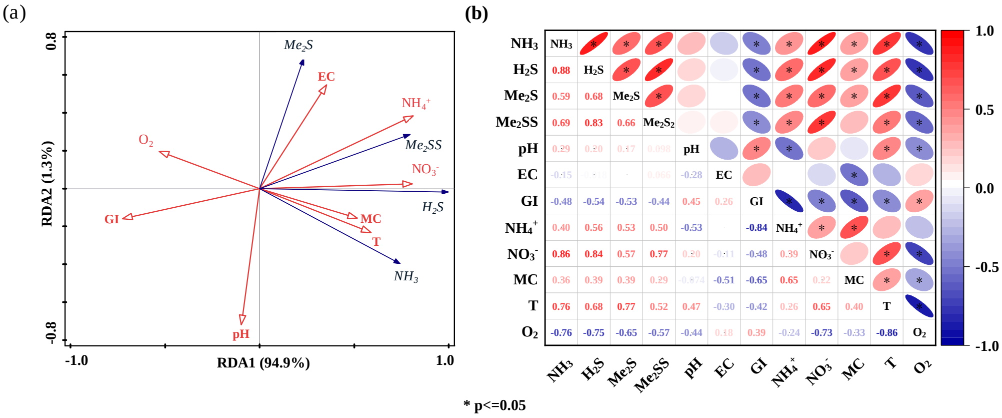

Fig 2. Redundancy analysis (RDA) of the effects of physiochemical characteristics on gaseous emissions (a); Pearson correlation heatmap between physiochemical characteristics and gaseous emissions (b). T: temperature; O_2: oxygen content; MC: moisture content.

Dynamics of bacterial community

The biochar, superphosphate and the combination of biochar, superphosphate and magnesium sulfate reduced the richness and diversity of bacteria, especially thermophilic bacteria. The combination of superphosphate and magnesium sulfate significantly reduced the richness and diversity of mesophilic bacteria. The biochar addition accelerated the evolution and stabilization of the bacterial community.

Succession of bacterial community

The biochar treatment had the highest Actinobacteria abundance, it is considered to be a sign of compost maturity. Except for SP+MS, the additive treatments compressed the thermophilic stage and increased the relative abundance of Proteobacteria in the mature stage. Actinobacteria and Proteobacteria performed crucial functions in N and S cycling. However, the SP+MS treatment had little effect on the bacterial community composition at the phylum level during the thermophilic stage. Compared with CK, the additive treatments both reduced the *Halocella* and *Hydrogenispora* relative abundance (Fig.1), which may explain the reduction of sulfur odor emissions.

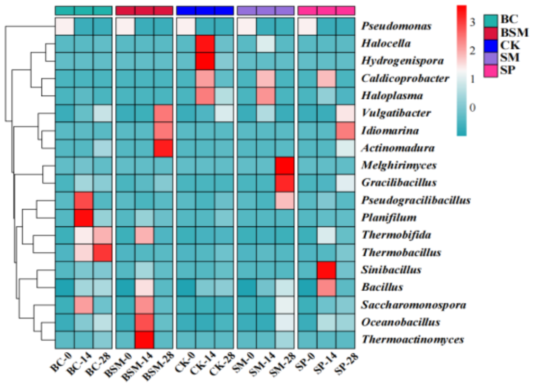

Fig.3. Variation of dominant bacterial community composition at genus levels (top 20) during chicken manure composting.

Functional bacteria of odors production

According to previous studies, 29 functional genera related to nitrogen conversion and 8 functional genera related to sulfur conversion were identified. Except SP, the additives all reduced the *Limnochorda* relative abundance, indicating that additives may reduce the generation of local anaerobic environment.

Caldicoprobacter, *Hydrogenispora*, *Planifilum*, and *Desulfitibacter* were detected as the dominant sulfur-transforming bacteria during composting. Among them, *Caldicoprobacter*, *Hydrogenispora*, and *Desulfitibacter* are typical sulfate-reducing bacteria, which can use sulfate as an electron acceptor to generate H_2S and other sulfur-containing odors under anaerobic or anoxic conditions. On the contrary, a large increase of *Planifilum* can weaken sulfate reduction and reduce the generation of sulfur-containing odor.

The BC and BC+SP+MS treatments with biochar addition significantly reduced the generation of sulfur-containing odor compared with CK. It may be mainly because the *Caldicoprobacter*, *Hydrogenispora* and *Desulfitibacter* relative abundance was decreased, and *Planifilum* relative abundance was increased. The SP treatment had a little effect on *Caldicoprobacter* and other key genera compared with biochar addition amendment. However, SP+MS treatment had slightly influence on *Hydrogenispora* and *Planifilum*, its weak effect on key genera confirmed that chemical action is the main pathway for sulfur odor reduction.

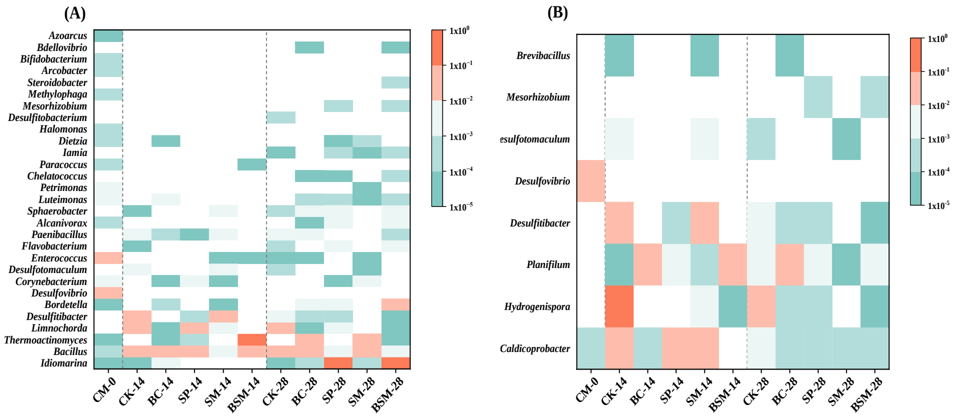

Fig 4. Variations in the nitrogen (a) and sulfur (b) functional bacterial community at the genus level during chicken manure composting.

Conclusions

The H_2S, Me_2S and Me_2SS were the main sulfur odor. The superphosphate amendment decreased sulfur odor by more than 50% due to the action of Ca^{2+} and S. The control of NH_3 by magnesium sulfate depended on Mg^{2+} content. The combination of superphosphate and Mg^{2+} simultaneously reduced 60.0% sulfur odor and 47.9% NH_3 emissions. Biochar was beneficial to reduce sulfur-containing odor production (72%). Additives also altered the community structure of key functional bacteria. And biochar stimulated the functional bacteria of N and S transformation, while the addition of superphosphate and magnesium sulfate reduced the odor emission mainly through chemical action.

Acknowledgement

This research was supported by the National Key R&D Program of China (2022YFD1900300)，the major science and technology project of Hainan Province in China (ZDKJ2021009), China Agriculture Research System of MOF and MARA (CARS-39)，the project of science and technology administration of Sanya Yazhou Bay in China (SYND-2021-09), and the 2115 Talent Development Program of China Agricultural University.

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Influence of Different Bulking Agents on Municipal Solid Waste Composting

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Composting is an effective and low-cost treatment method for the treatment of municipal solid waste (MSW), especially in developing countries. Municipal solid waste composting at the community level suffers from sourcing adequate and ideal bulking agents to obtain an effective composting process. Mainly, the dry leaves collected from the streets become the major bulking agent; however, the quantities are not adequate. The bulking agents enhance the composting conditions and the quality of the compost product in terms of composting temperature, porosity, water retention, particle-size distribution, pH, electrical conductivity (EC), nitrogen losses, humification indices, microbial numbers, enzyme activities, macro- and micro-nutrient contents, and toxicity to germination seeds. Therefore, this study aimed at investigating the influence of sawdust (SD), woodchips (WC), dry leaves (DL), and paddy straw (PS) as bulking agents in composting MSW. Four treatments were included in the study as follows: MSW+WC+SD (1:0.5:0.5), MSW+SD (1:1), MSW+PS (1:1), and MSW+DL (1:1), the mixing ration was in w/w dry basis. The mixtures were composted for 42 days in 25-L homemade composters. The temperature of the compost piles was monitored every day, while the moisture, pH, electrical conductivity (EC), total organic carbon, total Kjeldahl nitrogen, extractable ammonium, and C/N ratio were analyzed every week. The phytotoxicity of the compost was assessed using the seed GI.

The results revealed that in all treatments, the thermophilic phase was maintained for two weeks. The pH range at the end of composting was 6.45 to 7.86; and the electrical conductivity was less than 4 mS/cm in all treatments. When compared to other treatments, the MSW + DL treatment had the highest NH4+-N content, nitrogen content, and seed germination index. Results indicate that use of dry leaves as bulking agents in a 1:1 ratio with MSW significantly improved compost quality and reduced the composting period to six weeks.

Keywords: MSW, Bulking agents, Dry leaves, Paddy straw, Sawdust.

Control of Nitrogen and Odor Emission during Chicken Manure Composting with A Carbon-Based Microbial Agent Inoculation and Biotrickling Filter

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ABSTRACT. Although aerobic composting is commonly used in livestock manure disposal, the emission of odorous gases from compost causes the loss of nitrogen, sulfur, and other essential elements in products, resulting in a decline in product quality. The impact of biotrickling filter and addition of carbon-based microbial agent on compost maturity, greenhouse gas emissions and bacterial community during the chicken manure composting were evaluated in the present work. Results showed that adding a carbon-based microbial agent accelerated the heating time of the compost, shortened the high-temperature period, reduced the volatilization of ammonium nitrogen in the pile, and accumulated a large amount of nitrate nitrogen. In addition, the deodorization effect of biotrickling filter (BTF) was stable, and the removal rates of NH_3, H_2S, and TVOCs reached more than 90%, 96%, and 56%, respectively. Furthermore, microbial sequencing showed that carbon-based microbial agent effectively changed the microbial flora in the compost, protected the ammonia-oxidizing microorganisms, and strengthened the nitrification of the compost. This work provided important insight into mitigating greenhouse gas emissions and improving compost quality in livestock manure composting.

Keywords: Chicken manure composting; Odor, Nitrogen; Biotrickling filter; Carbon-based microbial agent

Introduction

Aerobic composting technique was an effective way to recycle livestock manure, which could transform organic substances into stabilized and hygienic final products via a variety of microbiochemical processes [1]. However, during the aerobic composting, a large number of malodorous gases are often released because of the high N content in livestock manure, such as ammonia (NH_3), hydrogen sulfide (H_2S) and total volatile organic compounds (TVOCs). These harmful gases will not only pollute the surrounding air, but also endanger the health of nearby people and animals. At present, a large number of studies have focused on the effects of carbon-based microbial agent on nitrogen.[2]. [3] inoculated compound bacterial consortium in sludge compost, discovered NH_3, H_2S and N_2O were decreased by 48.9%, 19.4% and 57.8%, respectively. The study found that although biological trickling filter make pile body odor are greatly reduced, but the nitrogen retention still has a large room to improve [4]. However, the effects of microbial agent in combination with biotrickling filter on odor and nitrogen content during composting are still unclear. In this study, the modified corn straw biochar was used as a carrier additive to select and cultivate nitrifying bacteria with high efficiency. Based on the optimal proportion, the efficiency of carbon-based microbial agent on nitrogen fixation in the chicken manure composting process was studied to reduce nitrogen loss and odor production. The biotrickling filter (BTF) treatment technology was combined to reduce odor emission further and recover effective elements in odor substances.

Material and Methods

Screening of strains and preparation method of carbon - based deodorant

The material of strains was collected from the livestock manure compost products of the Bioenergy Research Institute of Nanjing Tech University. The strains were enriched and isolated using ammonium sulfate as the only nitrogen source of heterotrophic nitrification medium. Finally, the target strains were determined by performance effect measurement.

Dried wheat bran mixed biochar was used as the adsorbent of carbon-based microbial agent. The dosage is 1 kg of adsorbent per liter of mixed bacterial solution, stir and mix well, and then dry for 16-20 hours at 45°C until the water content is 15-18%, that is dry bacteria agent.

Composting experiment design and sample collection

The chicken manure and straw were mixed together at the ratio of 2:1 (wet weight) for two treatments, the amount of carbon-based microbial agent was based on the initial feedstock in proportions of 10%, the moisture content was regulated to approximately 65% and composted for 30 days. The treatment groups were set as chicken manure + straw (CK) and chicken manure + straw + 10% carbon-based microbial agent (EG), respectively. Samples were collected from the upper, middle and lower layers of both reactors on days 0, 5, 10, 15, 20, 25, and 30, respectively and subjected to MC, pH, GI, TN, NH_4^+ and NO_3^- analysis.

Gas emission measurements

The sampling port was set at the exhaust port of the composting bioreactor and top of the BTF. A portable odor analyzer (Odor Catch/ SLC, Korea) was used to collect gas samples and measure the concentration of NH_3, H_2S, and TVOCs.

Microbial analysis of composting samples

The samples of 4, 14, and 24 days were collected on the CK group and the EG group. Genomic DNA was extracted from the samples, using Magnetic Soil and Stool DNA Kit (Tiangen Biotech, Beijing, China), the extracted DNA was dissolved in TE buffer and finally detected by 1% agarose gel electrophoresis.

Results and Discussion

Isolation and nitrification performance of strain

The degradation rate of ammonia nitrogen of the three strains after 70 h of culture was more than 40%. Among of them, TN loss of N2 (*Brevundimonas vancanneytii*) bacteria was 19.64%, nitrate accumulation was 17.46%, ammonia degradation was 42.54%; whereas TN loss of N3 (*Alcaligenes faecalis*) bacteria was 15.8%, nitrate accumulation was 49.65%, ammonia degradation was 68.3%, and the nitrification ability was the strongest. So, we chose N2, N3 to prepare carbon-based microbial agent and then add to the compost.

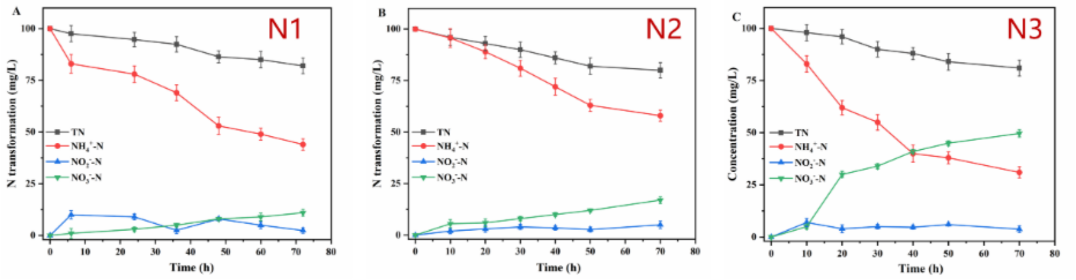

Fig. 1. Nitrogen transformation ability of three kinds of nitrifying bacteria

Effects of carbon-based microbial agent on physicochemical properties during composting

The temperature in EG group reached the maximum temperature of 70.1°C on the 4th day, and maintained the high temperature period for 13 days (>50°C), while the CK group reached the maximum temperature of 70°C on the 14th day. During composting, the moisture content of the two treatments showed a straight downward trend, and the final values were 31.16% and 32.35%, respectively. The pH showed an increasing trend in the initial stage and decreased in the cooling period due to the accumulation of organic acids. The addition of carbon-based microbial agent increased the content of organic matter in the reactor to a certain extent, and the growth activity of colonized bacteria also promoted the degradation of organic matter, so organic matter in EG group is degraded faster than CK group. By contrast, EG group with a higher degree of maturity.

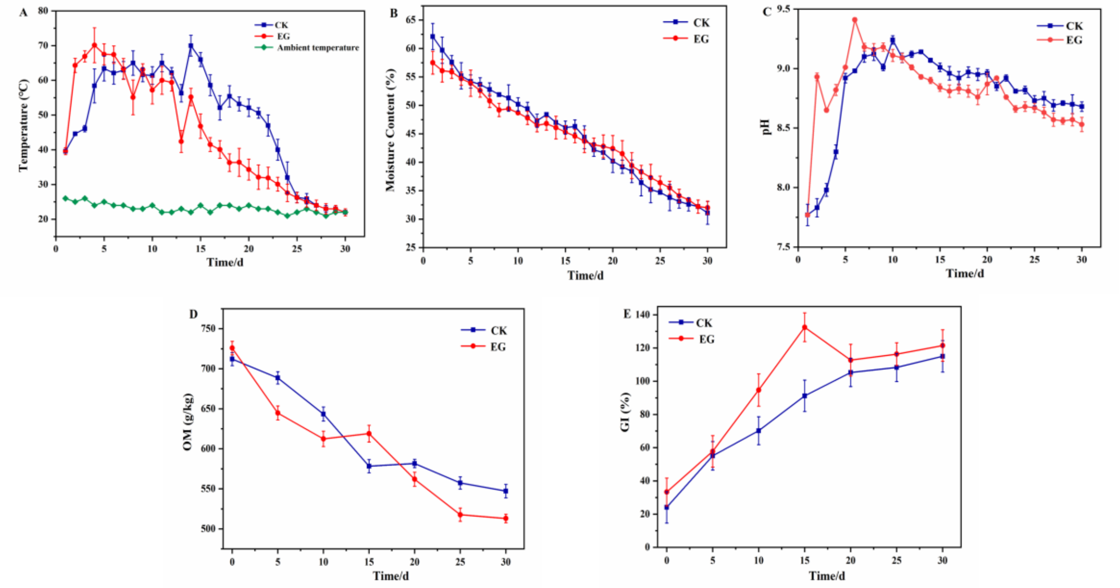

Fig. 2. Changes of temperature (A), MC (B), pH (C), OM (D), and GI (E) during the composting

Variation characteristics of different forms of nitrogen during composting

The addition of carbon-based microbial agent affects the conversion of nitrogen in compost and increases the content of TN during composting. The content of NH_4^+-N in CK and EG treatments increased rapidly during the high temperature period, then gradually decreased. The NO_3^--N content of CK and EG treatment always showed an increasing trend, and the NO_3^-- N content of EG group was 36.59% higher than that of CK group. Visible, the carbon-based microbial agent can promote the transformation of NH_4^+-N to organic nitrogen and NO_3^--N when applied to the composting, effectively control the volatilization of NH_3, reduced nitrogen loss and prevent the spread of odor [5].

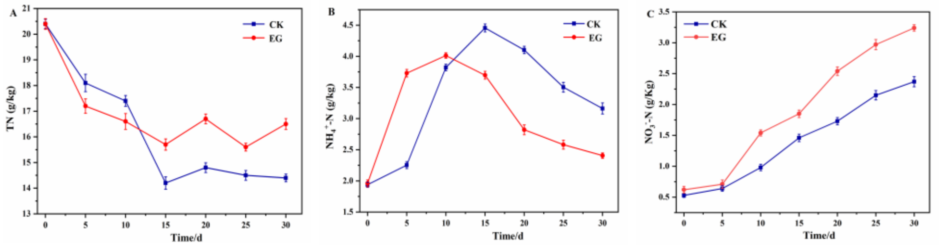

Fig. 3. Changes of TN (A), NH_4^+-N (B), and NO_3^--N (C) during the composting

Deodorization effect of carbon-based microbial agent

The average release concentration of NH_3 decreased by 25.06% compared with CK group, effectively reducing the generation of odor. H_2S in EG group was significantly lower than that in CK group, and the H_2S release in EG group was about 18.28% lower than that in CK group during the whole fermentation period. The average TVOCs release in EG group was 13.50% lower than that in CK group during the whole fermentation period. Herein, the deodorization efficiency of BTF was stable, and the removal rates of NH_3, H_2S and TVOCs were more than 90%, 96% and 56%, respectively.

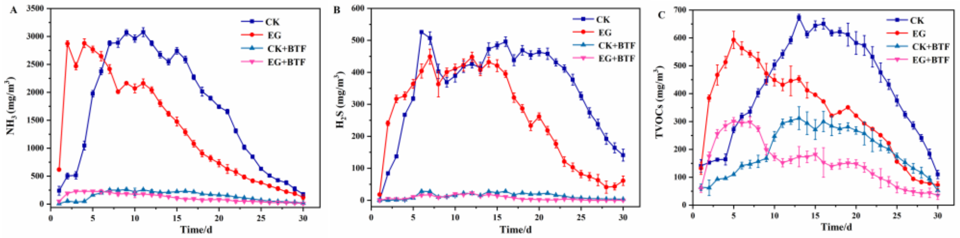

Fig. 4. Emission concentration of NH_3 (A), H_2S (B), and TVOCs (C) during the composting

Effect of carbon-based microbial agent on nitrogen cycling microorganisms during composting

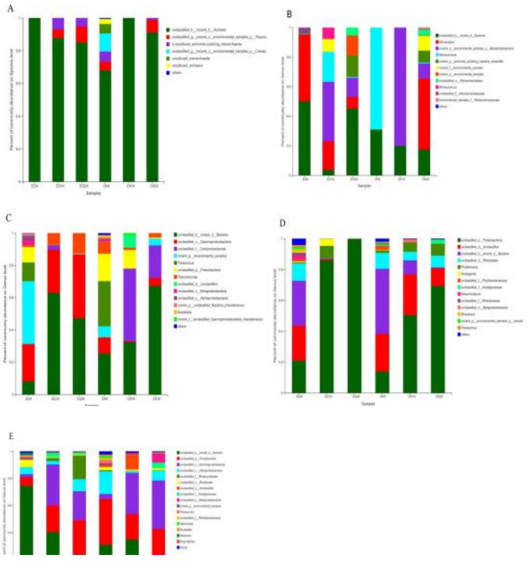

Fig. 5. Microbial community composition in response to amoAF/amoAR (A), amoA1F/amoA2R (B), nirS (C), nirK (D) and nosZ (E) in the two groups

Microbial sequencing showed that carbon-based microbial agent effectively protected the ammonia-oxidizing microorganisms, and strengthened the nitrification of the compost. AOA and AOB accounted for a relatively high proportion in the two groups, and ammonia-oxidizing bacteria still existed in EG group during the high temperature period.

Alcaligenes faecalis, as a carbon-based bactericide, can be found in both nirK and nosZ gene flora abundance map, and the abundance accounted for 4.51% in the cooling stage of EG group, which was also one of the reasons for the active nitrification in EG group. This bacterium was not active in the early stage of EG group, but became the dominant bacterium during 14-24 days of composting.

Fluorescence quantitative PCR analysis of *Alcaligenes faecalis*

In this study, fluorescence quantitative PCR (QPCR) was used to analyze the absolute number of *Alcaligenes faecalis* in the composting process. *Alcaligenes faecalis*, as a highly heterotrophic nitrifying bacteria, was prepared into a carbon-based bactericide and put into the heap to fix nitrogen. As shown in Fig.6, it was obviously found that the number of *Alcaligenes faecalis* in the experimental group was much higher than that in the control group during the whole composting period. Due to the dramatic changes of environmental factors such as temperature, the number of *Alcaligenes faecalis* decreased significantly during the high temperature period. In the cooling period, with the decrease of temperature and the increase of ammonium nitrogen and other substrates, the number of nitrifiers mainly composed of *Alcaligenes faecalis* increased greatly. *Alcaligenes faecalis*, as a carbon-based deodorant, has obvious effect and strong stress resistance, also has the potential of engineering application.

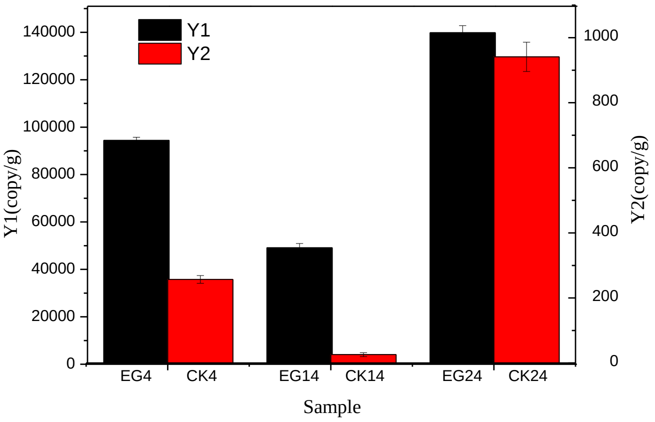

Fig. 6. Copies of Alcaligenes faecalis indiferent samples

Conclusions

Adding a carbon-based microbial agent accelerated the heating time of the compost, shortened the high-temperature period, reduced the volatilization of ammonium nitrogen in the pile, and accumulated a large amount of nitrate nitrogen. The deodorization effect of BTF was stable, and the removal rates of NH_3, H_2S, and TVOCs reached more than 90%, 96%, and 56%, respectively. Microbial sequencing showed that carbon-based microbial agent effectively changed the microbial flora in the compost, protected the ammonia-oxidizing microorganisms, and strengthened the nitrification of the compost.

Acknowledgement

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Dynamics of Oxytetracycline, Sulfamerazine, and Ciprofloxacin and Related Antibiotic Resistance Genes during Sewage Sludge Composting

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ABSTRACT. Sewage sludge is one of the most significant reservoirs of antibiotic resistance genes (ARGs) in sewage treatment plants. In this study, municipal sludge was taken as the research object to find the ARGs removal and microbial diversity effects of three composting treatments: ordinary compost without antibiotics addition (CK), compost with antibiotics addition at two concentration levels (T-Low and T-High). Metagenomic high-throughput sequencing was employed to analyze both the ARGs and microbial community composition. After composting, the abundance of ARGs in the CK was reduced by 23.08%, while the treatments of T-Low and T-High were reduced by 49.13% and 63.89%, respectively. Proteobacteria and Bacteroidetes were dominant in the CK, while Proteobacteria and Chloroflexi were dominant in the T-Low and T-High treatments after composting. The redundancy analysis indicated that the abundance of ARGs had a significant impact on changes in physicochemical parameters and bacterial communities during sewage sludge composting.

Keywords: *sewage sludge; compost; antibiotic resistance genes; microbial diversity*

Introduction

A diverse range of antibiotics has been discovered and extensively utilized for the prevention and treatment of human and animal diseases [1]. About 210,000 tonnes of antibiotics are annually administered in China for animal husbandry, medical treatment, and other purposes [2]. Studies have shown that a significant proportion of antibiotics (30-90%) are excreted unchanged in human and animal waste, resulting in substantial amounts of antibiotics entering wastewater treatment plants (WWTPs) without being metabolized [3]. Sewage sludge represents a significant reservoir of antibiotics and ARGs in WWTPs [4]. Studies investigated sludge samples from WWTPs, showed serious antibiotic and antibiotic resistance genes (ARGs) pollution[5, 6]. The levels of antibiotics in sewage sludge reached in the range from μg/kg to mg/kg, and the ARGs and antibiotic resistant bacteria (ARB) contents in sewage sludge were determined to be 10^6-10^9 copies/g and 10^4-10^9 CFU/g, respectively [7]. The application of improperly treated sludge as fertilizer to farmland soil can introduce significant amounts of antibiotics and ARGs.

Moreover, the presence of antibiotics further stimulates the production and dissemination of ARGs in the soil [8]. ARGs can be transmitted to humans through the food chain, potentially leading to antibiotic resistance and posing a significant threat to human health [1]. Composting has the potential to mitigate the diversity and abundance of ARGs present in sewage sludge [5]. Fu et al.(2021) observed a 72.7% reduction in the abundance of ARGs in sewage sludge following composting for 66 days [5]. On the contrast, the resistance genes *sul*1, *sul*2, *tet*Q, and *tet*X in sheep manure were enriched nine-fold through aerobic composting [9]. Cheng et al.(2021) observed antibiotics addition could be effectively removed the tetracycline resistance genes (TRGs) and fluoroquinolone resistance genes (FRGs) after composting [3]. Therefore, it is imperative to investigate the variations in ARGs and microbial communities during composting, as well as their interactions, in order to effectively eliminate antibiotics and ARGs.

In this study, we employed sewage sludge as a substrate to conduct aerobic composting with the addition of antibiotics, and investigated the impact of composting on the reduction of antibiotics and ARGs. The aim of this study was to: (1) quantify the dynamic changes of antibiotics and ARGs and (2) determine the relationship among ARGs, residual antibiotics, microbial communities and physicochemical properties during the composting process.

Material and Methods

Aerobic composting and samples collection

Sewage sludge was collected from a wastewater treatment plant located in Luoyang, Henan Province, China. Wheat straw and sawdust are dried and ground into fine powder. The total weight of the experimental material was about 50 kg, where the sludge, wheat straw and sawdust were fully mixed at a ratio of 3:2:1 (w/w/w) to adjust the C/N to ~25, moisture content adjust to 60%.

Three treatments were designed: compost without antibiotics addition served as the control (CK); 2 mg/kg oxytetracycline (OTC), 0.5 mg/kg ciprofloxacin (CIP) and 0.5 mg/kg sulfamerazine (SM1) addition served as the treatment of low antibiotic (T-Low); 20 mg/kg OTC, 5 mg/kg CIP and 5 mg/kg SM1 addition served as the treatment of high antibiotic (T-High) according to dry weight. Each treatment was repeated in triplicate. Composting was conducted for 43 days in rectangular foam containers with regularl artificial turning. Samples were collected on days 0, 1, 5, 15, 29 and 43. These samples were collected as mixed thoroughly and then divided into two parts, one was kept in 4 °C for moisture, pH, total organic carbon (TOC) and antibiotics content measurement; another part was stored at −20 °C for later extraction of DNA, determination of ARGs and the detection of the bacterial community. Extraction of antibiotic residues in samples was performed referencing to the method described by Zhang et al. (2022) using UPLC-MS/MS (Waters ACQUITY UPLC Xevo TQD, Waters, UK) [10].

DNA extraction and metagenomic analysis

Total genomic DNA was extracted from the compost samples in triplicate using the Powersoil DNA Isolation Kit (MoBio Laboratories, USA) according to the manufacturer's protocol. The concentration and Quality of DNA were NanoDrop 2000 (Thermo Fisher Scientific, Waltham, MA, USA).

The DNA was fragmented, purified, repaired, and amplified by PCR, followed by sequencing on Illumina sequencing platform. Beijing Biomarker Technologies Co., Ltd. performed the Illumina high-throughput sequencing as constructed a small fragment library by Paired-End sequencing. Metagenomic binning was using for analysis, which is the process of grouping metagenomic sequences by their organism of origin. The NCBI non-redundant protein sequence database and comprehensive antibiotic resistance database (CARD, version 3.0.0) were used for annotation of microbial taxonomy information and ARGs respectively.

Results and Discussion

Degradation of target antibiotics during composting

The variations of the three antibiotics during the composting process are illustrated in Fig. 1. The degradation efficiencies of OTC, CIP, SM1 were 91.21% and 88.67%, 78.54% and 63.48%, 87.07% and 78.85% in T-Low and T-High treatments, respectively. The removal rates varied depending on the molecular structures, thermal stability and biodegradability of antibiotics [8]. OTC exhibited the highest degradation rate, followed by SM1 and CIP. The relative high residues of CIP were detected at the end of composting, indicating a recalcitrance of fluoroquinolone to degradation through composting, as reported previously [11]. Moreover, the concentration of antibiotics was found to be a crucial factor in determining the change in antibiotic removal efficiency. The limited reparative capacity of microorganisms in compost substrate resulted in T-Low treatment exhibiting a higher degradation rate than T-High treatment [12].

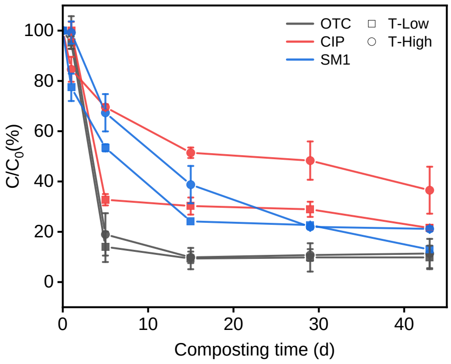

Fig. 1. Changes in the concentrations of OTC CIP and SM1 during composting.

Variation of ARGs during composting

Composting led to a significant reduction in the relative abundance of total ARGs in the CK, T-Low and T-High trearments (Fig. 2a). The relative abundance of total ARGs decreased by 23.08%, 49.13%, and 63.89% in the CK, T-low, and T-high treatments after composting, respectively. Improved reduction of ARGs corresponding to the added antibiotics was observed with composting, indicating its superior effectiveness in reducing ARGs [13]. However, the diversity of ARGs detected in T-Low and T-High treatments were increased and higher than the CK treatment (Fig. 2b). The diversity of ARGs significantly decreased from 529 to 265 in the CK during composting. While the diversity number of ARGs in the T-Low and T-High treatments increased to 515 and 619 compared with CK on the 43rd days. These results suggest that antibiotics addition reduced the abundance of ARGs in compost and improved their related diversity [14].

Variations of microbial community during composting

Fig. 3 depicts the microbial community structure at the phylum level during composting, revealing that Proteobacteria dominated on day 0 (D0, mesophilic phase), followed by Bacteroidetes. On the fifth day (D5, thermophilic phase), Firmicutes emerged as the predominant bacterial phylum, followed by Proteobacteria and Actinobacteria. During the cooling phase (D29) and maturation phase (D43), the abundance of Proteobacteria increased, re-establishing its dominance in all treatments including CK, T-Low and T-High. In general, the changes in Proteobacteria, Firmicutes, Bacteroidetes and Actinobacteria were similar across all three treatments during the early stage (D0-D29). However, Chloroflexi exhibited a significant increase on D43 in both T-Low and T-High treatments which is associated with amino acid metabolism and carbohydrate metabolism [15].

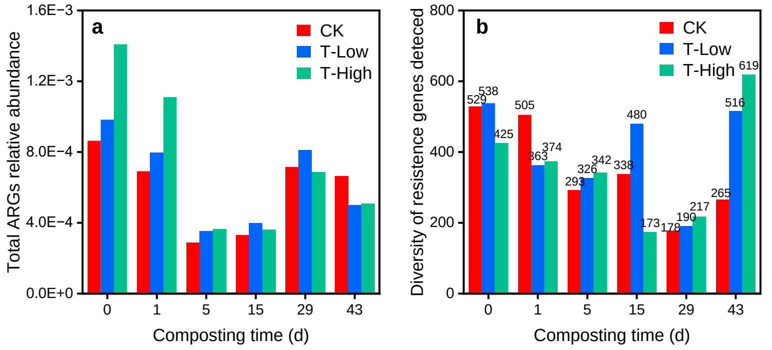

Fig. 2. Variations in the abundance of total ARGs (a) and diversity of resistance genes detected (b) during composting.

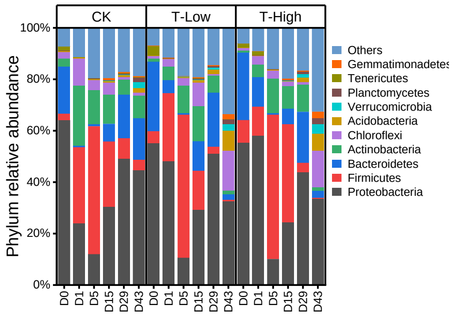

Fig. 3. Microbial community composition at the phylum level during composting process.

Relationships between the antibiotics, ARGs and the microbial community

An RDA analysis was performed using Canoco 5 to explore the relationships among environmental factors, bacterial communities at the phylum level, and ARGs (Fig. 4). The results indicated that the selected variables accounted for 89.74% of the total variation in ARG evolution quantified in this study. Proteobacteria and Bacteroidetes could explain the evolution of the ARGs decreased including *aad*A, *sul*1, *sul*2, *flo*R, *tet*36, *tet*X and *tet*C. Firmicutes and Actinobacteria mainly accounted for the evolution of the ARGs increased including *tet*L, *mdt*H and *poxt*A. Firmicutes was also previously demonstrated to contribute to the elevated abundance and enrichment of ARGs [16]. As far as the environmental factors were concerned in this study, TOC and moisture showed positive correlations with Firmicutes and Actinobacteria. The moisture level could affect the metabolic activities of microorganisms and antibiotics dissipation, thus it played a key role in shaping antibiotic resistome [17]. Furthermore, OTC, CIP and SM1 contribute to *aad*A, *sul*1, *sul*2, *flo*R, *tet*36, *tet*X and *tet*C. It was concluded that the bacterial community contributed the most to the ARG changes, followed by environmental factors.

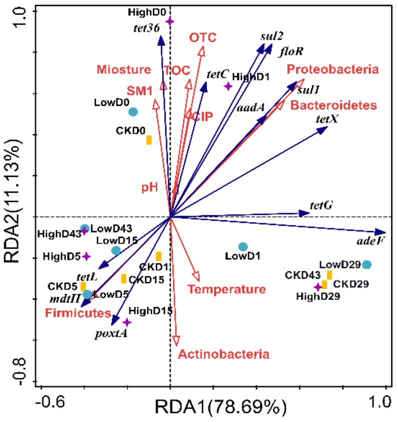

Fig. 4. Redundancy analysis (RDA), the blue lines and red lines represent the species variables and environmental variables; yellow box, blue circle and purple star triangle represented samples from CK, T-Low and T-High group, respectively.

Conclusions

This study conducted composting on sewage sludge contaminated with antibiotics and demonstrated that composting is an effective method for reducing the abundance of antibiotic resistance genes (ARGs). Compared to CK, ARGs diversity was higher in the T-Low and T-High treatment after composting. Antibiotics addition can effectively improve the degradation of ARGs. Statistical analysis shows that ARGs are influenced by microbes such as Proteobacteria and Bacteroidetes, as well as environmental factors. This work confirmed composting can effectively removing antibiotics and ARGs during sewage sludge composting, further optimizations need studies to increase the removal efficiency of ARGs during the composting.

Acknowledgement

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Co-composting of Food Waste with Organic Materials: Impact of C/N Ratio

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ABSTRACT. The study aimed to co-compost of food waste with different organic materials to develop a high antinutritional compost. The saw dust used for bulking agents. The organic materials Neem cake, sesame cake, peanut cake was used in this study. The food waste, saw dust are mixed with 1: 1 ratio and mixed with 10% of organic materials on dry weight basis. Three treatments were designed the study. A control without organic materials was also included. The mixtures were composted in 20-L in vessel composters for 42 days. Results show that adding 10% neem cake improve the compost quality and also reduce the nitrogen loss and electrical conductivity, compared with other treatments. Neem cake compost is distinctive nutritionally as a result of the presence of important primary and secondary metabolites, Neem cake addition was recommended for food waste composing to produce highly nutritive and best pesticide for plants and higher nitrogen content of the compost when compared to other materials.

Keywords: Food waste, Organic materials, Co-composting, Neem cake, Peanut cake, Sesame cake

Introduction

With the rapid increase of the population and industrialization, vast amounts of food waste are being generated. Developing countries generate large volume of organic solid waste including food, municipal and agricultural wastes (Yao et al., 2021). Food waste is the most abundant organic component of the municipal solid waste. According to the Food and Agriculture Organisation (FAO), a staggering 1.3 billion tons of food as waste each year. And 931 million tonnes of food go to waste each year which accounts 17% of global food production. As per the UN Environment Programme's (UNEP) food waste index Report, 2021 61% of food waste comes from households, 26% from food service and 13% from retail. Indians waste as much food as the whole United Kingdom consumes- food wastage is an alarming issue in India. In India, 40% of food is wasted which is equivalent to Rs 92,000 crore a year. Food waste undermine the sustainability of our food systems. When food is wasted, al the resource's that were used to produce this food- including water, land, energy, labour and capital- go to waste. Food wastages carbon footprint is estimated at 3.3 billion tonnes of Co_2 equivalent of GHG released into the atmosphere per year. Composting is one of the most undemanding and eco-friendly ways to recycle the food waste. Composting is a biological process convert the organic wastes into stable humus like compost. One of the major challenges in the selection and use of organic fertilizers in the compost is to reduce nitrogen losses and improve nitrogen use efficiency (NUE) and planting efficiency and uptake or recovery efficiency. So, this study to investigate the co composting of food waste mixed with 10% of different organic materilas to improve the compost quality and reduce the nitrogen loss. It is also provided the valuable information regarding the physiochemical evolution of the composting process. In addition of 10% neem cake more effective for reducing the nitrogen loss and produce highly nutritive and best pesticide for plants and higher nitrogen content of the compost when compared to other material.

2. Materials and methods

2.1 composting and feedstock materials

This experiment was performed in 20-Lbench-scale composters, in which the temperature and aeration were controlled. A synthetic food waste prepared by mixing bread, rice, cabbage and vegetables, dahl was used in the experiments, which simulated the real situation. All the components of the food waste were reduced to $0.5cm^3$. The sawdust was procured from the sawmill near Tirunelveli. The organic materials neem cake (NC), peanut cake (PC), sesame cake (SC) procured from the local fertilizer shop. The food waste and sawdust ratio were maintained at 1:1 in the control. The C/N ratio was calculated by sum of total carbon contents of each substrate multiplied by its weight (dry weight basis). The C/N ratio of all treatments was between 23 and 25 while the initial moisture contents varied between 55 and 60%. About 12 kg of composting mixture was prepared for each mixing ratio and composted for 42 days.

2.2 Experimental methods

Table 1.1. Physicochemical properties of synthetic food waste, sawdust, neem cake, peanut cake, and sesame cake used in the study

parameters	Food waste	Sawdust	Neem cake	Peanut cake	Sesame cake
pH	4.42±0.05	6.41±0.01	5.64±0.03	6.67±0.1.09	5.63±0.05
EC (mS/cm)	2.58±0.1	0.6±0.05	4.5±0.0	3.4±0.02	3.08±0.017
Moisture content (%)	70.0±0.02	7.22 ±4.0	7.44±4.0	7.02±4.6	6.40±4.7
Total organic carbon (%)	47.31±2.3	50.84±2.2	43.4±4.9	40.17±0.6	40.82±0.45
Total Kjeldahl nitrogen (%)	2.29±1.34	0.67±0.06	2.40±0.71	2.28±0.8	2.34±1.83
C/N ratio	20.65±1.0	75.88±3.07	18.08±0.2	17.61±0.3	17.44±0.3
Extractable ammonium(mg/Kg)	634±254.6	364±30.79	276±20.93	395±35.86	177±5.96

* - Mean ± SD of three replicates

The pH and EC level was measured in compost material and water with a ratio of 1:5. This water sample was also used for and extractable ammonium (available nitrogen) was measured in the study organic composts using TMECC's (2003) methodology. moisture content was determined by the weight loss of the compost sample using the gravimetric method (Walkley- Black method. The dried sample was further used for total organic carbon content was estimated using the modified Walkey-Black method. The total Kjeldahl nitrogen was estimated semi-micro Kjeldahl digestion procedure. Mustard seed used seed germination index *(Brassica juncea)* and the germination index that was determined according to the following formula to assess the compost maturity and phytotoxicity as described by the HKORC (2005) protocol.

GI (%) = (Seeds germination of compost sample × Root length of compost sample) / (Seeds germination of control × Root length of control) × 100

3. RESULT AND DISCUSSION

3.1 Temperature profile

A good thermophilic phase of at least 1 week is important for the effective removal of pathogenic organisms to produce hygienic compost. The temperature of the composting mass in all treatments increased sharply at the beginning of the composting process and reached the thermophilic phase (≥55°C) within two days (Fig.3.1) indicating that the easily available organic matter was rapidly degraded which could supply sufficient nutrients for microbial growth. Temperatures of the treatments showed a similar trend with an initial high temperature for two weeks before decreasing down to 35°C till the end of the experiment.

3.2 Changes of pH and EC

The pH of the treatments was periodically monitored from days 0 to 42, respectively. Initial pH of all treatment was rapidly decreased during the first weeks due to intense microbial activity and organic matter degradation. at the end of the experiment pH values of 8.09 were observed in FW+SD+NC10. The results suggest that the microbial activity in FW+SD+NC10, FW+SD+PC10 FW+SD+SC10 was highest organic matter. Electrical conductivity is used to estimate the concentration of soluble salts in the soil, and organically fertilized soil compost was evaluated throughout the period of experimental day 0 to day 42. However, the data of FW+SD+NC10, FW+SD+SC10 and FW+SD combination show an acceptable range of EC values, starting from 1.57 ± 0.00 on the 0th day to 2.30 ± 0.10 (mS/cm) on 42nd day in FW+SD+NC10. Where FW+SD+PC10, such as1.45 ± 0.02 on 0th day and 2.45 ± 0.05 Where 1.40 ± 0.03 on 0th day elevated to 2.35 ± 0.16 (mS/cm) in F+W+SD+SC10. Food waste with Saw dust compost was monitored with EC values of 1.26 ± 0.00 on the first day and 1.26 ± 0.15 (mS/cm).

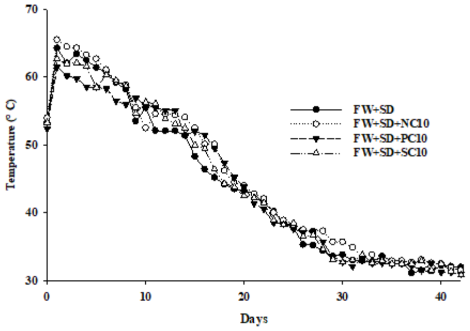


Fig 3.1. The changes in temperature during food waste composting

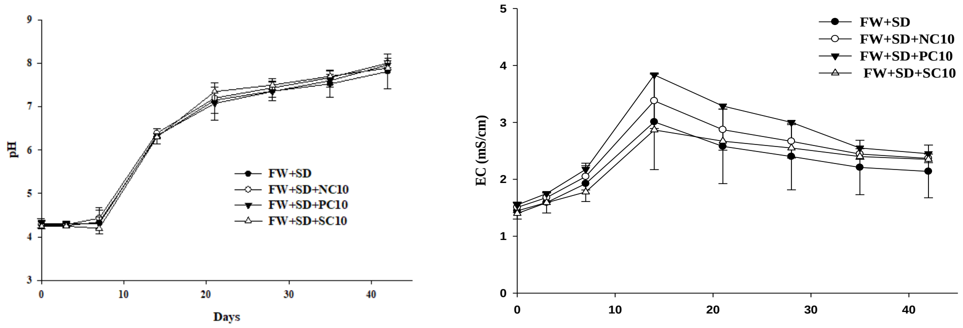
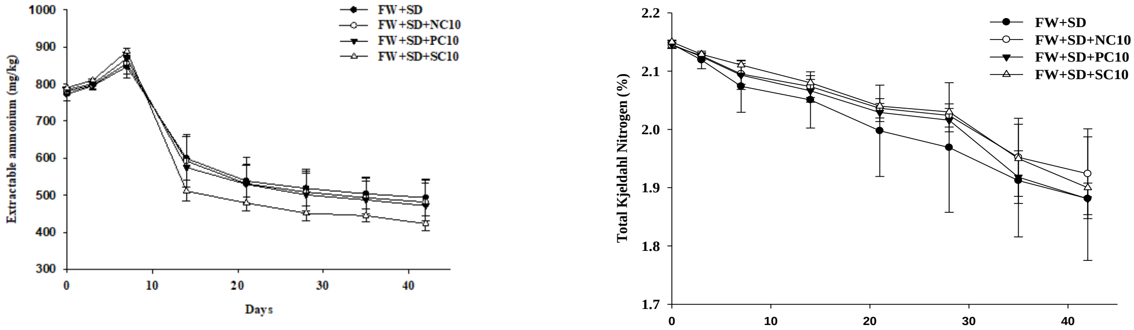


Fig 3.2 The changes in pH, EC during food waste composting

3.3 Changes of Extractable ammonium and Total Kjeldahl Nitrogen

Most of ammonia emission occurred during thermophilic phase. There was nearly no NH_3 emitted from the treatments due to their low pH (≥6.0) and low degradation, but NH_3 emission was observed at the later stage. In this experiment the NH_4 levels were relatively high in FW+SD+PC10 and FW+SD+SC10, at the beginning of the composting as a result of digestate which was rich in ammonia/ammonium and decreased after15 days by its volatilization under high pH and temperature. At the end of composting FW+SD and FW+SD+NC10 slightly decreased.

TKN was 2.15 ± 0.25 % in FW+SD+SC10 and FW+SD compost contained 2.15 ± 0.09 % of TKN. While other composts such as, FW+SD+NC10 and FW+SD+PC10 showed 2.14 ± 1.21 and 2.14 ± 0.08 % on the first day, respectively. The sustainable availability of TKN exhibited better soil compost for the finest crop productivity. Even on the 42nd day, the TKN content was estimated at 2.01 ± 1.21 % in FW+SD+NC10 and 1.97 ± 0.15 % in FW+SD+SC10. Whereas, the FW+SD+PC10 and FW+SD exhibited 1.86 ± 0.21 and 1.75 ± 0.24 %.



3.5 Changes of Total Organic Carbon

The higher organic carbon content was estimated in the initial days of composting, followed by a gradual decrease (< 40 mg/g) of TOC at the end of the composting period. FW+SD+NC10 quantified the TOC as 50.18 ± 1.17 %, 49.27 ± 2.0 % from FW+SD+PC10, 49.53± 1.79% estimated from FW+SD+SC10 and 51.61 ± 1.17 % of TOC in FW+SD compost on the first day. At the end of the composting period, the TOC content was reduced among all groups to 37.18 ± 0.98 % in FW+SD+NC10, 36.66 ± 1.8 and 36.27 ± 1.56 %in FW+SD+PC10 and FW+SD+SC10 compost. While in FW+SD compost, the TOC was observed to be moderately lower as 34.97 ± 2.25%)

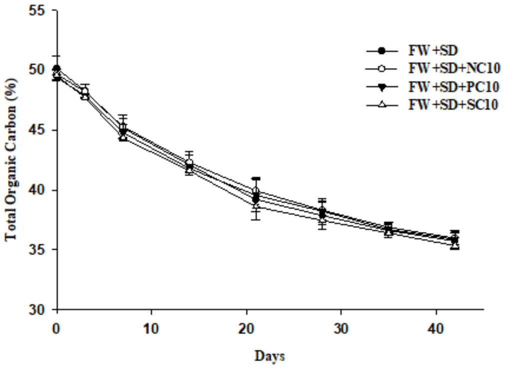


Fig. 3.5 The changes in total organic carbon during food waste composting

3.6 Seed germination index

FW+SD+NC10 exhibited a higher rate of seed germination of 42.70 ± 4.50 %, secondly, food waste with saw dust showed 34.00 ± 5.00 % of seed propagation. Whereas, the other two composts revealed lesser proficiency on seed germination, such as 4.90 ± 4.30 % in FW+SD+SC10 and 2.80 ± 1.90 % in FW+SD+PC10 on the first day. As the data showed, the higher percentage of seed propagation was achieved by FW+SD+NC10 (97.80 ± 5.00 %) followed by 93.80 ± 5.00 % obtained from FW+SD alone. Other composts, such as FW+SD+SC10 (72.70 ± 5.00 %) and FW+SD+PC10 (56.90 ± 5.00 %) were measured accordingly.

3.7 C/N ratio

The C/N ratio of formulated composts was measured and calculated as 23.5 ± 1.9 in FW+SD+NC10 on the first day and reduced to 19.0 ± 1.9 at the end of composting. FW+SD+PC10 compost shows a C/N ration of 23.0 ± 1.5 at the beginning and 19.3 ± 3.3 on the 42nd day. The composition of FW+SD+SC10 exhibited the ration of C/N, which was initially calculated as 15.8 ± 1.9 but afterward rose to 18.2 ± 2.3. On the other hand, composting of FW+SD only revealed 24.0 ± 0.6 primary, which subsequently condensed to 20.2 ± 3.1.

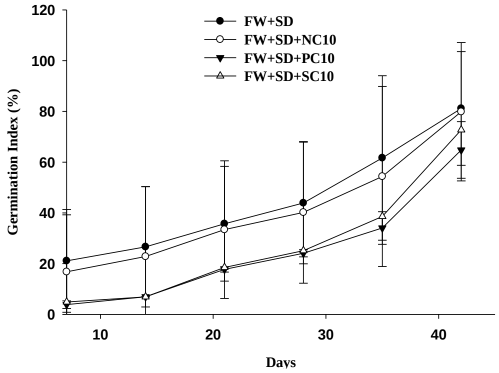


Fig. 3.6 The changes in seed germination index during food waste composting

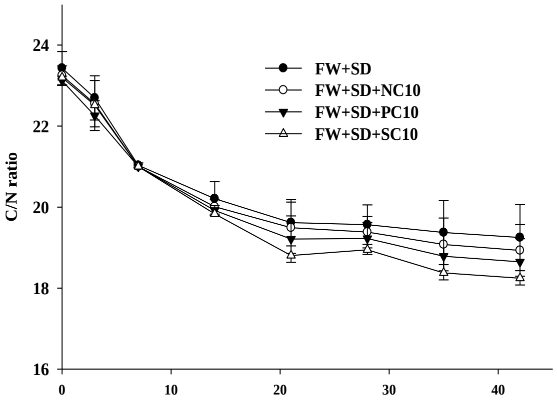


Fig. 3.7 The changes in C/N ratio during food waste composting

4. Conclusion

According to the data revealed, the compost of food waste saw dust with neem cake exhibited significant nutritional stability over other composts. So, the addition of 10% neem cake was recommended to support good composting and achieve good quality of food waste compost and produce highly nutritive and best pesticide for plants and higher nitrogen content of the compost when compared to other material.

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Nitrogen Retention and Emissions during Kitchen Waste and Fallen Leaves Aerobic Composting Covered with A Semi-Permeable Membrane

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Aerobic composting is an effective method for the treatment of kitchen wastes. However, this method also has some disadvantages, mainly reflected in that the composting process will release a large amount of NH3 and a certain amount of greenhouse gases, which not only reduces the fertilizer quality, but also causes secondary pollution to the air. In recent years, the new technology of aerobic composting covered with semi-permeable membrane has performed well in reducing gas emissions. The membrane-covered aerobic composting system itself will form a micro-high-pressure inner cavity, which makes oxygen flow and distribution in the material better, can significantly accelerate the ripening process of the material, and reduce the population and abundance of anaerobic microorganisms. This study is the first time to apply the membrane-covered system to the aerobic composting of kitchen wastes. In the experiment, fresh kitchen waste from school canteen was used as raw material, leaves were added as filler to adjust moisture content and C / N ratio, and non-membrane-covered aerobic composting was used as control. The composting performance, nitrogen retention and release and bacterial community succession characteristics of kitchen waste under membrane-covered aerobic system were studied systematically.

The composting experiment lasted 35 days. During the whole cooling period, the experimental group (EG) maintained a higher composting temperature than the control group (CG), which indicated that the experimental group experienced a more thorough process of organic matter degradation. At the end of composting, the NH4+ concentration in EG group decreased to 5.34 g/kg, which was 28.06% higher than that in the CG group (4.17 g/kg).At the end of composting, NO3− and NO2− concentrations reached 1.92 g/kg and 0.20 g/kg in EG group, and 0.93 g/kg and 0.13 g/k in CG group, respectively. The semi-permeable membrane effectively controlled the release of NH3. Compared with CG group, the emission of NH3 outside the membrane in EG group decreased by 48.50%. Compared with CG group, the N2O emission of EG outdoors decreased by 44.05%, and the EG inside also decreased by 31.46%. During the whole composting period, the TN concentration (dry matters) of EG group and CG group increased from the initial concentration of 17.8 g /kg to 21.22 g /kg and 20.64 g /kg respectively. From high temperature period to the end of composting, the TN concentration in EG group was higher than that in EG group

($P<0.05$). The higher retention and less emission of nitrogen in EG is significantly relevant to the bacterial community. More ammonia-oxidizing archaea and ammonia-oxidizing bacteria were found in EG in the thermophilic stage， these strains contributed to the retention of nitrogen by transforming nitrogen to nitrate and nitrite.

The results show that the use of membrane-covered aerobic composting technology to treat kitchen waste can promote the maturity of the compost, increase the nitrogen rate of the compost, which is an effective means to improve the emission of pollutants in the composting process of kitchen waste.

Keywords: Membrane-covered; Aerobic composting; Gas emission；Bacterial community.

Chicken Manure Composting: Effect of Initial Carbon / Nitrogen ratio

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Chicken manure is one of the important valuable resources as a soil fertilizer, providing a high content of macro- and micronutrients for the plant growth. The untreated chicken manure can cause very serious environmental problems such as emission of toxic greenhouse gases, leaching of nitrates, groundwater pollution, human and animal risks, etc. Composting is an effective, inexpensive alternative method for stabilizing the chicken manure. In this study, the physicochemical and biological parameters were examined to assess the effectiveness through stability and maturity indicators during the composting of chicken manure (CM) with different amount of sawdust (SD) at different initial C/N ratio of 20, 25 and 30 at lab-scale.

The composting process was monitored through the analysis of selected physicochemical parameters at regular intervals. The composting mixture with the initial C/N ratio of 30 showed prolonged period of thermophilic phase and maintained the temperature exceeding 60°C for more than 7 days which would be effective for the destruction of pathogens. But the composting mixtures with initial C/N ratio of 20 and 25 did not meet that requirement. The final electrical conductivity values of the composting products were 4.22, 4.10 and 3.75 mS/cm respectively while the total organic carbon values were 30.61%, 31.51% and 35.46% in the composting mixtures, respectively. The results of ammoniacal-N of the composting mixtures indicated that the transformation of ammoniacal-N into nitrate by nitrification activity. Three different crops, maize, sorghum and tomato were selected for assessing the compost stability and maturity. The composting mixture with C/N ratio 30 showed the seed germination 50-84%, and biomass 37-64% in the selected crops. The results of this study suggested sawdust used as bulking agent at the optimum C/N ratio 30 for the composting of chicken manure was ideal to achieve the rapid degradation of organic matter and great retention of essential nutrient elements.

Keywords: Chicken manure, Sawdust, C/N ratio, Compost, Nutrient transformation, Compost maturity.

Potential of Carbon Emissions Avoidance from Food Waste Composting in Higher Education Institution (HEI)

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Globally, the amount of food waste is estimated to be about 1.3 billion metric tons per year (FAO, 2011). The environmental impacts of food waste are substantial (FAO, 2013a). In 2013, the Food and Agriculture Organization (FAO) of the United Nations determined that the amount of greenhouse gas emitted annually due to food waste in landfills is almost equivalent to the total emissions of Cuba (about 3.3 billion tons of CO2e/yr). Among all the treatment technologies, composting is most recommended because it able to reduce waste disposal in landfills, while simultaneously recycling organic materials by converting them into a beneficial product. This study aims to calculate the potential carbon avoidance by using carbon footprint assessment via case study of an established composting system at Universiti Malaya from year 2012 until 2021. The avoidance of carbon emissions are calculated from the avoidance of food waste degradation in landfill and transportation of food waste to landfill, and saving of diesel used for the transportation. The result shows that composting of food waste has great potential in carbon avoidance. The finding from this study addresses climate change in a comprehensive way and promoting a sustainable solution that is easier to start and manage to reduce food waste from being disposed to the landfills from HEIs.

Keywords: Food waste; Carbon avoidance; Composting; Carbon footprint assessment; Sustainable.

Value-Added Recycling of Three-Phase Residue By A Two-Stage Approach Combining Larval Bioconversion And Membrane-Covered Aerobic Composting

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ABSTRACT. Three-Phase Residue (TPR) is a secondary organic solid waste generated from the anaerobic digestion process for kitchen waste disposal. Incineration is currently the main way to manage TPR. In this study, the recycling technologies of TPR were studied. The results showed that TPR could be used as a substrate for the bioconversion of housefly larvae, the bioconversion rate and reduction rate of TPR reached 16.07% and 44.64%, respectively. The frass produced after bioconversion could be decomposed in 15 days by the membrane-covered aerobic composting. The features of thermophilic stage, seed germination index and dissolved organic matter indicated the frass hold a good composting performance. By using this two-stage method, 1 ton TPR could produce 160 kg larvae products and 310 kg organic fertilizer.

Keywords: Three-Phase Residue; Bioconversion; Aerobic composting; Housefly larvae

1. *Introduction*

Over the past 20 years, the urban population in China has increased from 459 million in 2000 to 921 million in 2022. At the same time, the total amount of municipal solid waste has increased to about 240 million tons/year and kitchen waste accounts for 50–60% [1]. Since 2010, the Chinese government has started the recycling project of kitchen waste, gradually replacing landfills and incineration [2]. Aerobic digestion is the preferred technology for the recycling of kitchen waste in China due to a larger scale, cleaner process and lower carbon emissions compared with other technologies [3]. The anaerobic digestion of kitchen waste requires the pretreatment, which typically includes sorting, crushing, boiling and three-phase separation [4]. After three-phase separation, the oil phase, as the most valuable portion, is collected for the production of biodiesel. The slurry phase undergoes an anaerobic digestion for about 30 days and generates biogas. The solid phase (commonly referred to as TPR) is transported out and co-incinerated together with other urban wastes [5]. Currently, the annual output of TPR has reached 3 million tons in China and continues to grow. It is necessary to find more cost-effective alternatives to TPR incineration. In this study, two recycling technologies for TPR were explored, including aerobic composting and a two-step approach combining larval bioconversion with aerobic composting.

2. *Materials and methods*

2.1 TPR

The TPR used in this study was provided by Heyuetang Modern Agricultural Development Co., Ltd., Huai'an City, Jiangsu Province, China.

2.2 Treatments

Frass treatment: the TPR first undergone the bioconversion by housefly larvae for 72 h, and then, the aging larvae were screened out and the frass (larval feces) was further aerobic composted.

KW treatment: the same batch of TPR as the Frass treatment was directly aerobic composted.

2.3 Composting reactors

The aerobic composting was conducted in two 150 L stainless steel reactors. In order to prevent the escape of larvae left in frass while ensuring smooth airflow, the top of the reactor was covered with a polytetrafluoroethylene membrane, and the bottom was paved with an 80 mesh stainless steel filter screen. Aeration was provided at a flow rate of 0.5 L/min/kg (dry weight) through an aerator pump.

2.4 Sampling and determination of parameters

A total of 16 solid samples and 31 gas samples were collected during the composting. pH values were measured using a pH meter (PHSJ4F, China). Moisture content (MC) was determined using a drying method at 105 °C to constant weight. Seed germination index (GI) was used to assess compost maturity [6]. The dissolved organic matter (DOM) was characterized by a three-dimensional fluorescence spectrometer (Hitachi F-7000, Japan).

3. *Results and Discussion*

3.1 Bioconversion of TPR by housefly larvae

The bioconversion of TPR by housefly larvae was carried out in two 350 m^2 farming ponds. During the bioconversion, 28 tons of TPR and 0.9 tons of inoculum medium containing new-born larvae were consumed, and 4.5 tons of housefly larvae and 15.5 tons of frass were produced. The bioconversion rate and reduction rate of the TPR reached 16.07% and 44.64%, respectively, which were consistent with a previous report on the bioconversion of the fresh kitchen waste by housefly larvae [7].

3.2 Properties of the composting

The aerobic composting of two treatments lasted for 31 days. The thermophilic stage of the Frass treatment was from day 1 to day 10, and the KW treatment was from day 3 to day 17 (Fig. 1a), both of which met the standards for harmless composting [8]. During the composting, the MC of the Frass treatment decreased from 61.14% to 53.85%, and that of the KW treatment decreased from 61.68% to 51.13% (Fig. 1b). The pH of the Frass treatment was relatively stable slightly alkaline throughout the composting, while that of the KW treatment moved from slightly acidic to slightly alkaline (Fig. 1c). The GI of the Frass treatment was consistently higher than that of KW treatment, but the final GI values of both treatments exceeded 80% (Fig. 1d), indicating their phytotoxicity had been removed [6].

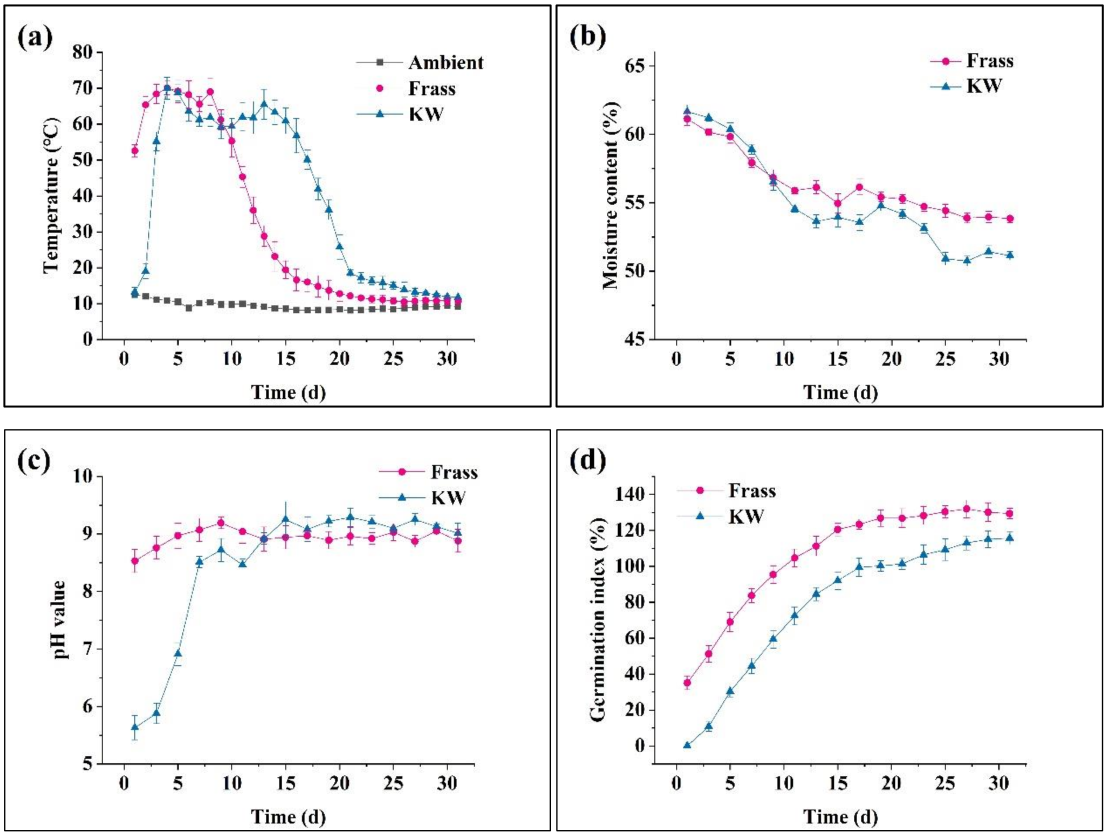

Fig. 1 Changes of physical and chemical parameters during the composting

3.3 Evolution of dissolved organic matter

The DOM characteristics indicated that the Frass treatment and the KW treatment had entered the maturity period of composting on the 13th and 19th days, respectively (Fig. 2). Overall the results of DOM, GI and temperature, we suggested that the aerobic composting periods for frass and TPR could be set at 15 days and 21 days, respectively. The reasons were that at this time, in both treatments, the GI values exceeded 100%, the DOMs were mainly humus, and the pile temperatures were close to the ambient temperature.

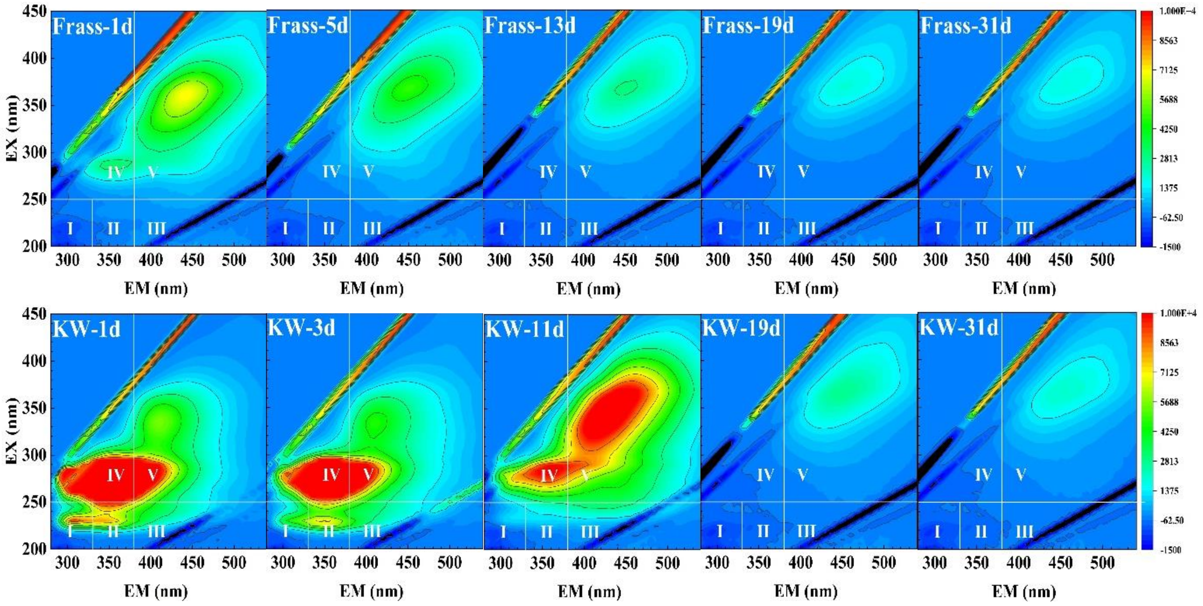

Fig.2 EEM fluorescence spectra of DOM during the composting

3.4 Economic feasibility

As shown in Fig. 3, when kitchen waste is transported into the anaerobic digestion plant, impurities more than 10% of the initial weight will be separated. The generated TPR accounts for 10-25% of the initial weight. If aerobic composting technology is used for the recycling of TPR, the period is 21 days, and 1 ton TPR (MC: 76%) can produce 540 kg organic fertilizer (MC: 30%). Calculated at 450 CNY/ton for organic fertilizer and a 30% profit margin, the output value and net profit per ton of TPR will be 240 and 70 CNY, respectively. If the two-step approach combining larval bioconversion and aerobic composting is used for the recycling of TPR, the period is 18 days, and 1 ton TPR can produce 160 kg larvae products and 310 kg organic fertilizer. Calculated at 5000 CNY/ton for housefly larvae products and a 40% profit margin, combined with the sales of organic fertilizer, the output value and net profit per ton of TPR will be 940 and 360 CNY, respectively.

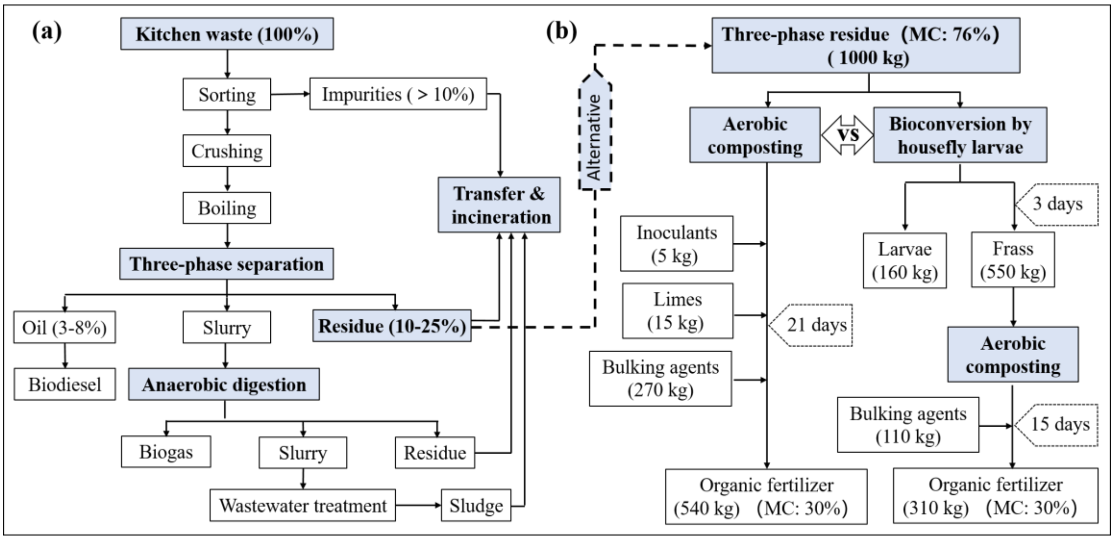

Fig. 3 Process of anaerobic digestion for KW disposal and the alternatives for the recycling of TPR

4. Conclusions

A two-stage approach combining the bioconversion by housefly larvae and the membrane-covered aerobic composting was proved to be a feasible alternative for the recycling of TPR. The economic feasibility analysis demonstrated the potential application prospects of this recycling method.

Acknowledgement

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Synergistic Effects of Biochar on Co-composting Food Waste and Swine Manure: Enhancing Composting Efficiency and Quality

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ABSTRACT. A considerable amount of the food produced each year is wasted, creating an urgent global problem with negative economic and environmental effects. Swine manure, a byproduct of intensive animal farming, can contribute to environmental issues if not properly managed. While biochar, a product of pyrolysis, can speed up the composting process and improve compost quality, sawdust is frequently used in composting to balance the carbon-to-nitrogen ratio. This study aimed to investigate the effects of biochar on compost quality in co-composting food waste and swine manure. Various experiments were conducted by manipulating the presence or absence of feedstock material. The findings revealed that a biochar concentration of 6% had a positive impact on the composting process. Furthermore, the presence or absence of feedstocks influenced the composting rate and the quality of the compost. The inclusion of biochar improved moisture balance and porosity, promoting beneficial microorganism growth. Moreover, biochar enhanced nutrient content and stability, that may lead to increased crop yields and improved soil health. We may support environmentally friendly waste management procedures and agricultural systems by keeping organic waste out of landfills and using biochar in the composting process. This study contributes for the the development of waste management strategies that are more effective and long-lasting and promote the development of a circular economy.

Keywords: Food waste; Swine manure; Biochar; Co-composting; Compost quality

Introduction

The issue of food waste is getting worse as the world's population expands. The Food and Agriculture Organisation (FAO) estimates that each year, nearly one-third of all food produced globally is wasted. There are enormous economic consequences to this problem. In addition to the lost economic value of the wasted food, food waste also contributes to greenhouse gas emissions, land use, and water consumption. When food waste decomposes in landfills, it releases methane, a strong greenhouse gas that accelerates global climate change. Swine production generates substantial waste from intensive animal farming, including feces, urine, and bedding materials. Swine manure, rich in nutrients like nitrogen, phosphorous, and potassium, can be beneficial as a crop fertilizer. However, improper management can lead to environmental issues, such as eutrophication and greenhouse gas emissions [1].

Sawdust is often used as an additive during composting to help balance the carbon-to-nitrogen (C:N) ratio of the composting materials. Sawdust is high in carbon and has a C:N ratio of around 200:1, which is much higher than most food waste and other organic materials, which tend to have a higher nitrogen content and a lower C:N ratio. By adding sawdust to the composting process, it helps to increase the carbon content and balance the C:N ratio of the materials being composted. The technique of pyrolysis, which includes heating organic materials like wood, agricultural waste, or animal dung without oxygen, is used to create biochar, a type of charcoal. A stable, carbon-rich substance that is rich in stability is the final product, and it can be utilized as a soil amendment to boost soil fertility, water retention, and carbon sequestration. Biochar can play a significant role in co-composting food waste and swine manure by enhancing the composting process and improving the quality of the resulting compost [2]. When food waste and swine manure are co-composted, they provide a mixture of organic matter that is high in nutrients. However, this mixture can also be quite wet and dense, making it difficult to compost effectively. Biochar can help to balance the moisture and porosity of the mixture by improving aeration and water-holding capacity. This helps to create a more stable composting environment that promotes the growth of beneficial microorganisms that break down organic matter.

In addition to improving composting conditions, biochar can also enhance the quality of the resulting compost. Biochar has a high surface area and a porous structure, which allows it to adsorb and retain nutrients and other beneficial compounds. The use of biochar in co-composting food waste and swine manure also contributes to sustainable waste management practices. By diverting organic waste from landfills and instead turning it into a valuable resource, we can reduce greenhouse gas emissions and create a circular economy that supports the health of the environment and society [3]. In this way, the combination of food waste, swine manure, sawdust, and biochar have the potential to address multiple environmental challenges simultaneously. By improving the efficiency and quality of the co-composting process, the experiment could contribute to the development of more sustainable waste management practices and agricultural systems. In this study with the aim to identify the optimal combination of additives for co-composting food waste and swine manure, different experiments were carried out by varying the presence and absence of feedstock material.

In our recent findings, we discovered that a biochar concentration of 6% is necessary for achieving a positive effect on the co-composting of food waste and swine manure. Remarkably, factors such as like the presence and absence of feedstocks can influence the effect of biochar amendments on the composting rate and the quality of the compost. To further expand our understanding in this field, this study aims to investigate the effect of biochar on the quality of the compost by exploring different scenarios involving the presence and absence of feedstock material. To analyse the outcomes, we conducted different analysis on the compost product.

Material and Methods

Raw materials

The food waste was collected the Suwon city food resource recycling facility. Swine manure was collected from local pig farm and sawdust was collected from the local wood industry. The biochar was purchased from local market.

Experimental design

The raw materials were manually mixed in various weight proportions to ensure homogeneity. Table 1 contains a summary of the proportion of raw materials. The initial moisture contents of the six different treatments were adjusted to 65%. The 50-day composting experiment took place in a vessel at a temperature of 21±2 °C, with periodic thorough mixing of the raw materials to ensure even distribution.

Table 1: Proportions of raw materials used in different treatments

Treatments	FW	SM	SD	BC	Salts	
					$MgCl_2$	K_2HPO_4
T1	70%(5.6kg)	10%(0.8kg)	20%(1.6kg)	-	-	-
T2	70%(5.6kg)	10%(0.8kg)	20%(1.6kg)	6%(480g)	-	-
T3	70%(5.6kg)	10%(0.8kg)	20%(1.6kg)	-	0.02 M	0.1 M
T4	-	10%(0.8kg)	20%(1.6kg)	6%(480g)	0.02 M	0.1 M
T5	70%(5.6kg)	-	20%(1.6kg)	-	0.02 M	0.1 M
T6	70%(5.6kg)	10%(0.8kg)	20%(1.6kg)	6%(480g)	0.02 M	0.1 M

Physicochemical analysis

Samples were collected during the active phase of composting at different intervals. The pH and electrical conductivity were measured at days 0, 7, 14, 21, 28, 35, 42 and 50. The pH and EC of each sample was determined by mixing sample in distilled water in the ratio of 1:10 (w/v) and analyzed using a pH meter and conductivity meter, respectively. The compost temperature was measured daily using a temperature sensor and data logger. The CO_2 and ammonia emission rate were measured daily by alkali trapping method and spectrophotometric method as described by Ren et al. The initial and final substrates of all the treatments were used for the analysis of bulk density and total porosity by following the standard methods. TGA and FTIR analysis were conducted for initial and final substrates to generate a temperature-dependent mass profile and to identify the functional groups

Statistical analysis

The data obtained from physicochemical analysis was analyzed statistically using Origin 2023 software and the significant differences between were determined.

Results and Discussion

Dynamics of physicochemical characteristics during composting

During the 50 days composting process, a significant change in the physicochemical characteristics of the compost which indicates the maturity was observed.

Temperature, pH and electrical conductivity

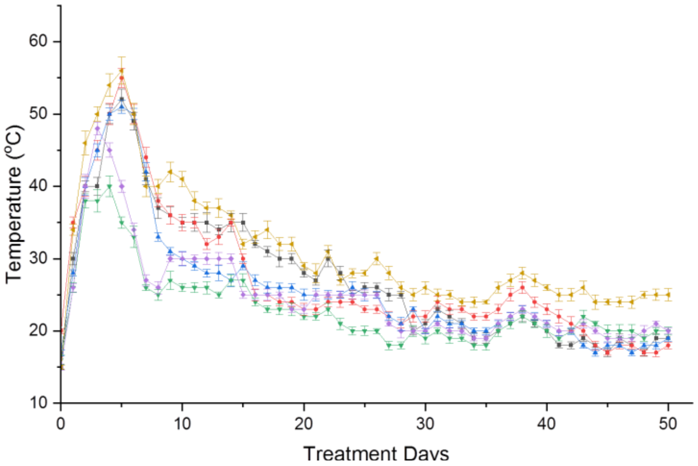

Figure 3: Dynamics of temperature trends observed in each treatment group

In this study, daily monitoring of temperature was conducted throughout the 50-day treatment period. Initial temperature of all the batches was 16.50 ± 2.00 °C. All the batches experienced a rapid rise in the temperature, of which batches T6, T2, T3 and T1 raised above 50 °C and remained in the thermophilic phase for 2-4 days. According to the temperature trends, the batches that lack either swine manure or the food waste couldn’t enter the thermophilic phase. The lower temperatures are likely because of the low moisture levels that could have limited the microbial growth and activity that enhances the decomposition and the heat generation. Batch (T6) that was composted in the presence of both along with biochar and salts maintained the temperature >50 °C for four consecutive days. Whereas batches that lack either biochar or salts could maintain thermophilic phase for only three days. However, the maintenance of thermophilic phase for 3 days is sufficient to provide standard sterilization of the compost. Thermophilic phase was followed by mesophilic phase which corresponds to temperature trends during usual composting. The highest temperature in this study was reached in the batch that has all the feed-stocks along with biochar and salts. B. Ravindran et al., in an earlier study have reported the favorable condition provided by biochar and the importance of addition of salts during composting [4].

The pH fluctuations followed a similar pattern, with a gradual increase in pH and reaching to around 7.5–8.0 on the 21st day and stabilizing at about 6.5–7.0 in the finished compost. The ammonization process that takes place during biodegradation, volatilization with subsequent release of greenhouse gases and nitrification are likely the reasons behind for the elevation in pH in treatment groups. The compost that had been amended with biochar alone maintained a higher pH. This was most likely caused by the high initial pH. The potential reason could be because of the inherent alkaline properties of the biochar, resulting in initial higher pH levels that continues during the composting process, leading to higher final pH values. Further, biochar synthesis process leaves residues of carbonate and ash, which when added to the composting mixture, may affect pH levels. Additionally, these treatments had a higher rate of ammonia release as a result of ammonification. Ammonification and mineralization during composting caused the pH to rise [5].

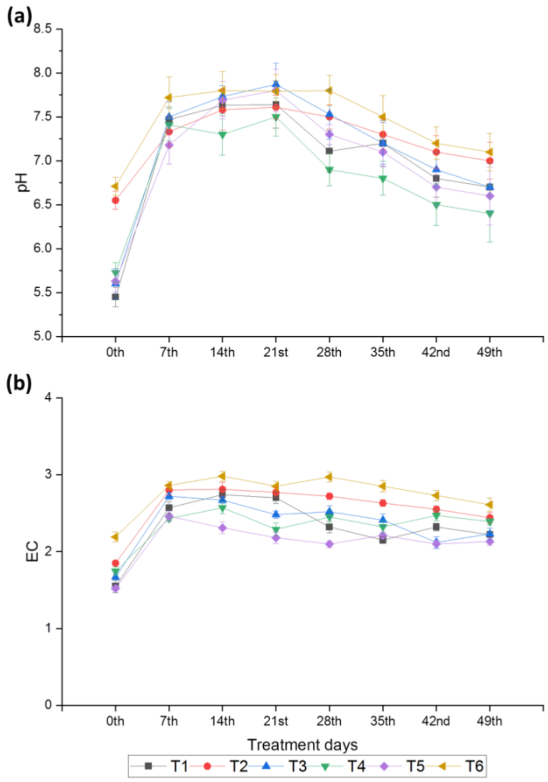

Figure 4: (a) pH and (EC) dynamics observed in each treatment group

The initial EC values varied among the different batches, reflecting the variations in the starting materials and their respective salt contents. The presence of food waste, swine manure, sawdust, biochar, and other additives influenced the initial EC levels in the composting mixtures. In the batches containing biochar, the EC values showed a gradual increase over time, indicating the breakdown of organic matter and the subsequent release of ions into the compost. The biochar may have also contributed to the overall ion concentration and conductivity due to its inherent properties and potential leaching of soluble compounds. Throughout the composting period, the EC values in the batches that lacked either food waste or swine manure remained relatively stable or increased at a slower rate compared to the biochar-amended batches with all the feedstocks present. These organic materials (food waste and swine manure) contain soluble salts and nutrients, which can enhance the conductivity of the compost. The breakdown and decomposition of these materials during composting can lead to the release of ions and an increase in EC. This suggests a lower level of salt accumulation and ion release in the treatments that lack these organic materials. Additionally, the biochar may have influenced microbial activity and metabolic processes, resulting in the release of soluble compounds and subsequent increases in EC [6].

Bulk density and porosity

Bulk density and porosity measurements were conducted to evaluate the physical characteristics of the composting materials and their influence on the composting process. The initial bulk density varied among the different batches, reflecting the composition and characteristics of the initial materials. Components such as food waste, swine manure, sawdust, and biochar influenced the initial bulk density values in the composting mixtures. The initial bulk density decreased as the composting process progressed, indicating a reduction in material density. This reduction in bulk density can be attributed to the breakdown and decomposition of organic matter, which results in the release of gases and the compaction of the composting materials [7].

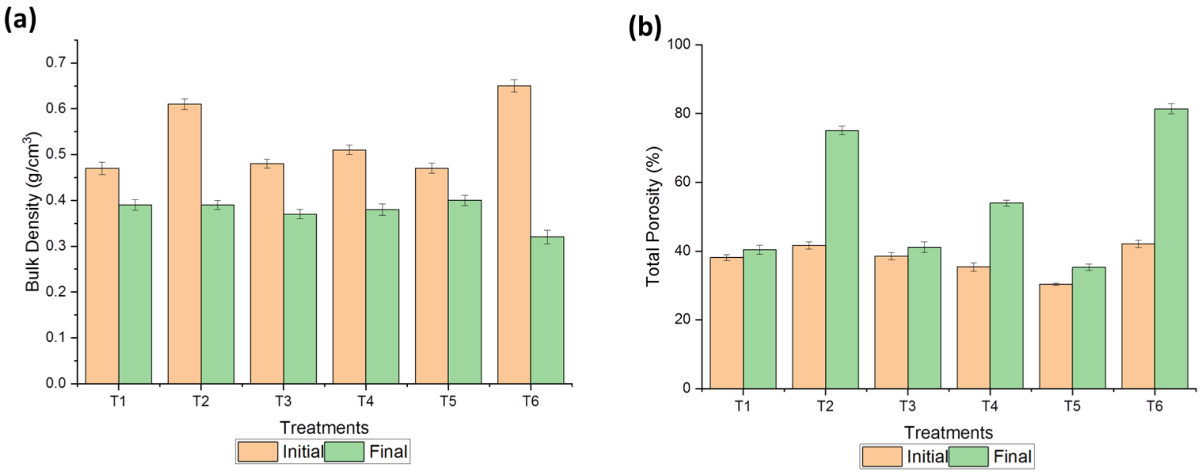

Figure 5: Dynamics of (a) bulk density and (b) total porosity observed in each treatment groups

Whereas, the initial porosity typically decreased as the composting process progressed, indicating a decrease in the air-filled spaces within the compost. This can be attributed to the compaction of the materials and the breakdown of organic matter, which leads to the generation of finer particles that fill the void spaces. The observed changes in bulk density and porosity during composting have significant implications for the composting process and resulting compost quality. A lower bulk density and higher porosity promote better airflow, moisture distribution, and microbial activity within the composting mixture [8]. These factors are crucial for the efficient decomposition of organic matter and the production of high-quality compost.

Gaseous emission

NH_3 (ammonia) and CO_2 (carbon dioxide) measurements were conducted to assess the levels of these gases during the composting process. The concentrations of NH_3 and CO_2 provide valuable insights into the biological activity and microbial transformations occurring within the compost. Here, we present the results of NH_3 and CO_2 measurements and discuss their implications. The initial NH_3 concentrations varied among the different batches, reflecting the variations in the starting materials and their nitrogen content. The presence of nitrogen-rich components, such as food waste and swine manure, influenced the initial NH_3 levels in the composting mixtures. NH_3 levels typically increased rapidly, then reached a peak and gradually decreased over time as the composting process progressed. The batches containing biochar showed different NH_3 concentration patterns compared to the batches without biochar. The biochar-amended batches exhibited lower NH_3 concentrations throughout the composting period, suggesting a reduced release of ammonia. This may be attributed to the adsorption capacity of biochar, which can adsorb and retain ammonia, thus reducing its gaseous release. The observed NH_3 concentration pattern can be attributed to availability of nitrogen-rich organic materials leading to higher NH_3 concentrations [9]. The reduction in NH_3 release in biochar-amended batches can be attributed to the adsorption capacity of biochar, which can help mitigate ammonia emissions.

On the other hand, the initial CO_2 concentrations increased steadily in all batches. The presence of biochar in the composting mixtures did not show a significant influence on the CO_2 concentrations. The CO2 production was primarily driven by the microbial activity, and the biochar itself does not directly contribute to carbon dioxide emissions. However, the overall CO_2 concentrations tended to be higher in batches with higher organic matter content, such as those containing food waste and swine manure. The CO_2 concentrations reflect the overall metabolic activity of microorganisms during composting. Higher organic matter content, as seen in batches with food waste and swine manure, promotes microbial respiration and subsequent carbon dioxide production. The biochar, although not directly influencing CO_2 concentrations, can indirectly affect microbial activity and carbon cycling processes through its interactions with the composting mixture.

Conclusions

In conclusion, the presence of feedstock materials, specifically swine manure and food waste, proved to be crucial in the co-composting process. The combination of swine manure and food waste created an optimal environment for diverse microbial populations to thrive, facilitating the decomposition process and ensuring the production of nutrient-rich compost. Biochar amendments in the co-composting of food waste and swine manure showed positive effects by improving pH regulation, temperature maintenance, electrical conductivity, ammonia emissions, bulk density, and porosity. Moreover, the inclusion of feedstock materials in co-composting practices aligns with the principles of sustainable waste management. This ensures the production of a high-quality compost that not only supports soil health and agricultural sustainability but also reduces the environmental burden associated with organic waste disposal.

Acknowledgement

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Vermitransformation of *Lantana Camara* Weed Biomass Amended With Biochar Into Value Added Vermifertilizer

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Jitngernmadan**ABSTRACT.** Composting systems benefit from biochar's properties since it enhances the quality of end products and composting. Weeds like *Lantana camara* are obnoxious and invasive in nature. The large biomass of *L. camara* can be utilized for vermicomposting as an ecofriendly option. In the present study, *Prosopis* wood biochar at the rate of 0, 2, 4, 6 and 8% level was amended with the precomposted *Lantana camara* +cow dung (1:1) and subjected to vermicomposting using the epigeic earthworm, *Eudrilus eugeniae* for 50 days. The physicochemical parameters, namely, electrical conductivity, total Kjeldahl nitrogen, total phosphorus and total potassium in 4% biochar amended vermicompost at the end of vermicomposting were higher than the other treatments; while pH, total organic carbon, C/N and C/P ratios were found to decline. The activities of the enzymes, *viz.*, cellulase, dehydrogenase, and urease were variable with reference to the duration of vermicomposting and the rate of biochar application. There was a significant difference between treatment with biochar and control without biochar regarding the activities of dehydrogenase, urease and cellulase.

Keywords: Enzyme activity; Epigeic earthworm; Vermicomposting; Weed biomass; Wood biochar.

Introduction

The use of earthworms in vermicomposting allows organic wastes to be converted into valuable organic fertilizer. In terms of organic waste recycling and pollution abatement, vermicomposting technology is both environmentally friendly and socially relevant [1]. Among the various organic wastes utilized for vermicomposting, weeds are occupying a vital position as they cause menace to the local biodiversity [2]. These weeds can be utilized for useful purposes such as composting and vermicomposting [3]. Soil enzymes are involved in metabolic processes and energy transfer associated with plant and microbial growth. Enzymes are thus potential indicators of soil biological activity and fertility. This is also true in case of vermicomposting process where various enzymes indicate the process of organic matter conversion and stabilization. Hence, it is very much essential to study the enzyme dynamics during vermicomposting.

Researchers across the world utilized various weed species available in their locality for vermicomposting employing mainly the epigeic earthworms. For example, in a two stage large scale process, the aquatic weed, *Eichhornia crassipes* biomass was converted into vermicompost using the earthworm, *Eisenia fetida* [4]. The Siam weed, *Chromolaena odorata* and cow dung in the ratio of 3:2 resulted in the enriched vermicompost production and supported the earthworm (*Eisenia fetida*) multiplication [5]. Several weed species including seaweeds have been successfully subjected to vermicomposting and vermicompost production [2,6]. However, the physicochemical changes and dynamics of degradative enzymes during the bioconversion of *Lantana camara* weed biomass amended with wood biochar has not been reported and requires much attention considering the availability of large biomass of the weed. Hence the present study has been carried to assess the dynamics of physicochemical changes and degradative enzymes during the vermiconversion of *Lantana camara* biomass + cow dung (1:1) by amending different proportions of wood biochar.

Materials and methods

Vermicomposting

After collecting and washing the leafy biomass of the weed, *Lantana camara* with tap water, it was chopped into 3-4 cm pieces and dried under shade for 7 days. Fresh cow dung was collected from nearby cow shed and shade dried for 7 days and used for the study. In order to amend the vermicomposting substrate, the *Prosopis* wood biochar was finely ground for obtaining biochar powder. Vermibed preparation was carried out by mixing cow dung and plant biomass in a 1:1 ratio on a dry weight basis (wt./wt.). During precomposting, 40-50% moisture was maintained in the substrate mixtures for 15 days. With different biochar concentrations, substrate mixtures were prepared (B1=0% biochar; B2=2% biochar; B3=4% biochar; B4=6%; B5=8% biochar). Watered to 70-80% moisture and allowed to stabilize for 24 hours, the precomposted substrate mixtures were placed in uniform plastic containers. Following this, each experimental setup was introduced with 20 mature clitellate earthworms (*Eudrilus eugeniae*). The experimental set-ups were replicated three times. Experiments were conducted in a dark room with a temperature of 27 °C ± 2 °C. During the vermicomposting process, water was added when necessary to maintain the substrate moisture content and the vermicomposting experiments were conducted for 50 days.

Macronutrient analysis

On 0, 10, 20, 30, 40 and 50 days of vermicomposting, the vermicompost samples from the vermibeds were sampled, and air dried for the analysis of pH, electrical conductivity, total organic carbon, total Kjeldahl nitrogen, total phosphorus, total potassium, C/N ratio and C/P ratio using standard procedures.

Evaluation of enzyme activity

All treatments and controls were sampled at regular intervals, including the control (0, 10, 20, 30, 40, and 50th day) for the analysis of the enzymes, cellulase, dehydrogenase, and urease using standard methods.

Statistical analysis

The physicochemical characteristics and the activity of different enzymes during vermicomposting were expressed as the mean ± standard error of the mean. The statistical variation of each enzyme between treatments and control treatments was done through the analysis of variance (ANOVA). The significance level was set at $P<0.05$ using Tukey's HSD comparison test.

Results and Discussion

The changes in physicochemical parameters during vermicomposting of *Lantana camara* are shown in Fig 1. Overall, the pH, total organic carbon, C/N ratio and C/P ratio showed decrease while the electrical conductivity, total nitrogen, total phosphorus and total potassium variably increased in different treatments with biochar. The results clearly reveal that the amendment of biochar at an optimum level is needed for obtaining vermicompost with high nutrient contents. The nutrients, total nitrogen, total phosphorus and potassium were higher in B3 treatment contained the *Lantana camara* biomass + cow dung (1:1) + 4% biochar. A maximum of 2.20% of total nitrogen was recorded in B3 vermicompost followed by B2 vermicompost (1.83%). Also, higher total phosphorus content of 1.46% was observed in B3 vermicompost. Similarly, the vermicompost in B3 contained an elevated level of 1.78% of total potassium content when compared with remaining treatments. The findings clearly show that 4% wood biochar amendment enhances the nutrient contents in the vermicompost of *Lantana camara* biomass. During vermicomposting process, earthworms and the microorganisms in the vermireactor take part in physical, mechanical and biological fragmentation of the substrates thereby improve the available nutrients [7]. Besides, the excrements of earthworms enhance the microbial population and nutrient contents in the vermicompost [8]. The findings of the present study fall in line with the earlier results [9].

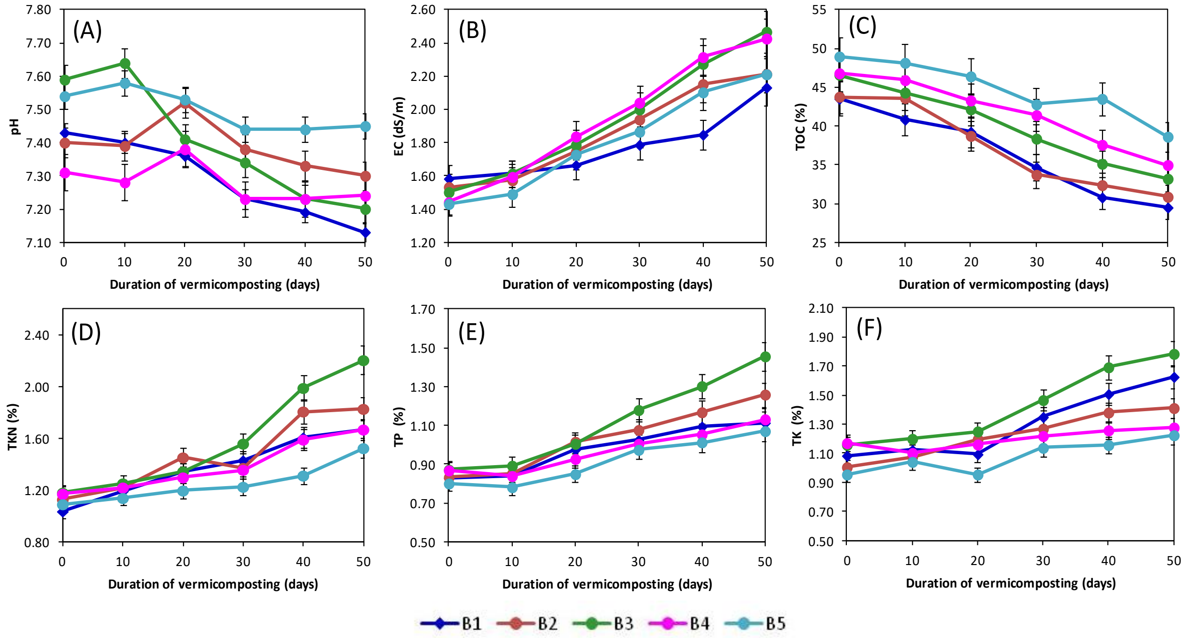

Fig. 1: Physicochemical changes during vermicomposting of *Lantana camara* leaf biomass+cow dung (1:1) amended with different doses of wood biochar. (A) pH, (B) Electrical conductivity; (C) Total organic carbon, (D) Total Kjeldahl nitrogen, (E) Total phosphorus and (F) Total potassium (Mean ± standard error).

The dynamics of enzyme activities *viz.*, dehydrogenase, urease and cellulase are given in Table 1. It is clear from the results that the enzyme activities are substrate-dependent which increases initially, attain maximum activity and start to decline towards the end indicating the maturation process of vermicompost. In general, the activity of the enzymes, dehydrogenase, urease and cellulase was higher in the substrates inoculated with earthworms over control with a significant ($P<0.05$) difference between control and respective vermicomposting treatments. Also, the individual enzyme activity varied greatly between treatments. The average activity of dehydrogenase was 53.36, 50.24, 57.39, 54.21, and 50.62 µg TPF g^{-1} dw h^{-1} respectively in B1, B2, B3, B4 and B5. A maximum urease activity was found in B3 with 4% biochar which was significantly different from B1, B2, B4 and B5 treatments respectively with 0, 2, 6 and 8% biochar amendments. Similar enhanced activity of cellulase was also observed in B3. It is a well known fact that the oxidation of organic matters of biological origin is a dehydration process where its dependency is vitally associated with dehydrogenase, and its higher activity is correlated to microorganisms and water-soluble organic compounds showing intensive activity during initial phases and declining activity towards the end as an indication of vermicompost maturity. In the present study also, ups and downs in dehydrogenase activity were observed in all the treatments with and the results comply with the previous vermicomposting studies.

Table 1. Average activity of dehydrogenase, urease and cellulase during 50 days vermicomposting of *Lantana camara* amended with biochar (Mean ± standard error).

Treatments	Dehydrogenase (µg TPF g^{-1} dw h^{-1})	Urease (mg $NH4^{+}$ g^{-1} dw h^{-1})	Cellulase (mg g^{-1} dw h^{-1})
B1	53.36 ± 1.21^{bc}	38.10 ± 0.86^{a}	85.17 ± 1.93^{d}
B2	50.24 ± 1.14^{c}	40.76 ± 0.92^{b}	87.69 ± 1.99^{c}
B3	57.39 ± 1.30^{a}	49.57 ± 1.12^{a}	104.35 ± 2.37^{a}
B4	54.21 ± 1.23^{b}	42.19 ± 0.96^{b}	93.27 ± 2.12^{b}
B5	50.62 ± 1.15^{c}	42.74 ± 0.97^{b}	77.51 ± 1.76^{d}

The different alphabets between treatments differ significantly at $P<0.05$ by Tukey's HSD multiple comparison tests.

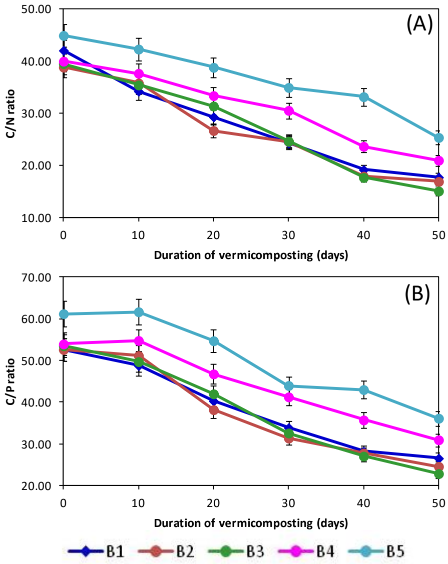

Fig. 2: Changes in (A) C/N ratio and (B) C/P ratio during vermicomposting of *Lantana camara* leaf biomass+cow dung (1:1) amended with different doses of wood biochar (Mean ± standard error).

The enzyme activity in the vermibed during vermicomposting is mainly due to the microbial population and their activity in the decomposition of complex materials into available forms [8]. Moreover, the study of enzymatic activities during biomass conversion in different organic waste mixtures helps to understand the mediators of bioconversion. In the present study, dynamics of the enzymes, dehydrogenase, urease and cellulase during the vermicomposting of *Lantana camara* biomass+cow dung amended with different proportion of biochar clearly indicate that the activity of enzymes is dependent on biochar concentration in the substrate. The C/N ratio and C/P ratio showed reduction towards the end of vermicomposting. The lowest C/N ratio of 15.07 was observed in B3 followed by 16.90 (T2). Similar trend was found in C/P ratio also (Fig. 2). The reduction of total organic carbon proportionately elevated the levels of total nitrogen and hence the reduction of C/N ratio. The optimum C/N ratio of <20 for agronomic application was attained in B3 and B2.

Conclusion

The amendment of biochar to the vermibed substrate improved the macronutrient contents. The findings of the present study suggest that the combination of 15 days precomposted *Lantana camara* biomass and cow dung in 1:1 ratio with the addition of 4% biochar improves the nutrient contents and the activity of degradative enzymes. Hence the B3 treatment combination, i.e., *Lantana camara* biomass + cow dung (1:1 ratio) + 4% biochar can be used to convert the weed biomass into valuable vermicompost.

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Biowaste Valorization

Insect-based Biorefinery for Organic Wastes Valorization

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Food security is at the forefront of the critical global concerns due to increased population growth, rapid urbanization, increased occurrences of climate-related disasters (e.g., extreme heat, droughts, floods, and storms), and pandemics like COVID-19. Growth in population and affluence is likely to increase the global food demand by over 50% by 2050. The conventional agricultural practices for producing food and feed are highly resource intensive (high use of fresh water and synthetic agrochemicals including fertilizer and pesticides), leading to eutrophication, soil degradation, greenhouse gases emissions, biodiversity loss, among others. At the same time, over a billion metric tons of food is being wasted each year, accounting for 17% of total food produced for human consumption. Moreover, organic waste management has been a long unsolved issue elsewhere, especially in low- and middle-income countries. In the context of environmental, economic, public health, and food security issues associated with the ever-increasing and non-sustainable way of using limited resources for food and feed production, coupled with the generation of large amounts of organic wastes, insect farming on organic wastes has gained significant research and development interest as one of the emerging industries for valorizing different organic wastes to high-quality food, feed, fertilizer, and bioproducts. Such interest is also reflected in the increased investment in the sector (insect industry for food and feed application), which is expected to increase from about US$ 1 billion in 2020 to over US$ 3 billion by 2025, while market value and market volume of the insect for food and feed industry is projected to reach US$ 9.6 billion and over 3.1 million metric tons by 2030, respectively. This presentation critically discusses the current state-of-the-art of bioconversion of organic wastes into food, feed, fertilizer, and bioproducts via insect farming; identifies the research gaps; and highlights the challenges associated with development and commercialization of the insect technology.

Keywords: Organic wastes, Insect farming, Bioconversion, Biorefinery, Bioproducts.

Integrated Genomic and Field Level Evaluation of Agricultural Waste Enriched Potential Streptomyces UP1A-1 for Plant Growth Promotion and Disease Control

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ABSTRACT. The current study planned to utilize the agricultural waste materials farm yard manure enriched talc-based *Streptomyces* UP1A-1 to evaluate the plant growth and bacterial wilt disease control of tomato and eggplant in different agricultural field conditions. In both field conditions the bio-formulation *Streptomyces* UP1A-1 was recorded the least disease incidence of 8.32 and 3.32 plant disease index in tomato and eggplant, respectively. Similarly, the FYM enriched bio-formulation *Streptomyces* UP1A-1 recorded the highest total yield of tomato and eggplant fruits by recording 39,387 kg/ha and 29,489 kg/ha of tomato and eggplant, respectively. The genome sequence was showed that the *Streptomyces* UP1A-1 genome has a total of 8,252,902 bp with 72.42% G + C content. PGP conferring genes such as siderophore production, indole-3-acetic acid (IAA) biosynthesis, phosphate solubilization, nitrogen metabolism and potassium metabolism were determined. Similarly, genes putatively responsible for disease control including chitinase production, peroxidase, superoxide dismutase, catalase, proline biosynthesis and glucose dehydrogenase were determined. These genes reveal the genetic adaptation of UP1A1 to versatile environmental conditions and the effectiveness of the isolate to serve as a biotic and abiotic stress controller.

Keywords: *Agriculture waste, Farm Yard Manure, Streptomyces, Whole genome sequencing, Plant growth, Disease control*

Introduction

Solanaceous crops are mostly susceptible to several infectious and non-infectious agents, restricting their growth. Among the many fungal, bacterial, and viral diseases that affect solanaceae crops, the bacterial wilt produced by *Ralstonia solanacearum* is the most severe one (Singh et al., 2012). The earliest indication of *R. solanacearum* in India was in potato crop, where it caused brown rot or bangle blight disease (Shekhawat et al., 1992). In Tamil Nadu, *R. solanacearum* was initially discovered in eggplant (Selastin Antony et al., 2015), followed by tomato (Balamurugan et al., 2018). Actinobacteria are active against various phytopathogens, including *R. solanacearum* (Elsayed et al., 2020). Several species of actinobacteria are utilized as biocontrol agents to control different soil-borne plant diseases due to their vast secondary metabolic potential and enzyme synthesis. *Streptomyces* were long known as merely free-living residents of soil, but recent discoveries have revealed the significance of their dynamic relationship with plants and other species is being uncovered (Dutta and Thakur, 2020). In view of the above information, the following study was conducted in field condition by *Streptomyces* against *R. solanacearum.*

Material and Methods

Antagonist

Antagonistic *Streptomyces* strain UP1A-1 was selected for field trail based on our pervious study (Manigundan et al., 2022a, 2022b).

Field location and condition

Field experiments were conducted in two different places, one at Kaaramadai (Lat. 11º23'N; Long. 76º91'E) Coimbatore district for tomato, Chengalpattu (Lat. 12º47'N; Long. 79º94'E) Tamil Nadu for eggplant, during 2021 cropping season. These fields were selected based on our pervious study showing the bacterial wilt disease incidence in the same field locations (Balamurugan et al., 2018; 2020).

Field study

The field experiments were conducted at two different areas separately to test the bio-efficacy of talc formulation of potential *Streptomyces* strain UP1A-1 against *R. solanacearum* causing bacterial wilt disease in tomato and eggplant. Field treatments included (1) Control; (2) organic fertilizer (OF); (3) SFYM (*Streptomyces* UP1A-1 enriched farm yard manure). The plots in all experiments were arranged randomly. Each plot was 15 m^2 (5 m×3 m) containing 10 seedlings. The application rate of BOF was 2.5 kg $plot^{-1}$ in the field plots. Each treatment with four plots was randomly arranged in the selected fields. In all experimental plots, standard agronomic practices were applied to culture the tomato and egg plants without the use of any other pesticides. The disease incidence was recorded regularly and yield was recorded for each harvest. Disease incidence, biocontrol efficacies and yield increase were calculated using the following equation:

Disease incidence = [total no of plant wilted/ total no of plants inoculated] x 100

Biocontrol efficacy = [(total no of plant in treatment − total no of plant in control)/ total no of plant in control] × 100

Yield increase by BOF = [(Average yield of tomato/ eggplant treated with BOF - Average yield of tomato/ eggplant in OF) / Average yield of tomato/ eggplant in control] x 100.

Genome DNA Extraction and Sequencing

Genomic DNA was isolated from *Streptomyces* sp. UP1A-1 culture initially grown on ISP-2 medium at 28°C for 7 days, following standard bacterial DNA isolation kit as per manufacturer's instructions. Purified high-quality genomic DNA was used for library preparation using NEBNext Ultra DNA Library Prep Kit (E7370) and sequencing on Illumina Hi-Seq 2500 platform. Raw Illumina reads were subjected to rigorous quality checking with help of FastQC (Andrews et al. 2018) and trim-galore. Further SPAdes *de novo* hybrid assembly was carried out using Unicycler tool (Wick et al. 2017).

Genome Assembly and Annotation

For further analysis, we submitted our hybrid assembly for PATRIC's Comprehensive Genome Analysis Service (PCGAS) (Wattam et al. 2017). For identification and characterization of biosynthetic gene cluster in *Streptomyces* sp. UP1A-1 assembled genome was configured using ViroBlast tool (Deng et al. 2007). This sequence was further submitted to the antiSMASH-3 webserver to understand the presence of various biosynthetic gene cluster. RAST server helped annotation of microbial genomes, built upon the frame work provided by the SEED system. The protein sequences encoded by genes were blasted with COG function database.

Statistical analysis

Mean differences of the treatment were evaluated with ANOVA using SPSS software by Duncan multiple post hoc comparison tests (version 16.0). The statistical significance of $P \leq 0.05$ was examined.

Results and Discussion

Field study

The field experiment was conducted in Kaaramadai area, Coimbatore district of Tamil Nadu, India clearly revealed that the treatment UP1A-1 comprising the talc formulation of *Streptomyces* UP1A-1 recorded the least disease incidence of 8.32 PDI as against 43.31 PDI in control and thus accounted for the highest disease reduction of 83.45% over control. Also, the treatment UP1A-1 recorded the highest total yield of tomato by recording 39,387 kg/ha, and it was followed by the treatments FYM alone by recording 29,548 kg/ha respectively (**fig. 1**). Similarly, eggplant field experiment from Murugampakkam area, Chengalpattu district of Tamil Nadu, India also revealed that the treatment UP1A-1 was recorded the least disease incidence (**fig. 1**). Similarly, Boukaew et al., (2011) reported that the efficient *Streptomyces philanthi* RL-1-178 was the potent biocontrol agent and reduced the wilt disease, resulting in 58.75% biocontrol efficacy of chili pepper.

Whole genome sequence, assembly and gene prediction

A total of 8,252,902 processed reads for UP1A-1 was obtained from genome sequencing. The average read length of UP1A-1 was 150bp whereas GC content was 72.42%. The strain UP1A-1 genome was finally assembled in 3 contigs. The estimated genome size based on the sequence data was 3.9 Mb. Similarly, the genome sizes of the members of this family have been reported to range from 2.8 to 5.8 Mb (Wang et al., 2021). Augustus tool which uses Hidden Markov model predicted 9661 protein coding genes in UP1A-1 genome. Similarly, Wang et al., 2021, have predicted 8110 genes for the species of *S. griseorubiginosus*. The annotation done against PATRIC's own manually curated databases revealed 9434 CDS regions, 64 tRNA, 18 rRNA, and 115 repeat regions. Gene annotation in RAST server predicted genes into 11 subsystems with 9661 predicted coding sequences. Selective superiority of UP1A-1 is corroborated as multiple genes involved in important functions regarding plant disease control, various stress control, plant growth promoting, soil and plant colonization and other relevant attributes of biotechnological interest, as has been reported in a *Streptomyces* strain such as NEAU-S7GS2 and Z38 genome (Costa et al., 2020; Liu et al., 2019).

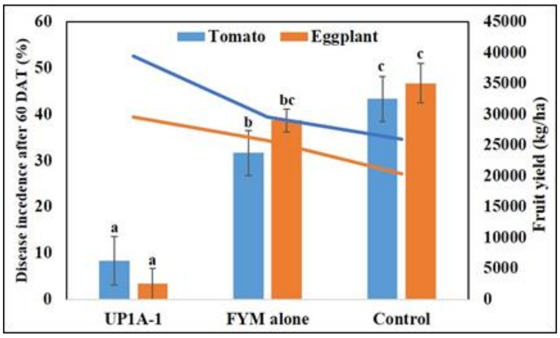

Figure 1. Effect of *Streptomyces* strain UP1A1 amended talc formulation for disease control and fruit yield enhancement in tomato and eggplant.

Predicted Genes for Secondary Metabolites

Streptomyces UP1A-1 genome had 25 putative gene clusters for secondary metabolites. For antimicrobial compound synthesis, there were five predicted gene clusters with 100% similarity to clusters for the synthesis of RiPP: Lanthipeptide- SapB, Coelibactin and albaflavenone. There was also two gene cluster with more than 90% similarity to the gene cluster for Streptothricin (95%) and Hopene (92%) synthesis and two more gene cluster with more than 80% similarity to the gene cluster for Candicidin (85%) and Desferrioxamin B / Desferrioxamine E (83%) paenibacterin synthesis.

COG functional classification

For the functional prediction using COG databases, 6225 unigenes were annotated with COG functional groups categorizing into 21 categories. Among these functional groups, the first five largest groups were found to be Function unknown category (1185 unigenes), Transcription category (807 unigenes) and amino acid transport and metabolism category (596 unigenes), carbohydrate transport and metabolism category (492) and signal transduction category (371 unigenes) indicated the better absorption capacity and response ability of UP1A-1 for amino acids and carbohydrates in the living soil environment.

Predicted genes for PGP and other related traits

The functional annotation by Prokka revealed the presence of several genes within the genome of *Streptomyces* strain UP1A-1 whose annotated products can have PGP characteristics. Those genes are related to processes that play a helpful role in plant growth and disease control such as siderophore production, phosphate solubilization, tryptophan synthesis, nitrogen metabolism, potassium metabolism, chitinase production, catalase. A set of genes responsible for the production of chitinases were detected within the genome of the *Streptomyces* strain UP1A-1. That suggests a strong antimicrobial activity of this strain. Also, the production of peroxidases, superoxide dismutase, catalase, proline synthesis, peroxidase, glucose dehydrogenase, oxidative stress response, GABA production, osmotic stress alleviation, cold shock protein, phenazine production, trehalose metabolism and heat shock protein catalases by rhizobacteria is a very helpful mechanism in plant stress tolerance (Sedeek et al., 2023), which is also detected within the genome of strain UP1A-1.

Conclusions

In the present work, we have developed talc-based bio-formulation for Solanaceae crops growth promotion and disease control against *R. solanacearum* and analyzed the whole genome sequence of the potential strain *Streptomyces* sp. UP1A-1. Genome analysis information including the presence of genes and metabolic pathways accentuated better performance ability of UP1A-1.

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Investigation of Morphological Characteristics of *Abelmschus esculentus* During Terrestrial Weed Compost Amendment in Soil

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Terrestrial weeds pose the greatest threat to agricultural ecosystems, wreaking havoc on nearby plants by impeding fruit production and weakening the leaves. In the current study, compost prepared from terrestrial weeds such as *Ageratum conyzoides*, *Parthenium hysterophorus* and *Lantana camara* was high in nitrogen (3.2, 2.47 and 2.74%), accessible phosphorus (3.62, 4.34 and 4.42 g/kg), and potassium (32.5, 51.5 and 34 g/kg). The compost to soil ratio was varied from 5, 10, 15, 20, 25, 35, 45, and 100% in a 10 L pot with a height of 50 cm and an upper diameter of 30 cm. Germination, quantity of leaves and fruits, and plant height of *Abelmoschus esculentus* were all monitored. Compost percentages ranging from 15 to 25% resulted in high germination rates ranging from 80 to 100%. The potassium content in the fruits was higher at 45% compost amended soil ranging between 750 to 1050 mg/kg. The heavy metal content such as lead in the fruits was higher than the permissible limit (0.1 mg/kg) ranging between 1.8 to 2.5% from 5 to 100% compost amendments. The 25% compost composition could be feasible composition in growing horticulture crops compared to edible crops as compost contains more lead content.

Keywords: Terrestrial weeds, Abelmoschus esculentus, Nutrient rich, Composting, Macronutrients.

Odor Characterization and Health Risk Assessment of Food Waste Bioconversion By Housefly (Musca Domestica L.) Larvae

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Bioconversion of food waste by insect is drawing increasing attention in recent years, due to the increasing food waste generation, growing protein demand, and promotion of source separation of municipal solid waste. Bioconversion by housefly (*Musca domestica* L.) larvae is a novel technology for reducing and recycling food waste. In this study, the odor characteristics and health risks of gaseous pollutants from food waste bioconversion by housefly larvae were investigated and compared with other treatment technologies for the first time. The air samples were collected from different areas in a full-scale food waste bioconversion facility (50 t/d), and their chemical compositions were quantitatively and qualitatively analyzed. Based on which, the odor contribution and annoyance were assessed with the odor activity values (OAVs) and their sum (SOAVs), and the health risks (carcinogenic and non-carcinogenic risks via inhalation and other risks) were evaluated. The total concentrations of volatile compounds were significantly higher in the breeding and biodegradation areas than in the other areas. The air composition in the breeding area was the most complex. Ethanol was the dominant odorant in the unloading, pretreatment, substrate storage, and breeding areas, while that was ammonia in the biodegradation and product areas. The SOAVs in the breeding and biodegradation areas were the highest (1171 and 756, respectively) with trimethylamine as the key odorant. Carcinogenic risk in the breeding area was unacceptable with acetaldehyde as the key carcinogen, and possible carcinogenic risks existed in the other areas except for the substrate storage area. Non-carcinogenic risk existed in the order of breeding area > biodegradation area > product area > pretreatment area with acetaldehyde, ethyl acetate, hydrogen sulfide, and ammonia as the dominant contributors. Corrosive, irritant, acute toxic, and health hazardous substances were detectable in all sampling sites. Odorants can form secondary pollutants, such as particulate matter (<2.5 μm) and ozone, which cause health risks. The breeding area was considered as the priority area for carcinogenic and non-carcinogenic risk control, followed by the biodegradation area. The bioconversion technology showed different odor characteristics and health risks from other treatment technologies. In terms of reducing sulfur compound emissions, insect-based bioconversion is favorable due to the enhanced oxygen transfer effect. Odor control and health protection measures should be taken based on the odor and health risk evaluation. The principle of similarity was proposed for the design of odorous gas collection, and health risks, SOAVs and major odor contributors were suggested to be considered for the design of ventilation rates and gas treatment methods. The findings provide a scientific basis for odor control and health protection in food waste bioconversion facilities.

Keywords: Odor, Health risk, Food waste, Bioconversion, Housefly larvae.

Bio-Waste Valorisation As Sorbent For Removal Of Methylen Blue From Aqueous Solutions

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Our objective is to prepare low-cost, environmentally friendly adsorbents for green chemistry by recovering waste from the agri-food industry, and to assess their capacity in water treatment. In this work, agro-wastes coming from sunflower seed shells are used as low-cost biosorbents to remove methylene blue (MB) from aqueous media. Batch experiments are performed under different experimental conditions investigating the effects of biosorbent amount and pH. The properties of sunflower seed shells were identified through characterization by different method namely: dosage of surface functions by the Boehm method and by infra red spectroscopy (IR), pH of point zero charge (pHpzc), iodine index, phenol index, methylene blue number. The characterization results show that this adsorbent has an acid character according to the three tests (IR, Boehm the existence of the dominant acid functions and pHpzc=4.9), In order to assess their adsorption capacity and develop a mathematical model describing the process and also to minimize the number of tests, we were interested in modelling the adsorption of methylene blue by the powder of sunflower seed shells (PSSS), using an experimental design, considering pH and mass as variables. The modeling results indicate that under optimal conditions of pH=10 in the pH study interval (between 4 and 10) and adsorbent mass = 0.5g in the study interval (between 0.5 and 1g), sunflower seed shells have significant capacitie of MB adsorption, it is of the order of QMB=1.15 mg/g. Finaly we can say that this adsorbent can retain and eliminate macro and micro molecules, it has an acid character therefore, it is favorable to the basic medium pH 10, and that the optimal mass of adsorption is equal to 0.5g.

Keywords: Adsorption, Adsorbent, Optimization, Experimental design, Methylene blue.

Potential of Bio-Risks in MSW Management System

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Microbial (bacteria and fungi) community structures and their distributions in urban household municipal solid waste (HMSW) were characterized in a sampling campaign in 38 cities of China covering 5 climatic zones. All these HMSW samples were collected from garbage containers in residential communities in winter (11 to 26 January) of 2022. A total of 110 species of bacteria belonging to 247 genera, 110 families and 22 phyla were identified among the samples. Firmicutes (44.3%), Bacteroidetes (33.77%) and Proteobacteria (21.54%) were the top 3 dominant phyla, and Arcicella (33.11%) and Leuconostoc (21.87%) were the dominant genera. Meanwhile, 234 species of fungi belonging to 124 genera, 84 families and 7 phyla were detected. Ascomycota was the most dominant phylum, with an average relative abundance of 77.31%. Hanseniaspora (24.03%), Debaryomyces (13.47%), Candida (12.18) and Cystofilobasidium (9.95%) were the top 4 dominant genera. Alpha-diversity index analysis showed that the species richness and diversity of bacterial and fungal communities of HMSW samples belonging to different climatic zones did not differ significantly. Correlation analysis between microbial community structure and local climatic showed that the microbial communities were more similar between HMSW samples from temperature and subtropical monsoon climatic zones, while those from temperature continental climatic zones were different. Nonmetric multidimensional scaling (NMDS) analysis demonstrated that climatic had an effect on microbial communities but did not show a significant correlation. In addition, the study identified 13 bacterial and 16 fungal species as pathogenic. The most abundant pathogenic bacteria and fungi detected were Pseudomonas putida (0.25%) and Sclerotinia sclerotiorum (2.12%), respectively. These findings provide valuable data for the prevention and control of biological risks associated with municipal solid waste (MSW) facilities.

Keywords: Municipal solid waste, Bacteria, Fungi, Biological risk.

Ecological Effects of Organic Fertilizers Produced from Agrowastes with Different Carbon-Nitrogen (C/N) Ratios on Corn Growth, Soil Chemical Properties and Earthworm Behavior

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Organic amendments in the form of compost, manure, and several other agricultural wastes are a source of plant nutrients that also improve soil quality. Currently, many existing composting technologies aim to convert raw materials into organic fertilizers that can be used in agriculture effectively. However, in most cases, organic fertilizer production has been restricted at higher C/N ratios of agrowastes. There should be a proper balance of C and N if decomposition is to proceed rapidly. An experiment laid out in a split-plot in a completely randomized design was conducted to determine the recovery and chemical properties of organic fertilizers produced from the decomposition of raw agrowaste mixtures with different C/N ratios and its effect on corn growth, soil chemical properties, and earthworm behavior. The preparation of different C/N ratios of poultry manure mixed with shredded rice straw and poultry manure mixed with carbonized rice hull was based on the moisture content, organic carbon, and total nitrogen analyses. To attain the 15:1, 20:1, 25:1, 30:1, and 35:1 C/N ratios of the mixture of two materials to be mixed, the determination of organic carbon, total nitrogen through chemical analysis, and moisture contents through oven drying were conducted. The organic carbon (C), total nitrogen (N), and moisture content data were plugged into the formula adopted from Cornell Waste Management Institute, Cornell University. For the seedling emergence test, the seeds were placed in pots in contact with soil treated with fertilizers derived from agrowastes with different C/N ratios. The effects were evaluated for 21 days after seedling emergence in the control group and all treated media. Endpoints were determined as visual assessment of seedling emergence, biomass measurements, shoot height, and the visibly damaging effects on different parts of the plant. The test was conducted to determine the dose-response curve, or at one concentration/rate as a limit test. Also, the earthworm avoidance behavior assay (ISO 17512-1:2008) was conducted as a rapid screening method for assessing the influence of contaminants and chemicals on earthworm behavior. Results show that increasing the C/N ratio increases the recovery rates of compost. Although the chemical properties of composts are considerably high, increasing the C/N ratio lowers the pH, organic carbon (OC), total phosphorus (P), total potassium (K), and total NPK. It is worth noting that its application significantly enhances corn growth and improves soil chemical properties such as pH, % OC, available P, available K, and CEC. No toxicity was found based on the earthworm avoidance test. Application of organic fertilizer to acid soils, a common problem in the Philippines, is recommended as it increases soil pH.

Keywords: Organic fertilizer, Ecological, Decomposition, Earthworm, C/N ratio.

Carbon Emissions in Treating Food Loss and Waste in China Based on Life Cycle Assessment

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More than 30% of food is transferred into loss and waste in the process of food supply chains. Treating food loss and waste (FLW) would consume a large amount of energy, generating obvious carbon emissions. Thus, the treatment of food loss and waste should be paid attention to, in order to mitigate carbon emissions. In this study, carbon emissions features of FLW treatment were identified in a life cycle assessment (LCA) framework. This study focused on the following stages of FLW treatment: (1) crop planting and livestock breeding; (2) food supply; (3) food production; and (4) food consumption. The following related waste treatment technologies were also incorporated in the system boundary: composting, incineration, anaerobic digestion, biomass reuse, and landfilling. In consideration of multiple uncertain conditions (i.e., FLW treatment, and food consumption), experiment design methods (e.g., copula sampling, Monte carlo simulation, and Latin hypercube sampling) were proposed. The results demonstrated that a large amount of carbon emissions in FLW treatment was generated in the production and storage stages. Alternative solutions in FLW treatment (e.g., such as biomass reuse) can mitigate a certain proportion of carbon emissions. Reducing food loss at consumption stage was also significantly important for mitigating carbon emissions. This study provided a nexus approach for analysing and quantifying the carbon emissions in treating FLW in China. The finding of this study can serve as a theoretical basis for setting reduction carbon targets and formulating mitigation measures in food management.

Keywords: Food loss and waste, Waste treatment, Life cycle assessment, Carbon emissions, Uncertainty analysis.

Environmental Evaluation of Emerging Bakery Waste Oil-Derived Sophorolipids Production by Applying Dynamic Life Cycle Assessment (dLCA)

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ABSTRACT. Currently, waste streams are widely used as feedstocks to enhance sustainability and reduce the cost of sophorolipids (SLs) production. **Objective:** To evaluate the associate environmental impact and guide technology development. **Methodology:** Dynamic life cycle assessment (*dLCA*) was employed to assess the environmental impact of SL production, focusing on the use of bakery waste oil (BWO) as a second-generation hydrophobic feedstock. **Results:** BWO had a more severe environmental impact than oleic acid, which is often used as a hydrophobic substrate. However, regulating the pH effectively reduced the environmental risks of BWO. The study also found that batch fermentation using BWO as a substrate was more environmentally friendly than using food waste. **Conclusion:** Combining multiple techniques, such as feeding with food waste and BWO, using fed-batch fermentation and *in-situ* separation, can further reduce environmental impact and guide experimentalists in the future.

Keywords: *Bakery waste oil; Biosurfactants; Environmental impact; Life cycle assessment; Sophorolipids*

Introduction

Surfactants are among the most widely used chemicals in industry and daily life. Compared with chemical surfactants, biosurfactants, which are surface-active macromolecules secreted by microorganisms, have more advantages. Among different kinds of biosurfactants, sophorolipids (SLs) have the largest global market share [1]. SLs consist of a dimeric sugar and a hydroxyl fatty acid linked by a glycosidic bond, and are mainly produced by yeast species *Starmerella bombicola* through fermentation [2]. However, the huge cost of the conventional substrates, including glucose, oleic acid and yeast extract, limits the widespread application of SLs. Therefore, waste materials have become a hotspot in this field. From an environmental perspective, the use of waste streams does not necessarily imply their environmental friendliness because of the involvement of different inputs and processing steps such as additional pretreatment procedures. Therefore, the associated environmental impact should be investigated to understand and improve the sustainability of the process. Life cycle assessment (LCA) is a powerful tool often employed in the early stage of a process design to evaluate and improve its sustainability [3]. Recently, our team proposed a dynamic LCA (*dLCA*) framework that can track the environmental impact of emerging technologies as they evolve [4]. In our previous studies, three traversals of the *dLCA* framework have been performed to continuously evaluate the environmental burden of the waste-derived SL production and suggested that further development should be focused on replacing oleic acid [5, 6]. In this study, the environmental impact of using bakery waste oil (BWO) as a second-generation hydrophobic substrate for SL production was investigated. Different types of waste stream substrates and processes were considered. The findings of this study can provide insights into the environmental impact of the complete SL production process using the latest technology and indicate suitable substrates for industrial-scale SL production.

Material and Methods

Description of the SL production process using BWO

The bioconversion process consisted of two stages. The first stage involved the preparation of the inoculum. A single colony of *S. bombicola* was isolated using the streak plate method. Then, two transfer steps were followed to further propagate the isolated colony. PDA, glucose, and yeast extract were provided for cell growth in this stage. In the second stage, 2% (v/v) of the inoculum was transferred to a 1.5-L bioreactor. Then, fermentation was conducted to produce crude lactonic SL. Glucose and oleic acid/BWO were added as hydrophilic and hydrophobic carbon sources, respectively. Aeration of compressed air, temperature, and agitation speed were controlled at 2.67 vvm, 30℃ and 600 rpm, respectively. 2M NaOH or 2M KOH was added to the bioreactor in different scenarios separately to maintain the pH level at 3.5, and the associated environmental impact were compared.

dLCA of the BWO-derived SL production

The *dLCA* framework used in our previous studies and this study are shown in Fig. 1a. The first three traversals were conducted in our previous studies, indicating the need to replace oleic acid [5, 6]. Therefore, BWO was selected as the second-generation hydrophobic substrate, and its associated environmental impact was examined in this study. The fourth traversal revealed the possibility of using BWO instead of oleic acid to produce SLs by investigating the potential environmental impact. The fifth traversal identified the most appropriate process regulation method to reduce the environmental burden caused using BWO as the substrate. The sixth traversal compared the environmental impact of different types of waste stream substrates (i.e., food waste and BWO) to identify the most effective SL production technique. A gate-to-cradle approach was employed in this study, in which BWO was collected before landfill disposal (gate) and used as a raw material in SL production (cradle). The functional unit (FU) is defined as the production of 1 kg of crude SLs to facilitate a comparison with the findings of previous studies in the sixth traversal.

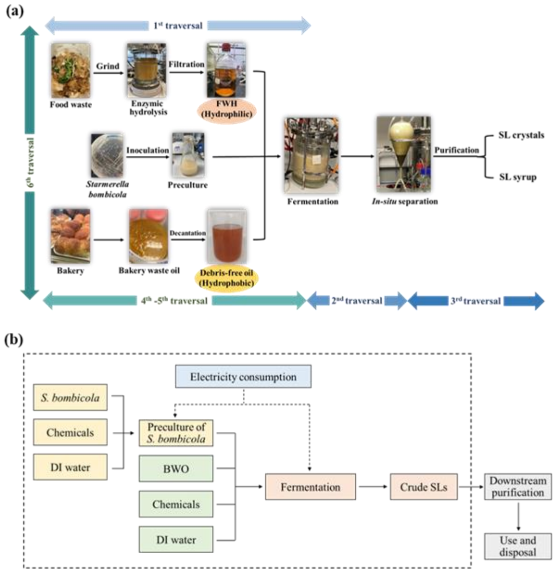

Fig 1. (a) Schematic diagram of the fermentation process using the waste stream as the feedstocks; (b) System boundaries for the fourth and fifth traversals of the *dLCA* framework.

System boundaries and Life cycle inventory

The system boundaries for the fourth and fifth traversals are illustrated in Fig. 1b. The consumption of materials and energy in both the preculture and fermentation stages was considered in this study. However, the downstream purification, use, and disposal phases were not included because this study mainly focused on the differences resulting from the use of diverse raw materials in the crude SL production process. Chemicals in the fourth traversal refer to the PDA, yeast extract, glucose, and oleic acid used in the preculture and fermentation stages. In the fifth traversal, alkali consumption was also considered in chemicals. Moreover, it should be noted that according to the zero-burden assumption, BWO is considered to be free of burden [7]. The primary data were collected from the conversion process of a laboratory in Hong Kong. Inventory data were collected from the Ecoinvent version 3.5 database.

Impact assessment and sensitivity analysis

All LCI data were processed and modeled using SimaPro 9.0.0. The cumulative energy demand (CED) v1.11, IPCC 2013 GWP 100a, and ReCiPe 2016 Midpoint (H) impact assessment method were used to calculate the primary energy consumption, global warming potential (GWP) and the environmental impact for 18 categories. Sensitivity analysis was performed to ensure the reliability of the LCA results. SL yield, electricity, preculture, oleic acid feeding, glucose feeding, and alkali use were selected as the SL production parameters. A range of variation (-10%, 10%) was considered to analyze changes in model outputs.

Results and Discussion

CED and GWP results of the fourth and fifth traversal of the dLCA for BWO-derived SL production

In the fourth traversal, the use of BWO resulted in higher CED and GWP values (15,803.3 MJ and 1,277.3 kg CO_2 eq., respectively), which were approximately 1.33 times the values obtained when using oleic acid (11,898.3 MJ and 959.6 kg CO_2 eq., respectively; Fig. 2). As a waste stream substrate, heterogeneous fatty acids in BWO reduced the carbon conversion rate, resulting in a lower titer and more energy consumption and CO_2 emission per kg of SLs produced. In the fifth traversal, the addition of NaOH increased the CED and GWP values to 1.25 times the values without pH regulation. However, when KOH was added to adjust pH, the CED and GWP values decreased to 9301.1 MJ and 751.7 kg CO_2 eq, respectively, which only accounted for 58.86% of the base case. The use of KOH resulted in more biomass, leading to a higher bioconversion efficiency, a higher SLs yield, a lower energy intensity, and lower greenhouse gas emissions.

Midpoint assessment results of the fourth and fifth traversal of the dLCA for BWO-derived SL production

The environmental impact of BWO feeding was higher than that of oleic acid feeding in most of the categories (Fig. 3a). However, BWO feeding was associated with lower land use (36.67%) and marine eutrophication (82.50%) values. In oleic acid-derived fermentation, the proportion of the contribution of chemicals significantly increased in all the categories, especially land use (80.49%), marine eutrophication (50.84%), stratospheric ozone depletion (30.54%), water consumption (21.95%), and mineral resource scarcity (18.38%); this increase was mainly caused by the production of oleic acid. However, when BWO was used as a hydrophobic carbon source instead of oleic acid, the proportion of the contribution of chemicals decreased significantly, indicating the necessity of replacing oleic acid in SL production. Compared with no pH regulation, NaOH regulation increased the environmental burden for all the categories by approximately 19.98%. By contrast, KOH regulation reduced the environmental burden for all the categories by approximately 32.90% (Fig. 3b). Among different stages, the fermentation stage was the most energy-intensive process, accounting for approximately 75.54% of the most midpoint impact categories. The harmful effects of chemicals were mainly observed on land use (21.33%) and marine eutrophication (11.86%) when KOH and NaOH were used as pH regulators. Among these, more than 94% of the environmental impact was caused by glucose feeding, indicating that the harmful effect caused by alkalis was negligible. Electricity usage contributed more than 95% of the impact in almost all the categories. However, the proportion of electricity would decrease when the process is conducted at an industrial scale.

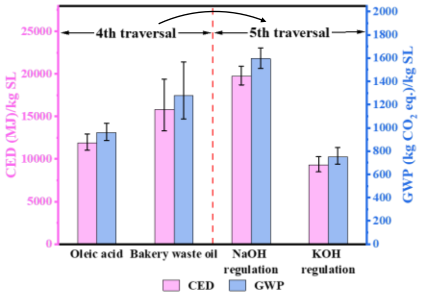

Fig 2. Results of the fourth and fifth traversals of the *dLCA*: CED and GWP values associated with producing 1 kg of crude SLs.

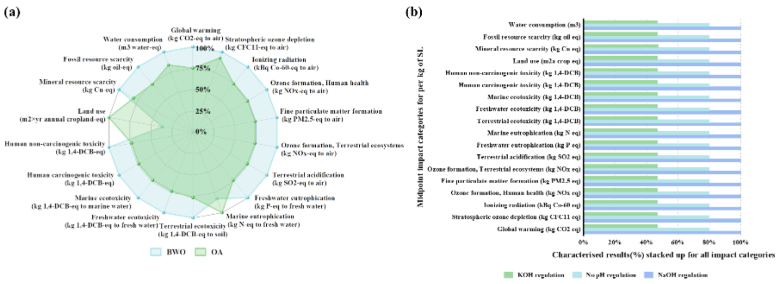

Fig. 3. The ReCiPe Midpoint (H) impact assessment results presented as relative values for the fourth and fifth traversal of the *dLCA*: (a) radar chart for the fifth traversal and (b) bar chart for the fifth traversal. The result of BWO in the fourth traversal was input as no pH regulation in the fifth traversal.

Sensitivity analysis

All the environmental sustainability metrics were more sensitive to the SL yield, with electricity usage being the most sensitive, followed by preculture. Regarding feedstocks, oleic acid feeding was a crucial factor affecting SL production. In contrast, glucose feeding was the least sensitive factor. Therefore, reducing the use of oleic acid instead of glucose can more effectively reduce the environmental impact. Alkali was identified as a less sensitive factor. The amount of alkali used in the process did not considerably influence the environmental impact of the entire system. Thus, BWO can be a promising substitute for oleic acid because of its lower economic costs and environmental impact, and the use of KOH as pH regulator significantly reduced the environmental risk of the production system. Changes in the SL yield and electricity consumption substantially also affected the CED value of the system, indicating that improving the SL yield and saving electricity are the key factors for developing a sustainable SL production system.

Sixth traversal of the dLCA for producing SLs by using BWO

BWO feeding resulted in a significantly lower environmental impact when the bioprocess was conducted in batch fermentation. The corresponding CED and GWP values were 15,803.3 MJ and 1,277.3 kg CO_2 eq., respectively, which were only 40% of the values obtained for FWH feeding (Fig. 4). In terms of process optimization, the use of KOH to adjust pH significantly reduced the CED and GWP values of BWO-derived SL production; these values were slightly lower than those of FWH-derived fed-batch fermentation equipped with a conventional separation method but still higher than those of FWH-derived fed-batch fermentation equipped with *in-situ* separation. Thus, SL production can become more environmentally friendly when BWO-driven SL production is conducted in a fed-batch mode coupled with *in-situ* separation technology.

Conclusions

Compared with the first-generation feedstock oleic acid, BWO-derived SL production resulted in a higher environmental impact. However, the use of KOH as a pH regulator significantly reduced the environmental impact of BWO-derived SL production by 41.14%. When the same fermentation technique was used, food waste-derived SL production led to a higher GWP value than the BWO-derived bioprocess due to differences in procedures and SL titers. Waste stream feedstocks (i.e., BWO and food waste) should be used to improve the sustainability of this process, and the integration of multiple techniques may lead to a low GWP value.

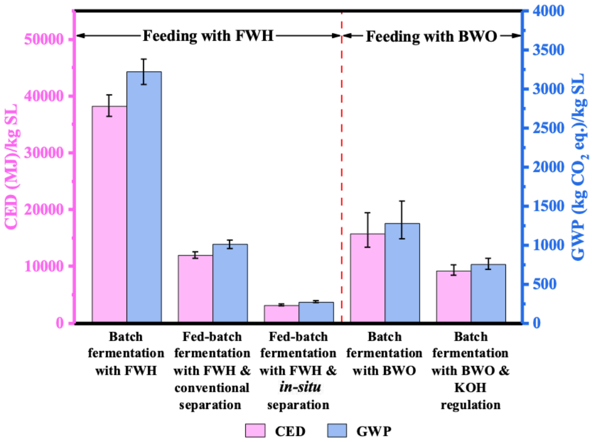

Fig. 4. Results of the sixth traversal of the *dLCA*: CED and GWP values associated with producing 1 kg of crude SLs by using FWH or BWO as feedstocks.

Acknowledgement

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Preparation and Characterization of Cellulose Triacetate from Cocoa Pod Husk (CPH)

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ABSTRACT. The valorization of agricultural residues into high value-added products is necessary to address global environmental concerns caused by agricultural waste pollution. The aim of this study was to highlight a new way of using cocoa pod husk (CPH) for the synthesis of cellulose triacetate (CTA). An alkaline treatment with sodium hydroxide (5 wt.%) followed by a bleaching process with hydrogen peroxide (2 v/v) proved effective for the extraction of cellulose from CPH with a percentage of 80.50% and a yield of 54%. CTA was synthesized by acetylation reaction in the presence of acetic acid, acetic anhydride and sulfuric acid. The CTA obtained had a degree of substitution of 2.87 and a percentage of acetylated group of 43.75%.

Keywords: *CPH (Cocoa pod husk); Cellulose; Cellulose triacetate; Acetylation; Degree of substitution*

Introduction

Côte d'Ivoire is the world's leading producer of cocoa beans, with an annual output of 2.2 million tonnes, or around 44% of world production.The cocoa beans produced are either exported or processed into numerous food products (chocolate powder, cocoa butter, chocolate bars, etc.).

As for cocoa pod husks (CPH), which represent 70% to 75% of the weight of the whole pod, they are discarded in nature as agricultural waste [1]. Their annual production in Côte d'Ivoire is estimated at over 6.5 million tonnes, hence their abundance in agricultural areas [2]. This abundance results in the proliferation of mosquitoes, flies as well as other insects harmful to cocoa and its surroundings [3] . To find a solution to this problem, the valorization of CPH becomes necessary to respond effectively to the problems of sustainable management of residual biomass, the valorization of CPH into bioproducts can constitute a concrete response for effective management of agricultural waste.

CPH are lignocellulosic biomasses rich in several elements such as fibers (cellulose, lignin, hemicellulose and pectin), minerals (notably potassium) and antioxidants (polyphenols, etc.) [3]. Given these characteristics, the valorization of CPH has attracted interest in many fields including soil fertilization, food and animal chemistry, plant nutrition, waste treatment and disposal, and thermal energy technology [2]. However, most of its areas have been widely exploited, while others such as the production of cellulose triacetate from CPH are new and deserve special attention. The aim of this study is to explore new ways of using CPH to synthesize cellulose acetate.

Material and Methods

Materials

Cocoa pod husks (CPH) used in this work come from Côte d'Ivoire. Ethanol (C_2H_5OH, 96%) and sodium hydroxide (NaOH) pellets were obtained from Sigma-Aldrich. Sulfuric acid (H_2SO_4, 98%) and glacial acetic acid (CH_3COOH, 99%) used are Merck brand. Acetic anhydride ($(CH_3CO)_2O$, 99%) was Scharlau brand, and hydrogen peroxide (H_2O_2) was purchased from Panreac Applichem. All chemicals and solvents used are of analytical grade and were used without further purification.

Fig. 6. Extraction steps of CPH powder: A (fresh CPH), B (sun-dried CPH), C (electrically dried CPH), and D (CPH powder).

Methods

The CPH powder was treated with boiled water and then dried at 105 °C in an oven for 24 h. The dry CPH powder was then treated with a 5% (w/v) aqueous solution of NaOH for 3 h at a temperature of 170 to 200 °C under constant mechanical stirring. The paste is then rinsed several times with distilled water until the alkali is neutralized and dried for for 24 h. After that, the sample was bleached with 2% of hydrogen peroxide (H_2O_2) at pH=12 at 70 °C for 3 h. Subsequently, the sample was filtered, washed with distilled water to neutral pH, and dried in an oven for 6 h at 105 °C.

The preparation of CTA from CPH involves dissolving 1.0 g of dried CPH cellulose in a solution of 40 mL of glacial acetic acid with a few drops of 98% sulfuric acid as the catalyst for the reaction. The system is refluxed at a temperature of 80 to 90 °C for 30 min. After cooling, 40 mL of acetic anhydride are added to the mixture and the system is heated again until the fibre has completely disappeared. A 20% aqueous solution of acetic acid is then added at the end of the reaction and the mixture is then heated at 70 °C for 10 min. After cooling, 50 mL of hot water was added slowly while stirring, when CTA precipitates. It was then filtered using Buchner funnel and the product is washed with cold water until a neutral pH. The product obtained is dried in an oven at 90 °C to a constant mass.

The chemical composition of the CPH powder and the cellulose extract of the CPH was carried out following the ASTM methods. The raw CPH powder first underwent solubilization in alternating solvents, hot water and 96% ethanol, to determine the content of extractables. Holocellulose content was determined by ASTM D1104-56 (1978), cellulose content per ASTM D1103-60 (1978), lignin content per ASTM D1106-56 (1974), and ash content per ASTM D1102-84 (2007). The hemicellulose content was obtained by subtracting between the holocellulose and cellulose contents. The degree of substitution (DS) of the CTA produced was determined by the titration method as described by Samios *et al* [4] . The degree of acetylation and the DS using Eq. 1:

$$\%\ \mathbf{Acetyl} = \frac{[(\mathbf{A-B})\mathbf{Nb}-(\mathbf{C-D})\mathbf{Na})]\times\mathbf{4.3}}{\mathbf{W}} \tag{1}$$

With :

$$\mathbf{DS} = \frac{(\mathbf{3.86}\times\%\ \mathbf{Acetyl})}{(\mathbf{102.4}-\%\ \mathbf{Acetyl})} \tag{2}$$

where A is the amount of NaOH added to the sample (mL); B is the amount of NaOH added to the blank (mL); N_b the normality of the NaOH solution; C the amount of HCl added to the sample; D the amount of HCl added to the blank (mL); N_a the normality of the HCl solution; W the sample weight (g); and 4.3 is a factor to calculate the (%) acetylation.

Results and Discussion

Lignocellulosic Composition of Cocoa Pod Husk and Cellulose Obtained from CPH

The lignocellulosic composition of CPH obtained from this study is summarized in Table 1. There is heterogeneity between the results obtained and those observed in the literature (Table 1). Indeed, according to Leygnima et al [2], these disparities between results could be attributed to environmental factors, biomass varieties, different analytical methods or solvents used, as well as the location of the collected materials.

Also, we observe a high cellulose content. This high content could be due to the fact that cellulose represents the main structural component of plant biomass and the one that gives it strength and stability to the plant cell wall [5].

Further on, we note a high lignin and extractable matter content. Hence the need for pre-treatment to release fermentable sugars [2].

Table 1. Lignocellulosic Composition of CPH and the Results of Some Previous Studies

Cellulose (%)	Hemicellulose (%)	Lignin (%)	Extractables (%)	Reference
30.23	12.58	20.58	21.43	This work
31.68	16.97	25.62	21.57	[2]
30.41	11.97	33.96	23.66	[6]
28.25	16.75	24.16	-	[7]

Cellulose isolated from cocoa pod husk

The results of the lignocellulosic composition of the cellulose isolated from CPH (CPH-C) are summarized in the Table 2 and is compared to that of the raw CPH.

After extracting the cellulose, it is noted that the product obtained has a high purity in which the cellulose content has increased from 30.23% to 80.5% compared to the raw CPH. Also, it can be observed that the contents of hemicellulose and lignin have considerably decreased. This could be explained by their solubilizations during the bleaching process.

With a low concentration of H_2O_2 (2%) at pH = 12 and in the presence of NaOH, good removal of the lignin content was observed during the bleaching process.

In this study, the yield of the CPH-cellulose obtained after the extraction process was 54%.

Table 2. Lignocellulosic Composition of Extracted Cellulose from CPH

Samples	Cellulose Extraction (Treatment)			Result			
	NaOH (%; w/v)	[H_2O_2] (%; v/v)	t (h)	Weight$^{(a,b)}$ (g)	C wt (%)	Hc wt (%)	L wt (%)
CPH-C	5	2	3	5.4 (b)	80.50	7.57	5.70
CPH	-	-	-	10 (a)	30.23	12.58	20.58

Weight$^{(a,b)}$: ^{a} (initial weight of CPH), ^{b} (final weight of extracted cellulose); C (cellulose); Hc (hemicellulose); L (lignin)

Percentage of acetyl groups and degree of substitution (DS)

The results of the percentage of acetylated groups and the DS are summarized in Table 3. The values for the percentage of acetyl groups and the DS are 43.75% and 2.87, respectively. These results are close to the values obtained by Shaikh et al. [8] and To Nu et al. [9] .

The DS (2.87) obtained in this study by the titration method indicates that the product obtained is cellulose triacetate [8]. Also, note that the data presented in Table 3 indicate that the acetyl group (%) and DS value increased depending on the purity of the extracted cellulose.

Table 3. Percentage Acetyl Content and DS of Prepared Cellulose Acetate

Samples	% Acetyl	DS	Yield	Reference
CA	43.75	2.87	60.01	This work
CTA-2	43.51	2.85	94.5	[8]
CA-2	43.05	2.80	51	[9]

Conclusions

Cocoa pod husk (CPH) is an important biomass rich in lignocellulosic elements. The alkaline pre-treatment and bleaching process resulted in an increase in cellulose (30.23% to 80.50%) and a considerable decrease in lignin (20.58 to 5.70%) and hemicellulose (12.58 to 7.57%). The production of cellulose triacetate (CTA) from cocoa pod husk residues was successful with a high yield of 62.96% and a degree of substitution of 2.87.

Acknowledgement

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Valorization of Cocoa Pod Husk in High Value Added-Products

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Cocoa pod husk (CPH) is a carbohydrate-rich lignocellulosic biomass, and it is abundant and readily available in Côte d'Ivoire for the production of materials and bioproducts. The present study aimed to produce cellulose triacetate (CTA) and microbial lactic acid (LA) from this residual biomass.

CTA was produced after isolating cellulose from CPH, by alkaline pretreatment with 5% (w/v) NaOH and bleaching with 2 % (v/v) hydrogen peroxide. A yield of 54 % (w/w) of cellulose was obtained. Then, TAC was synthesized by acetylation reaction of the extracted cellulose in the presence of acetic acid and anhydride catalyzed by sulfuric acid. A degree of substitution of 2.87 and an acetylation percentage of 43.75 % were obtained. FTIR results confirmed the formation of cellulose acetate by the appearance of ester group (C=O) and acetyl group (C-O) stretching. XRD gave a cellulose crystallinity index of 38.43 % while indicating the semi-crystalline nature of CTA. Morphology and elemental observation (SEM-EDX) showed small and medium rough and spongy particles within the structure of the TAC and the dominant presence of carbon (C, 87%) and oxygen (O, 13%).

Lactic acid was produced after optimization of the processes of delignification by KOH and acid hydrolysis by H_2SO_4. A biomass/solvent ratio of 9.14 % and a temperature of 128 °C, resulting in a degree of delignification of 93.87%. Morphological and elemental analysis (SEM-EDX) revealed several changes within the delignified matrix and the dominant presence of carbon, oxygen and potassium elements. Infrared (TF-IR) analysis confirmed almost complete removal of lignin. Optimal hydrolysis conditions were: 26.95 min, 9.53% (w/v) biomass/solvent ratio in 4.92% (w/v) H_2SO_4, yielding 18.77 g/L of reducing sugars. The hydrolyzate obtained after concentration was used to produce LA using lactobacillus fermentum ATCC 9338 in a biofermentor. A productivity of 1.25 g/L.h at the logarithmic phase after 72 hours of fermentation, a titer of 26.61 g/L and a yield of 0.52 g/g of lactic acid were obtained from 45. 55 g/L of glucose and 12.21 g/L of xyloses.

Keywords: Cocoa Pods Husk, Lactic acid, Cellulose triacetate.

Extremophile Extracts from Microalgae and Vegetals for the Food Industry

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The EE4FI PROJECT aims to create a pilot plant for the production of microalgae and plant extracts to be used in the food industry TO FIGHT MALNUTRITION: A) Consolidation of research and development activities carried out by scientific and industrial partners B) Analysis of nutritional needs, with particular reference to the populations C) Elaboration of nutritional models with the aim of improving and balancing nutrition – Models E) Identify the biocomponents necessary to improve the nutritional characteristics of the food – Identification F) Develop production processes on a pilot scale to extract biocomponents from microalgae and plants – Development G) Realization of pilot line of cultivation, production and extraction - Design and Implementation H) Market analysis and study of packaging for distribution in the nuraceutics and food channels – Marketing I) Validation of nutritional models, screening of patient samples under medical supervision – Validation L) Processing of results – Dissemination.

Biotransformation of Sorghum Syrup Derived HMF to FDCA Using Novel Rhodococcus Qingshengii C27

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ABSTRACT. The 2,5- Furandicarboxylic acid (FDCA) is one of the 12 uppermost chemical building blocks which can be synthesized from the biomass. In this study, biocatalytic approach was adapted for the conversion of HMF to FDCA. The biotransformation of HMF to FDCA was carried out using whole cells of novel isolate *Rhodococcus qingshengii* C27. In the batch mode biotransformation, 0.94 g/L of FDCA was yielded from 1 g/L of HMF concentration under optimal conditions (72 hours, 30 °C and pH 7.0) with the complete HMF utilization. In the fed-batch mode biotransformation in shake flask, 1.53 g/L of FDCA was obtained from 2.0 g/L of FDCA. Also the strain could tolerate up to 240 mM of HMF. Finally, the produced FDCA was recovered and purified with 94% of purity. Further work will be aimed at the life cycle analysis of the complete process.

Importance: The discussed process of HMF to FDCA using a highly HMF tolerant novel biocatalyst, *R. qingshengii* C27 is a state of the art approach with the promising environmental friendly operations for the green future.

Keywords: *FDCA; HMF; Biotransformation*

Introduction

According to the US Department of Energy, the biomass-based compound 2,5-furandicarboxylic acid (FDCA) is one of the 12 uppermost chemical building blocks. FDCA ($C_6H_4O_5$) can be used for the production of polymers and resins and is often referred to as “the sleeping giant” as it can replace the fossil-based terephthalic acid for the creation of novel products [1]. Polyethylene furanoate (PEF), a polymer of FDCA and ethylene glycol (EG), is considered to be the “biopolymer of the future”, which could substitute the polyethylene-terephthalate (PET) [2]. PEF could reduce the non-renewable energy (NREU) need from 51% to 43%, and the greenhouse gas emissions from 54% to 46% [3]. First generation feedstock such as starch and cereal crops are the main source for HMF and FDCA production [4], but lignocellulosic biomass (second-generation feedstock), which does not compete with food and feed markets, can also be a source of HMF/FDCA. HMF ($C_6H_6O_3$) is also known as sleeping giant, which is widely used in the chemical applications due to its functional groups (alcohol and aldehyde moiety) and furan aromatic ring. Dehydration of C6 sugars yields HMF. Through HMF oxidation 5-hydroxymethyl-2-furan carboxylic acid (HMFCA), 2,5-diformylfuran (DFF), 2-formyl5-furancarboxylic acid (FFCA), adipic acid, including 2,5-furandicarboxylic acid (FDCA) can be synthesized. Also, HMF can be transformed to 2,5-bis (hydroxymethyl)furan/ HMF alcohol (BHMF) via dehydrogenation. In route A, the aldehyde group is oxidized to carboxyl group and form HMFCA following which the alcohol group of HMFCA is oxidized to an aldehyde group, yielding FFCA, which is further oxidized to FDCA. In B route, the alcohol group of HMF is significantly oxidized to an aldehyde group to form DFF, following which the aldehyde groups of DFF are sequentially oxidized to carboxyl groups to yield FDCA via FFCA. Most of the industries are following chemo catalysis due to the higher activity, exciting wide range of different catalysts availability. Moreover, due to its robustness larger volume of product can be synthesized. Apart from these advantages, industries are facing high amount of energy usages specifically environmental issues. Other drawbacks are low selectivity, high costs for energy, high cost equipment and reagents using for the reactions and toxic chemicals make process unfavorable. These factors will lead to high waste generation also low recyclability issues [5]. So, the industries are looking for an alternative environmental friendly method for the production of this chemical via microbial conversion process where the starting raw materials include 5-hydroxymethyl furfural (HMF), fructose or renewable biomass. In the present study, a novel strain *Rhodococcus qingshengii C*27 was isolated from high altitude soil samples of Sikkim Himalaya in India. This isolate is able to grow in presence of HMF and could able to transform HMF to FDCA.

Material and Methods

I*solation and enrichment of HMF to FDCA producing strain*

To isolate the potential microorganisms for the production of FDCA from 5-Hydroxymethyl furfural, the collected soil samples were pre-cultured on minimal salt solution (MSS composition: g/l: $MgSO_4.7H_2O$, 0.2g; $CaCl_2.2H_2O$, 0.002g; KH_2PO_4, 0.5g; K_2HPO_4, 0.5g; NH_4Cl, 0.5g; Trace elements solution 10ml/l, Trace element composition mg/l: $FeSO_4.7H_2O$, 300mg; $MnSO_4.H_2O$, 50mg; $CoCl_2.6H_2O$, 34mg; $Na_2MoO_4.2H_2O$, 34mg; $ZnSO_4.7H_2O$, 40mg; $CuSO_4.5H_2O$, 50mg;) with varying concentrations of HMF (500mg/l to 2500mg/l) for 24 h. This was followed by spread plating of pre-cultured samples following standard serial dilution procedure on four different media (MSS agar, nutrient agar, potato dextrose agar and yeast extract peptone dextrose agar) supplemented with different concentration of HMF (500mg/l to 2500mg/l). The plates were incubated for a maximum of 48 h at 28°C and 37°C. Morphologically distinct isolates were streaked on fresh plates for obtaining single colony. Individual pure cultures were screened further for the production of FDCA.

Preparation of whole-cell biocatalyst

The pre-inoculum was prepared by growing *Rhodococcus qingshengii* C27 cells at 30 °C for 12 h on a rotary shaker (200rpm) in a Luria-Bertani (LB) medium (100mL). From the pre-inoculum 1% (v/v) were transferred to freshly prepared LB medium (100mL) and kept for 27 h for incubation with same conditions. After 27 hours of incubation, cells were harvested by centrifugation at 12000 RPM for 15 min at 4°C. Cells were washed twice with sterilized water and phosphate buffer (pH 8) to remove complete media components. The cell pellet was then transferred to mineral salt media (50mL) supplemented with HMF (500 mg/L) as a sole carbon source. The production media is kept for further analysis at 30°C on rotary shaker (200rpm). The supernatant from the reaction mixture was withdrawn in every 24h and analyzed using high performance liquid chromatography (HPLC) with optimized protocol [6].

Batch and Fed-batch biotransformation

The batch biotransformation experiments were carried out in flask level with 50 mL working volume. Cell harvesting and biotransformation conditions are as described earlier. Throughout the desired incubation time pH was monitored. The experiments were carried out with 1 g/L of HMF concentration. The FDCA yield and HMF conversion was calculated. In the fed batch mode strategy; HMF was fed at 0h, 24h, 48h and 72h in 0.5 g/L concentration. The fed batch biotransformation experiments were carried out in flask level with 50 mL working volume. Every 24 hour cells from production media were plated and CFU was counted. Also the culture sample was (1 mL) was withdrawn from the production flask (every 24 hours) and measuring the optical density at 600 nm in UVV-Visible spectrophotometer (Shimadzu series UV 1601).

Figures

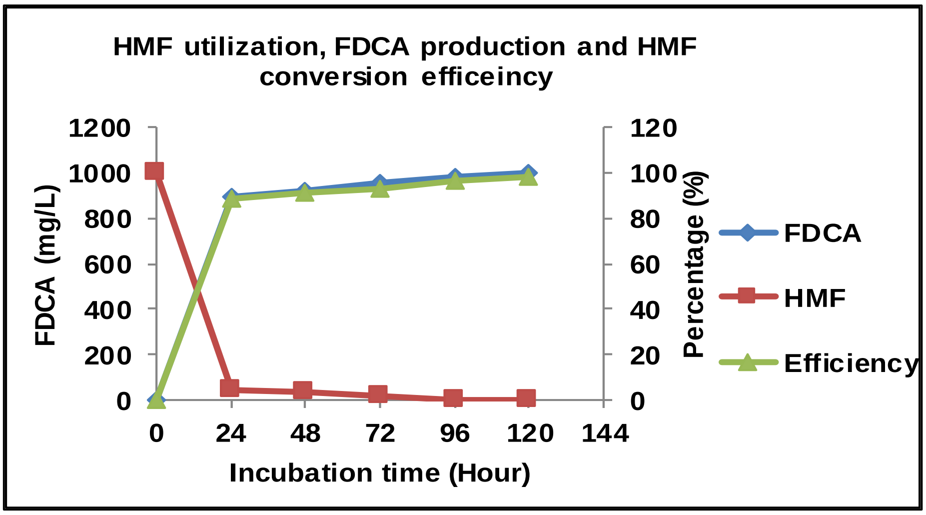

Fig.1. Batch level FDCA production efficiency.

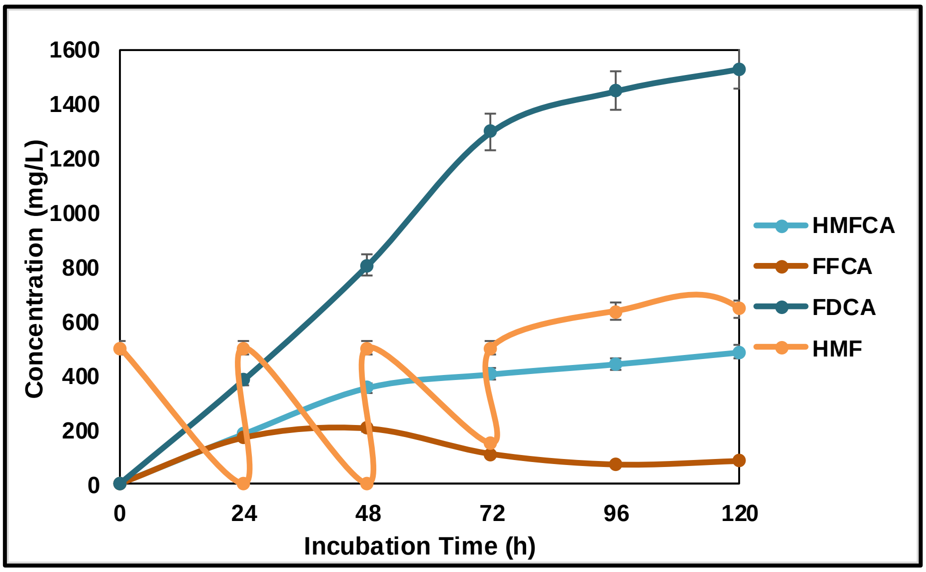

Fig.2. Fed batch level FDCA production efficiency.

Results and Discussion

Batch and Fed batch biotransformation

The experiments All the parameter optimization was completed in batch level HMF biotransformation. Under the optimized conditions, *R. qingshengii* C27 strain could convert the HMF (1 g/L) to FDCA with 94% yield (Figure 1). In batch level, the yield percentage was decreased while increasing the HMF concentration due to the substrate inhibition towards the cells. HMF utilization was studied in different HMF concentration (data not provided).

The fed batch experiments were carried out in different strategies. Compared to batch, the fed batch biotransformation could increase the HMF utilization and FDCA yield. In strategy 1, HMF was given at 0h, 24h, 48 and 72 h in 0.5 g/L concentration. Through the fed batch biotransformation, total of 1530 mg/L FDCA was obtained from 2000 mg/L HMF (Figure 2). The experiment result suggests fed batch strategy is getting better yield (76.5%) than batch biotransformation with respect to the higher HMF concentration. However, it was observed the HMF accumulation was started after 48 hours. After 72 hours, it was found almost 600 mg/L of HMF was unutilized. It was possibly due to the not only the substrate also the product inhibition. It was evident that the product inhibition towards the cells because the pH was coming down from 7.0 to 3.14. This fact was due to the formation of HMF derivatives like HMFCA, FFCA and FDCA in the production media.

Further in this study, it is proposed that by immobilization or continuous biotransformation, FDCA yield can be increased by increasing substrate concentration. Findings suggests that metabolic engineering of the strain may be an option for the improvement FDCA yield.

Conclusions

In this research, the different strategies were investigated for the improved FDCA yield. From the batch biotransformation, 94% of FDCA yield was obtained from 1 g/L of HMF concentration. Through fed batch strategy, 1.53 g/L of FDCA from 2.0 g/L of HMF was obtained. Further FDCA yield can be improved by membrane bioreactor. The Life cycle analysis (LCA) and Techno economic analysis (TEA) would give a new dimension for environmental impacts and economic feasibility.

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Spent Mushroom Substrate and Fruit Waste Bioconversion by Black Soldier Fly Larvae (Hermetia Illucens): Effect of Cow Dung Biochar Addition

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Food waste has emerged as an issue of global concern due to its high amount of production and poor handling and disposal practices, which led to several serious environmental issues. Bioconversion through black soldier fly (*Hermetia illucens*) larvae (BSFL) feeding could be a valuable approach to convert such wastes into larval biomass and bio-manure for sustainable agriculture practices. This study aimed to investigate the bioconversion of spend mushroom substrate (SMS) and fruit waste (FW) mixtures spiked with cow dung biochar (BC) using BSFL. SMS was mixed with FW in different proportions 30, 70, and 100% along with 5% BC and fed to BSFL until the emergence of adult fly and changes in waste physicochemical quality was analyzed. BSFL feeding caused a decrease in total organic carbon, NH_4^+-N and C/N ratio while an increase in NO_3^- -N, electrical conductivity, total phosphorus and total potassium. Fourier transform infrared spectroscopy suggested significant changes in the chemical composition of waste mixtures after BSFL feeding. Waste mixture 70% SMW + 30% FW showed better results of waste mineralization and BSFL growth. The waste reduction, feed conversion ratio (FCR), bioconversion ratio (BCR), growth rate, and larval weight showed better results in BC-amended setups of SMS and FW. The germination index study supports the potential use of frass (residual waste) in plant production. In summary, results suggested that BSFL could be a valuable tool for converting food production and processing wastes into multiple products: protein-rich larval biomass for animal feeding and biosolid (frass) for soil fertility management under a circular economy approach.

Keywords: Fruit waste, Spent mushroom substrate, Black soldier fly larvae, Biomanure.

EPS Production Using Glycerol as a Carbon Substrate: A Promising Approach for Sustainable Bioprocessing

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ABSTRACT.: Extracellular polymeric substances (EPSs) are eco-friendly, economical, and biodegradable microbial biopolymers used in various applications, including wastewater treatment plants, environmental remediation, and sludge flocculation. They are cost-effective and sustainable alternatives to chemical flocculants. However, their production is often influenced by stress or nutrient limitations, with expensive carbon sources hindering their advancement.

This study investigates the production of extracellular polymeric substances (EPSs) from microbial strains using waste substrates like crude and pure glycerol, with sludge, in addition to determining the different conditions such as washed/unwashed sludge , type of pre-treatment etc.

Crude and pure glycerol were used as the carbon substrates to provide solution to the expensive carbon sources being used for EPS production. Alkaline- thermal pre-treatment of sludge was used in this study as it results in high solubilisation, increase of soluble carbon and .Primary results illustrate unwashed sludge fortified with crude glycerol produced EPS of higher concentration (11.4 g/L) as compared to unwashed sludge with pure glycerol (8.3 g/L) at 96th hour of fermentation. A comparison between the EPS produced using crude glycerol (20 g/L) with NaOH vs $Ca(OH)_2$ as the alkaline sludge pre-treatment methods demonstrated NaOH to be a better agent as the EPS produced with NaOH (9.47 g/L) was higher than $Ca(OH)_2$ (8.23 g/L). NaOH treatment resulted in slightly better solubilisation of sludge as compared to

Keywords: Extracellular polymeric substances (EPSs), wastewater treatment, sludge, flocculation, biopolymers, bio-flocculants, landfill leachate.

Introduction

Extracellular Polymeric Substances (EPSs) are complex mixtures of biopolymers secreted by microorganisms that play a crucial role in the formation and functioning of biofilms. Glycerol, a by-product of biodiesel production and other industrial processes, has emerged as a potential carbon substrate for EPS production, which holds immense promise in various fields, including environmental biotechnology, bioremediation, and biopharmaceuticals [1,2]. EPS production traditionally relies on carbohydrates like glucose or sucrose, but exploring alternative carbon sources like glycerol offers numerous advantages, including abundant availability, low cost, and reduced competition with food/feed resources. Glycerol-based EPS has been investigated in various microbial systems, promoting EPS synthesis by diverse microorganisms. Process optimization parameters, such as glycerol concentration, nitrogen source, pH, and cultivation conditions, have been investigated to enhance EPS yields and tailor the properties of the produced biopolymers. This study aims to provide a comprehensive analysis of EPS production using glycerol as a carbon substrate, explore the use of other industrial by-products like waste cooking oil, and address challenges faced during EPS production. It also focuses on the impact of sludge conditions(washed/unwashed), the method pre-treatment chosen, and the substrate used on the EPS produced and its properties.

Material and Methods

Bacterial Strain

Bacterial strain (BRD 10) isolated in the INRS laboratory (INRS-ETE) was used in this study for EPS production. The strain was revived and sub-cultured from glycerol stocks on tryptic soy agar (TSA) and incubated for 30 °C for 24 h. For future studies, the strain was stored at 4 °C.

Innoculum and culture conditions

Innoculum preparation includes autoclaving 50 mL of tryptic soy broth (TSB) at 121°C for 15 minutes, cooling it to room temperature, and transferring a loop-full of an EPS-producing strain to create pre culture-1 (PC-1). PC-1 was incubated for 24 hours at 30°C and 200 rpm. PC-2 medium, mimicking the production medium, was inoculated using PC-1 and Pulp-paper wastewater activated sludge (PPWAS) from White Birch, Canada. The sludge was collected and analyzed for SS concentration. Two methods were used to pre-treat the sludge: adding calcium hydroxide and sterilizing it at 121°C for 30 minutes, or adjusting the pH to 11. The EPS production conditions are listed in Table 1. The mineral solution for PC-2 contained 6 NaHPO412H2O, 2.4 KH2PO4, 1.00 NH4Cl, and 0.50 MgSO47H2O. A trace element stock solution was prepared by filter sterilizing and adding 1 mL/L of this solution to the medium. The pH was adjusted to 6.8 using 4 N H2SO4 or 4 N NaOH. The flasks were inoculated with 10% (v/v) of PC-1 and incubated for 24 hours at 30°C and 200 rpm in a rotary shaker incubator[3]. Characterisation and composition of the glycerol used in this study is presented in Table 2. The characterisation and composition of the paper and pulp sludge from White Birch is illustrated in Table 3.

Shake Flask Fermentation

With a working volume of 300 mL, 1 L flasks were used for all the experiments. The production media (300 mL) was prepared with a 15 g/L SS concentration of sludge. The sludge was sterilized at 121°C for 30 minutes using $Ca(OH)_2$/NaOH, followed by sterilization of different solutions and minerals. The sludge, glycerol, minerals, and trace elements were combined aseptically, with water used as the volume and pH adjusted to 6.8. Flasks were incubated at 200 rpm for 96 hours at 30°C after inoculation with 10% PC-2. The average values were presented with a standard deviation of 5% or less. 15 mL broth samples were taken every 12 hours to measure CFU, glycerol, biomass, and EPS concentrations. EPS was evaluated for FA and carbohydrate-protein content every 24 hours[3,4].

Table 1 illustrates the different conditions of activated sludge and the pre-treatments used.

Conditions	**Carbon substrate**	**Sludge**	**$Ca(OH)_2$ pre-treatment**	**NaOH pre-treatment**
W-CG-Ca	Crude Glycerol	Yes	Yes	No
W-CG-Na	Crude Glycerol	Yes	No	Yes
W-PG-Ca	Pure Glycerol	Yes	Yes	No
W-PG-Na	Pure Glycerol	Yes	No	Yes
UW-CG-Ca	Crude Glycerol	Yes	Yes	No
UW-CG-Na	Crude Glycerol	Yes	No	Yes
UW-PG-Ca	Pure Glycerol	Yes	Yes	No
UW-PG-Na	Pure Glycerol	Yes	No	Yes
CG-Ca	Crude Glycerol	No	Yes	No
CG-Na	Pure Glycerol	No	No	Yes
WCO-Ca	Waste Cooking Oil	No	Yes	No
WCO-Na	Waste Cooking Oil	No	No	Yes

Analytical methods

Colony forming unit (CFU), extraction and dry weight, and flocculation activity (FA) of extracted EPS were calculated using the protocols previously used at INRS-ETE.

The samples for CFU were serially diluted in saline solution (0.85% w/v) followed by spread plating on nutrient agar plates. All the analysis was carried out in duplicates. The plates were incubated at 30 °C for 24 h and CFU was determined as

CFU= Colony count * {dilution factor/ volume of sample(mL})

Results and Discussion

Crude glycerol and pure glycerol have different composition based on the impurities of feedstock, type of industry among other attributes, hence, might have an impact on the production of EPS, its growth rate, and other characteristics. The comparison between production of EPS using sludge given different pre-treatments $Ca(OH)_2$ or NaOH and fortified with glycerol is given in figure 1. While simultaneous experiments concluded with the comparison of EPS concentration produced using sludge fortified with crude and pure glycerol as displayed in figure 2. SO what was conclusions from figure 1?

Unwashed sludge fortified with crude glycerol produced EPS of higher concentration (11.4 g/L) as compared to unwashed sludge with pure glycerol (8.3 g/L) at 96th hour of fermentation. Here you should compare the grphs (and make the graphs also) between washed and unwashed sludge for PG and CG. A comparison between the EPS produced using crude glycerol (20 g/L) with NaOH vs $Ca(OH)_2$ as the alkaline sludge pre-treatment methods demonstrated NaOH to be a better agent as the EPS produced with NaOH (9.47 g/L) was higher than $Ca(OH)_2$ (8.23 g/L) (figure 1) Don't you think this fig should be after fig 2. Because it compares CG pre-treatments (condition that was derived from fig 1). EPS production with pure glycerol entered stationary phase at the 72nd hour of fermentation whereas with the crude glycerol showed a slight rise until the 96th hour. The concentration of EPS produced with the carbon substrates deprived of sludge were compared. S-EPS concentration saw a rise by 1.5-3 times approximately by using sludge fortified with glycerol as compared to glycerol (no sludge) as the sole medium for EPS production. The usual trend of flocculation activity for all strains is an increase of FA with an increase in EPS concentration. Highest flocculation activity was observed in the EPS produced with $Ca(OH)_2$-treated sludge fortified with glycerol, with the least being in the EPS produced with no sludge. Flocculation activity showed an increase from 72% to 85% with the change in carbon substratef. Simultaneously, the number of bacterial cells, allowing measurement of the proliferation and differentiation ability of individual cells within a sample was estimated by calculating CFU/mL. Figure 3 illustrates the comparison of EPS biomass growth for the EPS produced with unwashed sludge fortified with pure and crude glycerol.

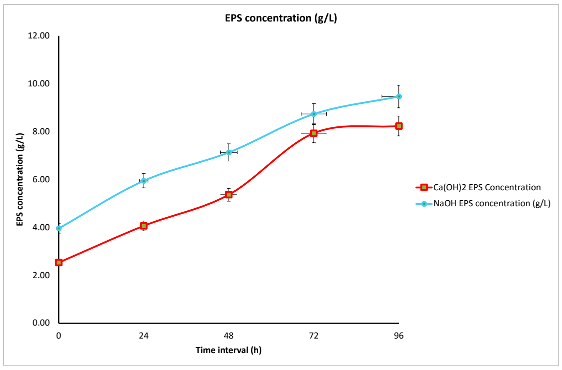

Fig 1 Production of EPS using sludge fortified with different pre-treatments $Ca(OH)_2$ or NaOH

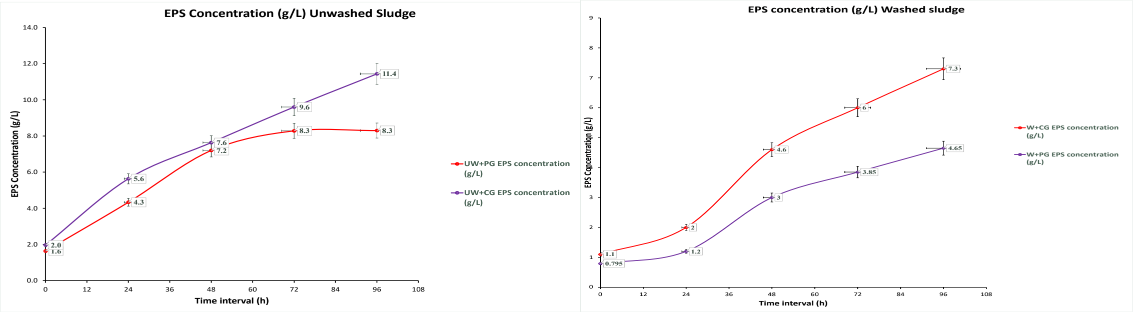

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Fig.2 Comparison of EPS concentration produced using washed vs unwashed sludge fortified with crude and pure glycerol

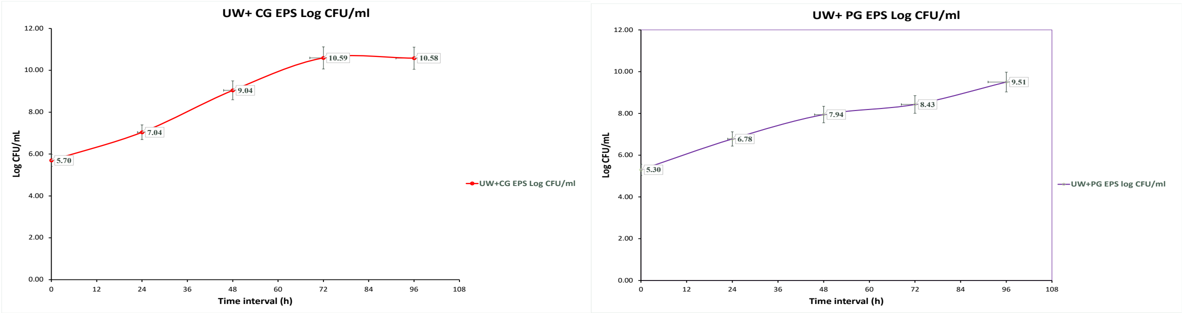

Fig.3 comparison of EPS biomass growth for the EPS produced with unwashed sludge fortified with crude and pure glycerol

Conclusions

The study evaluated the production and characterization of EPS using activated sludge augmented with different carbon substrates aimed at being an economic process. Both the alkaline pre-treatment methods implemented showed relative concentration of EPS produced, with NaOH leading by a minimal value. EPS as bio-flocculant can be considered an appropriate alternative to chemical flocculant, attributed to their good flocculation activity, economic impact and sludge settling among others. It could pave the way for solutions to issues such as sludge disposal, wastewater treatment, sludge dewaterability among many more.

Acknowledgement

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Bioplastics and Microplastics

Microplastics Pollution in Food Waste Biological Treatment

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ABSTRACT. Mismanagement of plastics is creating environmental pollution in aquatic, terrestrial and atmospheric ecosystems. The major problem of plastic pollution is the release of microplastics into the environment which leads to health risks for humans. In the past decade, extensive research has been conducted to understand the microplastic pollution. However, increase in plastic pollution in terrestrial ecosystem has demanded for systematic research to understand their effect. Microplastics pollution in food and food waste streams is a recent addition that concerns negative impact on its treatment facilities. Industrial processing, usage of plastic bags for food waste collection and single use plastics are the major sources of microplastics pollution in food waste. After reaching the treatment facility, the presence of microplastics in food waste affects the biological treatment such as anaerobic digestion and composting.

Keywords: Microplastics, Food waste treatment, Anaerobic digestion, Composting.

Introduction

Plastic pollution is ubiquitous in the present world as it is affecting the aquatic and terrestrial ecosystem. Around 300 million tonnes/year of plastic is produced globally that is nearly the entire human population weight. Due to the mismanagement of plastic waste, approximately 8-9 million tonnes per year of plastic is entering the oceans causing serious threats to aquatic life and ecosystem. In Hong Kong, plastic waste accounts for 20% of total municipal solid waste (Figure 1) (MSW) (EPD, 2021). An average of 9,684,741 plastic bags are disposed of every day which accounts for ~768 tonnes (7% of total MSW) causing the increase in micro plastics by 11 times in the past 3 years. The fate of mis-managed plastics in the natural environments are caused by several physicochemical activities which eventually leads to the formation of macro (> 5 mm), micro (< 5 mm) and nano (< 1 µm) plastics (Manu et al., 2023). It is estimated that humans are consuming a credit card of plastics in a week through water and food. Eventually, the plastics are ending up in food waste as well. The inevitable plastics pollution in food waste causes its further biological treatment processes such as anaerobic digestion (AD) and aerobic composting. The current mode of food waste collection in plastic bags followed by its mechanical breaking to remove the food waste is causing the microplastics contamination on food waste. In the food waste treatment facilities, the current practices do not have sufficient machineries to completely remove the plastics in food waste. The food waste contaminated with microplastics entering the anaerobic digesters and affecting the process performance. It is reported that the microplastics from the conventional plastics such as polyethylene terephthalate (PET), high-density polyethylene (HDPE), polyvinyl chloride (PVC), low-density polyethylene (LDPE), polypropylene (PP), polystyrene (PS or styrofoam) and others affect the microbial activities and affect the methane production in AD process and reduce the compost quality in composting process (Qi et al., 2021; Xu et al., 2022). United States Environmental Protection Agency (USEPA) has recently reported several research gaps associated with microplastics pollution in food waste and their impact on treatment and products (USEPA, 2021). The research gaps include assessment of particles sizes and type of plastics in food waste, compost and digestate along with their impact on the process performance of anaerobic digestion and composting.

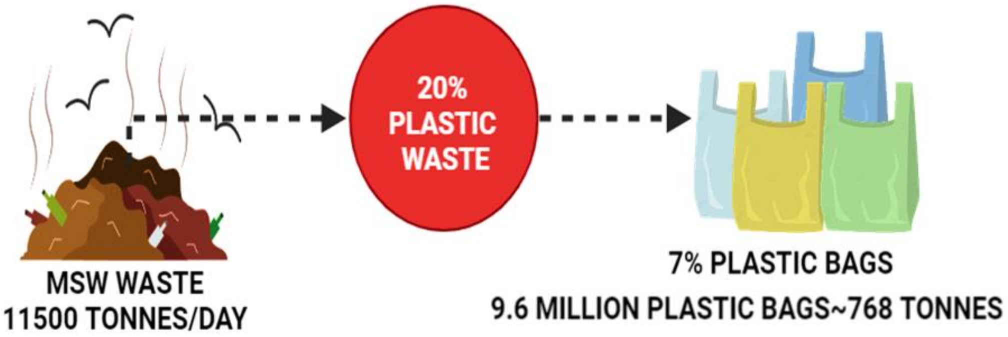

Figure 1. Plastic pollution in Hong Kong (EPD, 2021)

Microplastics in food waste and its products

The presence of microplastics in food items and food waste has become a common occurrence due to the current lifestyle practices. The industrial processing and packaging of food, food storage, fast food practice and dependency on use of plastics to collect discarded food/ food waste is a major route of plastic contamination in food waste. The biological food waste treatment includes anaerobic digestion and composting. Due to the increased production of food waste, many countries have adopted anaerobic digestion as a primary technology to treat food waste thereby reducing the burden on landfills and mitigation of carbon emissions. The industrial food waste biological treatment faciltieies include a pretreatment step to shred the collected food waste as well as to remove the unwanted/inorganic particles. The bigger plastics which are used to collect the food waste are expected to be removed at this stage. However, the current mechanical operations and machineries used in the treatment plants are not capable of removing microplastics in the food waste. As a result, the microplastics travels through the food waste treatment facility and negatively affect the performance. Recent studies have showed the presence of microplastics in food waste, digestate and compost in different countries (Table 1) (Porterfield et al., 2022). The abundance of microplastics in food varied in the range 0.03-5.6 % (w/w dry) from country to country due to several reasons. The commonly found microplastics were PE, PP and PS. Further, the abundance of microplastics in digestate was 0.01-0.25 % (w/w dry) which included PES, PVC, PP, PE, and PET. The compost produced from biowaste was also reported to have microplastics in the range 0.01-0.08 % (w/w dry). The common types of microplastics found in compost were PE, PVC, PP, PS and PET. The application of digestate and compost can act as a carrier to transfer the microplastics into soil ecosystem. Hence, immediate attention is need to address the issue of microplastics pollution in food waste treatment facilities.

Table 1. Abundance of microplastics in food waste, digestate and compost found in different countries (adapted from Porterfield et al., 2022)

Waste fraction	Abundance (% w/w dry)	Polymer type	Country
Food waste			
Kitchen and garden waste	0.5	-	Switzerland
Food waste	0.025	PE, PP, PS	Germany
Household biowaste	3-5.6	-	Austria
Digestate			
Kitchen and garden waste	0.12	-	Switzerland
Organic waste	0.02-0.08	PET	Germany
Food waste	0.25	-	USA
OFMSW	0.01-0.04	PES, PVC, PP, PE, PET	Germany
Compost			
Food waste	0.08	PE, PS, PET, PP	Lithuania
Biowaste	0.02	-	Germany
Organic waste	0.01	PET	Germany
OFMW digestate	0.05	PE, PVC, PP, PS, PET	Germany

Effect of microplastics on anaerobic digestion

Recent studies have reported that the presence of microplastics significantly affects the anaerobic digestion process. Different types of microplastics have various impact on the anaerobic digestion process by affecting different stages such as hydrolysis, methanogenesis. Further, the concentration or number of microplastics majorly influence the impact as the surface area plays an important role in microbe substrate interaction. The impact can be classified into direct and indirect roles wherein the direct impact involves the interaction of microplastics with microbial cells causing cell death. Further, indirect impact comes through leaching of toxic plastic additives and formation of reactive oxygen species. Overall, reduction of methane production and inhibition on hydrolysis and methanogenesis has been reported due to the presence of different types of microplastics during anaerobic digestion process (Table 2) (Manu et al., 20123).

Table 2. Impact of different types of microplastics on the performance of anaerobic digestion process (adapted from Manu et al., 2023)

MP type	MP concentration	Major findings
PVC	0.5 g/kg VS	Reduced methane production by 16.2%
PVC	10-60 particles/g TS	Decrease in methane production due to leaching of BPS
PE	1-4 g/L	4 g/L reduced biogas production by 7% due to the adsorption of inhibitors on MPs
PE	200 particles/g TS	Reduction in methane production by 6.1-13.8% due to the reduced methanogens
PE	10 mg/L	Reduction in methane production by 30.71% due to the reduction in acetogens and methanogens.
PE	10-200 particles/g TS	100 and 200 particles/g TS decreased methane production by 12.4-27.5% due to ROS synthesis and reduced enzyme activities
PET	1-6 mg/g TS	Increased methane production by 22%5 due the sludge pretreatment
Polyester	1-200 particles/g TS	Hydrolysis and methanogenesis were inhibited
Polyester	1-200 particles/g TS	Hydrolysis and methanogenesis were inhibited
PS	75 mg/L	Methane production was reduced by 6.7-16.2%
PS	50 mg/g TS	Methane yield decreased by 15.5%
PS	0.05-0.25 g/L	0.25 g/L reduced methane production by 18-19%
PS	0.05-0.2 g/L	0.2 g/L reduced methane production due to pitting of microbial cells by PS
PS	10-50 µg/L	20 and 50 µg/L reduced methane production by 19-29% due to leaching of SDS and ROS generation
Face mask containing PE, PP, PVC	4-20 masks	Reduction in methane production up to 18%, increase in lag phase by 7-14%
PBS	0.5 g/L	Inhibited methanogenesis by 10.2%

Conclusions

The microplastics exposure significantly affects the anaerobic digestion process performance by directly hindering the methane production. The mitigation of negative impact of the MPs on the anaerobic digestion process is not an easy way at the current waste management practices. Number of microplastics particles during the biological food waste treatment increases due to biological and mechanical ways. Replacing conventional plastics with bioplastics still has concerns due to their partial/ no degradation during food waste treatment. The available studies have been conducted using single MPs whereas the real conditions include exposure of multiple types of MPs on AD process which needs further investigation.

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Deciphering the Mechanism Shaping Bacterial Community in Plastisphere and Kitchen Waste Composting with PLA/PBAT Blends

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Biodegradable plastics has aroused increasing concern for reducing the negative environmental impact of plastic waste, however, the impact of biodegradable plastics mixed into kitchen waste (KW) on composting remains poorly understood, especially focusing on bacterial communities in the unique “plastisphere”. Here, KW composting for 120 days with adding poly lactic acid / poly butylene adipate-co-terephthalate (PLA/PBAT) plastics were conducted to reveal the dynamics of bacterial composition, succession, and assembly process in different ecological niches (compost and plastisphere). Results showed, after composting with 80% degradation of PLA/PBAT, there were prominent divergences of bacterial compositions between plastisphere, composts with PLA/PBAT and control. Co-occurrence network showed that PLA/PBAT plastisphere exhibited greater network complexity and stronger cohesion than those in compost, and PLA/PBAT increased bacterial module hubs, connectors, and network hubs in composting compared to control, but might enrich pathogens. Phylogenetic bin-based null model analysis indicated that stochastic processes critically shaped the communities on PLA/PBAT plastisphere, but compare to control, PLA/PBAT plastics increased the relative importance of deterministic processes on composting bacterial community assembly. These findings deeply understood the assembly processes and diversity patterns of plastisphere and composting processes, laying down a foundation on applying biodegradable plastics under the classification of domestic garbage.

Keywords: Biodegradable plastics, Composting, Co-occurrence network, Microbiome, Assembly processes.

Bioprocess Robustness of Newer Polyhydroxyalkanoate Producers as Sustainable and Persistent Industrial Strains

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ABSTRACT. Gram-positive polyhydroxyalkanoates (PHAs) utilization has been hampered by the incompetence of conventional fermentation that have elevated the cost competitiveness of PHAs. In this respect, the present study explores the potential of *B. cereus* IBA1 towards valorization of wastewater activated sludge (AS) as a propulsive waste feedstock. Hydrothermal sodium hydroxide pre-treatment was used to optimize the release of trapped nutrients from organic matter of AS over a range of pH and activated sludge solids (ASS). Production kinetics revealed pH 9.5 and ASS 15 g/L to be most optimum. Fermentation of the nutrient rich AS hydrolyzed fraction when supplemented with simple sugars (glucose) promoted *B. cereus* IBA1 to reach the biomass of 10.61 ± 2.7 g CDW/L with accumulated PHAs up to 52.38 (% w/w) and overall 4.92 ± 1.02 gPHA/L. Replacement of simple sugars with complex carbohydrate rich molasses also showed active PHA biosynthesis of up to 3.21 ± 0.21 gPHA/L.

Keywords: *Biopolymer; Sludge; Agro-industrial byproducts; Hydrothermal Alkaline Pretreatment; Waste valorisation.*

Introduction

Fast growing population and societal developments have been attributed to the consistent manufacturing of synthetic thermopolymers for various applications. This has led to over 390.7 million metric tons of unsustainable petro-plastic production annually which are further projected to outreach 590 million metric tons by 2050 [1]. Remarkably, half of this production is attributed to single-use products contributing to high amounts of plastic waste pollution globally [2]. Biopolymers have the potential to curb these issues as ‘green plastics’ by providing safer, biodegradable, and biocompatible alternatives. Among these, biobased polyhydroxyalkanoates (PHAs) have been rooted as most exceptional due to their competitive multifaceted properties such as insolubility in water, non-toxicity, piezoelectricity, elasticity, and thermoplasticity [3].

Despite of this, PHAs actual progress and sustainability has been hindered by the constraints within conventional fermentation bioprocesses that have elevated the cost of PHAs 5-6 times higher (US$ 4–6/Kg) then conventional plastics [4]. Majority of this production cost is attributed to the microbial incompetence towards both carbon feedstock utilization and complicated downstream processing (>50%) [5]. Alternatively, recent efforts have clarified certain gram-positive microbes to harbor industrially relevant characteristics. Among these *Bacillus* emend *cereus* clade naturally harbor intracellular PHA accumulation capacity using structurally unrelated carbon sources which can reach up to ~80% of cell dry weight and lacks PHA contaminating pyrogens [6]. However, actionable bioprocesses backing economical PHA production strategies have not been clarified enough to obtain commercially relevant gram-positive PHAs.

Reports clarify that sludge abstracted from different biological wastewater plants on average consists of carbon (50-70%), nitrogen (2-10%), phosphorus (1-1.5%), sulphur (0-2.4%) [7], components deemed essential for successful growth dependent PHA biosynthesis. Derived activated sludge (AS) has the most abundant organic matter as mineral particles and dead/alive bacteria suspended in water [7]. Upcycling of these trapped nutrients is highly sustainable as every 1000 tonnes (~1000 kL) of wastewater treatment generates 10-17 tonnes of wet AS [8]. Bioconversion of AS towards PHAs can propel multiple sustainable development goals (SDGs) encompass various aspects, including advancements in biorefinery domains to foster a circular economy, reduction of carbon footprint, and increased utilization as socially and environmentally friendly bioproducts.

Therefore, in the present work a roadmap for low-cost production of gram-positive PHAs was tailored with *B. cereus* IBA1. This proof of successful waste-to-value added compounds can fulfill the pivotal requirement of biopolymer industries in compliance with SDGs.

Material and Methods

Feedstock collection and identification

Activated sludge was collected from Sai Kung Sewage Treatment Works, Hong Kong. After thorough mixing, a predetermined quantity (wt) of the samples was loaded onto pre-weighed crucibles. These loaded crucibles were then placed in a 105°C oven and dried overnight. Subsequently, the crucibles were transferred to a muffle furnace and heated to a temperature of 550°C. The residues remaining in the crucibles were weighed at each stage of the process. These weighed residues were utilized to determine the contents of total solids (TS) and volatile solids (VS), respectively. Organic elemental characterization was conducted using CHNS elemental analyzer (Elementar vario MACRO cube, Germany) [9]. Additionally, supplemental carbon sources used were either pure glucose (Sigma-Aldrich, USA) or molasses depending on the stage of optimization. Molasses was purchased from a local vendor (Brer Rabbit) and nutrient compositions (carbohydrates, proteins, lipids, salts) were followed as per the manufacturer's quantification.

Pretreatment strategies

To increase the bioavailability of organic components within AS, hydrothermal alkaline hydrolysis was carried out through one-factor-at-a-time strategy. Active chemical cleavage was performed by sodium hydroxide at 121°C and 30 mins. pH was adjusted before and after each pre-treatment using a sterile pH probe (Mettler Toledo, USA). Optimization experiments to determine the pH requirements at a range of 8.5 to12.5 and AS solids from 10-30 g/L (dry weight basis) were carried out. Performance was confirmed for each sub-treatment by measuring the degree of solubilization (DS) of suspended material and batch fermentation kinetics. Statistical significance was determined using t-test and one-way analysis of variance (ANOVA) on GraphPad prism v 8.0.0 (California, USA).

Microorganism and batch fermentation setup

Present study used *Bacillus cereus* IBA1 previously isolated in our lab (CGMCC 23343) and preserved in 25% glycerol (master stocks) at −80°C. Thawed stocks were streaked onto nutrient agar plates (peptone 5 g/L, beef extract 3 g/L, sodium chloride 8 g/L, agar 12 g/L). Obtained single colonies were inoculated in 30 mL nutrient broth (peptone 5 g/L, beef extract 3 g/L and sodium chloride 8 g/L at pH 6.8) to grow seed cultures for 16 h at 37°C and 200 rpm. Further 10% seed culture was inoculated into batch shake flasks containing AS (pH adjusted to 6.8) derived from abovementioned pre-treatment strategies during which glucose (4% w/w) was used as the carbon source. AS optimized system was then coupled with valorization of molasses (4% w/w). All fermentations were carried out in triplicate (n=3) for 48h at 25°C and 200 rpm.

Growth, cell mass, PHA and substrate analysis

To determine cellular dry weight (CDW), and biomass PHA content, 10 ml culture after fermentation was harvested and centrifuged at 5000 rpm and 4°C for 10 min. The pellet obtained was washed twice with distilled water and lyophilized in a pre-weighed plastic tube. Both PHA and non PHA cell mass (NPCM) were quantified by processing acidic methanolized biomass through gas chromatography – flow ionization detection (GC-FID) (Agilent Technologies, Santa Clara, USA, Model 7690A) [10]. Substrate (glucose) quantification was conducted in the supernatant using high performance liquid chromatography (HPLC) (Agilent Technologies 1260 Infinity II, USA) equipped with an Aminex HPX-87H column (Bio-Rad Laboratories, CA) [11].

Results and Discussion

Activated sludge characterization

Characterization of AS revealed that moisture content of the feedstock (AS) was 91.89% (w/w) with a TS of 8.1% (w/w) and VS of 88.26% (w/w). The carbon and nitrogen contents of AS was 42.7% (w/w) and 7.7% (w/w), respectively. These can collectively form macromolecules such as carbohydrates (8-9% of TS w/w), and proteins (30-40% of TS w/w) [12–14], a prerequisite for growth dependent PHA accumulation pathway. To channel their release as soluble monosaccharides, amino acids, and volatile fatty acids, hydrothermal alkali sodium hydroxide pre-treatment was employed.

Optimization of growth performance

In the present study, hydrolysis of sludge carries out a major step to release the nutrients from the solid phase of AS to the solution phase for bacterial utilization, which depends on two main factors i.e., pH of treatment and activated sludge solids (ASS). Henceforth, pH range optimization of AS was examined through DS of treated sludge. While increasing pH, the DS increased significantly (2-folds) from 8.5 (38.46 ± 5.51%), 9.5 (44.26 ± 3.05%), 10.5 (52.31 ± 4.17%), 11.5 (61.88 ± 6.17%) to 12.5 (77.02 ± 6.35%) (Fig.

10.3 A) (p value ≤ 0.0001). It is important to note that although the degree of solubilization increased significantly from pH 8.5 to 12.5, the quality of hydrolysed molecules and bio-assimilatory of nutrients varied (Fig. 1). Biomass showed a consistent and significant (~1.3 folds, $p \leq 0.05$) decrease when the hydrolysed AS media were compared between pre-treated pH 8.5 to 12.5. Trend of substrate (glucose) utilization dropped by 1.5 folds to ~ 40% in production media of pH 10.5, 11.5 and 12.5 treatments ($p \leq 0.05$). Therefore, favourable conditions for *B. cereus* IBA1 growth were only permissible from low pH (8.5 and 9.5) hydrolysis. Further, the differential effect of these pH treated AS media on volumetric PHA concentration were also significant at lower pH pre-treatment.

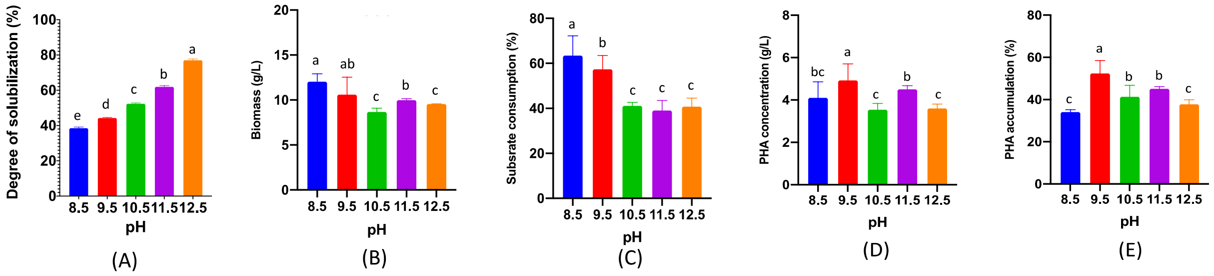

Fig. 1. Effect of pH on AS hydrolysis and derived medium fermentation. (A) Degree of solubilization, (B) biomass formation, (C) substrate utilization efficiency, (D) PHA concentrations and (E) intracellular PHA accumulation.

To optimise nutrient release and availability from AS for fermentation, different ASS (10-30 g/L dw basis) were pre-treated. At an ASS of >20 g/L AS the biomass production was inhibited ($p \leq 0.05$) (Fig. 2). Amongst these, the preferred ASS for growth was ASS 15 g/L as the biomass reached 9.47 ± 0.59 gCDW/L. Substrate utilization was also better at lower ASS (10-15 g/L) outreaching 60-64% of glucose consumption. Absence of such inhibitory phenomenon at lower ASS (10-15 g/L) allowed bioconversion of hydrolysed AS nutrients to intracellular PHAs. Additionally, *B. cereus* IBA1 performed better for PHA synthesis at ASS 15 g/L (4.72 ± 0.27 gPHA/L). This volumetric concentrations were 1.3 folds ($p \leq 0.05$) higher then ASS 10 g/L (3.61 ± 0.19 gPHA/L). Such differences in production levels were corroborated to the better cellular response at ASS 15 g/L where PHA accumulation extended to 49.84 ± 3.39 % (w/w). Based on *B. cereus* IBA1 performance kinetics and ability of cells to assimilate PHAs, pH 9.5 and ASS 15 g/L were accredited as the ideal pre-treatment combinations.

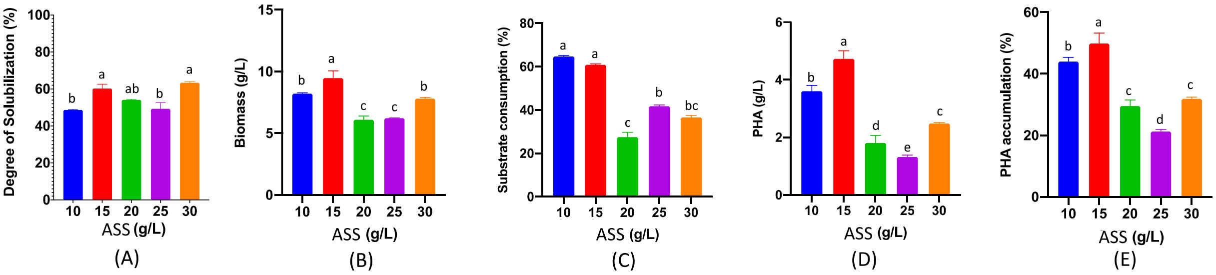

Fig. 2. Effect of ASS on hydrolysis and derived medium fermentation. (A) Degree of solubilization, (B) biomass formation, (C) substrate utilization efficiency, (D) PHA concentrations and (E) intracellular PHA accumulation.

Low-cost synthesis of gram-positive PHAs

Production of PHA from *B. cereus* IBA1 can only be attributed sustainable when all constituents are low cost as feedstock contributes 30–80 % of the total PHA production expenses. Experimentation clarifies that biorefinery towards molasses based PHAs can successfully allow *B. cereus* IBA1 to grow on this low-cost production medium, maintaining a biomass of 8.77 ± 1.23 gCDW/L at the end of batch bioprocess. This also allowed *B. cereus* IBA1 to accumulate intracellular PHAs up to 36.68 ± 3.32% (w/w). However, the accumulation content was lower than glucose based AS fermentation where PHA content reached 52.38 ± 6.14% (w/w). The product yield of PHA on molasses was 0.21 gPHA/g. therefore as a proof of concept, present research with molasses based AS fermentations can allow potentially sustainable PHA biosynthesis (3.21 ± 0.21 gPHA/L). However, further scale-up efforts are necessary to optimize and achieve industrially acceptable concentrations. Strategic mathematical approaches on a bioreactor scale can promote better understanding of the molasses interaction with AS towards higher PHA assimilations in *B. cereus* IBA1.

Conclusions

Cost competitiveness of gram-positive PHA bioprocess is one of the main factors hindering safer biopolymer progress in the present decade. Economization of PHA fermentation can be achieved by deriving nutrients for bioconversion from next generation (waste) feedstocks, replacing conventional substrate. Optimization of parameters pertaining to hydrolysis of activated sludge clarified low pH (9.5) and activated sludge solids (15 g/L dry wt basis) as ideal to facilitate PHA fermentation kinetics. Present study also provided a proof of concept for valorising pre-treated activated sludge (AS), supplemented with simple sugars (glucose) and complex carbohydrate by-products (molasses).

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Metabolic function under in PHA accumulation different alkaline conditions

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Waste activated sludge has been frequently used as mixed substrate to produce polyhydroxyalkanoate (PHA). However, insufficient research on microbial metabolism has led to difficulties in regulating PHA accumulation in mixed microbial cultures (MMCs). To explore the variation of functional genes during domestication and the effect of different alkaline conditions on metabolic pathways during PHA accumulation, MMCs were domesticated by adding acetate and propionate with aerobic dynamic feeding strategy for 60 days. As the domestication progressed, the microbial community diversity declined and PHA-producing *Brevundimonas*, *Dechloromonas* and *Hyphomonas* were enriched. Through bacterial function prediction by PICRUST, the enrichment of *rpoE* involved in starvation resistance of bacteria was found after the domestication. Untargeted metabolomics exhibited that neutral and weak alkaline conditions could promote the up-regulation of significant differential metabolites, while higher alkaline conditions caused the inhibition of metabolic activity. Functional annotation showed that weak alkaline conditions significantly affected Pyrimidine metabolism, resulting in an increase in PHA production. Regarding the pathways of PHA biosynthesis, acetoacetate was found to be significant in the metabolism of hydroxybutyric, and the weak alkaline condition could restrain the conversion from hydroxybutyric (HB) to the acetoacetate to protect PHB accumulation in MMCs compared with neutral condition. Taken together, the present results can advance the fundamental understanding of metabolic function in PHA accumulation under different alkaline conditions.

Identification and Removal of Microplastic Pollutants in Soil-like Materials from Landfills

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The huge amount of plastic waste accumulated in landfills has caused serious microplastic (MP) pollution to the soil environment, which has become an urgent issue in recent years. In the present work, the MPs in landfill soil were identified by pyrolysis-gas chromatograph/mass spectrometer (Py-GC/MS). To remediate the contaminated soil, a dielectric barrier discharge (DBD) system was applied to remove MP pollutants from the soil due to its strong oxidation capacity. The soil-like materials with severe MP pollution were sampled from a non-sanitary landfill in China. The procedure of flotation-digestion was adopted to extract MPs from the soil sample, which visually proves the MP pollution in the landfill soil sample. MPs observed under the stereomicroscope were divided into five types in terms of morphology: fragments, fibers, films, foams, and pellets. The indicator compounds corresponding to each MP polymer were selected. The Py-GC/MS results showed the soil samples contained four common MP pollutants, including polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyvinyl chloride (PVC) with sizes ranging from 50 to 1500 μm. The contaminated landfill soil was treated in a DBD device, and MP pollutants were rapidly removed under the action of reactive oxygen species (ROS) generated by DBD plasma. The maximum remediation efficiency represented by mass loss reached over 95% after 30 min treatment, realizing almost complete innoxious treatment. Compared with nitrogen, when air was used as the carrier gas, the remediation efficiency increased by 97%. The increased applied voltage could also promote the removal of MP contaminants. Sufficient air supply was conducive to thorough degradation. However, a higher air flow rate would shorten the residence time of ROS, resulting in reduced remediation efficiency. Gas products (mainly COx, accounting for ~90%) and liquid by-products were analyzed. The possible remediation mechanism was put forward: long-chain fracture, oxidation of substituent groups by ROS, decomposition into small molecular acids, and mineralization into carbon dioxide and water. This study provides initial evidence of MPs pollution characteristics in soil-like materials from landfill, and the results will foster the understanding of MPs fates in landfill systems. The proposed DBD plasma treatment showed superior energy efficiency and remediation performance, which provide a potential solution to solve MP pollution in the soil environment.

Keywords: Landfill, Microplastic pollution, Soil remediation, Plasma oxidation.

Aerobic Degradation of Deca-brominated Diphenyl Ethers (Deca-BDE): Novel Indigenous Microbes, Mineralization, Dehalogenation, Metabolites and Degradation Pathway

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Polybrominated diphenyl ethers (PBDEs), a group of persistent organic pollutants (POPs), and emerging contaminants (ECs) have raised the concern for human health due to their persistent nature, bioaccumulation potential and toxicity. Therefore, developing eco-friendly and sustainable remediation technologies for the removal of PBDEs from the environment is the need of the hour. In the present investigation, three novel bacteria having the potency to degrade and use BDE 209 as a sole carbon source were isolated from a PBDE polluted municipal waste dumping site in India. The bacteria were found to have 99.93%, 99.23%, and 99.23% similarity with the *Lysinibacillus capsici*, *Bacillus subtilis*, and *Lysinibacillus macroides* using 16S rRNA gene sequencing technique. These novel bacterial strains were named *Lysinibacillus capsici* strain BDE S2, Bacillus subtilis strain BDE S3, and *Lysinibacillus macroides* strain BDE S4. Genetic sequences of strain BDE S2, BDE S3, and BDE S4 were submitted to GenBank and their GenBank accession no. is MZ470736, MZ474476, and MZ474477, respectively. 94.35%, 84.31%, and 85.89% carbon content utilization and 66%, 60%, and 55% of initial BDE 209 concentration were removed by strain BDE S2, BDE S3, and BDE S4, respectively, within eight days of the incubation period. Also, 11.88%, 15.17%, and 11.67% debromination was observed by the strain BDE S2, BDE S3, and BDE S4, respectively. Hexa, penta, tetra and tri-BDE were detected as metabolic intermediates, which were further converted into non-BDE products with the possibility of generating CO2 and H2O as an end product. As per the analysis of metabolic intermediates, dehalogenation, breakdown of diphenyl ether bond, and cleavage of the aromatic ring were reported as probable breakdown pathways for BDE 209 by the screened bacterial strains. The present study is the first of its kind study reporting the screening and use of indigenously isolated bacteria for the aerobic breakdown of deca-BDE, which can provide new insight for removing these toxic flame retardants from the contaminated matrices.

Keywords: Polybrominated diphenyl ethers, Aerobic degradation, Bio-degradation, Efficiency, Pathway, Debromination.

Near-Infrared Spectroscopy Based Method for Rapid Detection of Microplastics/Plastics in Complex Environment

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Due to the abuse of plastics and loose waste management system, waste plastics are accumulated in the environment and resulting in white pollution. Besides, due to weathering, external forces and other factors, plastics in environment will be decomposed into small-scale plastics/microplastics, which will exist stably in nature. Many studies have found that microplastics can act as accessible vectors of organic contaminants or heavy metals to promote the transfer of pollutants in environmental media. The identification of microplastics has become a global concern. In this study, three machine learning classification models (random forest classifier, extreme gradient boosting (XGBOOST) and partial least square discriminant analysis (PLS-DA) models) and Hyperspectral imaging (HSI) technology are combined to identify microplastics directly on different media without complex separation steps. The commonly used plastic and rubber samples were used to train the models and reduce the possibility of being wrongly classified as other materials with similar spectra, and 11 household plastic items were collected as the external test set to verify the effectiveness of the model. The influence of transparency, color, roughness and background media on the identification of plastic materials were investigated. Most of the practical samples can be correctly classified by the model. However, the additives for achieving various material properties in some practical samples may result in the difference of their compositions compared with those of standard samples (plastic and rubber resin), leading to huge classification errors in the model. In order to make the model more widely applicable, more spectra of practical samples should be included for model learning. Spectral pretreatment can solve the problem of color and material surface wear and achieve high classification accuracy. Identification of fully transparent plastic materials is still a challenge, and environmental interference is a main factor. The identification of opaque plastic samples is basically independent of the background, and the identification of translucent and transparent plastics will lead to classification errors due to different background information. PLS-DA model can better identify the characteristic spectrum of transparent plastics superimposed with background information and achieve the best classification effect. The combination of spectral pretreatment and two-stage model recognition method is proposed to identify plastics in different backgrounds, which has excellent classification effect (with accuracy more than 95% for XGBOOST, 99.99% for PLS-DA). The combination of hyperspectral technology and machine learning classification model shows the potential of feature screening as a means of micro plastics classification.

Keywords: Hyperspectral imaging, Plastics, Machine learning, Classification.

Concomitant Production of Value-Added Co-Products During Polyhydroxyalkanoate (PHA) Production: Approaches for Building Circular Bioeconomy in PHA Process

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Polyhydroxyalkanoates (PHAs) are attractive alternatives to petro-plastics as they are biobased-biodegradable polymers produced by microbes. PHAs can be produced by variety of microbial strains using pure and renewable substrates under certain unfavourable conditions like availability of carbon, limitation of nitrogen, oxygen, or phosphorus. However, their penetration in market is still limited due to their high production cost. The ability to generate PHA from renewable and inexpensive materials such as lignocellulosic feedstock, cheese whey, waste lipids, crude glycerol can make the process cost-effective. During PHA production process, various value-added products can also be simultaneously produced such as microbial proteins, extracellular polymeric substances (EPS), lipases etc. Recovering useful biomaterials can further help in reducing the PHA production costs, improving the waste management and resource efficiency which is important for maintaining the circular economy in the process. In conventional PHA process, these value-added products are not targeted which end up as organic wastes in the liquid streams generated in the process. In this study, cheap waste substrates such as activated sludge, waste cooking oil and crude glycerol were studied for the simultaneous production of PHA, microbial proteins and EPS. Both PHAs and microbial proteins are intracellular products and fed-batch fermentation resulted in 25 g/L PHA (60% w/w) and 6-8 g/L proteins (13-15% w/w), respectively, at the end of fermentation. The microbial proteins were released in the supernatant obtained after cell disruption/pre-treatment conducted for PHA release outside the cells. Therefore, various protein precipitation methods were used for recovering the soluble microbial proteins from the supernatant/waste stream generated during the PHA downstream processing. The produced EPS (extracellular co-product) was further characterised in terms of flocculation activity, dewaterability, protein-carbohydrate content and structural analysis. Sludge volume index and protein precipitation was carried out by the produced EPS to understand its application prospects. After fermentative PHA production and downstream processing, various liquid streams (such as waste stream generated after treatment of PHA-rich biomass and wash waters) are released which are generally discarded. Various recycling strategies were developed for these streams to be used in the subsequent PHA production process. Therefore, the research aims at providing strategies to reduce the cost of PHA production by recovering high value-added co-products as well as minimizing the ecological risks by recycling precarious waste streams generated during the process in more than one fashion thus, maintaining circular bioeconomy.

Keywords: Polyhydroxyalkanoates, Biopolymers, Microbial proteins, Circular bioeconomy, Exopolysaccharides.

Production of PHA from Pineapple Residues by *Cupriavidus Necator*

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Nowadays, petrochemical plastic waste pollution is a global challenge due to its adverse effects on the environment and human health. Therefore, companies are interested in biobased and biodegradable thermoplastics such as polyhydroxyalkanoates (PHA). PHA are effective substitutes because they have a multidimensional use like conventional plastics but also a very short life cycle and complete elimination in the environment. This approach uses well-defined and efficient methods for PAH production. The use of pure substrates (carbon sources) for PHA production is complex and affects the production economics. Therefore, there is a requirement for replacing them with the cheaper waste substrates. New studies have been conducted to develop more cost-effective PHA production processes. These processes are based on a microbiological technique mixing a pure microbial culture of bacteria with agri-food waste (pineapple skin). Microorganisms, thanks to their ability to adapt to complex substrates such as agri-food waste, are excellent accumulators of PHA. This would allow the production of bioplastics using renewable waste as a carbon substrate while minimizing the cost of obtaining PHA. In this study, the production of PHA is based on the use of juice from pineapple waste as a fermentation substrate and *Cupriavidus Necator*. The pineapple waste was ground, pre-treated at 50°C for 30 min and filtered to obtain a substrate rich in reducing sugar (RS) and minerals for PHA accumulation. Experiments were performed for 96 h at 200 rpm at 30°C with pH 6.8 adjusted with 4N NaOH and 4N H_2SO_4. The initial concentrations of SR tested were 10, 15, 20 and 25 g/L in 2 L erlenmeyer flasks with a working volume of 300 mL. Several feeding models (batch and fed batch) on PHA production were also studied for 96 h. The batch mode was conducted in a 5 L total capacity bioreactor with a working volume of 3 L. The fed-batch mode was conducted in a 7 L total capacity bioreactor with a working volume of 4 L. It started in batch mode for 24 h and continued in fed-batch. The bioreactors are equipped with control systems for dissolved oxygen, pH, defoamer, turbine speed, aeration rate and temperature. Experiments reveal that the maximum suspended solids (SS) concentration obtained in erlenmeyer flasks was 10.78 g/L and the maximum PHA content was 90.1% with an initial SR concentration of 19.41 g/L and a C/N ratio (SR/NH_4Cl) of 20. Among the different fermentation modes that were evaluated, the fed-batch mode was found to be better. Indeed, with a constant fed-batch of the substrate of initial concentration SR of 26.85 g/L and a C/N ratio of 20, the maximum concentration of SS was 23.47 g/L and the maximum PHA content reached was 74.2%. The PHA synthesized were polyhydroxybutyrates (PHB) with a content of 99.3% and polyhydroxyvalerate (PHV) with a content of 0.7%. The results of this study show the efficiency of pineapple waste to produce high value-added products. This approach contributes to the waste management problems and constitutes a new economically profitable source.

Keywords: PHA, Pineapple waste, *Cupriavidus Necator.*

Dissolved oxygen impact on PHA production with kitchen waste as carbon source

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ABSTRACT. Polyhydroxyalkanoates (PHA) are biodegradable polyesters that has great potential to replace traditional petroleum-based plastics, but high production costs have been a barrier to their commercial adoption, with the cost of the carbon source accounting for about half of the total production cost. The production of PHA using volatile fatty acids (VFAs) from the fermentation of organic wastes such as kitchen waste and wastewater sludge as carbon source as it leads to reduction on the PHA production cost. On the other hand, PHA production can be improved by increasing carbon source utilization or reducing energy input. Dissolved oxygen (DO) concentration is a key factor for PHA accumulation and is highly correlated with energy input. The effect of anaerobic environment on PHA synthesis has not been clearly elucidated yet. The aim of this study was to investigate the possibility of obtaining high PHB production using short-chain fatty acids as carbon source under anaerobic conditions. It was found that the PHB accumulation in anaerobic environment reached 58.6% (g PHB/g cell dry weight) in a 30 °C shaker culture and maintained a good growth trend, which was about three times higher than that in aerobic environment (20.5%). This provided reference data for improving PHA production efficiency while reducing energy input.

Keywords: *Polyhydroxyalkanoates; dissolved oxygen; volatile fatty acids*

Introduction

With the accelerated urbanization and industrialization, the consumption of fossil energy is also increasing, while generating a large amount of waste and pollutants such as carbon dioxide. Polyhydroxyalkanoates (PHA) have attracted a lot of attention as a green material that can replace petroleum-based plastics and help reduce energy consumption and mitigate the greenhouse effect. PHAs are polymers produced by microorganisms as a source of carbon and energy in response to unfavorable environments (e.g. adequate carbon sources but nutrients such as nitrogen, phosphorus, oxygen, etc. are limited), and there are over 150 known monomeric components of PHA [1]. Due to the complex metabolic pathways of microorganisms and the rich variety of microorganisms capable of synthesizing PHA, the synthesis pathways of PHA vary among microorganisms under different carbon source conditions. There are eight known pathways for microbial synthesis of PHA, of which glycolytic pathway, fatty acid β-oxidation pathway, and fatty acid de novo synthesis pathway are the three well known major pathways [2]. Although PHA have many advantages and great potential, their commercial application has not yet progressed much because the cost of the production process is much higher than that of conventional plastics. Carbon source as a key substance for microbial growth and polymer synthesis, accounting for about 70-80% of the total raw material cost [3]. Therefore, choosing cheap and readily available carbon sources for PHA production could make it more economically attractive and feasible for biobased plastics to replace petroleum-based plastics. At present, many researchers have used low-cost raw materials to produce PHA, such as agricultural waste, food waste, waste cooking oil, etc [4-6]. In addition, all known PHA producers are exclusively or partly aerobic bacteria, and dissolved oxygen (DO) is a key substrate required for cell growth and other metabolic activities. The energy requirements for mixing and aeration required to maintain high oxygen levels in microbial PHA production also have a significant impact on the total cost of PHA production. Therefore, it is important to understand how DO affects the synthesis process of PHA. However, most of the current research still focuses on providing sufficient or excessive carbon sources and lack of nutrients such as nitrogen and phosphorus to stimulate microbial accumulation of PHA. Reports on the effect of oxygen limitation on microbial growth and PHA accumulation are relatively scarce, and few studies have focused on the mechanisms by which dissolved oxygen affects microbial PHA synthesis capacity in different synthesis pathways. The production of PHA by microorganisms is largely dependent on the carbon source provided, other nutrients and the growth environment. Therefore, a strategy needs to be introduced to induce PHA producers to convert more of the available carbon source into biopolymers rather than for cell growth. Under the oxygen limitation, it will limit the growth of aerobic bacteria to some extent, and it is speculated that more carbon sources may enter the PHA synthesis pathway and help to increase the amount of PHA synthesis. The growth and PHA synthesis of Pseudomonas putida LS46 using caprylic acid as carbon source under the gradient change of dissolved oxygen have been reported. As the volumetric oxygen mass transfer coefficient (kLa) gradually decreased, the accumulation of PHA gradually increased. The highest biopolymer content (57.3 ± 3.8% CDM) were obtained when DO was below the detectable limit (0% air saturation) [7]. However, some researchers found that Escherichia coli recombinants cultured with glucose in low stirring conditions (125 rpm) accumulated less PHB than in high stirring conditions (500 rpm), with PHB content decreasing from 37.2 to 20.4% (%PHA CDM) [8]. The fatty acid β-oxidation pathway is an oxidative process unlike the glycolytic pathway and the fatty acid de novo synthesis pathway. The effect of dissolved oxygen on the different synthetic pathways is also not much reported in the literature. Therefore, the focus of this study was to provide an experimental basis for the speculation that more carbon sources would enter the PHA synthesis pathway under dissolved oxygen-limited conditions. The effect of dissolved oxygen on microbial growth and PHA synthesis process was investigated when simulated kitchen waste fermentation broth was used as the carbon source.

Material and Methods

Microorganim and medium

The experimental strain was isolated from the sludge of a municipal sewage treatment plant in Shenzhen, and stored in a refrigerator at 4 ℃. Bacterial suspensions were prepared by gradient dilution with sterile water, coated on Luria-Bertrani (LB) agar plates for strain screening, and incubated at 30 °C for 24-48 h. After that, the colonies with different morphology were selected and put into 30 mL LB medium for activation and incubated for 24 h at 30 ℃, 150 r/min in shaker incubator. The culture solution was inoculated with 10% inoculum in triangular flasks containing 150 mL of fermentation medium for second screening, and the culture was replenished in batches under the same conditions as above. After 48 h, PHB was extracted from the fermentation broth and its content was measured. Bacterial suspension with better PHB accumulation was coated on LB AGAR plate, and the above operations were repeated until pure cultured strains with better PHB synthesis ability were obtained, which were inoculated on LB inclined AGAR medium and stored in refrigerator at 4 ℃. The main groups available in the fermentation liquid of kitchen waste are VFAs. Therefore, sodium acetate was used as an alternative carbon source in the pilot experiment. The composition of fermentation medium was described in the literature [9].

Shake flask cultivation

Erlenmeyer flask (500 mL flask, 150 mL working volume) was used for the fermentation reaction of the inoculum under different dissolved oxygen conditions, incubating the inoculum at 30 °C and 150 rpm in a shaker. The initial pH of the flask cultures was adjusted to about 7.2. To investigate the effect of dissolved oxygen on PHA synthesis, three different experimental strategies were used: (a) Aerobic culture. (b) Aerobic/anaerobic alternating culture, aerobic growth was carried out using sealing film for 24h after the start of the culture. After that, the anaerobic culture was closed with silicone plugs for 4h and changed to aerobic culture with sealing film for 20h, so that the anaerobic/aerobic culture was carried out alternately. (c) Anaerobic culture, sealed with silicone plugs at all times during culture. All three culture strategies were incubated for 72h and the carbon source was supplemented at 24h and 48h to stimulate the accumulation of PHB. Each set of experimental conditions should be replicated at least twice.

Analytical methods

Optical density (OD600) was used to monitor the growth of microorganisms. Samples (50 mL) were taken periodically and centrifuged at 5000 × g for 15 min. The pellets were washed once in PBS medium and resuspended with distilled water and centrifuged again. The supernatant was used for the analysis of pH and COD. Then, the bacterial sediment obtained by centrifugation was dried at 60 °C and analyzed for PHB content of biomass, and the total PHB content was determined as a percentage of cell dry weight (CDW) (wt%). The dried cells were decomposed using acidified methanol and measured by gas chromatography with flame ionization detector (GC-FID). The GC-FID method and operating parameters have been described previously [10].

Results and Discussion

Bacterial growth and PHB synthesis in different carbon sources

In this experiment, other components of the medium were fixed, and two carbon sources, sodium acetate and glucose, were selected for the test. OD600 and PHB contents were determined after 72 h of shock culture at 30 ℃ and 150 rpm. As shown in Fig. 1, the growth and PHA accumulation of strains screened from municipal sludge using sodium acetate and glucose under conditions of nitrogen limitation only (sufficient DO). As shown in Fig. 1 (a), the strains could grow in both sodium acetate and glucose as carbon source media, and the bacterial cell density (OD600) could reach the highest value of about 2.3 at 24 h, and then both decreased; however, the decreasing trend was more slowly in sodium acetate, which could still maintain above 2.0 at 72h, while the decrease was more rapid in glucose. As shown in Fig. 1 (b), although glucose supported the effective growth of the strain, almost no accumulation of PHB was observed. PHB was synthesized only when the strain was grown in sodium acetate. With the increase of time, the accumulation of PHB gradually increased and reached the highest value of 20.5% (wt%) at 72h.

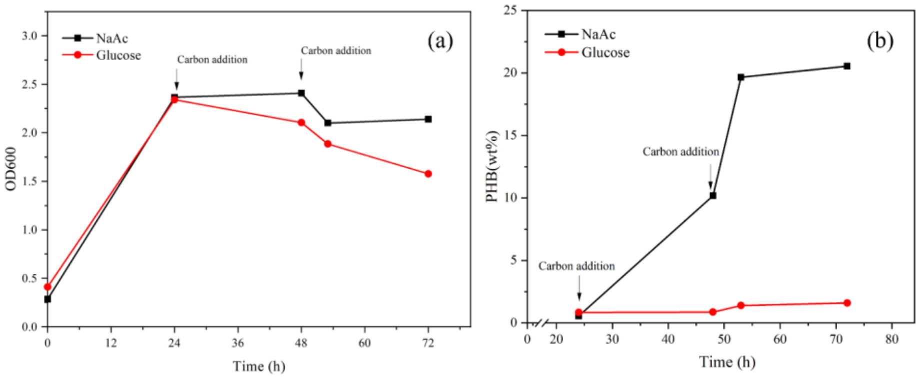

Fig.1. Utilization of sodium acetate and glucose by the screened strains under the condition of nitrogen limitation and sufficient DO (a) growth; (b) PHB accumulation

Effect of DO on PHB accumulation

To investigate the effect of dissolved oxygen on bacterial growth and PHB accumulation, three sets of experiments with different incubation strategies were carried out using sodium acetate as the carbon source. As shown in Fig. 2 (a), the effect of DO on the growth of the strain was negligible. After the carbon source was supplemented, the OD600 decreased in all three groups of experiments due to dilution, but the strain was still able to grow slowly between 52 h and 72 h in the anaerobic environment, and the increase in cell concentration of the bacterial solution in the aerobic and alternating anaerobic/aerobic environments was negligible. Also, it was found from the batch fermentation experiments performed in Erlenmeyer flasks that the accumulation of PHB all started during the stabilization period (after 24 h), indicating that the PHB synthesis process of the strain was not correlated with the growth process. Fig. 2 (b) shows that DO plays an important role in increasing the amount of biopolymers synthesized. The maximum accumulation of PHB was obtained after 72 h of incubation under aerobic, alternating anaerobic-aerobic, and anaerobic conditions, with 20.5%, 34.7%, and 58.6% (wt%), respectively. The amount of PHB synthesized by strains in DO-limited environments (anaerobic) was nearly three times higher compared to aerobic conditions.

Since DO is correlated with bacterial growth, less DO levels can cause stress in aerobic organism. It has been suggested that under DO-limited stress conditions, the level of adenosine triphosphate in microorganisms decreases, limiting the anabolic activities required for bacterial growth, so acetyl coenzyme A cannot be oxidized, leading to a blocked Kerbs cycle and more intermediates being used for PHA synthesis [11]. The high ratio of intracellular reduced to oxidized nicotinamide adenine dinucleotide (NADH: NAD) reported to be observed under oxidative stress conditions of hypoxia may contribute to the high levels of PHA observed [12]. The relationship between oxygen limitation and PHA accumulation was also confirmed early in the study of PHB synthesis from glucose in Azotobacter beijerinckii, where a redox imbalance may occur at low dissolved oxygen and lead to inhibition of key enzymes in the TCA cycle [13]. In this study, we attempted to explore the stimulation of PHB accumulation when short-chain fatty acids were used as a carbon source by maintaining relatively low DO levels to keep the strain in a stressful state. The experimental results demonstrated that the accumulation of PHB in strains grown in an anaerobic environment was significantly increased, indicating that more carbon sources were used for PHB synthesis, which is consistent with the description of the previous literature.

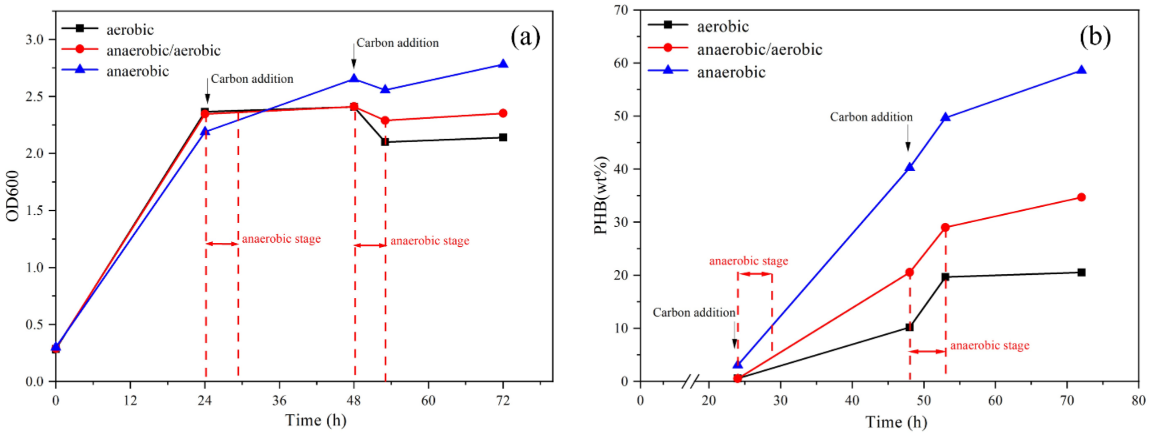

Fig.2. Growth and PHB synthesis of strains in different DO environments (a) growth; (b) PHB accumulation

Conclusions

Most of the known PHA producers are aerobic bacteria, and their PHA synthesis process optimization strategies depend on two main aspects, carbon source and other fermentation parameters. DO is essential for the vital activity of aerobic bacteria, but its effect on PHA production has not been fully investigated. The experimental results of this study verified that dissolved oxygen content plays an important role in the production process of PHB with short-chain fatty acids as the carbon source. Oxygen limitation can obtain higher PHB accumulation than conventional nitrogen limitation. At lower oxygen concentrations, microorganisms can still grow normally while PHB accumulation is greatly increased. This finding helps to improve the utilization of carbon sources in the PHA synthesis process and also helps to reduce the cost of the PHA production stage.

Acknowledgement

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Bioplastics: An Emerging Blue Technology Contributing to Green Economy

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India is covered by three side waters and delineated to the great Himalayas on the northern side which makes it a peninsular region. This geographical location contributes to the fact that the country can make humongous contribution to the blue economy and has been doing so in past decades. The aquaculture is proportional to the diversified oceanic water. With a developing economy and democratic nation, India has vividly developed new initiatives to uphold the ocean and its aquatic life. Out of 700 species of marine algae found across the Indian coast, 60 species are of utmost significance. Blue economy is one of the building blocks of a green economy leading to a sustainable future.

Marine seaweed also popularly known as macroalgae are the photosynthetic eukaryotes whose properties differ from plants with lack of vascular tissue. The seaweed are the algal species found in the ocean with multifunctional abilities like carbon capture, maintaining balance in ocean life etc. The natural polysaccharides like carrageenan, agar and alginate are extracted from the algae with a wide range of applications in medicines, food and beverage industry etc. With the current ongoing plastic pollution, the ban on its usage is soon going to be implemented on a larger scale. Hence the need for a substitute has hit a peak. Bioplastics is one of the emerging technologies with seaweed as a raw material. The polysaccharide extracted from each species of seaweed differ in yield or compositions. Seaweed farming is another important technique adopted across coastal lands generating revenues at a larger scale and met a production scale of 6,00,000 tons in the year 2000. Algae has soon become the commercial crop of every fisherman out there in the country. This in turn is compensating revenue losses of the monsoon periods and increasing living standards of fishermen. This foreseeable 3rd generation of bioplastics shall exponentially draw down the generation of solid waste and enhance the blue economy. The current research on bioplastics in different regions is carried out based on the different species of seaweed and till date the pilot scale of work done is to produce thin sheets. Further study is to produce it on a commercial scale and make it a perfect substitute fit for plastics. This can revolutionize the entire face value of plastics and take it to an eco-friendly platform keeping in mind the faster degradability rate.

The current paper aims to comprehensively review the 3rd generation of biodegradable plastic produced using seaweed from the species available across the coast of India. The research further gives some insights on the bioplastics contribution and the study done so far in India. It also highlights the statistical scenario of seaweed farming contributing to the economic status of the country. The future scope of work is to produce a firm plastic shaped into a product.

Keywords: Seaweed, Bioplastics, Blue economy, Polysaccharide.

Polyhydroxyalkanoates Production by Mixed Cultures Acclimated from Wastewater Sludge with Food Waste as Carbon Source in Continuous Fermentation

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ABSTRACT. This research belongs to the technical field of biodegradable plastic synthesis and waste Recycling, and relates to a high-yield Polyhydroxyalkanoates process based on the expanded culture of mixed flora. In order to address the issue of low output of PHA synthesis bacteria in the production stage, this study provides a method to increase the discharge of PHA synthesis bacteria in the production stage. The method uses the PHA synthesis bacteria discharged from the PHA synthesis bacteria production stage reactor as the bacterial source, continuously adding substrates in stages to achieve expanded cultivation of PHA synthesis bacteria, and then enters the third stage to complete PHA synthesis, greatly improving the overall PHA production and volume yield of the process.

Keywords:*Polyhydroxyalkanoates;bioplastic production; wastewater sludge; food waste;continuously*

Introduction

Polyhydroxyalkanoates（PHA）is a biopolyester, which is an energy storage substance synthesized by microorganisms in the cell to resist unbalanced external environmental pressure. PHA is similar in physical properties to traditional thermoplastic plastics, so it can replace traditional chemically synthesized plastics and alleviate the increasingly serious problem of "white pollution". At present, the commercial promotion of biodegradable plastics (PHA) is mainly focused on pure bacterial fermentation, but the relatively high raw material costs, disinfection costs, and microbial separation and purification costs limit the large-scale application of PHA. The mixed microbial community PHA production process, as a completely open fermentation process, does not require substrate sterilization and strict prevention of bacterial contamination. It can also utilize waste carbon sources, and is becoming a hot research topic on the basis of wastewater acid production regulation technology. This study developed a method to increase the discharge of PHA synthesis bacteria in the production stage. The method uses the PHA synthesis bacteria discharged from the PHA synthesis bacteria production stage reactor as the bacterial source, continuously adding substrates in stages to achieve expanded cultivation of PHA synthesis bacteria, and then entering the third stage to complete PHA synthesis, greatly improving the overall PHA production and volume yield of the process. The expanded cultivation mode of "carbon source storage/endogenous growth" introduced in the study bears a high process load, enabling the screening stage of PHA producing bacteria to achieve stable and controllable operation within a lower substrate load range, solving the contradiction between stable process operation and high PHA production, and effectively promoting the large-scale application of mixed bacterial PHA synthesis. Embedding the "carbon source storage/endogenous growth" expansion culture mode proposed in this study into the traditional three-stage process can significantly improve the overall PHA yield of the process, with a maximum PHA yield of about 80 times that of the original process.

Material and Methods

In this study, wastewater sludge was used as the seed of PHAs producing microorganism. Organic acids with chemical oxygen demand (COD) 610 mg/L were used as carbon source and its compositions was stimulated according to food waste anaerobic digestion. The process consists of two reactors, anaerobic reactor and aerobic reactor. During the PHAs producing microbe accumulation stage, 5 L of sludge with suspended solids (SS) concentration of 3000 mg/L was filled into anaerobic reactor and carbon source was added with a flow rate of 25 mL/min. After 4 h, the sludge was transferred to aerobic reactor and aerated for 6 h, then sent back to anaerobic reactor again. After 16 d, the PHAs content was increase to around 55% g/g MLSS. Thereafter, the continuous fermentation was performed. The flow rate, carbon source addition rate, cell recycling rate were optimized. This study will provide a new insight of PHAs production by continuous fermentation.

This includes the following steps:

1、 Establish a bacterial mud expansion system: The bacterial mud expansion system consists of N bacterial mud expansion reactors, each of which is divided into n repeated batches along time, each batch being divided into n-1 and n-2 stages;

2、 When each sludge expansion reactor in step 1 is started, a certain amount of sludge from the PHA synthesis section of the three-stage mixed bacteria PHA process is placed in the sludge expansion reactor, and the "carbon source storage/endogenous growth" expansion mode is adopted. That is, an appropriate amount of substrate A is added in the n-1 stage, and the mass ratio of substrate A to microorganisms is controlled to not exceed 6.4 g COD/g VS/d. Then, the mixed liquid is aerated to monitor the dissolved oxygen level of the reaction system, Make it not less than 3 mg/L; When the dissolved oxygen level in the system reaches saturation state, stop aeration and enter the static settling stage, discharge a certain volume of supernatant into the n-2 stage of this batch; Add substrate B of the same volume as the discharged supernatant to the original bacterial sludge expansion reactor, aerate the mixed solution, and monitor the dissolved oxygen level of the reaction system to ensure it is not less than 3 mg/L; After the consumption of ammonium ions in the system is completed, the reaction stops and enters the static settling stage. The supernatant is discharged and enters the next batch of operation: substrate A → aeration → static settling → drainage → substrate B → aeration → static settling → drainage; Repeat this cycle and gradually increase the amount of carbon source supplementation until the total biomass/initial biomass for expansion cultivation is between 40-60g/g.

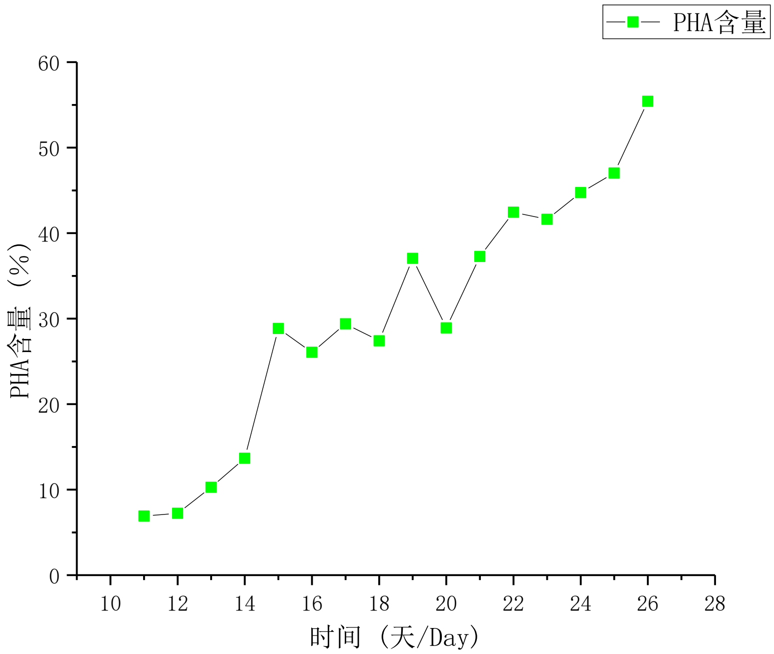

Fig.1. The variation of pha content with the number of days of reaction operation

Results and Discussion

Compared with existing mixed bacterial PHA, this study has the following advantages:

1. The "carbon source storage/endogenous growth" expansion culture mode proposed by the present invention can effectively maintain the PHA synthesis ability of the bacterial community while achieving significant proliferation of PHA producing biomass;

2. By embedding the "carbon source storage/endogenous growth" expansion cultivation mode proposed by the present invention into the traditional three-stage process, the overall PHA yield of the process can be significantly improved, with a maximum PHA yield of about 80 times that of the original process;

3. From the perspective of the overall process, the "carbon source storage/endogenous growth" expansion cultivation mode introduced by the present invention bears a high process load, enabling the screening stage of PHA producing bacteria to achieve stable and controllable operation within a lower substrate load range,

solving the contradiction between stable process operation and high PHA production, and effectively promoting the large-scale application of mixed bacterial PHA synthesis;

4. The carbon source used in the invention can be nitrogen deficient or nitrogen free high concentration organic waste carbon source, such as molasses wastewater acidification liquid, papermaking wastewater acidification liquid and crude glycerin (biodiesel by-product). While using the waste carbon source to achieve Recycling, it can also bring certain environmental benefits by reducing Biochemical oxygen demand.

Conclusions

In order to address the issue of low output of PHA synthesis bacteria in the production stage, this study provides a method to increase the discharge of PHA synthesis bacteria in the production stage. The method uses the PHA synthesis bacteria discharged from the PHA synthesis bacteria production stage reactor as the bacterial source, continuously adding substrates in stages to achieve expanded cultivation of PHA synthesis bacteria, and then completing PHA synthesis to significantly improve the overall PHA production and volume yield of the process.Thereafter, the continuous fermentation was performed. The flow rate, carbon source addition rate, cell recycling rate were optimized. This study will provide a new insight of PHAs production by continuous fermentation.

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Fate and Impacts of Bioplastics during Food Waste Anaerobic Digestion

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ABSTRACT. The escalating environmental concerns related to conventional plastics uses have spurred the exploration of bioplastics as a potential solution. Bioplastics, derived from renewable sources, present a more sustainable alternative with the potential to reduce the ecological burden. However, their behavior and impact within the anaerobic digestion process, a crucial component of organic waste management, remain areas of critical inquiry. This review investigates the destiny of bioplastics within various anaerobic digestion assays, exploring the varying degradation rates across different types based on their composition and processing methods. Furthermore, it delves into bioplastics' potential influence on biogas production, enlightening their role as potential microbial substrates, while also addressing challenges related to incomplete degradation and the accumulation of intermediate byproducts. Moreover, the discussion extends and summarizes the perspectives of bioplastics utilization in bioconversion processes.

Keywords: *Anaerobic digestion; Bioplastics; Biodegradation; Biogas; Plastics*

1. Introduction

Conventional plastics are a vital component of modern life and primarily used in food packaging, disposing medical items, and other household uses. Unfortunately, the lack of proper collection and engineered disposal of these plastic products are imposing global environmental threat [1]. Over the decades, the staggering plastic production has reflected considerable increase in plastic waste production, thereby accumulating as floating islands in the seas and oceans [2]. It is forecasted that global plastic production will rise to more than 600 million tonnes by the year 2030, which would be 1.67 times higher than 359 million tonnes of plastic production in the year 2018 [3]. It is investigated that in most of the countries, ~70% of the collected plastic waste is disposed in landfills or is thermally converted through incineration [4]. Nevertheless, the recycling of plastics is still unexplored comprehensively, with only 6% global recycling rates [3]. In order to cater the environmental pollution and management challenges associated with plastic pollution, most of the countries have banned the use of non-biodegradable, disposable plastic carry bags and single use plastic items [5]. Consequently, the uses of bio-based and biodegradable plastics are being promoted as they are manufactured by renewable raw materials and can be degraded through microbial actions [6]. The 'biodegradable plastics' are proving to be sustainable alternatives for single use plastics as they possess the ability to undergo biological decomposition in controlled aerobic and anaerobic environments along with release of gases, biomass and water. The recovery and recycling of conventional plastics incorporates multiple challenges, as waste streams containing plastics mixed with organic wastes, leads in contamination of both plastics and organic matter and demands effectiveness of separation, cleaning and sanitation systems [7]. Recently, oxo-degradable plastics have entered into market as combination of degradable fractions and conventional plastic polymers, thus reinforcing comparatively rapid degradation of these materials. However, they mostly contribute to microplastic pollution as they only promote faster degradation [8].

In recent times, the entry of bioplastics into waste treatment systems are becoming more frequent and obvious due to extensive uses instead of conventional plastics. Moreover, facilitation of zero landfilled waste policies enforced by various countries, it is expected that treatments of bioplastics must be carried out at designated waste treatment sites of a city [2]. In any waste treatment system, the organic fraction of municipal solid waste (OFMSW) is typically complicated waste as it may contain biopolymers that are currently practiced in waste collection or even in food packaging streams but has to be treated by conventional bioprocessing units [6]. Since, bioplastics and cellulosic biopolymers are projected as biodegradable alternatives to conventional plastics, they can enter the organic waste treatment units in the common forms of impurities [9]. For example, in 2019, Italian waste treatment plants accounted 3–4% of bioplastics along with OFMSW entry which is further predicted to increase [10]. In recent past, the biodegradability of paper bags made from cellulose materials and bioplastic bags used in collection systems are investigated in composting scenarios [11], whereas the studies on anaerobic digestion system are recently increased.

The aim of this paper is to review the biodegradability reported for various biopolymers in anaerobic digestion systems and their impact on overall performance in terms of organic matter stabilization and biogas production. Bioplastics being bio-based or biodegradable may also influence biogas production units while treating conventional organic wastes. Thus, a brief discussion of inhibition and/or promotion, if applicable is provided.

2. Bioplastic degradation under anaerobic conditions

Degradation of bioplastics depends on various factors such as chemical composition, polymer chains, complexities, crystallinities, and prevailing environmental conditions for degradation. Biodegradation entails of multiple stages as a result of biochemical actions. Initially, the alterations in physico-chemical and mechanical properties of polymers occur owing to microbial growth or external forces, which is referred as deterioration. In the second step, fragmentation of polymers occurs into oligomers and monomers through microbial actions. Further, the last step involves the bioconversion of carbon, nutrients and energy associated from fragmented bioplastic of second step occurs into carbon di-oxide, biomass and water, which is referred as assimilation [12]. Degrading conditions such as pH, moisture, temperature, pressure and microbial density also influence the degradation of bioplastics during anaerobic digestion process. Under a typical anaerobic digestion environment, the bioconversion of organic matter to methane, carbon di-oxide, and other trace gases occurs through sequential steps, viz. hydrolysis, acidogenesis, acetogenesis and methanogenesis. Following similar phenomena, the biodegradable plastics undergo solubilization into smaller organic molecules and fatty acids during hydrolysis/acetogenesis [9]. In subsequent phases, the fatty acids are converted into acetic acid, H_2 and CO_2 followed by formation of CH_4 and CO_2 [6]. In case of bioplastics commingled organic waste digestion, the assessment of stabilization under anaerobic conditions can be performed through incorporation of mass loss and recovery analyses. Primarily, surface deterioration and surface colonization are observed for bioplastics degradation along with assessment of chemical changes, thermal behavior and overall decrease in molecular weight [13]. Table 1 summarizes remarkable studies carried out to assess the biodegradability of biopolymers in anaerobic digestion or co-digestion systems. The degree of biodegradation of bioplastics during anaerobic digestion and their impact on biogas production as further discussed based on type of bioplastics.

2.1 Polylactide or Polylactic acid (PLA) bioplastics

Distinct reports are available on PLA degradation depending upon biodegradability and weight loss, inferring range from zero to complete mineralization [13]. Under mesophilic (35–37ºC) anaerobic digestion, approximately no degradation of PLAs was reported with mineralization rates varying between 1–7% for 40–150 days [14,15]. However, for longer duration of 150–280 days, even mesophilic anaerobic conditions fetched 10–66% PLAs degradation [14,16]. Apart from it, the mesophilic experimentation (37ºC) by Yagi et al. [16] also reported 7% degradation of PLA in 90 days, which further increased to 18–27% upon operating reactors for 182 days. Anaerobic treatment through soil burial experiments with 70:30 (soil: sludge mix) and 1% PLA fractions under thermophilic temperatures (52ºC) reported 60% PLA biodegradation in 75 days [17]. Furthermore, at elevated temperatures (~80ºC), faster rate of PLA degradation was observed. For example, PLA samples with 75-100% PLA content reflected 52-65% degradation in initial 3-4 days of treatment at elevated temperatures of 70-80 ºC [18].

Based on operating temperatures, the biogas generation from PLA materials and their inhibition in co-digestion system alters. During thermophilic digestion conditions, PLA made substrates produced 306 L/kgVS biogas than that of 125 L/kgVS produced in mesophilic digestion [14]. Generally, the hydraulic retention time of a typical biogas plant is lesser than time required for the degradation of PLA bioplastics. Therefore, significantly longer detention time or higher temperature or their optimized combination are needed for considerable PLA degradation in any anaerobic digestion system. Conclusively, the PLA did not participate in biogas production notably, except PLA film samples which doubled the biogas production [14]. Moreover, the studies investigating food waste co-digestion with PLA, reported diminishing behaviour of biogas production due to hindrances offered by PLA samples [9,13,14].

2.2 Starch based

Starch based bioplastics are largely used commercially and can be easily blend to other biopolymers such as PVA, PCL and PBAT, subjected to the application [19]. Mater-Bi® is one of the most frequently used. The starch blends bioplastics experienced 20-27.5% degradation rates at mesophilic temperature (35ºC) in 15 days of digestion, however, for Mater-Bi® 23-28% of degradation demanded ~28 days of digestion [15]. The starch bags while anaerobic digestion exhibited 12 and 15% degradation in 45-48 days, when co-digested with food waste and anaerobically digested sludge, respectively [20]. In this case, comparatively depleted degradation, 9% in 30 days and ~11% in 35 days were observed for distinct organic wastes sacks having Mater-Bi®, when co-digested with food waste and sludge. Comparatively higher degradation rates (30-50% increment) in Mater-Bi® during thermophilic anaerobic digestion was observed with maximum 36.5% of biodegradation in 15 days. Moreover, starch-based bioplastics powder was recorded to be degraded by 70% in 20 days at 52ºC, whereas starch mixed with PLA bioplastics degraded by 85% in 23 days under thermophilic range [21].

Depending on type and material composition of starch-based bioplastics, the biogas production also varied. Biomethane production of Mater-Bi® bags varied between 40-150 mL/gVS under mesophilic anaerobic digestion conditions [15]. However, thermophilic conditions were found more suitable for the degradation of starch blend bioplastics and such materials followed similar timeline that are close to hydraulic retention time of biogas plants [21]. Efficient degradation of starch-based biopolymers must be assisted with optimized composition of blends and additives, as excessive additives might adversely affect the degradability of starch bioplastics. Under most of the co-digestion conditions, they exhibited a synergistic effect on bioenergy production.

2.3 Polyhydroxyalkanoates (PHA) and Polyhydroxybutyrate (PHB)

The PHAs degradation reported as significantly better in anaerobic digestion systems. In fact, more than 92% degradation of PHAs was observed within 10 days of mesophilic anaerobic digestion [16]. Whereas PHB was observed to degrade by 42 and 93% in 4 and 7 days, respectively under similar mesophilic conditions [16]. However, Venkiteshwaran et al. [22] recorded relatively lesser degradation rates of PHB, which required 116-125 days to attain 79% of PHB degradation. Mesophilic conditions were found more appropriate for PHA and PHB degradation as distinct studies by Yagi et al. [16,23] reported 25-70% PHB degradation in 7-11 days, which was lesser than that of findings of mesophilic digestion. Similarly, Hegde et al. [24], also reported 28% of PHA degradation under thermophilic condition in 30 days, which was even lesser than 50% of findings obtained under mesophilic condition. Biogas production was observed to be improved when PHAs are co-digested with organic waste such as mix sludge, food waste and agro-waste [2,24]. Sole digestion of PHA was higher with film shaped samples than that of pellets [22].

Table 1 Summary of biodegradability of bioplastics under anaerobic digestion conditions.

Author	**Polymer**	**Material**	**Size**	**Innoculum**	**Volume**	**Temperature (^{O}C)**	**Degradation (%)**	**Time (d)**	**Biogas/ CH_4 Production**
Dolci et al. [20]	Cellulosic - Paper	Collection Bag	0.5x0.5-2x2cm	Food waste mesophilic digestate (paper bag only)	600 mL, bottles	35	55-58	35	225-235 mL/gVS - Yield
Battista et al. [2]	PHA	Granule	2mm	OFMSW digestate	0.5 L, reactor	37	N.D.	25	130 L/kgVS - Yield
Dolci et al. [20]	Cellulosic - Paper	Collection Bag	0.5x0.5 cm	Food waste mesophilic digestate (bioplastic)	600 mL, bottles	35	66	32	272 mL/gVS - Yield
Hegde et al. [24]	PHA	Film	1cmx1cm	Industrial food waste+manure	500 mL reactor	52	28	33	205 mL (avg.) - Production
Shrestha et al. [6]	Cellulose + Compostable Film	Film	3x3 to 1x1 cm	Sludge	500 mL, bottle	55	16.3-18.3	35	252-283 mL/gVS - Yield
Bandini et al. [21]	Cellulose		20x20mm	OFMSW Digester Sludge	250 mL, vial	55	100	23	N.A.
Zhang et al. [14]	Cellulose Based	Film	1x1cm	Anaerobic Sludge	4L, digester	37	93.4	147	410 L/kgVS - Yield

	Film (CBF)								
Zhang et al. [14]	Cellulose Based Film (CBF) – Barrier Enhanced	Film	1x1cm	Anaerobic Sludge	4L, digester	37	57.4	147	404 L/kgVS - Yield
Zhang et al. [14]	Cellulose Based Film (CBF) – Heat Agent	Film	1x1cm	Anaerobic Sludge	4L, digester	37	65.9	147	433 L/kgVS - Yield
Bátori et al. [25]	Cellulose Pectin	Film	-	Anaerobic Sludge	120 mL bottles	55	90	15	350 mL/g.COD-Yield

3. Conclusion

Biodegradation of bioplastics relies over their physical and chemical composition. Different bioplastics exhibit different degradation kinetics based on their compatibility with degrading conditions. For field scale applications, complexity of biodegradation process for bioplastics in anaerobic digestion system, challenges regulations and demands optimized digestion environment based on influent biopolymer types. Some bioplastics such as cellulose and PHA/PHB could be good substrates for mesophilic and thermophilic anaerobic digestion process. Moreover, starch-based and cellulosic polymers were found easily biodegradable under thermophilic temperatures. The PLA was not found suitable for degradation in anaerobic digestion facilities as it takes more time to degrade than prescribed retention timelines. Also, studies showed inhibition of PLA to biogas production in co-digestion systems. Co-digestion of bioplastics with organic waste showed mixed results of increase and decrease as per operational and feedstock quality. Nevertheless, in general, they did not severely restrain the anaerobic digestion and rather found synergistic. Future perspectives of accepting bioplastic in anaerobic digestion system are based on substrate quality, operational conditions and degree of treatment required.

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Comparative Study of Various Kitchen Waste (KW) Chemical Pre-Treatments For The Production of High-Value Products

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1. Abstract and introduction. The production quantity of kitchen waste (KW) is anticipated to rise because of accelerated urban and economic growth, particularly in Asian nations. Therefore, alternate applications of KW should be explored for its effective utilization to generate a sustainable source of energy that will ultimately avoid massive economic and energy losses. The main goal of this study was to investigate the combinational effect of thermochemical and enzymatic pretreatment on synthetic kitchen waste in order to enhance the release of fermentable sugars for the synthesis of value-added products such as polyhydroxyalkanoates (PHAs). The thermochemical pretreatment of KW samples was performed using 4N HCL, 4N H_2SO_4, and 4N NaOH at a concentration of 0–30% (v/v), 30–100 °C for 0–120 min treatment time. Variable enzyme dosages were added after acidic or alkaline pretreatments (0-3% (v/v) α-amylase and 0-3% (v/v) amyloglucosidase-AMG) while maintaining a constant pH = 5, T = 50 °C, and t = 30 min. Pre-treatment of KW with acid (15% (v/v) 4N HCl in water) at temperature 100 ^{0}C, followed by enzymatic hydrolysis i.e., 0.6% (v/v) α-amylase and 0.4% (v/v) amyloglucosidase (at pH = 5, T = 50 ^{0}C, and t = 60 min) resulted in the maximum concentration of fermentable reducing sugars.

Keywords: Kitchen waste, Pre-treatment, Fermentation, Bioplastics, lignocelluloses

2. Material and Methods

2.1. Preparation of the synthetic kitchen waste:

The synthetic kitchen waste (KW) was prepared using 35% (w/w) bread, 25% (w/w) cooked rice, 25% (w/w) cabbage, 15% (w/w) pork meat, and 2-3% (w/w) cooking oil. The wet sample (1 kg total) of the KW was homogenized using a laboratory grinder for characterization and use in chemical or enzymatic pre-treatment. The homogenized wet sample was dried at 60°C to a constant weight, and then manually crushed (final particle size less than 1 mm) to generate homogenized and representative dry material of KW for pre-treatment. To ensure stable characteristics, the KW mixture was stored at 4°C throughout the experimental period.

2.2. Pre-treatment techniques

2.2.1. Acid and alkaline hydrolysis

In the present study, different chemicals (4N HCl, 4N H_2SO_4, 4N NaOH) were used to hydrolyze the KW. The acid/alkaline solutions were prepared in different concentrations ranging from 0.7-30% (v/v) in distilled water. Then, 10 g of dry KW solids were mixed in 1 L of the respective acid/alkaline solutions prepared. This mixture was then incubated at 4 different temperatures, 50, 70, 100, and 120 °C, and the samples were taken at reaction times of 30, 60, and 120 min. After cooling the reaction mixture to ambient temperature, it was filtered through a 0.2 µm Nylon Whatman filter, and the filtered sample was further used for the analysis of sugar, and total proteins (Association and Association 1995).

2.2.2. Enzyme Hydrolysis

For the enzymatic hydrolysis of KW, two types of commercial enzymes were purchased from Sigma Aldrich i.e., α-amylase (A6211-1MU) and amyloglucosidase-AMG (10115). The enzymatic hydrolysis of KW was performed with three different conditions, 1g of KW pre-treated with an acid solution (15% (v/v) 4N HCl in water) at temperature 100 °C followed by enzymatic treatment using a) α-amylase alone, with enzyme dosage (0–0.2% (v/v) α-amylase (0-200 U/g dry substrate); b) amyloglucosidase-AMG alone, with enzyme dosage (0–0.2% (v/v) amyloglucosidase-AMG (0-200 U/g dry substrate); and c) combined levels of both the enzyme dosages, which was derived from GAME.opt software. The hydrolysis was conducted at constant pH=5.0, 50 °C and incubation time t = 30 min (according to AOAC Method 996.11, AACC Method 76.13).

2.3. Sugar spectrum analysis by LC-MS/MS

The filtered samples of hydrolyzed KW of various conditions were diluted 50 times with ethyl-acetate acetone: water (90:10) and analyzed for complete sugar spectrum with LC-MS/MS (Bystrom, Lewis et al. 2008)

2.4. Protein estimation

The protein estimation in this research was conducted according to Bradford method (Bradford 1976). The standards were prepared using Bovine serum albumin (BSA) (0-2000 µg/mL).

3. Results and Discussion

3.1. Characterization of Kitchen waste

A comprehensive physicochemical evaluation of KW was done prior to chemical processing. The sample's key feature was its high carbohydrate content making it appropriate for the synthesis of high-value products. Yan, Yao et al. (2012) reported comparable compositional analyses. Their examination of total solids (TS), and sugar levels aligned with the given results reported (Table 1).

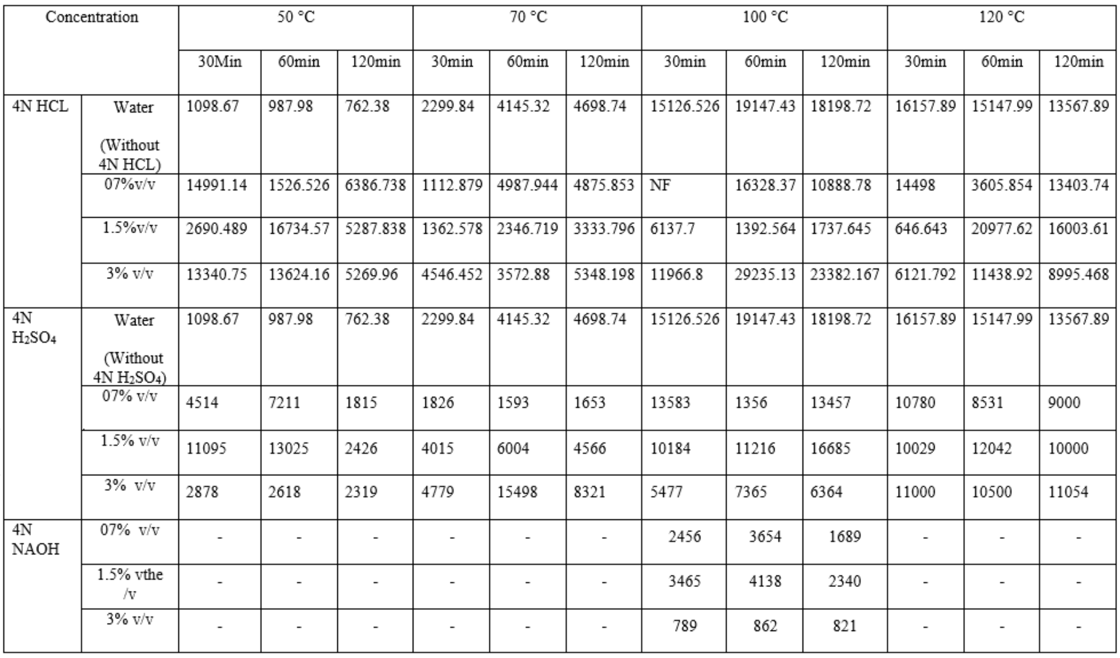
All values are means ± standard deviation and refer to the dried mass of the sample at 60°C, except TS and moisture content.

Table 1: Characterization of Kitchen waste

Parameter	Value (% w/w)
Total solids (TS)	16.846± 0.51
Moisture	77.333 ± 0.543
Total sugars	36087± 0.341 (mg/L)
Total phosphorus	0.12 ± 0.0066
Total nitrogen	4.99 ± 0.158
Proteins	14.69 ± 0.87

3.2. Effects of chemical and alkaline pre-treatments on total sugar, reducing sugar, and total proteins

Acid pre-treatment at 100°C exhibited high concentrations of soluble sugars. Chemical pre-treatment with 3% (v/v) 4N HCl in water for 60 min and 120 min at 100°C resulted in highest concentration of soluble sugars i.e., 29235.13 mg/L and 23382.167 mg/L, respectively, which are slightly close to the total sugar content of synthetic KW mixture (36087± 0.341 mg/L) (Table 1).



Concentration		50 °C			70 °C			100 °C			120 °C		
		30Min	60min	120min	30min	60min	120min	30min	60min	120min	30min	60min	120min
4N HCL	Water (Without 4N HCL)	1098.67	987.98	762.38	2299.84	4145.32	4698.74	15126.526	19147.43	18198.72	16157.89	15147.99	13567.89
	07%v/v	14991.14	1526.526	6386.738	1112.879	4987.944	4875.853	NF	16328.37	10888.78	14498	3605.854	13403.74
	1.5%v/v	2690.489	16734.57	5287.838	1362.578	2346.719	3333.796	6137.7	1392.564	1737.645	646.643	20977.62	16003.61
	3% v/v	13340.75	13624.16	5269.96	4546.452	3572.88	5348.198	11966.8	29235.13	23382.167	6121.792	11438.92	8995.468
4N H_2SO_4	Water (Without 4N H_2SO_4)	1098.67	987.98	762.38	2299.84	4145.32	4698.74	15126.526	19147.43	18198.72	16157.89	15147.99	13567.89
	07% v/v	4514	7211	1815	1826	1593	1653	13583	1356	13457	10780	8531	9000
	1.5% v/v	11095	13025	2426	4015	6004	4566	10184	11216	16685	10029	12042	10000
	3% v/v	2878	2618	2319	4779	15498	8321	5477	7365	6364	11000	10500	11054
4N NAOH	07% v/v	-	-	-	-	-	-	2456	3654	1689	-	-	-
	1.5% vthe /v	-	-	-	-	-	-	3465	4138	2340	-	-	-
	3% v/v	-	-	-	-	-	-	789	862	821	-	-	-

Table 2: Total soluble sugars (mg/L) after chemical pretreatment of kitchen waste with different chemical solutions (4N H_2SO_4 ,4N HCl and 4N NaOH (v/v)) at various concentrations and temperatures. *NF: Not found

Chemical pre-treatment with 4N HCl and 4N H_2SO_4 resulted in increased sugar yields with, 3% (v/v) and 1.5% (v/v) concentration at 100°C, respectively with the residence times 60 and 120 min compared to the untreated sample (Table 2). Alkaline pre-treatment demonstrated contradictory results to acid pre-treatment and can be attributed to the browning-promoting effect of glucose and fructose content of the KW sample. Furthermore, when the 1% (w/v) KW was hydrolysed with 3% (v/v) 4N HCL at 120°C and 120 min the total protein concentration was 4.629g/L.

Nevertheless, the temperature during hydrolysis had the most pronounced influence on enhancing soluble sugars when compared to the concentration of each chemical and the residence period. At all residence time values evaluated, 4N HCl proved to be more effective than 4N H_2SO_4 (Table 2).

3.3. Effect of variation of KW concentrations (g/L) in the reaction mixture at different concentration of 4N HCL (v/v) on KW hydrolysis to maximize the concentration of fermentable sugars

The temperature (100°C) and incubation time (30 and 60 min) were already optimized in the previous investigation. Therefore, different concentrations of chemical solutions 4N HCL (v/v) were studied at 100°C temperatures and 30 and 60 min contact times. The amount of released sugars were increased by increasing the concentration of 4N HCL from 5 to 20% (v/v). Maximum sugars were released when KW was hydrolyzed at 15% and 20% (v/v) 4N HCL. Furthermore, the amount of sugars released was increased at 60 min demonstrating that the increased sugar concentration as per increase in time and further availability of the reducing sugars for the fermenting bacteria for the synthesis of value-added products. However, the sugar concentration was reduced when KW was further treated with 25% and 30% (v/v) 4N HCL, which indicates the sugar decomposition or browning effect at a high concentration of the acid.

Furthermore, the effect of the concentration of KW variation on acid hydrolysis was further tested in acid hydrolysis pre-treatment. At 100°C temperatures and 60 min contact time, different concentrations of KW i.e., 2%, 3%, 5%, 10%, 15%, 20%, 25%, and 30% (w/v) were tested in 15% and 20% (v/v) of 4N HCL (that means, for 30% (w/v) KW, 30 g KW was mixed in 100 ml of 15% or 20% 4N HCl). The concentration of glucose increased as per the increase in the gram of KW in the acid solution. At 15% (w/v) KW in 4N HCL with the strength of acid 15% and 20% (v/v) in water, the maximum glucose released was 32.04g/L and 30.7g/L, respectively.

However, the glucose yield was more or less similar for hydrolysis of 20%, and 25% (w/v) of KW. For 20% (w/v) of KW, the glucose concentration was 32.7 g/L and 32.25 g/L for 15% and 20% (v/v) of 4N HCL hydrolysis, respectively. For 25% (w/v) of KW, the glucose concentration was 34.9 g/L and 40.1 g/L at 15% and 20% (v/v) of 4N HCL hydrolysis, respectively. Finally, for 30% (w/v) of KW, the glucose yield was slightly decreased to 33.05 g/L and 39.15 g/L at 15% and 20% (v/v) of 4N HCL hydrolysis, respectively. The reduction in the glucose concentration in the hydrolysate was probably be due to the formation of inhibitors such as phenolics or xylo-oligomers during acid hydrolysis (Kim, Kreke et al. 2013).

Therefore, considering the results, 15% and 20% (w/v) of dry solids of KW was further considered. Also, for the acid hydrolysis of KW, 15% (v/v) of 4N HCL was utilized to release maximum reducing sugars, which will be subsequently utilized for high-value products.

3.4. Enzyme hydrolysis of kitchen waste with and without acid pre-treatment

When KW was hydrolyzed with α-amylase and amyloglucosidase alone with various concentrations, very less amount of reducing sugars were obtained demonstrating that alone α-amylase or amyloglucosidase are not enough to generate the maximum amount of reducing sugars. Therefore, 9 different combinations of these two enzymes were tested different set of experiments. The enzyme treatment of KW was followed after the acid pre-treatment. Among 9 different combinations of enzymes, the maximum reducing sugar concentration was obtained with following conditions, 1% (w/v) of KW was treated with 15% (v/v) of 4N HCl in water for 60 min at temperature 100^0C, followed by the addition of 0.6% (v/v) α-amylase and 0.4% (v/v) amyloglucosidase (at pH = 5, T = 50 ^{0}C, and t = 60 min). The glucose concentration achieved under the aforementioned conditions, in particular, increased significantly (4.61% (w/v)) as compared to soluble glucose in raw KW (3.6% (w/v) -Table 1).

3.5. Thermophilic PHA production in synthetic kitchen waste hydrolysate using sludge isolated thermophilic bacteria

In order to study the potential of synthetic KW as a carbon source for PHA production, preliminary study was conducted by using hydrolyzed KW. The PHA production was conducted using shake flask fermentation strategy with thermochemical and enzymatic treated KW as a sole carbon source using thermophilic bacteria isolated from paper and pulp industrial activated sludge. The production of biomass, PHA and microbial protein during the 96h fermentation is presented in Figure 1. The SS increased from 8.9 to 14.2 g/L with PHA% (w/w) accumulation up to 16.20% by the end of 96 h. It was observed that the total protein in the fermentation broth was decreased from 4.984 g/L to 1.937 g/L during 0 h to 96 h of fermentation. Additionally, reducing sugar consumption was observed from 15.461 g/L to 10.424 g/L during 0 h to 96 h of fermentation. An increase in the PHA concentration was observed after 24 h i.e., from 1.050 g/L at 24 h to 2.37 g/L at 96 h.

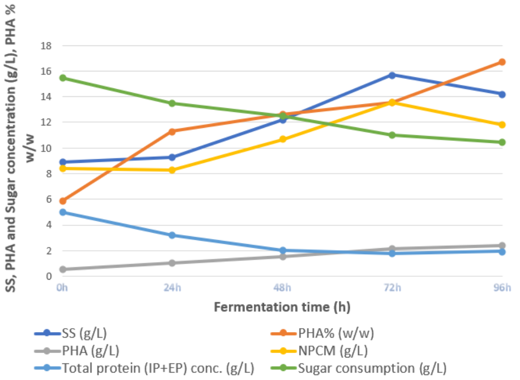


Figure 1: Fermentation pattern for PHA production during 96h fermentation (300ml-Shake flask study) using pre-treated synthetic KW as a sole source of carbon in thermophilic conditions.

4. Conclusion and future prospects

The objective of this study was to hydrolyze a representative KW sample with the aim of reducing starch and organic matter, removing lignin and hemicellulose that impedes enzyme access to cellulose, and thus significantly increasing the permeability of the substrate and facilitating its subsequent biochemical conversion to fermentable sugars. Hence, KW was subjected to a thermo-chemical pre-treatment process that included the use of acid or alkaline solutions prior to enzymatic hydrolysis, hence increasing enzymatic digestibility. Moreover, the effect of KW solids concentration (% w/v) in the reaction mixture on carbohydrate solubilization into fermentable sugars was also investigated utilizing the combination of thermo-chemical-enzymatic conditions. The maximum fermentable sugars were obtained at the 15% (w/v) and 20% (w/v) KW solids concentration. However, increasing the KW solids concentration to 30% (w/v) using only thermo-chemical hydrolysis of KW resulted in slight decrease in total soluble sugars. Pre-treatment of KW with acid (15% (v/v) 4N HCl, for 60 min at temperature 100^0C), followed by addition of 0.6% (v/v) α-amylase and 0.4% (v/v) amyloglucosidase (at pH = 5, T = 50 ^{0}C, and t = 60 min), resulted in the maximum concentration of fermentable reducing sugars. Chemical and enzymatic hydrolysis of KW are critical for the bioconversion of KW to bio-products and the aim is to increase the fermentable sugars in the hydrolysate; consequently, optimizing hydrolysis stages (chemical and enzymatic) may result in both environmental and economic benefits. As a result, this research examined the effect of combined chemical pre-treatment and enzymatic hydrolysis (in terms of dilute chemical concentration, enzyme concentration, time, and temperature) on the conversion of KW to glucose and other fermentable sugars at the laboratory scale in preparation for the potential implementation of either of the proposed methods to KW to PHA production.

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Sustainable Waste Management

Comprehensive Recycling of Fresh Municipal Sewage Sludge to Safely Fertilize Plants and Achieve Low Carbon Emission

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Recycling nutrients in municipal sewage sludge (MSS) to soil would support sustainable development. In this study, a comprehensive recycling using specific plants able to grow in the fresh MSS and an indirect application technique was developed. Fresh MSS was placed in permeable containers next to *Handroanthus chrysanthus* plants to provide indirect fertilization. Sludge treatment plants (*Alocasia macrorrhiza* and *Pennisetum hybridum*) were grown directly on the Fresh MSS to produce plant biomass and treat MSS. The basal diameters of the *H. chrysanthus* plants were markedly increased by the treatment. Nutrients were extracted from MSS more readily and more biomass was produced by the *P. hybridum* than the *A. macrorrhiza* plants. The heavy metal contents of the soil did not increase significantly and not generate potential ecological risk, but the organic matter, nitrogen, and phosphorus contents increased markedly. The fresh MSS leachate met the relevant fecal coliform and heavy metal irrigation water standards. At the end of the treatment, the MSS mass had markedly decreased and the treated MSS was used as a substrate for two garden plant seedlings. The net carbon emissions from the comprehensive recycling are estimated as -15.79 kg CO_2e (CO_2 equivalent) per ton fresh sludge, in contrast, the emissions from composting treatment are estimated as 8.15 kg CO_2e. The method allows nutrients in MSS to be recycled without causing heavy metal pollution and without net carbon emission, while gives plant products with commercial value.

Keywords: Sewage sludge, Indirect application, Sludge treatment plant, Garden plant, Greenhouse gas emissions.

Energy Economics of the Municipal Solid Waste Process

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With increasing needs and moderation, the generation of municipal solid waste (MSW) is growing exponentially. In this study, MSW physical characterisation was carried out for six months of a MSW management plant, the average percentage of plastic, rubber, wooden, clothes, glass, metal, stone, sand, bone and organics were 11.67 %, 3.52 %, 10.82 %, 11.08 %, 1.84 %, 0.14%, 5.16%, 1.58%, 0.24%, 2.69%, and 52.38% respectively. Moreover, the efficiency of mechanical pre-treatment of mixed MSW into organic fraction of municipal solid waste (OMFW) at the waste management facility is evaluated, as well as the average amount of biogas produced per tonne of feed, compost production, compost quality, dry matter generation, calorific value of dry waste. This study also evaluates the energy economics and operational economics of the bioenergy plant. MSW generated per tonne requires 13.07 KW of electricity for treatment, and the amount of electricity generated per tonne is 64.26KW. About 20,000 units of electricity are produced each day, of which about 4,000 are used for captive consumption. For processing MSW costs around ₹ 328 per tonne and compost production costs around ₹ 1950 per tonne. The selling price of loose compost is ₹ 2800 to 3200/tonne while the selling price of packaged compost is ₹ 4200-4500/ tonne. On the basis of the overall economics, operating the MSW seems to be economically feasible.

Keywords: Energy Economics, Municipal solid waste, Anaerobic digestion, Biogas, Compost.

Separation of Low-Grade Phosphate Ores by Novel Semi-Through Hydraulicbarrier Hydrocyclone

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With the decrease of high-quality phosphate ores (P2O5≥30wt%), the use of low-grade phosphate ores (P2O5≤20wt%) is becoming more and more emergent. Hydrocyclone was one of the common equipment for separation of mixing ores in aqueous media, with the advantages of high separation efficiency and low cost. There still existed some problems in traditional hydrocyclone such as the particle dislocation, the "fishhook" phenomenon, the low separation efficiency, etc., due to the phenomena as the particle entraining, the random fluctuation in multiphase flow, and the high short-circuit flow (>10%), etc. Herein, a novel semi-through hydraulicbarrier hydrocyclone was suggested for the separation of low-grade phosphate ores. The fluid dynamics simulation showed that compared with the conventional hydrocyclone, the adaptation of the semi-through hydraulicbarrier hydrocyclone led to the reduce of the short-circuit flow rate from 13.3% to 7.17%, the increase of the separation efficiency from 92.3% to 97.5%, the increase of separation accuracy from 0.88 to 0.95, and the elimination of the fishhook effect. The influences of pressure, velocity, turbulent kinetic energy, the air core and the multiphase streamline on separation processes were discussed in detail. The experimental results indicated that the novel semi-through hydraulicbarrier hydrocyclone was effective for the separation of low-grade phosphate ores, leading to the increase of the P2O5 contents in phosphate ores from 17.5wt% to 23.6wt%.

Keywords: Hydraulicbarrier-hydrocyclone; Separation of low-grade phosphate ore; Simulation and experiments.

Designing Low-Carbon Cements for Stabilization/Solidification of MSWI Fly Ash

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Low-carbon and high-efficiency binder is desirable for safe disposal of municipal solid waste incineration fly ash (MSWI FA). In this work, CaO or MgO was used to activate ground granulated blast furnace slag (GGBS) to form calcium silicate hydrate (C-S-H) and magnesium silica hydrate (M-S-H) gel for stabilization/solidification (S/S) of hazardous MSWI FA. Experimental results showed that the potentially toxic elements (PTEs, e.g., Pb and Zn) significantly inhibited the formation of reaction products in CaO-GGBS system due to the complexation between $Ca(OH)_2$ and PTEs, whereas PTEs only had insignificant inhibition on transformation from MgO to $Mg(OH)_2$ in MgO-GGBS system, resulting in lower PTEs leachability and higher mechanical strength. Stabilization/solidification experiments demonstrated that MSWI FA (70 wt%) could be recycled by MgO-GGBS binder (30 wt%) into blocks with desirable 28-day compressive strengths (3.9 MPa) and immobilization efficiencies for PTEs (99.8% for Zn and 99.7% for Pb). This work provides mechanistic insights on the interactions between PTEs and CaO/MgO-GGBS systems and suggests a promising MgO-GGBS binder for the low-carbon treatment of MSWI FA.

Keywords: Waste incineration fly ash, Hazardous waste treatment, Low-carbon stabilization/solidification, PTEs leachability, Sustainable waste management.

Process Optimization for the Pretreatment of *Lantana Camara* Using Combined Acid and Deep Eutectic Solvent for Sugar Production

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The supply of fossil fuels is limited and their usage is creating havoc on the ecosystem. There is a need for renewable energy sources that have a lower environmental effect. Recently, lignocellulosic biomass is becoming increasingly popular as a renewable energy resource for producing biofuels. Invasive weeds can be used as feedstock for producing biofuels because of its high holocellulose content. However, pretreatment is a prerequisite step for increasing the enzymatic digestibility of biomass. Therefore, in the present study the potential of *Lantana Camara* as a feedstock to produce fermentable sugar was explored. The biomass was sequentially pretreated with sulphuric acid (H_2SO_4) in the first stage and for the second stage acid pretreated biomass was further pretreated with DES (Choline-chloride/Urea). The biomass was pretreated with 1:2 molar ratio of ChCl/U for (1h, 3h, and 6h) at 80℃. Further, SEM, XRD, FTIR, and TGA analyses were employed to study the structural and functional changes in biomass after pretreatment. A combination of 1% H_2SO_4 and 1:2 ChCl: U for 3h at 80℃ yielded the highest amount of reducing sugar i.e. 2.69 mg/ml. In conclusion, *Lantana Camara* can be a potential raw material to produce fermentable sugars for bio refineries that can be further converted to biofuels and other value-added products.

Keywords: Lignocellulosic, Sequential pretreatment, DES, Reducing sugar.

Effective Utilisations of Discarded Reverse Osmosis Post-Carbon for Dye Adsorption

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The common contamination in the distribution network of municipal water treatment plants urges the re-treatment of treated natural water resources. In common practice, the re-treatment can be done via advanced purification technologies like membrane-based technology. Out of the relative multitude of membrane technologies, Reverse Osmosis (RO) is a technology that is well known for both its ability to purify water and for some of its drawbacks, such as the generation of concentrated liquid streams and post-carbon that is typically dumped in an open environment. The post RO-carbon contributes toward the improvement of water quality by removing extra fine dirt, sand, silt, rust and thus, discarded RO-carbon has several inorganics and volatiles adsorbed onto it. It has been extensively documented in the literature that adsorbed inorganic and volatiles are effective in improving the surface morphology of the material due to the release of various gases that diffuse through already existing pores. Thus, the discarded post-carbon can be a viable candidate for wastewater treatment. This study has considered the deployment of post RO-carbon as a sorbent for dyes removal. The post RO-carbon was thermally activated at 900°C (RO900) and the material thus obtained exhibited high surface area *viz.* 753 m^2/g. In the batch system, the maximum adsorption capacity of RO900 for Methylene Blue (MB) and Methyl Orange (MO) were found to be 223 and 158 mg/g respectively. The comparatively higher MB adsorption was attributed to the electrostatic attraction between sorbent and MB. In addition to electrostatic interaction, the dye adsorption was the outcome of various other interactions like π-π, and n-π, H-bonding, dipole-dipole, and lewis acid-base interactions. The thermodynamic findings revealed the process as spontaneous, endothermic, and accompanied by entropy increment. Additionally, real wastewater containing dyes was treated, and 87.5 % of the methylene blue was successfully removed. To simulate an industrial perspective, methylene blue adsorption onto RO900 was carried out in continuous mode as well. The initial dye concentration, effluent flow rate, and bed height were among the process parameters that were optimized using the continuous mode of operation. Further, the experimental data of continuous mode was fitted with Adams- Bohart, Thomas, and Yoon-Nelson models. The cost and low toxicity associated benefits of discarded RO-carbon over other sorbents reveal the significance of the present study.

Keywords: Adsorption, Dye removal, Kinetics, Reverse osmosis carbon.

Enhancing Compressive Strength of Rubberised Concrete with Sodium Hydroxide Coupled with Microwave Devulcanization Treatment

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ABSTRACT. Previous studies have shown that the introduction of tire aggregates in concrete significantly reduces the mechanical properties of the material developed. The purpose of this study is to improve the compressive strengths of rubberized concrete by treating rubber aggregates with NaOH solution on the one hand and with NaOH coupled with microwave devulcanization treatment on the other hand. Eight rubberized concretes have been developed in different treatment conditions. Ordinary concrete and concrete incorporating untreated rubber aggregates were also developed and used as references. The different concretes were characterized by the determination of their compressive strength at 28 days. The results obtained initially show a decrease in the compressive strength of rubberized concrete incorporating untreated aggregates of 30.28% compared to ordinary concrete. After treatment, the best result was obtained with NaOH coupled with devulcanization treatment where the compressive strength reduction at 28-day was 21.83% compared to ordinary concrete.

Keywords: Concrete, Compressive strength, Rubberized concrete, Surface treatment, Used tire.

Introduction

According to a report by Global Industry Analysts, every year the world produces around 1.75 billion used tires that need to be recycled [1]. For the ecological management of used tires, several research projects are being carried out into their use in the construction industry. In recent years, works have been published on the use of rubber aggregates from used tires as a partial replacement for natural aggregates such as sand and gravel in the manufacture of cementitious materials [2–4]. However, the incorporation of tire rubber aggregates into cementitious matrices results in a reduction in the mechanical properties of the composites produced, due to the poor adhesion between the rubbers and the cementitious matrix [2]. For example, the work of Ozbay et al. [5] showed a reduction in compression strength from 4% to 70% for tire particle content ranging from 5% to 50% for particle sizes ranging from 0.075 mm to 6 mm. Adhesion between rubbers and the cementitious phase is strongly linked to surface properties. Consequently, it is necessary to modify the surface properties of rubber aggregates by appropriate treatment to improve their adhesion to the cementitious phase. The purpose of this study is to improve the compressive strengths of rubberized concrete by treating rubber aggregates with NaOH solution on the one hand and with NaOH coupled with microwave devulcanization treatment on the other hand.

Material and Methods

Concrete mix designs

The concrete mixes were designed according to the Dreux-Gorisse method [6]. The target compressive strength of the control mix (CM) was 25 MPa on 160x320 mm cylinder at 28-days. All mixes were designed with constant slump of 7 cm. Nine rubberized concrete (RC) samples were developed, in which rubber aggregates were used as a partial replacement of sand by volume. One sample RC_0 incorporated untreated rubber aggregates and eight samples $RC_{i=1}^{8}$ incorporated treated rubber aggregates according to the treatment conditions presented in Table 1. The mixing procedure for the rubberized concrete was as follows: all the aggregates (sand, gravel, rubber) are introduced into the mixer and mixed for 3 min to ensure good dispersion of the rubber among the concrete's natural aggregates. Cement is then added, and the whole mixture is mixed for 1 min. Finally, water is added progressively until the desired slump is reached. The same procedure was followed for the control mixed without rubber aggregates.

Table 1. Proportions of concrete

	Rubber treatment conditions				**Mix proportions (Kg/m^3)**				
Mix code	Rs (%)	NaOH concentration (%)	NaOH treatment duration (min)	Devulcanization time (s)	Cement CPJ 42,5N	Gravel 5/15mm	Sand 0/5mm	Rubber 0/5mm	Water
CM	0	0	0	0	350	911.50	817.86	0	219
RC$_0$	10	0	0	0	350	911.50	736.07	26.41	212.8
RC$_1$	10	10	10	0	350	911.50	736.07	26.41	212.8
RC$_2$	10	30	10	0	350	911.50	736.07	26.41	212.8
RC$_3$	10	10	60	0	350	911.50	736.07	26.41	212.8
RC$_4$	10	30	60	0	350	911.50	736.07	26.41	212.8
RC$_5$	10	10	10	30	350	911.50	736.07	26.41	212.8
RC$_6$	10	30	10	30	350	911.50	736.07	26.41	212.8
RC$_7$	10	10	60	30	350	911.50	736.07	26.41	212.8
RC$_8$	10	30	60	30	350	911.50	736.07	26.41	212.8

Rs, per cent of sand volume replaced by rubber.

Compressive strength test and SEM analyze.

The 28-day compressive strength tests on the concrete specimens were carried out in accordance with standard NF EN 12390 - 3. To avoid irregularities on the bases of the specimens, they were surfaced with a sulfur coating (a molten mixture of sulfur flower and fine silica sand). The specimens were then positioned in the center of the loading plate of a Matest-type compression press with a maximum load of 1500kN. Uni-axial compression was applied continuously at a speed of 0.5 MPa/s until the material failed. High resolution scanning electron microscopy (SEM) was used to observe the surface of the rubbers before and after treatment. Analyses were carried out using a HIROX SH-400M SEM and a Sigma 300 SEM (ZEISS, Germany).

Results and Discussion

Compressive strength

The compressive strengths of the various concretes are shown in Figure 1. These results obtained initially show a decrease in the compressive strength of rubberized concrete RC$_0$ incorporating untreated aggregates of 30.28% compared to control mix. This is in line with the work of Abendeh et al. [7] that report a 30.55% reduction in compressive strength as result of 10% replacement of sand with rubber aggregates.

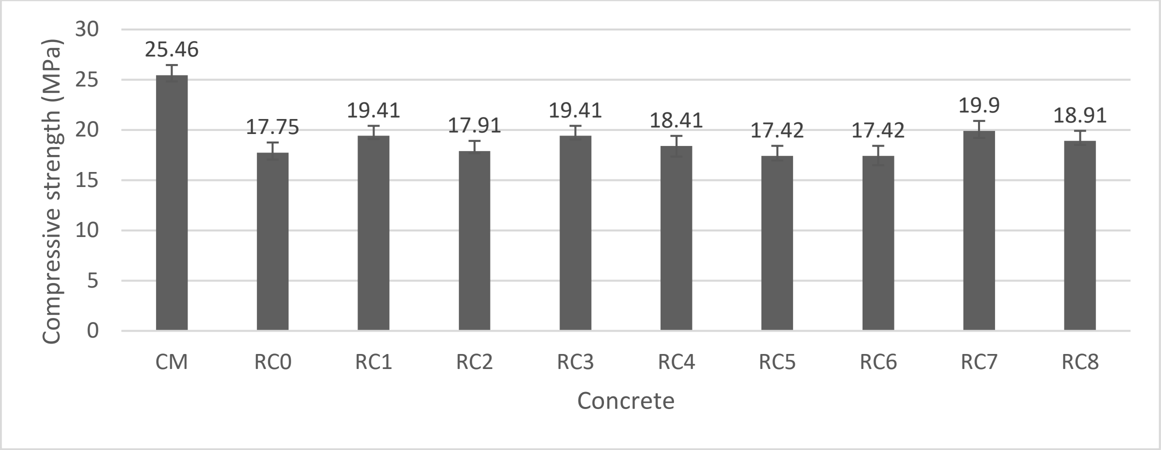

Fig.1. Compressive strength of the control mix and the rubberized concrete

The reduction in compressive strength is due to the rubber's smooth surface (figure 2) and the lack of adhesion between the rubber particles and the cement paste which accelerates the failure of the rubber-cement matrix [7,8].

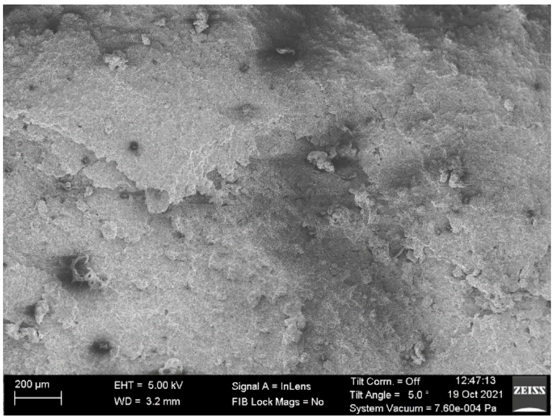

Fig.2. SEM image of untreated rubber aggregate

The results also show an increase in the compressive strength of rubberized concrete incorporating treated rubber aggregates compared with rubberized concrete incorporating untreated rubber aggregates, with a maximum increase of 10.80%. This maximum is obtained when the rubber aggregates are treated with 10% NaOH for 60 min and devulcanized, which corresponds to the treatment condition for rubberized concrete RC_7. Figure 4 shows the SEM image of rubber aggregates treated in this condition. We can see that the rubber surface is much rougher than that of the untreated aggregate, contributing to the improvement in compressive strength.

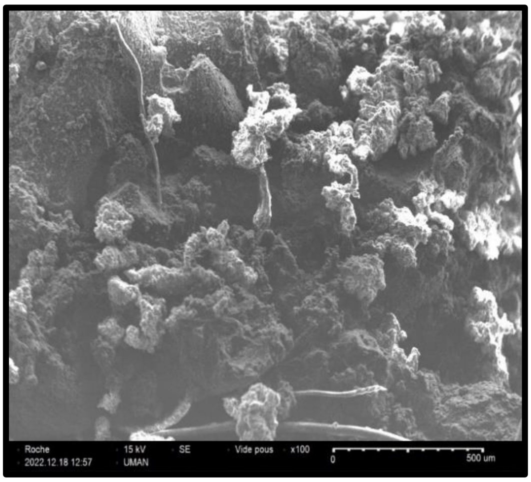

Fig.3. SEM image of rubber aggregates are treated with 10% NaOH for 60 min and devulcanized.

According to Youssf et al. [9], the treatment of rubber aggregates with NaOH increases their surface roughness and creates more polar functions on the rubber surface, resulting in increased adhesion between the rubber and the surrounding cement paste and thus an increase in strength. Moreover, according to Garcia et al. [10], microwave devulcanization promotes the breakdown of sulfur cross-links and consequently reduces the elasticity of rubber, which in turn reduces its deformability during concrete curing. And devulcanized particles are more chemically reactive, giving them better adhesion. This could explain the maximum improvement in compressive strength observed when rubber aggregates are treated with NaOH coupled with microwave devulcanization.

Conclusions

The purpose of this study is to improve the compressive strengths of rubberized concrete by treating rubber aggregates with NaOH solution on the one hand and with NaOH coupled with microwave devulcanization treatment on the other hand. The results obtained have shown that the best improvement in the compressive strength of rubberized concrete is obtained when the rubber aggregates are treated with NaOH coupled with microwave devulcanization. In this case a maximum increase in compressive strength of 10.80% is obtained for rubberized concrete incorporating rubber aggregates treated with 10% NaOH for 60min and devulcanized compared with that for concrete incorporating untreated rubber.

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The Impact of COVID-19 on Quantification and Characterization of Solid Waste in the Bagmati River Corridor of Kathmandu Valley, Nepal

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ABSTRACT. The main aim of this study was to quantify, characterize the solid waste (SW) and evaluate the impact of COVID-19 on the status of household SW. A study was conducted for 400 households (HHs) using a cross-sectional survey questionnaire to collect data from the municipalities of the Bagmati River Basin (BRB), Nepal. The study revealed that the total HH SW generation is 0.21 kg/capita/day, out of which biodegradable waste generation is 0.16 kg /capita /day. Although commercial activities were not fully operational during the study time, SW production was not decreased, indicating a shift of SW production from commercial to household. The COVID-19 pandemic not only increased HH waste but also increased the biodegradable fraction. The biodegradable fraction seems to have increased from 65% to 75% on average during the COVID-19 pandemic. More frequent cooking at home and excessive online food delivery services led to increasing food waste without adequate meal planning. The higher percentage of biodegradable waste in the study area shows the higher potential to manage it at source through HH composting.

Keywords: SW quantification and characterization, Biodegradable waste, SWM benchmark indicator, Composting.

Introduction

Solid waste management (SWM) is one of the major challenges for municipalities of Nepal, including Kathmandu Valley's municipalities. The situation is further worsening as the volume of solid waste has immensely increased over the past few years in the municipalities of Kathmandu Valley (KTMV), Nepal due to rapid urbanization and economic development. Poor management and the people's mind set of 'out of sight out of mind' of wastes have intensified environmental pressures, including unorganized waste disposal on the bank of the Bagmati River of KTMV. Due to the direct discharge of sewerage into the river and illegal dumping of solid waste (SW) on the riverbank, the holy Bagmati River of Nepal has been turned into a waste collection drain. COVID-19 has further exacerbated the already existing challenge of SWM and the crisis triggered by the COVID-19 pandemic has changed the dynamics of waste generation globally [1]. It had a tremendous impact on the waste infrastructure of municipalities because of an unusual increase in the amount of waste, primarily infectious medical waste [2, 3]. During the pandemic time, there was not only a tremendous increase in medical waste but also a significant increase in household waste as a result of the higher level of consumption, including purchasing food in bulk, panic buying cleaning products and sanitizers, online orders, and the related packaging [3, 4]. However, most of the waste quantification and characterization study was conducted from online surveys and telephone interviews rather than physical sampling and measurement [5]. Although, these types of qualitative studies helped to draw the waste generation and characterization trend, questionable in exact quantity. To the authors' knowledge, there is no quantitative data for municipalities of Bagmati River Corridor, a main urban centre of Nepal that accounts for the generation and composition of household (HH) solid waste during the COVID-19 pandemic. Even in a normal situation, municipalities of Nepal do not have the appropriate system for the treatment and management of both municipal solid waste and healthcare waste due to a lack of reliable data, appropriate technology, and resources and generally practicing open dumping, burning, and burial in the municipalities of Nepal [6]. Hence, accurate estimates of waste generation and waste characteristics are crucial to implement proper waste management strategies or to optimize the design of the required waste management infrastructure and facilities [7]. Moreover, without benchmark indicators, the performance of any SWM activities can't be objectively evaluated. Therefore, there is a need to develop a comprehensive and updated database on the state of SWM. The main aim of this study was to quantify, characterize the SW and evaluate the impact of COVID-19 on the status of HH SW as well as to explore SWM knowledge, attitude, and practices of the community in the study area which is ultimately used for the development of SWM benchmark indicators and to design community awareness initiatives and community-based SWM infrastructures in the Bagmati River basin.

Material and Methods

Study Area and Sampling

A stratified random sampling technique using a cross-sectional survey questionnaire was used to collect data from three municipalities; Kathmandu Metropolitan City (KMC), Lalitpur Metropolitan City (LMC), and Kirtipur Municipality (KM) of the Bagmati basin as shown in Figure 1.

Four wards (11, 12, 14 and 32) from KMC, four (2, 3, 4 and 9) from LMC and two wards (6 and 9) from KM were selected. Each ward was split into four clusters. The enumerator examined 10 households in each cluster, for a total of 40 households in a ward.

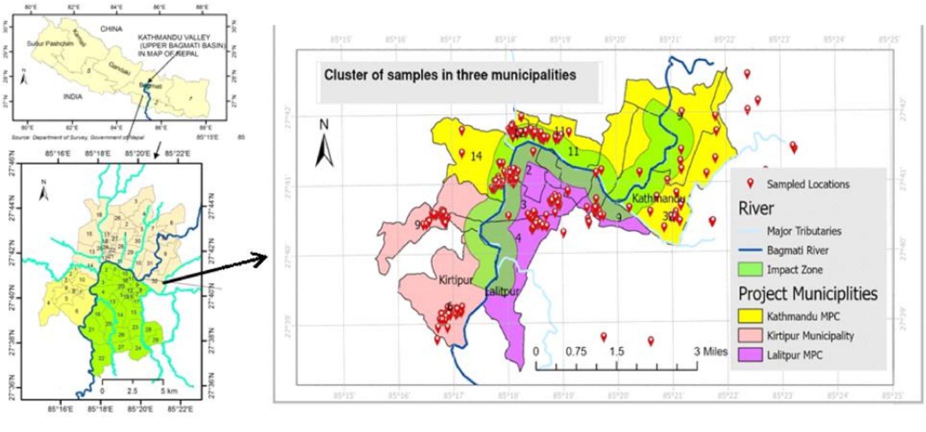

Fig.1. Study are and waste survey location

From the three municipalities, a total of 400 households, 100 institutions/offices, and 100 commercial establishments (shop/hotel/restaurant) were studied in the survey, and data were analyzed using SPSS and Excel spreadsheet. This size of the sample produced results with +/-5 % of the error margin at a 95% confidence level in the study area. Given the limited resources, one-day sampling was undertaken. The SW was collected the next day by the enumerators to determine the quantity (on a wet weight basis) of the 9 various wastes categorized as degradable, plastic, paper/cardboard, rubber, textile, glass, metals, sanitary pads/diapers, and others.

Results and Discussion

Waste quantification and characterization

The study revealed that the total HH SW generation is 0.21 kg/capita/day, out of which organic waste generation is 0.16 kg /capita /day and the remaining, is non-degradable waste. The average SW generation from the shops in the study areas is 1 kg/shop/day, and from the hotel/restaurant, it is 4.32 kg /restaurant/day. On average, the SW generation rate from offices in the study areas was 0.67 kg/office/day, out of which 0.31 kg/office/day is bio-degradable. Combining HH waste, and waste from commercial and institutional establishments, per capita MSW generation rates are 0.28 kg/day, 0.42 kg/day, and 0.49 kg/day for KM, LMC, and KMC respectively as shown in Table 1.

Table 1. Per capita HH and MSW generation in different time in the municipalities of Kathmandu Valley

Municipality	**HW-UWGR (kg/cap/day)**		**MSW-UWGR (kg/cap/day)**	
	ADB (2013)	Our Study (2021)	ADB (2013)	Our Study (2021)
Kathmandu	0.23	0.245	0.464	0.49
Lalitpur	0.19	0.209	0.37	0.418
Bhaktapur	0.16	-	0.35	
Madhyapur Thimi	0.14	-	0.27	
Kirtipur	0.15	0.169	0.25	0.282

The average per capita MSW of the study area has become 0.396 kg/day. When comparing the per capita generation rate with [8] of the study area, in two studies from 2012 and 2021, unit HH waste generation in KMC, LMC, and KM seems to have increased by about 10 % over the last 10 years as shown in Table 1. Currently, eighteen municipalities of KTMV generate more than 1262 t/d MSW, which is 25% of the total MSW in Nepal. Overall MSW production was not decreased though most of the commercial and institutional establishments were not in full operation due to the fear of the COVID-19 pandemic, which led to a shift of SW production from commercial to household. After COVID-19, people followed the government's stay-at-home order, worked from home, and moved less outside the home for eating due to fear of transmission of the virus. More frequent home cooking and eating raised HH waste. Rooftop and backyard farming increased to produce more vegetables at home in the study area, which also raised more organic waste in the household. Moreover, the shift from eating out to online food delivery services led to an increase in food waste, due to the order of excessive amounts of food without adequate meal planning and management. A similar observation was reported by [5], which showed almost half of the participants believe there has been some increase in their waste generation; 54% have felt an increase in their organic waste. Other researchers also indicated an increase in food and plastic waste generation [9], packaged food and take-out food waste [4]; and HSW in general [10]. The largest percentage of household waste (77.5%) is biodegradable in the surveyed area. In the waste from shops, organic waste covers 34% of the total waste followed by paper and cardboard (25%). In the waste from hotels/restaurants, organic waste is the highest amount (70.21%). However, paper and cardboards cover a larger portion (46%) of the office waste. This study reveals a higher value of biodegradable fraction in the HH waste of the study area than the previous report published by ADB in 2013, which indicates only 65% of biodegradable waste in household waste of KMC. The COVID-19 pandemic, not only increase HH waste but also increased the biodegradable fraction. This fact is supported by the recent study conducted by the KMC during the period of COVID-19 has reported a 75% biodegradable fraction in household waste of KMC [11].

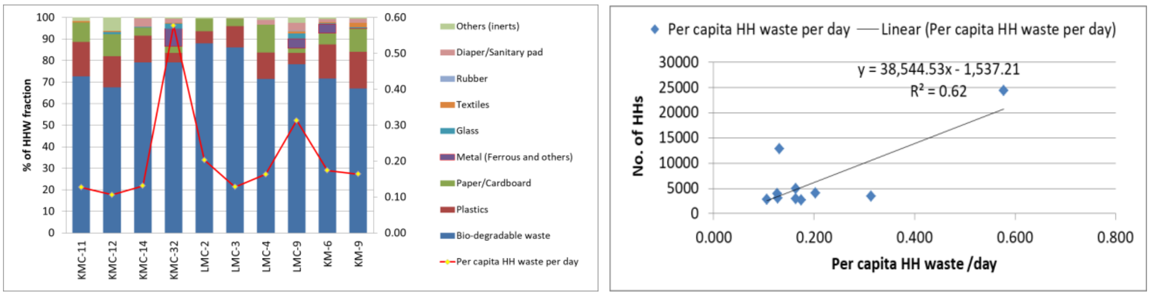

Fig.2. Per capita HH waste generation and composition in study wards of project municipalities (left) and relation between per capita HH waste generation and population size (right)

Determinants of waste generation and composition

The household waste generation rates varied depending upon the economic status of the households. The HHs with higher average expenditures generated a higher amount of waste per day as shown in Figure 3 (left). According to the study, the HH SW generation rates varied depending on the family's expenditure. Figure 1 shows that HHs that have higher average expenditures also have generated a higher amount of waste per day. Average waste generation for HHs with a monthly expenditure of NRs 40,000 and above generates 1.53 kg/HH/day, which is more than twice 0.39 kg/HH/day for households with a monthly expenditure of less than NRs 10,000. A similar trend was obtained for municipalities of Nepal in previous studies [8, 7]. A HH that spends a lot means that they might have high consumption rates, which resulted in more generation of waste.

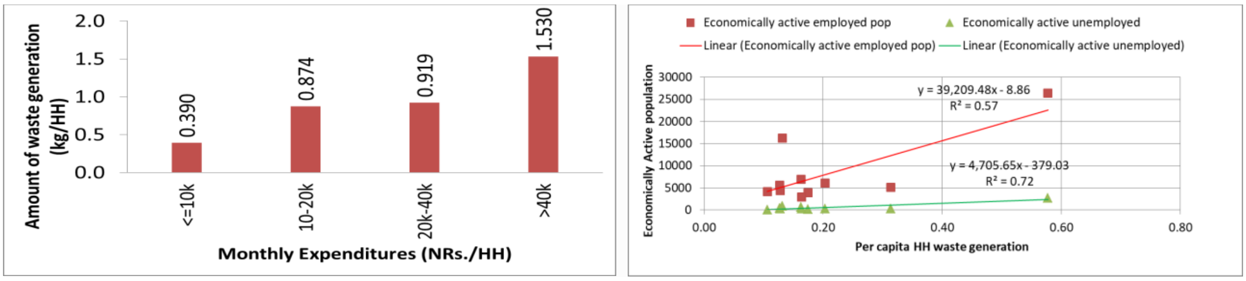

Fig.3. Status of average HH waste generation with variation of monthly expenditure (left) and relation between economically active population and per capita HH waste generation in the study area (right)

Figure 3 (left) also indicates the strong correlation of per capita HH waste generation with an economically active population. It indicated that the people with good economic status spent more on foods and other commodities, which resulted in more generation of waste. Interestingly, the economically active but unemployed population has a good correlation with per capita HH waste generation during COVID-19 time as shown in Figure 3 (right). Moreover, daily unit HH waste generation was found to be strongly influenced by population size. The bigger the population size, the greater the amount of unit HH waste produced, as shown in Figure 2. The right side of Figure 2 shows that population size is strongly correlated with the daily per capita HH waste generation.

Conclusions

This study revealed that total MSW production was not decreased through very limited commercial activities during the COVID-19 pandemic, which led to a shift of SW production from commercial to household. In addition to the increase in the quantity of HH waste, it seems the increase of biodegradable fraction in HH waste from 65% to 75% on average during COVID-19 time. Interestingly, the HH-level waste reduction program through HH composting was initiated for many years but could see visible results after the COVID-19 pandemic, which resulted in increase in urban farming. As the interest in rooftop gardening and urban farming is increasing, compost can be used, which helps to manage the major fractions of waste at sources to create resources by activating the community, which ultimately prevents littering and improve the environment of the Bagmati River basin.

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Evaluating Circular Economy Applications for Plastic Waste Management in Hong Kong

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ABSTRACT. This contribution discusses three cases of circular applications to manage waste plastics in Hong Kong with its main objective centring on a qualitative and quantitative performance evaluation. The results of the analysis show that the city's pilots and schemes on waste plastic management can yield success, however only if these are inclusive of stakeholder interests and make adequate use of financial means.

Keywords: Circular Economy; recycling; plastic beverage containers; informal collectors; Hong Kong

Introduction

The Circular economy (CE) is a concept on the rise in environmental management. However research and practitioners often neglect that circularity in resource management goes beyond the practice of recycling. Indeed, a research on CE applications in the Netherlands [1] has outlined a hierarchy of 10 R-practices, ranking from refuse, rethink and reduce at the top to the lowest ranking principles of recycle and (energy) recovery. This exemplifies the ideals of CE solutions to conserve resource use first and prevent the discards of waste. While the R-hierarchy provides for an operational framework that enables solution finding from economic and engineering perspectives, a substantial lack pertains to the societal domain [2]. Little attention has so far been paid to the role of stakeholders, be that decision-makers, material/ product manufacturers, consumers and stakeholders in waste management (WM). The critical problem entailed by this neglection pertains to the question of effectiveness. CE practices, as represented in the R-principles, constitute solutions for waste prevention and resource conservation. In order to be workable and generate effective outcomes, such solutions need to exhibit (1) a type of technical effectiveness, which is quantitatively measurable, and (2) a qualitative effectiveness, which represents a measure of stakeholder interest-inclusiveness. That is to say, circular solutions as institutions (e.g. rules, regulations, business routines, consumption habits) will only be effective if they produce measurable results and are supported by all involved stakeholders.

In Hong Kong, the CE has so far gained little traction as officially codified WM strategy [3]. Nevertheless, single, isolated measures that feature R-principle approaches have been adopted for managing waste plastics over the past years. With a focus on postconsumer plastics this contribution will address the following questions: First, to which extent have CE applications been implemented on waste plastics? Second, how well have these performed quantitatively and qualitatively in terms of R-principle effects (e.g. refuse, reduction, reuse, recycling)?

Material and Methods

In terms of methods, the analytical framework is borrowed from an earlier work of the first author [4], which centres on institutional (rule-based) evolution and explores rule effectiveness on the basis of quantitative and qualitative premises. The former asserts that mechanisms can only perform effectively if they solve a resource related challenge in technically verifiable manner. E.g. for waste collection, a regulation performs technically effective if it increases collection rates. The latter accounts for the inclusion of stakeholder interests in rule design. Again for the case of collection, a mechanism only performs effectively, if stakeholder preferences are taken into account. Hence, collection systems have to consider the interests of (a) generators, (b) collectors and (c) system designers. These pertain among other factors to (a) convenience of bin access and individual cost-benefit assessments, (b) income from service provision and work intensity, as well as (c) budget costs, recovered quantities and material purity.

As for materials, outputs of the paper are based on desk research including secondary literature, government announcements and public opinions surveys. Moreover, the contribution incorporates first hand findings by the authors obtained in the course of field research in Hong Kong (September and October 2021) among collectors and recycling stations (pre-processors) that engaged in waste plastic beverage container (WPBC) recycling [5].

Results and Discussion

Hong Kong's institutional setting for a CE on plastic waste

When compared to other regulatory systems, a substantial institutional shortcoming of Hong Kong is that it does not feature a single, comprehensive law WM. Rather the city's government regulates aspects of environmental protection and sustainability via single statutes. Among these, the 1980 issued Waste Disposal Ordinance constitutes the outset for subsequent developments in WM and the CE, which also includes regulations on waste plastics and CE management approaches. To assess the extent that the CE plays for managing waste plastics in Hong Kong, a heat-mapping approach is adopted to explore the government's emphasis of (and by implication its interest for) R-practices in regulations on waste plastic management. This approach implied to screen each legal document for the frequency of R-principles mentions. The resulting institutional heat map (Fig. 2) displays R-principle dominance on the basis of 'shade intensity': Darker shades indicate a high frequency of R-principle mentions, lighter shading indicates less emphasis and blank spaces indicate no mention. Equal shading for two or more principles suggests equal emphasis of the practice. The resulting analysis in Fig. 2 shows the government's strong institutional preference for reduction approaches to waste plastics. In terms of the CE, this indicates a positive departure from the traditionally prevalent focus on landfilling [6]. However, from a quantitative perspective the reduce approach has gained little traction for plastics generation. Previous research has found that plastic waste quantities arriving at landfill sites have been overall increasing since 2006. The general consensus documented in previous research attributes this to the lack of specific regulations targeting the various plastic sub-streams and the absence of compulsory or financial incentive based measures [7].

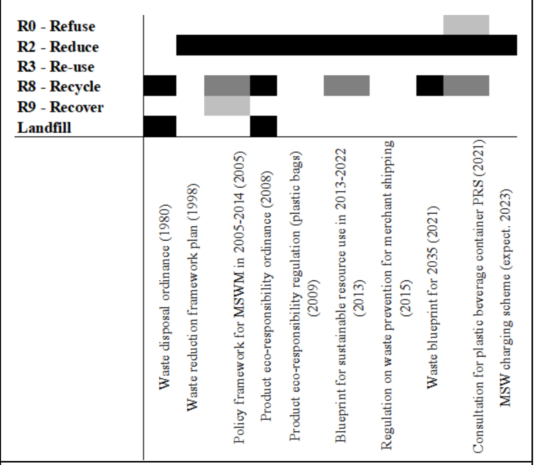

Fig. 2. Heat map on R-principle emphasis in Hong Kong's regulations on waste plastics [7]

General schemes and pilots on plastic waste in Hong Kong

In the absence of a formal regulatory framework, the government has opted to trialling pilots and various financial schemes to tackle plastics. The chronologically oldest is the plastic bag levy aiming to reduce consumption, which saw gradual implementation in 2009 and charged customers HK$ 0.5 per bag (US$ 0.06). By 2015, the scheme had reached full coverage of the retail sector and diverted 540 million units from landfill over a four-year period [8]. The scheme's limitation however emerged over subsequent years, when bag consumption rebounded – potentially due to low fees and the absence of follow-up regulations [3]. To curb consumers' behavioural adjustments, the government responded in 2022 by raising the levy to HK$ 1 (US$ 0.06) per bag, which induced a reduction in consumption by 60% over a period of four months [9]. Assuming the pattern of regulation vis-à-vis consumer behaviour routines to continue along an evolutionary trajectory [4], the consumption of bags is likely to rebound again, if the government refrains from developing a consumer- and inflation-adjusted rule mechanisms.

A second more recycling-centred approach is the Green@community network (G@CN), which consists of stationary and mobile recovery stations, stores and spots that take back a wide range recyclable waste. The stations offer citizens 'GREEN$' in exchange of waste recyclables, which in turn can be used to acquire gift items [10]. While modern in its appearance, the network performs poor in density and accessibility across the topographically diverse and in population density varying districts of Hong Kong. Moreover, a study from 2018 has shown that the 33 stationary nodes of the G@CN require monthly expenditures of HK$ 14 million, which are largely spent on rent ranging around HK$ 130/sq.ft. (US$ 16.6) [9]. Alternative locations, which due to higher consumer frequency appeal more to generator convenience, are stalls at Hong Kong's public markets. Rents there are about HKD 0.5-32 (US$ 0.06-4.1) [11], which would substantially improve cost-effectiveness of the scheme. Interestingly, the government has responded to these arguments first brought forward by a local NPO and decided to integrate G@CN stores into public markets [11].A third problem remains, however, which is the recovery capacity of G@CN stations. Based on publicly available figures documented by individual stations [12], median recovery quantities for waste plastics are about 14.4

tons/station/month or 471 kg/station/day. As outlined below, these capacities fall below a more recent pilot scheme on WPBCs that required less budget and mostly built on traditional recovery networks.

A pilot for recycling waste plastic beverage containers (WPBCs)

Formed as a working group in 2017, the Drink Without Waste (DWW) alliance comprises producers, retailers, recyclers and NGOs involved in the sale and management plastic beverage containers. Under the name Neighbourhood Bottle Reward Scheme (NBRS, 區區有樽賞) this alliance launched a government subsidised pilot (HK$ 5.6 million) to explore a recycling network for single-use WPBCs. Over the course of operations (November 2020 to September 2021) the scheme recovered 1,231 tons in PET, PP and HDPE based WPBCs via 37 continuously participating recycling stations (RS) [5]. These RS were composed of traditional corner-shop recyclers and mobile recycling pop-up trucks that operated at designated locations. WPBCs were mostly delivered by informal waste collectors (35.7-47%wgt.), residential/ street cleaners (17.8-39%wgt.) and retired residents (16.6-30%wgt.). Field investigations comprising observational data records on WPBC quantities transacted between delivering stakeholders and RS indicate a median of 558 kg/RS/8-hour-working day. These figures on WPBCs alone surpass the plastic recycling performance of G@CN rendering the NBRS technically more effective at a lower cost level. To further incentivise the reclaim effort, a subsidy of HK$ 0.11 (US$ 0.014) was allocated per returned container, out of which 0.05 was given to collecting stakeholders, 0.035 to RS managers and 0.025 accrued in management costs [5].

While the pilot constitutes an innovative and effective institution in terms of stakeholder inclusion and recovery capacity, some caveats apply. Firstly, when contrasted with container sales data, i.e. what was put on the market in 2020/21, the scheme merely recovered around 3% of WPBCs. Even if the pilot had included all existing RS that engage in plastic recycling in Hong Kong, it could at best have recovered 22-23% [13]. Secondly, the system critically depends on RS and moreover informal collectors. Yet, interviews during the field survey with both stakeholder groups indicate that neither exhibited particular interest in the stream, be that due to reasons of hygiene or low profit margins [5]. Moreover, the strongest performers in collection, i.e. cleaners and informal collectors, are of very old age. Out of all interviewed stakeholders (n=37), 62% were respondents of these two groups and identified as over 60 years in age. This has substantial, limiting implications for the scheme's sustainability, should it be considered for future continuation. Finally, the pilot ran on relatively low redemption values per container, which might have critically impaired recovery performance. The need for such reimbursement was verified during field research: Once the pilot and thus subsidy provision ended (October 2021), individual WPBC deliveries plummeted (Fig. 3). While being hailed as success by DWW, low reimbursement-per-container levels may fall short of delivering effectiveness. Historically, this was exemplified in Hong Kong's first WPBC return pilot (2005-2007), which failed to generate recovery rates due to a low-valued, non-monetary redemption scheme that fell short of motivating container returns by generators [14]. Second, best practice examples from international frontrunners operating Extended Producer Responsibility schemes on WPBCs exemplify that deposit-refund-systems (DRS) need to price containers sufficiently well. When comparing these countries and Hong Kong on the basis of a purchasing power parity index for WPBCs, results show that the index median for effective performance is around 3.1%. Hong Kong's HK$ 0.11 redemption value used in the pilot and now officially elaborated by the government only ranges at 0.5% in that index [8]. Finally, three public opinion polls between 2020-2023 indicate consumer acceptance of higher redemption values [13]. Particular a HK$ 1 was indicated as a strong incentivising benchmark by surveyed consumers (n=1,008) either to participate in a DRS (61%) or in a basic return scheme featuring redemption values (78%) [15]. In light of these findings, the pilot subsidy level appears to ignore consumers' and waste collectors' interests and in turn might have prevented the NBRS from yielding substantial success.

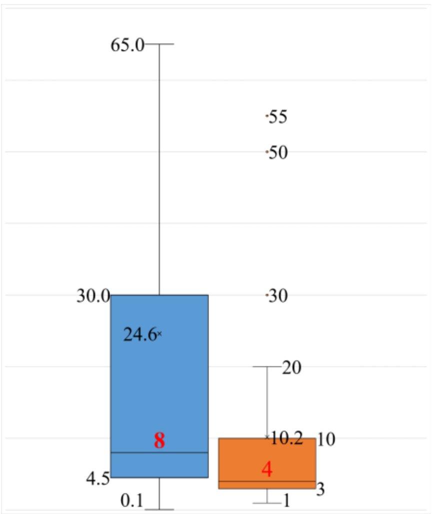

Fig. 3. Quantitative ranges of individual WPBC deliveries to RS in September (blue) and October (orange) 2021 [13]

Conclusions

While the Hong Kong government has so far fallen short of implementing a comprehensive framework on waste plastics, experimentation with pilot schemes provided valuable insights on a way forward, particularly for upcoming regulations on single-use plastic tableware as well as food and beverage containers. However, the above discussed cases also indicate a set of recurring shortcomings. First, waste recovery and return networks need to be further developed with a focus on cost-effectiveness and high-density infrastructure. Second, interests and preferences of generating (consumers) and operating (collectors and pre-processors) stakeholders need to be better accounted for. Doing so could pave the way for improved recycling mechanisms and even for higher-ranking, R-principle based solutions, e.g. plastic packaging substitution [14]. Finally, financial fees and fiscal support measures tend to be applied in an overly tacit/ parsimonious manner, which has impaired CE schemes from yielding more effective outcomes.

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Sustainable bioenergy, economic, and environmental impacts of resource recovery from organic fraction municipal solid waste in Penang, Malaysia

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Rapid increment in the global municipal solid waste production with time raises up the concern in terms of environmental impacts including greenhouse gas emissions, landfill issues, and water quality deterioration. Thus, this study focuses on the potential bioenergy and resource recovery from organic domestic waste using anaerobic digestion and its economic, and environmental impacts in Penang, Malaysia. Accordingly, approximate and elementary analyses of organic solid waste samples were carried out to estimate the potential production of biogas and bio-fertilizer. The economic and environmental benefit analysis was investigated. It was found that 534748.5 t/year of total domestic waste was collected from Penang island and 1,143,995.00 t/year was collected from Penang mainland. Anaerobic digestion of organic domestic waste has the potential to produce electricity with a total amount of 250390.34 kWh/day and bio fertilizer with a total amount of 211413.95 kg/day, reducing the land used for landfilling by 233.27 m^2 /day, and avoid the production of 99.37 m^3/day. The cumulative revenue of RM 1337 million/year can be generated within 3 years, whereby the project return of investment (ROI) requires 3 years 5 months with initial capital expenditure. The results are promising and can motivate investors and decision-makers to recover resources from organic solid waste.

Keywords: Municipal solid waste, Bio fertilizer.

Transition towards Circular Economy: Policy Insights from a Developing Country

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ABSTRACT. The circular economy is a sustainable model that aims to use resources for as long as possible, extract their maximum value, and recover and regenerate products and materials at the end of their life cycle. It contributes to global agendas such as the Paris Agreement and Sustainable Development Goals (SDGs). Besides protecting the environment, it presents economic opportunities by reducing waste, stimulating business growth, and creating jobs. Many developed countries have implemented circular economy policies and strategies, with emerging technological solutions and innovations. Developing countries, including Malaysia, are also transitioning to circular economies to address sustainability and climate change issues. Malaysia has implemented green growth initiatives to accelerate its transition. This study provides an overview of Malaysia's policy trajectory towards sustainable development and identifies barriers industries encounter when implementing circular economy practices. Finally, the study presents several broader strategic frameworks of transitioning to circular economy in Malaysia.

Keywords: *circular economy, SDGs, sustainable production and consumption, green growth*

Introduction

Presently, economic growth around the world is largely supported by a linear economic model that is unsustainable and detrimental to the environment. Strategies for a more sustainable and greener economic growth and development are needed to ensure the protection of the environment and a sustainable use of scarce natural resources while simultaneously still achieving improvements in living standards and reducing poverty [1]. Green growth policies play an integral part of the structural reforms needed to foster inclusive and more sustainable economic growth, particularly in developing countries. Many developing countries, including Malaysia, focus primarily on integrating environmental management and addressing environmental challenges into national economic and social development plans [2]. Malaysia has begun its green growth efforts since 1980s by putting in place institutions and policy agenda that promote and facilitate green growth initiatives. Current policy actions and initiatives to promote sustainable development goals (SDGs) have primarily focused on the last stage of the linear economy in which products reach their end of life and discarded as waste. While linearity is deeply institutionalized, policy frameworks and recommendations at the macroeconomic and sectoral levels for the circular economy have yet to be established in Malaysia.

Materials and Methods

This study provides an overview of Malaysia's policy trajectory towards sustainable development, specifically towards transitioning and implementing circular economy practices. In doing so, we identify policy initiatives and programs undertaken by several government agencies tasked to implement broader green growth efforts. The study also highlights challenges in implementing some of the policies and programs in accelerating circular economy in the country.

Results and Discussion

Figure 1 and Table 1 below highlights policies and initiatives that have been implemented in pursuing green growth and sustainable development in Malaysia in recent years. As indicated both in Figure 1 and Table 1, Malaysia has gradually incorporated sustainable development goals into its economic development agenda and this can help accelerate the transition from a linear to a circular economy that will improve human and environmental well-being. Table 2 summarizes green growth efforts embedded in recent economic development plans. Our analyses show that policy areas such as economic, agricultural, manufacturing, transportation, waste management and disposal, and innovation and technology need to be articulated in a cohesive and integrated approach to include circular economy framework and best practices in these policy areas. Policies that promote green growth need to be implemented alongside other policies such as renewable energy and green technology policies for green growth efforts to be more effective in the long run. Many of the objectives of these policies such as resource efficiency and waste management largely focus on the output side of resource flows (i.e., emissions and waste) while the input side is either completely overlooked or addressed through aspirational, non-mandatory targets, scattered across policy documents. Further analysis also suggests that Malaysia requires a more systematic approach to promote circular economy at industry, organization, and society levels.

Fig. 1. Policies and initiatives in pursuing green growth and sustainable development in Malaysia from 2009 to 2021

Table 1. Selected programs and initiatives in promoting sustainable development and environmental sustainability in Malaysia.

Year	Action Plans/ Programs	Description
2001	Small Renewable Energy Power Program (SREP)	Policy mechanism to promote small-scale renewable electricity.
2005	National Strategic Plan for Solid Waste Management	Provides basis for solid waste management (SWM) policies, legislation, action plans, and measures.
2013	Government Green Procurement (GGP)	Acquisition of products, services, and work in public sector that takes into considerations environmental criteria to conserve natural environment and resources and reduces negative impacts of human activities.
2013	National Biomass Strategy 2020	Promotes and utilizes high-value biomass, particularly oil palm biomass; introduces incentives to support and enhance development of biomass industry.
2016	National Sustainable Consumption and Production (SCP) Blueprint 2016-2030	Provides directions on delivering green growth in sustainable production and consumption; Builds on existing efforts and aligns with major national policies and international approaches towards sustainability.
2021	Malaysia Plastics Sustainability Roadmap 2021-2030	Outlines strategies and action plans to achieve plastics circularity and supports the government and global agenda towards sustainable production and consumption.
2022	Voluntary Carbon Market Exchange (VCME)	Enables companies to purchase voluntary carbon credits from climate friendly projects and solutions; Acts as a catalyst and encourages investment in high-quality carbon offsetting projects that can generate positive environmental and societal benefits.

Table 2. Recent Malaysia Plans (MP) incorporating sustainable development and environmental sustainability in Malaysia.

Year	Malaysia Plan	Sustainable Development and Sustainability Key Focus Areas
2011-2015	10th Malaysia Plan	Focuses on 2 main areas: (1) developing roadmap for climate resilient growth through, among others, promoting energy efficiency, improving waste management, conserving and enhancing sustainable forest management, reducing GHG emissions and managing climate change risks; (2) enhancing conservation of the country's ecological assets through enhancing forest and wildlife conservation efforts and ensuring sustainable and safe utilization of resources.
2016-2020	11th Malaysia Plan	A strategic thrust *"Pursuing Green Growth for Sustainability and Resilience"* focuses on strengthening the enabling environment for green growth, adopting the sustainable consumption and production (SCP) concept, conserving natural resources, and strengthening resilience against climate change and natural disasters.
2021-2025	12th Malaysia Plan	*Advancing Sustainability* theme focuses on socioeconomic policies that considers environmental sustainability to ensure sustainable growth, improve resource efficiency, and maintain ecosystem resilience. *Advancing Sustainability* also promotes the adoption of the circular economy and streamlines energy related-policies as well as the adoption of the integrated water resource management (IWRM) to increase the efficiency of water management.

Several key challenges remain in the areas of policy development and formulation, policy implementation, and policy monitoring. The green growth policies have remained fragmented among different ministries and government agencies, which can lead to duplicative and wasteful programs and fund allocation. The alignment of goals of ministries, state and local governments, research funding agencies, higher education institutions, and social and market-based entities is vital so that the focus on green growth are considered in all its dimensions including the circular economy. Several options for policy action can be pursued in order to accelerate the circular economy transition in Malaysia. These include policy on eco-design, extended producer responsibility (EPR) mechanism, sustainable taxation model and incentives, integration of public procurement, circular economy funding alternatives, and industrial symbiosis.

Despite the benefits of the circular economy on environmental sustainability are well recognized in the research and policy arena, the adoption of the circular economy principles among the industry players in the country are still lagging. Industries are aware of circular practices, in terms of long-term economic and environmental benefits, but they encounter barriers and challenges in adopting circular practices. Some of the barriers and challenges are well-identified in the extant literature. One of the key challenges that hinder the transition towards circular economy are the financial constraint faced by industries. The transition to circular manufacturing typically involves changes to the production design and processes and these changes can be costly for industry players [3]. Further, some green investments are not yet profitable or have lower rates of return compared to traditional investments, making them less appealing to investors [4]. The lack of technological and innovation capacity also poses challenges to the development of required economic and human resources for circular economy enabling technologies [5]. Digital platforms play increasingly important role in the transition to circular economy. However, many industry players face obstacles to scale up and improve circularity due to the lack of access to affordable digital platforms and digital knowledge as well as skills [6].

Conclusions

In reducing costs and increasing public and market acceptance of more circular business models, several enablers can be taken into considerations when the government formulates future circular economy related policies. First, the involvement of businesses and consumers are important in designing and implementing circular business models. Businesses engage with consumers to understand their needs and preferences and incorporate these insights into their design of their products and services, thus helps promote sustainable production and consumption patterns. Institutions also play a critical role in strategizing policy frameworks for circular economy initiatives by developing and implementing policies that incentivize circular practices and create market demand for circular products and services. Second, while circular economy initiatives already exist in the country, most of the circular economy programs have been focused on the environmental perspectives with limited role of businesses, technological innovations and financial markets which are imperatives for accelerating the circular transformation. Therefore, future CE-related policies and their implementations need to consider CEPA (communication, education, and public awareness) programs by engaging with internal and external stakeholders from government agencies, industry players, R&D institutions, and local communities to promote and improve circularity. Finally, CE implementing agencies need to promote and facilitate collaborations between the financial sector, regulators, and other public and private institutions in accelerating the scaling up promising circular innovations and circular business models at different levels.

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Understanding, Consensus, and Willingness to Implement Solid Waste Management Policy of Citizens in Municipalities of Vietnam

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Municipal solid waste is forecasted to rapidly increase due to population growth, industrialization, and modernization. If no solution is found, the overloading of waste will become a threat to humanity because of waste pollution and its effects on human health. Citizens play an important role in implementing waste management activities. Therefore, it is necessary to propagate national policies and strategies on waste management to encourage people to understand and support waste management activities. The more people know about waste management regulations and policies, the more they show their interest in waste pollution issues. However, very little research has been done on people's understanding of solid waste management policies in developing nations that are facing waste pollution. This study aims to find out how well people in three municipalities of Vietnam including Hanoi, Da Nang, and Ho Chi Minh know about waste management policies. In addition, consensus with regulations, willingness to participate in waste management activities, and sharing their knowledge and interest in local environmental issues are also found through the in-depth interview methods for a total of 346 respondents. Survey results were cleaned and statistically processed using SPSS v. 29.0.0.0 through descriptive and inferential statistics. The results showed that 85% of people shared they had never heard of national waste policies, while this figure for the understanding of local regulations was 44%. There are three main pieces of information that people know including waste disposal location, collection time, and collection fee. 78% of citizens agree with the solid waste collection, transportation, and treatment method of local authorities. The waste classification regulation is the most objectionable one, with up to 66% of respondents disagreeing. The difficulty of the classification (56.4%), the lack of synchronization between the classification and the collection (20.3%), and the lack of time (12.3%) are the primary causes of disagreement. In addition, the results revealed that 52% of respondents stated that they had never attended a local waste management propaganda program, while 32% stated that they had known them. However, only 11% of respondents were able to participate at a level ranging from frequent to always. Finally, 78.9% of people in the three municipalities rated that waste pollution had serious effects on the environment and their health, and 55.8% of people rated the management of local authorities as mediocre. This research results also support the development of a comprehensive plan for the implementation of the national waste management policy, the issuance of sanctions to deal with violations, and the strengthening of the organization of propaganda programs in solid waste management are important tasks for resolving the current issues. In order to fully comprehend the issue and support a national solid waste management strategy at the same time, similar studies should be extended to urban and rural areas. Sustainable solid waste management is a complicated endeavour that necessitates society-wide attention, support, and participation.

Keywords: Citizen’s understanding, Consensus and willingness, Municipal solid waste, Policy implementation.

The Challenge of Plastic Beverage Container Recycling in Hong Kong - Perspectives and Performances of Local Recyclers

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Recycling is an effective strategy to mitigate environmental pollution caused by the excessive consumption and discarding of plastic beverage containers. In Hong Kong, plastic beverage container collection and recycling mostly relies on individual, often non-registered stakeholders. Yet, given the containers' low market value in the city, collection and recycling rates have been relatively low. What complicates matters is the absence of an encompassing waste management (WM) regime and particularly an Extended Producer Responsibility (EPR) scheme for plastic beverage containers. Such regulatory shortcomings leave key WM responsibilities unallocated and render recycling operations solely dependent on market dynamics.

The aim of this paper is to first highlight the qualitative (operational) and quantitative performance of local plastic recycling (collection, pre-processing, and downstream transfers). These findings are then used to identify international best practices and finally juxtapose these against upcoming measures planned by the Hong Kong government.

In terms of analytical framework, the paper proposes a multi-disciplinary approach that combines value-chain analysis, material flow accounting and institutional economics to explore qualitative and quantitative elements of Hong Kong's plastic recycling system. The data used for the study stems from field research in the city during September and October 2021. Over this period, we conducted over 40 in-depth interviews with collecting and pre-processing stakeholders involved in post-consumer waste recycling. Additionally, over 470 instances of recyclable waste transactions were documented to explore the quantitative dimension of the local recycling value chain.

The results indicate that policy intervention and measures are inevitable to achieve a sustainable, circular plastic WM system in Hong Kong. First, international WM regime comparisons show that an EPR system with high container unit deposits is feasible and indeed needed to enable an effective reverse logistics structure. Second, general taxation and insufficient subsidies are critical challenges for recyclers to maintain economically viable operations. Third, costs and usability of as well as storage space related to infrastructure create uncertainty and impair capacities of stationary pre-processing stakeholders. What on the other hand works well is the synchronisation of how operational routines between waste collecting and waste pre-processing stakeholders. The smooth interaction among these stakeholder groups in fact proves that plastic recycling in Hong Kong can benefit from a reliable network structure, which may with relatively low economic incentives (1.4 HKD/ kg of plastic beverage container) realise a sustainable, more circular system. Limitations of the study are the relatively short survey period, which renders further long-term observations and additional interviews with a broader stakeholder base critical for exploring the shortcomings of plastic beverage container recycling in Hong Kong.

Keywords: Hong Kong, Plastic beverage containers, Recycling, Reverse logistics, Collection.

Municipal Solid Waste Management in West Bank/Palestine (Challenges And Solutions)

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Currently, Solid waste (SW) is one of the most pressing issues around the world , as the world population is growing at a fast pace (11 million tons per day in 2100).Since More than 3.5 million tons per day in 2010, global waste generation will reach 6 million tons per day by 2025 and probably about 11 million tons per day in 21006 (According to The World Bank's specialists).As a negative effects, increasing the pollution of soils and water and potentials for health crisis will face many countries, on the other hand it is most probable that developing countries will suffer the most from unsustainable waste management policies.

In west bank (Occupied Palestinian Territory (OPT)), solid waste management is also a crucial issue: the rapid growth of the population and consumption, the limited area of land, water resources and the climate conditions are important factors to be taken in consideration for any future sustainable solid waste management. In addition to the modest capacity of the municipalities in terms of expertise and at the technical and financial levels makes these municipalities in a state of great confusion in dealing with this sector in an appropriate manner.

The Municipalities are the main managers of the solid waste generations in west bank, since the poor Municipal management will lead to unstable on the national level. The common way of waste management in (Occupied Palestinian Territory (OPT)) is disposal at random landfills where the 3R principle (reduce, reuse and recycle) is still not applied nor forced by legislations. Therefore, the municipal situation should be improved on the levels of finance, technical and social awareness.

This paper aims to give an overview about the role of the municipalities in the current situation of solid waste management and in West Bank (WB), at the legislative, technical, financial and social levels . The research examines first the inter ability of the municipalities to manage the SW sector in their areas and second, the municipal solid waste, i.e. the waste collected by or on behalf of municipalities, that is generated by households, and by commercial, industrial and institutional activities, similar in nature and composition of household's waste. In addition, the management of some of the hazardous and infectious waste, which can be present mainly in industrial, commercial and health care activities, is described and takes into account the fact that, in the Occupied Palestinian Territory (OPT), this type of waste is not systematically collected and treated separately.

There are many challenges facing municipalities in managing solid waste sector in West Bank/ Palestine, but on the other hand, there are many qualitative proposals to address these challenges, as the most prominent of these proposals is the Public–private partnership (ppp) principle to reduce solid waste production and raise the social awareness in the communities and raising the ability of the municipalities by improving performance and allocating appropriate financial budgets to this sector.

The study relies on collecting information directly from the municipalities and from some experts in this field at the local and national levels.

Key words: Solid waste management, Ability of Municipality, Social awareness, West bank.

When and How Solar Photovoltaic Waste Would Become a Burden for Hong Kong? and the Actionable Insights for Effective Management

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Hong Kong's first solar photovoltaic (PV) installation dates back to 1985 as the power source for weather stations in remote locations. Later a PV system was installed on the remote island of Hei Ling Chau to power the drug addiction treatment center. Following this, with the government's push towards renewables, many small and conventional stand-alone applications-based PV installations and the most advanced installation types, including Building Integrated Photovoltaic (BIPV) on high-rise buildings and Floating Solar Photovltiaics (FSPV) on water reservoirs, have become popular. Recently, environmentalists and other stakeholders' started expressing concerns about aging solar PV panels due to the lack of end-of-life (EoL) regulations specific to solar panels. Given the existing issues with the city's e-waste management and favoring feed-in tariff policy that is taking the solar installations in a fast-paced manner, we aim to investigate 'when and how solar photovoltaic waste would become a burden for Hong Kong with evidence-based, actionable insights for effective management'.

For this, we first applied a data-driven approach for identifying and mapping solar PV installations in and around Hong Kong to estimate the exact time for different installations' aging for further quantification of possible e-waste. Second, the consequences of not having a regulation leading to various environmental risks are estimated.

The results show that many government-owned solar PV installations have already reached EoL 12 years back from the referenced year 2022, and the first installed non-government solar PV installations will reach EoL in the coming two years (i.e., 2024). The observed environmental risks include the metal's leaching potential, cadmium exposure, and potential chances for water contamination. It is also observed that the existing e-waste guidelines of Hong Kong and the type of material recovery units at Hong Kong's eco-park can potentially recover valuable materials from the EoL solar panels if regulation and infrastructure support are provided, thus promoting local recycling. Overall, this study offers an aging timeline for solar panels and secondary material inventory when solar panels are recycled under various methods, suggesting the Hong Kong government take immediate action on formulating EoL regulations for solar panels.

Keywords: Photovoltaic waste, E-Waste in Cities, Solar in Hong Kong, Material recovery, Solar waste regulations.

Cross-border Industrial Symbiosis Over in-City Industrial Symbiosis for Hong Kong City's Circular Dream

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In the last five years, Hong Kong's waste disposal rate has snowballed, and it is expected to grow further. But the resource recovery rates from the generated waste have remained consistently low due to a lack of effective waste management centers for all kinds of generated waste. Thinking of solutions, a globally more recognized solution, i.e., the circular economy, is believed to facilitate better resource utilization and waste reduction. But for a city to become more sustainable and circular, effective waste management under the principles of industrial symbiosis (IS) is needed. IS is a process where the waste of by-products produced by one company becomes a valuable material for another, facilitating a reduction in the consumption of virgin materials, water, and energy. So, this study aims to investigate the role of IS in Hong Kong city's circular dream. For this, a data-driven approach is explored considering various resources coming into and going out of Hong Kong city along with manufacturing facilities and available waste management industries. Later, these are mapped with the IS principles to see the possibility of establishing in-City IS. The investigation outcome suggested that in-City IS for Hong Kong is difficult at this stage. But a close look at EcoPark tenants and their waste inputs and recovered outputs suggests that in-City IS is impossible unless major regulatory changes and a diversity push happen. The results also suggest that IS geographic extension leading to cross-border IS could be another best option for achieving Hong Kong city's circular dream.

Keywords: Circular economy, Cross-border industrial symbiosis, International industrial symbiosis, Waste management regulations, Hong Kong circularity.

Solid Waste Management in Different Economic Settings: A Case Study of uMsunduzi Catchment, South Africa

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South Africa is faced with water quality challenges which are mainly associated with waste management that introduces pollutants into the water resources. Insufficient management of solid waste is a palpable cause of stress to the environment, budget processes, community participation challenges, institutional arrangements, finance issues and unsustainable waste disposal. According to the United Nations, ~11.2 billion tonnes of solid waste is collected worldwide and almost all of it comes from humans alone. South Africa is one of the major contributors of solid waste generation globally with an estimated 108 million tonnes of waste contribution; 59 million tonnes of which was classified as general waste. Therefore, it is important to find ways how to manage this waste and come up with strategies that will sustainably manage such waste. Understanding and education about the waste end-results are fundamental but not equally distributed between different economic backgrounds, with the communities from rural and peri-urban areas not fully understanding the impact of solid waste.

UMsunduzi catchment, in South Africa, suffers from poor water quality as well as flooding during the rainy season. Solid waste is only collected and disposed of properly in urban areas of this catchment. The rest of the communities are left to handle their waste and most of it finds its way to stormwater management systems thus impacting their functionality and therefore contributing to flooding and impairment of freshwater systems. As part of the non-structural best management practices (BMPs), it is important to educate the communities on waste management. To lay the foundation, this study aims to explore how well do people in different economic backgrounds within this catchment handle their solid waste and their understanding of its impact. In so doing, using random quantitative sampling methods, communities from rural, urban, and informal settlements will be interviewed to gauge their views on solid waste management and current practices. Overall, this study will highlight the necessity of communities' involvement in the design of BMPs of the catchment and possible adaptation for other catchments with similar problems.

Keywords: Best Management Plans, Environmental Pollution, Solid Waste Management.

Zero Waste Management Community adapted in Karaikudi, Tamil Nadu, Environmental Problem Solving, and Sustainable Development

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The Zero Waste Management Community (ZWMC) initiative was launched in India with the goal of enhancing waste disposal and village cleanliness in transhipment hubs that had been identified. Communities around ZWMC's manufacturing facilities are targeted. The main components include door-to-door waste collection, lane and road cleaning, waste separation, composting of wet waste, and awareness raising. Solid waste disposal is a widespread problem in many developed and developing countries. In the Indian state of Tamil Nadu's Sivagangai district, Karaikudi is a Greater Municipality. According to figures from the 2021 census, it is the 21st largest urban agglomeration in Tamil Nadu.The town is administered by the Karaikudi municipality, which covers an area of 100 km2 (39 sq mi) and contains 32 wards with 628 streets. The town had apopulation of 3,17,041 as of 2021, with 1,55,690 males and 1,61,303 females. Land filling, The most common and mature waste disposal technologies are incineration and composting by the Karaikudi municipality. Traditional methods of transporting solid waste include the use of three types of vehicles: fuel-type vehicles, electric-type vehicles, and man-powered tricycles.There are many types of waste generated that are organic, inorganic, degradable, non-degradable, plastic, metal, rubber, and glass, and these are mostly separated as wet and dry waste. In Karaikudi, approximately 48 metric tonnes of waste are generated per day along this line. Municipal trash Collection is a major part of waste management, including the collection of household waste; this allows waste to be transferred from its original location to the location of its treatment. This includes source reduction and reuse, animal feeding, recycling, composting, fermentation, landfills, incineration, and land application. The residential level of waste secretion is higher. when compared to others. Residential waste is the primary source of waste leakage in Karaikudi. The other important sources are commercial waste, including waste from markets, hotels and restaurants; institutional waste, including waste from schools, colleges, and universities; and government offices; medical waste from hospitals and clinics; and construction and demolition waste. And particularly on the weekends like Sunday and Monday, waste accumulation is higher than on other days. The initial aim is to minimise the waste, starting at the house level. In this study, we analyse the people knowledgeable about garbage disposal and their handling methods in-house. This study is to observe the current system of collection, segregation, and treatment of municipal waste in Karaikudi and create an efficient system of processes at every level that will sustain itself in the future. For example, collecting and glass waste one or two days per week will help in the segregation process and prevent the dry and wet waste from becoming contaminated. And to reduce the burden for the municipality, Alagappa University can handle campus waste on its own using an organic waste management system. It will minimise the waste accumulation on the university campus and produce the compost that will be used in the garden.

Alagappa University assisted in the completion of this project in Karaikudi, Tamil Nadu, India. The Alagappa University launched the Clean Transport initiative with the goal of enhancing waste disposal and cleanliness in Karaikudi, a designated transshipment hub. Customers in transportation hubs have their demands met by ZWMC. The main characteristics include door-to-door rubbish pickup, lane and road cleaning, waste segregation, composting of wet waste, and the establishment of end-of-life spaces is a significant project that the government has initiated. Over 500 individuals used the ZWMC and an excellent to prevent their disposal in landfills.

Keywords: Zero Waste Management Community, segregation, , composting, Solid waste disposal, fermentation, landfills, incineration.

An Analytical Study on Management of Bio-medical Waste in Selected Hospitals of Patna Municipal Ward: A Northern City of India

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The World Health Organization (WHO) considers health as a “state of complete physical, mental, and social well-being and not merely the absence of diseases or infirmity”. In the last few decades, the rapid growth in the urban population with better living standards and demands for better endorsed medical facilities led outnumbering of hospitals in the town without proper planning and management of bio-medical waste (BMW). Large amounts of potentially infectious and hazardous wastes are generated from these hospitals. Indiscriminate disposal and exposure of these BMWs without specific norms like segregation, storage, and management is a serious threat to the environment and human health. The non-availability or shoddy data is a major concern for chalking out appropriate procedures for the remediation of BMW. To investigate the existing bio-medical waste management (BMWM) status, a minor research with a two-step analysis methodology was performed in a few municipal wards of Patna City. The Participatory Urban Appraisal (PUA) methodology was applied to estimate the context and the organization of BMW management as well as to get a clear view of the work culture of the municipal authorities and problems of local residents, staff, and administration of the hospitals. The sampling of data was in the form of structural questionnaires in which 104 health workers, 38 doctors, and 62 nurses from different hospitals participated. The results revealed that the healthcare sectors are still struggling with proper planning & management of generated bio-medical wastes due to non-compliance with the existing guidelines of the Government of India. Based on the survey carried out, appropriate management plan for BMW was suggested.

Keywords: WHO; Patna City; Sampling: Bio-Medical Waste, Participatory Urban Appraisal.

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Waste Utilization and Recycling

Electrocatalytic Upgrading of Furfural, a Platform Chemical from Hemicellulose-rich Feedstocks

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The development of a multifunctional electrocatalyst for biomass-derived platform molecules can diversify the product outcome of biorefinery and strengthen its role in the current petroleum-dominated economy. This study demonstrated how the structural phase distribution of a transition metal dichalcogenides (TMDs) catalyst, MoS_2, can be exploited to control the reaction pathway between electrocatalytic hydrogenation (ECH) and electrocatalytic dimerization (ECD) of furfural. A series of carbon supported MoS_2 electrodes with different structural phase distributions, 1T and 2H, were prepared and fully characterized. The electrodes displayed good stability and successfully converted over 98% of furfural to target products. Under optimized conditions, the 1T-rich MoS2 electrodes were highly selective in producing an ECH product, furfuryl alcohol, with a selectivity of 94.4% over the ECD product, hydrofuroin, whereas the 2H-rich MoS_2 electrodes achieved up to 42.7% selectivity for an ECD product. Mechanistic investigation with underpotential hydrogen desorption (HUPD) studies and density functional theory (DFT) calculation revealed that 1T and 2H-MoS_2 played very different roles during the electrolysis of furfural. The HER-active 1T phase was less friendly to furfural's adsorption than the 2H phase, but its ability to generate adsorbed hydrogen (Hads) provided the necessary component to complete the ECH process. The 2H phase was a better platform for furfural and its radical intermediate adsorption, but its Hads deficient surface led to more ECD product. This study expands the opportunity to design multiphasic materials to control product selectivity during the electrocatalytic reduction of aldehyde compounds.

Keywords: MoS_2, Phase effect, Electrocatalytic hydrogenation, Furfural, Biomass upgrading.

Three Dimensional Activated Carbon Derived from Luffa Fiber Biomass for Capacitive Energy Storage Application

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ABSTRACT. Agricultural biomass waste derived three dimensional (3D) activated carbons have a great interest in capacitive electrical energy storage devices such as supercapacitors (SC) due to their low cost and abundance with interconnected, multi-channelled, and electrically conductive porous structure. In the present work, the 3D activated carbon was prepared by carbonization of Luffa fiber biomass waste, collected from a local agricultural farm, through hydrothermal technique with a chemical activation process at 800 ºC in Argon atmosphere. The prepared activated carbon honeycomb-like morphology with more voids and a surface area of 138 m^2/g. The degree of carbonization of the Luffa fiber was identified by Raman Spectroscopy and X-ray photoelectron spectroscopy techniques. Moreover, the electrochemical properties of the prepared activated carbon were evaluated in the typical three electrode system in 3 M KOH aqueous electrolyte using Cyclic voltammetry (CV), galvanostatic charge discharge (GCD), and electrochemical impedance spectroscopy (EIS) techniques. The current-voltage profile demonstrates the as-prepared electrode material shows a rectangular-like shape, which indicates the electric double layer capacitance (EDLC) characteristics in the potential window -1.0 to 0.0 V vs Ag/Cl. The value of specific capacitance 909 F/g at the current density of 1A/g was calculated from GCD curve. In the electrolyte solution, the electrical conductivity of the activated carbon was very less when compared with other activated carbons from different biomasses. Finally, we assembled asymmetric SC using the activated carbon (EDLC material) as a negative electrode material and Nickel-copper cobaltite (NiCuCo_2O_4 - pseudocapacitive material) as a positive electrode material PVA/KOH gel electrolyte and the performance of the device was tested CV, GCD, and EIS techniques. From CV curves at different scanning rates (0 to 1.4 V) and it was evident that both EDLC and pseudocapacitive behaviour was exhibited. The specific capacitance of the device was calculated as 220 F/g@ 1A/g with an energy density of 65 Wh/kg at a power density of 500 W/kg. This energy density was relatively higher than the similar type of the SC already reported. From the results, it has been concluded that the 3D activated carbon network from naturally abundant biomass can be an effective material for high energy density capacitive energy storage devices and also it would contribute to the sustainable circular economy.

1. Introduction

Among several energy storage devices, supercapattery has attracted significant interest in the recent past due to its fast dynamic response, high-power density, and excellent cycle life [1,2]. Based on the energy storage behavior, the electrodes of supercapacitors are classified as materials based on traditional carbon and transition-metal based materials. The earlier supplies of electrical energy by electrostatic aggregation of surface charge, whereas the terminal is associated with a fast reversible faraday reaction on the surface, ensuing in high energy density [3,4]. Nevertheless, for many transitions metal-based electrodes, high energy density is attained by offering cycling lifetime and power density, which delays their significant application in electronic trades. Hence, many researchers focused on supercapacitors with efficient cycle life and high-power density electrodes [5]. The SC, excellent electrochemical energy storage, integrates the high energy storage ability of conventional batteries with the high-power producing capacity of supercapacitors [6]. Many probes were developed in the hybrid energy storage device. So far, various reports have classified their work to be capacitive, which revealed the battery-like performance due to the misleading of pseudo capacitors. The new term supercapattery was made to identify the electrochemical properties between battery-like and capacitor-like hybrids. As called asymmetric supercapacitors, which are fabricated with redox material as positive electrodes and carbon-based as negative electrodes were misnamed and should be supercapatteries [7]. The activated carbons have emerged as a promising candidate for supercapacitor electrodes due to their high surface area, low cost, high electrical conductivity, chemical stability, and wide availability. These properties make activated carbons a reliable and high-performance solution for energy storage and delivery, with potential applications in various fields, such as electric vehicles, renewable energy systems, and portable electronics. Nickel cobaltite (NiCo^{2}O^4) has received high attention for its energy storage applications because of its low cost, free-environmental in nature, especially high theoretical capacitance, and multi-talent chemical states (Ni^{2+}/Ni^{3+} and Co^{2+}/Co^{3+}) [9]. The current work describes a solid-state device for energy storage encompassing a positive electrode prepared from nickel-copper cobaltite, whereas luffa sponge-derived activated carbon serves as a negative electrode. After extensive characterization of the device, its performance concerning the current density and the retention capacity after prolonged repeated cycles will be investigated.

2. Experimental section

2.1. Preparation of luffa sponge-derived activated carbon and Electrochemical measurement

Porous activated carbon was prepared from a luffa sponge, obtained from a local market. The sponge was sliced into small pieces, washed with DDW, and then hydrothermally dried at 150 ºC for 12 h. After overnight heating at 100 ºC, the product was crushed using a mortar pestle. The resulting powder was mixed with KOH (2:1) and annealed at 800 ◦C for 2 h at 5 ◦C/min in an Ar atmosphere. The final product was washed a few times with diluted HCl and DDW to remove organic contaminants and dried overnight at 80 ºC, resulting in porous structured activated carbon.The electrical conductivity, charge transportation, and energy storage properties of the prepared electrode materials were studied by using an electrochemical workstation (BioLogic SP-150). Electrochemical measurements of all the prepared electrode materials were studied in three-electrode cell setups such as Pt, Ag/AgCl, and Ni foam-based synthesized materials, which correspond to the counter electrode, reference electrode, and the working electrode, respectively. The 3 M KOH aqueous solution is used as an electrolyte. The working electrode was prepared by the following procedure, the polyvinylidene fluoride (PVDF), acetylene black, and synthesized samples (NCC-5) were at a weight ratio of 10: 10: 80 and evenly mixed with the help of N-Methylpyrrolidone (NMP) solution to form a slurry. The prepared slurry was coated on one surface of the pre-cleaned Ni foam and dried in a vacuum oven overnight at 100 ºC. Cyclic voltammetry (CV), galvanostatic charge–discharge (GCD), and electrochemical impedance spectroscopy (EIS) were performed. The specific capacitance and specific capacity of the prepared electrodes are estimated by the GCD discharge time.

2.2. Fabrication of solid-state supercapattery

The assembling of solid-state SC based on disc-shaped NF with a 1 cm radius was used instead of square-shaped NF (anode and cathode). In the fabrication process of SC, a solid-state gel of PVA/KOH was coated on the surface of Whatman filter paper and then placed between the two thin Pt discs (current collector) of a Swagelok-type cell. The BioLogic SP-150 instrument was used to perform electrochemical studies. The electrochemical properties of solid-state supercapattery were studied by CV, GCD, and EIS techniques. The real-time SC was fabricated by the as prepared NCC-5 and the activated carbon in PVA/KOH gel electrolyte.

3. Result and Discussion

The structural characteristics and the phase purity of as prepared activated carbon were examined by powder X-ray diffraction pattern. This XRD pattern confirmed the non-crystalline nature as shown in Fig. 1 (a). The major diffraction peaks of 24.75º and 43.50º are associated with activated carbon as the lattice planes are (002) and (011), respectively [10]. The lateral size (L_a) and stacking height (L_c) characteristics of the activated carbon (LPAC) produced from the biomass of luffa sponges were determined from the X-ray diffraction (XRD) patterns using the Scherrer equation. The Scherrer constants, $k_c = 0.9$ for the diffraction planes of (002) and (011), were used to calculate L. The wavelength of the X-ray employed was 0.15 nm the full width at half maximum of the diffraction plane (002) and (011). The calculated L_a and L_c are 184 nm and 240 nm, respectively. The structural defects and disordered nature of carbon-based materials were analysed by Raman spectroscopy.The two main peaks are attributed to D and G [11]. As shown in Fig. 1(b), the G band represents the 1st-order Raman

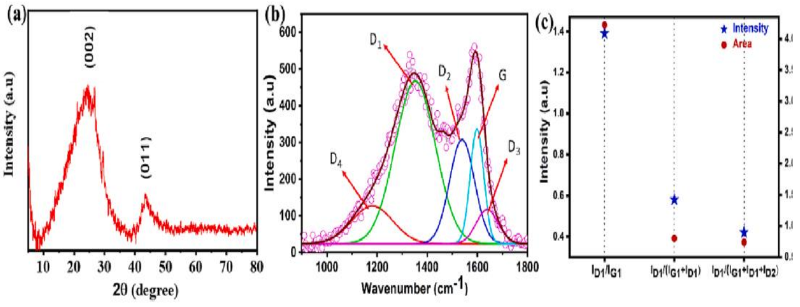

Fig. 1. (a) XRD pattern, (b) Raman spectra for activated carbon, and (c) calculation of the different ratios involving G1, ID1, and ID2 bands.

peak and carbon atoms bonded in hexagonal lattices at 1592 cm^{-1} for sp^2 hybridization (C–C bond stretching of all pairs). However, this correlation can be used in different forms as $(ID1/G)_{A,H}$ or $(ID_1/(IG + ID_1))_{A,H}$. The A and H indicate that the ratio is based on integrated intensities of peak height. Instead of using the peak height ratio, the $R_2= (ID_1/(IG_1 + ID_1 + ID_2))_{A, H}$ equation is taken into account and the intensity values are obtained from the integration of the D and G bands [12]. The Raman spectra of activated carbon samples were deconvolved into G and D1 peaks in the first order by fitting as a sum of the Lorentzian-shaped peaks of G, D1, D2, and D4 bands and the Gaussian-shaped D3 band. Fig. 1(b), shows the fitted curve of activated carbon. Three separate forms are used to characterize carbonaceous materials with distinct absolute values. The FWHM variations are well fitted by comparing the three distinct forms peaks, we determine that the variations of FWHM are fit. Fig. 1 (c) displays the relationship of the ID1/G1 form, ID1/(IG1 +ID1)A, H, and ID1/(IG + ID1 + D2). The resulting data indicated that the activated carbon was successfully formed, and its structure was altered after activation. Fig. 2(a–c) displays the FE-SEM images of various magnification. images of as-synthesized activated carbon. From this image, pores are noticeable and have more voids (honeycomb-like morphology) and irregular shapes which are helpful for the ion/charge storage in EDLC type- based material. Moreover, the huge number of pores to enhancing the high-rate charge storage performance of supercapacitor applications.Furthermore, the average pore size of ~2 to 3 µm. The as-prepared luffa sponge biomass-derived activated carbon (LPAC) can analyze the various electrochemical studies of cyclic voltammetry, galvanostatic charge–discharge, and electrochemical impedance spectroscopy was evaluated using 3 M KOH aqueous electrolyte. The current–voltage profile demonstrates the as-prepared LPAC/Ni foam electrode shows a rectangular-like shape, which indicates the EDLC characteristics. Fig. 3(a) displays the CV profile of LPAC/Ni foam at various scan rates. Moreover, while increasing the scan rate the peak current is increased, and still, the rectangular shape was retained at a higher scan rate indicating good EDLC characteristics and confirming the superior material performance. Similarly, the charge–discharge profile establishes the linear and symmetric shape of the derived activated carbon at different current densities of 1 A g^{-1} to 10 A g^{-1} as shown in Fig. 3(b). From this GCD profile, we confirmed the EDLC characteristic behaviour. Furthermore, we concluded that discharge time was decreased while increasing the various current densities this behaviour might be due to inadequate time to penetrate the ions at higher current densities. Fig. 3(c) shows the specific capacitance values of 909.0, 664.6, 560.3, 506.8, 458.4, 415.6, 400.5, 360.9, 339.1 and 315.0 F g^{-1} corresponding current densities of 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 A g^{-1}, respectively. The electrical conductivity was investigated through electrochemical impedance spectroscopy in the frequency range of 0.01 Hz to 1 MHz at 5 mV AC amplitude. Fig. 3(d) shows the Nyquist plot of LPAC/Ni foam that implies the lesser equivalent series resistance (ESR) and solution resistance (R_s), and it demonstrates superior electrical conductivity.

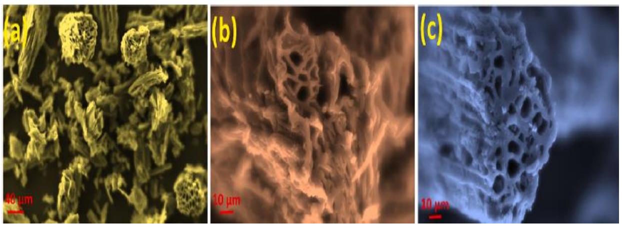

Fig. 2. (a-c) FE-SEM images for activated carbon at different magnifications

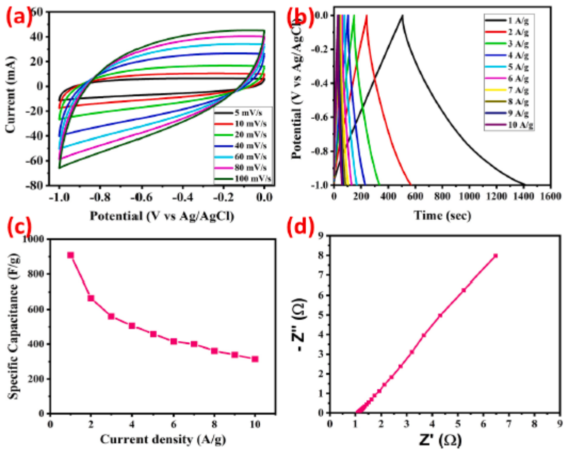

Fig.3. (a) CV curves of the LPAC /Ni foam electrode at different scan rates, (b) GCD curves of the LPAC Ni foam electrode at different current densities, (c) specific capacitance vs current density curve for LPAC /Ni foam electrode, and (d) Nyquist plot of the LPAC/Ni foam electrode.

The real-time application of SC was constructed using the as prepared nickel copper cobaltite-5 nanomaterial (NCC-5) as the positive electrode and luffa sponge-derived activated carbon as a negative (LPAC) for high-performance energy storage application as shown in Fig. 4(a). The constructed SC was tested by CV, GCD, and EIS under the PVA/KOH gel electrolyte. Fig. 4 (b) shows the cyclic voltammetry of the NCC-5 electrode (0.0–0.4 V) and LPAC (-1.0 to 0.0 V) at the same scan rate of 40 mVs^{-1}, respectively. Fig. 4(c-d) shows the typical CV curves of the NCC-5//LPAC SC at various potentials and different scan rates ranging from 0 to 1.4 V. The SC exhibited CV curves and it was evident that both electric double-layer capacitance and pseudo capacitance occur. The peak current was increasing while increasing the scan rates with the uniform quasi-rectangular shape that demonstrates the hybrid charge storage features and established the higher electrochemical performance as shown in Fig. 4 (d). Fig. 4(e-f) shows GCD performance at different voltage windows and current densities, with the supercapattery achieving the 1.4 V cell potential to provide the highest energy and power density. The galvanostatic performance of SC devices at different current densities establishes well-defined hybrid charge storage characteristics.

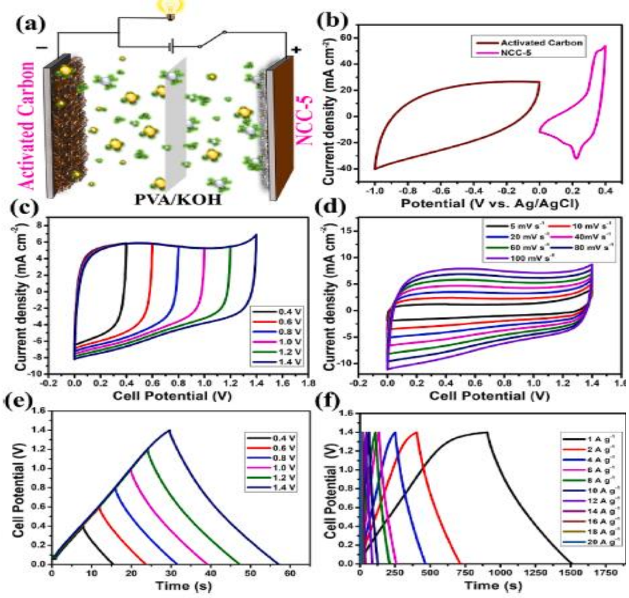

Fig. 4. (a) Systematic illustration of solid-state SC, (b) CV curves of assembling of a positive and negative electrode, (c) cyclic voltammetry performance at various voltages, (d) cyclic voltammograms at different scan rates, (e) GCD performance at various voltage, and (f) GCD performance at different

4. Conclusion

In brief, a one-step a chemical method were used to synthesize and luffa sponge biomass-derived activated carbon (LPAC) as cathode and $NiCuCo_2O_4$ as a anode for the fabricated supercapattery. The physicochemical properties of the synthesized electrode materials were analyzed by XRD, FTIR, FE-SEM, TEM, XPS, and BET, respectively. The anode delivered a high specific capacitance of 1048 F g^{-1} at 0.5 A g^{-1} with excellent rate performance and cycling stability. The luffa sponge biomass-derived activated carbon (LPAC) material (cathode) shows a high specific capacitance of 909 F g^{-1} at 1 A g^{-1}. The assembled NCC-5//LPAC supercapattery also exhibits remarkable cyclic stability up to 10,000 cycles and a high energy density of 65 W h kg^{-1} at a power density of 500 W kg^{-1} in the potential window of 0–1.4 V.

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Efficient Recovery of Phosphate from Aqueous Solution by Calcium Peroxide Decorated Iron-Rich Sludge Carbon: Adsorption Performance and Mechanism

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A large amount of waste containing phosphorus is produced in human production and life, which results extensive waste of phosphorus resources, and also leads to the formation of eutrophication of receiving water due to excessive phosphorus. In addition, a large amount of iron-rich sludge is produced in the process of coking wastewater treatment, which is currently treated as hazardous waste, and the targeted recycling technology is very lacking. Based on the environmental protection concept of waste treatment waste, this study calcined iron-rich sludge from coking wastewater treatment process into iron-rich sludge carbon, and loaded with calcium peroxide in appropriate proportion to prepare the function material (FeSC-Ca) for phosphorus recovery in wastewater. The results showed that FeSC-Ca had high phosphorus adsorption performance in a wide pH range (4.5~9.5) and under different water quality conditions, conforming to pseudo-second-order kinetics, and the maximum adsorption capacity reached 48.39 mg/L (calculated by P). The characterization analysis results showed that $Ca_5(PO4)_3(OH)$ and CaHPO4 precipitate were mainly formed in the phosphate adsorption process. In addition, CaO_2 hydrolyzed to produce H_2O_2, which accelerated the reaction speed and promoted the formation of iron-containing secondary minerals, thus further improving the adsorption performance of phosphorus. The research results are expected to provide theoretical and technical support for sludge resource utilization and phosphorus recovery.

Keywords: Iron-rich sludge carbon, Calcium peroxide, Phosphorus recovery, Resource utilization, Secondary iron ore.

Efficient Catalytic Hydrogen Production from FA over Pd Nanoparticles Loaded on Chitosan Biochar at Room Temperature

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The combustion of non-renewable fossil fuels leads to an increase in CO2 emissions and poses a serious environmental problem such as glacial melting, extreme weather occurrence and ocean acidification. Replacing fossil fuels with sustainable, clean energy is urgent to achieve carbon neutrality. Hydrogen with a high energy density (120 MJ Kg^{-1}) is a promising clean energy carrier and has already widely used in fuel cells. However, the safe and efficient storage and release of hydrogen has been a pressing challenge. Formic acid (FA) with high hydrogen content (4.4 wt%) has been extensively studied as a promising carrier for hydrogen storage. Designing highly efficient, low-cost and recyclable catalysts for FA dehydrogenation is a major challenge. Herein, N-doped biochar was prepared as a carrier for metallic Pd using N-rich chitosan as a precursor, the heterogeneous catalysts with excellent dehydrogenation performance were synthesized. TEM characterization showed that the Pd size of catalysts were mainly distributed between 2.2 and 2.6 nm. The small particle size and uniform distribution of Pd enabled the catalyst to achieve 100% conversion of formic acid to hydrogen in a short time. XPS analysis showed that the carrier was rich in pyridine N, which is benefit on the electron transfer between the N element and Pd. Strong metal-carrier interaction greatly enhanced the catalytic performance of catalysts. The initial TOF of the catalyst reached 615 h^{-1} with an activation energy of 39 KJ mol^{-1}.

Keywords: Hydrogen production, FA dehydrogenation, Pd-based heterogeneous catalyst, Chitosan biochar support.

Evaluation of Carbon Emission and Economy of Carbon Dioxide Mineralization for Building Materials Technology

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China's greenhouse gas emissions, mainly carbon dioxide (CO_2) is huge. The rapid peak CO_2 emissions and neutralization require the timely transformation of energy-intensive industries and the rapid deployment of new low-carbon technologies. Among them, the building materials with Portland cement industries are under great pressure of emission reduction and difficult to carbon removal. CO_2 mineralization combined with industrial solid waste resource utilization technology has opened up a path of large-scale energy saving and carbon reduction for building materials industry with lower cost attribute. Because of long asset life and high degree of marketization of products, early deployment of CO_2 mineralization has obvious economic benefits. In recent years, many related pilot projects have been reported one after another, promoting the improvement of technical maturity. However, for commercialization, this kind of technology still faces the following problems: (1) mismatch between raw materials and carbon sources; (2) uncertainty in operating costs; and (3) uncertainty in carbon prices. The research of the existing demonstration projects clearly points out the opportunities and effects of the reduction of operating costs and carbon price on the landing of the industry. Therefore, in principle, carbon pricing and further incentive policies are necessary measures for the implementation of CO_2 mineralization for building materials technologies. In this paper, three typical CO_2 mineralization for building materials technologies, namely CO_2 mineralization for precast, CO_2 mineralization for enhancing recycled aggregate and CO_2 mineralization for ready-mixed concrete, are systematically evaluated for the Life-cycle CO_2 emission reduction potential and technical economy. Here, compared to conventional technology, precast blocks, recycled aggregate, and ready-mixed concrete can achieve life-cycle carbon emission reduction of -195.34 kg CO_2-eq/m^3 (-120%), -64.73 kg CO_2-Eq/m^3 (139%), and -73.35 kg CO_2-Eq/m^3 (25%). While, the operational cost has a slight advantage, which can effectively reduce the technical cost by reducing the content of cement and using the lightweight aggregate. CO_2 mineralization technology can not only enable the carbon removal of building materials, but also have a significant premium and technological competitive advantage in the future carbon trading market and carbon neutrality policy scenario. Compared with the traditional process, the CO_2 mineralization process can achieve additional benefits of ~100 yuan/m^3, ~38 yuan/m^3, and ~19 yuan/m^3 in precast blocks, recycled aggregate and ready-mixed concrete products, respectively. This work can provide reference for the third-party decision-making of technological transformation and new technology commercialization investment.

Keywords: CO_2 mineralization, Industrial solid waste, Building material, Life-cycle CO_2 emission, Technical economy.

Sustainable Production Of Jet-Fuel Range Hydrocarbons And Carbonaceous Materials From Biowaste Catalytic Co-Pyrolysis

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Biomass provides a renewable and sustainable source of energy with the advantages of being carbon neutral and available in abundance. Bio-oil derived from algae thermochemical conversion shows high quality and conversion efficiency. Carbonaceous material is of interest in carbon capture and sequestration, green chemistry and material science due to its highly recalcitrant properties and benefits in climate change. Thus, this study investigated the production of jet-fuel range hydrocarbons and carbonaceous materials from in-situ catalytic co-pyrolysis of algal biomass and animal manure in CO_2 atmosphere. This study highlighted a sustainable treatment of algal bloom and animal manure with enhanced energy recovery and high-quality products. The results showed an enhancement of CO and H_2 production using CO_2 as pyrolysis medium. The major presence of $Ca_xMg_yCO_3$ in animal manure resulted in a higher production of aliphatic hydrocarbons in the pyrolysis of algal bloom. The presence of Mg_xFe_yK in algal biomass contributed to a large surface area of carbonaceous materials in the pyrolysis of animal manure. Catalytic co-pyrolysis is of interest in achieving sustainable waste management. The technological approach can be applied to other types of bioresources. Thus, this work provides a feasible approach in the conversion and management of marine and biowaste resources.

Keywords: Algal biomass, Biowaste, Catalytic co-pyrolysis, Jet-fuel range hydrocarbons, Carbonaceous materials.

Blockchain-based Artificial Intelligence of Things Nutrient-Rich Food Waste Selection Framework for Food Waste-derived Medical Textiles

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Medical textiles usage has multiplied over the decade. In the last two years, the use has exponentially increased due to Covid-19 across the nations creating supply chain-related issues and excessive resource consumption. This triggered sustainability-related questions highlighting the need for a sustainable resource for producing medical textiles. Very recently, researchers in the field suggested the food waste to fiber concept showing an excellent alternative for producing medical textiles. Nevertheless, the key concern here is the food waste selection with specific nutrients that maximizes the overall yield. Considering this as a serious concern, we explored a digital solution, i.e., the blockchain-based artificial intelligence of things (BAIoT) nutrient-rich food waste selection framework for food waste-derived medical textiles. This study provides conceptual proof and opportunities for leveraging BAIoT protocols in the biorefinery. We also discussed the BAIoT-enabled sustainable and transparent sourcing of food waste and the potential for creating the life cycle inventory of the food procured.

Keywords: Blockchain for waste management, Artificial intelligence of things, Nutrient-rich food waste, Food waste selection framework, Food waste-derived medical textiles.

Optimization of Wet Waste Pre-treatment Process and the Removal of Inert Fine Particles

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The amount of wet waste in Shanghai was 9,000 tons each day after the implementation the policy of waste sorting in China. It can be treated by the method of anaerobic digestion. While the poor performance of pre-treatment process has limited the application of anaerobic digestion. This paper takes a wet waste anaerobic digestion plant in Shanghai as a case study. Several measures were proposed to improve the performance of pre-treatment process. Firstly, replacing the pre-treatment with double-screw feeding to reduce the burden on the large material sorter based on the balance analysis of organic carbon in each processing unit. Secondly, controlling the moisture content in the material sorter below 70% to prevent the loss of organic matter. Thirdly, combining fine separator and pulper to reduce the loss of organic matter with large particle size. Meanwhile, the software of COMSOL Multiphysics was used to simulate the flow of kitchen waste slurry in a Venturi-like design pipeline. The results show that there is obvious inert accumulation in the 5 to 6 meters of the inert particle pipe section. The deposition simulation is carried out for different working conditions and different inert particles, and the initial concentration and the particle size of the inert particles have a great influence on the settlement effect. The optimized conditions in velocity, the initial concentration of inert matter, density and the diameter of pipeline was 1m/s, 5%, 1500kg/cm^3 and 8 mm, respectively. The proposal of this research scheme can effectively optimize the performance of wet garbage anaerobic digestion process.

Keywords: Wet waste, Anaerobic digestion, Pre-treatment, Inert particulate matter, Numerical simulation.

Employing ASPEN Plus for Process Modellng of Syngas Production from Municipal Solid Waste

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ABSTRACT. The mounting scale of global municipal solid waste (MSW) generation has triggered a compelling shift towards harnessing the untapped potential of waste recycling as an abundant and sustainable source of renewable energy. Waste to Energy (WtE) technologies offer a cost-effective and environmentally friendly solution to produce clean energy. The aim of this research work is to model the gasification process via simulation using ASPEN plus v10.0. Using simulation methodology and to find an optimum operating condition for gasification so as to increase the quantity of syngas produced and reduce the ash formation.A kinetic free equilibrium model using ASPEN Plus simulated the gasification of MSW, studying the impact of temperature and Steam/MSW (S/M) ratio on syngas yield. Optimum conditions for MSW-to-fuel conversion were determined, revealing that high syngas yields were achieved at temperatures above 800°C and S/M ratios in the range of 0.2-0.4. Specifically, gasification at an S/M ratio of 0.3 and 850°C led to increased syngas production and reduced CO_2 emissions. These findings have implications for efficient waste management and renewable energy generation.

Keywords: *Simulation; Syngas; Gasification; Carbon emission*

INTRODUCTION

The increasing global generation of municipal solid waste (MSW) has led to a growing interest in using waste as a renewable energy source. Waste management practices have evolved to include energy recovery and recycling techniques. Waste-to-Energy (WtE) technologies, such as gasification, have emerged as environmentally friendly solutions for generating clean energy while reducing dependence on imported oil (Hemidat et al.,2022).

Gasification is a highly effective WtE method that converts MSW into fuel gas in a low-oxygen environment. This process produces gases like carbon monoxide, methane, and hydrogen, which can be used to generate heat and electricity (Mohanty et al., 2021). Gasification offers significant volume and mass reduction of MSW. To optimize the gasification process, a kinetic free equilibrium model has been developed using ASPEN Plus, a popular process simulation software. The model examines the impact of temperature and Steam/MSW (S/M) ratio on syngas yield (Moretti et al., 2022). The results suggest that temperatures above 800°C and S/M ratios between 0.2-0.4 yield the highest syngas production. Gasification at an S/M ratio of 0.3 and a temperature of 850°C resulted in increased syngas quantities and reduced CO2 emissions (Vikram et al., 2022).

The study also explores the potential of blending MSW with rice husk in an 80/20 ratio and analyzes its effect on the product composition. Waste biorefineries, which convert organic MSW substances into biofuels and specialty chemicals, are highlighted as sustainable solutions for energy and resource conservation. The use of ASPEN Plus simulations provides valuable insights into process behavior, facilitating the evaluation and optimization of waste gasification. Simulation-based approaches enable researchers, academics, and students to explore sustainable MSW management strategies and optimize WtE technologies to minimize environmental impact. Through these simulations, the aim was to optimize the gasification process conditions and analyze their effects. The results and their implications are further discussed in subsequent chapters.

Gasification stands out among various WtE technologies due to its lower emissions and water usage compared to conventional coal-fired power plants. This report focuses on modeling the gasification process using ASPEN Plus v10.0 to simulate and monitor product composition and its environmental impacts without depleting resources. The study aims to analyze the effects of gasification temperature and S/M ratio on syngas yield, determine optimal operating conditions for increased syngas production and reduced ash formation, and investigate the impact of blending MSW with rice husk.

This study encompasses a detailed comparison of various WtE technologies and the selection of appropriate methodology for energy recovery from waste. In addition to that, new arenas would be explored for optimization of these technologies so as to reduce the consequences caused during waste processing.

MATERIAL AND METHODS

Process Assumptions

The ASPEN Plus simulation of MSW gasification assumes a feed rate of 1000 kg/hr, isothermal conditions, and a steady state process. The ash is considered inert, while consistent pressure and temperature are assumed inside the gasifier. Heat and pressure losses are neglected, and the product is assumed to have no unconverted carbon. These assumptions provide a framework for modeling and analyzing the MSW gasification process, ensuring efficient and simplified calculations.

Process Description

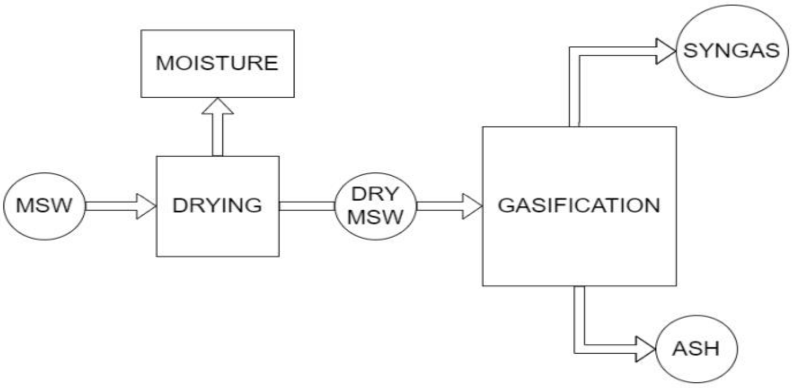

Fig 1: Block-diagram for syngas production via gasification of MSW

The gasification of municipal solid waste (MSW) was simulated using ASPEN Plus v10.0 process simulator. Non-conventional components were defined for modeling the MSW sample and ash. Enthalpy and density calculations utilized the HCOALGEN and DCOALIGT models, while the Peng-Robinson equation of state with Boston Mathias alpha function (PR-BM) estimated physical parameters accurately.

The process flowsheet for MSW gasification involved several units. The feedstock, initially at 40 °C, underwent drying in a dryer at 100 °C to remove moisture. A separator block (SEP1) was used to separate the moisture, and the dried feedstock was then directed to the combustion unit (B3). In this unit, the dried MSW was heated at temperatures ranging from 400 °C to 1000 °C. The resulting mixture was fed into the gasifier (B4), where further decomposition occurred in the presence of steam, producing syngas and ash. Separation of ash was achieved using the SEP2 unit, while the product gases were collected from the top end. The quantity of syngas in the product gas depended on factors such as gasification temperature, steam-to-MSW (S/M) ratio, and any additives blended with the feedstock (Varjani et al., 2022).

The simulation involved three scenarios: (1) examining thirteen temperatures ranging from 400 °C to 1000 °C with a constant S/M ratio of 0.5 to identify the optimal temperature for maximum syngas yield, (2) investigating ten S/M ratios ranging from 0.1 to 1 while maintaining the temperature at the optimum condition, and (3) blending MSW with rice husk in an 80/20 ratio and conducting gasification at the determined optimal conditions (Hadiya et al., 2022).

RESULTS AND DISCUSSION

The gasification of MSW was simulated using ASPEN Plus v10.0, analyzing the effects of temperature, S/M ratio, and blending with rice husk. Optimal conditions for maximum syngas yield were found at temperatures above 800 °C and S/M ratios of 0.3-0.4, resulting in a syngas content of about 88.82%. Higher steam input increased carbon dioxide emissions. Blending MSW with rice husk (80/20) increased H_2S release but lowered carbon dioxide emissions, with a syngas content of 79.22%.

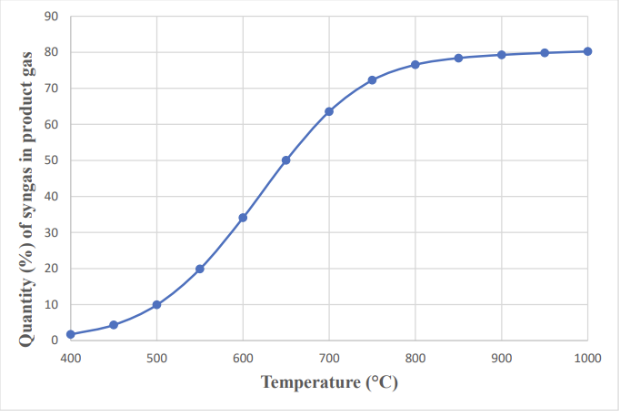

Fig 2:Variation in amount (%) of syngas in product gas with temperature

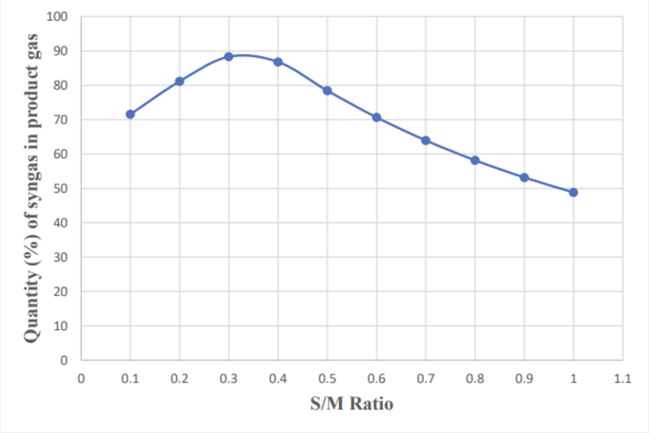

Fig 3: Variation in amount (%) of syngas in product gas with changing S/M ratio

Similar findings were supported by previous studies on wood and MSW gasification. It is advisable to maintain S/M ratios between 0.2-0.4 and temperatures above 800 °C for optimal output, with slight variations possible under real operating conditions. These results contribute to evaluating WtE technologies and optimizing the conversion of MSW into valuable products.

Eikeland et al. (2015) simulated the gasification of birch wood using CSTR models and the Gibbs reactor. It was unfolded that the maximum variation in product gas composition was found in the temperature range of 800 °C to 1000 °C which supports our results. Deng et al. (2019) modelled the gasification of MSW in the temperature range of 550 °C to 1000 °C at the S/M ratio of 0.4. They found that above 800 °C the syngas component in the product gas becomes stable and monitored that while moving from the S/M ratio of 0.1-1 the yield of H_2 and CO increases up to the value of 0.4 (optimum value) and then starts decreasing, which supports our claim of the maximum yield lying in the range (optimal) of 0.3-0.4 S/M ratio. Acar & Boke (2018) simulated the gasification of rice husk in the presence of steam, it showed that the yield of syngas increased and observed a fall in CO_2 emissions with the rise in temperature, supporting our findings.

CONCLUSIONS

The modeling of the process of gasification in ASPEN Plus is helpful for studying the chemical make-up of the gas that is produced. A detailed comparison of various WtE technologies in practice was done portraying the merits, and demerits along with their environmental impacts, and the most appropriate alternative was simulated for converting MSW to value-added products. The gasification of MSW was simulated under varying operating conditions using ASPEN plus v10.0 and the effects of changing temperature, S/M ratio, and blending with rice husk were analyzed thoroughly, yielding fruitful results.

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Performance Evaluation of Interlocking Paving Bricks Incorporating Waste Plastic as Alternative Aggregates

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Recycling is now necessary due to the problems caused by plastic waste's ongoing growth. Globally, 76% of the total plastic produced has been discarded as waste and less than 10% of this waste is recycled. Plastic can be recycled mechanically, chemically, or thermally, while mechanical recycling is still the most popular method. Without the requirement for chemical alterations or breakdown, mechanical recycling entails grinding and/or shredding with the potential for reuse as replacement materials. However, plastic waste still contributes to landfill and water pollution. Therefore, the purpose of this study is to assess how well waste plastic performs when combined with various aggregates for paving bricks. The mechanical properties of paving bricks with fully conventional aggregate as the control, paving bricks with coarse aggregate made of plastic waste, and paving bricks with fine aggregate made of plastic waste will be investigated using compression strength, flexural strength, freeze-thaw, absorption resistance, and slip tests. Additionally, three types of plastic waste (low-density polyethylene, polystyrene, and polyethylene terephthalate) will be put to the test to determine which type performs the best in terms of compressive strength. The acquired results will be contrasted with the standard PB's structural performance. This research will clarify how waste plastic can be used in PB and address the management issue raised by waste plastic disposal.

Keywords*:* Plastic waste; paving bricks; waste management; recycling.

Monitoring of Beach Litter in Waters of Hong Kong Using Aerial Drone

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Litter in the environment is a problem that affects the shores throughout the world. It causes ecological concerns due to its potential impacts on biodiversity and marine wildlife. As indicated by the HKEPD, western and southern waters of Hong Kong receive large amount of marine debris from the Pearl River Delta, especially during wet season. In order to set up a better strategy for marine conservation, quantification of beach litter is vital. In this study, we employed commercial aerial drone to detect litters on twelve ecologically important beaches scattered from north-western New Territories to southern Hong Kong Island, either categorised as coastal protection area or marine park/reserve. Sites were then ranked against their cleanliness for better follow-up action for marine conservation. The developed method will be readily transferred to the public or organisation of interest.

Keywords: Aerial drone, Beach litter, Plastics.

Choline Chloride-Dicarboxylic Acid Based Deep Eutectic Solvents for the Valuable Metal Recovery of Waste Printed Circuit Boards

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Waste printed circuit boards (PCBs) generated are growing exponentially yearly, and their management has gradually become a waste management problem. Until now, most waste PCBs have been landfilled, incinerated, or stored in recycling stations, but these operations may result in severe pollution of the surrounding soils by toxic heavy metals in PCBs, which is potentially harmful to the environment and human health. In addition, it is estimated that PCBs contain 13-26 times higher Cu content than ores. Therefore, PCBs are an attractive resource in urban mining. The recovery of valuable metals from waste PCBs is beneficial not only to environmental protection and health safety but also to renewable metal resources. The mature recycling process of valuable metals from waste PCBs mainly involves hydrometallurgy. The processing routes are typically very energy intensive, need strong acid for leaching, and generate large volumes of solid residues and wastewater, which must be further treated and disposed of in the subsequent operation. Thus, there is a challenging issue in developing clean and environmentally sound processes to realize efficient resource recovery from waste PCBs. Deep eutectic solvents (DESs), as a new type of green solvent, are generally eutectic mixtures formed by a hydrogen bond donor (e.g., carboxylic acid) and a hydrogen bond acceptor (e.g., choline chloride). DESs are involved in a complex hydrogen bonding network, thus resulting in significant freezing point depression compared to the parent compounds. The functional groups contain lone pair electrons, such as Cl^- and carboxyl in the DESs, to preferentially form complexes with metal ions in their oxide compounds and achieve efficient leaching. In recent decades, the great potential of the inexpensive, available, and environmentally friendly DESs to replace inorganic acids, has been demonstrated in the work of metal leaching. This study aims to develop a highly effective and green technique for leaching and recovery of valuable metals from metal powders obtained from the crushing and separation of waste PCBs. Considering the cost and leaching performance in relatively low temperatures, the hydrogen bond receptor is choline chloride ($C_5H_{14}ClNO$), and the oxalic acid ($C_2H_2O_4$), malonic acid ($C_3H_4O_4$), succinic acid ($C_4H_6O_4$) and adipic acid ($C_6H_{10}O_4$) are selected to be the hydrogen bond donor. The leaching kinetics using these DESs on the metal oxides (CuO, Fe_2O_3, ZnO) and elemental metal (Ag) were demonstrated. CuO can be dissolved in DES in the form of $[CuCl_4]^{2-}$, while it is expected that Fe_2O_3, ZnO, and Ag would be insoluble to reach Cu separation. The difference in leaching induced by different dicarboxylic acids can be further explored by density functional theory (DFT) calculations and Fourier-transform infrared spectroscopy (FTIR). The separation procedure of Cu in DES is also investigated by solvent extraction, multi-step precipitation procedures, and the direct addition of pure water to form copper precipitates, such as copper oxalate. In addition, the recovery feasibility using DES on the mixed-phase materials obtained from PCBs is also discussed.

Keywords: Deep eutectic solvent, Dicarboxylic acid, Metal recovery, Printed Circuit Board, Green leaching.

Effect Of 7, 8 Dihydroxycoumarin Protects Environment Toxicity of Cadmium Induced in Zebrafish (Danio Rerio) Embryos

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ABSTRACT. Cadmium (Cd) is one of the precedence pollutants in the environment which menaces the aquatic organisms. Cd is also shown to have deleterious health impairments causing male and female infertility in humans. In this study, we investigated the role of 7, 8- DHC as a potent rescuer of Cd induced toxicity using zebrafish (Daniorerio) model. We induced Cd toxicity in zebrafish embryos at 100-µM concentration and the intoxicated embryos showed a significantly reduced survival, delayed hatching and phenotypic aberrations at 24, 48, 72 and 96 hours post fertilization (hpf). Similarly, Cd intoxicated embryos showed an expressively increased cardiac function (170 ±1 beats/min and 172± 1 beats/min) at 48 and 60 hpf. Furthermore, the rescuing effect of 7,8-DHC was analysed via treatment of Cd intoxicated embryos at dosage dependent manner. At 100 µg, 7,8-DHC showed significantly reduced heart beat compared to the Cd intoxicated embryos. Moreover, 50 and 100 µg of 7, 8-DHC treated groups showed 103± 1 beats/min and 104±1 beats/min respectively.

Keywords: *Cadmium, 7,8 –DHC, Treatment, Toxicity, Zebrafish Embryo.*

Introduction

Pollution due to heavy metal causes severe deterioration of various biological processes in numerous life forms. Particularly, water pollution leads to accumulation of heavy metals in fish and thus hampering its breeding and development. Cadmium (Cd) is a non-essential environmental toxicant heavy metal, earlier known to have no beneficial role in the human body. However, recent studies revealed that its exposure at even low concentration is reported to have severe health impairments such as adversely reduced fertility effect in humans and increased miscarriage during pregnancy etc[1].Globally; this potential toxicant was released into the environment by natural or anthropogenic activities such as mining, refining and the manufacturing and application of phosphate fertilizers.7,8-Dihydroxycoumarin (Daphnetin) as represented in the coumarin derivatives, is an active compound and also a potent anticancer, antioxidant, anti-inflammatory, anti-hypoxic, neuroprotective, anti-proliferative, anti-diarrheal and antiparasitic compound. Daphnetin is shown to have inhibitory effect on kinase activity *in vitro* and to exhibit significant free radical scavenging activity and inhibitory effects on lipid peroxidation.

Material and Methods

Chemicals and Reagents: The chemical compounds 7,8- Dihydroxycoumarin (7,8-DHC) (98% purity), 1,1-diphenyl- 2-picrylhydrazyl DPPH and acridine orange (AO) were purchased from Sigma Aldrich Chemicals (St Louis, MO, USA) and all other chemicals were purchased from Merck India Pvt. Ltd.

Maintenance of Zebrafish and embryo collection: Adult zebrafishes (both sex) were commercially purchased from local aquarium and maintained in a 50 L glass tank at temperature of 26±1°C according to described protocol with 14:10 hrs light/dark photo-cycle. The maintained zebrafish was fed with commercial spirulina micro pellets twice a day. Embryos were obtained from natural spanning of male and female (1:2 ratios) fishes overnight.

Experimental schedule: Zebrafish embryos at 5 hpf (hours post fertilization) were randomly sorted into six groups (n=15) in 6 well culture plates. Embryos maintained in E3 medium alone served as control. Group 2 was served alone only with 100 µM of Cd maintained in E3 medium. Similarly, embryos in groups 3-6 were treated with 100 µM of Cd with different concentrations of treatment compound 7, 8-DHC (1, 10, 50 and 100 µg/ml) in E3 medium for 96 hrs. The observation parameters including survival, hatching, heart rate and developmental changes were monitored at specific time intervals (12, 48, 72 and 96 hpf) under light microscope (MagnusMLXi, Olympus, Japan).

Developmental toxicity screening: The Cd exposure to the developmental toxicity profiles such as survival, embryo histopathological malformation, hatching and heart rate were monitored at 12 hrs time intervals for 96 hrs as described. Survival rate was calculated using the resting state of heart beat and the morphological deformities were studied.

Statistical analysis: All experiments were conducted in triplicate and the data values were represented as mean ± SEM. The IC50 and hypothesis testing such as one way analysis of variance by ANOVA by Dunnett's test were performed to determine the statistically significant differences ($P<0.05$) between the means by using graph pad Prism, version 5.0 (San Diego, USA).

Results

Effects of 7,8-DHC in survival, hatching and Heart beat rate on Cd intoxicated embryos:

A significant reduction in the survival rate of the embryos approximately around 60% was observed in Cd intoxicated embryos as observed in the control Cd treated group (Fig.1A). However, co-treatment with different concentrations of 7,8-DHC (1, 10, 50 and 100 µg) significantly retained the survival rate to 50-90% and at concentration of 100 µg, 7,8-DHC showed maximum survival of zebrafish embryos when compared to 100 µM Cd at 96 hpf (Fig.1A).

Fig.1A

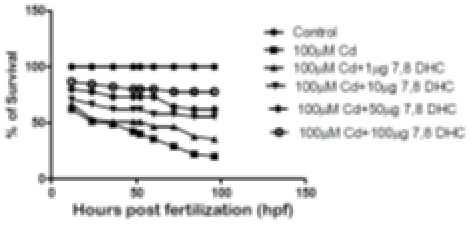

Fig.1B

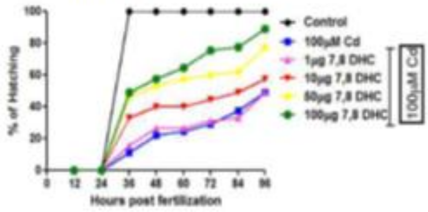

Fig. 1A: Influence of 7, 8-DHC on survival of zebrafish embryos after exposed to Cd toxicant. Experiments were performed in triplicate and the values are represented as mean ±SEM.

Fig.1B: Effect of 7,8 –DHC on hatching success of zebrafish embryos after exposed to Cd toxicant. Experiments were performed in triplicate and the values are represented as mean ±SEM.

Delayed hatching were observed in embryos exposed to Cd relative to the control group whereas the hatching rate increased under the presence of increasing concentrations of 7,8-DHC (Fig.1B). The overall inference of the assay is that the higher concentration of 7,8-DHC (100 µg) yields the higher hatching rate as observed as the control group. Only 54.3% of the Cd group came out of their chorines while the increased under the presence of increasing concentrations of 7,8-DHC (Fig.1B).

Fig.2A

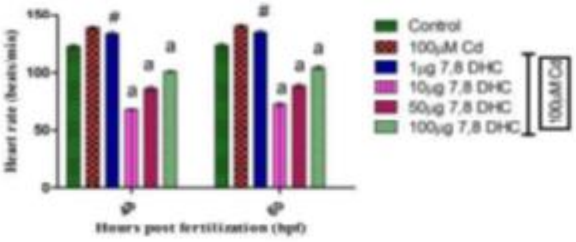

Fig.2B

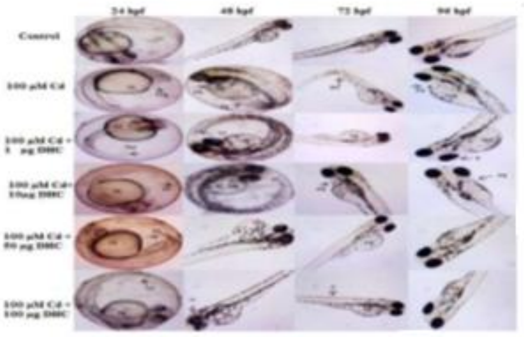

Fig.2A: Heart beat rate in zebrafish embryo exposed with Cd and Co-treated with 7, 8-DHC (1, 10, 50 and 100 µg/ml)at 48 and 60 hrs time intervals. Values represent the mean ± SEM for three replicates.

Fig. 2B: Microscopic analysis of zebrafish embryos pre-exposed to Cd intoxicant and co-treated with varying concentrations of 7, 8 –DHC for 96 hpf (Magnification x4).

The overall inference of the assay is that the higher concentration of 7,8-DHC (100 µg) yields the higher hatching rate as observed as the control group. Only 54.3% of the Cd group came out of their chorines while the percentage of hatched embryos significantly increased to 72.9, 86.2 and 93.3 % for the 10, 50 and 100 µg 7,8 –DHC group respectively.

The heart rate regulatory effect of 7,8 –DHC on zebrafish embryos intoxicated with Cd at specific time interval 48 hpf and 60 hpf exhibited normal heart rate (122 ±1.2 beats/ min) without any lesions of abnormalities as in control. In contrast, Cd induced groups (100µM) exhibited significantly ($P<0.05$) increased heart rate (138 ±0.8 beats/min) along with a severe bradycardia noticed at 48 and 60 hpf when compared to control. However, 7,8-DHC (1, 10, 50, 100 µg) treated embryos showed significantly ($P<0.05$) decline in the heart rate (134 ± 1.5,68 ± 0.5,86 ±1.52 and 101 ±0.5 beats/min) respectively when compared to Cd group whereas 100 µg of 7,8– DHC treatment showed maximum normalizing effect on heart rate of zebrafish embryos at 60 hpf when compared with other doses, but not significant with each other. Hence, the above results depict the protective effects of 7,8 –DHC on Cd exposed zebrafish heart rate (Fig.2A).

Developmental toxicity screening: Microscopic clarifications revealed embryos treated with Cd at the dose of 100 µM exhibited severe alterations in the developmental process. The control embryos exposed to embryo medium hatched normally without any sign of aberration. Embryo intoxicated with Cd (100 µM) exhibits significant lethal effects including yolk sac edema (YSE), a defect in the eyes (E), head (H), bent spine (BS), pericardial edema (PE), tail (T) curvature and tail tip (TT). The co-treatment with 7,8-DHC (1, 10, 50 and 100 µg) showed significantly decreased phenotypic malformations in embryos at 24, 48, 72 and 96 hpf whereas embryos exposed to 50 and 100 µg of 7,8 –DHC showed (Fig.2B) complete salvage of Cd induced phenotypic alterations. This result represents the protective effect of 7,8-DHC against Cd toxicity and this effect might be due the antioxidant mediated stabilization of free radicals, thereby minimizingthe damage caused by free radicals.

Discussion

In survival analysis, we observed that Cd intoxicated embryos exhibited drastic decline in survival rate ofzebrafish embryos. We believe that the reduction in survival rate might be due to the strong oxidative capacity of Cd[2] whereas, treatment with 7,8-DHC significantly enhanced the life span of zebrafish embryos at higher dosage exposure and improved the survival rate depicting its protective effect against Cd toxicity and it might be its strong redox scavenging ability. Thus our study corroborated with the few reports demonstrating the antioxidant potential of coumarin family in the elimination of radical ions[3].

Earlier reports showed that entrapment of metals in the chorion of the embryo induces physical stress resulting in reduced movement of embryos leading to hatching delay[4].We also found in our study that pre-treatment with Cd caused delayed hatching ability in embryos. On the other hand, 7,8-DHC treated groups showed increasing hatching ability. Thus might be due to the synergistic effect due to the endogenous antioxidant enzymes and thiol-based antioxidants participation integrally in the overall redox defense during redox challenged cellular environment.

The formation of the heart in the zebrafish provides a useful platform for the investigation of teratogenic and toxic effects. Indeed, the heart rate has been used as marker in assessing cardiac function of fish[5].Our results depicted that embryo intoxicated with Cd showed increased heart rate at 48 hpf and 60 hpf when compared to control, whereas the antioxidant 7,8-DHC treated groups showed decreased heart beats. We also found that the concentration at 100µg 7,8- DHC treated group showed normalized heartbeat compared with other lower concentrations of DHC. It is likely that the Cd interacted with reactive thiols in the mitochondrial membrane and generated ROS by modulating the electron transport chain, increasing the heart rate.

Conclusion

Our overall findings demonstrated the developmental toxicity in zebrafish embryos after exposure to Cd. The observed developmental toxicities were the resultant of general stress responses of embryos exposed to toxicants. Interestingly, we found in our study that the toxicities induced by Cd metal were significantly rescued upon treatment with 7,8-DHC. This property can be further extrapolated in the environmental removal of Cd from the effluents and thus preventing the teratogenic effects of Cd toxicity and preserving the biodiversity.

Acknowledgments

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Generation and Utilization of Garden Waste in Shanghai: Status Quo, Challenges and Countermeasures Analysis

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Abstract: With the urbanization and increasing of green space, the generation of garden waste has continued to increase. The resource utilization of garden waste is an important boost for to build a "green", "low-carbon" and "waste-free" city under the strategy to achieve carbon peak and carbon neutrality. As a megacity in the world and the science and technology innovation center in China, Shanghai was taken as a case to study the status quo of garden waste generation and resource utilization, as well as the challenges for its utilization. The experiences of resource utilization of garden waste in some typical cities were summarized. The systematic problems of garden waste utilization were analyzed, and suggestions to promote resource utilization of garden waste were proposed.

Keywords: Garden Waste; Generation; Resource Utilization; Countermeasures.

1 Introduction

Due to urbanization and the demand for a better life, the urban landscaping industry in Shanghai is thriving, resulting in an increase in garden waste [1]. Despite early efforts to recycle and utilize garden waste, Shanghai still faces challenges in achieving the dual-carbon strategy. About 70% of garden waste requires a more scientific approach for resource utilization. This study aims to analyze the current situation and challenges of garden waste utilization in Shanghai and propose measures to benefit the dual-carbon strategy.

2 Current situation of generation and utilization of garden waste in Shanghai

2.1 Garden waste generation

Shanghai's garden waste comes from plant residues like dead branches, leaves, grass, flowers, and pruning of garden plants. It mainly comes from urban green spaces like roads, parks, residential areas, and public facilities. The waste is composed of trimmings, natural litter, potted plants, and extreme weather residues. The components may vary due to green space and seasonal differences [2, 3].

Shanghai plans to create a functional ecological network framework system with increasing new green space (Table 1). The green coverage rate of built-up areas in Shanghai was 37.3% in 2020, with 8.5 m^2 of park green area per capita. This has led to a rise in urban garden waste. Two methods are used to obtain data on garden waste generation: calculation by class and garden department statistics. The amount of garden waste per unit of urban green space area varies from 0.53 kg/m^2 to 1.83 kg/m^2, and the amount reported by the garden department varies from 0.70 kg/m2 to 1.55 kg/m^2[3]. The average generation rate of garden waste is approximately 1.0 kg/m^2 in parks and large public green spaces, 0.6 kg/m^2 in residential areas, 0.6 kg/m^2 in green space, and 50 kg/plant for street trees [3-5]. Based on the area of green space and the number of street trees from 2009 to 2020, the estimated generation of garden waste in Shanghai is shown in Table 1, using a generation rate of 0.6 kg/m^2 for comprehensive green space and 50 kg/plant for street trees.

Table 1 Estimated generation of garden waste in Shanghai from 2009 to 2020

Year	Garden waste generated by comprehensive green space			Garden waste generated by street trees			In Total/t
	Area[4, 6] /×10^4 m^2	**Generation rate [3] /(kg/m^2)**	**Amount /t**	**Number of trees[4, 6] /×10^4 plants**	**Generation rate [3] /(kg/plant)**	**Amount /t**	
2009	116 929	0.6	701 574	76	50	38 000	739 574
2010	120 148	0.6	720 888	81	50	40 500	761 388
2011	122 283	0.6	733 698	93	50	46 500	780 198
2012	124 204	0.6	745 224	98	50	49 000	794 224
2013	124 295	0.6	745 770	99	50	49 500	795 270
2014	125 741	0.6	754 446	103	50	51 500	805 946
2015	127 332	0.6	763 992	110	50	55 000	818 992
2016	131 681	0.6	790 086	113	50	56 500	846 586

Year	Garden waste generated by comprehensive green space			Garden waste generated by street trees			In Total/t
	Area[4, 6] /×10^4 m^2	**Generation rate [3] /(kg/m^2)**	**Amount /t**	**Number of trees[4, 6] /×10^4 plants**	**Generation rate [3] /(kg/plant)**	**Amount /t**	
2017	136 327	0.6	817 962	115	50	57 500	875 462
2018	139 427	0.6	836 562	128	50	64 000	900 562
2019	157 785	0.6	946 710	129	50	64 500	1 011 210
2020	164 611	0.6	987 666	132	50	66 000	1 053 666

Table 1 shows Shanghai's increasing green area and street tree numbers. In 2020, garden waste in Shanghai was estimated at 1.0537×10^6 t with an average moisture content of 45%. Organic carbon, total nitrogen, total phosphorus, and total potassium content averages were 40%, 1%, 0.2%, and 1%, respectively. Lignin, cellulose, and hemicellulose content averages on a dry basis were 25%, 40%, and 30%, respectively. Garden waste in Shanghai has a resource potential with 1.185×10^5 t of lignin, 1.896×10^5 t of cellulose, 1.422×10^5 t of hemicellulose, 4.215×10^5 t of organic carbon, 1.054×10^4 t of nitrogen, 2.107×10^3 t of phosphorus, and 1.054×10^4 t of potassium.

2.2 Current situation of garden waste utilization

2.2.1 Policies and regulations on the recycling and utilization of garden waste in Shanghai

Shanghai has made significant progress in its policies and regulations for garden waste recycling [3]. National laws, such as the Law on Environmental Pollution Control by Solid Wastes, Circular Economy Promotion Law, and Municipal Solid Waste Management Measures, cover garden waste management. Shanghai has been a pioneer in exploring the resource utilization of garden waste and has issued relevant policies, technical standards, and special plans. The recycling rate of garden waste was included in the "12th Five-Year Plan" green development plan in 2010, which was critical to its promotion. Regulations define flowers and plants as "wet waste," with administrative departments developing rules for recycling and supporting use in public green spaces and agriculture. The 2021 Guiding Opinions call for expanding resource channels, promoting eco-friendly methods, and creating a "zero green waste discharge" demo zone. Several standards regulate garden waste collection, transportation, processing, and utilization. These include national standard GB/T 40199-2021, group standard T/HW 00019-2020, and local standards of Shanghai DB31/T 404-2009 and DB31/T 1035-2017.

2.2.2 Shanghai Garden waste recycling system

Shanghai has a mature garden waste recycling system, including source classification, decentralized collection and transportation to a central treatment and product recycling plant (Figure 1). This model relies heavily on the collection, transportation system and terminal treatment system. Additionally, the transportation costs are high.

Figure 1 Photo of a small underground transfer and pretreatment station for garden waste in Shanghai

2.2.3 Main processes for garden waste recycling in Shanghai

Shanghai recycles garden waste through source classification and decentralized collection, but only 30% is currently utilized due to challenges such as difficult site selection, high treatment costs, and application effectiveness. Land use after composting [6] is the main method of resource utilization, followed by mulch and other methods used as supplements. Composting has several advantages, but limited land area, difficult site selection, long processing cycles, and difficulty in product marketization pose challenges. Garden waste mulch can benefit plants [7-9], and Shanghai has explored other utilization methods such as biomass fuel and cavernous concrete [5, 10-11]. Collaborative disposal of garden waste in cement kilns is being explored to reduce fossil fuel consumption and relieve garden waste pressure.

3 Main issues in the garden waste recycling in Shanghai

Shanghai has a good technical foundation for garden waste recycling, but its utilization rate is low. Compared to domestic and foreign recycling efforts, there are shortcomings in policies, department coordination, and financial support.

1) Insufficient mandatory policies. Although the state and Shanghai have issued policies to promote garden waste recycling, most are focused on advocacy and lack mandatory requirements. This contributes to enterprises' wait-and-see attitude towards garden waste recycling. The newly revised Law of the People's Republic of China on the Prevention and Control of Environmental Pollution by Solid Wastes emphasizes waste reduction and requires organizations and individuals to promote solid waste utilization. The Circular Economy Promotion Law of the People's Republic of China and the Measures for the Administration of Urban Domestic Waste and Shanghai Municipal Domestic Waste promote recycling, but only for urban domestic waste. Compared to foreign countries, there is a lack of legal norms governing garden waste recycling, hindering its promotion.

2) Multi-party governance in garden waste recycling needs better synergy. Currently, the government, enterprises, and social organizations lack effective communication and coordination, leading to independent actions. The government mainly manages garden waste utilization, with less focus on system construction and service. Enterprises lack motivation to participate without mandatory regulations and incentives. Social organizations pay little attention to garden waste recycling.

3) Better coordination among government departments is needed to improve garden waste recycling efficiency. This systematic project involves collection, processing, production, and application, requiring coordination among various departments such as urban greening, land planning, and environmental protection. Unclear responsibilities lead to challenges in collecting garden waste and obtaining site approvals, hindering progress.

4) Industry supervision must improve to ensure effective garden waste utilization. Clear responsibility for collecting garden waste from urban green spaces is lacking, leading to untimely collection and unclear waste destination during transportation. Certification institutions for garden waste recycling products are insufficient, resulting in uneven product quality. Additionally, the utilization process does not include the amount of products used for garden waste recycling in relevant assessments. To address these issues, a clear responsibility system must be established, certification processes for garden waste recycling products improved, and relevant assessments expanded to include garden waste product utilization.

5) The enthusiasm of enterprises to participate in governance needs to be improved. To improve enterprise participation in governance, the government can offer subsidies or tax incentives, establish a certification system for green and low-carbon enterprises, encourage technology development, and strengthen supervision and guidance. Publicity and education should also be enhanced to increase awareness and participation in garden waste recycling.

6) Scientific and technological support and decision-making must be improved for effective garden waste recycling in Shanghai. The management system should be refined, intelligent, and digitized, with strong IT support for stable waste supply. Scientific response strategies should be established based on investigation and demonstration. Resource utilization technologies and operational modes should be developed to suit urban characteristics.

4 Foreign experiences in the garden waste recycling

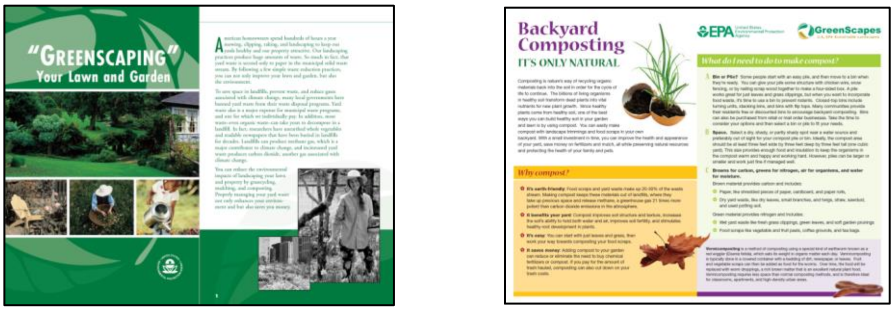
The United States, Japan, Germany and other developed countries started garden waste recycling earlier and have relatively mature laws and standards systems and advanced experience in product application and promotion.

4.1 Policies and regulations

Europe, the United States, and Japan value the recycling of organic waste such as garden waste. Europe, the US, and Japan prioritize garden waste recycling and have established policies and regulations for its treatment and utilization [12-15]. The US EPA's Composting Law and Japan's Basic Law on the Environment and Law on the Disposal of Wastes clarify management modes for garden waste recycling. The US and Japan also provide policy and financial support, including inclusion in government procurement and renewable resources catalogues, to promote a full-process closed-loop and green, low-carbon, and recycling development. Other countries promote garden waste recycling through legal and economic measures, such as increasing landfilling and incineration costs and introducing incentives and subsidies for recycling. Laws and regulations strengthen planning guidance and standardize development direction, while government procurement catalogues encourage multiple entities to participate.

4.2 Management model

The US, Japan, and other countries have established a comprehensive management system for garden waste, which includes classification, collection, transportation, treatment, and product application. There are four key takeaways from their approach. Firstly, adopting a "centralized+local" processing model can reduce pressure on centralized treatment plants and lower costs [15]. Secondly, designing suitable collection and treatment sites and managing different types of urban solid waste together is an effective solution. Thirdly, composting is a mature technology with strong process supervision and mechanization. Lastly, integrating production, research, and application can ensure scientific disposal of garden waste and create market opportunities for resource products.



"GREENSCAPING" Your Lawn and Garden

Backyard Composting
IT'S ONLY NATURAL

(a) "Greenscaping — your lawn and garden" (b)"Backyard Composting" Guiline[28]

Figure 2 Guidelines for Residents to Compost in Their Own Backyard Issued by EPA

5 Suggestions on the garden waste recycling in Shanghai

Recycling garden waste is necessary for green, low-carbon, and high-quality development in urban and rural areas. However, unclear national legal positions and policies have led to long-term problems such as inadequate land use guarantees, financial subsidies, unclear departmental responsibilities, and limited technical application. To establish a comprehensive garden waste treatment and utilization system, key barriers such as land use planning, collection and transportation, and product market promotion must be overcome. A unified system for planning, classification, collection, transportation, treatment, promotion, and application of garden waste resources should be developed. The following suggestions are proposed for systematic development.

5.1 Improve the standard system and establish incentive mechanisms

The lack of mandatory policies hinders enterprise participation in garden waste resource utilization. Shanghai should introduce mandatory local standards under the national framework to encourage involvement. Utilize the advantages of a people's city and a modern metropolis to promote standard sharing in the Yangtze River Delta. Capital subsidy policies, such as financial subsidies, tax relief, and green credit, should be implemented to boost enterprise motivation. Enhancing the green credit system and integrating it with garden waste recycling is crucial.

5.2 Strengthen industry supervision and improve department coordination

Develop and implement a garden waste management system in Shanghai that suits the local situation. Use conventional methods like composting and organic mulching, and promote the "local+centralized" treatment model for garden waste resources. To improve recycling, a third-party agency should oversee the entire process, from collection to marketing, enforcing standards, monitoring production, conducting testing, and ensuring compliance with sales regulations. Coordination among relevant departments is crucial for efficient recycling. The mechanism should be improved, and departments should clarify their functions and implement management responsibility. Practical problems can be addressed through multiple modes and departmental coordination.

5.3 Strengthen scientific and technological innovation and explore new modes and methods

Develop a new garden waste recycling model in Shanghai with modern industry. Collaborate with institutions, universities, and enterprises to research recycling methods and enhance scientific and technological means. Diversify products and explore new treatment methods like crushing, carbonization, and biodegradation. Commercialize and industrialize recycling by collaborating with research institutions and universities for market-oriented R&D. Explore new technical methods like collaborating with cement kilns to enhance efficiency and reduce costs. Focus on better products and R&D to compete effectively and meet market needs.

5.4 Promote publicity and spread regional pilot projects

Promote green lifestyles through social media and showcase pilot projects to educate citizens about garden waste recycling. Use "Weibo, WeChat, and TikTok" to spread environmental concepts in communities, schools, institutions, and factories. Demonstrate the entire process of recycling, classification, collection, transportation, and treatment of garden waste to showcase the effectiveness of the new model. Educate and motivate the public to participate in garden waste recycling.

6 Conclusions

Shanghai has initially established a system for the recycling and utilization of garden waste. However, the system is still far from being refined. First of all, it is necessary to further advance specific policies and regulations based on existing laws, establish standard norms, and create incentive mechanisms to guide enterprises to participate in garden waste recycling and improve their enthusiasm. Meanwhile, there is a need to strengthen the supervision and coordination among various government departments. This includes establishing a system of co-governance to share information among the government, enterprises, social organizations, and the public. This will help in the development of a "government-led, enterprise-driven, and multi-participated" model for the utilization of garden waste resources. Secondly, in terms of technological innovation, it is necessary to promote efforts in science and technology to enable the resource utilization of garden waste, and to achieve refinement, intelligence, and informatization in garden waste resource utilization. Finally, with increased publicity and education, the leading demonstration of pilot garden waste recycling should be spread to the public.

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Potential Utilization of Sewage Sludge for Cost Effective Natural Farming in India: Characterization and Treatment

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ABSTRACT. For the study purpose, treated sludges from twenty-two sewage treatment facilities were characterized to develop the quality control indices in India. The findings revealed that except for K, all the dewatered sludge samples have pH, electrical conductivity, total organic carbon, TN, TP, and C:N ratios within the threshold range of the Indian Standard (Fertilizer Control Order (FCO) 2009). The heavy metals concentrations meet USEPA Class B sludge quality criteria. This study used Fertilizer Index (FI) and Clean Index (CI) as a tool for categorizing sludge utilization into different classes (A, B, C and limited use classes LU-1, LU-2, LU-3) by their fertilizing potential, toxicity level, pathogen presence. All sludge samples belong to class C category due to metals, pathogens. Overall, FI value is reported ranging from 4.1 to 4.9 and CI value ranging from 2.5 to 5.0 and which indicates compost is good in quality having high-value potential and low heavy-metal content which is suitable for organic farming.

Keywords: Sewage sludge, Quality control indices, Heavy metals, Pathogens

Introduction

Sewage sludge is a potential source of energy and value-added products. On a dry basis, sludge contains around 30 - 60% of organic matter, 1.5 - 4.5% nitrogen and 1.0 - 2.2% phosphorus, minerals in ash like quartz, calcite or microcline, and heavy metals (Fe, Cr, Ni, Cu Zn, Pb, Cd, Hg) [1]. A significant fraction of nitrogen, phosphorus, and potassium in sewage sludge makes it suitable to reuse as compost or soil conditioner. Sewage sludge composting transforms the organic fraction into a nutrient-rich fertilizer. Nevertheless, sewage sludge often contains pathogens and toxic pollutants such as heavy metals and hazardous organics, which limits its usage for land application. Thus, sewage sludges must be treated to mitigate the contaminants pollution problems before being used in agriculture or as landfill cover.

In India, Solid Waste Management rules 2016 have elaborated solid waste disposal methods along with ceiling concentrations for heavy metals and faecal coliforms. But as of now, there are no proper guidelines for sludge management involving safe disposal and reuse in India. North America, European Union and India have enacted regulations to control the commercialization of composts of desired quality [2]. These quality control guidelines, however, do not differentiate between different classes of sludge quality as compost. Dewatered sludge must be graded since it lacks uniform characteristics, particularly in terms of pathogens and toxicity. There is an awful need to classify the sludge for variable usage, such as raising food crops, high-value crops, non-food crops, establishing gardens or lawns, reclamation or rehabilitation of specific types of degraded lands, is also anticipated to be made more accessible by this approach. There are limited studies on sludge characterization to realize its reuse and safe disposal potential in India [3]. Therefore, a study to characterize the dewatered sludge from sewage treatment plants (STPs) in different cities across India was undertaken to assign quality indices for grading it through their fertilizing and clean (environmental impact) index owing to presence of pathogens, heavy metals, and vectors attraction potential.

Material and Methods

Experimental and quantitative analyses were combined with qualitative research to provide a quantitative component to the methods used to define the usage and safe disposal of dewatered sewage sludge. Sewage sludge samples were characterized in terms of its chemical, physical, and microbiological properties and to evaluate its potential as organic compost. The heavy metal concentrations were also assessed to determine if dewatered sewage sludge is suitable for use.

Quality grade of sludges

The current quality control regulations prohibit the commercialization of composts that exceed a specific threshold for several quality control criteria to protect the environmental and public health. An indexing system [5] was applied to the sludge samples to assess the quality of the dewatered sludge and its indexing in terms of fertilizing and clean values. For both cases, weighing factor is taken with respect to fertilizing index (FI) and clean index (CI). The FI and CI scores varied from 1-5 for soil productivity and phytotoxicity potential of heavy metals, respectively.

The 'Fertilizing index' of the sewage sludge is calculated using following formula:

$$Fertilizing\ Index = \frac{\sum_n^{i=1} S_i W_i}{\sum_n^{i=1} W_i}$$

The "Clean Index" value was determined using the following formula:

$$Clean\ Index = \frac{\sum_n^{i=1} S_i W_i}{\sum_n^{i=1} W_i}$$

Where "Wi" is the weighing factor for the "i" th fertility parameter and "Si" is the score value of the analytical data.

Results and Discussion

a. Fertilizer potential of sludges

Organics and nutrients

Total organic carbon (TOC) contributes to healthy soil conditions. The FCO compost standard 1985 suggests that the TOC should be 12 % on a dry basis. The TOC in sludge samples ranged from 12.4% to 41.6%, with median values of 26.1% on a dry weight basis. Potassium, phosphorus, and nitrogen are essential parameters to compost quality as these are key nutrients uptake by plants from the soil. Total P (as P_2O_5), Total N, and K (as K_2O) in the sludge samples ranged from 0.9- 5.7%, 1.2- 3.8%, and 0.1- 1.5% with median values of 2.0%, 2.2%, and 0.3% on a dry weight basis, respectively.

Carbon to Nitrogen ratio

Soils with a carbon-to-nitrogen (C:N) ratio of 24:1 have the optimum ratio for soil microbes to stimulate release of nutrients for plants' uptake. The sludge samples have an optimal C:N ratio and can provide a good balance of carbon and nitrogen to microbes.

Heavy metals

The application of sewage sludge in agriculture is a common practice as it is cheap, abundantly available, and organic and nutrient rich. The high concentrations of heavy metals in sludge often limit its reuse for soil amendments. Analysing the heavy metals concentration in sludge is essential to protect the soil environment from heavy metals pollution. The sludge samples contain heavy metals in the ranges of 0.0- 68.0 mg/kg As, 0.0- 64.7 mg/kg Cd, 0.0- 440 mg/kg Cr, 0.0- 2700 mg/kg Cu, 0.5-114.9 mg/kg Pb, 0.0- 895.3 mg/kg Mo, 0.0- 280.0 mg/kg Ni, 0.0- 245.0 mg/kg Se, 17.6- 2887.3 mg/kg Zn, and corresponding median values of 3.4 mg As/kg, 1.0 mg Cd/kg, 29.6 mg Cr/kg, 107.2 mg Cu/kg, 34.9 mg Pb/kg, 6.0 mg Mo/kg, 16.4 mg Ni/kg, 0.0 mg Se/kg, and 2924.0 mg Zn/kg on a dry weight basis.

Microbiological characterization

Sewage sludge typically contains similar microbiological characteristics as wastewater. Fecal coliform, Helminthes eggs, and *Salmonella sp.* are the key microbiological parameters to consider when sewage sludge is used as a fertilizer, soil conditioner, or land application. The fecal coliforms in sludge samples vary from 12000- 120000 MPN/g of dry solids with a median value of 53000 MPN/g. The *Salmonella sp.* in sludge samples ranged from 8- 80 MPN/4g of dry solids and had a median value of 27 MPN/4g of dry solids. Helminth eggs are exceptionally resistant to environmental stresses and can withstand standard wastewater and sludge disinfection treatments [4]. The helminth eggs were found in the range of 25-1450 Numbers/4g of TS in sludge samples.

b. Indexing of sludges

Fertilizer index

The fertilizing value of compost is increased by various analytical characteristics, including the total C, N, P, and K contents and the C: N ratio. According to the category listed in Table 1, these characteristics are given a "score" value. The analytical importance of fertilizing factors from the [5] was taken into account to determine score values. The optimal carbon to nitrogen ratio in compost helps bacteria to break down nutrients and make them available to plants. C: N ratio was given a higher weighting factor. The fertilizer value of sludge is vital if it is to be used as a soil conditioner and is insistent on nitrogen (N), phosphorous (P), and potassium (K) concentrations. Each element was given a weighting factor based on its function in plant growth and nutrition and how often it is deficient in soils.

Table 1. Benchmarks for designating 'weighing factor' to fertility criterion and 'score value' to analytical figures

Parameters	**Score value (Si)**					**Weighing factor (Wi)**
	5	**4**	**3**	**2**	**1**	
Total Organic Carbon (%)	> 20.0	15.1-20.0	12.1-15.0	9.1-12.0	<9.1	**5**
Total nitrogen (%)	> 1.25	1.01-1.25	0.81-1.00	0.51-0.80	<0.51	**3**
Total Phosphate as P_2O_5 (%)	> 0.60	0.41-0.60	0.21-0.40	0.11-0.20	<0.11	**3**
Total Potassium as K_2O (%)	> 1.00	0.76-1.00	0.51-0.75	0.26-0.50	<0.26	**1**
C/N ratio	< 10.1	10.1-15.0	15.1-20.0	20.1-25	>25	**3**

The "Fertilizing index" values of dewatered sludge samples ranged from 4.07 to 4.87, with a mean value of 4.49 on a 5.0-point scale. The "Fertilizing index" of sludge samples with pure sewage and industrial mix sewage showed a slight variation.

c. Clean (heavy metal) index

The analytical value of each heavy metal was assigned a score following the criteria shown in Table 2.

Table 2. Benchmarks for designating 'weighing factor' to heavy metal criterion and 'score value' to analytical figures

Heavy metals (mg/Kg)	**Score value (Si)**						**Weighing factor (Wi)**
	5	**4**	**3**	**2**	**1**	**0**	
As	<5	5.1-10.0	10.1-20.0	20.1-41.0	41.1-75.0	>75.0	5
Cd	<2.5	2.6-5.0	5.1-10.0	10.1-39.1	39.1-85.0	>85.0	5
Cr	<25	25.1-50.0	50.1-100.0	100.1-250.0	250.1-500.0	>500.0	5
Cu	<150	150.1-300.0	300.1-600.0	600.1-1500.0	1500.1-4300	>4300.0	2
Pb	<50	50.1-100.0	100.1-200.0	200.1-300.0	300.1-840.0	>840.0	3
Mo	<5	5.1-10.0	10.1-25.0	25.1-50.0	50.1-75.0	>75.0	4
Ni	<25	25.1-50.0	50.1-100.0	100.1-200.0	200.1-420.0	>420.0	1
Se	<5	5.1-10.0	10.1-20.0	20.1-36.0	36.1-100.0	>100.0	4
Zn	<500	500.1-1000.0	1000.1-2000.0	2000.1-2800.0	2800.1-7500.0	>7500.0	1

The quality control limit values established by [6], US EPA Class A and B Sludges, and CPHEEO- 2013 were considered while determining score values. There is also a specific "weighing factor" for each heavy metal, i.e., the more toxic the metal, the higher the weighting factor. The higher the quality control limit value, the lower the weighting factor. The higher the scoring system for each heavy metal, the less likely the heavy metal will be detected in the final product. The calculated 'Clean index' values ranged from 2.5 to 5.0, with a median value of 4.07 on a 5-point scale (Table 3). Sludge samples from wastewater treatment facilities receiving only sewage recorded higher 'Clean index' values than those receiving industrial effluent mixed sewage. Sludge samples with a clean index greater than 4.0 satisfy the limiting heavy metal concentrations. Similarly, sludges with a clean index between 4.0 to 2.0 meet the heavy metal threshold of USEPA Class A Biosolids set for ultimate disposal (landfill, land applications, reclamation, reuse) of sludge.

Table 3. Categorization of dewatered sludge for marketability and use for various purposes

Class	**Fertilizing Index**	**Clean Index**	**Pathogens and Vector Presence**	**Remarks**
	(TOC, TN, TP, K, C: N)	(Heavy Metal Index)	(Fecal Coliforms, Salmonella species, Helminthes Eggs)	
A	> 4.0	> 4.0	Complying thresholds of US EPA Class A	**Best-Quality Compost**, Low levels of heavy metals, high potential for manure, and application to high-yield crops in organic farming
B	> 3.1	> 3.0	Complying thresholds of US EPA Class A	**Good Quality Compost,** Medium fertilizing potential and low levels of heavy metals
C	> 3.0	> 2.0	Complying thresholds of US EPA Class B or	**Medium Quality Compost,** Medium fertilizing potential and medium levels of heavy metals

Conclusions

All the sludge samples analyzed in this study fall under Class- C (medium quality) and comply with a threshold of fecal coliform concentration as per USEPA Class B biosolids. All dewatered sludge could follow the pathogen and vector reduction criteria for Class A, if they go under various sludge treatments of composting, aerobic and anaerobic digestion, stabilization, etc.

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Simultaneous Adsorption Abilities of Inorganic-organic Modified Montmorillonite as Affected by Different Adding Sequences

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This study investigated the modification of montmorillonite, one of the major components in construction waste materials, to simulate their application for the fabrication of adsorbents, followed by the simultaneous adsorption abilities of these adsorbents towards hexavalent chromium (Cr) and bisphenol A (BPA). The adsorbents, inorganic-organic montmorillonite (IOMMts), were synthesized with three different adding sequences of keggin Al_{13} complex (Al_{13}) and hexadecyltrimethyl ammonium (HDTMA), where montmorillonite (MMt) was modified by a) Al_{13} first then by HDTMA (O-Al-MMt); b) HDTMA first then by Al_{13} (Al-O-MMt); c) Al_{13} and HDTMA simultaneously (Co-MMt). For comparison, MMt was also modified by Al_{13} and HDTMA individually (Al-MMt and O-MMt). The amounts of Cr and BPA adsorbed by IOMMts in a single pollutant system and a binary pollutants system were determined using HPLC-DAD. Furthermore, the adsorption isotherms of IOMMts towards Cr and BPA in these two systems were studied. The adsorption mechanisms were investigated based on the physical-chemical characteristics of IOMMts, which were determined by X-ray diffraction (XRD), thermogravimetric analysis (TGA), Fourier transform infrared spectroscopy (FTIR), scanning electron microscope coupling with energy dispersive X-ray detector (SEM-EDX), and BET surface area analysis. The adsorption results in single system revealed that Al-O-MMt and Co-MMt had better adsorption ability towards Cr and BPA than MMt, Al-MMt, O-MMt and O-Al-MMt. The TGA and adsorption results indicated that the decomposition temperatures of HDTMA and the adsorption abilities were similar for Al-O-MMt and Co-MMt, but different for O-Al-MMt. It supposes that the status of HDTMA in the interlayer of montmorillonite was affected by Al_{13}, providing IOMMt with a better adsorption function. In the binary pollutants system, the amount of BPA adsorbed onto IOMMts was reduced. On the other hand, the amount of Cr adsorbed onto IOMMts in the binary pollutants system was better than in the single pollutant system in lower concentration of Cr. It might be because the synergistic effect from BPA on the adsorption process of Cr is significant in lower concentration. In addition, the amount of Cr adsorbed increased with increasing concentration of BPA up to 100 mg/L, but decreased when the concentration of BPA was more than 100 mg/L. This could be due to the occupation of adsorption sites by BPA, preventing from adsorbing Cr.

Keywords: Bisphenol A, Hexavalent chromium, Inorganic-organic modified montmorillonite, Simultaneous adsorption.

Preparation of Nano-$CaCO_3$ By-product of Biogas Decarbonization with Microfluidic Device

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Biogas is a renewable resource, which contains about 50%-65% methane (CH4), 35%-50% carbon dioxide (CO2), water vapor and a small amount of hydrogen sulfide (H2S) in biogas. The existence of carbon dioxide will not only reduce the combustion heat value of biogas, but also cause corrosion to production equipment. Therefore,purification of biogas is one of the key technical links in biogas production . Nowadays, several technologies such as high-pressure water washing, absorption, membrane separation, and pressure swing adsorption are used to remove CO2. However, these processes are expensive and may lead to high CH4 losses. In addition, these methods do not make effective use of CO2. Reducing carbon dioxide emissions is a huge challenge. Carbonation appears to be a successful method because it allows long-term storage of carbon dioxide from industrial gas streams. f there are industrial wastes such as slag and carbon dioxide, it is beneficial to the environment to use them to produce precipitated CaCO3. This approach saves natural resources such as limestone, reducing energy consumption and overall CO2 emissions. Therefore, a new technology is needed that can not only purify biogas to obtain high-purity methane and recover carbon dioxide, but also produce high value-added products. Micro reactor or microfluidic equipment can be used to generate ultra-fine particles by mixing reaction materials through micro channels. Controllable preparation of ultrafine particles requires accurate control of the mixing flow field, residence time and concentration field in the microreactor. In the micro reactor, the key factor is the control of flow field to realize the controllable preparation of uniform particles. Especially, in the process of multiphase mixing, which involves the formation of liquid masses, droplets or bubbles in the micro channels. The dynamic change characteristics of dispersed phase are related to the nucleation and growth process of particles closely. In this report, the flow characteristics in the microreactor will be studied from the perspective of hydrodynamics, and the computational fluid dynamics (CFD) simulation method will be used to reveal the process law under the flow regulation to provide theoretical guidance for the design and operation of the microreactor and improve the understanding of the internal flow and reaction process of the microreactor. In the research work, we designed brand new microfluidic device and designed different microfluidic chips. It was used to prepare calcium carbonate particles with different particle sizes, and efficiently obtained high value-added nano-scale calcium carbonate particles. The CO2-enriched water was prepared by high pressure water scrubbing. Then the CO2-enriched water was used in the microfluidic device to react with Ca(OH)2 to form nano-CaCO3. After the preparation, our work also analyzed the properties of nano-CaCO3 particles. At the end of the research work, we also used the Computational Fluid Dynamics (CFD) method to simulate the micro-mixing reaction process. The results show that keeping the flow rate of carbon dioxide solution unchanged, increasing the flow rate of calcium hydroxide solution will reduce the conversion rate of calcium hydroxide, but will improve the conversion rate of carbon dioxide and promote the formation of calcium carbonate. While keeping the flow rate of calcium hydroxide solution unchanged, increasing the flow rate of carbon dioxide solution will reduce the conversion rate of carbon dioxide, but it can improve the conversion rate of calcium hydroxide and increase the production of calcium carbonate.Secondly, Increasing the feed concentration of carbon dioxide will increase the molar flow of carbon dioxide at the outlet, more unreacted carbon dioxide will flow out of the reactor, the conversion rate of carbon dioxide will be reduced, the conversion rate of calcium hydroxide will be improved, and the generation of calcium carbonate will be promoted. In addition, the simulation calculation shows that increasing the distance between the reaction feed pipe and the discharge pipe can increase the contact area between carbon dioxide and calcium hydroxide effectively. Therefore, increasing the distance between the feed pipe and the discharge pipe is conducive to improving the conversion of carbon dioxide and calcium hydroxide and increasing the output of calcium carbonate at the same time. Finally, compared with circular chips, when semi-circular chips are used, although the conversion rate of calcium hydroxide is slightly reduced, the utilization rate of carbon dioxide is greatly improved, and the output of calcium carbonate is also improved. The main reaction area of calcium hydroxide is near the semi-circular chip, which makes the concentration far away from the reactor outlet reach a very low level.

Interfacing Biosynthetic CdS with Engineered Rhodopseudomonas Palustris for Efficient Visible Light-Driven CO_2-CH_4 Conversion

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ABSTRACT. The engineered photosynthetic bacterium (PSB) *Rhodopseudomonas palustris* has an excellent capability of one-step CO_2 biomethanation while it tends to use near-infrared light sources due to the limitations of the native photosynthetic system. To maximise the capture of sustainable solar energy for CH_4 production. The precipitation of CdS nanoparticles is induced on the surface of *R. palustris*, and 155 nmol/mL of the biological CH_4 production is achieved after optimization under visible light (VL) irradiation, nearly 13.4-fold of the pure *R. palustris*. The transcriptome profiles reavealed that gene expression related to electron transfer chain (ETC), nitrogenase, nanofilaments and redox stress defendence was activated. Thus, the greatly enhanced CO_2 biomethanation process in biohybrid system was attributed to the remarkable increase of intracellular reducing power and the stronger rigidity of the cells with the assistance of photoexcited electrons from CdS NPs.Our discovery encourages a novel insight and promising strategy for the improvemnet of the current CO_2-CH_4 biomanufacturing system.

Keywords: Biohybrid catalyst；*Rhodopseudomonas palustris*; Carbon dioxide reduction;

Introduction

Inspired by natural photosynthesis, interfacing living cells and abiotic inorganic semiconductors has led to a pioneering conception of photo-assisted biosynthesis, termed as semi-artificial photosynthesis. Such biohybrid system allows for efficient capture of solar energy stored in chemical bonds, integrating the advantages of biocatalysts (high product selectivity) and abiotic catalysis (high energy conversion rate). Targeting CO_2-CH_4 conversion, great progress has been achieved in the construction of the biotic-abiotic hybrid system based on methanogenic archaea[1].

Recently, non-conventional methanogenesis processes are gradually being explored in oxic environment of nature, involving the metabolic behaviour of photosynthetic organisms such as cyanobacteria, algae, fungi and purple non-sulfur bacteria (PNSB), greatly broadening the range of candidates for biomethanation. *R. palustris* (Rp) with recombinant [MoFe]-nitrogenase retain its inherent metabolic diversity and rapid growth, while allowing for novel one-step CO_2-CH_4 conversion[2].

In this work, we have integrated the advantages of genetic engineering technology and material-catalysis chemistry to construct a light-driven methanogenic biohybrid system based on photosynthetic bacteria and nano-photocatalytic materials. The visible light-responsive CdS nanoparticles (NPs) were simply biosynthesized and precipitated in situ on the surface of *R. palustris* by incubating the precursor reagents to the cultivation. This biohybrid system significantly activated intracellular CO_2 metabolism of recombinant nitrogenase through the injection of photoelectrons from the CdS NPs. A series of electrochemical and spectroscopic experiments have verified its involved properties of photoelectron transfer. Finally, transcriptomic analysis was used to delve into the underlying molecular mechanism of the enhanced CH_4 production.

Material and Methods

Bacteria strains and construction of R. palustris (N2ase)-CdS biohybrid*

The engineered phototroph *Rhodopseudomonas palustris* CGMCC 1.2180 was used in this study, described as *R. palustris* (N2ase*). L-cys and $CdCl_2$ were injected into *R. palustris* (N2ase*) solution of the mid-log growth phase at an interval of 24 hours, and the final concentration was controlled to be 1mM.After 2-3 days of cultivation, the initial pink suspension changed to milky white and finally yellow, indicating the formation of *R. palustris* (N2ase*)-CdS biohybrid. The CdS were centrifuged and then measured by TEM, UV-vis and XRD.

Light-driven CO_2-CH_4 conversion experiments

The Pure bacteria and biohybrid were resuspended to a certain concentration (OD= 1.5) and transferred into the strictly anaerobic NFM medium, with $NaHCO_3$ as sole carbon source and L- Cystine (L-Cys) as sacrificial electron donor (SED). The photocatalytic reaction was performed in the anaerobic photo-incubator (30°C, 180 rpm) with 50W LED light for illumination .CH_4 and H_2 production by the pure bacteria and biohybrid were monitored using a gas chromatograph (GC7890PLUS, RUIHONG, China) equipped with flame ionization detector (FID) and thermal conductivity detector (TCD).

Photoelectrochemical characterization

An ITO conductive glass slide (1cm ×2cm) were used as the working electrode, and Ag/AgCl (KCl saturated) and platinum wire were used as the reference and counter electrode, respectively. Typically. 10 μL prepared suspension was dropped onto the ITO glass and fixed in air for 30 min after addition of the appropriate amount of Nafion solution (10 wt%) were used as electrolytes. The photoelectrochemical properties such as the photocurrent (I-t), electrochemical impedance spectroscopy (EIS) and linear sweep voltammetry (LSV) were recorded in 0.1M phosphate-buffered solution (PBS) (pH=7) using CHI660E electrochemical workstation (Chenhua Inc., Shanghai, China).

Transcriptome sample treatment and data analysis

Cell samples were subject to library construction and sequencing on the Hiseq sequencing platform (Illumina, California, USA) to achieve the raw reads of each sample. After quality control of the raw reads, high-quality data for each sample were retained and mapped to the genomes of *R. palustris* CGMCC 1.2180 (GenBank assembly accession: GCA_013415845.1). the percentage of total reads mapped to the reference genomes for all the samples were above 76%. Mapped reads were normalized with fragments per kilobase per million mapped reads (FPKM) as previously reported for downstream analysis using Majorbio Cloud digital sequencing analysis platform (Majorbio, Shanghai, China).

Results and Discussion

Characterization of biohybrid and biosynthetic CdS NPs

With the successive introduction of L-cys and Cd^{2+}, the color of the culture medium turned white and eventually bright yellow, indicating the progressive ripen of the biosynthetic CdS NPs. As Figure 1 showed, transmission electron microscope (TEM) revealed that the CdS NPs irregularly precipitated on the cell surface and energy dispersive X-ray spectroscopy (EDX) confirmed the element composition of sulfur and cadmium. A significant proportion of nanoparticles were concentrated at two cell poles, presumably associated with the localization of photosynthetic intracytoplasmic membranes (ICM)[3]. Further, the CdS NPs were isolated from the cell surface. Disc-shaped morphology was observed by TEM, similar to previous study[4].The XRD pattern matched the hawleyite CdS standard sample (JCPDS No. 42-1411) with three distinct diffraction peaks at 2θ values of 27.2°, 44.8° and 52.1°. The intrinsic band gap estimated with Tauc plot was 2.73 eV, larger than that of the chemically synthesized CdS, owed to quantum confinement of nanoparticles. Based on the reduction potential of Cd^{2+}/Cd^0 at -1.06 V versus NHE measured by linear sweep voltammetry (LSV), the band edge of the CdS NPs could be determined. The above experiments confirmed the nano-sized structure and visible light absorption property of CdS NPs.

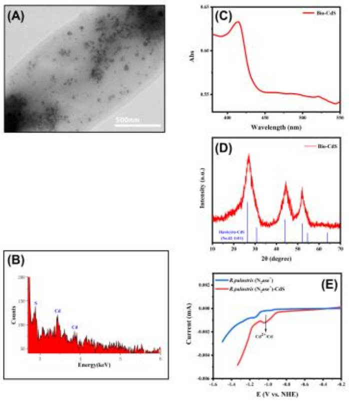

Figure 7 .Characterization and LSV of the biohybrid.

Light-driven CO_2-CH_4 conversion performance of biohybrid

The CH_4 production in the biohybrid under visible-light irradiation was far outperforming of other controls. To further improve the efficiency of CO_2-CH_4 conversion in the biohybrid,

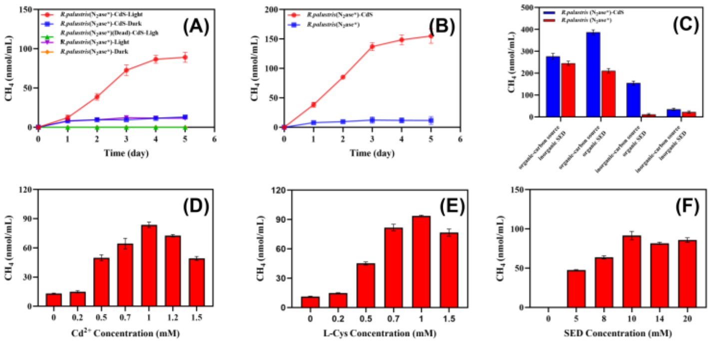

Figure 8. CO_2-CH_4 photosynthesis by the biohybrid and condition parameter optimization

critical concentration parameters were optimized. At a concentration of 1 mM of cadmium and sulfur ions, the best synergy was obtained between photoelectron injection from the loading CdS and intracellular biometabolism. L-cys was chosen with the characteristics of low oxidation potentials and biological toxicity. After optimization, the CH_4 production increased in a nearly linear fashion up to 3 days and finally achieved 155 nmol/mL after 5-day photocatalytic experiments, a 13.4-fold increase compared to the pure bacterial system.

Electron transfer efficiency and biocompatibility of biohybrid

Compared with the untreated group, methane production was reduced by 82% under 5U/mL protease K treatment, highlighting the importance of intact cell membranes. The charge transfer potentials of biological and hybrid systems were evaluated by electrochemical impedance spectroscopy (EIS) and transient photocurrent response experiments. As shown in the Nyquist diagram, biohybrid has higher electronic conductivity, and this was in accordance with observation of the amperometric I-t curve. These results validate the excellent photocatalytic activity of biological hybrids based on fast electron transfer. Meanwhile, with the successive of L-cys and Cd^{2+}, a hop-up was observed due to the formation of CdS NPs. The value of OD_{660} rose slightly and then plateaued in the subsequent days. The consistent green fluorescence of living cells before and after photocatalytic reaction suggested that high cell viability was maintained throughout the reaction.

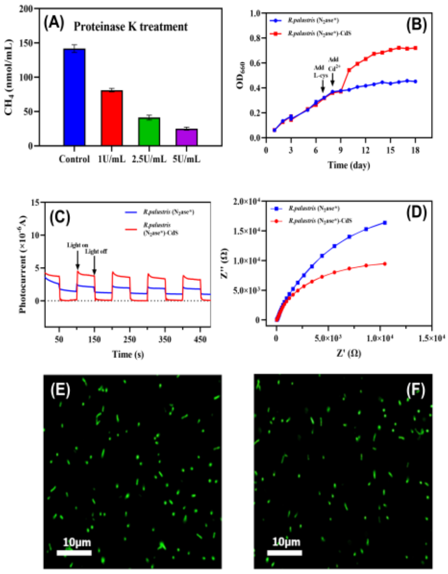

Figure 9. Characterization of photoelectric properties and cell viability

Transcriptional analysis of the biohybrid under photoautotrophic condition

Photoelectron from CdS NPs enhanced great photoautotrophic ability at three levels: membrane interface, intracellular and whole cell shown in figure 4. With the help of the cytochromes in the ETC, partial photoelectrons participated in cycle photophosphorylation, significantly enhancing ATP synthesis. Other part of photoelectrons transferred directly into the cell as a supplementary source of bioelectrons. In order to divert excess intracellular energy and electrons, *R. palustris* selectively activated nitrogenase for redox balance. The metabolic shift from CO_2 fixation of the Calvin cycle to CO_2 biomethanation weakened competition from other intracellular electron acceptors in a self-regulated way. Further, whole-cellular conductivity and resilience were enhanced by high expression of related proteins to maintain a high level of reactivity of the biohybrid system.

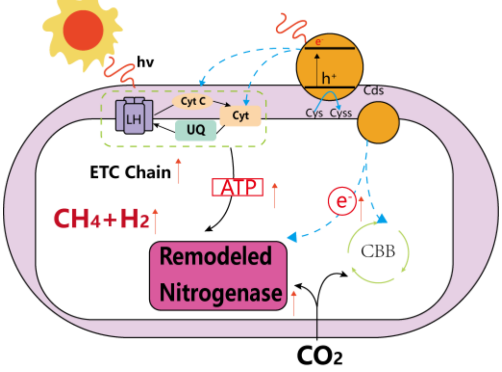

Figure 10. Pathways of electron transfer and CO_2 biomethanation in *R. palustris* (N2ase*)-CdS biohybrid system

Conclusions

The phototroph *R. palustris* converted cadmium ions into photoresponsive CdS NPs decorated on the cell surface through endogenous biodetoxification, which fabricated the phototroph-semiconductor biohybrid in an elaborate way. Photoelectrons derived from the CdS NPs as a complement to bioelectrons substantially enhanced CO_2 biomethanation performance.

Acknowledgement

This work was supported by the Natural Science Foundation of Jiangsu Province (Carbon neutralization, BK20220003), the Jiangsu Province Science and Technology Program Special Fund (Hong Kong, Macao and Taiwan Science and Technology Cooperation) (BZ2022052).

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Application of Hybrid Solar-Powered Electrocoagulation and Electrooxidation System for Textile Wastewater Treatment

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The textile industry is one of the significant consumers of dyestuff, chemicals, and water. As a result, a large amount of wastewater is generated. During the dyeing process at the dyeing unit, 30% of the dyestuffs remain unbound with the cotton cellulose fibers. The wastewater discharged from the textile dyeing industry is challenging to treat using conventional treatment methods as these effluents are complex, toxic to microorganisms, and recalcitrant to biodegradation. Limited studies have demonstrated that the hybrid electrocoagulation-electrooxidation (EC-EO) process is an efficient technology for eliminating different pollutants. However, the potential of this technology to tackle the problem of the textile industry in developing countries like Ethiopia has not been optimized. In addition, a very concentrated dye solution, equivalent to textile effluent, was used to test the efficacy of the treatment method, which is also not commonly considered in other studies. Furthermore, the current global concern related to the energy crisis and climate change demands the use of renewable energy as a power source. Therefore, to address this problem, a hybrid solar-powered electrocoagulation (EC) and electrooxidation (EO) process has been evaluated for its capability to remove color, total organic carbon (TOC), and chemical oxygen demand (COD). Aluminum (Al) and iridium oxide coated on titanium (IrO_2/Ti) were selected as anode/cathode for EC and EC-EO experiments, respectively. The results were evaluated based on the interaction effects of operating parameters of the treatment methods on the percentage of COD, TOC, and color removal. The hybrid EC-EO process obtained 97% COD, TOC, and color removal efficiency. In addition, the results of the combined spectroscopy analysis confirm the complete degradation of organic contaminants to carbon dioxide and water. Moreover, the optimum operating conditions are tested for real industrial wastewater effluents and show excellent performance in removing pollutants. Besides, the optimal working conditions were also evaluated using direct solar modules and showed comparable removal performance with conventional electricity. Thus, this study demonstrated that the treatment method using mesh IrO_2/Ti electrodes is a promising technology to meet the discharge limit for textile industrial effluents. Furthermore, this study can provide an effective solution for areas where electrical energy is an issue.

Keywords: Cotton textile wastewater, Hybrid electrocoagulation and electrooxidation, Solar powered, FTIR and NMR, Dye degradation extent.

Biodegradability of Non-biodegradable and Biodegradable Plastic through Circular Economy

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Abstract: Plastics are ubiquitous in nature. They are used almost in every fields of technology due to their longer durability, high tensile strength, elasticity and non-degradable nature. Today's world is known as "the plastic age". Accumulation of plastics in soil and water has shown harmful effects on agricultural plants by inhibiting plant growth. While, ingestion of micro and nano sized plastics through food chain causes dreadful diseases to humans and animals. Biodegradable plastics which are made up of biodegradable biopolymers can be a solution as biodegraders can utilize them as metabolic products and sole source of carbon and oxygen for their growth and proliferation. However, not all biodegraders are able to biodegrade biodegradable and non-biodegradable plastics completely. Indepth study is required to unwind complete biodegradation process by enzymes secreted by plants, bacteria, and fungi. This review highlighted few putative genes, alternatives of plastics, biodegradability assays, and pathways.

Keywords: *Biodegradation; plastics, microplastics, biodegraders*

Introduction

Biodegradation of non-biodegradable plastics releases small sized secondary pollutants in the form of microplastics (MPs) [1] as shown in Fig.1. These MPs accumulate around plant seed pores, result in germination delay and inhibit or slower the growth rate of terrestrial vascular plants [1]. Plastic additives such as, bisphenol A, and phthalates behave as endocrine disruptors [1]. Harmful impacts of plastics on humans include skin diseases, lung problems, dizziness, birth defects, reproductive defects, cardiovascular problems, genotoxic, gastrointestinal effect, respiratory diseases, vision failure, and irritation in the eye, cancer, liver dysfunction and neurodegenerative diseases. High-density plastics sink to the sediments whereas low-density plastics float on seawater. Internal tissues easily absorb small particles of plastics that can cross the blood-brain barrier. Inhalation, dermal contact and ingestion are three most common exposure pathways of micro and nano sized plastics in living organisms. Not all microorganisms have the capability to degrade plastics. Photodegradable and biodegradable plastics are the two main categories of degradable plastics. Both of them are different based on their mechanism, chemical and physical properties as well as degradability properties. Biodegradable plastics are usually composed of raw materials which include lignin, cellulose, starch and bioethanol. Polyhydroxyalkanoate (PHA), polyhydroxybutyrate (PHB), polyhydroxybutyrate valerate (PHBV), polylactic acid (PLA), polycaprolactone (PCL) are common biodegradable and commercially available natural polymers in the market as shown in Fig.2. Upregulation of 3-hydroxyacyl-CoA dehydrogenase (regulator of lipid transport and metabolism) promotes the synthesis of 3-hydrobutyryl-CoA and Lactyl-CoA which in turn enhances the PHB and PLA production as carbon storage respectively [2] as shown in Fig.3, Fig.4, and Table 1. Biodegradable plastics are ultimately not a promising solution to solve the global plastic pollution. Hydrophobic or water-insoluble polymers are very tough to degrade completely. For this reason, biodegradation process is the only technique which converts those hydrophobic polymers into disintegrated hydrophilic monomers and degrades them completely. Assays such as, pH-stat titration, visual observation, CO_2 production, O_2 consumption, activation sludge tests, weight loss are used to determine the capability of individual biodegraders.

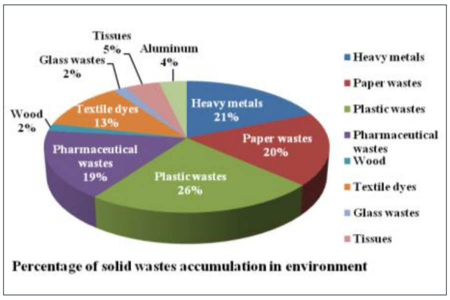

Fig.1. Percentage distribution of emerging solid waste pollutant accumulation in the environment.

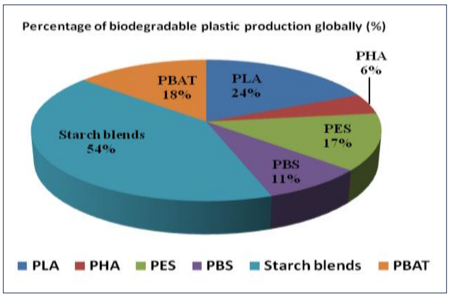

Fig.2. Percentage distribution of global biodegradable plastic production.

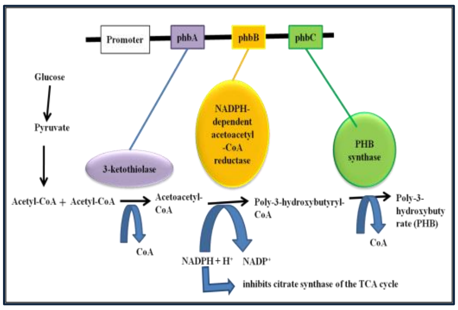

Fig.3. Genes and enzymes involved in the biosynthesis of polyhydroxybutyrate biodegradable polymer in microbial cell.

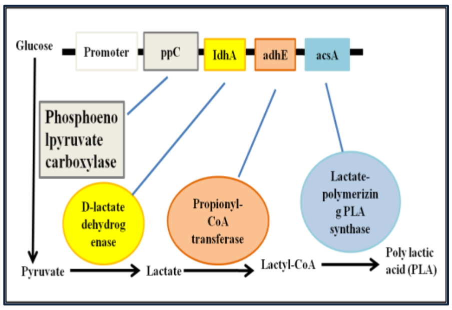

Fig.4. Genes and enzymes involved in the biosynthesis of polylactic acid biodegradable polymer in microbial cell.

Table 1. Potential genes and enzymes involved in plastic biodegradation

Polymer degrading Genes	**Enzymes**	**Polymer type**	**References**
relA	alarmonesynthatase	Polylactic acid (PLA)	[2]
tphA2	terephthalate 1,2-dioxygenase	Polyterephthalate (PET)	[3]

Factors influencing microplastic formation

Plastics are recalcitrant to degradation in environment and longer accumulation of them may result in microplastic formation. Abundance of MPs are present in ocean surface waters, deep sea regions, and coastal zones. Wave action, photodegradation, hydrolysis, migration, and sedimentation are the important factors for the MPs formation especially in aquatic environments as shown in Fig.5. MPs are not completely degradable. They are more hazardous than mesoplastics.

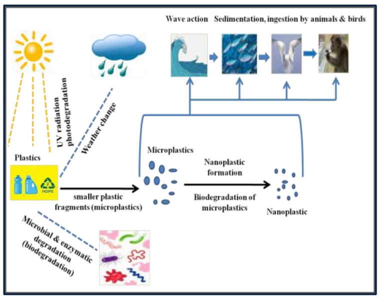

Fig.5. Mechanism and influensive factors involved in microplastic formation & accumulation in the environment.

Current scenario on biodegradation of microplastics

Biodegradation process involves mainly 4 steps, biodeterioration, bio-fragmentation, assimilation, and lastly mineralization. *Agromyces mediolanus* degraded PET-MPs efficiently within 168 days [4](Torena et al. 2021). Another research study has shown excellent removal efficiency of microplastics of polyethylene polymer by *Zalerion maritimum* [5] (Paco et al. 2017) as depicted in Table 2.

Table 2. Potential biodegraders for microplastic biodegradation

Biodegraders	**Microplastic type**	**Initial microplastics (MPs) concentration, or particle size**	**Biodegrader concentration**	**Incubation period**	**Temperature, and pH**	**Biodegradation efficiency (%)**	**Final weight loss (%)**	**References**
Agromyces mediolanus PNP3	PET-MPs	2.63 g/L	-	168 days	30^0C pH= 7-7.5	17%	5.3%	[4]
Zalerion maritimum	PE-MPs	0.130g	0.500g	14-28 days	25^0C	82.0%	20%	[5]

Conclusion

Putative genes like *alkM*, *tphA2*, & *relA* have distinct role in metabolic pathways during plastic biodegradation. TCA cycle is the major metabolic pathway for plastic biodegradation. It is an eco-friendly method. Researchers have used novel bio-additives during plastic formulation. These new bioadditives and fillers reduce the accumulation of plastics in aquatic and terrestrial environment. More emphasis should be on algal based biopolymer development & biodegradation. Development of suitable microbial based plastics will help to reduce the toxic effects from the environment. This study will inspire researchers to improve plastic biodegradation and to develop more alternatives of plastics.

Acknowledgement

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Utilization of Baobab Fruit Shell Waste as a Filler-Fibre for Enhancing Polyethylene Biodegradation and Improving Soil Fertility

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ABSTRACT. Herein, baobab fruit shell waste (BS) was used as a filler-fibre mixed with polyethylene (PE) and investigated for its biodegradation behaviour when used as a mulch. The BS was screened for impurities, crushed and mixed with PE at three levels (PE/BS: 95/5, 90/10, and 85/15 wt%) while using pure PE as the control. The extruded mixtures were characterized using scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDS), thermogravimetric analysis (TGA), and dynamic mechanical analysis (DMA), following standard methods. The results revealed that beneficial compounds and essential nutrients were found in the BS, which plants need, thus making it a potential source of plant nutrients when used as mulch. Also, TGA and mechanical properties analyses showed faster degradation of the new PE/BS compared to the control. Hence, it will be paramount if the BS and other organic waste can be further valorized into value-added products for environmental sustainability.

Keywords: *Baobab fruit shell; Polyethylene; Biodegradation; Micro-plastics; Soil fertility*

Introduction

Baobab (*Adansonia digitata*) is a majestic tree majorly found in the arid and semi-arid areas of sub-Saharan Africa, with most of its parts (fruit-pulp, seeds, leaves, and fibrous filaments) considered to have over 300 different applications ranging from medicine, food, building materials, and so on [1,2]. However, baobab fruit shell (BS), which occupies more than 80% of the baobab fruit [3], is considered waste and discarded indiscriminately, posing a danger to the environment. Currently, BS is poorly managed, and in some places, they are even burned in the open air, which negatively affects the environment in many ways (air, land, and water pollution) [4]. Interestingly, previous literature has found many beneficial compounds and essential nutrients in the BS and other parts of the baobab tree [5]. Some researchers have considered producing activated carbon from the BS to create economic value instead of just discarding it as a waste [4,6,7]. Thus, considering the benefits mentioned above and the potentialities of BS, it can therefore be considered a potential filler fibre that could enhance plant growth by providing the needed nutrients such as C, O, P, K, Ca, Na, Mg, Cu, etc. [8]. Also, when incorporated into the soil, if used as a filler fibre to produce mulch, the BS can help hasten the biodegradation of synthetic plastic materials, especially PE, mostly used in producing most of the currently available mulch.

Generally, the usage of mulch cover cannot be overemphasized, as it gives farmers many advantages by enhancing crop ripening and speeding its growth. Mulch covers are made from either low-density polyethylene (LDPE) or high-density polyethylene (HDPE), which can be black or clear in colour depending on the intended use (the black types warm the soil more than the clear types). However, there is a great challenge, especially when the materials become old and need replacement or after cropping season, which mostly ends with pieces of plastic buried in the soil [9]. Besides, the cost, management, and high-temperature generation under the mulch cover were additional disadvantages associated with plastic mulch [10], which will be investigated during our study. Therefore, this study aims to investigate the usability of BS mixed with PE to produce a mulch that can biodegrade faster than the conventional and readily available mulch in the market. The research also investigates whether the essential nutrients stacked in the BS can improve soil fertility by leaching the essential nutrients into the soil. During the analyses, standard methods and laboratory procedures were employed, such as scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDS), thermogravimetric analysis (TGA), dynamic mechanical analysis (DMA), and soil burial test.

Material and Methods

Materials

Baobab fruit shell (BS) was supplied from Kano, Nigeria, while the extrusion grade low-density biodegradable polyethylene (PE) was purchased from Dongguan Zhanyang Polymer Materials Co., Ltd. (Guangdong, China). The grinder, mixer, and characterization devices were all available at the Zhejiang University laboratories.

Methods

Synthesis and characterization of PS/BE blends

Before mixing, PE granules and BS were vacuum-dried for 24 h at 60 and 37°C, respectively. PE/BS at 95/5, 90/10, and 85/15 were dry-mixed using a laboratory mixer (GM-300, Retsch GmbH, Germany) at 1,000 rpm after grinding the BS into powder (approximately 90 mm mesh sieve). The various blends were then added into a batch mixer (CW Brabender, United States) at 180°C using a rotor speed of 20 rpm and extruded as reported in the literature [11]. Subsequently, the synthesized PE/BS blends were characterized using SEM, EDS, and TGA techniques and checking their mechanical properties, as reported elsewhere [11]. Pure PE was used in this study as the control. At least three replicates were considered during the analyses. Fig. 1 illustrates how the BS sample can be sourced from the baobab trees and how it ended up when considered as a waste.

Fig. 1. Illustration of how the BS is sourced from the baobab trees

Results and Discussion

Morphological and Elemental Characterisation of the PE/BS Blends and pure PE

Based on the result obtained following the characterization techniques stated above, it has been noted that the new PE/BS blend was enriched with some essential elements, as depicted in Fig. 2. These essential elements were uniquely in charge of metabolism in cells, and function as enzyme co-factors for structural stabilization of proteins as well as promoting denitrifiers' abundance in microbial cells [12,13].

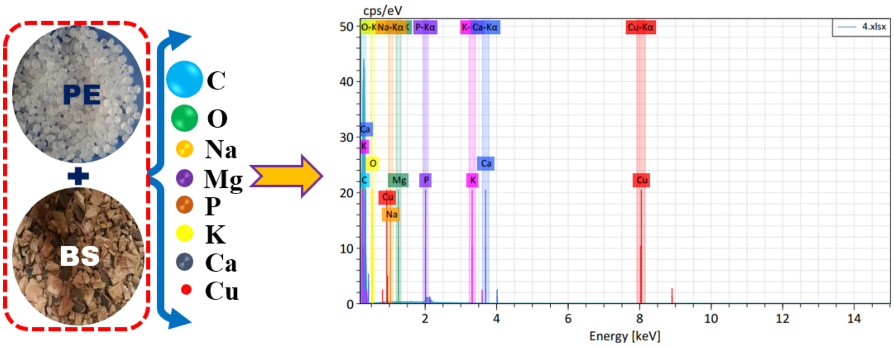

Fig. 2. Representative EDS images showing elemental contents of the PE/BS (only 85/15 wt% is shown)

Moreover, the SEM-EDS results (Fig. 3) depicts the morphology of PE/BS blends (Fig. 3b-d) and pure PE (Fig. 3a) to assess how the surface structure of the materials changes due to the incorporation of the BS. Coarser micro-voids can be seen occupying the surface of the pure PE (Fig. 3a). In contrast, smoother surfaces were observed in the case of PE/BS results (Fig. 3b-d) with the smoothness increasing as the BS ratio increases, which indicates that the PE/BS blends were more prone to degradation than the control (pure PE).

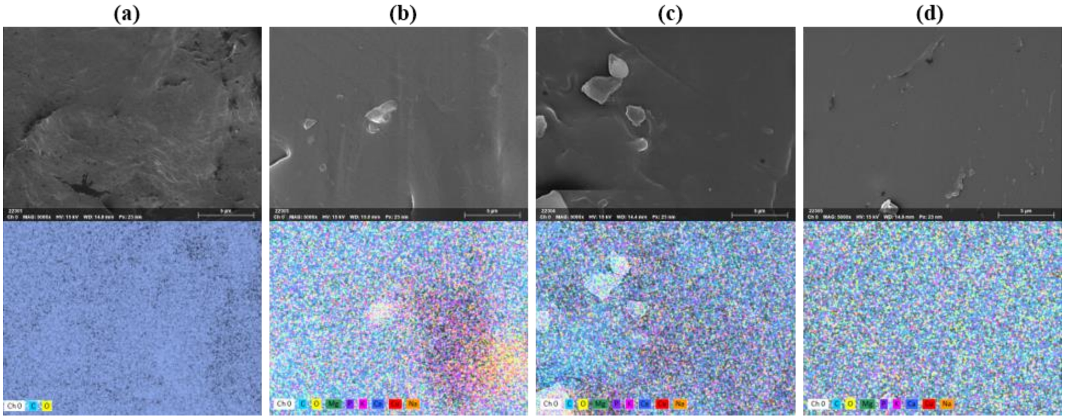

Fig. 3. SEM-EDS micrographs showing the elemental enrichment of (a) Pure PE and PE/BS blends at: (b) 95/5; (c) 90/10; (d) 85/15 wt%

Thermogravimetric and mechanical property analyses of the PE/BS Blends and pure PE

The TGA results, which show the thermal stability of the samples, revealed that the thermal degradation of the blends started at a much lower temperature compared to the control (pure PE). This indicates that the new materials will degrade faster than the pure PE if mulch is made from it. For the mechanical properties of pure PE and PE/BS blends (Table 1), it was discovered that both the tensile strength and the elongation of the PE were reduced as the weight ratio of BS was increased in the blend, which is consistent with when baobab was mixed with poly(butylene succinate [11].

Table 1. Mechanical properties of pure PE and PE/BS blends.

Materials	Tensile strength (MPa)	Elongation (%)	Young’s Modulus (MPa)
Pure PE	14.17	256.23	47.29
PE/BS(95/5)	11.55	114.00	58.68
PE/BS(90/10)	11.19	71.83	73.29
PE/BS(85/15)	10.67	52.76	86.27

PE- Polyethylene, BS- Baobab fruit shell

Conclusions

This study mixed pure PE with BS to produce PE/BS blends. As revealed by the TGA results, the addition of BS led to a decrease in the thermal stability of PE. The mechanical properties analysis of the samples showed a reduction in the strength of pure PE as the BS ratio increased. Besides, the SEM micrographs revealed improvements in degradation rates and enrichment of pure PE with some elements, as evidenced by the EDS. Thus, in the future, BS’s potential to enhance soil fertility and improve the degradation of synthetic plastic materials will be broadly studied.

Acknowledgement

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Fe^{3+} Addition for Enhancing the Formation and Stabilization of Aerobic Granular Sludge

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Aerobic granular sludge (AGS) has grained great attention due to its good settling property and high pollutant removal efficiency. However, it was found that AGS requires longer time to form the granular and has poor stability when it is used to treat wastewater with low COD concentration such as municipal wastewater. In this study, Fe^{3+} was employed to enhance the AGS formation and stabilization to treat municipal wastewater. During the cultivation of AGS, 3~5 mg/L of Fe^{3+} was continuously added. The results showed that Fe^{3+} addition accelerated the formation of AGS cultivated with simulated domestic sewage (COD 250~300 mg/L), and the granulation was achieved in 7 days, and mature AGS was cultivated on 25 days. However, AGS was not formed until 25 days in the control group without Fe^{3+} addition. After the AGS was matured, it was used to treat the synthetic municipal wastewater. It was observed that the continuous addition of Fe^{3+} was beneficial to the stability of the AGS, while the mature AGS without further addition of Fe^{3+} gradually disintegrated. After continuous operation for 300 d under the optimized parameters, AGS has achieved stable removal on COD, NH_4^+-N, TN and TP which were 90%, 94%, 69% and 42%, respectively. The study reveals that Fe^{3+} addition has shortened the AGS formation period and improved the stability of AGS. It provides a solution for AGS application to treat municipal wastewater.

Keywords: Municipal wastewater, Granulation, Stabilization, Long-term operation.

Optimum Strategies Of Regional Kitchen Waste Treatment Against A Background Of Carbon Mitigation

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Kitchen waste treatment (KWT) accounts for 6% of the global carbon emissions. Reducing the carbon emissions of KWT is regarded as an effective way to achieving the goal of carbon mitigation. In order to realize the carbon emission targets of our country, it is necessary to study the carbon emission characteristics and carbon emission reduction path of kitchen waste management system. In this study, a hybrid method, combining life cycle analysis (LCA), Copula functions and an interval linear programming model, was proposed. The carbon emissions of four technologies (i.e., landfilling, incineration, anaerobic digestion, and composting) for KWT were evaluated based on the LCA framework. Strategies for the multiple technologies were obtained using the interval linear programming model. This method can effectively identify the potentials for carbon mitigation in the KWT technologies with consideration of their eco-economic performance. To confirm the effectiveness of the method, a case study was conducted in the urban agglomeration of the Zhaoqing City of Guangdong Province in China. According to the characteristics of different treatment technologies, reduction strategies (combined incineration and landfill with biochemical treatment technologies) and simple strategies (combined landfill with biochemical treatment technologies, and landfill with incineration) were considered in this study. The results showed that the contribution of energy recovery efficiency and carbon mitigation would be the most obvious in anaerobic digestion combined with other treatment technologies. The optimization results showed that the performance of economic and carbon mitigation in the reduction strategy would be better than that in the simple strategy. Under the background of carbon mitigation, the application ratio of incineration and landfill combination, anaerobic digestion, incineration and landfill combination, as well as aerobic composting, incineration and landfill combination in 2025 would be 82.04%, 3.03% and 14.92%, respectively.

Keywords: Kitchen waste, Carbon emissions, Life cycle analysis, Interval linear programming models, Zhaoqing City.

Influence of C_{14} Alkane Stress on Cd and Nutrient Elements Uptake By Four Potential Petroleum Hydrocarbon Remediation Plants

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With the rapid industrialization and urbanization, soil contaminated with cadmium (Cd) and petroleum hydrocarbon has become a severe environmental and human health concerns. Petroleum hydrocarbon is a complex mixture of hydrocarbons, among which short chain alkane is a kind of pollutant with high component content and high toxicity. Thus, the influence of C14 alkane on growth, mineral nutrient elements uptake, and Cd uptake characteristics of four potential petroleum hydrocarbon remediation plants (*Lolium perenne* L. (ryegrass), *Ricinus communis* L. (castor bean), *Amaranthus hypochondriacus* L. (amaranth) and *Mirabilis Jalapa* L. (marvel of peru)) were investigated. The results indicated that the dry biomass yield of shoot and root of four plants gradually decreased with the increasing of C14 alkane concentration. The growth inhibition ratios of shoot and root at 1% treatment exceeded 60% and 40%, respectively. The interesting result is that C14 alkane elevated the concentration of Cd in the shoot of plants. 0.1% and 0.2% C14 alkane treatment increased ryegrass and amaranth Cd concentration in shoots. When the C14 alkane concentration increased to 0.5%, the Cd concentration in shoot of castor bean significantly increased 1-fold. The Cd uptake amounts of ryegrass and marvel of peru significantly elevated at 0.1% C14 alkane treatment, then gradually decreased with the increase of C14 alkane concentration. The Cd uptake amounts of castor bean and amaranth significantly decreased in the presence of C14 alkane. The C14 alkane treatment also significantly affected the nutrient elements concentration in shoot and root. It is noteworthy that C14 alkane treatment significantly increased the manganese (Mn) concentration in shoot and root of the four plants. The increase of soil DTPA-Cd and Mn concentration may be an important reason for the increase in plants Cd and Mn concentration. However, the inhibition of plant growth by C14 alkane reduced the Cd uptake by plants. This study provides a theoretical basis for understanding phytoremediation of Cd- C14 alkane co-contaminated soil.

Keywords: Soil, Cadmium, C14 alkane, Phytoremediation, Nutrient elements.

Carbon-Driven Persulfate Activation for Nonradical Antibiotic Degradation in Aquatic Surroundings

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Carbon-driven nonradical persulfate activation exhibits compelling advantages due to its good reactivity in complex aquatic surroundings. However, the catalytic capability of pure carbonaceous materials is dissatisfied. To seek the eco-friendly and efficient carbon-based persulfate activator, the following work was conducted. Enhanced adsorption and persulfate-driven oxidation of pollutant were simultaneously achieved on single boron-doped carbon, originating from a facile pyrolysis of glucose and boric acid. Boron with vacant p orbital can act as Lewis acid site to increase the adsorption capacity. High catalytic activity toward persulfate was attributed to the generation of carbon-based structural defects, and BC_3/BC_2O functionalties induced by B doping. Of note, the adsorptive and catalytic behaviors were significantly affected by B doping amount. With 0.82% B (CB-0.9), the best performance of 96.1% removal efficiency and 79.7% mineralization rate were obtained within 90 min by degrading sulfamethoxazole (SMX). Correspondingly, the rate constant (k_{obs}) was up to 0.0340 min^{-1} and the adsorption capacity was 56.20 mg g^{-1}. Furthermore, our findings suggested that adsorption positively promoted the subsequent oxidation. The effects of inorganic anions, pH, humic acid, and real water matrix were investigated. Combined with LC-MS analysis and frontier molecular orbital theoretical calculation, six possible degradation pathways were proposed. The toxicity effects of intermediate and parent SMX were monitored by the growth inhibition of Chlorella. Radical and non-radical pathways jointly resulted in the catalytic degradation of SMX, in which $^1O_2$ dominated the oxidation, $SO_4^{\cdot -}$/$^{\cdot}OH$/direct electron transfer process played the secondary role, and $O_2^{\cdot -}$ served as the precursor for $^1O_2$ production.

Keywords: Persulfate, Advanced Oxidation Processes, Carbocatalyst.

Odor Emission Characteristics from Unorganized Source of Kitchen Waste Management Plant and Control Strategy

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ABSTRACT. Odor emission has become a great issue for kitchen waste management plants. The complain from public requires responsible response. Odor emission from unorganized sources are the key problem. It is necessary to understand the odor emission characteristics and proper control solution is highly demanded. In this study, a typical kitchen waste treatment plants located in Guangdong Province of China was selected. The unorganized odor emission source of the treatment plant was the pretreatment workshop. The samples were collected and the odor concentration was measured and analyzed by three-point comparative odor bag method. Quantitative analysis of all aspects of the odor concentration were analyzed by three-stage cold trap, high/low resolution gas chromatography mass spectrometry (GC-MS) and liquid chromatography. The results showed that 105 odorous gases were detected in the plant. Sulfur compounds, oxygen-containing organic compounds and terpenes were the main odorous gases. Ethanol, acetic acid, methylmercaptan, α-pinene, methioether and limonene. were the main odorous pollutants treated by threshold dilution ratio analysis. Based on grey correlation, principal component analysis (PCA) and step-up regression analysis, methyl mercaptan was found to be the most closely related to the odor concentration. The CFD stimulation was employed to optimize the pretreatment workshop entrance design and the air exchange system, the setting of 45° inclined suction tuyere was helpful to reduce the control of odor release. The study provides the clear cause of odor which assists researchers to target the treatment.

Keywords: *Kitchen waste; Threshold dilution ratio; Typical malodorous substance; PCA; CFD*

1. Introduction

Since 2005, the whole country, led by Shanghai, has begun to implement measures for the disposal and management of restaurant -kitchen waste. In 2008, the Ministry of Housing and Urban-Rural Development put forward technical requirements for the recycling of restaurant -kitchen-waste. Since then, the number of pilot plants and the disposal capacity of restaurant -kitchen-waste have been greatly increased. In the process of treatment, restaurant -kitchen waste will undergo dehydration and fermentation after collection, storage, transportation, discharge and crushing, and finally be used for landfill, incineration, feed, compost, fuel and other purposes, so as to realize the resource utilization and treatment of restaurant -kitchen waste [1-4]. In the process of its treatment, the odor pollution problem has become a major environmental hazard factor. According to the Analysis of National Odor/Odor Pollution Complaints from 2018 to 2020, the odor gas problem of kitchen and garbage accounts for more than 16.3% of the total environmental problems. The malodorous gases produced by the treatment of kitchen waste mainly include hydrogen sulfide, ammonia, methyl mercaptan, methyl sulfur, dimethyl disulfide, carbon disulfide and other substances with acute toxicity. Generally speaking, malodorous gas will cause discomfort to human sense of smell and lead to some functional diseases, such as dyspnea, anorexia, insomnia, memory loss and irritability, when living in an environment polluted by malodorous gas for a long time [5-7]. In addition, high levels of odor can cause serious illness and even death, for example, if inhaled at slightly higher levels of hydrogen sulfide, it can be fatal in a short time. In addition, low concentrations of hydrogen sulfide can affect the eyes, respiratory system and central nervous system [8]. Wang Pan et al. detected a total of 60 kinds of organic substances in the odor gases produced by the food waste feed processing plant, among which ethanol, acetaldehyde, propanal, ethyl acetate, limonene, α-pinene, β-pinene, methylmercaptan and dimethyl disulfide were the main characteristic pollutants [9]. ZHANG et al. investigated and analyzed odorous substances in kitchen waste composting plants and found that odorous pollutants were mainly hydrogen sulfide, dimethyl sulfide, carbon disulfide, dimethyl disulfide, 1, 3-dimethyl benzene and o-xylene [10]. Zhang Yan et al. analyzed the test results of three restaurant processing plants in Xining, Ningbo and Beijing, and determined that ethanol, limonene, hydrogen sulfide, methyl mertan, methyl sulfide, dimethyl disulfide, acetaldehyde and ethyl acetate were typical odor substances in these three enterprises [11]. Therefore, the effective identification of odor gases is of great significance.

This study investigated the problem of odorous gas leakage in a kitchen factory in Shenzhen, conducted sampling and detection on the pretreatment workshop and the residue dewatering room with unorganized discharge, explored the emission characteristics of odorous gas, and carried out calculation and simulation on the control of odorous substance leakage, hoping to provide support for the selection and application of deodorization process.

2. Material and Methods

2.1 Sample collection

The pretreatment workshop and the residue dewatering room of Plant A of Shenzhen Restaurant Kitchen Waste Treatment Plant were selected with the same process. Samples were taken in autumn 2022 and spring 2023 respectively at the temperature of 20℃ and 27℃. Each point was sampled twice in different periods, and one parallel sample was taken each time. The workshop with odor protection facilities is not considered this time, so the sampling point is set in the middle of the working surface. Since the biochemical treatment of kitchen waste is carried out in the workshop, other environmental factors such as wind speed, wind direction, humidity and ultraviolet light during sampling have no significant influence on the results.

2.2 Test method

For the whole-substance analysis of samples, different detection methods were adopted for different substances, as shown in Table 1 below.

Table 1. Detection methods of gas samples

Test item	Test method
Total analysis	Three stage cold trap/high resolution gas chromatography mass spectrometry
Sulfides (11 kinds), terpenes, alcohols, esters (19 kinds)	Three stage cold trap/gas chromatography mass spectrometry
Nitrogenous compounds (5 kinds)	Gas chromatography
Organic acids (7 kinds)	Thermal desorption/gas chromatography mass spectrometry
Aldoketones (15 kinds)	Liquid chromatography

2.3 Model building

According to the actual layout of the plant, a three-dimensional model of the pretreatment workshop was established, as shown in Figure 1. The quadrilateral grid is used to divide the physical model, and the grid division of the pretreatment pool, the exhaust outlet and the door is locally encrypted to ensure the calculation accuracy. The exhaust outlet is set as the speed inlet (negative value), the intake outlet (discharge door) is set as the pressure inlet, the leakage outlet is set as the mass inlet, and the other parameters remain default. The basic equations based on the calculation process include continuity equation, component transmission equation, etc., and the standard k-ε model is adopted [12,13].

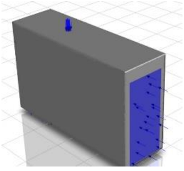

Fig.1. Calculation model of preconditioning workshop in food processing plant

3. Results and Discussion

3.1 Characteristics of volatile gases

A total of 105 kinds of substances were detected in the quantitative analysis of gas samples from plant A, including 11 types of substances such as alkanes, alkenes, halogenated hydrocarbons, benzene series, esters, aldehydes, ketones, alcohols, sulfides, organic acids and nitrogen compounds.

In spring, a total of the above 11 types of substances were detected in the gas samples of the pretreatment workshop, among which alcohols accounted for the highest mass percentage, reaching 63.91%, followed by organic acids, aldehydes and esters, accounting for 13.49%, 6.94% and 6.68%, respectively. Nitrogen-containing compounds and other 6 kinds of substances accounted for 8.98%, as shown in Figure 2; The dewatering room of spring residue, pretreatment workshop of autumn residue and dewatering room of autumn residue are shown in Figure 2. In terms of the complexity of gas samples, the order from most to least is spring pretreatment workshop = spring residue dehydration room > autumn residue dehydration room > autumn pretreatment workshop.

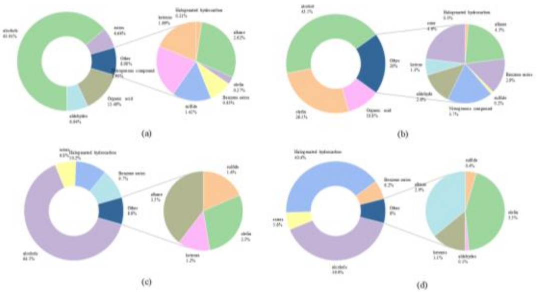

Fig.2. (a) Characteristics of volatile gases in spring pretreatment plant; (b) Characteristics of volatile gases in pretreatment workshop in autumn; (c) Characteristics of volatile gases during dehydration of residues in spring; (d) Characteristics of volatile gases during dehydration of residues in autumn

To sum up, there are some obvious differences in gas sample types at different periods, which may be related to people's living habits. In spring, the odor pollutants of gas samples are mainly alcohols, aldehydes, organic acids, esters and alkenes. In autumn, alcohols, esters, halogenated hydrocarbons and benzene series are the main substances, and alcohols and esters occupy a considerable proportion in the odor gases of the two plants.

3.2 Threshold dilution multiple analysis

At present, the stink pollution management is gradually improving in China, and the stink of kitchen waste is still dominated by VOCs [14]. It is found in Table 1 that according to the current Emission Standards for Odorous Pollutants (GB14554-1993), the concentrations of odorous substances (such as ammonia, hydrogen sulfide and styrene, etc.) specified in the current standards meet the corresponding requirements, and the simple substance concentration cannot largely determine the source of odorous substances. Considering that odorous gases mainly affect people's sense of smell, in order to further highlight the degree of irritation of odorous gas pollutants and the odorous gases to be controlled first, domestic and foreign researchers have introduced olfactory threshold as an evaluation index, that is, the lowest mass concentration value that can cause people's olfactory response, and carried out related studies such as the determination of odor threshold [15-17]. In order to confirm the contribution rate of each odor gas more objectively, the odor threshold of each odor gas is taken as a reference, and the ratio of substance concentration to odor threshold, i.e., the threshold dilution ratio, is used to display the contribution rate of each odor gas [16,18]. The larger the threshold dilution ratio is, the greater the odor contribution rate will be. Through the analysis of threshold dilution factor, the difference between different workshops at different time periods was obvious. Ethanol was a common characteristic substance. From the perspective of substance type and quantity, the pretreatment workshop in spring was > autumn pretreatment workshop > spring residue dehydration room > autumn residue dehydration room. In spring, the highest threshold dilution times were acetaldehyde and acetic acid, which were more than 150, followed by ethanol, methyl-2-allyl disulfide, diallyl disulfide, n-butyl aldehyde, acetaldehyde, α-pinene, allyl methyl-sulfur, glutaraldehyde, methioether, limonene and ammonia. According to the threshold dilution ratio, acetic acid > α-pinene > limonene > ethanol > n-butyl aldehyde > methyl-2-allyl disulfide > glutaraldehyde were the seven substances in the dehydration period in spring. In autumn, the pretreatment plants were hydrogen sulfide > ethanol > methylmercaptan > α-pinene > methylsulfide > toluene > dimethyl disulfide > limonene. The dehydration sequence of autumn residue was methyl mercaptan > ethanol > butyl acetate > limonene > α-pinene > methyl sulfide. From the point of view of the same time period, the number of main substances in the workshop is different, which may be related to the gradual classification and reduction of kitchen waste in the process of treatment, resulting in the reduction of the number of odor gases, and the corresponding threshold dilution multiple is also reduced. From the different phases, the odor gases in spring were mainly oxygen-containing organic compounds, followed by sulfide and terpene. Thirteen typical odor substances, such as acetic acid, hexal, ethanol, diallyl disulfide, n-butyl aldehyde, acetaldehyde, α-pinene, allyl methyl sulfide, glutaraldehyde, methyl-2-allyl disulfide, methioether, limonene and ammonia, could be considered as typical odor substances. In autumn, sulfur compounds were the main substances, followed by oxygen containing organic compounds, terpenes and benzene. Hydrogen sulfide, ethanol, methyl mercaptan, α-pinene, methyl sulfide, toluene, dimethyl disulfide, limonene and butyl acetate were considered as the typical odor substances. To sum up, the odor gases in Shenzhen A plant are mainly sulfide, oxygen-containing organic matter and terpene. Due to the current situation of unorganized discharge in some restaurant -kitchen waste treatment plants in Shenzhen, the typical odorous substances in the unorganized discharge facilities of restaurant -kitchen waste treatment plants were initially considered as ethanol, acetic acid, methylmercaptol, α-pinene, methioether and limonene, taking the threshold dilution ratio as the final index and substance concentration and toxicological properties as auxiliary indexes.

3.3 Grey correlation degree/Principal component (PCA)/stepwise regression analysis

According to grey correlation analysis[19,20], the top ten substances were methyl mercaptan, butyl acetate, toluene, methyl sulfide, ethanol, dimethyl disulfide, hydrogen sulfide, limonene, a-pinene and acetaldehyde in order of correlation degree. Principal component (PCA) [19,21] analysis showed that due to the small number of samples, the effect was not significant enough, and the KMO test and Bartlett test values were not ideal. obtained by stepwise regression analysis[19, 22], the result analysis of F test showed that the significance P value was 0.013, showing horizontal significance, rejecting the original hypothesis that the regression coefficient was 0. For the collinearity of variables, VIFs are all less than 10, so there is no multicollinearity problem in the model, and the model is well constructed, as shown in Figure 3. Model of the formula is as follows: $y = 1334.077 + 823.359 \times$ methyl mercaptan.

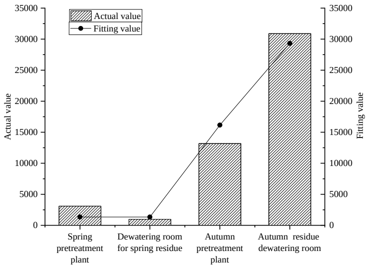

Fig.3. Stepwise regression fitting effect

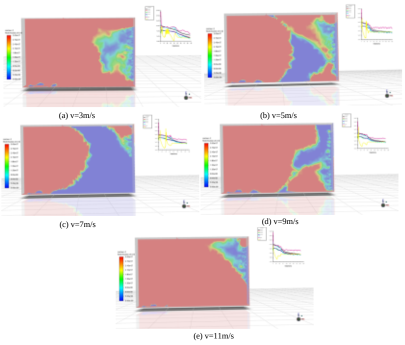
(a) v=3m/s
(b) v=5m/s
(c) v=7m/s
(d) v=9m/s
(e) v=11m/s

Fig.4. Cloud map of odor concentration distribution under inclined suction tuyere with different blowing velocity

3.4 Additional simulation of suction measures

Change the wind direction of the suction tuyere to 45° oblique downward, that is, set the components of x and z directions to 0.5. Simulation was carried out under the wind speed of 3m/s, 5m/s, 7m/s, 9m/s and 11m/s, and the cloud diagram of odor concentration distribution was obtained, as shown in Figure 4. According to FIG. 14, it can be seen that under the condition of v=7m/s, the odor is basically concentrated in the left area of the pretreatment room. The distance between the boundary of the odor body and the unloading door can be up to 6m or so, which can well reduce the odor leakage caused by the temperature influence or external interference and other conditions.

Conclusions

A total of 105 odorous pollutants were detected in the gas samples from Shenzhen Plant A. Based on the survey data and analysis results, it was found that ethanol, acetic acid, methylmercaptan, α-pinene, methioether and limonene were the main odorous substances to be treated. The gray correlation, principal component (PCA) and stepwise regression analysis showed that methyl mercaptan was closely related to odor. CFD software was used to analyze the model, and it was found that under the condition of 45° oblique suction air, the odor leakage caused by temperature influence or external interference could be well reduced.

Acknowledgement

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Electrolytic Treatment of Septic Tank Sludge

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Septic tank systems are the most used treatment systems for the treatment of domestic wastewaterfrom isolated residences. The septic tank system produces sludge and scum due to sedimentation. The BFS is generally untreated due to the lack of methods for its management and treatment.

This project aims to treat, stabilize, and condition the septic tank sludge by electrolytic means andthis, by in situ generation of a bactericidal oxidant. This electrolytic system should allow the elimination of organic and inorganic molecules that generate foul odors while improving the filterability of septic tank sludge. The dehydrated sludge can then be reused as compost or for soilamendment in agricultural areas.

For this purpose, an electrochemical reactor of parallelepipedal type (500 mL of useful volume) including respectively electrodes, graphite cathode (surface of 110 cm²). Two types of anodes weretested, one of boron-doped diamond (BDD, active surface of 65 cm²) and titanium coated with ruthenium oxide (Ti/IrO2, active surface of 65 cm²) were used. The initial pH was set at 4 while imposing current intensities between 0.2A and 1A for electrolysis times varying between 10 and 40 min.

Following the electrochemical treatment, the sludge was flocculated with an organic polymer Percol 789 (Cationic polymer) at concentrations between 1 and 5 kg/tbs. A vacuum filtration unit including a Bruckner and a 25µm fiber filter is used for sludge dewatering.

The septic tank sludge came from the Neuville eco-center located in the Quebec City area. The initial total solids concentration of the sludge varied between 15 and 17 mg/L (1.5 to 1.7 % solids).

The application of electrochemical treatment improved the filterability of the septic tank sludge. A dryness of 28% was recorded following the application of electrochemical treatment, comparedto a dryness of 8% obtained with untreated sludge, but flocculated only. This increase in dryness allows for an 80% reduction in the mass of sludge generated. Additional analyses will have to be carried out to evaluate the sludge stabilization from a microbiological point of view (capacity to eliminate total and fecal coliforms) and the deodorization of the sludge while maintaining the fertilizing properties of the septic tank sludge.

Effect of Partial Replacement of Feed with Biofloc on Water Quality and Growth for Indian Major Carp (IMC) Culture

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The basic principle of the biofloc technology (BFT) is the retention of waste and its conversion to biofloc as a natural food within the culture system. Biofloc technology has recently gained attention as a sustainable method to control water quality, with the added value of producing proteinaceous feed *in-situ*. The present study was conducted to design an optimum feed mix for growth of Indian Major Carps (IMC) in light limited indoor culture with biofloc as a component along with commercial fish feed. Five numbers of tanks of individual capacity 1000 L was utilised for producing biofloc using aquaculture effluent from a nearby carp culture pond. Fifteen different feed mixes were prepared using fish feed and biofloc in dry (4% moisture content) and wet (90% moisture content) form at different proportions and used in feeding trials (three replications) conducted in 45 nos. of 50 L capacity glass aquarium stocked with three nos. of IMC fingerlings with average individual weight of 20 g for a period of 90 days. Fish survival was 100% in all the treatments. Mixture design was used to obtain a solution of best combination of feed source to obtain the optimum growth parameters of IMC. Optimum growth parameters (net yield, specific growth rate, protein efficiency ratio and feed conversion ratio) of IMC were obtained at feed mix containing 50% commercial feed and 50% wet floc. The nutritional quality of biofloc was found to be quite suitable for IMC. The images of 3-week-old biofloc captured in scanning electron microscope (SEM) indicated the presence of different types of bacteria, algae, protozoa, rotifers, etc.

Keywords: Biofloc, IMC, Dry floc, Wet floc, Mixture design.

Development of An Electrolytic Process Dedicated to the *In-situ* Treatment of Septic Sludge as An Adaptation Measure to Climate Change

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This research is part of the technological development useful for the management of septic sludge. By way of establishing a circular economy combined with an adapting approach to climate change, this work is based on exploiting the potential of decentralized electrolytic treatment of these residual effluents. Conventionally, the emptying of septic tank sludge is an essential activity ensuring the sanitation of isolated residences but generates non-negligible impacts in terms of greenhouse gas emissions since the emptied sludge must be transported, by vacuum trucks, to centralized processing centers. Beyond the costs associated with the transport of these effluents and their treatment, several municipalities complain of the emptying lack on their territory, due to the limitations of the management capacity and the workforce, which generates serious contamination of the surrounding environment.

In the light of this work, by following a parametric study followed and statistical modelling, the decentralized electrolytic treatment of septic sludge makes it possible to limit the travel of vacuum trucks by around 40%, and consequently makes it possible to reduce greenhouse gas emission. The treatment channel studied consists of stabilizing the sludge by electrooxidation, conditioning it by adding cationic polymer and dewatering it by filtration under pressure. The dry matter content of the sludge is increased by an average factor of 5.3, which implies a final dryness around 37.5%. In addition to the conventional approach, this system also ensures the complete disinfection of sludge, the elimination of odors and the improvement of the filterability structure. The operating costs related to this treatment, including the mobility of the system, its consumption of electricity and polymer, are 4 times lower than the conventional approach. Downstream of the treatment, this process makes it possible to take advantage of the physico-chemical properties of the dewatered sludge instead of their conventional disposal either by incineration or by burial. The resulting cake, namely dehydrated sludge, can be reused as a soil amendment since it is rich in nutrients. With a view to CO_2 sequestration, the resulting cake can be hydrothermally carbonized to produce hydrochar. The latter is considered as carbon sink but can also be used, under certain conditions, as a fertilizer or a source of energy.

Keywords: Septic sludge dewatering, Decentralized electrolytic treatment, Sludge valorisation, Carbone sequestration.

Characterization and Valorization of Marine Sediment

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Large volumes of marine sediments are dredged annually in ports, but changes in regulations will tend to restrict their disposal at sea. The recovery of part of these sediments as raw materials s in the feld of construction help to limit their storage and give them added value. Our study is then oriented towards the caracterization and the valorization of marine sediment.

This work focuses on the feasibility of using dredged marine sediment from TENES port as partial replacement of sand in mortar. Physical, chemical, mineralogy, and rheology characterization were carried out. This study revealed that the substitution of sand by sediments can be considered as a suitable option of their valorization. This solution should have a great economic and environmental interest.

Keywords: Marine sediment, Characterization, Valorization, Mortar.

Insights on Comprehensive Qualitative and Quantitative Approaches for Diverse Microbial Community Analyses, Wastewater Characterization, and Biochemical Process Performance of Full-scale SBR Plant in Roorkee, India

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This study was dedicated to a detailed analysis of the 3-MLD capacity full-scale SBR treatment plant installed at IIT- Roorkee to investigate the activated sludge communities and the insights into the processes that govern their presence and growth. This is one of the original comprehensive long-term investigations of the microbial community in the full-scale wastewater treatment plant in India, where conventional identification, molecular identification by quantitative 16SrRNA Ilumina-based metagenomic sequencing of anoxic selector compartments and aeration tank, and extensive process information related to treatment plant design and process performance have been compiled. Additionally to many other well-established factors, local conditions are elementary conditions of sharp change studied in wastewater characteristics from place to place. Pre-anoxic selector-equipped sequencing batch reactors (SBR) perform efficiently in removing different water quality parameters and Fecal Coliforms. The supervision of 3-MLD Full-scale SBR established at IIT, Roorkee, drew interest to the processes concerning simultaneous nitrification and denitrification (SND) and biological phosphorous removal (BPR) undergoing with the deviations in influent wastewater, particularly the readily biodegradable COD (rbCOD), and their effects on the microbiota.
Customary examining of all the SBR units for a period of two years disclosed that on the whole average removal efficiencies were >94% COD, >95% BOD_5, >95% TSS, >96% NH_4^+-N (0.7 ± 0.5 mg/L in effluent), >86% TKN, >69% TN (9.7 ± 3.0 mg/L in effluent), >42% Ortho-PO_4-P (1.6 ± 0.5 mg/L in effluent) and >46% TP and achieved <50 MPN/ 100 mL fecal coliform in the final effluent after disinfection. Anoxic tri-sectional selector and an aeration tank constituted one SBR followed by the other availed 76 ± 9% SND at rbCOD/ TCOD ratio of 0.12 ± 0.04 (R^2= 0.8 and $p<0.001$), rbCOD/ sCOD of 0.33 ± 0.10, sCOD/ TCOD of 0.35 ± 0.10, and COD/TN of ~12.8. The sludge volume index (SVI) of the aeration sludge was <50 mL/g. The qualitative optical microscopic experiments showed intracellular polymers (polyhydroxy butyrates (PHB) and polyphosphates), protozoa, floc morphology, and few types of filamentous bacteria (*Microthrix parvicella*, *thiothrix*, and *Nostocoida limicola)* in the sludge of the plant. Advanced three months' study by lowering SRT to 10days reduced the $TP_{effluent}$ to 1.7 mg/L. The microbial community dynamics after 16SrRNA analysis of the biomass revealed the presence of ammonia oxidizers (22%), nitrite reducers (5%) and denitrifiers (10%), sulfate-reducing bacteria (2%), and potentially resembling polyphosphate accumulating organisms (16%). Organic compounds oxidizers, i.e., Alphaproteobacteria, include the species of nitrifiers (*Nitrosomonas*, *Nitrospira*, and *Nitrospirillum*), and the species of *Pseudomonas*, *Rhodococcus, Flavobacterium*, and Beta proteobacteria class were liable for the denitrification process. The major genera responsible for P-removal were observed as *Acinetobacter, bifidobacterium,* and *Paracoccus*. Both the anoxic-aerobic sequential phases have benefitted the plant for higher treatment quality and proper growth of functional microorganisms; moreover, the influence of wastewater characteristics played a significant role. The study clarifies the degree of variations in wastewater and the composition of microbes are the key factors for laying out an optimized treatment system for COD, Nitrogen, and Phosphorus removal for the decentralized systems in the Indian scenario.

Keywords: Bio-selectors, Polyhydroxybutyrates, Readily biodegradable chemical oxygen demand, Sequencing, Sequencing batch reactors.

Circular and Green Economy in Solid Waste Management

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Biochar is a key solution to handle and manage the solid wastes generated from industries. It is a charcoal-like substance that is made by treating solid wastes in a controlled process called Thermal Cracking. Biochar has various applications such as adsorbent, fuel, fertilizer etc. The advantages of char over sludge are that raw sewage sludge cannot be applied or stockpiled directly to the land but biochar can be directly applied. Because, char does not have any pathogens so will not contaminate the land and grazing animals. Also, the calorific value of char is higher than that of sludge so it can also be used as fuel. Managing the solid wastes with current methods such as Land filling, Incineration, Stockpiling has many environmental issues such as risk of nutrient leaching, greenhouse gas emissions etc. Results based on the reaction carried out in our Rotary Kiln reactor with 10 kg of feed shows a 62 to 68 % conversion of STP sludge into biochar. Also, application of biochar as a fertilizer in different ratios carried out in mustard plant showed good results in the plant growth. The best way to manage sludge is to convert it into biochar and utilizing it as a fuel or fertilizer. On processing the bio solids, one not only could produce valuable biochar but also could reduce the quantity of waste disposals. It also makes much profit for the industries by reducing the energy needs and the cost on waste disposal. The production of char from solid wastes comes under circular economy and follows 3R system (Reduce, Reuse and Recycle) and thus will be sustainable resources.

Keywords: Solid waste, Biochar, Thermal cracking, Circular economy, Sustainable.

A Study on Improving the Mechanical Properties of Asphalt Concrete by Using EAF Stainless Steel Slag

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Along with the rapid growth of Taiwan's economy, the volume of road traffic has been continuously rising which leads to the fact that the strength of the current asphalt concrete can no longer support the present and future traffic load. Under the context of the United Nations' active promotion of the Sustainable Development Goals (SDGs), people around the world have gradually begun to focus on issues of the sustainability of resources. This study uses a by-product of steelmaking which is EAF stainless steel slag to replace fine natural aggregate with 0%-40% substitution to improve the mechanical properties of asphalt concrete. This study uses Marshall design to find the optimum asphalt content, and evaluate the effect of EAF stainless steel slag on the mechanical properties of asphalt concrete by conducting tests such as stability value, indirect tension, residual strength by water immersion, modulus of rebound, and latent change. According to the results of the tests, the optimum oil content of asphalt concrete decreases with the increases of EAF stainless steel slag substitution, which is helpful to reduce the total cost of asphalt concrete. Asphalt concrete containing EAF stainless steel slag has better resistance to water damage than the one without, and the resistance to water damage increases with the amount of the substitution of EAF stainless steel slag. According to the test results of stability value, indirect tension, modulus of rebound, and latent change, the strength and the resistance to deformation of asphalt concrete increase with the increase of EAF stainless steel slag substitution, and therefore indicates that the EAF stainless steel slag will help to improve the mechanical properties of the asphalt concrete.

Keywords: EAF stainless steel slag, Asphalt concrete, Mechanical properties.

Preparation of Purified Gypsum from Phosphogypsum via Selective Adsorption Route

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The annual production of phosphate fertilizer in China was more than 16 million tonnes, with a by-produce of 80 million tonnes of phosphogypsum per year. At present time only less than 45% of phosphogypsum was used as the cheap and primary building materials as cement retarder and gypsum board, etc., and most of the phosphogypsum was still unused yet. Calcium sulphate dihydrate, which was the main component of phosphogypsum, can be used to prepare high quality gypsum-based building materials and chemical fillers, etc., owing to its perfect cementation and high stability, but the co-existence of impurities (silicon, fluorine, phosphorus, iron, carbon, magnesium, aluminium, etc.) in phosphogypsum limited the practical application. The conventional methods of removing impurities from phosphogypsum as sieving, cyclone, water washing, acid leaching or alkali treatment, etc. were simple and easy to be adapted commercially, but only some of the impurities can be removed, producing the gypsum with a purity usually less than 95%. The present work reported a novel selective adsorption way to fabricate purified gypsum (with a purity ≥98%) from phosphogypsum. The experiments were carried out at $pH<2.3$ and with a solid ratio of 25%, adding a little amount of organic acids ($R<5$) to resist the interference of silica-aluminium-iron impurities. The organic impurities adhered on surface of phosphogypsum was removed by the reverse adsorption of sulfonate surfactants.

Keywords: Phosphogypsum, Impurity removal, Selective adsorption.

A Study on Improving the Mechanical Properties of Asphalt Concrete by Using EAF Stainless Steel Slag

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Along with the rapid growth of Taiwan's economy, the volume of road traffic has been continuously rising which leads to the fact that the strength of the current asphalt concrete can no longer support the present and future traffic load. Under the context of the United Nations' active promotion of the Sustainable Development Goals (SDGs), people around the world have gradually begun to focus on issues of the sustainability of resources. This study uses a by-product of steelmaking which is EAF stainless steel slag to replace fine natural aggregate with 0%-40% substitution to improve the mechanical properties of asphalt concrete. This study uses Marshall design to find the optimum asphalt content, and evaluate the effect of EAF stainless steel slag on the mechanical properties of asphalt concrete by conducting tests such as stability value, indirect tension, residual strength by water immersion, modulus of rebound, and latent change. According to the results of the tests, the optimum oil content of asphalt concrete decreases with the increases of EAF stainless steel slag substitution, which is helpful to reduce the total cost of asphalt concrete. Asphalt concrete containing EAF stainless steel slag has better resistance to water damage than the one without, and the resistance to water damage increases with the amount of the substitution of EAF stainless steel slag. According to the test results of stability value, indirect tension, modulus of rebound, and latent change, the strength and the resistance to deformation of asphalt concrete increase with the increase of EAF stainless steel slag substitution, and therefore indicates that the EAF stainless steel slag will help to improve the mechanical properties of the asphalt concrete.

Keywords: EAF stainless steel slag, Asphalt concrete, Mechanical properties.

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Innovative Waste Management Practices

Toxic Metal Transformation Characteristics of Fly Ash from Different Cooling Zones after Municipal Solid Waste Incinerator

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ABSTRACT. To interpret the distribution and multi-phase transfer mechanism of heavy metals during the cooling process of flue gas from economizer to emission in municipal solid waste incineration (MSWI) , this study collected ashes and deposit from the economizer, spray dryer absorber (SDA), and bag filter (BF). These samples were separately subdivided into five fractions for in-depth analysis due to the particle size distribution(PSD). The scanning electron microscope (SEM) revealed the morphological characterization of subdivided particular matter (PM) samples. The contents and leaching toxicity of typical heavy metals (Cd, Pb, Cu, Zn, Cr and Ni) for each fraction were determined. The results showed that the proportion of fine particles were increasing along the order from economizer to SDA and to BF due to the sedimentation of gas flow. Semi-volatile metals, including Cd, Pb, Zn, and even Cu, tended to be enriched in fine particles with the size bellowed 53μm. Non-volatile metals, including Cr and Ni, tended to accumulate in large particles, settling prior to the BF. The different distribution reflected the condensation mechanism and multi-phase transfer of heavy metals during the cooling process of flue gas. Pb and Cd should be the critical control factors of heavy metals because they can migrate further with the fine particles in the flue gas to the BF. For the sake of better control of critical heavy metals, fly ashes generated from distinct nodes during the cooling of flue gas had better to be collected and treated separately, instead of employing a mixed collection and disposal approach.

Keywords: *fly ash, toxic metal, particle size, transfer characteristic*

Introduction

Fly ashes generated from MSWI plants should be carefully dealt with because they contain toxic metals, with the rapid development of incineration plants in China and around the world[1]. The finer fraction of the particulates (PM size<200 μm) are entrained in the flue gas during combustion, and subsequently deposited within the cooling zone after incinerator, or be captured by the air pollution control devices (APCDs) which are defined as fly ash[2]. Full-scale incinerator experiments showed that approximately half of the inert ultrafine particles (PM size < 1μm) settle in the boiler and are treated as slag, while the remaining particles majorly turn out to be fly ashes [3]. Finer particles with porous structure may contain more toxic metals, given to their larger surface area[4]. At first, toxic metals vaporized in the furnace, followed by their subsequent condensation in the flue gas cooling system[5]. Particular, chlorinated metals formed by the reaction with Cl or chloride can migrate further to the back-end of the system[6, 7].Therefore, researchers are more concerned about the environmental risks of toxic metals in fly ash because of their high concentrations and leaching toxicity[8-10].

The common treatment of fly ashes are through landfill disposal after undergoing chemical stabilization treatment, which has unique advantages including lower control cost and small compatibilization compares to other treatment technologies. However, it is hard to make a balance between the cost of the agent input and the long-term stability of toxic metals in practical application[11, 12]. The most critical issue is that fly ashes extracted from different cooling zones, such as the economizer, SDA and BF, is mixed collected and treated, which would lead to unstable chelating effects of toxic metals, and difficulties in tracing and supervision of unqualified fly ashes.

To review the rationality of mixed collected and treated strategy of fly ash, in this study, residues from the economizer, SDA, BF were collected separately to investigate the distribution and transfer characteristics of toxic metals: (1) The leachate concentration of toxic metals(Pb, Cd, Cu, Zn, Cr and Ni) in each samples were tested to identify the most risky location and elements; (2) Laser Particle Analyzer and SEM detection were used to get more details of the characterization of PSD and PM morphology. Besides, these observations also provide insights for a proper particle size screening scheme; (3) Samples from economizer, SDA, BF were screened into 5 fractions separately, and the content of toxic metal in each fractions were determined.

Material and Methods

Sampling of fly ash

The fly ashes were collected from a full-scale MSWIP plant in the Pearl River Delta area. This plant has four waste incineration lines to dispose of waste from shared refuse pit. Each line possesses a treatment capacity of 300 tons/day, equipped with a rotary kiln and a chain furnace, distinguishing it from other MSWI plants in China. Flue gas was treated by APCDs, including SDA and BF, and powdered activated carbon was injected in front of the BF. More details regarding APCDs can be found in previous studies[13].

The residues samples were collected in parallel from each of the four lines in a single day, including economizer, SDA and BF. Table 1 shows the temperature of flue gas in different cooling zones after the incinerator.

Table 1. Temperature of flue gas in different cooling zones after incinerator.

location	Line 1 Temp.(℃)	Line 2 Temp.(℃)	Line 3 Temp.(℃)	Line 4 Temp.(℃)
outlet of the furnace	947	873	936	933
outlet of the superheater	390	387	388	388
outlet of the economizer	213	206	210	209
outlet of the SDA	152	163	152	153
outlet of the BF	143	146	142	142

Particle size distribution and grading

The particle size distribution of the fly ash samples was measured by the Laser Particle Analyzer.

To separate fly ash samples into different PM sizes, a multi-layer ultrasonic vibrator with stainless-steel mesh size was used to divide ash samples into five fractions: D212μm (PM size≥212μm), D212-100μm, D100-53μm, D53-20μm and D20μm (PM size< 20μm). All subdivided PM samples were weighed at a constant temperature.

SEM

The surface morphology was observed with a field emission scanning electron microscope (FESEM, Hitachi SU8220) at a voltage of 5 kV. In order to improve the surface conductivity of the samples, a layer of Pt film was plated in the ion sputtering instrument before testing.

Chemical analysis of toxic metals

The determination of fly ash moisture content and the preparation of leaching solution were conducted following the standard *Solid waste-Extraction procedure for leaching toxicity-Acetic acid buffer solution method* (HJ/T 300-2007).

The total concentrations of typical toxic metals(Pb, Cd, Cu, Zn, Cr and Ni) in different fractions of particle-sizes of fly ash samples were determined by inductively coupled plasma optical emission spectrometry (ICP-OES) following *Solid waste-Determination of 22 metal elements - Inductively coupled plasma optical emission spectrometry* (HJ 766-2015). The leachate concentrations of toxic metals were determined by ICP-OES as well.

To estimate the enrichment of different kinds of toxic metals in different fractions of PM samples, the relative percentage of mass and toxic metals content in each subdivided PM sample were calculated as follows:

$$P_{wi} = \frac{m_i}{\sum m_i} \quad (1)$$

$$P_{C_i} = \frac{c_i \times m_i}{\sum c_i \times m_i} \quad (2)$$

m_i is the mass of subdivided PM samples, c_i is the content of toxic metals in each subdivided PM sample, *i* represents the five fractions:D212μm, D212-100μm, D100-53μm, D53-20μm, D20μm.

Results and Discussion

Size distribution and morphological characterization

Fig.1 illustrates the PSD of the residues collected from the economizer, SDA, BF, measured by the Laser Particle Analyzer. The economizer and SDA ash samples had a broad size distribution with diameter from 0.1 to 300μm, while the maximum size of the BF fly ash sample shrunk to 100μm. The proportion of fine particles increased in the following sequence: economizer＜ SDA＜BF. This observation is supported by the cumulative distribution of D20μm, which accounted for 31%, 56%, 78% in the economizer, SDA, and BF, respectively. Moreover, finer particles(PM size below 10μm) were presented 46% in SDA and 60% in BF, higher than the result reported by other literature that about 36% finer particles in mixed fly ash collected from both SDA and BF[4].

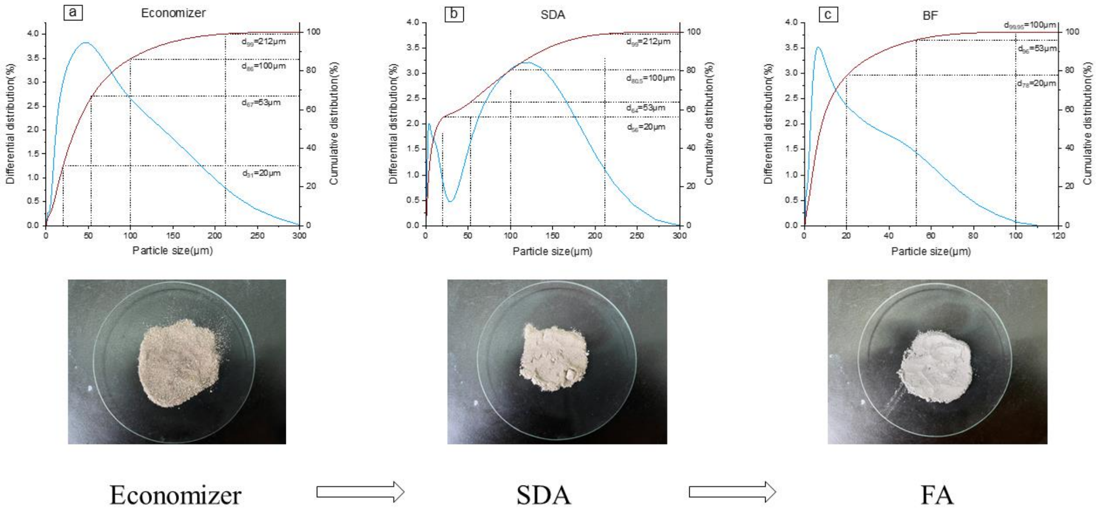

Fig.1. Distribution of PM size in residues samples collected from economizer, SDA, BF.

In order to investigate the distribution of toxic metals in different PM size, a sieving experiment of samples was conducted as previously described. The proportion of each subdivided PM sample is presented in Table 2. Compared to the result detected by Laser Particle Analyzer, this sieving experiment potentially resulted in an overestimation of the distribution of larger particles and, conversely an underestimation of finer particles. Finer particles were difficult to acquire because of the influence of agglomeration. Nevertheless, the subdivided samples performed well in the subsequent experiments, including the analysis of surface morphology and toxic metal content in different PM size.

Table 1. Particle size cumulative distribution and mass distribution of subdivided PM samples.

location	economizer	particle size cumulative distribution	mass distribution
economizer	D20μm	31%	7%
	D20-53μm	36%	32%
	D53-100μm	19%	21%
	D100-212μm	13%	20%
	D212μm	1%	20%
SDA	D20μm	56%	3%
	D20-53μm	8%	6%
	D53-100μm	16%	27%
	D100-212μm	15%	42%
	D212μm	5%	22%
BF	D20μm	78%	2%
	D20-53μm	18%	17%
	D53-100μm	4%	41%
	D100-212μm	/	41%
	D212μm	/	0.2%

It has been reported that toxic metals tended to enrich in fine particles[4], D20μm PM samples from the economizer, SDA, BF were detected by SEM. Due to the separation of PM particles lager than 20μm through sieving, SEM clearly displayed the surface morphology about finer particles to demonstrate the differences and characteristics of fly ash during the transfer process. First, SEM was adjusted to a magnification of 500 times to observe the concentrated distribution of particles (Fig.2 a, b, c), and then the focus was shifted towards representative PM through 1000 times magnification photomicrograph (Fig.2 d, e, f). As shown in Fig.2, Subdivided samples in D20μm contained abundant finer PM with irregular structure and they tended to be agglomerated. The observed morphological characteristics of fly ash in this study exhibited similarities to those reported in previous research studies[14, 15]. The fine particles from the economizer looked rougher than others, possibly related to the unique structure of the economizer. In the economizer, heat exchange tubes were arranged in multi-layers with an interconnected structure, leading to continuously condensation of toxic metals and fierce collision of PM. More glossy particles were identified from the SDA sample, which were possibly affected by the injection of water-based de-acidifying agent, such as Calcium hydroxide solution. In contras, the BF sample exhibited a large quantity of block-shaped particles with a regular structure.Possible contributing factors for this phenomenon include the application of powdered activated carbon and the layered dust filtration within the BF.

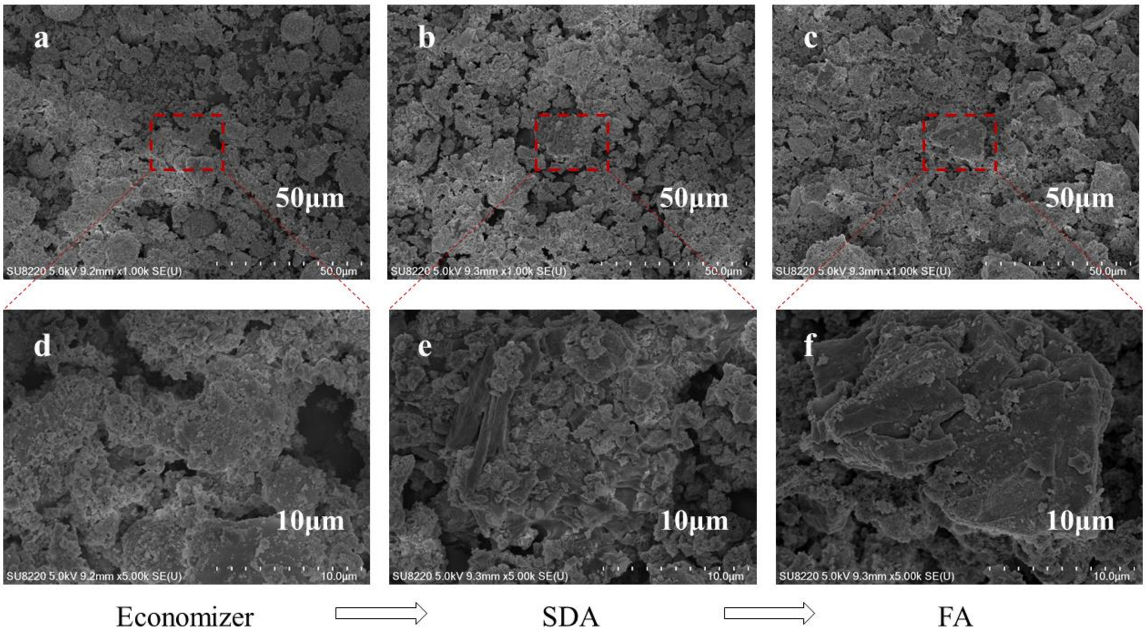

Fig.2. SEM photomicrograph analyses of PM in subdivided samples.

Distribution characteristics of toxic heavy metals in subdivided PM samples

The distribution of mass and toxic metals content in each subdivided PM samples were calculated according to the equation (1) and (2), and the results were shown in Fig.3 so as to intuitively discern the varying degrees of enrichment of different toxic metals in different PM sizes.

In the economizer ash sample(Fig.3 a), the total amount of toxic metals in D20-53μm accounted for a relatively high proportion, and the content ratio of Cd, Pb, Zn, Cu in D20-53μm was higher than the corresponding mass ratio, as the calculation result was $P_{D20-53} > Pw_{D20-53}$. In terms of the overall distribution trend, Cd, Pb, Cu and Zn were more easily enriched in fine particles less than 53μm, which is consistent with the result reported in previously paper[4].

As for the sample from SDA (Fig.3 b), D53-100 fraction accounted for a higher proportion of the total amount of toxic heavy metals, and the content ratio of Cr, Ni, Zn, Cu in D53-100 was higher than the mass ratio, as the calculation result was $P_{D53-100} > Pw_{D53-100}$ All of the six toxic heavy metals tended to be enriched in larger particles size over 100μm.

For the sample obtained from BF (Fig.3c), the calculation indicated that the content ratio of Cd, Pb, Zn, Cu in D20μm was higher than the mass ratio, as the calculation result was $P_{D20} > Pw_{D20}$. In fact, large particles were agglomerated by fine particles, resulting in a higher content ratio of Cd, Pb, Zn, and Cu in the

D53-100 and D100-212 compared to the mass ratio, as the calculation result was $P_{D53\text{-}100} > Pw_{D53\text{-}100}$ and $P_{D100\text{-}212} > Pw_{D100\text{-}212}$.

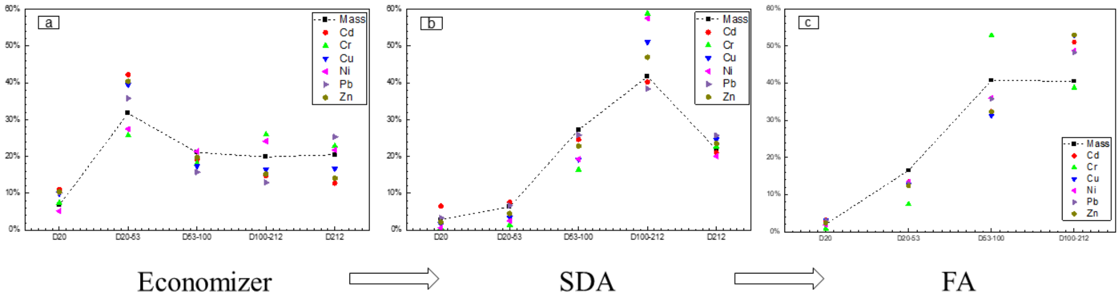

Fig.3. Comparison on PM mass ratio and content ratio of toxic metals.

Fig.4 presents results of six toxic metals content in all subdivided PM samples in the order of economizer, SDA, BF.

In all particle size samples, the content of Pb and Cd decreased from economizer to SDA, and then increased from SDA to BF. The highest content of Pb and Cd was identified in all BF subdivided samples except D20-53μm. The total content of Pb and Cd in the economizer sample was found to be very closed to that of the BF sample, with only a 12% and 25% reduction compare to the BF, respectively. Additionally, fine particles in D20μm had higher content of Pb and Cd compare to other fractions. These data indicated that semi-volatile metals, such as Pb and Cd, possessed the capacity to migrate alongside the fine particles within the flue gas, ultimately reaching the BF. Although heavy metals with lower-volatility, such as Cu and Zn, had a transfer tendency similar to Pb and Cd, it was shown that their migration ability comparatively weaker, for the content of Cu and Zn in the economizer were higher than that in BF in all subdivided samples except D20-53μm.In addition, non-volatile metals, such as Cr and Ni, tended to accumulate in large PM, and settled in the front location. In all samples of different particle sizes, the content of Cr and Ni decreased from the economizer to SDA and to BF. The capability of toxic metals to transfer further in cooling zones after incinerator were significantly influenced by their volatility characteristic and particle sizes.

Leaching behavior of toxic metals in fly ash

Table 2 lists the leaching toxicity of typical heavy metals in three kinds of residues collected from four incineration lines. The results indicated that Pb, Cd and Ni were the risky element in the BF fly ash, because their leaching toxicity failed to meet the standard control limits. In the SDA fly ash, Cd, Cr and Ni should be treated to meet the standard. However, the leachate concentrations of toxic metals in the SDA fly ash were lower than those in the BF, which was correspondent to some previous studies [16]. Besides, ash in the economizer could pose a great environmental risk as all six toxic metals exceeded the established limits in this test.

Conclusions

The present study focused on investigating the particle size distribution and leaching toxicity of heavy metals in ashes and deposit collected from economizer, SDA, and BF. All three samples were screened separately into five fractions in the following order：D212μm, D212-100μm, D100-53μm, D53-20μm and D20μm. The content of toxic heavy metals in subdivided PM samples were determined. The SEM revealed the morphological characteristic of subdivided PM samples.

The proportion of fine particles followed an increasing trend in the order of economizer＜SDA＜BF. Semi-volatile metals, including Cd, Pb, Zn and even Cu, had a broad distribution and considerable amount of content in different particle sizes, with enrichment in fine particles size less than 53μm. Pb and Cd showed the ability to migrate further with the fine particles in the flue gas, reaching the BF.Cu and Zn had a migration tendency similar to Pb and Cd, but their ability of migration was comparatively weaker. Non-volatile heavy metals, such as Cr and Ni, tended to accumulate in large particles and settle before the BF.

Leaching test indicated the environmental risk of toxic metals in fly ash. Pb and Cd were the crucial elements to control, but the leachate concentrations of toxic metals in the SDA fly ash were lower than those in the BF. Besides, ashes in the economizer should not be neglected for their high leachate concentrations of toxic metals.

More innovative measures should be explored to control the environmental risk caused by toxic metals from MSWI fly ash. It is important to focus on crucial toxic metals. In addition, fly ashes from different locations were recommended to be collected and treated separately instead of mixed collection and disposal.

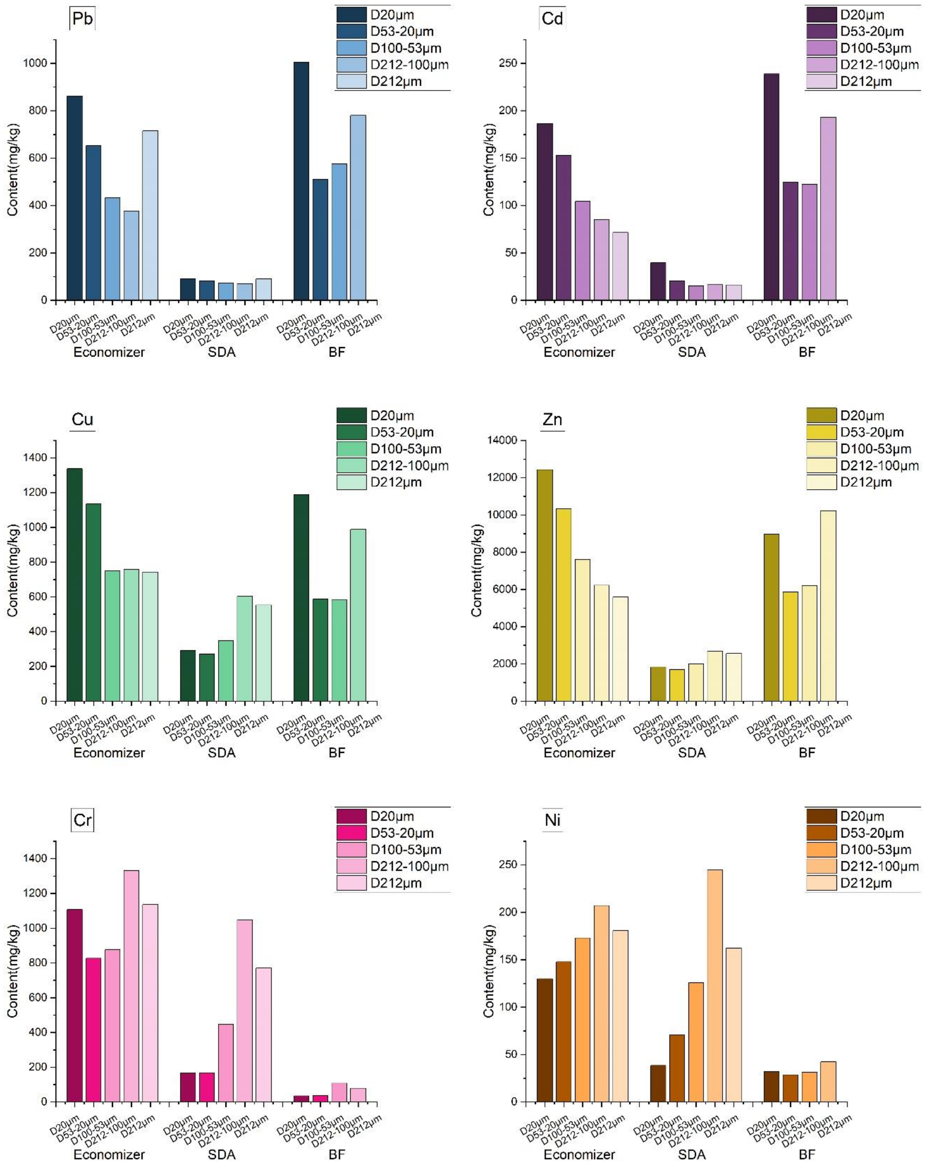

Fig.4. Content of toxic metals in different particle sizes.

Table 2. Leachate concentration of toxic metals.

Toxic metals	economizer	SDA	BF	Limited Value [b]
Pb	2.37±2.73 [a]	0.019±0.016	1.36±1.15	0.25
Cd	4.99±0.74	0.38±0.25	5.5±3.57	0.15
Cu	11.09±8.17	0.35±0.43	7.26±7.36	40
Zn	132±16	4.63±6.08	56±52	100
Cr	12.1±1.36	6.93±3.99	0.54±0.36	4.5
Ni	1.54±0.11	0.47±0.25	0.39±0.3	0.5

[a] Mean ± Standard deviation (n=4):mg/L; [b] GB 16889

Acknowledgement

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Remediation & Reuse of Mercury Contaminated Site By Unique Two Stage Process Of Waterwash And Retord - Hazardous, Industrial And Special Waste Management

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A unique remediation process for mercury contaminated site in a sensitive residential-cum-tourist location has been developed for ensuring environmental protection and reuse for plantation. The mercury released from thermometer manufacturing process caused soil pollution, occupational health issues and made the land unusable. This resulted in the closure of the entire manufacturing facility and directions from environmental protection authorities for remediation in a land area of more than 40000m^2. The procedures, protocols and standards have been developed for remediation of mercury polluted soil surrounded by trees and plantation in a slopped area. The contamination of Hg ranges from 100 to 400mg/kg of soil and made the fertile land into a polluted barren land. This land has to be remediated to remove the mercury contamination and make the land fit for plantation. The unique remediation process started with detailed environment impact assessment study on the levels of mercury contamination inside the factory and the entire surroundings of more than 5km radius and water stream leading to the reservoir for a distance of about 20km. Development of suitable remediation process of more than 15000 tons of contaminated soil and sludge around the thermometer factory without causing damage to the tall trees and plantations in slope terrain is a major challenge. After detailed investigation, study, research and developments with lab and pilot scale remediation, a two-stage process of water wash and retard systems were designed and implemented the remediation of the entire contaminated area in the hilly terrain. The contaminated soil was taken in batches for remediation process by making contour trenches and the area is controlled by providing silt traps and retaining walls. The remediated soil after two stage treatment process with less than 20mg/kg is amended with nutrients and refilled in the trenches. The recovered highly concentrated hazardous category mercury from the contaminated soil is to be further concealed by adopting solidification process. After solidification, the hazardous category sludge is taken to the exclusive cells developed with water tight Reinforced Cement Concrete structures and High Density Poly Ethylene liners. The remediation program with the involvement of many national and international scientists and experts from multidisciplinary field is under final stage of implementation with a huge investment of nearly 20 million US Dollars which is first of its kind in Asia.

Keywords: Hazardous waste, Remediation, Mercury pollution, Environmental health.

Performance of Food Waste Pre-treatment System with the Aid of Solar-Heated Water

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Food waste is the most significant municipal solid waste (MSW) disposed of in Hong Kong landfills, accounting for 30% of the total MSW. Biodegradable food waste is currently disposed of at landfills, and methane would leak to the atmosphere result in global warming. Still, this practice is not environmentally desirable. Nevertheless, the popularity of food waste recycling is predicted to rise with the passage of the waste-charging scheme. This research analyzes the common food waste segregation habit in Hong Kong, and the rate of digestion of food waste using solar-heated water. In addition, the satisfaction rate of the system was assessed in terms of cleanliness and security. The food waste recycling process was reimagined by creating a mechanism for pre-treating food waste. The first Food TranSmarter in the world is in operation. Food waste is locally turned into slurry using this unique process, which is subsequently transported to the Tai Po Sewage Treatment Works for biogas generation. To collect and pre-treat food waste more efficiently, an improved version of a patented technology was developed called Mobile Food TranSmarter. It could be appropriate for locations and events like concert, expo, festival, and exhibition that have year-round consistent food waste supply. Food waste sampling from different sources was conducted to analyze the characterization of the food waste including the total solid content, volatile solid, pH value and chemical oxygen demand. Solar water heating systems can help speed up the process of food waste digestion rate. Mobile Food TranSmarter liquidized food waste by bio-mechanical actions with increase temperature without drawing more energy. The inorganic items maintained within the system included enormous bones and tools. Throughout the process, hot water is added to speed up the digest of food waste. Following the system's test run, the operators and site owners took part in a review session to evaluate the operation of the system. Nevertheless, there were several limitations throughout the test. The COVID-19 outbreak caused less frequent dining out and as a result less food waste was collected. During the study period, there was an average daily collection and handling of 200 kg food waste. All food waste was processed into a slurry and sent to a decentralized food waste facility. Forks and knives were seen to be among the items that were screened out of the system in the system. This suggests a problem with the food waste sorting procedure and the need for more training in this area. Different amounts of water were used depending on the feeding rate of food waste. By looking at the occupied system's volume, the food waste digestion rate was calculated. The site owner's assessment session gave excellent feedback about the odour and cleanliness issues. Since the system was sealed entirely and under negative pressure, there were no complaints.

Keywords: Food waste, Pre-treatment, Solar-heated water, Food waste digestion, Food waste sorting.

Evaluation of Bioaerosol Risk During Insect-Protein-Production of Biowaste

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Food waste management is an undressed challenge for all economies. Bioconversion using insects gradually become a promising technology for biowaste management and protein production, however, knowledge about the microbiological risk of bioaerosols is sparse and conventional methods failed to provide evidence of high-risk species. In this study, a panorama analysis of microbiological risk including distribution of endotoxin, antibiotic resistance genes (ARGs), mobile gene elements (MGEs), and virulence factor genes (VFGs) in bioaerosols during biowaste biodegradation by housefly (species: *Musca domestica*) were conducted. Results revealed that there is no connection between concentrations of 16S rRNA gene and endotoxin, bioaerosols in Fly rearing room possess the highest ARGs abundances, including 13 highest risk ARGs, and plasmids diversity. Conventional methods, such as PCR amplicon sequences and network analysis, fall short of providing the information of environmental microbes and infeasible in small sample size studies. Herein, through a metagenome and binning approach developed in this work, higher resolved taxonomic assignments at species level together with compelling evidence of ARGs/VFGs' host assignment from genetic perspective were provided. Totally 7381 ARGs copy number were assigned to 122 MAGs, bacterium in Acidobacteria phylum trend to harbour MLS-, bacitracin-, tetracycline-, and vancomycin-resistance genes. In contrast, Proteobacteria was the major bacteria phylum host for multidrug-resistance genes. Totally 181 VFGs copy number were assigned to 51 MAGs, higher VFGs copy number were detected in pathogen related genera *Burkholderia* and *Pseudomonas_B* (31 and 23, respectively), more precisely, at species level, *Burkholderia gladioli*, *Pseudomonas_B psychrotolerans_B*, and *Ochrobactrum_A pseudogrignonense* MAGs were the highest VFGs harbours. Bioaerosols in Bioconversion and Maggot separation zone were identified to own high density of metagenome-assembled genomes (MAGs) that carrying both ARGs and VFGs. Proteobacteria, Actinobacteriota, and Firmicutes phyla were predominate hosts of both ARGs and VFGs. Multidrug-Motility, Multidrug-Adherence, Beta Lactam-Motility, and Beta lactam-Others pairs were the most common ARGs-VFGs co-occurrence pattern in this study. Results obtained shed new lights on potential risks of insect-based conversion technologies, which are of great significance for precisely microbiological risk management and highlight the great power of metagenome and binning approach in microbiological risk assessment. Furthermore, if the insect conversion technology will be applied in larger scale to treat more biowaste, the scale impact on microbiological risk level should be prudentially considered before large-scale insect conversion plants construction.

Keywords: Antibiotic resistance genes, Virulence factor genes, Endotoxin, Metagenomics.

Development of Cushioning Materials from Water Hyacinth Fibers and Bagasse

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ABSTRACT. Cushioning materials for packaging are in high demand as online purchases continue to increase. However, more research is still needed on biodegradable materials. This experimental study aimed to develop cushioning materials using water hyacinth and bagasse fibers and compare their effectiveness with other commonly used cushioning materials, such as foam beads and plastic air bubbles. The experiment was conducted from August to October 2022. It involved forming natural cushioning materials by separating fibers through a chemical process, spinning the water hyacinth fibers, drying them in the sun, and cutting them into 7x8 cm sheets. The bagasse fibers were cut into sheets, rolled into a worm shape, and shredded into fibers. The drop resistance test was performed by dropping boxes containing each cushioning material and glass ceramics from heights of 1, 1.5, 2, 3, and 4 meters. The moisture content of the cushioning materials was also tested according to TIS 867-2547 standards. The results showed that the water hyacinth fiber sheets passed the drop resistance test, with no cracking of the glass ceramics at any height. In comparison, other cushioning materials caused the glass ceramics to break and crack at heights ranging from 3 to 4 meters. The moisture content test results also showed that the cushioning materials from water hyacinth fibers and bagasse passed the TIS 867-2547 standard, with a 3% to 14% moisture content range. As a result, water hyacinth fibers should be considered for further commercial use in cushioning materials.

Keywords: *Compostable material, Shockproof, Packaging*

Introduction

The increase in online purchasing during the COVID-19 pandemic has increased waste from cushioning materials. With more people shopping online due to social distancing measures and stay-at-home orders, there has been a corresponding increase in the number of packaging materials used to protect and transport products during shipping [1]. This includes cushioning materials such as foam peanuts, airbags, and bubble wrap. While these materials help protect products during shipping and prevent damage, they can also create significant waste [2]. Many cushioning materials are made from plastic, a non-renewable resource that can take hundreds of years to break down in the environment. Plastic cushioning can also break down into microplastics, harming marine life and the food chain and potentially affecting human health. Some plastic cushioning materials can also release hazardous chemicals, such as phthalates and brominated flame retardants, into the environment and the human body, with potential health impacts such as developmental and reproductive harm [3]. Furthermore, plastic cushioning is non-biodegradable and takes up valuable landfill space, releasing greenhouse gases [4]. The trend for cushioning materials in online purchasing has shifted towards sustainable, environmentally friendly, and healthy materials. Consumers are becoming more aware of their purchases' impact on the environment and health and are seeking products that align with their values. As a result, a growing demand for cushioning materials made from natural and biodegradable materials, such as plant-based cushioning materials such as bamboo, hemp, water hyacinth [5], natural latex, and wool. Besides, there has been an increase in the availability of cushioning materials made from recycled materials, such as recycled polyester and cotton [6]. Some companies are implementing more efficient packaging practices to reduce waste, such as using minimal or reusable packaging materials [7]. There are several alternatives to traditional plastic cushioning materials that are more environmentally friendly and sustainable. These include paper cushioning made from recycled paper, which is biodegradable and compostable [8]; corn starch cushioning made from biodegradable corn starch [9]; mushroom cushioning made from the mycelium of mushrooms [10], which is both biodegradable and compostable. Plant fibers are processed into various shapes, such as mats, batting, and foam-like materials, for bedding, furniture, and packaging. As consumers become more conscious of their purchases' effects on the environment and their health, the demand for natural cushioning materials is expected to increase. These sustainable alternatives can minimize environmental harm and be economical while providing equal protection to conventional plastic cushioning materials.

The creation of cushioning materials from sustainable sources, such as water hyacinth fibers and bagasse, is crucial in developing eco-friendly products. Water hyacinth fibers are obtained from a rapidly growing aquatic plant and are known for their high elasticity and durability, making them suitable for cushioning. Similarly, bagasse, a fibrous material leftover from sugarcane juice extraction, is a renewable resource with high mechanical strength and biodegradability. They are easily grown and replenished and sometimes less expensive to produce than traditional plastic cushioning materials, making them a cost-effective option. Companies can use these materials to reduce their environmental impact and promote sustainability while effectively protecting their products. However, further research is needed to optimize high-quality end products' processing and production methods. While cushioning materials made from water hyacinth fibers and bagasse have the potential to be more sustainable and environmentally friendly than traditional plastic cushioning materials, there is currently a gap in the research and development of these materials. This study aims to create cushioning materials from water hyacinth fibers and bagasse as a substitute for conventional plastic cushioning materials. The objective is to minimize the environmental damage caused by plastic waste by utilizing these sustainable resources while maintaining the same degree of protection and comfort in packaging and cushioning uses.

Materials and Methods

This experimental research aims to develop cushioning materials from natural materials, water hyacinth fibers, and bagasse. The shockproof test was conducted using materials prepared at the Environmental Health Laboratory within the College of Medicine and Public Health at Ubon Ratchathani University. Water hyacinths were collected from the final pond of the Ubon Ratchathani wastewater treatment plant, and bagasse was collected from the sugar cane juice shop in the market. The method for preparing hyacinth and bagasse pulp is adapted from the research of Anchalee Kitjawatana et al. [11].

Prepare cushioning materials from water hyacinth and bagasse

First, choose the water hyacinth stalks around 30-35 centimeters long. Allow them to dry completely in the sun for 3-4 days, then cut them into pieces that are 4-6 centimeters in size to make it easier to separate the pulp during the next step. Next, combine 3 liters of water and 270 grams of sodium hydroxide in a stainless-steel pulping pot. Then, add 2 kilograms of water hyacinth and boil the mixture at 100°C for 2 hours to break down the fibers. Rinse the pulp 3-4 times with clean water, and then test it by hand for any slickness. Leave the mixture to dry in the sun for 4-5 days. To create a cushioning pad, take 1 kilogram of separated fibers and mix it with 1 liter of water. Agitate the mixture by spinning it 3-4 times to disperse the fibers. Then, form the mixture into a thin sheet of 2-3 mm. on a tray using a scoop. Leave it to dry in the sun for another 4-5 days, then cut it into 7x8 centimeter sheets. As shown in Figure 1. The method for processing bagasse also uses the same proportions as water hyacinths at each step. Finally, it rolls the bagasse pulp into a worm shape and cuts it into fuzzy threads, as shown in Figure 2.

Figure 1 Process to prepare cushioning materials from water hyacinth

Figure 2 Process to prepare cushioning materials from bagasse

A test was conducted to determine the impact resistance of the newly developed cushioning material. It was compared to the market's commonly used polystyrene foam cushioning and compressed air cushioning sheets. A glass-ceramic material weighing 213.39 grams was used in the shockproof test. The test was conducted using a paper box (11 x 17 x 10 cm) containing glass ceramic and various cushioning materials. The ceramic glass was wrapped in paper one layer and placed in the center. Then, the box was sealed with tape and dropped from five different heights (1, 1.5, 2, 3, and 4 meters), as shown in Figure 3 [12]. The time taken from the start of the drop until the box hit the floor was recorded. Examine the box's interior by removing its contents and checking for damage. Capture the picture and written notes. Conduct the test three times on each sample and record the results. The cushioning materials used were: shockproof water hyacinth sheet, sugar cane fibers, and bagasse worm cushioning (330 g); compressed air plastic sheet (Air Bubble Cushion) with 30 cm in width and 60 cm in length; and shockproof foam (300 g) put into a carton.

Figure 3 Different heights of the test from 1, 1.5, 2, 3, and 4 meters

The moisture content test began by weighing the 200 x 200 mm test piece before being placed in an oven set at 103 ± 2 °C for 10 minutes. After being removed from the oven, the test piece was allowed to cool in a desiccator before being weighed again. The moisture value was calculated using the following formula:

$$\text{Moisture content (\%)} = (\text{Wet weight (g)} - \text{Dry weight (g)}) / (\text{Dry weight (g)}) \times 100$$

The test results were compared with the TIS 867-2547 standard, which states that the moisture content should not exceed a range of 4% to 13% to prevent damage from mold.

Results and Discussion

The characteristics of water hyacinth cushioning fibers are a greyish-green color, rough texture, lightweight, and a fiber thickness of 1 cm. They do not clump together well and cannot be rolled into other shapes or cut into thin strips. The fibers are soft and can easily be torn apart when touched with bare hands. The characteristics of bagasse cushioning fibers, on the other hand, are light yellow, have a rough texture, are lightweight, have a fiber thickness of 1 cm, clump well into sheets, can be rolled into other shapes, and can be cut into shredded fibers. These fibers are tough and do not easily tear when touched with bare hands. The drop resistance test showed that the water hyacinth fiber cushioning had the strongest performance, as no cracks or breaks in the glass ceramic were observed at any height. On the other hand, the cushioning provided by bagasse and polystyrene foam resulted in the breaking of the ceramic glass at a height of 4 meters, and the impact-resistant bagasse fibers and compressed air plastic sheets caused breaks in the glass ceramic at heights of 3 and 4 meters, respectively, as illustrated in Figure 4. The results of the moisture content test on cushioning materials made of water hyacinth fibers and bagasse indicated that both materials met the TIS 867-2547 standard with a moisture content range of 3% to 14%. The bagasse's moisture content was 12.57 percent, while that of the water hyacinth fibers was 13.80 percent. Hence, it can serve as a substitute for other cushioning materials without increasing the moisture content of the packaged product and without the risk of mold growth that could harm the product.

Figure 4 The condition of ceramic after the fall test

It is noticeable that all the materials can absorb shock at heights of 1, 1.5, and 2 meters. Still, the cushioning made from bagasse and polystyrene foam can only handle a fall from 3 meters. On the other hand, the shockproof bagasse fibers and air bubble cushioning fail to withstand drops from heights of 3 and 4 meters, respectively. The superiority of bagasse cushioning in worm form over bagasse fibers is attributed to its design featuring a central hole that reduces the gap between the ceramic glass and the container. Initially, the researcher tried to create a shockproof bagasse sheet, but it was found to be ineffective in cushioning after undergoing a drop test from a height of 1 meter. The pattern was then altered to a worm and fringed form, which was more effective. On the other hand, water hyacinth fibers are effective in cushioning when used in sheet form. The lower effectiveness of bagasse fibers as a cushioning material can be traced to their thinness and hard texture, unlike the soft texture of water hyacinth fibers. Furthermore, water hyacinth fiber sheets possess properties similar to foam cushioning materials, such as thickness, softness, lightweight, and the ability to support significant weight, which helps to reduce impact to a greater extent. Lignin content can also affect the fall test performance of cushioning materials made from water hyacinth and bagasse. Lignin is a natural polymer that gives plant fibers strength and stiffness. The higher the lignin content, the denser and stiffer the fibers are, making them better at absorbing impact. According to a study by Wittawat Jiratpong et al. [13], water hyacinth fibers contain 25.33% lignin, higher than the 22.91% lignin found in sugarcane bagasse. This may explain why cushioning made from water hyacinth fibers performs better in fall tests than bagasse fibers. However, it's important to note that other factors, such as the number of layers, placement of the product and cushioning, and material composition, can also influence the performance of cushioning materials in fall tests.

Conclusions

This study involved the creation of an environmentally friendly cushioning material made from water hyacinth fibers, and sugarcane fibers, which can be used as a substitute for traditional cushioning materials. The impact resistance tests showed that cushioning made from natural materials, such as water hyacinth fibers, performs better than plastic materials in preventing falls from heights greater than 3 meters. Still, there is no significant difference in drop resistance at heights below 2 meters. Given that most goods transportation involves objects being thrown from heights of 1-2 meters, this research suggests the potential for further commercial development of water hyacinth fiber cushioning. This would reduce foam and plastic cushioning materials, which take a long time to decompose, contribute to waste, and make more efficient use of local resources while reducing the abundance of weeds. However, it is important to note that the exact results can vary depending on the processing methods and the specific conditions of each study. Further research and development are needed to fully understand the potential and limitations of using water hyacinth fibers as a sustainable cushioning material.

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Utilization of Corn Wastes as Biochar in Amending Acidic Soil Grown with Corn

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Acidic soil is one of the major problems that farmers are encountering, for it can cause various complications in growing high-value crops. To address problems related to soil acidity, one of the solutions is to amend the soil. Biochar is one of the materials popular nowadays that is used as soil amendment. Biochar may come from different raw materials that were subjected to pyrolysis. In this study, the waste materials used were corn husk and corn cob. Another solution is applying organic fertilizer available in the locality, and in this case, chicken manure was applied. To determine the effectiveness of biochar derived from corn husk and corn cob and application of chicken manure in neutralizing soil pH, a 3 x 4 factorial pot experiment following the randomized complete block design was conducted. The first factor was the application of biochar such as (B1) without biochar, (B2) corn husk biochar, and (B3) corn cob biochar. The second factor was fertilizer materials such as (F1) farmer's practice (60-30-30), (F2) recommended rate of inorganic fertilizers (120-60-60), (F3) chicken manure, and (F4) combination of inorganic fertilizers and chicken manure. The result of this study revealed that application of biochar derived from corn husk and corn cob at the rate of 30tons/hectare and chicken manure at the rate of 10tons per hectare could increase soil pH from 4.25 to 5.40 and 5.35, respectively. Growth and yield of corn were significantly better in treatment applied with biochar and chicken manure and the combination of chicken manure and inorganic fertilizer. This is attributed to the increment of the soil pH, which is close to the optimum pH in growing corn, which is 5.80 to 6.20. This study suggests that applying biochar derived from corn husk and corn cob, and chicken manure can help neutralize acidic soil to make it more productive, particularly in growing corn. However, further study is recommended to test their effectiveness in field conditions and using other waste materials as biochar.

Keywords: Acidic soil, Chicken manure, Corn, Corn cob biochar, Corn husk biochar.

Study on Calculation Method of Carbon Emission Reduction of Industrial Solid Wastes Based on Fossil Carbon Fraction

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Incineration is the most attractive solid waste treatment solution. By 2020, 54.0% of all collected solid waste was mass burned for energy recovery in China. It is essential to address the greenhouse gas(GHG) mitigation caused by solid waste incineration. In this study, fossil carbon fraction(FCF) of different kinds of solid waste was taken into account. FCF was determined by 14C method using accelerator mass spectrometry(AMS). A modified Clean Development Mechanism (CDM) calculation methodology was proposed based on fire coal coupled solid waste to calculate CO_2 emission reductions of waste incinerators. The results indicated that when industrial solid waste was used to replace most of the coal at a 12:1 ratio in two 110t/h circulating fluidized bed boilers in a co-generation plant in Zhejiang Province, 179200 tons of annual standard coal could be saved. The annual carbon dioxide emission could be reduced to 178700 tons and the CO_2 reduction factor converted into solid waste carbon could be increased to 1.38 tCO_2e/t through the methodology. It was also found that synthetic rubber, artificial leather, plastics and other kinds of solid wastes showed differences in FCF content. As a result, there were some deviations between the computed results calculated with factual values and default values offered by Intergovernmental Panel on Climate Change (IPCC). This study provided a more accurate and effective way for the calculation of carbon emission reduction in China.

Key words: Solid waste, CO_2 emission reduction, CDM methodology, Fossil carbon, 14C method, AMS technique.

Treatment of Black Water by Advanced Anaerobic Baffled Reactor

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Problems with sanitation, water, and hygiene account for over 98.8% of fatalities in developing countries. Septic Tank (ST) is extensively used as an on-site wastewater treatment system for black water, but it can only remove about 50-55% of the BOD & COD from the black water. Present study demonstrated a possible future application of the anaerobic baffled reactor (ABR) for blackwater treatment are presented. For this purpose, an advance ABR system inoculated with enriched microorganism and bio augmented with microbial consortium was optimized and treatment efficiency of advanced ABR was simultaneously compared with the common septic tank. advanced ABR and Septic Tank (ST) were operated for more than seven months to treat synthetic faecal and real human faecal at water temperatures ranging from 25°C to 30°C.

Performance of advanced ABR & ST was evaluated in terms of removal efficiencies of COD, BOD, TSS, NH_4+-N, TN, & TP in advanced ABR & ST on the basis of different OLR were calculated. The COD Removal for advanced ABR, and ST was 94±1.2%, and 75±4%, respectively, for OLR 0.5 Kg COD/ m^3.day, whereas it slightly changed to 90±3.2%, and 78±6.5%, for OLR 0.25 Kg COD/ m^3.day. The BOD Removal for advanced ABR and ST was 95±1.2%, and 74±3.9% for OLR 0.5 Kg COD/ m^3.day whereas it was 89±1.9% and 77±4.6%, for OLR 0.25 Kg COD/ m^3.day. The TSS Removal for advanced ABR and ST was 92±3.2% and 75±1.2%, respectively, for OLR 0.5 Kg COD/m^3.day whereas it was 80±4.5% and 81±3.5%, for OLR 0.25 Kg COD/ m^3. Day. The NH_4+-N Removal for advanced ABR and ST was 4.8±6% and 1.2±7.9%, respectively, for OLR 0.5 Kg COD/ m^3.day whereas it was -6.9±16% and -1.5±15%, for OLR 0.25 Kg COD/ m^3.day.The TN Removal for advanced ABR and ST was 1.2±6.2%, and -2.5±8.3%, respectively, for OLR 0.5 Kg COD/ m^3.day whereas it was -11.2±173% and -6±19%, for OLR 0.25 Kg COD/ m^3.day.The TP Removal for advanced ABR and ST was 4.9±17%, and 3.14±17%, respectively, for OLR 0.5 Kg COD/ m^3.day whereas it was 2.3±19% and 3.7±15%, for OLR 0.25 Kg COD/ m^3.day. After the stabilization phase, advanced ABR was performing well in terms of COD, BOD and TSS, with a removal efficiency of more than 90%. The efficiency was not affected by the variation of organic loading to half, i.e., 0.25 kg COD/m^3. d. The TN, TP and coliform removal efficiencies was insignificant in advanced ABR and ST both.

Metagenomic analysis revealed that the top 5 most abundant bacterial phyla in all the steady- state digester samples were Firmicutes, Bacteroidetes, Proteobacteria and Chloroflexi. The phylogenetic tree demonstrated that the bacterial population of advanced ABR is more or less homogenous than for ST. Hence, the COD, BOD & TSS removal efficiency of advanced ABR was observed to be higher than the ST in the stabilized period.

Keywords: Advanced anaerobic baffled reactor, Septic tank, Phase separation, Blackwater treatment.

Food waste-Energy-Water-Emissions (FEWE) Nexus in the Food Service Sector: Comparative Life Cycle Assessment of Locally Produced vs Imported Meal

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Food waste, energy, water, and emission (FEWE) nexus in food service sector (FSS) should be analysed in order to ensure proper procurement and management of materials and energy flows to minimize environmental impacts from food systems. Life cycle assessment (LCA) is the method applied to analyse amount of energy use, water consumption, and emission along food supply chain (FSC). The FSC stages include all activities from agricultural production to consumption. In this study, the inventory of imported food ingredients and energy flows from pasta meal cooking at commercial kitchen in Hong Kong were audited then processed by SimaPro software. Similar process was repeated for the pasta cooked in Australia then shipped to Hong Kong as ready-to-eat meal. The pasta ingredients were unsalted butter, cheese, wheat flour, eggs, fresh truffles, and salt. When a comparative LCA is performed, amount of carbon footprint, energy footprint, and water footprint per meal portion is determined. Furthermore, food waste produced along the FSC is analysed using the FAO developed methodology in which the food waste is the function of quantity of food available at each stage along the food supply chain, food wastage percentages, conversion factors, and allocation factors. The results discussed the FEWE nexus trade-offs among the impact results along the FSC for both cases. The results shows that the ART meal's indirect global warming potential (GWP) causes higher carbon emissions than the LMO meal. Also, the direct CED of the ART meal is higher than that of the LMO meal. The direct WC of the ART and LMO do not differ. Furthermore, the indirect ART food waste (FW) is less than the LMO one, while direct FW for both ART and LMO meals is negligible. The study concluded that cooking meal in Hong Kong using imported ingredients results in better environmental performance than importing ready-to-eat meal.

Keywords: Food systems, Food service sector, Commercial kitchen, Environmental impact, Ingredients.

Rapid Determination of Moisture Content of Multi-source Solid Waste Using ATR-FTIR and Multiple Machine Learning Methods

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Rapid determination of moisture content plays an important role in guiding the recycling, treatment and disposal of solid waste, as the moisture content of solid waste directly affects the leachate generation, microbial activities, pollutants leaching and energy consumption during thermal treatment. Traditional moisture content measurement methods are time-consuming, cumbersome and destructive to samples. Therefore, a rapid and nondestructive method for determining the moisture content of solid waste has become a key technology. In this work, an attenuated total reflectance-Fourier transform infrared spectroscopy (ATR-FTIR) and multiple machine learning (ML) methods was developed to predict the moisture content of multi-source solid waste. A large number (1,272) of different types of solid waste samples were selected, including the most common solid waste components that have a great impact on moisture content: textiles, paper, leather, and wood. The collected samples were directly analyzed by ATR-FTIR to ensure the unity of the experimental conditions, which differs from the complexity of data sources in other studies. A combined model was proposed for moisture content regression prediction, and the applicability of 20 combinations of five spectral preprocessing methods and four regression algorithms were discussed to further improve the modeling accuracy. The hyperparameters of different combinations of ML models were optimized, and the performance, application prospects and limitations of the hybrid models were evaluated. Furthermore, the prediction result based on the water-band spectra was compared with the prediction result based on the full-band spectra. The results showed that ATR-FTIR-based measurements combined with spectral preprocessing and ML regression algorithms can be very powerful for determining the moisture content of multi-source solid waste. Based on the full-band spectra, the combination of first derivative preprocessing and the SVR (Support vector regression) algorithm was preferable for predicting the moisture content of multi-source solid waste, while ATR correction preprocessing combined with the SPA (Successive projections alogorithm)-SVR algorithm performed better for the water-band spectra. After the hyperparameter optimization, the R^2 (R-squared) values of the validation and test datasets and the RMSE (Root mean square error) value for the prediction based on the water-band spectra were 0.9604, 0.9660, and 3.80, respectively. The excellent performance indicated that the proposed combined models can rapidly and accurately measure the moisture content of solid waste, which is significant for the existing waste characterization scheme, and for the further real-time monitoring and management of solid waste treatment and disposal process.

Keywords: Machine learning, Solid waste, Prediction, Moisture content, Spectra preprocessing, Regression algorithms.

Environmental Friendly Approach of Treatment of Commercial Laundry Wastewater Using Extracellular Polymeric Substances (EPS)

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The problem of management and treatment of wastewater from commercial laundries is a matter of concern. The present study provides an effective and eco-friendly solution to the treatment of wastewater from commercial laundries in Quebec (Canada) by using extracellular polymeric substance (EPS) as bio-flocculant. EPS was produced from valorization of crude glycerol and paper mill sludge by a bacterial strain (BS-04). Two different types of EPS: Slime EPS (S-EPS) and Broth EPS (B-EPS) were used for treatment of commercial laundry wastewater (CLWW). This is the first study for treatment of CLWW using bio-flocculant EPS. A comparison between the conventional treatment of laundry wastewater (LWW) by chemical coagulants ($FeSO_4$, $CaCl_2$, Alum) and enhanced treatment by bio-flocculant EPS has been drawn in the study. Moreover, LWW treatment by combination of EPS and chemical coagulants was also investigated. It was observed that S-EPS (0.6 g/L) gave better flocculation activity (FA) than B-EPS. S-EPS alone can remove 83.20% of turbidity, 77.69% suspended solids (SS) and 76.37% chemical oxygen demand (COD). The best results were obtained by combining S-EPS (0.6 g/L) together with alum (300 mg/L) at pH 7 for treatment time of 30 min. This combination was able to remove 98% of turbidity, 95.42 % of SS and 83.08% of COD from LWW. When treatment time has been increased to 4 h at pH 7, it resulted in more than 88% COD removal from CLWW.

Transfer Learning Based Visual Geometry Group Network (Tlvggnet) for Classification of Recyclable Waste in China: Estimation of Energy Saving Potentials, CO_2 Emission Reduction, and Economic Analysis

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Smart municipal solid waste (MSW) sorting and recycling could effectively reduce greenhouse gas emissions. Developing an intelligent and efficient method for recyclable waste sorting is necessary in terms of policy demand and environmental benefits. The benefits brought by the classification of recyclable waste using the deep learning has been rarely discussed. Therefore, four types of Visual Geometry Group Networks (VGGNet) based on transfer learning (TLVGGNet) were performed for recyclable waste classification. Additionally, cyclical learning rate was adopted to quickly find the best global learning rate. Potentials of energy saving, CO2 emission reduction and economic benefit analysis were also discussed. Results showed that the method of transfer learning could shorten the training time (344.39 s to 266.64 s) and improve the performance of the TLVGGNet-11 model in the training dataset (97.66% to 99.75%), validation dataset (99.34% to 99.64%), and test dataset (84.60% to 88.10%). TLVGGNet-11 was considered the best model for recyclable waste sorting in terms of training time (266.64 s), accuracy (88.10%), precision (88.80%), recall (88.10%), and F1 score (88.00%). Reducing energy consumption and CO2 emissions are about 7.18~7.28 Mt standard coal (tce) and 219.21~219.26 kt CO2, respectively, by using TLVGGNet models. In addition, the economic benefit can be improved from 427.05 k¥/d to 1567.30 ~ 1602.03 k¥/d with the function of TLVGGNet models.

Keywords: Recyclable waste classification; Deep learning; Economic analysis; Environmental analysis.

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Thermal Treatment Technologies

Co-pyrolysis of Food Waste and Agricultural Waste: Mechanism and Process Optimization Study

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Co-pyrolysis of food waste with agricultural waste to produce hydrogen is considered as an effective strategy for clean waste treatment and high value-added product synthesis. This study investigated the co-pyrolysis mechanism and hydrogen yield of food waste with coconut fiber, rice straw and chinar leaves, respectively, at different mixing ratios by thermogravimetric analysis. Friedman, Kissinger-Akahira-Sunose and Flynn-Wall-Ozawa conversion techniques were applied to investigate the kinetic properties of pyrolysis of feedstocks with different mass ratios to reveal the pyrolysis behavior and apparent activation energy in all conditions. Based on this, response surface methodology (RSM) was applied to optimize the microwave co-pyrolysis parameters, thus the predicted maximum hydrogen yield. This study reflects the feasibility of industrializing the co-pyrolysis of food waste and agricultural waste, which contributes to ameliorating the potential for solid waste microwave co-pyrolysis for value-added products production, therefore providing a reference for the further development of clean disposal technology and waste resource utilization.

Keywords: Food waste, Co-pyrolysis, Biomass, Thermogravimetric and kinetic analysis, Microwave pyrolysis.

Study on Pyrolysis of Ultra-High Grade Oil Shale and Characteristics of Three-Phase Products

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Experiments on the oil shale pyrolysis are carried out in an electrically heated fixed-bed reactor to investigate the characteristics of three-phase products. In the range of 450~650 ℃, the yield of semi-coke gradually decreased with increasing temperature, the yield of pyrolysis gas gradually increased, and the yield of liquid gradually increased and then decreased, reaching a maximum of 32.29% at 500 ℃. The maximum value of 32.29% was reached at 500 ℃. Comparing the FTIR spectra of the original oil shale sample and the semi-coke, the pyrolysis process mainly occurred through the cracking of aliphatic compounds, the organic matter in the semi-coke was mainly aromatic compounds, and the inorganic matter was mainly clay minerals containing Si-O-Si; the alicyclic ether C-O-C cracking occurred at 500~550 ℃, which was related to the release of CO_2 and CO. The percentage of H_2, CO, CH4, and CO_2 in the pyrolysis gas was measured by gas chromatography, and it was measured that the per-centage of CO in the pyrolysis gas was the highest, decreasing from 83.77% to 71.43% with the increase of pyrolysis temperature; the percentage of H_2 decreased and then increased with the increase of pyrolysis temperature, and the percentage of H_2 decreased from 16.23% to 9.58% at 450~600 ℃ and increased to 11.64% at the pyrolysis temperature of 650 ℃. The production of CH_4 needs to be higher than the pyrolysis temperature of 450 ℃, and a further increase in the pyrolysis temperature will decrease the percentage of CH_4. The results of GC/MS analysis of shale oil showed that aliphatic hydrocarbons were the main components of shale oil, and the percentage of aliphatic hydrocarbon carbon chain shortened and decreased when the pyrolysis temperature increased, and the percentage of aromatic hydrocarbon components increased. The simulation results show that at a pyrolysis temperature of 500 ℃ and an excess air coefficient of 3.17, the system can be self-balancing by using pyrolysis oil and gas and 0.4% of coke for combustion, and the resulting high-temperature flue gas to heat the pyrolysis process. At the same time, 60.86% of the coke product is output. The high temperature flue gas produced by the system can also be used for other waste heat utilization processes.

Keywords: Ultra-high-grade oil; Pyrolysis; Three-phase products; Distribution characteristic, Aspen Plus, Self-balanced.

Synthesis Gas Production from Co-pyrolysis of Straw Biomass and Polyethylene Agricultural Film

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ABSTRACT. Co-pyrolysis of straw biomass and polyethylene agricultural film at different mass ratios was carried out in a small fixed bed. The resulting synthesis gas production, liquid and solid products, and pyrolysis kinetics were studied by gas chromatography and thermogravimetric analysis. The results showed that yields of CH_4 and C_2H_4 increased linearly with increasing proportion of plastic in the feedstock, reaching as high as 67.14 and 100.54 mL/g feedstock, while H_2 and CO yields correspondingly decreased. The highest low heat value of 43.36 kJ/Nm^3 was obtained when the feed ratio is 100% polyethylene agricultural film. Straw and polyethylene agricultural film provided greater contributions to formation of carbon oxides and hydrocarbons, respectively. Kinetic analysis of the process showed that the activation energy and pre-exponential factor exhibited increasing and decreasing trends, respectively, when the proportion of polyethylene agricultural film and heating rate increased. Fitted linear correlation coefficients for all pyrolysis stages exceeded 0.99.

Keywords: *Co-pyrolysis; Biomass; Plastic; Kinetics; Syngas*

Introduction

Biomass is deficient in hydrogen and rich in oxygen, with values of H/C_{eff} (effective H/C ratio) varying between 0 and 0.3[1], while plastic agricultural film is mainly composed of polyolefin, and its H/C_{eff} is 2[2, 3]. Co-pyrolysis of biomass and plastic agricultural film can improve hydrocarbon yield, produce high-value products and reduce recycling cost due to the synergistic effect between these materials[4]. Therefore, co-pyrolysis of biomass and plastic agricultural film was explored in this study to understand the nature of the products and pyrolysis characteristics.

To date, several studies have been carried out on the co-pyrolysis of different types of biomass and plastics. Xu et al.[5] conducted catalytic co-pyrolysis of rice husk and polyethylene (PE) in a small fixed bed using Ni/char as catalyst. These researchers found that low PE proportions (< 50 mass%) undermined catalytic activity because more oxygenated compounds tended to be absorbed by the catalyst to form amorphous coke, which encapsulated Ni active sites and negatively influenced the H_2 yield; at higher PE proportions (75 mass%), more hydrocarbon gas from plastic pyrolysis condensed on the catalyst and promoted the growth of carbon nanotubes via dehydrogenation and polymerization, simultaneously generating H_2. Chattopadhyay et al.[6] conducted catalytic co-pyrolysis of paper biomass with high-density polyethylene (HDPE), polypropylene (PP), and polyethylene terephthalate (PET), and investigated the effects of pyrolysis temperature and material proportions on the compositions of the liquid and gas products. Hydrogen gas production peaked at 47 vol.% when the feed blend had a biomass: plastic mass ratio of 5:1. Gu et al.[7] studied the thermogravimetric characteristics and product distribution of the co-pyrolysis of corncob xylan and HDPE. The results showed that addition of HDPE promoted the release of hydrocarbons (CH_4, C_2H_2, C_2H_6, C_3H_6, C_3H_8) and aldehyde derivatives (CH_3CHO, CHO^+), but hindered production of H_2 and H_2O. When the proportion of HDPE was 75 mass%, formation of CO_2 was inhibited and the yields of alkanes and olefins were maximized.

In this study, co-pyrolysis and thermogravimetric analysis (TGA) of straw biomass (SB) and polyethylene agricultural film (PAF) were carried out using different material ratios. The composition and syngas yield were analyzed by gas chromatography (GC). The synergistic effect of mixed materials on the co-pyrolysis process was observed by comparing the theoretical and experimental values of the three products. The mass loss of the mixed materials was measured by TGA. The effect of heating rate on pyrolysis behavior was studied, and the activation energy and pre-exponential factor were calculated for each pyrolysis stage. The objective of this study is to provide theoretical guidance and direction for the co-pyrolysis of biomass and agricultural film.

Material and Methods

Materials

The SB was obtained from Surui Straw Processing Plant in Lianyungang City, Jiangsu Province, China. The PAF was supplied by Huai'an Agricultural Film Plastic Factory, Jiangsu Province, China. The SB was crushed using a solid mill, screened to a particle size of 0.18–0.25mm, and then dried in an oven at 105℃ for 12 h to remove moisture. PAF has the flexibility of film, so common crushing technologies are unable to break it. The film was therefore manually reduced in size using scissors and then screened to a particle size of 0.25–0.28mm. The two components were homogeneously mixed to give PAF mass ratios of 0, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100%.

Experimental procedure

The pyrolysis of SB, PAF, and their mixtures was carried out at atmospheric pressure in a horizontal quartz reactor with a length of 1500 mm and inner diameter of 52 mm, as shown in Figure 1. The experimental device included three parts: air intake, thermostatic pyrolysis, and gas cooling, drying, and collection. To obtain an inert atmosphere, the reaction was carried out in a nitrogen flow of 150 mL/min; the system was purged for 30 min before each experiment. Prior to each experiment, 3 g samples with different proportions of SB and PAF were placed in an alumina crucible on the left side of the reactor. The duration of each heat treatment was 40 min and the reaction temperature was 700°C. The discharge end of the quartz tube was bound with an adhesive belt to prevent condensation of pyrolytic tar that could block the outlet. The oil produced by the pyrolysis process is collected by the first bio-oil collection unit placed in ice water. The gas produced by thermostatic pyrolysis was continuously cooled from the outlet in two sequential porous washing bottles placed in an ice bath, then passed into U- tubes filled with activated carbon and color-changing silica gel for drying. Finally, the gas was collected in an air-collection bag.

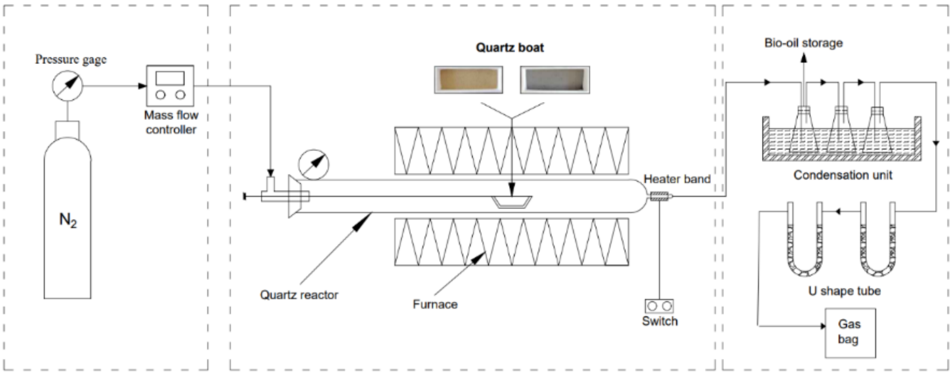

Figure 1. Schematic of pyrolysis system.

Results and Discussion

Oil composition

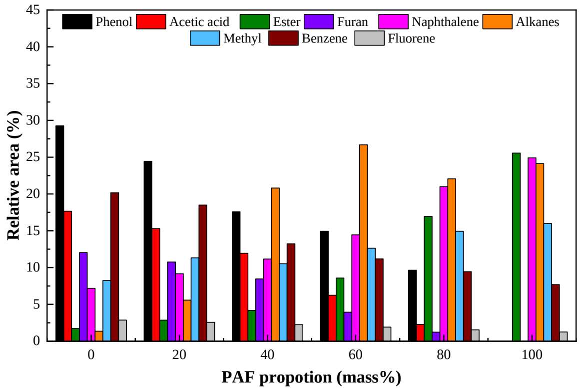

Figure 2. Effect of co-pyrolysis of SB, PAF and their mixtures on the selectivity of bio-oils.

Figure 2 shows the effect of SB, PAF and their mixture ratio on the component selectivity of bio-oil by GC-MS. The results show that when PAF is added in the process of co-pyrolysis, the phenol and aromatic hydrocarbons gradually decrease. When PAF content increases from 0 to 80%, the selectivity of phenol decreases from 29.28% to 9.64%. In the mixture, the volatile of SB will react hydrocarbon pool mechanism and Diels-Alder reactions to produce aromatic hydrocarbons at a lower temperature. However, the selectivity of alkanes and esters increased significantly, which may be because the addition of PAF provided a large number of hydrogen donors for the C-C coupling reaction of carboxylic acid molecules to generate alkanes, thus reducing the selectivity of aromatic hydrocarbons in bio-oil. At the same time, with the increase of PAF in the mixture, the selectivity of alkanes reached 26.69% when the proportion of PAF was 60%. In summary, the co-pyrolysis of SB and PAF shows unique properties in terms of decreasing the selectivity of aromatic products and increasing the selectivity of alkanes.

Effect of mixture ratio on syngas production and composition

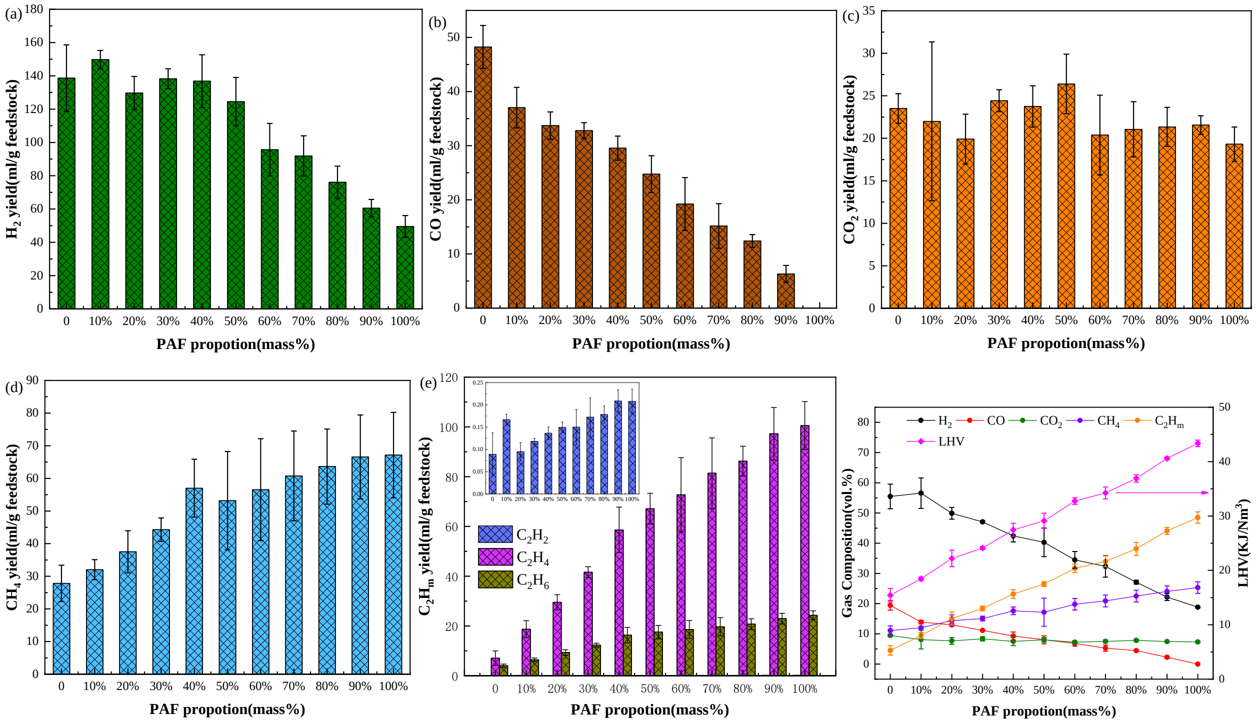

Figure 3. Effect of mixture ratio on syngas production and composition

Figure 3 depicts the experimental yields of SB and PAF catalytic co-pyrolysis at different ratios, including the error analysis derived from three sets of parallel experiments. As shown in Figure 3 (a), a lower proportion of PAF in the raw material had little effect on H_2 yield. When the proportion of PAF was 50% to 100%, hydrogen production was significantly reduced, indicating that when the PAF content in a mixed feed was high, increasing the PAF proportion had a negative synergistic effect on H_2 yield in the co-pyrolysis process. Figures 3 (d) and (e) show that when the proportion of PAF reached 100%, hydrogen in the raw materials was more completely transformed into hydrocarbons, such as CH_4, C_2H_2, C_2H_4, and C_2H_6, among which methane and ethylene were most obvious, reaching 67.14 mL/g and 100.54 mL/g, respectively. PE is a long chain of vinyl monomer polymer. Its pyrolysis process of depolymerization and decomposition can produce a large number of paraffins and olefins. Olefins will be further decomposed into light alkane and alkene gases, such as CH_4, C_2H_4. Therefore, with increasing PAF proportion in the feed, the production rates of these two gases increased and larger outputs were achieved. CO yields decreased with the increase of PAF because of the low oxygen content in the feedstock. As shown in Figures 3 (b) and (c), the experimental CO yield was almost zero when the feed contained 100% PAF. The linear behavior of CO_2 yield at different mixture ratios indicated that CO_2 production during co-pyrolysis was insignificantly affected by the feed composition. These results are consistent with the experimental results of Xu et al.. For the co-pyrolysis of biomass and plastic, CO and CO_2 are mainly generated from the pyrolysis and reforming process of thermally unstable carbonyl (C=O), carboxyl (–COOH), and ether (–C–O–C) groups. During the co-pyrolysis of SB and PAF, the synergistic effect may produce more hydroxyl radicals, which can attack polymer chains in the plastic or aromatic rings in the biomass, and then react with aliphatic species to produce CO and CO_2. These results indicate that hydrogen can be transferred from PE to oxygen-containing compounds derived from biomass, which can slow down the polymerization and cross-linking reactions to form char, and inhibit the decarboxylation reaction to form CO and CO_2.

Conclusions

Comparison of experimental and theoretical values of the three-phase products showed that co-pyrolysis of SB and PAF has a positive synergistic effect on the production of the oil and gas phases, and promotes generation of hydrocarbon gases such as CH_4 and C_2H_4, while inhibiting the generation of H_2 and CO. The highest LHV of 43.36 kJ/Nm^3 was obtained when the feed comprised 100% PAF.

Acknowledgement

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Ash Fusion Characteristics of Sewage Sludge and its Inhibitors to avoid Slagging during Incineration

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ABSTRACT. In this article, the purpose is to clarify the ash characteristics and ash fusion temperature of sewage sludge collected in Shanghai. Furthermore, some trials were conducted to enhance the ash fusion temperature of SS through blending a certain amount of clay additive in order to avoid slagging phenomena in incinerator. The main results include: (1) The ash fusion temperatures of most sewage sludge samples are lower than 1150°C, as mainly due to higher level of Fe content in ash. (2) The Si-Al additive, e.g. kaolin and bauxite, is not effective to change ash fusion temperature of SS with little dosage. However, much more amount of Si-Al additive is useful to increase fusion point if the amount of bauxite blended beyond 50wt% or kaolin added over 100wt%. (3) Limestone works well to increase the fusion temperature to 1238°C through blending 5wt% limestone. (4) Some Mg-bond minerals could also increase the ash melting temperature to 1236°C with adding 5wt% of additive. The research is significant to direct the incinerator operation with avoiding the slagging during incineration with SS.

Keywords: Sewage sludge, Incineration, Ash fusion temperature, Slagging.

1. Introduction

Sewage sludge (SS) is a by-product from urban waste-water treatment. At present, the yield amount of sewage sludge is much increasing year by year in China with urbanization development. The incineration is an effective disposal approach towards sewage sludge, not only reducing the waste volume but also utilizing the heating value as a sustainable fuel in the waste-to-energy facility.

2. Ash characteristics of sewage sludge

The SS samples, collected from various water-waste plants, has been tested. And the ash fusion temperatures of sewage sludge samples of S5 and S6 are lower than 1150°C, as mainly due to higher level of Fe content in ash, shown in Table 1 and Figure 1. The slagging trend is related with eutectic mixture with rich Fe and alkali metal combined during the incineration process of sludge.

Table 1 Fusion temperatures tested of six sewage sludge samples

samples	S1	S2	S3	S4	S5	S6
Deformation temperature	1430	1250	1240	1130	1090	1080
Soften temperature	>1500	1300	1260	1140	1100	1100
Hemisphere temperature	>1500	1320	1270	1150	1110	1120
Fluid temperature	>1500	1340	1280	1160	1120	1150
AFI	1444	1264	1246	1136	1094	1088

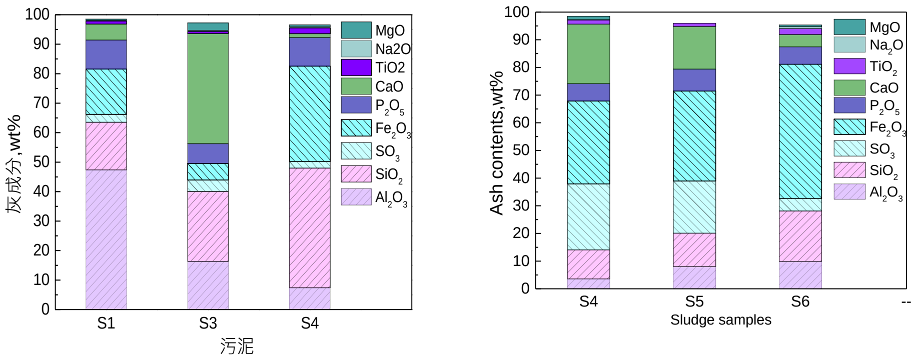


Figure1 Ash contents in different SS samples

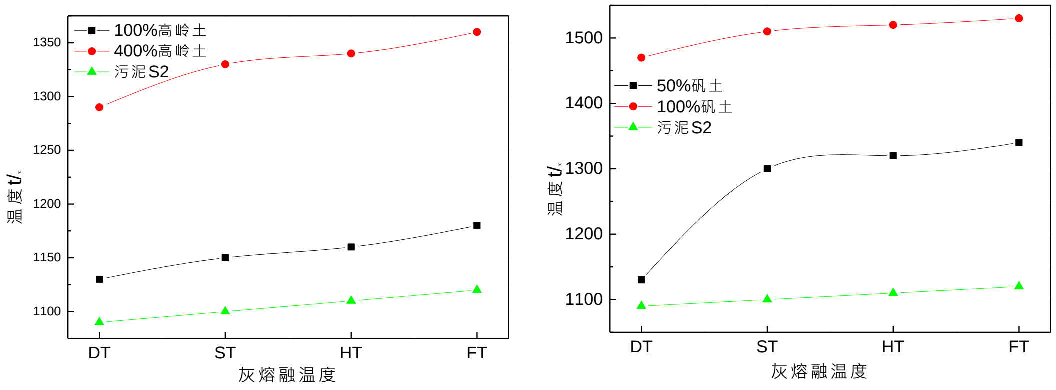
3. Influence of clay additives on fusion process of SS

The influence of several additives, incl. kaolin, bauxite, limestone and magnesium carbonate, on ash fusion point was investigated respectively upon use of many tests, e.g. XRF, XRD, SEM morphology analysis, EDS energy spectrum and ash fusion point test. The experimental cases shown in Table 2, which designed to analyse the influence of additives on sludge S5.

Table 2 Blending ratios of Additives in the SS samples

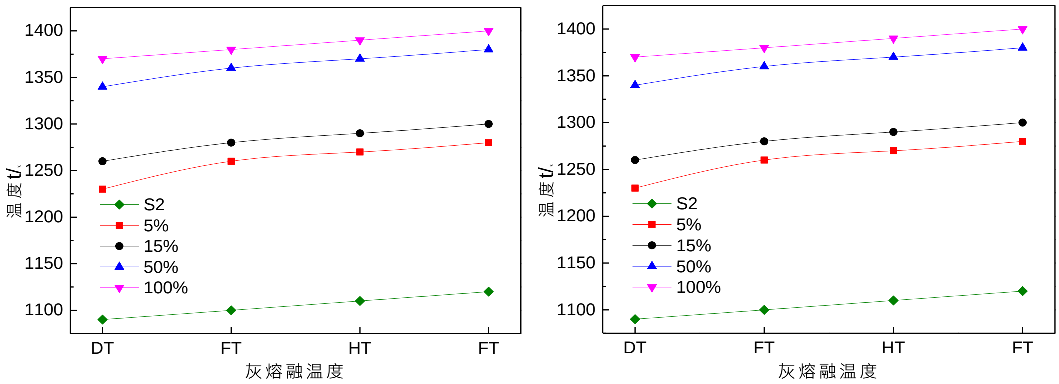
Additives	Adding ratio based on raw sludge	Adding ratio based on sludge ash
Kaolin	100%, 400%	196%, 784%
Bauxite	50%, 100%	49%, 196%
$CaCO_3$	5%, 15%, 50%,100%	5.5%,16.7%, 54.9%, 109.8% *
$MgCO_3$	5%, 15%, 50%,100%	4.7%,14%, 46.7%, 93.3% *

* Data show the effective adding content, e.g. CaO or MgO, which comes from thermal decomposition of $CaCO_3$ or $MgCO_3$



(a) (b)

Figure 2 Influence of additives of Kaolin or Bauxite on the fusion points of S5 sample: a) Kaolin; b) Bauxite

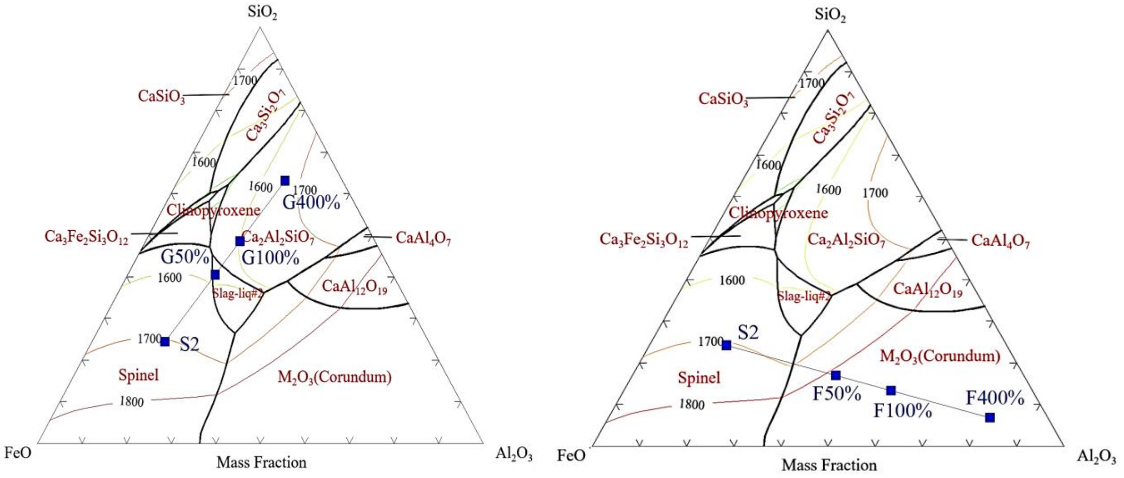


(a) (b)

Figure 3 Influence of additives of limestone or magnesium carbonate on the fusion points of S5 sample: a) limestone; b) magnesium carbonate.

The Si-Al additive, e.g. kaolin and bauxite, is not effective to change ash fusion temperature of SS with little dosage. However, much more amount of Si-Al additive is useful to increase fusion point if the amount of bauxite blended beyond 50wt% or kaolin added over 100wt%, as shown in Figure 2. Compared with Si-Al additive, limestone works well to increase the fusion temperature to 1238°C through blending 5wt%

limestone into sludge ash samples. Some Mg-bond minerals could also increase the ash melting temperature to 1236°C with adding 5wt% of additive, as shown in Figure 3.

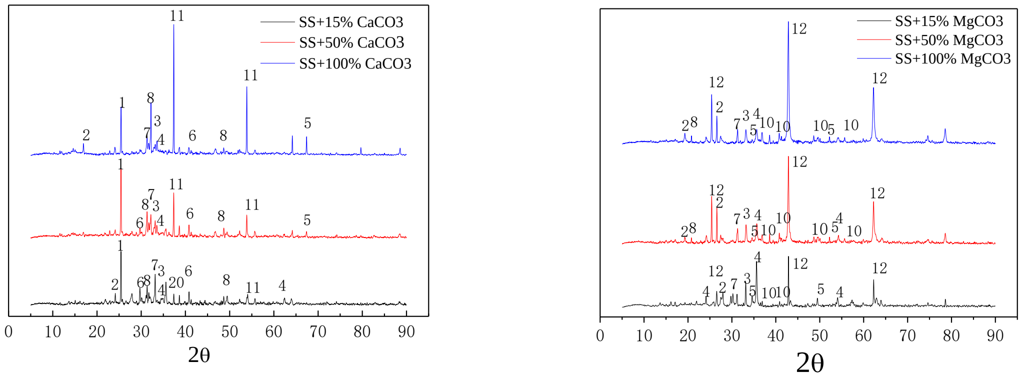


(a) (b)

Figure 4 Ternary phase diagrams to demonstrate the relationship between adding levels of kaolin (a) and bauxite (b) and fusion temperature.

The analyses based on ternary equilibrium phase diagram, e.g. SiO_2-CaO-Al_2O_3 could help understand the influence of the additive and the required quantity, shown in Figure 4. It is required to effectively enhance fusion temperature with a more amount of additives.

The addition of CaO or MgO into SS ash, as formed from limestone and magnesium carbonate blended, could convert Fe metal in the low-temperature eutectic to crystal ferrate. The function of alkaline earth metals is significant to increase the fusion point of sewage sludge ash and to decrease slagging trend in an incinerator, shown in Figure 5 and 6. The effects of mineral inhibitors are important to control the ash characteristics, as could help to direct the suitable design about the incineration process of sewage sludge.



(a) (b)

Figure 5 XRD tests of SS sample and additives of limestone (a) or magnesium carbonate (b) under 1100°C

1.$CaSO_4$, 2.SiO_2 , 3.Al_2O_3 , 4.Fe_2O_3 , 5.$CaSiO_3$, 6.$Ca_2Fe_2O_5$, 7.$Al_6Si_2O_{13}$, 8.$CaAl_2Si_2O_8$, 9.$Ca_7Mg_2P_6O_{24}$, 11.Mg_2SiO_4 , 20 CaO, 21 MgO

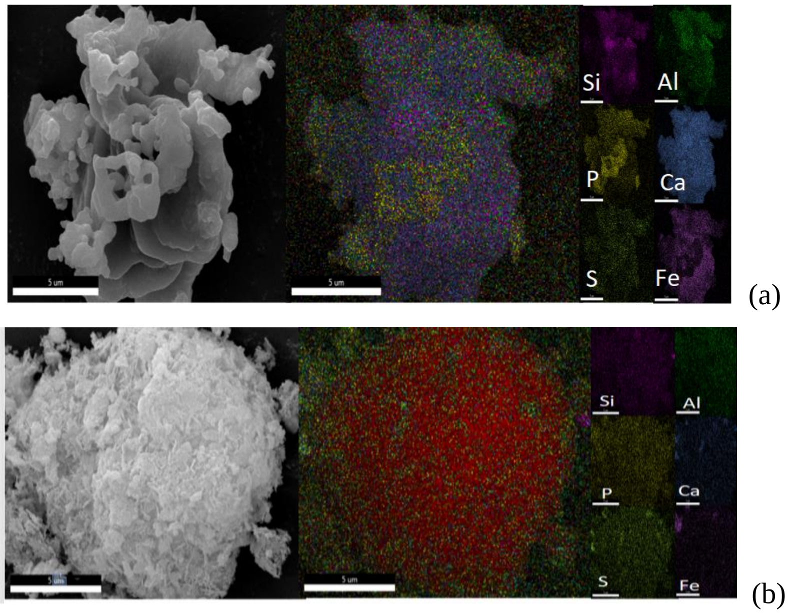


Figure 6 SEM mapping demonstrations with sludge blended with limestone (a) or magnesium carbonate(b)

4. Conclusion

Regarding the slagging phenomena during sewage sludge incineration with higher iron content, the effective additives is a good suggestion to increase the fusion temperature and avoid slagging. This paper discussed four additives, e.g. kaolin, bauxite, limestone and magnesium carbonate. The adding dose is much higher about kaolin or bauxite used. The influence of limestone and magnesium carbonate is obvious with little dose on increasing sludge fusion temperature, as could convert Fe metal in the low-temperature eutectic to crystal ferrate.

Emission and Distribution of Dioxin in a Coal-fired Power Plant Coupled with Garbage and Biomass

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This paper reports dioxin emission from the coupling of anaerobic pyrolysis of garbage and the co-combustion of biomass in a coal-fired power plant. In this work, the concentration and composition characteristics of dioxins in flue gas from chimney outlet and fly ash in front of dust collector were tested before and after coupling with garbage and biomass in a 55MW unit, and the impact of coupling treatment on environmental quality was analyzed, which can provide basic data for domestic coal-fired power plant collaborative disposal of garbage and biomass engineering environmental emissions, and lay a foundation for the development of this technology. The results showed that the total content of dioxins in flue gas was 0.0061 ng TEQ/m^3 when there was no co-combustion of other fuels. The total content of dioxins in flue gas is 0.0053 ng TEQ/m^3 when the ratio of co-burned garbage carbon was 1%. The content of dioxins did not change significantly before and after the garbage pyrolysis coupling, which was lower than the local emission standard. However, the actual emission concentration and toxic equivalent concentration of dioxins increased when the ratio of co-burned garbage carbon increased to 3%, and there was a risk of dioxin emissions. Therefore, garbage pyrolysis coupling is more suitable for low proportion coupling conditions. Under the condition of 10% biomass co-firing, the total dioxin content in the flue gas was 0.0018 ng TEQ/m^3, which was significantly lower than that in the raw coal condition and far lower than the local emission standard, indicating that the high proportion co-combustion of biomass is feasible and can promote the reduction of dioxin emissions.

Keywords: Dioxin, Coal-fired power plant, Garbage, Biomass, Co-combustion.

Fabrication of Hydrophobic Composite Material using Residues Derived from Incineration of Textile Waste

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Textile waste is one of the contributors that cause serious environmental pollution around the world. Even though large amounts of textile wastes can be separated from other municipal solid wastes, the end-of-life cycle of those textile wastes is disposed of by incineration, and the residues from incineration are usually dumped into landfills. The aim of this study was to develop a new pathway to improve the recycling of textile waste, and to increase the quality of residues after incineration processes via relevant pre-treatments of textile wastes for their application in fabrication of hydrophobic composite material to achieve sustainability and promote circular economy. The pre-treatment of textile waste was carried out by using polyvinyl alcohol (PVA) and oxidizing agents, formaldehyde and concentrated hydrochloric acid (HCl). After the pre-treatment for modifying the textile waste, the pyrolysis of modified textile waste at 900°C was carried out, producing a stable aggregate of residues. The microstructural changes of residues derived from incineration for non-modified and modified textile waste samples were determined using X-ray diffractometry (XRD), Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM) coupling with energy disperse spectroscopy (EDS), Brunauer, Emmett and Teller (BET) surface area analysis, and particle size distribution (PSD) analysis. The results indicated that the hydrophobicity of residues derived from modified textile waste was enhanced significantly. These residues revealed a stable and dense structure, and enhanced water resistance, which can be applied as a hydrophobic composite material for construction projects.

Keywords: Circular economy; Hydrophobic composite material; Hydrophobicity; Textile waste; Water resistance.

Production of A Novel Catalyst from Oil Palm Waste and Chitosan for Application in Catalytic Microwave Pyrolysis of Algae

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Oil palm wastes (OPW), comprising palm kernel shell (PKS), mesocarp fiber, and empty fruit brunch, are abundant wastes discharged from palm oil plantations. Improper management of the OPW causes serious pollution to the environment. Alternatively, the lignocellulosic-rich OPW can be fabricated into chitosan-rich catalyst for microwave pyrolysis of algae. In this study, OPW were engineered and converted into chitosan coated biochar (CTS/biochar) followed by examination of its application as a novel catalyst in the microwave pyrolysis conversion (MCP) of algae in value-added oil product. The results obtained revealed the production of biochar with different characteristics significantly affected the coating of chitosan and properties of the resulting biochar composite. PKS with the desired surface morphology and highest surface area (210 m^2/g) provided more contact area for the loading of chitosan and thus produced a chitosan-rich catalyst. The application of CTS/biochar in MCP of algae enhanced the thermal decomposition and 2-fold higher yield of pyrolytic oil compared to that without catalyst. The presence of chitosan enhanced the depolymerization of cellulose and hemicellulose in algae, resulting in an increase in the yield of pyrolytic oil. GC/MS revealed that the pyrolytic oil contains a mixture of acids, aldehyde, ketones, esters and hydrocarbons. Our results demonstrated the combination of CTS/biochar catalyst and microwave pyrolysis as a promising approach for waste and biomass recovery.

Keywords: Microwave extraction, Cocoon, Chitosan, Biofuel.

Utilization of Mechanochemically Pretreated Municipal Solid Waste Incineration Fly Ash For Supplementary Cementitious Material

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In recent years, municipal solid waste incineration (MSWI) has gradually become the mainstream technology of waste disposal in China, and the output of MSWI fly ash has increased to 8.5 million tons per year. MSWI fly ash was recognized as a hazardous waste because of its potentially toxic elements, including dioxins and heavy metals. The effective disposal and recycling utilization of MSWI fly ash has been attracting increasing attention. Mechanochemical (MC) treatment as a green and non-thermal method shows good stabilization on heavy metals and degradation of dioxins in MSWI fly ash. In the present work, the inhibition effect on heavy metals leaching with $CaSO_4$, $Ca_3(PO_4)_2$, NaH_2PO_4, and composite additives (50%NaH_2PO_4+50%CaO) as additives were investigated. The environment impact was assessed by Risk assessment code. Moreover, milled fly ash used to prepare high-volume fly ash blended cement mortars was investigated. The composite additive(50%NaH_2PO_4+50%CaO) showed the best inhibitory effect on heavy metals, and the leaching concentration of Cd, Cr, Cu, Ni, Pb, and Zn decreased by 95.21%, 46.84%, 99.42%, 49.91%, 99.83%, and 99.55%, respectively. The main products of the reaction between fly ash and phosphate was hydroxyapatite, in which calcium ions can be replaced by various metal ions through ion exchange reaction to form M-apatite. The sequential extraction procedure (SEP) results demonstrated that insoluble phosphates residues were generated. The overall heavy metal risk index (RI) of samples for MCFA-$CaSO_4$ MCFA-$Ca_3(PO_4)_2$, MCFA-NaH_2PO_4, MCFA-Composite additives were 1545, 1302, 1054, 481.3, 53.79 respectively. The raw fly ash belongs to the level of high risk and the MC treatment with composite additives showed the best control effect on environmental risk. In addition, the MC treatment reduced the particle size of fly ash, which decreased from 35 to 2um, and improved the chemical reactivity for resource utilization. Therefore, when MC treated fly ash was used as supplementary cementitious material (SCM), which will produce a filling effect and a pozzolanic effect improving the performance of fly ash concrete blocks. The MC fly ash provided nucleation sites and has a higher water-holding capacity continuously releasing water to carry out a hydration reaction to generate C-S-H. Compared to the untreated fly ash, the compressive strength of the MC treated fly ash concrete blocks curing for 28 days increased by 35.5% and exceeded 40 MPa, which was close to the strength of OPC. For dioxins, the concentration of PCDD/Fs of concrete blocks is only 4.70 ng-TEQ/kg, much lower than the Europe Union End-of-Waste proposal (20 ng TEQ/kg). In conclusion, the MC treatment effectively inhibited the leaching of heavy metals in fly ash and the utilization of MC-treated fly ash as SCM delivered a promising method for a green fly ash disposal.

Keywords: MSWI; Fly ash; Mechanochemical treatment; Heavy metal; Supplementary cementitious material.

Improving Biochar Properties by Pyrolysis of Palm Biomass for Use as Cement Based Materials

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Cement has been widely used in the construction industry. Production of cement generates carbon dioxide, which is a greenhouse gas. To reduce the utilisation of cement in the construction industry, it is proposed to use biochar as a supplementary cementitious material. Biochar is produced from readily available biomass such as palm kernel shell and empty fruit bunch. From the palm oil extraction process, there is a large amount of palm biomass that are available as wastes. Palm biomass were collected from a palm oil processing mill. They were washed and dried in an oven. After that, they were milled and sieved to a fraction of 2 mm. A tubular reactor was used to conduct the pyrolysis process. Temperatures between 200 to 800 ℃ were chosen as the operating temperature. A heating rate 10 ℃/min and holding time of 70 min were set all pyrolysis runs. Biochar yield was determined after the cooling process. Biochar was also analyzed with Thermogravimetric Analyzer (TGA), Scanning electron microscopy (SEM) combined with energy-dispersive X-ray spectroscopy (EDX) to understand its properties to be used as cement-based materials. The results obtained from the study shows that there is a potential for palm biomass to be used as feedstock as biochar production which can be utilised as cement replacement.

Keywords: Palm biomass, Pyrolysis, Cement replacement.

A Study on the Effects of Waste Glass Sand on the Properties of Bricks Contained with Incinerator Bottom Ash

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ABSTRACT. The objective of this study is to investigate the effect of waste glass sand (WGS) on the properties of bricks. Additionally, the improvement of bricks containing incinerator bottom ash (IBA) was studied. Results from the water absorption test showed that the surface of the WGS was smooth with fewer pores and was suitable for use in improving the water absorption of bricks containing IBA replacements. The use of both IBA and WGS replacements in bricks led to a reduction in the compressive strength of the bricks. Furthermore, the test results showed that the use of IBA replacements alone in bricks could not meet the requirements set by the specifications. When the kiln temperature exceeded 950°C, the use of WGS could improve the compressive strength of bricks, which met the requirements set for class III bricks.

Keywords: *Waste glass sand, Incinerator bottom ash, Bricks.*

Introduction

In recent years, the amount of waste liquid crystal glass has increased significantly due to the vigorous development of the high-tech industry. In Taiwan, about 500,000 to 600,000 metric tons of waste glass are not effectively reused each year, and instead are landfilled or incinerated. Sabba [1] found that waste glass possessed good hardness and strength and was suitable for manual crushing and grinding. However, waste glass sand (WGS) was commonly considered unfavorable for recycling. To improve the recyclability of glass sand, Daigo et al. [2] proposed a linear model to minimize the depletion of natural resources. Nafisa et al. [3] found that replacing natural sand with glass sand improved the strength, resistance to chloride permeability, and alkali-aggregate reaction of concrete, suggesting that glass sand was a suitable engineering material. Yubo et al. [4] showed that the use of glass sand improved the workability of concrete but had no influence on the elasticity and split tensile strength of concrete. Silva et al. [5] suggested that glass sand was a valuable material that could be used as a natural resource to improve the physical, mechanical, and environmental properties of tiles. Barrachina et al. [6] applied glass sand to the manufacture of tiles and found that the crystal phase of anorthite ($CaAl_2Si_2O_8$) in the interior structure of glass sand improved the flexural strength and mechanical properties of tiles. In this study, WGS and incinerator bottom ash (IBA) were used to partially replace clay in bricks. Tests, including specific gravity, specific surface area, and compressive strength, were performed. Moreover, the use of WGS in bricks containing IBA replacements improved the strength and water absorption of the bricks.

Material and Methods

Basic properties of Materials

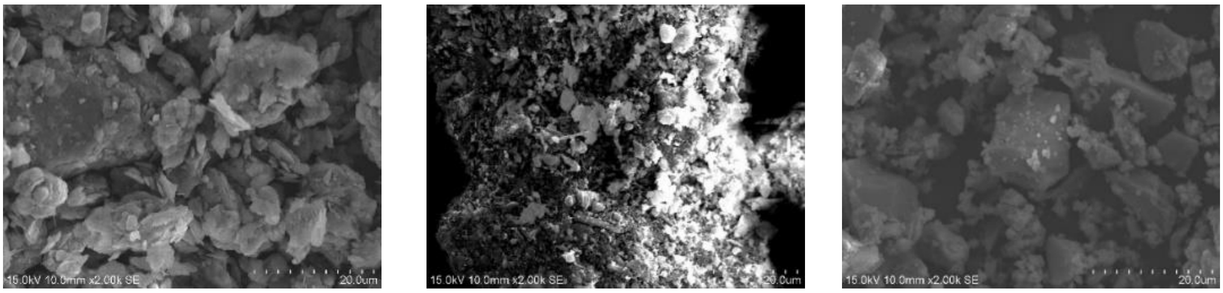
In this study, before using the clay, IBA, and WGS, they were passed through a #50 sieve, and their basic properties were measured and recorded in Table 1. As shown in the table, the specific gravity of the clay was 2.65, while IBA had a lower specific gravity of 2.57. The specific gravity of WGS was 2.47. The specific surface area test results showed that the specific surface area of the clay was larger than that of IBA and WGS, suggesting that the overall particle size of the clay is finer. The plasticity index of the clay was found to be 10.5%.

Table 1. Basic properties of materials

	Clay	IBA	WGS	Standard
Specific gravity	2.65	2.57	2.47	CNS 5090
Specific surface area, cm^2/g	3035	716	651	CNS 2924
Plasticity index, %	10.5	NA	NA	CNS 5088

SEM-EDS test

Figure 1 shows SEM images (x2000) of (a) clay, (b) IBA, and (c) WGS. As shown in Figure 1(a), the clay minerals exhibited a hexagonal crystalline structure. In Figure 1(b), the crystal structure of the IBA was found to be complicated due to its origin as a by-product of incinerated waste cooled by water quenching at high temperatures. The grain shape of the WGS in Figure 1(c) resembled that of a water chestnut, with a smooth surface and fewer observed pores. When WGS was used in the manufacture of bricks, the amount of water required inevitably decreased with increasing WGS replacement. Table 2 shows the results obtained from EDS analysis of the clay, IBA, and WGS.



(a) Clay (b) IBA (c) WGS

Fig.1. SEM images for the raw materials

Table 2. EDS results of the raw materials

Element	O	Na	Mg	Al	Si	S	Cl	K	Ca	Fe	Zn	Zr	Sr
Clay, %	51.6	-	1.3	9.4	27.6	-	-	3.5	-	6.7	-	-	-
IBA, %	55.0	1.7	1.0	2.1	6.9	1.4	2.6	1.0	23.0	0.8	1.1	3.4	-
WGS, %	54.9	-	1.5	7.7	26.7	-	-	-	2.4	-	-	-	6.8

TGA test

Because the weight change of the materials applied in this study in the high temperature environment is important to the bricks, the TGA tests were performed to study the weight changes of the clay, IBA, and WGS at 25-1000°C. Figure 2 shows the results obtained from the TGA tests for clay, IBA, and WGS. As shown in the figure, the main component of the IBA was $CaCO_3$, which decomposed into CaO and CO_2 at 700°C and completed at 800°C. Hence, a drop in the figure is noticed. Furthermore, the weight losses on WGS were not changed within the temperature tested. It implies that when WGS applied to the manufacture of the bricks, the weight loss on ignition of brick would reduce with the increasing amount of WGS replacement.

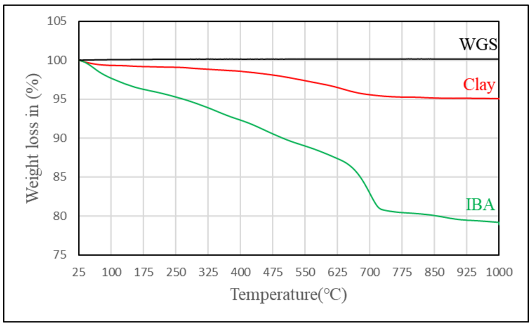


Fig.2. TGA test results of raw materials

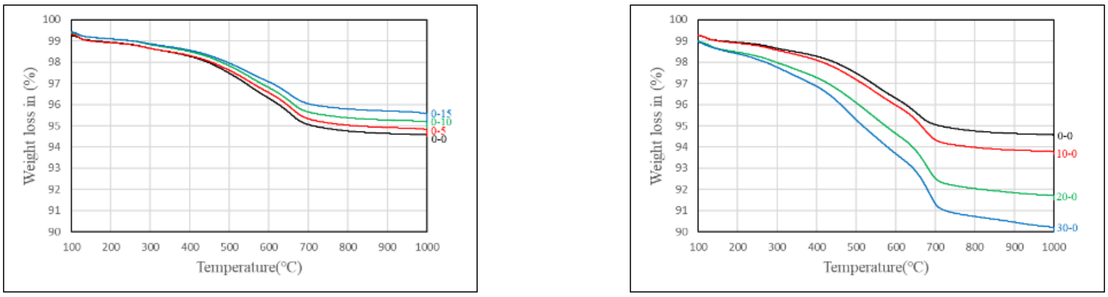
Results and Discussion

Mixture design

To study the effects of the WGS on the bricks containing IBA, different amounts of clay were replaced by the WGS in the bricks. The kiln temperature and the amounts of IBA and WGS were set as the experiment parameters. The kiln temperatures were set at 850, 900, and 950°C. The amounts of IBA and WGS replacements were assigned at 0, 10, 20, and 30%, and 0, 5, 10, and 15%, respectively. Tests such as the weight loss on ignition test, water absorption test, and compressive strength test were performed to analyze the physical property changes in the bricks.

Weight loss on ignition test

Figure 3 shows the relationship between weight loss on ignition and different amounts of WGS replacements for bricks containing varying amounts of IBA and fired at different kiln temperatures. As shown in the figure, the weight loss on ignition of the bricks increased with the increasing amount of IBA content at kiln temperatures of 850-950°C. Moreover, because SiO_2, the main component of WGS, melted rather than decomposed at high kiln temperatures, the weight loss on ignition of the bricks reduced with the increasing amount of WGS replacement.

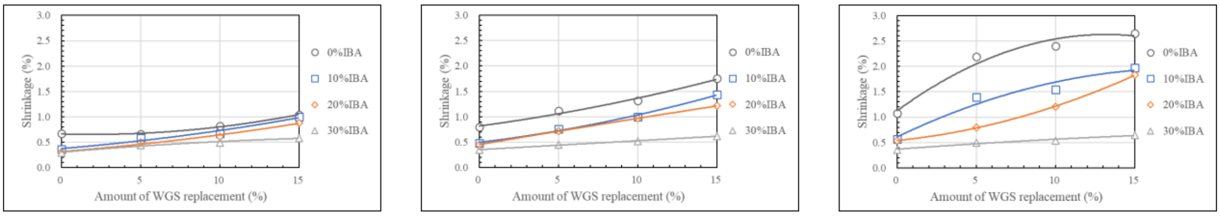


(a) The bricks with different amounts of WGS (b) The bricks with different amounts of IBA

Fig.3. TGA test results of bricks

Water absorption test

Based on the CNS 382 specification, three levels of water absorption are classified: level 1 (below 10%), level 2 (below 13%), and level 3 (below 15%). Figure 4 shows the relationships between water absorption and different amounts of WGS replacements for bricks containing varying amounts of IBA and fired at different kiln temperatures. The water absorption of the bricks increased greatly with the use of IBA replacement. When the amount of IBA replacement was only 10%, the water absorption of the bricks exceeded the level 3 requirement set by the CNS specification. However, test results showed that although the use of WGS improved the water absorption of the bricks, the decrement in water absorption was limited. Furthermore, the water absorption of bricks containing 0% IBA replacement was 15.46% when fired at a kiln temperature of 850°C. However, when the amount of WGS replacement reached 15%, the water absorption was improved to 14.86%, which met the level 3 requirement set by the CNS specification.

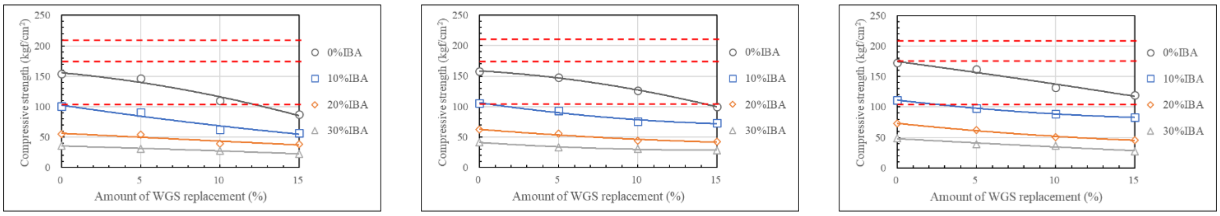


(a)850°C (b)900°C (c)950°C

Fig.4. Water absorption at different kiln temperature

Compressive strength test

Based on the CNS 382 specification, three levels of compressive strength are classified: level 1 (above 300kgf/cm^2), level 2 (above 200kgf/cm^2), and level 3 (above 150kgf/cm^2). Figure 5 shows the relationships between compressive strengths and different amounts of WGS replacements for bricks containing different amounts of IBA and fired at different kiln temperatures. Test results show that the compressive strength of the bricks increased with the increasing kiln temperature at 850-950°C due to the more compact interior structure of the bricks driven by heat. As a result, the use of WGS in the manufacture of the bricks had limited effect on improving their compressive strength. Hence, the bricks without the use of IBA and WGS at a kiln temperature of 850-950°C, and those with only 5% WGS at a kiln temperature of 950°C, both met the level 3 compressive strength requirement of the CNS 382 specification in this study. Moreover, the test results show that the use of IBA replacement alone in bricks did not conform to the requirement set by the specification. When the kiln temperature was higher than 950°C, the use of WGS in the bricks could improve their compressive strength, and the suggested maximum amount of WGS replacement was 5%.



(a)850℃ (b)900℃ (c)950℃

Fig.5. Compressive strength of specimen at different kiln temperature

Conclusions

The application of IBA replacement alone in bricks cannot meet the requirements set by the specifications. However, when the kiln temperature reached 900℃ or higher, tiles with no IBA replacements met the specification for Class III bricks. Moreover, for the application of WGS replacements to bricks, the kiln temperature needs to be increased to 950℃ to meet the specification for Class III bricks.

Acknowledgement

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Migration and transformation characteristics of molten heavy metals from MSWI fly ash under different additives

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The fly ash produced by MSWI (municipal solid waste incineration) is a kind of hazardous waste. It contains pollutions such as dioxins, heavy metals, and other harmful substances. The main disposal methods include solidified landfill, melt landfill and industrial materialization. However, the disposal of fly ash from MSWI is hindered by the closure and control management of the infected areas around the novel coronavirus epidemic. This paper investigates the effects of additives on the melting characteristics and heavy metal migration of MSWI fly ash，which is based on melt landfill treatment with waste recycling and energy saving as the starting point. It provides theoretical support for the high-temperature melt treatment of MSWI fly ash in terms of microscopic morphology and composition. Firstly，based on CFB (Circulating fluid bed) MSWI fly ash, three additives are designed for ash melting characteristics experiments, including CaO, SiO_2 and Al_2O_3. By varying the content of the three, we derive the pattern of their variation on the melting temperature: all of them have a minimum range of additive to make the flow temperature, when insufficient and excessive additives will rise the flow temperature. Secondly, with different additives, the characteristics of heavy metal migration of MSWI fly ash are investigated. We find that CaO can effectively inhibit the volatilization of various heavy metal chlorides with low melting points. SiO_2 and Al_2O_3 have a facilitating effect on the formation of stable silica-aluminate crystals. Silica-aluminate crystals are the key to improve the solidification rate of chemical heavy metals and inhibit leaching. In the actual process, it would be best if a low-cost, silica-aluminate rich clay ore could be used. Finally, based on the melting characteristics, heavy metal migration and stabilization characteristics of MSWI fly ash under different additives, we analyze the microstructure and composition of MSWI fly ash after melt treatment and find that：Some heavy metals are solidified in chemically stable crystal structures after exchange with calcium ions and other ions. Some exist in the form of solid solution between the crystal lattice structure. Others are encapsulated by the crystal structure and not easy to leach, which is the main reason to inhibit the leaching of heavy metals. For achieving the reduction, harmlessness and resourcefulness of domestic waste to the maximum extent, we are steadily moving towards the goal of "waste-free city", responding to the sustainable development goal of the United Nations.

Keywords: MSWI fly ash, Melting, Heavy metals, Sustainable development.

The Application of Laser Ionization-Time-of-flight Mass Spectrometry Online Detecting System for Dioxins in a Municipal Solid Waste Incineration Plant

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With the increasing strict emission standards and supervision of dioxins from municipal solid waste incineration in China, and in order to explore the optimal operating conditions for incinerators to control dioxins emission, laser ionization-time-of-flight mass spectrometry online detecting system for dioxins was used to continuously monitor dioxin emission in the flue gas of a circulating fluidized bed incinerator. In this study, operating conditions were adjusted by putting phase-change heat exchanger into operation at the tail of incineration system to reduce the flue gas temperature, adjusting the quality of activated carbon (AC) and optimizing the combustion, and change trend and emission level of dioxin under different operating conditions were monitored, so as to determine the optimal operating conditions for the incinerator to control dioxin emission. The results showed that the dioxin average concentration decreased by 35.11%, from 0.131 ng TEQ/Nm^3 to 0.085 ng TEQ/Nm^3 after the phase-change heat exchanger was put into operation. When AC with iodine adsorption value of 800 mg/g was adjusted to 1000 mg/g, and kept the amount at 10 kg/h, the concentration of dioxin remained unchanged at 0.08 ng TEQ/Nm^3. After reducing the amount of treated solid waste, selecting the waste with more uniform crushing degree and adopting auxiliary combustion measures, the dioxin emission became low and stable, with an average concentration of 0.068 ng TEQ/Nm^3. Therefore, it was an effective way to control dioxin emission by stabilizing the combustion condition, fully burning solid waste and reducing dioxin generation from the source.

Keywords: Circulating fluidized bed incinerator, Dioxins, Online detection, Operating condition adjustment.

Humic Acid from Hydrochar: Correlation Between Unsaturation and Hydrothermal Humification of Hydrochar

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Biomass-derived hydrochar characteristics will change with hydrothermal conditions varying, which may influence its humification degree under alkaline hydrothermal treatment. This study prepared the hydrochars in different hydrothermal temperatures and pH, and revealed their potential for HHA production under alkaline hydrothermal conditions (denoted as HHAalk). The hydrochars, prepared under high temperature (200 °C) and strong acidic (pH 0) conditions, achieved high HHAalk yields (67.9 wt% and 68.8 wt%). It ascribed that the high content of acid-insoluble components in hydrochar (lignin-derived hydrochar, HHA and humins), up to more than 90 wt%, was favorable for HHAalk production. Cellulose and hemicellulose content in hydrochar and hydrochar yield were negatively correlated with HHAalk yield while acid-insoluble component content had a positive correlation. The unsaturation degree of hydrochar was suggested as a representative indicator for evaluating the humification potential of hydrochar. This study provides scientific support for preparation of suitable hydrochar with efficient hydrothermal humification potential.

Keywords: Hydrochar, Humic acid, Hydrothermal temperature, pH, Linear correlation.

High-Quality Syngas Generation from Waste Plastics by Catalytic Pyrolysis Over Iron-Based Oxygen Carriers

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Waste plastic is one of the most concerned solid waste issues all over the world. Converting waste plastics into value-added syngas ($H_2/CO/CH_4$) has attracted considerable attention. Herein, we reported on the innovative strategy of high-quality syngas production catalyzed by iron-based oxygen carriers. Synthesized and natural iron-based oxygen carriers have been applied for syngas generation from waste plastics, and both exhibited high catalytic performance.

Iron oxide complexes ($FeO_x/CeO_2@C$) were synthesized by the sol-gel combustion method. Microwave irradiation was applied for reaction enhancement and catalyst regeneration. The catalyst showed high selectivity towards syngas, which was over 94 vol% for high-density polyethylene (HDPE). The power of microwave irradiation showed a slight influence on the syngas yield and selectivity. This may be attributed to the intrinsic selective heating nature of microwave. The selectivity of syngas was maintained at ~95 vol% after three cycles while the syngas yield was reduced. The robust catalytic capability resulted from the synergetic effect between FeO_x and CeO_2. FeO_x possesses high dehydrogenation activity and CeO_2 could provide highly active oxygen vacancies by Ce^{4+}/Ce^{3+} valence states shift. The coke formed by dehydrogenation could be transformed into CO to promote syngas generation. Therefore, synthesized iron-based oxygen carriers showed high potential in waste plastics utilization.

Bauxite residue (BR) is a promising natural iron-based oxygen carrier with a high annual yield. The main components of bauxite residue are Fe_2O_3, Fe_3O_4, and alkali metals, which are highly active for syngas generation and dechlorination, respectively. Therefore, it shows a high potential for polyvinyl chloride (PVC) recovery, which is a challenge for thermal treatment. However, the catalytic reaction mechanism of PVC over BR has rarely been reported. We applied BR for simultaneous dechlorination and syngas production from PVC and obtained the highest dichlorination efficiency of 92% and syngas yield of 0.34 Nm^3/kg. The alkali metal compounds contributed to HCl adsorption at lower temperatures and were transformed into NaCl cubic crystals under high treatment temperatures. Dechlorinated PVC was then pyrolyzed and oxidized over FeO_x active sites to form H_2, CO, and CH_4. The higher reaction temperature and appropriate BR dose are conducive to high syngas yield.

Iron-based oxygen carriers have exhibited great potential for syngas production from a variety of waste plastics. The application of natural waste iron-based oxygen carriers and waste plastics is of great significance for circular economy and sustainable development.

Keywords: Waste plastic, Syngas, Iron-based oxygen carriers.

Evaluation of the Efficiency of Wet Torrefaction of EFB Fibre and Palm Fronds for Solid Fuel Production

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The empty fruit bunch (EFB) is the most abundant biomass from the palm industry, it has a low market value in the pelletization industry due to its inorganic content, mainly potassium. The removal of this bound inorganic content by water or acid washing is not effective. Palm fronds also have low market value due to its heterogeneous nature and high bulk density. Wet torrefaction destroys the cellular matrix of the biomass through breakage of polymer chains. This will allow the biomass to be depolymerized into organic compounds with low molecular weight. Therefore, wet torrefaction of EFB and palm fronds will improve the fuel properties of these biomasses, resulting in higher market value for these products and a reduction in the dependency of fossil fuels and the associated impact on the environment.

The wet torrefaction reactions were conducted in a high-pressure reactor autoclave. Samples were loaded with the required amount of distilled water and the reactor was sealed. The temperature used ranged from 180ºC to 220ºC. The residence time varied from 15 to 45 minutes. After the residence time was reached, the reactor was cooled to room temperature. Liquid product was collected for composition analysis in GC-MS and solid product was dried prior to analysis. Proximate and ultimate analysis was conducted on the solid product, along with heating content (HHV) analysis, functional group analysis, surface property analysis, and grindability, strength and pelletization tests.

Keywords: Empty fruit bunch, Fuel properties, Palm fronds, HHV, Wet torrefaction.

Co-pyrolysis of Food Waste and Rice Straw: Hydrogen Yield Optimization Study

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Physico-chemical characteristics of kitchen food waste (KFW) and rice straw (RS) were explored to determine the optimum feedstock ratio for biohydrogen production. An in-depth investigation on the thermogravimetric degradation was conducted at different heating rates. Friedman, Kissinger-Akahira-Sunose, and Flynn-Wall-Ozawa iso-conversional techniques were applied to investigate the kinetic properties of different mass ratios of the feedstocks. The average apparent activation energy (Ea) increased for all co-pyrolysis blends, reaching a maximum for 75KFW blend samples. A microwave reactor was used to investigate product yields for different blend proportions. Gas chromatography analysis showed that co-pyrolysis improved production of biohydrogen. This work considers an experimental study of KFW and RS waste produced in Nanjing, China, performed over a catalyst to maximize synthesis of biohydrogen. The data obtained will be useful when considering establishment of industrial scale pyrolysis plants for biohydrogen in regions plagued with similar waste problems. Overall, this study reflects the viability of scaled-up KFW and RS co-pyrolysis as a waste management alternative and an effective and sustainable source of biohydrogen.

Keywords: Food waste, Microwave pyrolysis, Co-pyrolysis, Rice straw, Thermo-kinetic studies.

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Biochar and its Applications

Enrichment of Biochars for Improved Soil Conditions and Crop Productivity

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Development on the potential of biochar application includes infusion of nutrients within the biochar matrix supplied by mineral and organic fertilizer. Aside from the separate contributions of the fertilizers and biochar to soil health and productivity, enrichment is done for the complimentary positive effects of fertilizer within the biochar matrix. However, only a few studies have been found about the amount and combination mixture ratios of biochar (BC) and organic fertilizer (OF). This paper attempts to investigate the influence of biochar-enriched fertilizer (BEF) on the physicochemical properties of an acidic sandy soil (*Cumulic Hapludolls*) after application, and on the performance of purple yam. Coconut husk and swine manure were collected and prepared for thermal treatment using slow pyrolytic biochar producing stove at temperatures ranging from 300 to 650°C. The organic fertilizer was produced following the Philippine National Standards for Organic Soil Amendments. The resulting biochar was air-dried, pulverized, and enriched with OF at 1:4 (20% BC) and 2.3:4 (30% BC) biochar: organic fertilizer ratio. A series of comprehensive studies was conducted with all treatments applied at 5 t/ha as follows: (T1) OF only, (T2) enriched swine manure-OF pellets (20% biochar), (T3) enriched coco husk biochar-OF pellets (20% biochar), (T4) enriched coco husk biochar-OF pellets (30% biochar). Results showed that T1 yielded more aboveground parts of purple yam while higher tubers from enriched BC treatments, that can be attributed to the availability of nutrients for use by the crops for longer periods compared to the loose powder form. The combination ratio of 1:4 outperformed the other treatments on the above-and below ground fresh weight. The soil organic carbon (SOC) increased after harvest at treatments with enriched BC-OF mixes. The results imply that a lower requirement for organic fertilizer can sustain or improve the crop yield when combined with enriched BC, and economic benefits for crop production can be achieved with BC and OF combination. Very significant positive correlations were observed between the OC and Mg in the soil and aboveground dry weight with (r= 0.869) and (r=0.830), respectively. The amount of K remaining in soil after harvest were observed to be negatively correlated with aboveground dry weight strongly(r=-0.704) and tubers dry weight (r=-0.843). The positive influence of enriched BC on plant growth and soil properties suggests that enrichment is an effective way to overcome biochar's inherent low plant nutrients, making it a suitable technique helping to refine farm-scale nutrient cycles.

Keywords: Organic carbon, Organic fertilizer, Enriched biochar, Swine manure, Coconut husk.

Applicability of Commingled Food Waste Biochar as a Potential Fertilizer

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Food waste is one of the major components of domestic solid waste, comprising around 1.3 billion tonnes per year worldwide. Generally, the food waste is disposed of in polyethylene covers along with plastic bottles, spoons, etc., which makes it difficult for proper segregation and waste management. The present paper discusses the applicability of biochar obtained from microwave pyrolysis of commingled food waste (FW along with low-density polyethylene) as a soil improver where the release of nitrogen (N) and phosphorous (P) was studied. The pH_{zpc} and average pore diameter of the commingled food waste biochar (CFWB) were found to be 6.85 and 44 nm respectively. Leaching studies were performed to investigate the N and P release kinetics from the biochar. Four kinetic models namely the pseudo-first-order model, pseudo-second-order model, Elovich model, and Higuchi model were compared, and the study revealed that both N and P release followed Pseudo-second order kinetics. The average release of phosphate from the CFWB is calculated to be 273.30 mg/kg of biochar, which is comparable with the phosphate release rate of a chemical fertilizer named uncoated diammonium phosphate (DAP) i.e., 280 mg/kg. Similarly, the average release of nitrate from the CFW biochar is calculated to be 134.98 mg/kg of biochar, compared to the required range of 175–225 mg/kg by chemical fertilizers. Further, the toxicity analysis performed on the CFWB has proven it to be negligibly toxic to the microorganisms. Hence the aforementioned nutrient-laden biochar can be used as potential fertilizer in the farmlands.

Keywords: Commingled food waste biochar, Nutrient removal, Kinetics, Fertilizer.

Investigation on the Synthesis Strategy of MgO-biochar Catalysts for Glucose Isomerization to Fructose

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The biorefinery is an important approach for the current needs of energy and chemical building blocks for a diverse range of applications, which may gradually replace current dependence on fossil-fuel resources. Glucose isomerization to fructose is one of the most important reactions in the field of biomass valorization, which has been widely used in industrialized high-fructose corn syrup (HFCS) production. While HFCS application demands strict operating conditions, bears on high cost and long reaction time. Consequently, an alternative efficient solid catalyst is required which will exhibit high activity and stability. Lewis acid and Brønsted base catalysts have both been reported with effective catalytic performance for glucose isomerization. However, Sn-beta zeolites as one of the Lewis acid catalysts has been reported to have complex synthesis process and easy deactivation. The side reactions between most amines and reducing sugars (i.e. Maillard reaction) may occur with organic amines as Brønsted base catalysts, which could be a concern to the reaction efficiency. Various heterogeneous metal oxide basic catalysts such as MgO, CaO and TiO2 were also actively investigated for the catalytic performance of glucose-to-fructose isomerization. Among them, MgO has gained increasing interest due to its intrinsic basicity and wide availability from the natural environment. However, the MgO would be subjected to Mg leaching during the reaction and nanosized MgO may be prone to agglomeration. Therefore, effective dispersion of active MgO moiety on a porous support can be a solution to the above issue. To this end, the MgO-biochar catalysts for glucose conversion to fructose were prepared through three different synthesis methods followed by the subsequent characterization analysis and glucose conversion experiments. We also intend to scrutinize the difference in interactions between MgO precursor and carbonaceous support under varying synthesis conditions. In this study, effective isomerization was realized with ~26% fructose yield at only 80 °C for 2 h in water. Catalyst 3 prepared from one-step synthesis, although having the lowest loading amount of MgO, showed the highest activity and stability compared to those produced by two-step synthesis. Overall, this work provided a basis for advancing the design of metal–biochar composites.

Keywords: Biomass valorization, Heterogeneous catalysts synthesis, MgO, Biochar.

Synthesizing Yard Waste-Derived Biochar for Microwave-Assisted Degradation of PPCPs: Performance of Various Oxidants

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Yard waste is one of the most ubiquitous urban wastes in Hong Kong. As a lignocellulosic biomass material, it can be pyrolyzed to biochar, which shows superiorities over other carbon materials due to its low cost and carbon neutrality. The produced biochar can catalyze advanced oxidation processes owing to its tuneable characteristics depending on various pyrolysis conditions and modification approaches by contributing to the oxidant activation especially in the microwave-irradiated system because of its microwave absorbability. Compared to conventional heating, microwave irradiation can achieve rapid and volumetric heating and activate oxidants to generate highly reactive species (e.g., free radicals), which can significantly improve degradation efficiency. Pharmaceutical and personal care products (PPCPs) have been emerging contaminants in wastewater. It has been reported that the concentration of oxytetracycline (OTC) is extremely high in the effluent from the antibiotics production facilities, which is prone to be transformed yet difficult to mineralize. This study compared the OTC mineralization efficiency of various catalytic systems with different heating approaches and oxidants. It was found that microwave irradiation was significantly more efficient than conventional heating. With microwave irradiation, up to 100% of OTC was mineralized at 80°C within 1 min, while conventional heating can remove < 40% of the total organic carbon (TOC) with 5 times longer time for ramping to 80°C. In particular, H_2O_2 addition might not be efficient for the improvement of mineralization compared to the oxidant-free systems, while the most efficient is the $Na_2S_2O_8$ oxidant activated by CuO_x-loaded biochar, where only 1% Cu loading can achieve 95.6% TOC removal, indicating the critical roles of Cu species. Besides, it was interesting to find that NaClO can achieve 60.5% TOC removal without catalyst, which can be further increased to 85.9% after dosing CuO_x-loaded biochar. These results can further imply the importance of microwave irradiation and Cu species for NaClO activation. Based on the characterization results of Electron Spin Resonance, X-ray Photoelectron Spectroscopy, Raman Spectroscopy, X-ray Diffraction, etc., the high efficiency of the microwave-irradiated catalytic systems was ascribed to the generation of reactive species such as free radicals, as the amount of which was significantly higher than those in conventional heated systems. The plausible relationships between biochar properties and the interactions with microwave were also revealed. Besides, the generation of reactive species also increased with CuO_x loading, suggesting the Cu species could contribute to the oxidant activation. It was also found that the Cu species were stably loaded onto biochar by forming the Cu-N bond. Therefore, the synthesized biochar catalyst shows great potential for larger-scale application.

Keywords: Wood waste biochar, Catalytic degradation, Microwave irradiation, Wastewater treatment, PPCPs degradation.

Straw and Straw Biochar Differently Affect Microorganisms and Soil Organic Carbon Pools in Farmland Soil Under Different Water Regimes

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Incorporating amendments of straw and straw biochar can change soil organic carbon (SOC) components and biological properties. There are many studies on straw or straw biochar application influence of biochar on active SOC fractions associated with soil microbial activity, but the addition of straw and straw biochar comprehensive utilization remains poorly understood in the tobacco-late rice rotation system. We studied the change in the total SOC concentration, active SOC fractions and soil microbial communities with condition of alternation of wetting and drying, and long-term flooded in a 90-day incubation experiment. The results showed that upon straw addition, there was an increase in microbial biomass carbon (MBC), dissolved organic carbon (DOC), and easily oxidizable carbon (EOC). Upon biochar addition, there was an increase in SOC and water-soluble organic carbon (WOC). Revealed that the biomass of fungi and bacteria increase after straw and straw biochar addition. We further found that the fungal richness decreased, whereas biochar did not influence soil bacterial diversity in all treatments. A redundancy analysis showed that straw and straw biochar addition changed the community structure of bacteria and fungi by increasing soil carbon pools, and their community structures were regulated by SOC components. Our findings suggested that straw and straw biochar can improve soil labile organic carbon pools and soil microorganism's communities better than biochar, instead of straw biochar in the tobacco-late rice rotation system.

Keywords: Rice straw, Tobacco stems biochar, Soil carbon pool, Soil microbial community composition.

Synthesis of Ternary CeO_2/Fe_2O_3/R-GO Nanocomposite Loaded Biochar for Photocatalytic Degradation of Organic Pollutants

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Abstract

This work synthesized a novel CeO_2/Fe_2O_3/r-GO-biochar hybrid nanocomposite through a one-step hydrothermal process followed by a thermal annealing route with biochar derived from pea nutshells. The structural, morphological, electrical, and optical properties and their photocatalytic activities were studied in detail. This novel hybrid nanocomposite-biochar material displayed excellent adsorption characteristics, photocatalytic activities, and excellent stability performance. Furthermore, the catalytic degradation efficiency of synthesized nanocomposite-biochar was performed with methylene blue and methylene orange under constant visible irradiation light. The degradation efficiency showed that the methylene blue and methylene orange were 90 % and 86 % for the CeO_2/Fe_2O_3/r-GO/BC hybrid composite, which was much higher than pure CeO_2, pure Fe_2O_3, ternary CeO_2/Fe_2O_3/r-GO composite. Based on the performance, the CeO_2/Fe_2O_3/r-GO-biochar composite is considered an effective catalyst for photocatalytic applications.

Keywords: CeO_2/Fe_2O_3/r-GO-biochar Hybrid nanocomposite, Biochar, Photocatalytic Degradation

Introduction

Technology and fast industrialization have increased water pollutants in natural resources enormously in two decades. Lifestyle improvements have cost the environment and natural resources. Toxic metal ions, organic molecules, dyes, carcinogenic, and mutagenic chemicals are trashed from the industry. Many approaches have been suggested to solve this problem, even though, they have certain limitations. Considering this improvement, the researchers are interested in biochar-based photocatalyst in the dye-degradation process because of its low cost, efficiency, and ease of use [1]. Due to its high oxygen storage capacity, strong UV absorption, good chemical stability, and nontoxicity, cerium dioxide CeO_2, is widely used as photocatalyst, and electrocatalyst. However, the wide band gap energy and significant charge carrier recombination of CeO_2 limit its photocatalytic usage [2]. Metal loading, morphological regulating, and heterojunction generation can overcome this limitation of metal oxides. This way, heterojunction creation is commonly used to improve charge separation and transfer, and photocatalytic performance. Under visible light irradiation, connecting a wide bandgap semiconductor to a narrow one increases light absorption and photoexcited charges. Fe_2O_3, a small band gap n-type semiconductor (2.2 eV), is widely employed as electrochemical electrodes, gas sensors, and photocatalysts [3]. Appropriate support is needed to separate photogenerated electron-hole pairs and migrate them to surface reaction sites to increase CeO_2/Fe_2O_3 nanocomposite photocatalytic activity. Graphene oxide (GO) supports charge transport and separation due to its oxygen functional groups, high electron mobility, and high surface area CeO_2/Fe_2O_3 nanocomposite improved photocatalytic applications most by hybridizing with reduced graphene oxide (r-GO). r-GO's electron conduction improves photocatalytic capabilities of r-GO metal oxide nanocomposite materials [4]. Biochar (BC) possesses excellent adsorption properties and a high surface area. It purifies drinking water, treats sewage, and cleans the environment. Thus, low-cost and abundant materials like agricultural waste have become increasingly popular for BC preparation [5].

Material and Methods

2.1. Preparation of GO

GO was synthesized by the modified Hummers method [6].

2.2. Preparation of BC

Peanut shells were pyrolyzed to make biomass charcoal. The preparation process was typically as follows. Firstly, the peanut shells were thoroughly cleaned with water in multiple times, then rinsed with deionized water under ultrasonic treatment to remove impurities, then dried in the oven at 60°Cfor10h. secondly, the dried peanut shells were pulverized into powders and sieved using a 0.2-mm sieve to remove bigger broken bits. Thirdly, suitable peanut shell powders were moved into porcelain crucibles with lids in an electric muffle furnace without nitrogen protection and heated to 600 °C for 6 hours. Muffle boiler heating was 20 °C/min.

2.3 Preparation of CeO_2/Fe_2O_3/r-GO/BC hybrid nanocomposite

An equal amount (1:1) of Cereus nitrate hexahydrate (Ce $(NO_3)_2.6H_2O$) and Iron (III) nitrate nonahydrate [Fe $(NO_3)_3 \cdot 9H_2O$] was dissolved in 50 mL of double-distilled water under magnetic stirring. To create a homogenous solution, 0.1 M Urea (CH_4N_2O) was added. Ultrasonicate was used to disperse GO (0.1 g) and Biochar for 30 minutes each. The solution was agitated for 1 hour at room temperature. After that, the mixture was put into a 100-mL Teflon-lined stainless-steel autoclave, sealed, heated at 180 °C for 18 h, and cooled naturally to room temperature. The precipitate was collected and centrifuged dried at 100 °C, and calcinated at 400 °C for 2 h to obtain the CeO_2/Fe_2O_3/r-GO/BC hybrid nanocomposite.

Results and Discussion

Structural Analysis

Figure 1 depicts the XRD patterns of CeO_2, Fe_2O_3, CeO_2/Fe_2O_3/r-GO and CeO_2/Fe_2O_3/r-GO/BC nanocomposites. The diffracted patterns of CeO_2 were 28.3, 33.02, 47.36, 56.10, 58.82, 69.38, 76.60, 79.19, which matched JCPDS card (34–0394) crystal planes (111), (200), (220), (311), (222), (400), (331), (420). [2]. Similarly, the α-Fe2O3 diffraction pattern at 24.12, 24.6, 33.17, 35.44, 40.86, 49.47, 54.15, 57.47, 62.43, 64.10, 72.24, 75.27 attributed (012), (120), (104), (110), (113), (024), (116), (214), (300), (119), (220) planes could be indexed to rhombohedral structure and matched JCPDS card (89–0599) [7]. The (002) plane of the r-GO JCPDS card (75–1621) also caused amorphous r-GO diffraction peaks at 26.2 [8]. BC's XRD spectra show a strong and weak peak at 25, respectively, correlating to (002) amorphous nature of the activated carbon phase [9]. In addition, the CeO_2/Fe_2O_3/r-GO/BC had no additional peaks, confirming that the nanoparticles possessed excellent purity and matched with JCPDS.

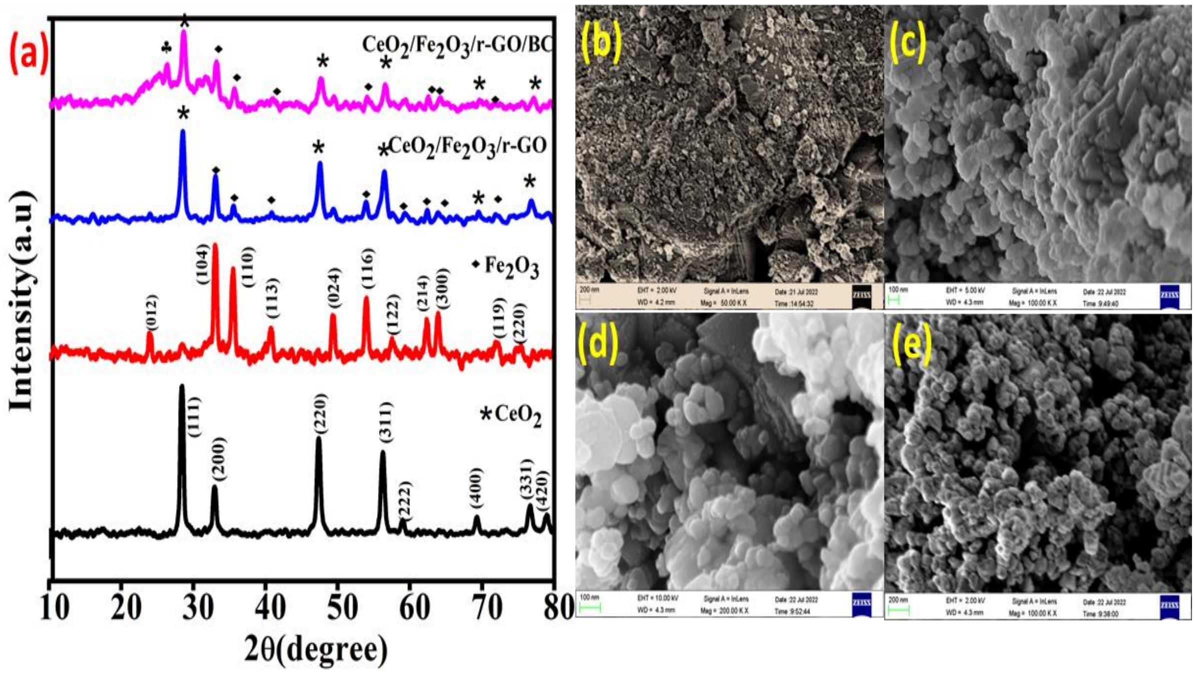

Fig.1 (a) XRD pattern and (b-e) FESEM images of CeO_2, Fe_2O_3, CeO_2/Fe2O_3/r-GO and CeO_2/Fe_2O_3/r-GO/BC hybrid nanocomposite.

Surface Morphological Analysis

The surface topographical studies of the as-prepared CeO_2, Fe_2O_3, CeO_2/Fe_2O_3/r-GO, and CeO_2/Fe_2O_3/r-GO/BC hybrid nanocomposite as shown in Fig.1. In this Fig (b) clearly shows the nanorods are densely covered and formed the flower-like CeO_2 nanostructures. Fig (c) shows that the Fe_2O_3 microspheres are well formed during hydrothermal process. Fig (d) displays the SEM images of the CeO_2/Fe_2O_3/r-GO composite, during the composition the nanostructures are agglomerated and reduced the particle size. The CeO_2/Fe_2O_3/r-GO/BC hybrid nanocomposite the size of the nanoparticles still decreased

(Fig 1(e)). It may be due to incorporation of r-GO sheets and biochar with CeO_2 and Fe_2O_3.

Photocatalytic activity for MB and MO

Dye degradation efficiency was evaluated by measuring photocatalytic activity on as-prepared CeO_2, Fe_2O_3, CeO_2/Fe_2O_3/r-GO, and CeO_2/Fe_2O_3/r-GO/BC. The degradation of MB and MO was produced in the presence of a 500W Halogen light. The solution was agitated continuously for 30 minutes while maintained in the dark before being exposed to light in order to reach an adsorption/desorption equilibrium. The photocatalytic experiment then involved irradiating the fluid using a halogen lamp. Images of methylene blue and methylene orange were captured after 20 minutes of exposure to the respective colors. The MB and MO solutions have distinctive absorption peaks at 663 and 465 nm, respectively. Dye concentration decreases as irradiation time increases, leading to a lower absorption intensity peak. Figure 2 depicts the photocatalytic activity of as-prepared samples for MB and MO dye solution as a function of irradiation time. The ternary composites outperformed the individual components of the photocatalysts during the dye-degradation process. Therefore, it was confirmed that the photocatalytic activity under stimulated light irradiation was greatly enhanced by the hybrid nanocomposite composition of CeO_2/Fe_2O_3/r-GO/BC. Because of the lower band gap energy, low recombination rate, and longer life duration of photogenerated electron-hole pairs, CeO_2/Fe_2O_3/r-GO/BC exhibited a greater degrading efficiency of 90 %. This data also shows that the nanocomposites synergistic combination of CeO_2, Fe_2O_3, CeO_2/Fe_2O_3/r-GO, and CeO_2/Fe_2O_3/r-GO/BC significantly aided in the enhanced photocatalytic degradation of dye molecules. The findings of this experiment demonstrate the promising potential of the ternary nanocomposite in the degradation of methylene blue dye and methylene orange.

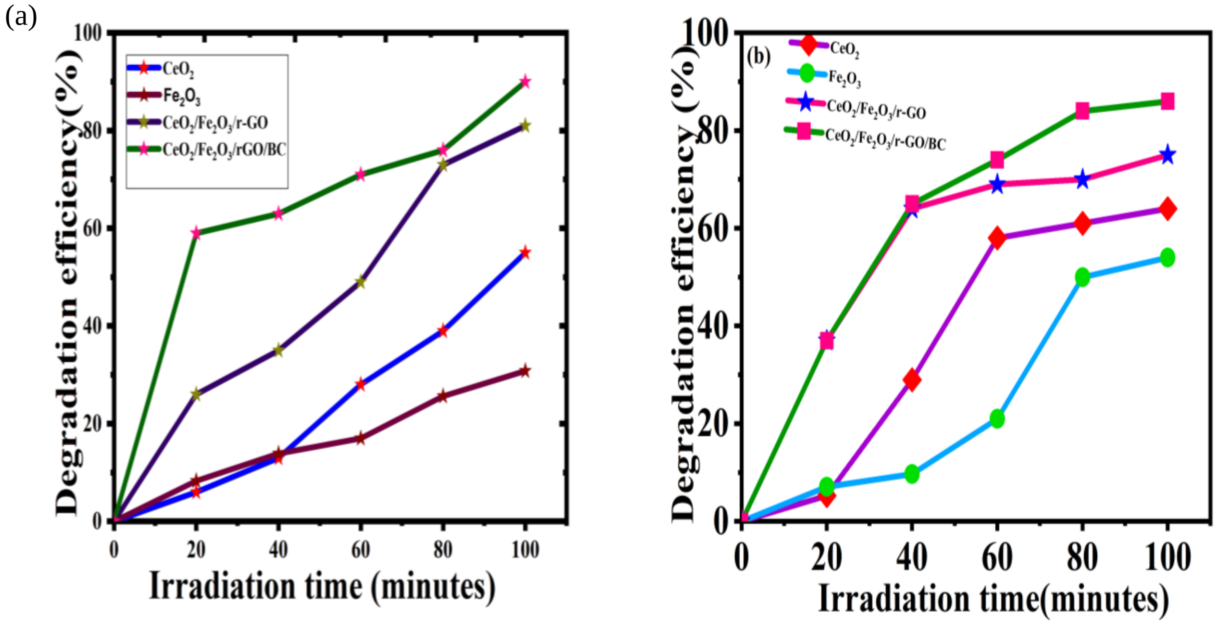

Fig.2. Photocatalytic efficiency of the prepared samples for (a) MB (b) MO degradation

Conclusion

In summary, CeO_2/Fe_2O_3/r-GO/BC catalyst was prepared via a simple one-step hydrothermal method for the photocatalytic application. The prepared catalyst was confirmed by the various analytic techniques. The as-synthesized CeO_2/Fe_2O_3/r-GO/BC hybrid nanocomposite delivers better dye-degradation efficiency of MB (90%) and MO (86%) in organic dyes. In addition, adequate charge transportation and low photo-excited charge transport recombination rates of r-GO and BC are crucial to increasing photocatalytic activity.

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Melaleuca Bark-Based Biochar for Triclosan Adsorption and Energy Storage Applications

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Biomass-based carbon materials have generated tremendous interest in energy storage and pollutant removal. Herein, hierarchically porous biochar with high surface areas was synthesized based upon a simple two-step carbonization process using agricultural and forestry waste melaleuca bark as raw materials with less KOH activation. The results indicated that the as-prepared biochar had a high specific surface area of 1768.0 m^2 g^{-1}. Besides, the biochar showed excellent adsorption performance to triclosan, and the effects of initial dye concentration, adsorption time, initial pH, adsorption temperature and recycling performance were studied. As a triclosan absorbent, melaleuca bark-based biochar displayed a high removal rate up to 95.5% at 10 min. Moreover, the biochar exhibited a high specific capacitance (358 F g^{-1} at 0.5 A g^{-1}) as a supercapacitor electrode in aqueous alkaline electrolyte with a stable cycling performance after10, 000 charge/discharge cycles. The excellent adsorption capacities and electrochemical performance suggested that the obtained melaleuca bark-based biochar could be a promising candidate as an adsorbent and electrode material for supercapacitors.

Keywords: Melaleuca bark, Carbonization, Biochar, Triclosan, Adsorption, Supercapacitor.

Co-Application of Sewage Sludge-Chinese Medicinal Herbal Residues-Biochar to Antibiotics and Antibiotic Resistance Genes in Soil-Plant System

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Sewage sludge (SL), Chinese medicinal herbal residues (CMHRs) and biochar (BC) are normally treated as wastes that are potential soil amendments to tackle environmental risks. Antibiotics are a ubiquitous medication to promote health safety and productivity. However, the excessive use has contaminated the terrestrial environments and lead to the intractable booming of antibiotic resistance genes (ARGs). In this study, the fate and distribution of eleven pervasive ARGs (*tet* A, *tet* B, *tet* C, *tet* E, *tet* M, *tet* O, *tet* S, *tet* X, *sul* I, *sul* II and *sul* III) in environments were examined with different soil amendment treatments (SL-BC and SL-CMHRs-BC) with different proportions (5%, 10% and 20%, dry weight basis). Lettuce (*Lactuca sativa* L.) was grown in the soils and irrigated with low (3 µg/L) or high (30 µg/L) antibiotic-contaminated water to evaluate the capacity of ARGs spreading into the food web. The results of the real-time quantitative PCR (qPCR) indicated the abundance of ARGs in soils and lettuce leaves/shoots were significantly reduced by the types of soil amendments (SL-CMHRs-BC > SL-BC > control) and the antibiotics concentration in the irrigation water (3 µg/L > 30 µg/L). 20% SL-CMHRs-BC was considered as the most optimal proportion for the reduction of antibiotic concentration and corresponding ARGs in this study ($p < 0.05$). The accumulations of six ARGs (*tet* A, *tet* C, *tet* O, *sul* I, *sul* II and *sul* III) were relatively higher among the soil and crops samples, while the remnant five (*tet* B, *tet* E, *tet* M, *tet* S, *tet* X) were lower. The co-application of SL-CMHRs-BC was proven in our previous study for the alleviation of antibiotics contamination in soils. We continued the study and conferred another insight of evaluating the impact of SL-CMHRs-BC on antibiotic concentration and their relative ARGs. The antibiotic concentrations in all soil samples were greatly corresponded to their ARGs ($R^2 > 0.9$). Moreover, the ARGs of lettuce leaves/shoots were more positively affected by the antibiotic concentrations than of soils. The results implied the co-application of SL-CMHRs-BC could reduce the antibiotic concentration and the abundance of ARGs in soils and crops, which could promote a safer food system in the environment.

Keywords: Antibiotics, Antibiotic Resistance Genes, Sewage Sludge, Chinese Medicinal Herbal Residues, Biochar.

Molecular Simulation Combined with DFT Calculation to Guide the Directional Design of Heteroatom-Doped Biochar for Efficient CO_2 Capture

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ABSTRACT. Heteroatom doping technology is widely used in the field of adsorption and separation due to its ability to significantly alter the physical and chemical properties of materials. For stable gases such as CO_2, traditional carbon materials cannot exhibit good adsorption performance, while carbon materials doped with heteroatoms significantly improve their adsorption performance for CO_2 due to changes in their electronic structure, polarity, and other characteristics. In this study, Density Functional Theory (DFT) was used to calculate the adsorption energy and theoretical selectivity of several element doped biochar for CO_2. Three doping forms, BCO_2, P-C, and C-S-C, were selected through DFT calculations. Then, the corresponding model of heteroatom doped disordered biochar was constructed, and the adsorption performance of different biochar for CO_2 was simulated by Grand Canonical Monte Carlo (GCMC). The GCMC simulation results indicate that heteroatom doping can improve the CO_2 adsorption capacity at low pressure, while the CO_2 absorption capacity at high pressure is determined by the pore structure. Finally, according to the theoretical calculation results, heteroatom doped biochar was prepared by the one-step pyrolysis method. Among them, the phosphorus doped biochar (PBC) prepared with corncob powder, K_2CO_3 and K_3PO_4 at 800 °C showed the highest CO_2 adsorption capacity (1.34 mmol/g at 72 °C and 1 bar) under the same conditions, about 10% higher than the pristine biochar. It is worth noting that the adsorption experiment shows that as the adsorption temperature increases, the doping effect of heteroatoms will gradually manifest. This effect not only includes an increase in adsorption capacity and selectivity, but also optimization of the adsorption kinetics process. In addition, heteroatom doped biochar also has excellent thermal, chemical and cycling stability. This work guides experiments with theoretical calculations, greatly reducing the trial and error costs of experiments, and providing a simple and practical approach for subsequent material design.

Keywords: Heteroatom doping, Biochar, CO_2 capture, DFT, Molecular simulation

Introduction

The excessive emission of CO_2 has caused a series of problems such as global warming. Heteroatom doped biochar combines the advantages of simple preparation method, wide source of raw materials and low cost of biochar, as well as the specific adsorption caused by heteroatom doping, and has a good application prospect. Currently, the heteroatom doped carbon materials for CO_2 adsorption mainly focus on nitrogen doping, while research on other atomic doping is limited. Zaman et al. prepared a sulfur doped carbon material with p-toluenesulfonic acid as the precursor and sodium chloride as the pore forming agent[1]. However, the maximum CO_2 adsorption capacity of the material at 0.15 bar and 25 °C is only 0.78 mmol/g, which is relatively limited.

In this study, heteroatom doped biochar was directionally prepared for CO_2 adsorption by theoretical calculation. This study not only puts forward an idea of theoretical calculation to guide the design of materials, but also proves the promotion mechanism of heteroatom doping on CO_2 adsorption by combining experiments with calculation, which has a certain reference significance for the design of subsequent heteroatom doped materials.

Material and Methods

Preparation and characterization methods of heteroatom-doped biochar

Heteroatom-doped biochar was prepared by the one-step pyrolysis method we mentioned earlier[2]. In this study, corncob powder was selected as carbon source (CP), potassium carbonate (K_2CO_3) as activator, potassium metaborate (K_2CO_3), tripotassium phosphate (K_3PO_4) and potassium sulfate ($K_2B_2O_4$) as heteroatom dopants respectively. First, the CP, K_2CO_3 and dopant were physically mixed into the mortar at the mass ratio of 1:3:1. Then the mixed raw materials were carbonized in a muffle furnace at 800 °C for 1 h, where nitrogen was used as protective gas, the flow rate was 100 mL/min, and the heating rate was 10 °C/min. After carbonization, the black solid can be washed, filtered and dried to obtain heteroatom-doped biochar (BBC, PBC and SBC). The pristine biochar (BC) can be obtained without dopant. The pore structure characteristics of the material were tested by a fully automated specific surface area and porosity analyzer (Micromeritics ASAP 2460, USA). The distribution of surface elements was measured by X-ray photoelectron spectroscopy (XPS, Thermo Scientific K-Alpha, USA). Raman spectroscopy was completed on Horiba LabRAM HR Evolution (Japan). The thermal stability test was completed on the thermogravimetric analyzer (TGA, STA-7200).

CO_2 adsorption experimental method

The CO_2 adsorption performance was obtained through TGA testing. The specific testing process is as follows: Place about 10 mg of adsorbent into a crucible. Firstly, degas at 100 °C in nitrogen for 15 min, and the mass at this time is recorded as m_0. Subsequently, lower the temperature to the target temperature and maintain it for 10 min, with the mass recorded as m_1. Switch nitrogen to CO_2 with the same flow rate and adsorb for 60 min, and the mass after adsorption is recorded as m_2. The N_2 adsorption capacity of the adsorbent can be calculated based on m_0 and m_1, and the CO_2 adsorption capacity can be calculated based on m_0, m_1 and m_2. If chemical stability and cyclic stability tests are to be conducted, the desorption can be carried out by heating up in nitrogen after adsorption is completed, and the mass after desorption is recorded as m_3. After the desorption is completed, secondary adsorption can continue. The chemical stability of the material can be evaluated based on m_1 and m_3, and the recyclability of the material can be evaluated based on the two adsorption amounts.

Theoretical calculation details

The theoretical calculations of this study are divided into DFT calculations and GCMC molecular simulations. DFT calculation is completed on the Quantum chemistry calculation package ORCA 5.0[3]. The structural optimization calculation level is r^2SCAN-3c, and the single point energy calculation level is RI-ωB97M-V/def2-TZVP. The GCMC simulation is completed on the RASPA program[4]. The CO_2 and N_2 models used by GCMC are three center models derived from the TraPPE force field. The Lennard-Jones (LJ) parameters of C, H, O in the disordered biochar model are all referred to the research of Tenney et al.[5], while the LJ parameters of other atoms are derived from the Dreiding general force field.

Results and Discussion

DFT calculation for screening the optimal doping form

The adsorption energies of CO_2 on biochar doped with different atoms in different forms are shown in Table 1. The adsorption energy of pristine biochar for CO_2 is-16.04 kJ/mol. In contrast, BC_2O and BCO_2 in B atom doping can improve the adsorption energy of CO_2. Both two P doping forms can improve the adsorption energy of CO_2. However, the improvement of adsorption energy caused by S element is not as good as that caused by B and P doping. In addition, the adsorption energy of N_2 by different heteroatom-doped biochar was also calculated. The adsorption energy of N_2 by pristine biochar is -9.79 kJ/mol. Compared with it, the effect of heteroatom doping on N_2 adsorption energy is almost the same as that on CO_2 adsorption energy. The ratio of CO_2 adsorption energy to N_2 adsorption energy is defined as CO_2/N_2 theoretical selectivity. The theoretical selectivity of pristine biochar is 1.64. Compared with it, it can be found that among all the doped forms, only P-C and B-O can reduce the theoretical selectivity. Taking the CO_2 adsorption energy as the main reference and the theoretical selectivity as the auxiliary reference, the three doping forms of BCO_2, P-C and C-S-C are selected for further research.

Table 1 The adsorption energy and theoretical CO_2/N_2 selectivity of CO_2 and N_2 on different heteroatom doped carbon surfaces calculated by DFT.

	$E_{ad\ CO2}$ (kJ/mol)	$E_{ad\ N2}$(kJ/mol)	$S_{CO2/N2}$
biochar	-16.04	-9.79	1.64
biochar_C-S-C	-16.43	-9.82	1.67
biochar_C-SO-C	-15.46	-9.27	1.67
biochar_C-SO_2-C	-16.28	-9.71	1.68
biochar_P-C	-18.32	-13.39	1.37
biochar_P-O	-16.24	-9.80	1.66
biochar_B	-15.64	-9.03	1.73
bicohar_BC_2O	-22.19	-11.91	1.86
biochar_B-O	-13.87	-8.50	1.63
biochar_BCO_2	-22.24	-12.64	1.76

GCMC simulation results

To further confirm the conclusion of DFT calculation, GCMC calculation was carried out using a more realistic disordered porous biochar model. The CO_2 adsorption capacity of four heteroatom doped disordered porous biochar models at 25 °C is shown in Table 2. It can be seen that the CO_2 adsorption capacity of B-doped biochar is the highest (8.08 mmol/g) at 10 bar, followed by the pristine biochar (7.01 mmol/g). Combined with the pore structure parameters, it can be found that the adsorption performance of biochar under high pressure is determined by the pore structure. The CO_2 adsorption capacity of these models at 1 bar is in the order of biochar_B (1.45 mmol/g) > biochar_P (1.23 mmol/g) > biochar_S (1.20 mmol/g) > biochar (1.09mmol/g). The CO_2 adsorption capacity of heteroatom doped biochar is higher than that of pristine biochar under low pressure, indicating that heteroatom doping plays a role under low pressure.

Table 2 CO_2 adsorption capacity on four heteroatom-doped nanoporous carbon materials simulated by GCMC under different pressures at 25 °C.

Pressure	CO_2 Adsorption capacity (mmol/g)			
(bar)	biochar	biochar_B	biochar_P	biochar_S
0.01	0.01	0.02	0.01	0.02
0.05	0.06	0.09	0.07	0.07
0.20	0.23	0.36	0.27	0.29
0.50	0.57	0.82	0.67	0.68
0.80	0.86	1.22	1.01	1.01
1.00	1.09	1.45	1.23	1.20
3.00	2.77	3.54	3.03	2.91
5.00	4.28	5.23	4.31	4.24
7.00	5.53	6.55	5.43	5.35
10.00	7.01	8.08	6.60	6.63

Characterization results of materials

The pore structure parameters of four kinds of biochar are shown in Figure 1a. Heteroatom dopants can increase the specific surface area and total pore volume of biochar at the same temperature. The ultra-microporous areas of BC, BBC, and PBC are all around 760 m^2/g, and the volume of ultra-micropores is 0.21 cm^3/g. Although SBC has the highest specific surface area and total pore volume, its number of ultra-micropores is the lowest. This proves that different dopants have different effects on the formation of different pore sizes. From the distribution of pore structure, it can be inferred that BC, BBC, and PBC will have higher CO_2 adsorption capacity than SBC due to their more ultra-micropores. The element contents of four kinds of biochar are shown in Figure 1b. Each biochar has more oxygen content (8.53-10.80%) in addition to its own doped heteroatoms. The content of B, P, and S elements in BBC, PBC, and SBC is 1.56, 0.32, and 2.31 Atomic%, respectively. The thermal stability of the four materials is shown in Figure 1d. It can be found that only B-doping improves thermal stability (the loss rate of the carbon skeleton is only 9.79%), while the other two types of doping reduce thermal stability. Raman spectroscopy analysis shows that heteroatom doping affects the thermal stability of the material by changing the ratio of large to small rings in the material (Figure 1c).

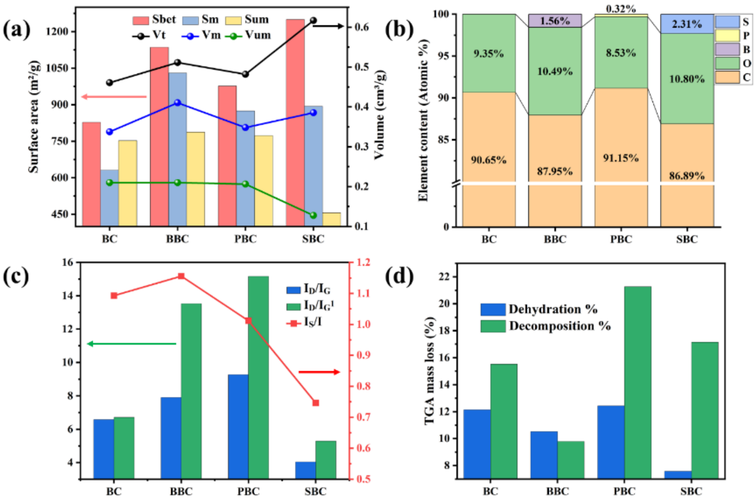

Fig. 1 (a) Pore structure characteristics, (b) element distribution characteristics, (c) Raman spectrum fitting ratio, and (d) thermal stability of heteroatom-doped biochar.

CO_2 adsorption experimental results

The adsorption capacity and selectivity of biochar at different temperatures obtained by TGA dynamic adsorption test are shown in Table 3. It was found that the adsorption capacity of CO_2 and N_2 decreased with the increase of adsorption temperature, because the adsorption of these two gases on biochar was exothermic. At the same temperature, the CO_2 adsorption capacity of PBC and BBC was higher than that of BC. According to the results of pore structure analysis, the enhancement of CO_2 adsorption by BBC and PBC is mainly attributed to the doping of heteroatoms. The rules of N_2 adsorption and CO_2 adsorption of the four kinds of biochar are almost the same, which shows that the adsorption of N_2 in biochar is also determined by ultra-micropores and heteroatom doping. In addition, the selectivity of biochar doped with three heteroatoms is higher than that of BC, which is basically consistent with the results calculated by DFT. And the selectivity of all biochar increases with the increase of adsorption temperature, which proves that the effect of heteroatom doping increases with the increase of adsorption temperature.

Conclusions

In this study, nine kinds of biochar models doped with different forms of B, P and S elements were first constructed. DFT was used for configuration search, CO_2 and N_2 adsorption energies, and CO_2/N_2 theoretical selectivity calculations. The calculation results show that only BCO_2, P-C, and C-S-C doping models among the nine different doping models can significantly improve the CO_2 adsorption energy and CO_2/N_2 theoretical selectivity. Then, three heteroatom doped disordered biochar models were constructed based on the three doping forms selected by DFT calculation, and the CO_2 adsorption isotherms were simulated by GCMC. The CO_2 adsorption capacity on the heteroatom doped biochar model at low pressure is significantly higher than that of the pristine biochar model when the difference in pore structure characteristics is very small. Under high pressure, the CO_2 adsorption capacity of several biochar models is positively correlated with the specific surface area, indicating that the heteroatom doping has little effect on the CO_2 adsorption under high pressure. Finally, according to the theoretical calculation results, biochar doped with the above three heteroatom forms was prepared by one-step activation method. The experimental results of CO_2 adsorption almost perfectly confirm the theoretical calculation results. Heteroatoms doping improves both CO_2 adsorption capacity and CO_2/N_2 selectivity, and the effect of heteroatom doping becomes more significant as the adsorption temperature increases. In addition, heteroatom doping can also optimize the adsorption kinetics of CO_2 on biochar.

Table 3 Adsorption capacity and selectivity at different temperatures obtained by experiment.

	Adsorption capacity (mmol/g)						CO_2/N_2 Selectivity		
	37 °C		55 °C		72 °C				
	CO_2	N_2	CO_2	N_2	CO_2	N_2	37 °C	55 °C	72 °C
BC	2.45	0.44	1.65	0.23	1.21	0.10	5.54	7.06	11.89
BBC	2.59	0.45	1.80	0.24	1.34	0.10	5.76	7.54	12.82
PBC	2.60	0.45	1.78	0.24	1.34	0.11	5.74	7.40	12.45
SBC	1.61	0.28	1.09	0.15	0.82	0.06	5.68	7.34	12.78

Acknowledgement

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Study on Water Retention of Biochar Prepared from Coffee by-Products

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ABSTRACT. In order to solve the problem of resource waste and environmental pollution caused by coffee by-products. In this paper, water absorption, water retention, and repeated water absorption were studied with biochar produced from coffee peel, coffee shell and coffee grounds. It was concluded that the coffee peel biochar prepared by thermal cracking at 600°C for 2h had the best water retention performance. Pot experiment was conducted to study the soil water retention in dried soil with 5%(w/w) coffee peel biochar under drought condition. The results showed that coffee peel biochar could improve the water holding performance of soil, reduce the content of >1mm particle size aggregate, and significantly increase the content of 1~0.25 particle size aggregate.

Keywords：Biochar; Coffee by-product; Water retention.

Introduction

Biochar is a carbon-rich product prepared by pyrolysis carbonization of biomass under anoxic or anaerobic conditions, with developed pore structure, large specific surface area and abundant functional groups [1], which can improve the physical and hydraulic characteristics of soil [2], promote plant growth, and improve soil agglomeration structure [3]. There have been a large number of reports on the application effect of biochar in agriculture, and Glaser et al [4] found through field experiments that the soil with biochar added increased the water holding capacity by at least 18% compared with the soil without biochar.

In this study, water absorption, water retention, and repeated water absorption of biochar with produced from coffee peel, coffee shell, and coffee grounds were investigated. The soil water holding capacity was measured in a drought experiment. Our study may provide a potential strategy for solving the problem of resource waste and environmental pollution caused by coffee by-products in.

Material and Methods

Test material

Soil types: The test soil was red soil collected from the 0~20cm soil layer of Chenggong Campus of Yunnan University, which removed impurities in the soil, dried naturally, and then screened 4 mm for reserve.

Biochar preparation: Coffee by-product, which is crushed after drying, put into a crucible, capped and sealed in the muffle furnace, so that it is in a hypoxic environment, and the biochar is produced in different temperatures (400 °C, 500 °C, 600 °C) and different times (2 h, 3 h, 4 h), then cooled to room temperature, ground, screened (20 mesh).

Experimental design

Excellent performance biochar was screened out for coffee seedling pot experiment, and there were four treatments in this test. Dried soil with 5%(w/w) coffee by-products biochar and commercial charcoal, were treated with drought, which were recorded as K and S, respectively. No biochar applied for drought treatment, which is recorded as T. No biochar applied for normal irrigation, recorded as CK.

The drought treatment is: 25%~30% of the maximum water holding capacity of the soil, after 30 days of pre-cultivation, the drought treatment is 60 days and then rehydrated for 30 days. Normal irrigation is: the soil maintains 50%~55% of the maximum water holding capacity. Set 4 repetitions per process.

Test method

①The determination of biochar water absorption, water retention and repeated water absorption performance refer to the method in the article Liu Y[5] and Li Y[6].② The soil water retention performance was carried out by Wang H et al. [7].③ The content of aggregates of each particle size in the soil was determined using the Savinov classification dry sieve method[8].

Results and Discussion

Water absorption, water retention and repeated water absorption properties of biochar produced by coffee fruit peel, coffee fruit shell and coffee grounds under different preparation processes

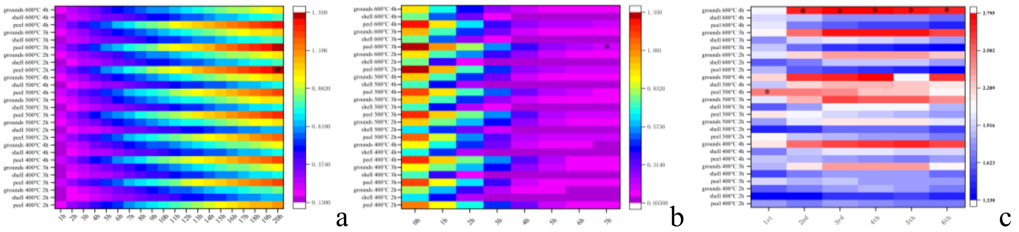


Fig. 1 Water absorption rate (%) (a). Residual moisture content (%) (b). Repeated water absorption rate (c). Biochar of coffee peel, coffee shell and coffee grounds in different preparation processes.

After absorbing water in the incubator for 20 hours, the water absorption rate of biochar prepared by coffee shell and coffee grounds was much lower than coffee peel biochar. The highest water absorption rate of coffee peel biochar was the biochar prepared under the preparation process of 600 °C and 2 h, and the water absorption rate was 134.61%.

The moisture content of biochar gradually decreased with time, but the residual moisture content of coffee peel biochar is higher than coffee shell biochar and coffee grounds biochar after seven hours, and the residual moisture content of coffee peel biochar under the preparation process of 600 °C and 3 h is the highest(18.33%). The residual moisture content of biochar with the best water absorption (coffee peel biochar produced at 600 °C and 2 h preparation process) was 17.33% after seven hours, which was no difference with coffee peel biochar at 600 °C and 3 h. The mechanism of water adsorption of biochar is mainly hydrogen bonding, such as surface functional groups, especially oxygen-containing functional groups, play an important role in the water holding capacity of biochar. It showed that coffee peel biochar has richer oxygen-containing functional groups than biochar produced by coffee shell and coffee grounds, which could retain more water.

The first time the highest water absorption rate is 2.45 of coffee peel biochar under the preparation process of 500°C and 4h. In the next five water absorption tests, the highest water absorption rate was biochar produced by coffee grounds under the preparation process of 600 °C and 4h, which were 2.66, 2.76, 2.79, 2.73 and 2.69, respectively.

Combining the indicators of water absorption, water retention, repeated water absorption and energy consumption (temperature and time) for preparing biochar, the biochar prepared by coffee peel maintained at 600°C for 2h is a multifunctional material with water retention performance in agricultural production for drought management.

Effects of biochar on soil water retention

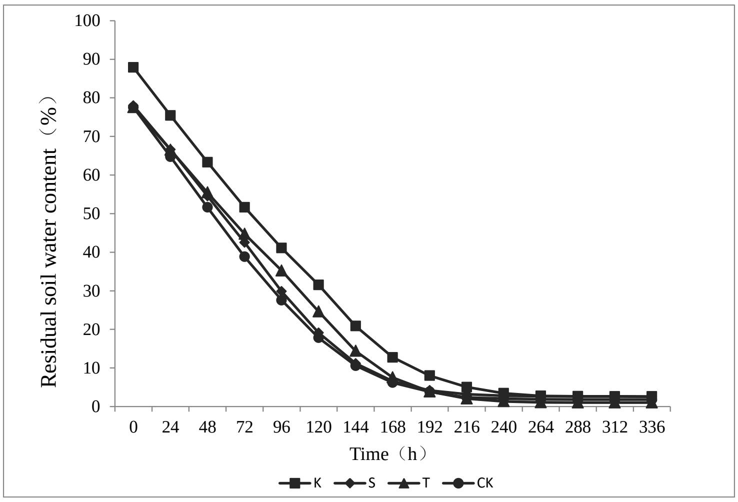
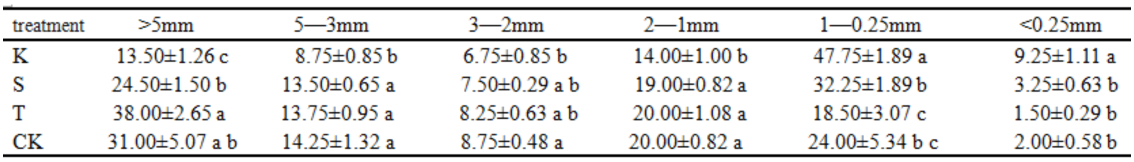


Figure 2: Water retention of soil with different treatments

The soil water retention of treatment K in drought treatment was better than that of the other three treatments. The application of coffee peel biochar can increase the soil permeability and improve the water retention capacity. A large number of experimental results show that the application of biochar can effectively improve soil water content and reduce water evaporation, especially in sandy soils [9,10].

Effect of coffee peel biochar Addition on Soil Particle Size Distribution (Dry Screening Method)

Table 1 Distribution of soil particle size under different treatments (%)



treatment	>5mm	5—3mm	3—2mm	2—1mm	1—0.25mm	<0.25mm
K	13.50±1.26 c	8.75±0.85 b	6.75±0.85 b	14.00±1.00 b	47.75±1.89 a	9.25±1.11 a
S	24.50±1.50 b	13.50±0.65 a	7.50±0.29 a b	19.00±0.82 a	32.25±1.89 b	3.25±0.63 b
T	38.00±2.65 a	13.75±0.95 a	8.25±0.63 a b	20.00±1.08 a	18.50±3.07 c	1.50±0.29 b
CK	31.00±5.07 a b	14.25±1.32 a	8.75±0.48 a	20.00±0.82 a	24.00±5.34 b c	2.00±0.58 b

Note: Different letters indicate significant differences between different treatments ($P < 0.05$).

Biochar application reduced the content of >1mm particle size aggregate, and the effect of coffee peel biochar was greater than commercial charcoal. The content of 1~0.25 particle size agglomerate was significantly increased, accounting for 47.75%, in coffee peel biochar treatment than that of commercial charcoal. Biochar has no obvious promoting effect on the increase of large aggregates in soil after application, which may be due to the low content of inorganic colloids in soil, and it is difficult to form stable large aggregates [11]. Wu et al [12] reported that it was difficult to significantly improve the soil physical properties in the short term of biochar application into the soil.

Conclusions

(1) The best water retention, and the residual moisture content was 18.33%. The biochar produced bCoffee peel biochar produced at 600 °C and 2h has best water absorption performance, with a water absorption rate of 134.61%. Coffee peel biochar with produced at 600 °C and 3 h had ty coffee grounds under 600°C with 4h has the best repeated water absorption performance.

(2) The addition of coffee peel biochar can improve the water holding performance of the soil, but reduce the capillary water holding capacity of the soil. The application of biochar reduces the content of >1mm particle size aggregate, and the effect of coffee peel biochar is greater than commercial charcoal, but the content of 1~0.25 particle size aggregates is significantly increased.

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Biochar Derived from Miscanthus sinensis and its Applications: Removal of Antibiotics from Aqueous Media

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Antibiotic pollution is a significant concern in aquatic habitats like surface water, groundwater, wastewater treatment plant effluents, aquaculture water, and hospital wastewater. A wide range of antibiotics with high concentrations has been detected in aquatic environments, particularly in the surface water next to livestock farms. The pollution by antibiotics raises antibiotic resistance in the environment and generates more environmental risks. Therefore, effective remedial strategies to remove antibiotics from the water environment are the need of the hour. Plant biomass-derived biochar is a potential adsorbent to remove antibiotics from the water environment. Plant materials are still a valuable resource for solving many global issues. This study assessed the functionalized biochar derived from *Miscanthus sinensis* to remove antibiotics from wastewater. Various antibiotics such as ampicillin, ciprofloxacin, oxytetracycline, penicillin, and streptomycin were investigated for their removal. Standardization of analyses of the antibiotics namely ampicillin, ciprofloxacin, oxytetracycline, penicillin, and streptomycin was also investigated. SEM-EDAX (Scanning electron microscopy with energy dispersive X-ray analyser), XRD (X-ray diffraction), and Thermogravimetric Analysis (TGA) were used to characterize the biochar after the removal of antibiotics. The results showed that the adsorbent could remove antibiotics such as (oxytetracycline) from aqueous solutions so that it can remove more than 92% (ampicillin) in less than 2 h from aqueous solution. A further study of the mixed antibiotics removal process will be developed to apply in wastewater treatment plants.

Keywords: Biochar, *Miscanthus sinensis*, Antibiotics, Functionalized biochar.

Effective Degradation of Chloramphenicol in Wastewater by Activated Peroxymonosulfate with Fe-rich Porous Biochar Derived from Petrochemical Sludge

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Excess sludge produced from biological wastewater treatment plant in petroleum industry is a kind of hazardous solid waste. Incineration and landfill are two types of conventional methods to treat and dispose the hazardous sludge, but high capital input is required for sludge transformation, oven configurations or membrane materials purchase. Conversion of hazardous sludge into biochar by pyrolysis method under oxygen limited condition has been considered as a good option to overcome the above challenges. This is not only an approach to reduce its environmental risk, but the sludge biochar has been also recovering resources and increase economic efficiency in removing organic pollutants from water body. In this study, metal-rich petrochemical sludge was used to produce activated sludge biochar (ASC) via a two-step method of pyrolytic carbonization (400 °C-800 °C) and subsequent KOH activation (abbreviated as ASC 400-800). The physio-chemical properties of ASC 400-800 were characterized by Fourier transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), Scanning electron microscopy (SEM), and Brunauer-Emmett-Teller (BET) and Raman. Further, the effect of the pyrolysis temperature of petrochemical sludge to obtain biochar catalyst with good adsorption capacity and catalytic performance for CAP removal in the sludge biochar/PMS system. The CAP removal was treated with different initial PMS concentration, initial pH value, and initial catalyst dosage and collected the treated wastewater and analyzed for the removal efficiencies of CAP, TOC, and High-performance liquid chromatography coupled with mass spectrometry (LC-MS). Hence arrived the optimum treatment conditions in catalytic CAP degradation f with the petrochemical sludge biochar.

Results showed that porous sludge biochar was prepared by the two-step method in which petrochemical sludge was sequentially treated by pyrolysis and KOH activation. XRD analysis revealed that Fe_3O_4, Fe^0, and graphitized carbon formed in ASC at 600-800 °C. At 800 °C, the specific surface area of ASC reached the highest value of 202.92 m^2 g^{-1}. The results showed that the increase in sludge pyrolysis temperature from 400 °C to 800 °C resulted in the enhancement of ASC adsorption capacity on CAP removal efficiency increased from 8.4% to 39.0%. ASC 800 showed higher CAP adsorption capacity with CAP removal efficiency of 39.0%. The CAP removal efficiencies of ASC 400/PMS, ASC 500/PMS, ASC 600/PMS, ASC 700/PMS, and ASC 800/PMS systems were 14.1%, 20.8%, 27.1%, 33.0%, and 49.4%, respectively. Among ASC 400-800, good characteristics made ASC 800 exhibited the best CAP removal performance in ASC 800/PMS system by the adsorption combining with catalytic degradation. The optimal conditions identified for 0.31 mM CAP removal were ASC 800 2.0 g L^{-1}, PMS 6.2 mM, and pH 2.0. The CAP removal efficiency of the ASC 800 was recorded as 95.7%, as well as TOC removal efficiencies of 55.7% within 120 min. $SO_4^{\bullet-}$, •OH, and $^1O_2$ may contribute to CAP degradation. Additionally, the possible catalytic mechanisms and CAP degradation pathways in ASC800/PMS system were proposed, intermediates from CAP degradation were identified by using LC-MS. Finally, intermediate products may be further degraded to small molecule products or mineralized to H_2O, CO_2, NO_3^-, NH_4^+ and Cl^- by reactive radicals in ASC 800/PMS system. Overall, this study confirmed that porous biochar derived from petrochemical sludge was an effective adsorbent or PMS catalyst to remove organic pollutants from wastewater.

Keywords: Petrochemical sludge, Fe-rich sludge biochar, Peroxymonosulfate activation, Adsorption, Chloramphenicol removal.

Synthesis of Waste Face Masks Assisted Magnetic-Biochar for The Removal of Malachite Green from Aqueous Solution

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The main cause of all illnesses on living organism is contaminated water. Dye is one of the water pollutants that, even in trace amounts, render water unfit for human consumption. The presence of low amounts of hazardous dyes in water has a significant environmental impact. Malachite green oxalate (MG) is a cationic toxic dye and used for product coloration in the textile, paper, rubber, leather and food sectors. Due to the discharge of untreated industrial waste water, surface and groundwater are contaminated with dyes. Malachite green exposure can have harmful effects for the body, including mutagenesis, teratogenicity, chromosomal mutations, pulmonary toxicity, fractures, and cancer. The removal of MG dye from water is very essential to providing safe drinking water. MG dye can be removed from water using a number of techniques, including photocatalytic, electrochemical, membrane, and adsorption. Adsorption stands out among them as the finest alternative approach for treating water because of its special qualities, including being easy, non-toxic, affordable, and sustainable. In COVID pandemic, the use of face mask is the primary tool to prevent the spread of virus and lessen exposure to virus. It was estimated that globally 1.6 million tonnes of disposable face mask were daily evolved as waste in pandemic situation. In developing nations, there is a dearth of information about appropriate management and disposal techniques, which has an impact on the environment. Creating valuable material from used facemasks for practical purposes could offer a variety of benefits.

The purpose of this study is to develop functional carbonised materials by the controlled pyrolysis of disposable face masks. The facemask waste mass was transformed into a useful carbonised material at the appropriate pyrolysis temperature, which ranged from 500 to 600 ^{o}C. The synthesised carbonised material has a high adsorption capacity, but it creates a bottleneck during filtration. To address this shortcoming, magnetically assisted waste facemask biochar (Fe_3O_4@FMBC) was created for the removal of MG dye from water. To achieve the highest adsorption capacity, several adsorption factors, including the impact of the initial concentration, contact time, various pH levels, co-ions, and dose, were tested. In order to understand the equilibrium data of the synthesised Fe_3O_4@FMBC, Freundlich and Langmuir adsorption isotherms were investigated. The findings of this study demonstrated that the Fe_3O_4@BC made from the waste face mask biomass is an efficient adsorbent.

Keywords: Waste Face Mask; Carbonization; Fe_3O_4; Environmental Applications.

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Catalytic Conversion Technologies

Nitrogen-doped Carbon as Efficient Catalysts for Metal-free Conversion of 5-Hydroxymethylfurfural to 2,5-Furandicarboxylic Acid

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Biomass conversion to value-added products through sustainable catalytic conversion is a pressing priority. The ever-rising global temperatures due to unsustainable industrial practices such as the use of rapidly depleting fossil fuels for the production of chemicals and their derivatives and fuels have led to a shift in the research focus toward the development of clean and green technologies. Biomass can be converted into platform chemicals such as 5-hydroxymethylfurfural (HMF) through acid dehydration of sugars which upon further oxidation can be transformed into the monomer of bioplastic, 2,5-furandicarboxylic acid (FDCA). FDCA has gained attention as it can be used for the production of green polymers thereby alleviating our dependency on fossil fuels. The oxidation of FDCA can be achieved through heterogeneous catalysis by the use of noble/transition-metal-based catalysts. The use of these catalysts not only increases the cost of operation but also poses technical barriers such as leaching/ deactivation of the catalysts during the reaction. To circumvent these issues, the current study demonstrates the use of metal-free N-doped carbon catalyst derived from biomass for the conversion of HMF to FDCA. A series of metal-free catalysts were synthesized by pyrolyzing chitosan and melamine as precursors and the thermal oxidation was conducted in methanol at 160ºC for 6 h. The as-synthesized catalysts displayed >90% HMF conversion with a promising yield of 5-formyl-2-furancarboxylic acid (FFCA) in 6 h. The metal-free catalyst prepared with chitosan and potassium carbonate as the activator displayed 43.3% FDCA yield, which can be attributed to heteroatom substitutions (graphitic N), high BET surface area (1487.7 m^2/g), and abundance of defects as observed through Raman analysis. It was noteworthy that the extent of different heteroatom substitutions (N and O) greatly impacted the catalytic performance of the catalyst. For the first time, the adsorption of the reaction intermediates, FFCA and FDCA is reported in the study. Through careful analysis, it was found that the catalysts with high C-O functionalities aided the adsorption of FFCA and high C-N content was responsible for the adsorption of FDCA. This study not only presents a cost-effective and efficient catalyst for HMF conversion but also demonstrates the mechanistic insights and roles of different heteroatom substitutions during HMF oxidation to FDCA.

Keywords: Biomass, 5-Hydroxymethylfurfural, 2,5-Furandicarboxylic acid, Metal-free catalyst.

Synthesis of Pd-CNT Based Hybrid and Its Application in Hydrogen Production from Formic Acid at Ambient Temperature

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The efficiency and sustainability of biomass energy have long made it a desirable energy source for hydrogen production. Dehydrogenation of formic acid has been extensively investigated for safe and easy hydrogen production. Thereby, various catalysts have been developed for aqueous formic dehydrogenation (FAD) reaction to efficiently produced hydrogen. However, there is still a lack of understanding of the reaction mechanism. Herein, to fundamentally comprehend the aqueous FAD reaction mechanism, we prepared carbon nanotubes (CNTs) as the preferred choice of support and treated at three different function groups (CNT, CNT-$_{COOH}$, CNT-$_{NH2}$) for the deposition of Pd nanoparticles. CNTs were used as the preferred support material for decomposing Pd nanoparticles were thoroughly characterized using XRD, XPS, SEM, TEM-EDX, BET, and FTIR. Significant difference in catalytic performance between PdCNT, PdCNT-$_{COOH}$, and PdCNT- $_{NH2}$ particles. The PdCNT- $_{COOH}$ catalyst provided higher catalytic performance than impregnation catalysts because it has a smaller particle size and a higher exposure to Pd than impregnation catalysts. A Pd catalyst supported on CNTs was then used to dehydrate formic acid over a sodium formate catalyst to generate H_2. The turnover frequency was measured at 395.24 mol H_2 Pd/h^{-1} after 5 minutes. H_2 production process is expected to be a much more efficient, sustainable, and economical process for H_2 production from biomass. Moreover, we have been performed to gain insights into the reactivity and decomposition of CO_2 feeding along two-reaction pathways on Pd (111), Pd (011) and Pd (001) surfaces. This work could provide promising strategies for the fabrication of cost effective and high-active Pd-based catalysts for formic acid dehydrogenation.

Keywords: Hydrogen, formic dehydrogenation, palladium, carbon nanotubes, turnover frequency.

Insight Into PCDD/Fs Catalytic Decomposition Mechanism Using Two Model Objects: Experiment and DFT Calculation

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Since the active temperature of conventional selective catalytic reduction (SCR) catalyst (e.g., V_2O_5-WO_3/TiO_2) for PCDD/Fs destruction (200-300 ℃) is higher than the actually temperature supplied by the catalytic reactor (generally below 200 ℃). Flue gas reheat always required to achieve high conversions, that consumes extra energy and needs additional device. In order to avoid flue gas reheat, developing catalysts that achieving PCDD/Fs decomposition effectively at low temperature is strongly needed. Accurate understanding the catalytic decomposition mechanism of PCDD/Fs is crucial. Most studies on PCDD/Fs catalytic decomposition mechanism selected chlorobenzenes as a model instead of using PCDD/Fs directly, due to the high toxicity, expensive detection and hard to obtain stable generating device of PCDD/Fs. Using chlorobenzenes as the model merely considered the chlorobenzenes ring structure but ignored the oxygen heterocyclic ring of PCDD/Fs, resulting in the incomprehensive understanding of the PCDD/Fs catalytic oxidation mechanism. In this study, o-dichlorobenzene and furan were used together as model substitutes, referring to chlorobenzene ring and oxygen-containing heterocycles structures in PCDD/Fs respectively. MnO_2-CeO_x/TiO_2 (MnCe/Ti) catalysts were selected and prepared by impregnation method. We planned to reveal the priority reactive groups in PCDD/Fs through investigating the interaction between o-dichlorobenzene and furan during the adsorption and oxidation decomposition processes over MnCe/Ti catalyst. Results indicated that competition adsorption effect existed between the o-dichlorobenzene and furan, while furan adsorption capacity increased gradually with temperature increasing and was larger than that of o- dichlorobenzene. For oxidation decomposition, the catalytic oxidation efficiency of furan achieved almost 100% in 150-300 ℃ and was not affected by the preadsorption of o-dichlorobenzene. However, o-dichlorobenzene catalytic oxidation was relatively weaker but enhanced instead when the catalyst was preadsorbed with furan, especially at low temperatures (≤200℃). In addition, higher CO/CO_2 selectivity (>85%) was obtained during furan catalytic oxidation. In light of these results, it was found furan was preferred to be adsorbed and oxidized by catalyst rather than o-dichlorobenzene. Therefore, we speculated that oxygen heterocyclic ring was more likely to be the priority reactive group in PCDD/Fs adsorption and oxidation. Based on several characterizations (such as EPR, Raman, XPS, H_2-TPR, NH_3/O_2-TPD, and in situ DRIFTS, etc.), furan preferred to adsorb on top site of Mn metal atom (Lewis acid) via its O atom, whereas o-dichlorobenzene tended to adsorb on surface oxygen vacancies via Cl atom. The redox ability of catalyst was enhanced after furan adsorption and oxidation for the amount of surface reactive oxygen species on the catalyst surface increased. However, the redox ability of catalyst was weakened after o-dichlorobenzene adsorption and oxidation. It can be ascribed to the anchor of Cl atom on surface oxygen vacancy that inhibited the formation of surface reactive oxygen species. This study provides theoretical and experimental guidance for the design of novel catalyst, that can achieve the decomposition of PCDD/Fs effectively at low temperature.

Keywords: PCDD/Fs, O-dichlorobenzene, Furan, Decomposition mechanism.

Solar-Driven Reforming of Waste Polyester Plastics for Hydrogen Evolution Over CdS/NiS

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To date, more than 8 billion tons of plastics have been produced, but 79% of them haven't been disposed of properly, contributing to the increasingly serious ecological problem. While the existing technologies are inadequate for the efficient and continuous disposal of plastic waste, photocatalytic technology has attracted wide attention in recent years. Photo-reforming technology provides an uncomplicated route to simultaneously recycle plastics and facilitate hydrogen (H_2) production, meeting the requirements of sustainable development. Herein, pure H_2 was produced from waste plastics through visible-light-driven reforming over the CdS/NiS (NiS modified CdS nanorods) photocatalyst. The CdS/NiS composite could be easily synthesized through a hydrothermal method and show efficient photocatalytic activity under normal temperature and pressure without expensive precious metals. The loading of NiS on CdS was proven could effectively reduce the recombination of photoexcited electrons and holes, which greatly improved the photocatalytic performance. Therefore, a variety of widely-produced polyester plastics, including polylactic acid (PLA), polyethylene terephthalate (PET), polybutylene adipate (PBA), polybutylene terephthalate (PBT), and poly-(butyleneadipate-co-terephthalate) (PBAT), were used as the feedstocks to successfully produce H_2 and organic chemicals through this photocatalytic path. Among them, the PLA exhibited the highest H_2 production rate, which was over 60 $\text{mmol}\cdot\text{g}^{-1}\cdot\text{h}^{-1}$ under optimized conditions. Furthermore, CdS/NiS could also reform real-world waste plastics (the commercial PLA drink straws) with photostability for at least 12 h, suggesting the stability and applicability of this system. Moreover, the mechanism of waste plastic photo-reforming via CdS/NiS catalyst was also proposed. The catalyst would generate photoexcited electron-hole pairs under illumination, then the photoexcited electrons reduced water to produce H_2. Meanwhile, the holes oxidized the plastics into value-added organics, including ketone, aldehyde, and acid products. As such, this photo-reforming system offered a sustainable approach to eliminate plastic pollution and simultaneously convert solar energy into carbon-free H_2, assisting the global sustainability goals and contributing to a carbon-neutral future.

Keywords: Photocatalytic, Plastic upcycling, Hydrogen production.

Catalytic Fast Pyrolysis of Lignocellulosic Biomass For Liquid Fuel Production

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ABSTRACT. Biomass waste could be converted to renewable fuels or chemicals through the catalytic fast pyrolysis process, in which the performance of the catalyst is the key factor for the yields and qualities of products. In this research, single atom iron was loaded on the substrate of montmorillonite clay by the pyrolyzing coordinated polymer method for fuel production by catalytic pyrolysis of biomass waste. The results showed that the liquid yields increased, and the gas products yield decreased in catalytic pyrolysis compared with direct pyrolysis. The highest bio-oil, char, and gas yield were 56.9 wt. %, 41.3 wt. %, and 32.4 wt. % in corn powder, wheat straw, and sawdust, respectively. This research could significantly improve the utilization efficiency of the supported metal to reduce the cost of the catalyst and improve the yield of liquid products, providing an effective method for the volume reduction and reutilization of biomass waste.

Keywords: *Renewable fuels; catalytic fast pyrolysis; biomass; montmorillonite*

Introduction

Lignocellulosic biomass is the largest source of renewable polymers, which is widely used for construction, furniture, animal feed, and energy. Through catalytic pyrolysis, the solid state of biomass could be converted to the liquid fuel with a higher energy density. The key factor is the properties of catalysts. Rahman et al. [1] studied the sawdust pyrolysis process with ZSM-5 as the catalyst and the liquid yield was 26.3% at 500 °C. In the research of Persson et al.,[2] sawdust was treated by acid and the liquid oil yield was 56.2% at 500 °C. In this research, single atom iron was loaded on the substrate of montmorillonite clay by the pyrolyzing coordinated polymer method for fuel production by catalytic pyrolysis of biomass waste, i.e. bamboo straw, corn straw, corn powder, sawdust, and wheat straw. This research could significantly improve the utilization efficiency of the supported metal to reduce the cost of the catalyst and improve the yield of liquid products, providing an effective method for the volume reduction and reutilization of biomass waste.

Material and Methods

Equipment for pyrolysis

The pyrolysis system was equipped with a horizontal fixed-bed reactor (made of stainless steel), the schematic of which was shown in Fig. 1. In each test, 3 g of biomass was consumed. The mass ratio of the catalyst and the raw material was 1:10. The feedstock was located at the bottom of a quartz tube. The catalyst was placed at the top of the feedstock, which was separated by the glass wool. Then the glass wool was added at the opening of the feedstock container to prevent the solid particles from escaping the quartz tube. When the reactor reached the designed temperature (500 °C), the quartz tube, loading the feedstock and catalyst, was conveyed to the middle of the reactor. Nitrogen was applied as the protecting gas in the whole process with a flow rate of 50 ml/ min. The gases from the reactor passed through an intermittent spiral quartz condenser at -10 °C. The condensed liquids were collected by a glass container at the bottom of the condenser. The non-condensable gas was collected by the gas bag. Each test lasted for 60 minutes. After the reaction, the temperature of the whole system returned to normal under the nitrogen atmosphere. Then pyrolysis system was disassembled and weighted for calculating the yields of products.

Analysis methods

The characteristics of catalysts were analyzed by XRD, SEM/ TEM, BET, TPD, and XPS, for the phase structures, morphology, textual structures, acidity, and elemental valence/ composition, respectively. The detailed information for the catalyst characterization were shown in Table 1. The catalytic performance was mainly evaluated by the yield of oil. In mass balance analysis, the weight of liquid (oil) was calculated by the different masses of the condensation system before and after the reaction. Char consisted of two parts: one is from the direct cracking of raw materials, and the other is from the carbon deposited on the catalyst.

The used catalysts were treated in a muffle furnace at 500 °C for 5 hours to test the carbon deposition. The gas was calculated by differences. The condensation system was cleaned with methanol (10 ml). All the mixture (methanol and pyrolysis liquid) was collected and filtrated.

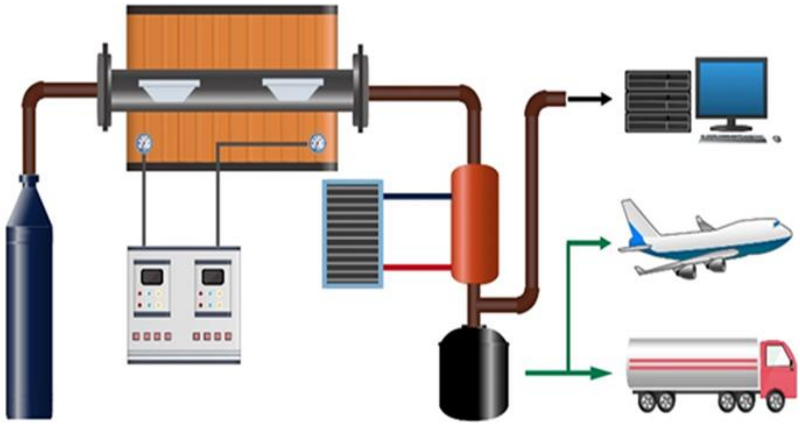

Fig. 1 The schematic diagram of the pyrolysis equipment

Table 1. The detailed information for the catalyst characterization and products analysis

		Type	Main Parameters
1	XRD	Bruker D8 Advance	Radiation source: Cu Kα, Voltage: 40 kV
2	SEM	Zeiss Sigma 500	Electron high tension voltage: 10 122 kV, Working distance: 7.8-8.0 mm
3	TEM	FEI Tecnai G2 f20 s-twin 200kV	Resolution ratio: 0.2 nm, Voltage: 200 kV
4	BET	Micromeritics ASAP 2460	Analysis adsorptive: N2, Degasing temperature: 120 oC for 12 h
5	NH3-TPD	Quantachrome 126 TPRWin v3.52	Adsorbate: 5% NH3, Detector current: 135.0 mA
6	XPS	Thermo K-Alpha+	Radiation source: Al Kα, Voltage: 15 kV
7	GC/MS	Agilent 7890A/5975C GC-MSD	Column: Agilent J&W DB-5MS (30 m, 0.25 mm, and 0.25 μm)
8	GC	Agilent 7890A GC-TCD	Column 1: Agilent J&W HP-PLOT/Q (30 m, 0.32 mm, and 20 μm) Column 2: Restek Packed Column ShinCarbon ST 80/100 (2 m, 2 m ID, 1/8 OD), only for hydrogen and carbon monoxide

Results and Discussion

Characteristics of catalysts

The functional groups of catalysts before and after the experiments were analysis by FTIR, which was shown in Fig. 2. The peaks information (wavenumbers and assignments) were indicated in the figure. A great similarity between fresh catalyst and used catalyst was found. But the peak at 3640 cm-1, which was assigned to the stretching interlayer of Al–OH group [3], was only observed in the fresh catalyst (5% Fe-Mont). The missing peak in used catalysts might be the carbon deposition on the catalyst. The peaks at 3425 cm-1 and 1640 cm^{-1} were the stretching and bending of absorbed water, respectively [4].

Catalytic performance

Products distribution was shown in Table 2 and Table 3. The oil yields were calculated by the weight differences of the condensation system. The char yields were obtained by the remains of the feedstock and the carbon deposition on the catalysts. The gas yields were calculated by differences. Under the same condition, corncob generated a more liquid product, which is a more suitable feedstock for the liquid fuel production. The liquid yields of corncob were 49.1% and 56.9%, in direct pyrolysis and catalytic pyrolysis, respectively. The catalysts increased the oil yield, except the wheat straw.

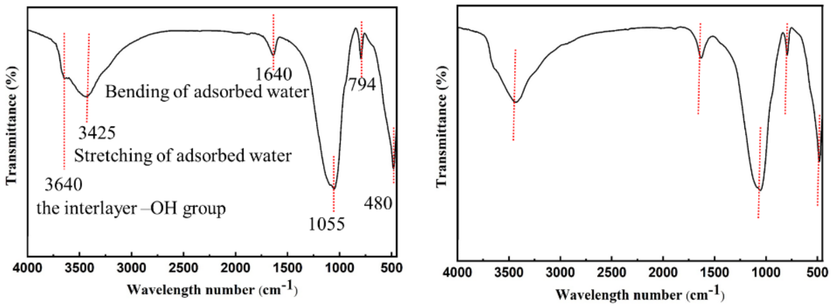

Fig. 2 FTIR analysis of catalysts

The oil yield of wheat straw was slightly decreased by the catalyst. When using the wheat straw as the feedstock, the oil yields were 36.5% and 36.0% for direct pyrolysis and catalytic pyrolysis, respectively. The char yield were all increased by the catalysts, partly due to the carbon deposition on the catalysts. Ravikumar et al.[5] found that the oil yield from corncob was the highest (42.1%) among sawdust, rice straw, corn straw and corncob under the same conditions in pyrolysis research with microwave. In the research of Biswas et al.,[6] the oil yield of corncob was higher than that of rice husk, rice straw, and wheat straw, which was 47.3%, 38.1%, 28.4%, and 36.7%, respectively.

Table 2 The product distribution in direct pyrolysis

	Bamboo straw	Corn straw	Corn powder	Sawdust	Wheat straw
Oil	31.2	37.5	38.2	37.9	47.1
Char	21.5	33.3	30.5	24.0	40.7
Gas	47.3	29.1	31.3	38.1	12.3

Table 3 The product distribution in catalytic pyrolysis

	Bamboo straw	Corn straw	Corn powder	Sawdust	Wheat straw
Oil	38.2	49.8	45.3	38.5	55.1
Char	22.2	34.8	31.8	25.2	41.3
Gas	39.7	15.4	22.9	36.3	3.6

Liquid composition analysis

The pyrolysis mechanism was studied by the structures and contents of chemicals in liquid oils from corncob experiments. Top 10 chemicals detected in liquid oils by GC/MS in direct and catalytic pyrolysis were shown in Table 4 and Table 5. There were 14 kinds of chemicals in the table, for 6 kinds of chemicals were the same in direct pyrolysis and catalytic pyrolysis. The area percentages of those chemicals were all increased by the catalyst, except dodecane, 1,1-dimethoxy-. The catalyst dramatically increased the content of methyl formate. The area percentages of methyl formate in direct pyrolysis and catalytic pyrolysis was 5.29% and 11.15%, respectively. The chemical with the highest area percentage in direct pyrolysis and catalytic pyrolysis was dodecane, 1,1-dimethoxy- (5.36%) and methyl formate (11.15%), respectively.

Table 4 Top 10 chemicals in direct pyrolysis

	PK	RT (min)	Area Pct (%)	Library/ID	CAS	Formular
1	36	17.8389	5.3579	Dodecane, 1,1-dimethoxy-	14620-52-1	$C_{14}H_{30}O_2$
2	2	1.4894	5.294	Methyl formate	000107-31-3	$C_2H_4O_2$
3	45	20.4897	4.9462	Benzofuran, 2,3-dihydro-	000496-16-2	C_8H_8O
4	37	18.5771	4.0678	Phenol, 4-ethyl-	000123-07-9	$C_8H_{10}O$
5	21	9.316	3.3795	Phenol	000108-95-2	C_6H_6O

6	73	28.4673	3.2027	D-Allose	002595-97-3	C6H12O6
7	18	7.6131	3.0317	2,4-Dihydroxypyridine	000626-03-9	C5H5NO2
8	29	14.7351	2.8429	p-Cresol	000106-44-5	C7H8O
9	1	1.4223	2.8246	Hydrazine, 1,1-dimethyl-	000057-14-7	C2H8N2
10	42	19.7096	2.8005	Propanoic acid, 2-methyl-, 2-methylpropyl ester	000097-85-8	C8H16O2

Table 5 Top 10 chemicals in catalytic pyrolysis

	PK	RT (min)	Area Pct (%)	Library/ID	CAS	Formular
1	1	1.4895	11.1535	Methyl formate	000107-31-3	C2H4O2
2	55	20.4898	5.559	Benzofuran, 2,3-dihydro-	000496-16-2	C8H8O
3	47	18.5688	5.232	Phenol, 4-ethyl-	000123-07-9	C8H10O
4	35	14.71	3.6791	p-Cresol	000106-44-5	C7H8O
5	44	17.8306	3.6081	Dodecane, 1,1-dimethoxy-	014620-52-1	C14H30O2
6	51	19.5419	3.5254	Catechol	000120-80-9	C6H6O2
7	25	9.2742	3.4139	Phenol	000108-95-2	C6H6O
8	2	1.6322	3.0977	Guanidine, methyl-	000471-29-4	C2H7N3
9	21	7.5126	2.9122	1H-Pyrazol-4-amine, 3,5-dimethyl-	005272-86-6	C5H9N3
10	11	2.6052	2.4228	Pyrazole, 1,4-dimethyl-	001072-68-0	C5H8N2

Conclusions

Fe atoms were loaded on the bases of Mont. With the loading of Fe, the surface area, pore volume, and pore size of Mont. were all decreased. After reaction, surface area and pore volume were all decreased. The highest bio-oil, char, and gas yield were 56.9%, 41.3%, and 32.4% in corn powder (with catalyst), wheat straw (with catalyst), and sawdust (without catalyst), respectively. In direct pyrolysis, the corn powder generated the highest yield of oil (49.1%), which is a more suitable feedstock for the liquid fuel production. Catalysts promote the cracking of macromolecules.

Acknowledgement

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Fabrication of Cobalt Manganese Spinel for Highly Selective Oxidation of 5-Hydroxymethylfurfural to 2,5-Furandicarboxylic Acid

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With the rapid development of modern society, the plastic pollution as well as microplastic contamination have raised public concern. Bioplastic has attracted great attention due to the green raw materials and biodegradable property. 2,5-furandicarboxylic acid (FDCA), could be used as the precursor to produce green bioplastics such as polyethylene furanoate (PEF). Accordingly, the synthesis of FDCA could also be realized through the oxidation of 5-Hydroxymethylfurfural (HMF). However, the selective oxidation of HMF into FDCA remains challenging due to the lack of high-efficient catalysts.

Herein, cobalt manganese spinel catalysts with tailored structural symmetry and composition were synthesized through facile solution-based oxidation–precipitation and insertion–crystallization process as well as low-temperature calcination. Surface morphology of catalysts were characterized by Transmission Electron Microscopy (TEM) and Scanning Electron Microscope (SEM). The specific surface area was calculated following the multipoint N2-Brunauer–Emmett–Teller (BET) adsorption method. Element composition of catalysts were characterized by X-ray photoelectron spectroscopy (XPS).

Catalysts with different ratios of cobalt and manganese and different calcination temperatures showed different catalytic performances and experimental results suggested that Co2MnO4 behaved the highest catalytic efficiency. By adjusting the molar ratio of cobalt and manganese, Co1.2Mn1.8O4-400, Co1.5Mn1.5O4-400, Co2MnO4-400, Co2.2Mn0.8O4-400, and Co2.5Mn0.5O4-400 were synthesized. When the ratio of Mn and Co of the catalyst was changed from 2 to 0.5, the FDCA yield increased from 31.53% to 76.38; when the ratio of Mn and Co of the catalyst was changed from 0.5 to 0.2, the FDCA yield decreased from 76.38% to 5.57%. Besides, Co2MnO4-X (X represents the calcination temperature of 200, 300, 400, 500, 600 °C) were also prepared. Similarly, Co2MnO4-400 still presented the best catalytic performance.

Keywords: 5-Hydroxymethylfurfural; 2,5-furandicarboxylic acid; Cobalt manganese spinel; Lattice oxygen.

Sodium Alginate Based Carbon Aerogel Supported ZIF-8 Derived Porous Carbon as an Effective Adsorbent for Methane Gas

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Adsorption natural gas (ANG) is a technology in which natural gas is stored on the surface of porous material at relatively low pressures, which are promising candidates for adsorption of natural gas. Adsorbent with large surface area and porous structure plays a significant role for ANG technology, which is promised to increase the storage density of natural gas while decreasing the operating pressure. Here, we demonstrate a facile synthetic method for rational construction of sodium alginate (SA)/ZIF-8 composite carbon aerogel (AZSCA) by incorporating ZIF-8 particles into SA aerogel through a directional freeze-drying method followed by carbonation process. The structure characterization shows that the AZSCA has a hierarchical porous structure, in which the micropores originated from MOF while the mesopores are derived from the three-dimensional network of aerogel. The experiment results show that AZSCA achieved high methane adsorption of 181 cm^3/g at 65 bar and 298 K, along with higher Q_{st} throughout the adsorption range. Thus, the combination of MOF powders with aerogel can find potential applications in other gas adsorption.

Keywords: Carbon aerogel, ZIF-8, Sodium alginate, CH_4 adsorption, Hierarchical porosity.

The Impact of Water on Photocatalytic 5-Hydroxymethylfurfural Conversion over Cd-based Catalyst

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HMF (5-Hydroxymethylfurfural) is an important biomass derived platform chemical. It can be further oxidized to a series of derivatives, including Diformylfuran (DFF), 5-hydroxymethyl-2-furancarboxylic acid (HMFCA), 5-formyl-2-furancarboxylic acid (FFCA), and 2,5-furandicarboxylic acid (FDCA). Among them, DFF is a useful building block, including as a monomer in the synthesis of polymers, as an intermediate for pharmaceuticals or antifungal agents, precursor for conducting polymers and cross-linking agent for poly (vinyl alcohol). Therefore, there has been a great deal of concern about the synthesis of DFF from HMF in high yield and selectivity by improving catalytic strategies.

Photocatalysis is an alternative choice for DFF production, which can avoid high temperature and pressure during traditional thermal catalysis but only need light irradiation in mild condition. Although researchers have reported some successful examples on DFF production over photocatalysts, such as TiO_2, g-C_3N_4, CdS, BiW_2O_6 and $ZnIn_2S_4$, the production rates of DFF are generally very slow as a consequence of low concentration of initial HMF substrate or long reaction time, in order to obtain high yield of DFF and superior selectivity. Particularly, the complicated catalyst design is also highly needed because the conversion of HMF is sensitive to the condition. The existed studies indicate that DFF can be obtained when ACN was used as reaction solvent, almost without over-oxidize. However, the detailed mechanism is still not clear in molecular level. We recently found that the reaction of DFF production in ACN ceased even the conversion of HMF less than 45% accompanying with only 22% yield of DFF (10 mM HMF). Nevertheless, the reaction process can be conducted persistently after adding trace amount of water into ACN, and the yield of DFF can reach about 66% with more than 90% HMF conversion in 6 hours' reaction, much higher than that in pure ACN or water. What's more, yield of DFF can still achieve more than 60% even the initial HMF concentration was increased to 20 mM in the presence of trace water. For comparison, almost no DFF was detected in pure water under same condition even 100% conversion of HMF. Our control experiment suggests both oxygen and water are indispensable for efficient DFF production and HMF conversion in current condition. This work provides a feasible way for achieving efficient photocatalytic DFF production only by reaction solvent regulation without catalyst design, and it is very promising for us to further reveal the solvent-dependent product selectivity during photocatalytic HMF conversion.

Keywords: Photocatalyst, HMF, Selective oxidation, DFF, Solvent.

Construction of Direct Dual Z-System Ceo_2@N-GO/G-C_3N_4 Photocatalyst for Enhanced Waste Water Degradation

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Photocatalytic removing of contaminants in waster is an ultimate and utmost strategy to resolve the environmental problems. Our study aimed to develop a specific type of direct dual Z-system photocatalysts was construct. The results of the characterization showed that the CeO2 load g-C3N4 and N-doped grapheme oxide (N-GO) Z-system (CeO2@N-GO/g-C3N4) was successfully prepared by hydrothermal method. The best degradation rate closed to 100% for removing 2-Mercaptobenzothiazole (MBT), which is more than two times of pure g-C3N4 and CeO2. The enhanced photocatalytic performance may be related to the introduction of GO accelerates the electron transfer and enlarges the specific surface area of the composites photocatalyst, which can increase the contact with MBT. Also, the direct dual Z-system systems significantly improve the delocalized ability of the photoinduced charge carriers, which efficiently prolongs the lifetime of the charge carriers and reduces the electron-hole recombination rate. Meanwhile, the active species capture experiment and ESR analysis demonstrate that •OH, •O2−, and h+ are generated in the direct dual Z-scheme CeO2@N-GO/g-C3N4 photocatalytic system.

Keywords: Direct dual Z-system, MBT, Carbon Nitride, Wastewater, Degradation.

A Novel Nickel Catalyst Supported on Coal Gangue for Producing High-Value Carbon Nanotubes and Hydrogen

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Pyrolysis catalysis is a promising way to transform waste plastics into high-value products from an economic and environmental perspective. Low-cost catalyst is very important for batch treatment of waste plastics. In this study, a nickel-supported coal gangue catalyst was developed using low-cost coal gangue as catalyst support. In a two-stage fixed-bed reactor, polyethylene was pyrolyzed to produce carbon nanotubes and hydrogen. The catalyst and generated carbon are analyzed using a variety of characterization methods, including temperature-programmed oxidation, X-ray diffraction, scanning electron microscopy and Raman spectroscopy. The results showed when the catalytic temperature is 800 °C, the Raman IG/ID of the product is 1.01, and the maximum hydrogen production is about 35.2 mmol/gPE. The high catalytic effect may be attributed to the rich metal iron in coal gangue. The nickel bimetal has a synergistic effect on the catalytic process. Therefore, nickel catalyst supported coal gangue is an efficient catalyst for the production of valuable carbon nanotubes and hydrogen for waste plastics.

Keywords: Coal gangue; Pyrolysis; Catalysis; Carbon nanotubes; Hydrogen.

Biochar-Fabricated Magnesium Ferrite (BC@MgFe2O4) Nano-Bio Composite for the Removal of Emerging Pharmaceutical Pollutants from Water

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Pharmaceutical contaminants are frequently discovered in water sources and wastewater treatment facilities as a result of their extensive consumption, poor metabolic efficiency, and careless disposal. Ampicillin is one of the antibiotics and used to treat some bacterial infections that affect the membranes surrounding the brain and spinal cord. Over the past year, the use of ampicillin has increased because it kills many infectious microbes. Many water researchers have noted that the surface water is highly contaminated by antibiotic-resistant pathogens. Eventually, it causes many impacts on the environment, human and animals due to the consumption of antibiotic-contaminated water. Neomycin is one of the aminoglycoside antibiotics, and it is used to prevent or treat bacterial skin infections. The neomycin in water affects both humans and aquatic animals. The removal of these antibiotics from water is very essential to providing safe drinking water. Several methods, like photocatalytic, electrochemical, membrane, and adsorption, have been reported for the removal of antibiotics from water. Among them, adsorption is the best alternative method to water treatments due to their unique features, such as being easily handled, non-toxic, economic, simple, and sustainable. In the last few decades, many adsorbents, like silica gel, graphene, metal oxides, etc., have been examined for the removal of antibiotics from waste water. Carbon-based biochar from plant wastes is the superior adsorbent material due to its unique properties, like its huge surface area and biodegradability. Hence, in this research, an attempt was made to synthesise and characterise the carbon-rich biochar from the waste *Annona reticulata* seeds (ARS biochar) for the removal of ampicillin and neomycin from aqueous medium. In addition, magnetic-based adsorbents possess many advantages, like a high adsorption capacity, a fast adsorption rate, and easy separation. Biochar-fabricated magnesium ferrite (BC@$MgFe_2O_4$) nano-bio composite was synthesised for the removal of ampicillin and neomycin from water. The different adsorption parameters, like the effect of the initial concentration, contact time, different pH, co-ions, and dosage, were carried out for the maximum adsorption capacity. Freundlich and Langmuir adsorption isotherms were examined to explain the equilibrium data of the synthesised ARS biochar and BC@$MgFe_2O_4$ bio-composite. Thermodynamic studies revealed whether the adsorption process was endothermic or exothermic. Kinetics models such as the pseudo-first order and pseudo-second-order models were investigated. The reusability of the synthesised BC@$MgFe_2O_4$ bio-composite was studied using a suitable eluent. The results of this study proved that the plant biomass-derived biochar-assisted BC@$MgFe_2O_4$ bio-composite is a potential adsorbent for the removal of emerging pollutants.

Keywords: Adsorption, Biochar, Magnetic, Antibiotic removal, Annona reticulata.

Functionalized rGO Nanoconfined Membrane-Induced Ultrafast Molecular Oxygen Activation for Enhanced the Gas-Solid-Liquid Interfacial Mass Transfer

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Molecular oxygen (O2), as an environmentally friendly oxidant, has unparalleled advantages over other oxidants because of its high selectivity, sustainability and efficiency. However, the limitation of dissolved oxygen (DO) amounts in aqueous solution and limited mass transfer efficiency and ultrashort reactive oxygen species (ROS) lifetimes will inevitably repress pollutants' degradation efficiency. To improve the reactions between pollutants/O2 and catalysts, we designed the gas-solid-liquid reaction interface-dominated tri-phase O2 system using a functional hydrophobic rGO membrane with an enrichment/activation layer of DO and pollutants. In the tri-phase system, the oxygen vacancy-rich rGO/CoFeOx hydrophobic membrane simultaneously improved the interface adsorption performance of emerging pollutants and DO, leading to a marked enhancement of interfacial pollutant concentration and DO levels. This led to a 100% removal of bisphenol A in 20 min at the reaction rate constant of 0.047 ms-1, which was 6-8 orders of magnitude higher than those of the conventional di-phase and suspension systems. Importantly, the nanoconfined membrane influenced the selective production/utilization of ROS, and the 1O2 yield reached a high value of 2.914 mmol/L, which was higher than that of the suspension system. Our findings first highlighted the importance of solid-liquid tri-phase reaction interface, design and providing low energy consumption and environmentally friendly wastewater treatment strategy.

Keywords: Molecular oxygen, Tri-phase reaction interface, Mass transfer, Functionalized rGO hydrophobic membrane, Reactive oxygen species.

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Remediation of Toxic Effects of Parthenium Hysterophorus Through Circular Economy by Using it for the Removal of As, Sb, Cd, Cr, U, F and other Heavy Metals from Waste Water

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ABSTRACT. Rapid proliferation and dispersion of invasive *Parthenium hysterophorus* (PH) have many negative impacts on biodiversity. Direct or indirect contact with this weed can induce diseases to all life forms. Its invasive trait, seed dormancy, and remarkable phenotype plasticity have induced less or no crop productivity. Manual management strategies like uprooting, burning, ploughing, & chemical herbicide utilization cause allergic reactions to workers and native crops. Even burn ashes of this weed influence drastic environmental pollution. Another major problem is toxic heavy metal(s) (HMs) accumulation in water bodies. Common sources of HMs are tannery, nuclear, and textile industries. Thus, this study highlighted a novel idea of bioremediation method through circular economy. This approach will solve two serious environmental issues in a large scale, First is PH accumulation and management strategy. Second is toxic HMs accumulation in water bodies utilizing PH mediated nanoparticles (NPs).

Keywords: *Parthenium hysterophorus*; adverse effects; nanoparticle synthesis; heavy metals; wastewater management strategy; bioremediation; circular economy

Introduction

Parthenium hysterophorus is an invasive allelopathic weed species that competes aggressively with other plants. The major colonizing areas of this prolific weed species include roadsides, wastelands, railway sides, fallow lands, rock crevices, water courses, and cultivated fields [1]. Furthermore, Trichomes, pollen and other parts of *Parthenium* contain toxins which exhibit significant risk to human health, livestock, the environment, soil, and agriculture. The detrimental health effects of *Parthenium* weed are attributed to the sesquiterpene lactones and in particular parthenin in the plant which are poisonous to farm animals and responsible for allergic diseases in humans [2]. Moreover, crop production is severely reduced due to its allelopathy effect. Diseases caused by *Parthenium's* roots and leaves to humans include dermatitis, rhinitis, asthma, atopic dermatitis, hay fever, excessive water loss, diarrhea, and burning or swelling around the eyes [2]. On the other hand, in case of animals, consumption or indirect contact with the weed on a regular basis may cause death, rashes, alopecia, anemia, anorexia, diarrhea, pruritis, skin depigmentation and to some extent psychological behavior of animals can also be influenced by *Parthenium* [3]. It may also affect grazing animal's milk production and meat quality. Discharge of allelochemicals of *Parthenium* into the soil by leaching or decomposition affects plant growth directly or indirectly by affecting the soil's physico-chemical characteristics [4]. Unintentionally *Parthenium's* seeds are dispersed across large distances by means of vehicles, machinery, livestock, grain, and feedstock. While water and wind mediate them to shorter distances. Therefore, *Parthenium's* rapid invasion ability in non-native surroundings often replaces the native indigenous species and thus poses a severe threat to biodiversity. Heavy metal contamination in wastewater systems is also a parameter of these consequences. Even, the presence of heavy metals in water at lower concentration can cause severe health problems to the living communities if used for a longer period of time. Managing invasive by utilizing them for the nanobiosorption of heavy metals from various types of wastewater is important in order to control the economic losses as well as to protect the trophic levels of the ecosystem. This technology is much more feasible, less time consumption as well as environmental friendly than other existing techniques. Management of *Parthenium* species through circular economy (CE) reduces the chances of uncurable infections and diseases to the grazing animals and human population as shown in Fig.1. Moreover, Use of heavy metal-free treated water will neither cease plant growth nor cause fluorosis, cancer, knee aches, and other kinds of diseases in living organisms.

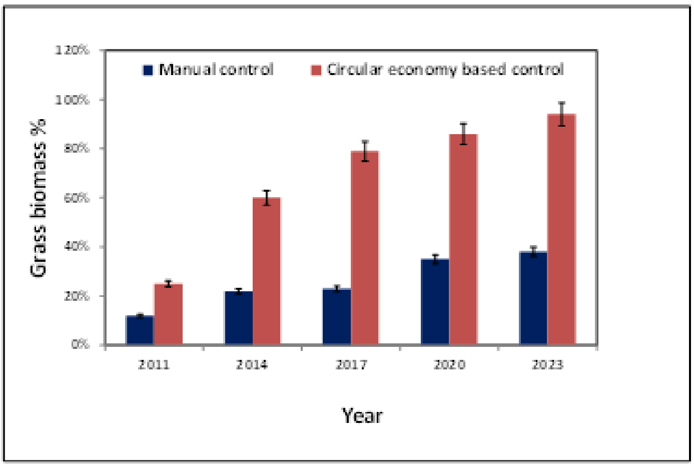

Fig.1. Annual *Parthenium* grass biomass percentage comparison between circular economy based management strategy and manual management strategy.

International, National and Local Scenario

Most national botanical gardens in India, Africa, South Africa, and Ethiopia have been affected by this weed. In Ethiopia, this harmful weed is reported to induce sorghum grain yield losses between 40-97% if it is left uncontrolled throughout the season [5]. In Ginir district of Southeastern Ethiopia, other plant species richness was high in *Parthenium* non-invaded regions than the invaded region [2]. In the present era of climate change 65% of the total area in India is suitable for its potential invasion with three invasion hotspots identified namely Western Himalaya, North-East and parts of Peninsular India [6]. In Nepal, reports have shown disturbance in grassland ecosystem due to change in nutritional properties of soil in the area invaded by *Parthenium* [3]. The obnoxious *Parthenium* weed has shifted its climatic niche in the invaded range of India more due to niche unfilling. Thus, it is evident that there is a need to develop climate change integrated as well as niche-specific invasion management strategies worldwide. Globally, this weed has shown negative impacts on growth of various crucial plants such as *Oryza sativa*, *Triticum aestivum*, *Brassica oleracea*, *Glycine max*, *Sorghum vulgare*, and *Brassica campestris* [7]. Manual uprooting which is a labour intensive and uneconomical method has increased the incidences of dermatitis and few allergic reactions among farmers around the globe [7]. Heavy metal polluted waste effluents have been verified in the regions of Uttarpradesh, Uttarakhand, and West Bengal [7]. In these regions, heavy metal concentration in wastewater is higher than the maximum permissible limits.

Application of *Parthenium*-mediated nanoparticles through circular economy

In the past few years, research in different parts of the world has focused to find economic importance of different invasive weeds especially *Parthenium*. Scientists have found plenty of pharmacological, industrial and medicinal benefits of *Parthenium*. Many nanoparticles have been synthesized using leaf extract or digested slurry of *Parthenium hysterophorus* such as zinc oxide (ZnO) NPs [8], iron NPs [9] to evaluate their therapeutic potentials (e.g., larvicidal, antibacterial, and antifungal activity) as some of them are shown in Table 1. Almost none of these reported NPs synthesized from PH have been used for HM removal from wastewater except PH mediated zinc oxide (ZnO) NPs, which was used for the removal of chromium from tannery industrial wastewater [10] as shown in Table 2. There are no reports of removing toxic HM ions from industrial textile wastewater using neither invasive weed extract nor NPs derived from PH. There is a need to research more about *Parthenium* facilitated competent nanoparticles for toxic heavy metal (e.g., As, Sb, Cd, Cr, U and F) nanobiosorption (NB) from different kinds of wastewater.

Table1. Therapeutic applications of Parthenium-mediated nanoparticles.

PH-mediated NPs	**Therapeutic application**	**Microorganism**	**zone of inhibition (mm)**	**Ref**
Silver NPs	Antibacterial	*E.coli* (ATCC25922)	19.7 mm	[4]

Zinc oxide NPs	Antibacterial	*Enterobacter aerogenes*	36 mm	[8]

Table 2. Potency of *Parthenium*-mediated nanoparticles for heavy metal remediation.

Plant species	NPs synthesized	Concentration of NPs-nanobiosorbent	Targeted heavy metal	Initial concentration of heavy metals	Source type	Contact time, pH	Final oncentration of heavy metal	Removal/adsorption efficiency	Ref
Parthenium hysterophorus	Zinc oxide	50 mg	Cr (VI)	30 mg/L	Industrial tannery waste water	5h, pH 3	-	99%	[10]

Conclusion

Invasive *Parthenium* mitigation and heavy metal removal through circular economy is necessary to increase the crop productivity, to protect useful plants, to reduce severe health issues and most importantly to remove other secondary pollutants for a better greenery ecosystem. These findings highlight the urgent need to initiate stable and efficient *Parthenium* management strategies for food production and natural resources. Therefore, there are plethoras of reasons that indicate the urgent need of effective eradication of pernicious *Parthenium* weed as well as remediation of heavy metals from the polluted water bodies globally.

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Emission Characteristics and QSAR model interpretation of PCDD/Fs in a Large-scale Hazardous Waste Incinerator under Different Operation Conditions

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Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) emissions from hazardous waste incinerators (HWIs) have emerged as a great threat to environmental safety and human health, resulting in urgent effective control of the high emissions. In this study, the emission characteristics of PCDD/Fs from a large-scale HWI in China were studied under different conditions (inhibitor injection; feeding waste component). The operating conditions of the incinerator system will continue to change with the change of the feeding waste (the proportion of Cl% and S% content), the injection of inhibitors, and the parameters of air pollution control devices (APCDs). The emission characteristics of dioxins and the distribution of isomers have been analyzed in large-scale waste incinerators and laboratory conditions, but there is a lack of theoretical calculations that combine the molecular structure characteristics of dioxin isomers. The study not only reveals the effects of hazardous waste composition and APCDs parameters on PCDD/Fs emission characteristics, but also provided theoretical explanation through Quantitative Structure-Activity Relationship (QSAR) model. Results showed that the total concentrations of CBzs and PCDD/Fs in stack gas from the HWI ranged from 2.18 to 22.94 μg/Nm^3 and 0.98 to 18.53 ng/Nm^3, respectively. Increased chlorine content of feeding waste led to increased PCDD/Fs concentrations, especially PCDDs. The inhibition efficiency of $NH_4H_2PO_4$ with thiourea and $Ca(OH)_2$ is 42.2% and 9.4% respectively. 2,3,4,7,8-PeCDF (30.7%-44.2%) was the dominating congener of I-TEQ values under all conditions. Furthermore, the relationship among PCDD/Fs, CBzs, traditional pollutants (carbon dioxide, sulfur dioxide, nitric oxide, hydrogen chloride, and particulate matter), and operational parameters were analyzed under six conditions. Results indicated that PeCBz (r=0.764), HCBz (r=0.814), and quench tower water spray rate (r=-0.796) present strong correlations with I-TEQ values. After QSAR model analysis, the effect of C-H average bond length was weakened and the effect of C-Cl average bond length enhanced with the increase of chlorine content of feeding waste. The bond length increases, the bond energy decreases. The results indicated that reaction proceeds in the direction of the enhanced chlorine substitution reaction. Also, the effect of the highest occupied molecular orbital energy was enhanced, the molecule was more likely to lose electrons, and the molecular stability was reduced. Under the inhibition conditions, the enhancement effect of C-Cl average bond length with the addition of $NH_4H_2PO_4$ with thiourea was better than that of $NH_4H_2PO_4$ with $Ca(OH)_2$, which indicated that $NH_4H_2PO_4$ with thiourea had better inhibition efficiency on 17 toxic PCDD/Fs.

Keywords: Hazardous waste incinerator; Quantitative structure-activity relationship; Polychlorinated dibenzo-p-dioxins and dibenzofurans.

Electrooxidation Treatment and Dewatering of Septic Tank Sludge

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Septic tank systems are the most used form for treating domestic wastewater from isolated residences. Present bacteria in septic tanks partially degrade the domestic effluent and with sedimentation the effluent is separated to three layers, from the top we have scum, clarified effluent and at the bottom we sludge. Septic tank sludge is generally untreated due to the lack of management and treatment methods. This project aims to decontaminate and stabilize septic sludge using electrooxidation for the first part, the second part is dewatering the treated sludge by adding a cationic polymer for flocculation then separating the solid and filtrate using a vacuum pomp. This process of combining electrooxidation and dewatering should allow the elimination of organic and inorganic molecules that generate foul odors while improving the filterability of septic tank sludge. The dehydrated sludge can then be reused as compost or for soil amendment in agricultural areas. The process starts by a physicochemical characterisation of septic sludge sampled at an eco centre in Quebec, CA. Control tests of dewatering the raw sludge by only adding quantities from 1kg/tds (ton dry sludge) to 6kg/tds of cationic polymer (Percol 789). Before electrooxidation the sludge is acidified to pH 4 using sulfuric acid 2N. A parallelepipedal electrochemical reactor (500 mL of useful volume), a graphite cathode (surface of 110 cm²) and two types of anodes were tested, one of boron-doped diamond (BDD, active surface of 65 cm²) and titanium coated with iridium oxide (Ti/IrO_2, active surface of 65 cm²) were used for electrooxidation. Then dewatering, the sludge was flocculated with a cationic polymer Percol 789 (solution preparation 1g/L) at concentrations between 1 and 5 kg/tds then separated using a vacuum filtration unit including a Bruckner, vacuum pomp and a 25µm fiber filter. three parameters were studied, the current was varied between 0.2A and 1A, the time of the electrooxidation between 10min and 40min and polymer quantity between 1 kg/tds and 5kg/tds. The application of acidification and electrooxidation treatment improved the filterability of the septic tank sludge. A dryness of 28% was recorded following the application of electrochemical treatment, compared to a dryness of 8% obtained with untreated sludge, flocculated only (control test). This increase in dryness allows for an 80% reduction in the mass of sludge generated. Additional analyses will have to be carried out to evaluate the sludge stabilization from a microbiological point of view (capacity to eliminate total and fecal coliforms) while maintaining the fertilizing properties of the septic tank sludge. The quantity of foam generated during electrooxidation can't be neglected, hence the use surfactant like TWEEN 80 which was also degraded by electrooxidation and didn't help. Other methods will be tested like recirculation of the effluent during electrooxidation using a pomp.

Keywords: Septic sludge, Electrooxidation, Dewatering.

Toward the Adoption of Circular Economy in Africa: Prospects and Challenges

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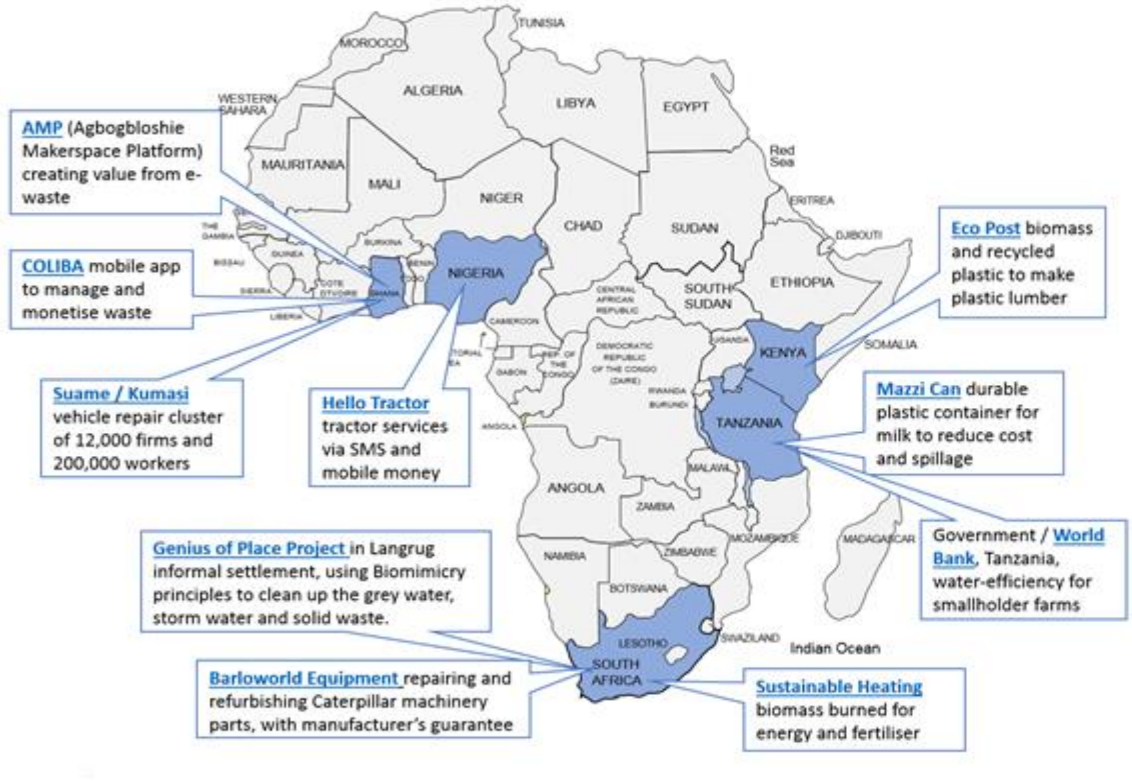
ABSTRACT. Rapid urbanization growth in African cities poses a daunting challenge to municipal solid waste management (MSWM). The linear economy (LE) method of MSW management increases greenhouse gas and climate change. The adoption of circular economy (CE) practices will help preserve natural resources in line with United Nations Sustainability Development Goals (UNSDG). This study seeks to identify the benefits and challenges of adopting CE MSW management in Africa. This paper uses a literature survey to investigate CE awareness and practices in African countries. The collated data was carefully analysed. The result shows that South Africa, Mauritius, Ghana, Nigeria, Rwanda, Côte d'Ivoire, Burkina, etc. have partially adopted CE strategies. Nevertheless, lack of political willingness, financial instability, inadequate infrastructures, etc. is some of the challenges needed to be addressed toward the adoption of CE. Adoption of CE would reduce the green gas emission, create jobs and conserve natural resources.

Keywords: *Africa; Circular economy; Municipal solid waste; Sustainability*

Introduction

The circular economy aims to eradicate waste and natural resource depletion through processes and product redesign [1]. This involves reusing materials in production cycles reducing the need to use natural resources for production [2]. In the CE model of production and consumption, products and resources are shared, leased, reused, repaired, renovated, and recycled as much as feasible [3]. CE is quickly gaining awareness as a new model for sustainable growth in African countries as shown in Figure 1.



AMP (Agbogbloshie Makerspace Platform) creating value from e-waste

COLIBA mobile app to manage and monetise waste

Suame / Kumasi vehicle repair cluster of 12,000 firms and 200,000 workers

Hello Tractor tractor services via SMS and mobile money

Eco Post biomass and recycled plastic to make plastic lumber

Mazzi Can durable plastic container for milk to reduce cost and spillage

Government / World Bank, Tanzania, water-efficiency for smallholder farms

Genius of Place Project in Langrug informal settlement, using Biomimicry principles to clean up the grey water, storm water and solid waste.

Barloworld Equipment repairing and refurbishing Caterpillar machinery parts, with manufacturer's guarantee

Sustainable Heating biomass burned for energy and fertiliser

Fig. 1. Circular Economy practices in African Countries adopted [13]

The CE is a new waste management approach being implemented by developed countries to tackle waste management challenges [4]. Africa is at an advantage to these evolving opportunities of CE because of the huge waste generated and rapid population growth. Current research has shown that developed countries like France, Germany, Sweden, etc. are committed to adopting and implementing the CE model as a result of huge financial and environmental benefits [4]. Although CE is not an entirely new concept in African countries. It has not been fully practised because of numerous challenges including a lack of consumers' protection against dangerous chemical items during material recycled; lack of awareness of waste segregation practices, inadequate waste data collection, lack of training on how proper recycling methodology, poor waste management legislation policy and enforce regulation to guide every sector on waste management, lack of finance, poor infrastructure, and technical know-how [5]. To address the growing African population, which is expected to reach 3.9 billion in 2100 at a growth rate of 2.5%, the CE offers a possible alternative path for industrial development and employment generation.[6]. Natural resources and material consumption would increase as a result of population growth and cause environmental, social, climate, biodiversity loss, waste, and pollution challenges. However, the increased population growth will promote CE sustainability and therefore create green wealth [7]. The mission of the African Circular Economy Alliance (ACEA), which was established in 2016, is to build Africa's CE ecosystem. Some African countries are gradually developing CE initiatives under the ACEA development goal [8]. There is sufficient literature on the CE adoption framework and the role of government in CE policymaking. This paper focuses on the CE awareness campaign, its benefits and the challenges of adopting CE in African countries.

Material and Methods

Research Design

This study purposes to explain the current trend of MSWM in African countries and the benefits of CE. The study chose to conduct a systematic literature review, which involved gathering literature from various research works.

Methods for Gathering Data

Peer-reviewed articles from Scopus, Google Scholar, IEEE Web of Science, and other databases were taken into account in the research study. Keyword criteria, title, and abstract were used in the search.

Data Analysis

The peer-reviewed published articles with a higher number of citations, and the co-occurrence of keywords were among some of the parameters that were analysed.

Results and Discussion

Municipal Solid Waste Management in Africa

According to available data, 125 million tonnes of MSW were produced in Africa annually in 2012, with 81 million tonnes (or 65%) coming from sub-Saharan Africa [9]. This figure is expected to rise to 244 million tonnes by 2025. However, nearly half of the MSW generated in African cities and towns is not properly managed, with many of them being dumped on the streets, open fields, and rivers. The average MSW collection rate in sub-Saharan Africa varies among the cities, ranging from less than 20% to 90%. The average MSW collection rate for the continent is expected to increase to only 69% by 2025 [10]

CE benefits in Africa

CE has economic, environmental, social, and health benefits which were discussed below:

CE Economic Benefits

Operational costs can be reduced by using recycled materials in place of new ones while creating new products. Reusing existing materials also reduces the need for resources that are otherwise scarce and expensive. Prevalent adoption of CE results in increased Gross Domestic Product (GDP). Reported that \$3.2 trillion worth of materials in 2020 year, however only 20 % of those materials were recycled.

Environmental Benefits

Unlike the LE approach, a CE seeks to protect environmental borders by increasing the segment of recyclable resources while reducing the consumption of raw materials and energy, thus reducing the emissions and loss of resources. The adoption of CE produces clean soil, water, and air, and satisfies ecosystems. If products are reused, pollution and contaminated substances will get to the soil, air and water bodies. Therefore, the environment would be safe and free from depletion.

Social benefits

The CE provide innovations when it comes to food production, packing, transportation, and reuse/disposal. a circular food economy emphasis on regenerative farming and organic agricultural method. This will enhance the quality and nutritious foods. Additionally, CE agricultural method would involve a shift toward farming techniques that improve the quality of soil, such as crop rotations and the use of organic fertilizers.

Health benefits

Food is produced generatively in a CE. This benefits the overall health of the home grown ecosystem while also promoting good human health and protecting natural habitats. Eliminating the cruelty of climate change through reduced emissions and waste will result in less severe weather, less illness due to air pollution, and improved access to safe drinking water and nutritious food.

Challenges of CE in Africa

It will be difficult to fully benefit from CE adoption without making a conscious effort to eliminate the obvious challenges that limit the practice of CE in African countries [11]. The following practices need to be implemented to maximise the CE prospect: to balance consumers against toxic chemicals during material recycling; create robust awareness on waste segregation and enforce it; promote adequate waste data collection; regular training on quality recycling practices; energy recovery from waste; and legislate and enforce of regulations to guide every sector on waste management, promote environmental awareness in the rural and urban areas, providing access to financing, Stakeholders should provide needed infrastructure, technical skills and technologies that support CE

Future of CE in Africa

A circular approach to production and consumption not only **r**educes greenhouse gas but also makes the environment, economies and societies more regenerative and resilient for the future. There is sufficient evidence in the literature to show that CE can bring great opportunities and positive impacts to society’s development and job creation. Making better use of natural resources such as metals, minerals, forests, soil, water, and air is central to the CE philosophy. The circular economy, according to research, presents a $4.5 trillion economic opportunity through lowering waste, fostering innovation, and generating jobs. Every year, almost 300 million tons of plastic garbage are produced worldwide. [12]. The transition from LE to CE could create a net increase of 6 million jobs by 2030.

Conclusions

In conclusion, adequate awareness of the six CE principles such as, reduce, recycle, reuse, repair, renewable energy usage, and redesign were examined among the African countries. However, it was observed that recycling and repair received more attention compared to the rest CE principles. Adoption of CE would help to design waste out of the African continent and promote a sustainable continent free of pollution, and environmental degradation to green wealth, reduce greenhouse gas, enhances the overall health of the local ecosystem, and increased GDP and job creation. Policies and enforcement mechanisms on CE adoption across the African continent are recommended.

Acknowledgement

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Assessed online on 08/02/2023

Extraction of Iron from industrial metal waste using bioleaching process

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Metallurgical industries usually generate enormous quantities of hazardous waste. In the process of extraction of iron zinc smelting industries produce a type of waste called as jarosite. Approx 142,000 tonnes or more quantities of jarosite is produced globally including India which is also one of the major jarosite producing country. Jarosite contains substantial amount of heavy and hazardous metals like As, Cd, Zn, Ga, Cu and so on which makes it one of the major environmental pollutants which was identified using XRF analysis. To identify the morphological properties of jarosite techniques such as XRD, FTIR, SEM, and EDS were performed. Due to direct disposal technique such as open tailing dumps it can cause acid mine drainage or can contaminate groundwater due to immobilization of heavy metals when stored for a long run. Conventional methods for treating jarosite can release pollutants like carbon dioxide etc and requires a good capital to operate. An eco-friendly and economical solution to problems is bioleaching of jarosite. With great respiratory flexibility to thrive in both aerobic as well as anaerobic conditions we took Shewanella putrefaciens our study to leach out iron from the jarosite. The extraction of iron was quantified by using ICP-OES which can create more commercial value of the waste and helps in reduction in environmental load.

Keywords: Shewanella putrefaciens, acid leaching, bioleaching, metal recovery.

Hazardous Industrial Waste Co-processing in Cement Plants

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India is the second largest producer of cement with annual capacity of 545 million tonnes. Cement manufacturing is an energy & resource intensive process. It consumes 9.10% of the total industrial energy, making it the third largest consumer of energy. Further each tonne of cement generates approximately 0.7 – 0.93 tonne of CO_2 depending on the kiln technology used. Thus, cement industry worldwide is adapting alternative methodologies for reduction of energy and resources during manufacturing process. Indian cement industries are no exception and are actively looking at innovative methodologies, such as co-processing of waste materials, to make the cement manufacturing a low carbon process. Substitution of the traditional fuels and raw materials (TFRs) with alternative fuel and raw materials (AFRs) i.e hazardous industrial waste, leads to sustainable cement production through resource circulation. The study thus analyzes two experimental trials with different hazardous industrial waste in different part of India and based on the data, the sustainability of the process was gauged. The clinker quality, cement property and leach behavior analysis was evaluated. The study also revealed environmental sustainability as no effect on emission was reported. The study thus showed the sustainability of process and resource circulation potential in Indian cement plants thus enhancing circular economy.

Keywords: Hazardous Industrial Waste, Cement plant, Co-processing, India.

Automation and Coding to Tackle SDG 11 & 12 – A Thai-EU Higher Education Institutions' Project

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ABSTRACT. The contribution to the governments' commitment to Sustainable Development Goals (SDGs) are contemporary challenges for research and business. The EU-funded project on Education & Training for Automation 4.0 in Thailand (ETAT) demonstrates a possible approach to this challenge. ETAT brings together 6 Thai universities from the Eastern Economic Corridor with 6 European universities. Jointly they have developed automation-controlled simulation systems and are working on the respective education and training materials.

The Thai Kasetsart University (KU) as one of the project partners has put its focus on the environmental engineering sector and has developed an automation-controlled solid-waste-conveyor-simulation system as a simulation of the real world. This simulation reflects the needs of Thailand's challenges in the field of waste management and demonstrates how to contribute to the objectives of SDG 11 and 12, while offering a state-of-the-art education programme and lifelong-learning opportunities in the field of automation engineering.

Keywords: Waste segregation, SDG 11 & 12, Automation

Introduction

The terms sustainability and climate change are dominating calls for research funding in the same way as companies' approaches to sell their products and services. The Education and Training for Automation 4.0 in Thailand Project (ETAT) [1, 2] focuses on automation to find an adequate response to the challenges in the field of climate change and sustainability. The ETAT proposal has been awarded for implementation by the Erasmus+ Programme of the European Union. The main purpose of the ETAT-Project is to build capacity of Higher Education in Industry 4.0 and Automation in Thailand to support the newly created Eastern Economic Corridor/EEC (https://www.eeco.or.th/en) in the most sustainable way possible.

The ETAT-Project is guided by the terms of sustainability and climate change. The knowledge transfer comes from the EU partners in the ETAT Project. Within this collaboration, the industrial automation knowledge together with the necessary training equipment was built and transferred to six Thai partners, which are composed of universities and polytechnics (universities of applied sciences). Each Thai partner joined the ETAT project with the specific training and research focus assigned by the EEC framework such as manufacturing, agriculture, infrastructure, environment, etc. Additionally, the Thai partners have used this opportunity to enhance the existing equipment in their laboratories that the individual partners were enabled to work on the specialization assigned to their organisation.

Kasetsart University (KU) - located in North of the EEC area [3] - is one of the Thai partners in the ETAT project. In the enhancement of the basic ETAT equipment issue, KU decided to construct a teaching and training simulation system that contribute to Thailand's commitment to tackle UN Sustainable Development Goals in the field of waste management and creates the bases to raise awareness to the SDG 11 as well as SDG 12 by demonstrating the business opportunities explicitly seen in the objectives indicated for these SDGs. Precisely, KU has established together with the European partners a practice set to develop programming, control and display skills over the internet of things (IoT) with an automation-controlled conveyor simulation system. KU's project outcome comprises learning and teaching tools aligned with the most suitable methodology.

Material and Methods

A brief screening on Thailand's commitment to the SDG 11 and 12 shows that the Thai government follows the United Nations' wording in these SDGs and their subsequent targets. Therefore, the key point in this section refers to KU's waste selection process.

KU's part of ETAT project is focusing to approach recyclable solid waste that comes on one side from the industries and on the other side from households. For this purpose, KU constructed a simulation of a sorting system that is automated controlled via PLCnext equipment, which is a part of the basic equipment in the ETAT project. The KU team added suitable sensors to the system for detecting the different kinds of solid waste that 'ingrade recovered' waste would be put into the correct disposal container. 'Ingrade recovered' waste increases the value of the waste material and provides the recycling industry better quality of material for the sequent process. The used sensors detect steel, aluminum, and plastic. Other techniques to detect the different types of waste have been studied such as the work of Thokrairak, T. et al. which describes the object detection based on pre-trained AI model and is optimized to detect plastic bottles, cans, and glass bottles [4]. Furthermore, KU collects and processes data produced during the sorting process for further analysis in the future. Figure 1 shows the schematic of this automated controlled sorting simulation system.

The PLCnext plays the main role of this sorting system. It can be programmed with standard IEC 61131-3 programming languages such as Ladder diagram or Function Block diagram. After programming, it controls the sorting conveyor. Specific sensors such as the Magnetic Proximity Sensor recognizes metal, or the Color Sensors detects aluminum, and plastic as shown in the current case in Figure 2 (a). Another specific functionality of this PLCnext is to collect and upload the process data during the running process to an on-premise or on-cloud server. This data is available to be analyzed with proper algorithms in order to gain useful insights of the data and to discover so far unseen issues. Furthermore, the data will be processed to visualize facts and figures for the further decision-making process as well as for the company's periodic reporting system.

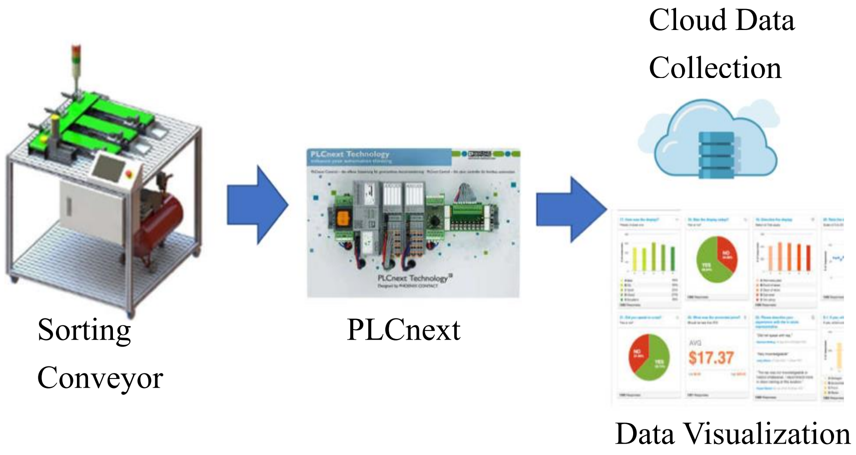

Fig.1. Schematic of the automated controlled sorting simulation system

Results and Discussion

The ETAT project focuses on the teaching and training in the use of automation in view of a better use of material adding to production processes the sustainable use of input factors and to consider the impact of production processes to the climate change. Therefore, several points in the constructed system training material have been developed. Starting with the PLCnext programming, which is a part of the regular learning process for students in the engineering and computer science study programmes. Students have their opportunity to follow the learning-by-doing approach on a simulation of real world equipment in a simulated environment, which reflects factors and conditions from a real company environment. Unexpected errors might occur, so that the students can learn to solve problems by themselves. Figure 2 (b) shows a student demonstrating what he has learned and presents his programmed PLCnext for sorting conveyor simulation system.

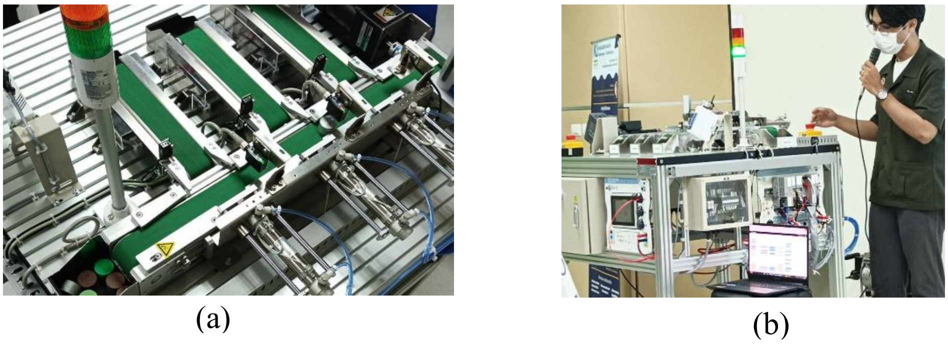
(a) (b)

Fig.2. (a) Conveyor sorting system and (b) Sorting system in action

Furthermore, this system should encourage the workforce in the EEC area for further education as well as life-long learning. In this specific case, the KU uses the contact channel of the EEC Human Development Center (HDC) to connect to the nearby industry in the EEC area and contributes to the capacity building of the automation knowledge and skills in the EEC area. Highly qualified work force is considered as the main incentive to gain investors' interests as laid out in the concept of EEC.

The KU plans – besides the study programmes - to offer several short courses on automation within the industry 4.0 programme for the recycling sector based on PLCnext technology – which has been developed on a modular basis. These short courses will address different target groups – technicians as well as engineers and decision-makers. A distinct collaboration with the TVET sector and the industry is under discussion that this simulation plant can be optimally used and if necessary extended to new challenges. In line with the requirements of the EEC HDC, trainings will be offered within the framework of life-long-learning in form as re-skilling and up-skilling the work force in the EEC area. Certificates will be issued jointly with the EEC HDC.

As mentioned above, the automated controlled sorting conveyor system functions as expected. The PLCnext works in controlling and collecting process data as planned. In the first test-run with the KU students, the system upgraded students' knowledge and skills in programming as well as raised students' awareness about the importance of sorting the solid waste in the right way. Furthermore, this system has been demonstrated to our National Resonance Group (NRG) composed of company representatives from different sectors interested to collaborate with KU. The feedback of the NRG is encouraging. However, the PLCnext technology is a new technology and needs to be promoted among decision makers.

In a next step, it is planned to search for research collaboration at an interdisciplinary level. Foremost, it is in the interest of the project team to raise awareness about the value of recyclable waste as raw material. This will bring new challenges to the project team. It is expected that more precise segregation of 'ingrade recovered' waste will be demanded by the recycle industry that more refined material can be processed. This brings a very dynamic and multidisciplinary research focus to the researchers in this team. A variety of topics from different disciplines will invite students from the different faculties to elaborate their bachelor and master thesis.

In response of the multidisciplinary challenges coming along with the SDG 11 and 12, the project team is interested to invite researchers and students from faculties of economics, sociology and environmental studies to bring their focus into this project that there is the most appropriate coverage of the topics/targets/indicators linked with SDG 11 and 12.

Among other objectives assigned by the United Nations the following are related directly to KU's simulation plant and the subsequent training

- SDG 11 is an order to all decision makers in politics and industry and is defined as ‚reduce the adverse per capita environmental impact of cities, including by paying special attention to municipal and other waste management. The Target 11.6.1 is the proportion of urban solid waste regularly collected and with adequate final discharge out of total urban solid waste generated, by cities [5].
- SDG 12 is a clear order for the decision makers respectively to the engineers. The Target 12.5 states: "By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse". The successful achievement of this target is measures by the indicators: national recycling rate, tons of material recycled [6].

Conclusion

In this work, the authors demonstrated that the knowledge transfer of the European partners to the Thai partners in the ETAT project affects the way that the technical solution on automation has a wider impact on the SDGs 11 and 12, while the ETAT is focusing on the capacity building in automation. The management of solid waste respectively 'ingrade recovery' of waste is an essential contribution to the overall sustainability and climate change: the better the waste is sorted, the better waste as raw material can be used, without challenging scarce natural resources or environmentally heavy impacted processes to gain raw material.

The technology such as automation (PLCnext in this case) is the bases to construct an effective business-like-training simulation system in a regular learning system for the students at the Kasetsart University as well as life-long learning opportunities for the workforce from the industry within the EEC area. It also provides the bases for further research topics in the field of sorting of valuable material within waste.

Multidisciplinary research approaches are planned in order to communicate in a better way how this simulation system contributes to the objectives/targets/indicators of SDG 11 and 12.

In general, the collaboration between EU and Thai partners closes the technology gap and ensures that the knowledge transfer will occur fluently. However, the knowledge transfer and the outreach to the decision-makers, companies, and stakeholders in the EEC area is the task of the KU together with the Thai ETAT team.

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Impact of Pre-To-Post COVID-19 Lockdowns on Air Quality Index (AQI): A Tale of Three Cities With Different Lockdown Policies and Strategies

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In recent decades, there has been increased concern and apprehension with the disclosure of air pollution problems. Especially for susceptible people, their respiratory and cardiovascular systems are more likely to be affected by airborne pollutants. The coronavirus disease (COVID-19) quietly appeared at the end of 2019 and brought the world unprepared suffering and havoc. As of today, the gloom of COVID-19 still hangs over us, the sudden stagnation of human activities gives us an opportunity to explore the complicated and intimate relationship between air pollution, meteorological climate, and human activities. In this work, a multi-scale comparison of air quality concentrations of PM2.5, PM10, CO, SO_2, NO_2, and O_3 in Wuhan before and after the "lockdown" is presented. Due to the different attitudes of each country towards the outbreak, this work also compare the trends of air quality indexes (AQI) in Wuhan, Los Angeles, and Hong Kong under the influence of different lockdown durations, quarantine policies, and social regulations. The results analyzed from the open-source data show that levels of NO_2, PM10, PM2.5, CO, and SO_2 generally decreased from previous year during the same time period. Climate and air humidity also play a role in the concentration of pollutants in the environment. The implication of this work is that both the epidemic and the irreversible climate effects threaten human survival and health. The Covid-19 epidemic is a signal to the world that human activities have an impact on nature and that most of the global air pollution problem can be solved by changing human activities. It should be advocated that everyone should act to move toward a future of better air quality.

Keywords: COVID-19, Lockdown, AQI, Health Impact, Government policies.

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Landfill and Leachate Management

A Novel Sustainable Landfill Cover System Using Recycled Construction Waste Aggregates

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Due to the increasing population and urbanization, the production and management of municipal solid waste (MSW), including construction waste, have become a worldwide concern. The efficient use of recycled construction waste materials can reduce waste generation and preserve natural resources. However, no available study investigates the use of recycled concrete aggregates (RCA) as a landfill cover subjected to high rainfall intensity under humid climates. Based on advanced unsaturated soil mechanics, a new three-layer landfill cover system without a geomembrane is proposed to promote environmental protection and sustainability under all weather conditions. In this study, one-dimensional (1D) soil column, two-dimensional (2D) flume model and full-scale field tests were carried out to evaluate the hydrological performance of the novel landfill cover system using RCA under humid climates. This three-layer system consists of a top layer of fine-grained and a middle layer of coarse-grained recycled aggregates (i.e., FRC and CRC, respectively) overlying the bottom silty refuse soil. In addition, numerical simulations were conducted to back analyse the physical tests. Consistent results were obtained between the measured data and computed results. Even after the extreme rainfall with more than 100-year return period in Hong Kong, relatively high matric suction was well-retained in the new cover system. The 2D flume model test and numerical simulations revealed that the middle CRC layer could switch from a capillary barrier layer to a drainage layer to reduce infiltration into the bottom layer even under heavy rainfall. Most infiltrated rainfall water (i.e., more than 95% of total precipitation) can be diverted as surface runoff and lateral drainage through the two upper RCA layers. The rest of infiltrated water is stored in the cover system. During the field monitoring conducted in Shenzhen Xiaping landfill, the measured annual percolation through the cover system meets the recommended criterion by USEPA. The physical tests and numerical simulations consistently verified the effectiveness of the proposed sustainable three-layer landfill cover system using RCA without a geomembrane under humid climate.

Keywords: Unsaturated soil, Recycled construction waste, No geomembrane, Landfill cover, Field monitoring.

Assessing the Effectiveness of Iron Oxide Activated Carbon Nanocomposite and Iron Oxide Nanoparticles in landfill leachate treatment

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This study assessed the effectiveness of Iron Oxide Activated Carbon (IOAC) Nanocomposite and Iron Oxide Nanoparticles (IONPs) in landfill leachate treatment. Batch study experiments were carried out to investigate the effect of adsorbent dosage, contact time, and temperature on the removal efficiency of COD, DOC, colour, and UV_{254}. Results show that the optimum dosage was 17.5 g/L which resulted in a maximum removal of COD of 78.3% and 55.7% using IOAC and IONP, respectively. In addition, the effectiveness of IOAC and IONP to remove DOC was higher than COD with a maximum removal efficiency of 81% and 45%, respectively. However, the removal efficiency of colour was less using IONP (36.3%) but still high using IOAC (83.8%). Also, the removal efficiency of UV_{254} showed a relatively good performance using IOAC and IONP with a maximum removal efficiency of 87.5% and 46.8%, respectively. The contact time was found to be influential factor where the increase of contact time resulted in the increase of removal efficiency for all parameters. The optimum contact time was chosen to be 60 min where after this time, no significant removal was observed. For temperature effect on removal efficiency, no significant change in removal efficiency was observed with varying temperature. The regenerated IOAC showed excellent reusability and consistency as compared to the original IOAC with a decrease of 2.72–3.61% in the adsorption efficiency. Overall, this study confirmed that the IOAC and IONP could be used as powerful adsorbents for landfill leachate treatment.

Keywords: Iron oxide carbon nanocomposite, Iron oxide nanoparticle, Landfill leachate, COD, Colour removal.

Laboratory-Scale And Pilot-Scale Study On Chemical Co-Precipitation Treatment Of Old-Age Landfill Leachate

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ABSTRACT. Old-age landfill leachate typically contains high concentrations of refractory organics (e.g., humic acid and fulvic acid), which contribute to high color intensity, chemical oxygen demand (COD) and specific ultraviolet absorbance (SUVA). In this study, a 100 m^3/d pilot-scale post-chemical treatment system, which equipped with a dissolved-air floatation (DAF) unit, was set up in the North-East New Territories Landfill in Hong Kong. An on-site pilot trial was conducted in wet and dry season to evaluate the concentration variation of pre-treated leachate and its effect on the chemical co-precipitation process. More than 90% of color intensity and 70% of COD in pre-treated landfill leachate were removed after the post-chemical co-precipitation treatment with DAF unit, while the SUVA of leachate was significantly decreased from 18.5 to 5.2 cm^{-1}. The post-chemical co-precipitation system could be introduced as a final polishing step to the existing landfill leachate treatment plant. It could greatly reduce the organic loading and improve the UV disinfection efficiency in the downstream sewage treatment works.

Keywords: *Landfill leachate; Chemical co-precipitation; refractory organics*

Introduction

Landfill leachate is the liquid generated from rainwater and degradation of waste material. Landfill leachate consists of inorganic component, heavy metals, dissolved organic matter and anthropogenic organic compound. Leachate composition depends primarily on the landfill age, waste type and composition, and season. There are four phases of leachate transition: (0-5 years), acid-formation (5-10 years), methane fermentation (15-20 years) and final maturation (>20 years) [1]. Leachate from young landfills normally has high COD, NH_3-N and biodegradability (BOD/COD = 0.4-0.7), while old-age leachate contains a high level of refractory organics (BOD/COD < 0.1) [2]. These refractory organics mainly consist of humic acid and fulvic acid, which contribute to the dark brown color and COD of old-age leachate [3]. They are classified as recalcitrant and fail to be removed by biological treatment process. Various types of physiochemical treatment methods are commonly used in leachate treatment, such as coagulation/ flocculation [4,5], adsorption [6], chemical oxidation [7] and electrochemical oxidation [8]. The optimum coagulation pH is normally found in acidic environment using single coagulant, so a neutralization step is required after chemical coagulation. From our previous laboratory study [9], a composite chemical precipitating agent was developed that could effectively remove the color intensity and COD in old-age landfill leachate by co-precipitation at a neutral pH (6.5). In this study, the single-step post-chemical treatment process was further examined in a pilot-scale system. Laboratory studies were conducted to simulate the UV disinfection process in downstream sewage treatment works in the presence of landfill leachate.

Material and Methods

Characterization of landfill leachate

Pre-treated landfill leachate was collected from the effluent of landfill leachate treatment plant in North-East New Territories (NENT) landfill. NENT landfill is in Ta Kwu Ling, Hong Kong, and receives municipal construction and special waste. It commenced operations in 1995 and could be categorised as old-age landfill leachate. Color intensity and COD of samples were measured using a Hach DR3900 Vis spectrophotometer.

Pilot-scale landfill leachate post-chemical treatment plant

A pilot-scale post-chemical treatment plant with a 100 m^3/d treatment capacity was set up at NENT landfill (Fig. 1). The pre-treated leachate was pumped from the discharge lagoon in the leachate treatment plant to the pilot plant for post-chemical treatment. The pilot plant consists of a reception tank, chemical reaction tank, chemical dosing unit, lamella clarifier, dissolved-air flotation unit, sludge tank, and effluent tank.

Two types of solid/liquid separation methods, lamella clarifier and dissolved-air flotation unit, could be operated separately to compare the performance between sedimentation and floatation. The pilot plant was operated during the wet season (July - Aug 2021) and dry season (Nov - Dec 2021) to evaluate the seasonal change of leachate. The color intensity and COD of pre-treated and chemical-treated leachate were analysed daily.

Laboratory study on UV disinfection

To evaluate the effect of post-chemical treatment on the UV-disinfection efficiency in downstream sewage treatment works, a series of laboratory studies was conducted to simulate the effect of landfill leachate on the UV disinfection process. The experimental setup of UV-disinfection is displayed in Figure 2. The pre-treated landfill leachate and the post-chemical treatment effluent were diluted with sewage sample at a predefined volume ratio (30x dilution), based on the historical flow record of domestic sewage and landfill leachate. Domestic sewage sample was collected from Sha Tin Sewage Treatment Works (STSTW), which does not contain landfill leachate. The diluted sewage sample was pumped through a UV chamber (UV dose = 1.3 mJ/cm^2) for the disinfection process. The *E.coli* levels of the sewage samples before and after the UV-disinfection process were analyzed to estimate the UV disinfection performance. Specific UV absorbance (SUVA) of samples was measured using a Hach DR6000 UV-vis spectrophotometer.

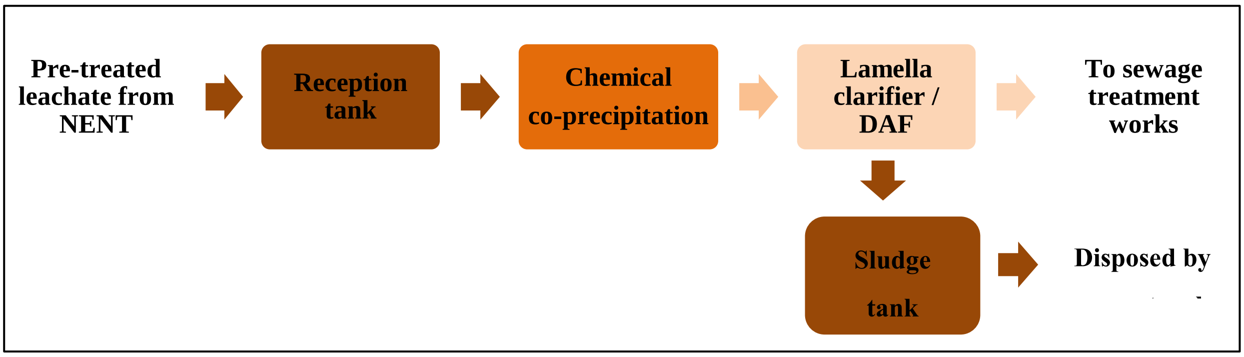

Fig.1. Flow schematic diagram of the pilot-scale post-chemical treatment plant.

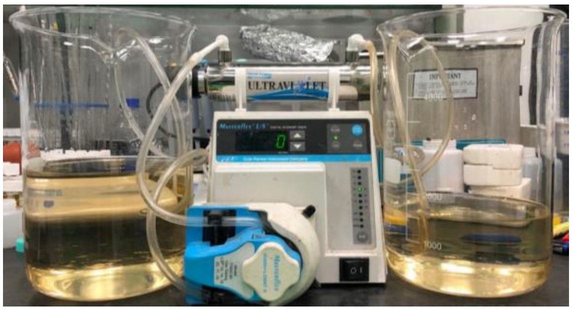

Fig. 2 Experimental setup of UV disinfection.

$$\% \, inactivation = \frac{E.Coli \; after \; UV \; treatment}{E.Coli \; before \; UV \; treatment} \times 100\%$$

$$Log \; E.Coli \; kill = Log_{10} \frac{E.Coli \; before \; UV \; treatment}{E.Coli \; after \; UV \; treatment}$$

Results and Discussion

Characterization of landfill leachate

Table 1 summarizes the wastewater characteristics of pre-treated landfill leachate collected from NENT landfill during the wet and dry seasons. The pre-treated leachate exhibited low BOD (<20 mg/L) and NH_3-N (<5 mg/L), but high color intensity and COD. Existing landfill leachate treatment plant in NENT landfill consisted of an ammonia stripping process and sequential batch reactor. The ammonia nitrogen (NH_3-N) and biodegradable organic matter (BOD) were effectively removed by existing landfill leachate treatment plant. However, the old-age landfill leachate contains high level of refractory organics, which were resistant to biological degradation [10]. That explained the low BOD/COD ratio of pre-treated leachate. In addition, refractory organics contributed to yellowish-brown color of old-age landfill leachate. The existing treatment process is designed for treating the young age landfill leachate with high ammonia nitrogen and biodegradable organic matters. Biodegradability of landfill leachate would continue decreasing as the landfill has been operated for nearly 20 years. Those kinds of refractory organics failed to be removed by existing biological treatment. The pre-treated landfill leachate with high color intensity would affect the UV disinfection process in downstream sewage treatment works. Therefore, a post-chemical treatment was crucial for refractory organic removal.

Table 1. Characteristic of pre-treated landfill leachate.

Parameters	Wet season	Dry season
Color (Pt-Co)	2500	5500
COD (mg/L)	1100	1800
BOD_5 (mg/L)	10	20
BOD/COD	0.009	0.011
NH_3-N (mg/L)	< 5	< 5

Pilot-scale landfill leachate post-chemical treatment plant

As shown in Table 2, the DAF unit shows stable color and COD removal compared to the lamella clarifier. The pilot results show that the DAF unit could achieve stable color removal at around 93%, while the color removal efficiency of the lamella clarifier drastically fluctuated from 71% to 96%. Similarly, the DAF unit provided more stable COD removal performance with an average value of 73% removal, but COD removal by sedimentation varied from 36% to 76%. The testing results demonstrated the seasonal changes in leachate concentration and stable removal of color intensity and COD. The color intensity of the pre-treated landfill leachate was 2500 and 5500 PtCo in the wet and dry seasons, respectively. The DAF unit achieved reliable color removal at an average of 92% and 84% during the wet and dry seasons, respectively. Although the COD value of pre-treated leachate varied from 1100 to 1800 mg/L between the wet and dry seasons, the DAF unit also provided stable COD removal (73% removal in the wet season; 62% removal in the dry season). These results affirmed that the DAF unit is a reliable solid/liquid separation technique at different influent concentrations.

Table 2. Removal efficiency of color intensity and COD from the pre-treated leachate in a pilot-scale post-chemical treatment plant.

Parameters		Wet season		Dry season
		Lamella clarifier	DAF unit	DAF unit
% Color removal	Max.	96%	93%	91%
	Min.	71%	90%	72%
	Ave. (SD)	82% (±9%)	92% (±1%)	84% (±5%)
% COD removal	Max.	76%	68%	72%
	Min.	36%	80%	54%
	Ave. (SD)	56% (±11%)	73% (±4%)	62% (±5%)

Laboratory study on UV disinfection

Table 3 summarizes the specific UV absorbance (SUVA) of domestic sewage and landfill leachate samples in the dry season. The results clearly show that SUVA of pre-treated landfill leachate was significantly reduced from 18.5 to 5.2 cm^{-1} after post-chemical treatment. Therefore, post-chemical treatment would be a promising process for improving the SUVA of sewage in downstream sewage treatment works.

Table 3. Specific UV absorbance (SUVA) of wastewater samples in the dry season.

Samples	SUVA (cm^{-1})
Domestic sewage	0.1
Pre-treated leachate	18.5
Chemical-treated leachate	5.2

A laboratory-scale UV disinfection study was carried out to estimate the improvement in UV disinfection efficiency in downstream sewage treatment works. The pre-treated landfill leachate and chemical-treated leachate were diluted with the sewage sample based on the flow data of domestic sewage and landfill leachate in downstream sewage treatment works. The *E.coli* levels of the sewage samples before and after UV-disinfection process were analyzed. The results of the UV disinfection study are summarized in Table 4. The results indicated that the % E. Coli inactivation by UV disinfection could be enhanced from 74% to 99% if all the landfill leachate from NENT was treated by post-chemical treatment. In addition, the log *E. Coli* kill is another parameter to express disinfection efficiency. Typically, 2 - 2.5 log kill should be achieved in a UV disinfection system. For the sewage sample with chemical-treated leachate, 2.18 log kill was yielded. The results imply that a full-scale post-chemical treatment plant in NENT could minimize the negative effect of landfill leachate on the UV disinfection process in SWHSTW.

Table 4 Results of UV disinfection laboratory study

Parameters	**Pre-treated leachate**		**Chemical-treated leachate**	
	Before UV	**After UV**	**Before UV**	**After UV**
E. Coli (cfu/100 ml)	92,000	24,000	93,000	620
% inactivation	73.9%		99.3%	
Log E. Coli kill	0.58		2.18	

Conclusions

This pilot-scale study confirmed that the mentioned post-chemical co-precipitation process could effectively remove colored refractory organics in old-age landfill leachate. The DAF unit is a reliable solid/liquid separation technique. A post-chemical treatment system with a co-precipitation process and a DAF unit could be introduced as a final polishing step to the existing landfill leachate treatment plant. It could greatly reduce the organic loading and improve the UV disinfection efficiency in the downstream sewage treatment works.

Acknowledgement

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Landfill Leachate Treatment Using A Combination of Biological and Electrochemical Methods

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Landfilling is the most familiar and easy way to dispose solid waste. Landfill is generally received via wastes from municipal near to a landfill. The waste collected is from commercial, industrial, and residential areas and many more. Landfill leachate (LFL) is formed when rainwater passes through the waste placed in landfills and consists of several dissolved organic materials, for instance aquatic humic substances (AHS), volatile fatty acids (VFAs), heavy metals, inorganic macro components, and xenobiotic organic matters, highly toxic to the environment. These components of LFL put a load on it, hence it necessitates the treatment of LFL prior to its discharge into the environment.

Various methods have been used to treat LFL over the years, such as physical, chemical, biological, physicochemical, electrical, and advanced oxidation methods. This study focuses on the combination of biological and electrochemical methods- extracellular polymeric substances and electrocoagulation(EC).

The coupling of electro-coagulation process with extracellular polymeric substances (EPS) (as flocculant) as pre and\or post treatment strategy provides efficient and economical process for the decontamination of landfill leachate contaminated with suspended matter, metals (e.g., Fe, Mn) and ammonical nitrogen. Electro-coagulation and EPS mediated coagulation approach could be an economically viable for the treatment of landfill leachate along with possessing several other advantages over several other methods. This study utilised waste substrates such as activated sludge, crude glycerol and waste cooking oil for the production of EPS using fermentation technology.

A comparison of different scenarios for the treatment of landfill leachate is presented- such as using EPS alone as bioflocculant, EPS and EC with EPS being the 1st stage and EPS and EC with EC being the 1st stage. The work establishes the use of crude EPS as a bioflocculant for the treatment of landfill leachate and wastewater from a site near a landfill along with EC being successful in removal of some major pollutants such as COD, turbidity, total suspended solids. A combination of these two methods is to be explored more for the complete removal of all pollutants from landfill leachate.

Keywords: Landfill leachate, extracellular polymeric substances, electrocoagulation, bioflocculant.

Tertiary Treatment of A Mixture of Composting and Landfill Leachates Using Electrochemical Processes

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The study investigated the treatment efficiency of coupled electrocoagulation (EC) and electrooxidation (EO) processes for composting and landfill leachate treatment in batch and continuous mode. These processes have been studied to evaluate the possibility of replacing the conventional physico-chemical processes of clarification and disinfection by the electrolytic approach. The EC process (using iron anode and graphite cathode) at a current density of 18.2 mA/cm2 for 2.5 min treatment time resulted in COD, turbidity, total phosphorus, total coliforms and fecal coliforms removal of 58.1, 72.9, 98.5, 97.9, and 97.2% respectively. Under the same operating conditions, the coupled EC/EO (using Ti-Pt anode, bipolar iron electrode, and graphite cathode) processes showed that the COD, turbidity, total phosphorus, total coliforms, and fecal coliforms removal of 56.5%, 78.3%, 96.3%, 97.2% and fecal coliforms 72.7%, respectively. The energy costs associated with the EC and EC/EO were 0.11 and 0.25 $/m^3$, respectively. Compared to the batch configuration, the continuous configuration of EC resulted in similar processing performance. However, the EC/EO process resulted in the production of chlorates, perchlorates, and trihalomethanes as by-products. Moreover, the continuous process slightly increases the pH and ammonia concentration of the leachate and also resulted in the metallic sludge production with an average dryness of 4.2%. The simultaneous clarification and disinfection by the electrochemical approach could be achieved in a single treatment step. The toxicity tests determined that the treated effluent was not toxic to *Rainbow trout* and *Daphnia* and meet the discharge criteria.

Keywords: Leachate treatment, Electrocoagulation treatment, Electrooxidation treatment.

Assessment of Total Content and Leaching Potential of Heavy Metals from Landfill-mined Fine Fractions Under Various Reuse Scenarios

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ABSTRACT. The study investigates the reuse potential of fine fraction (FF) obtained from landfill mining (LFM) at Boragaon dumpsite in Assam, India. The FF, finer than 4.75 mm, are assessed for their total heavy metals (HMs) content and leaching potential. The high concentrations of Cu and Cr limit the reuse potential of FF as agricultural compost. Several batch leaching tests were conducted to simulate different leaching scenarios, including EN 12457-2, toxicity characteristic leaching procedure (TCLP), and synthetic precipitation leaching procedure (SPLP). The EN 12457-2 leaching test results show that FFs are non-hazardous but not inert due to elevated Cr leaching. The TCLP test also confirms the non-hazardous nature of FFs, while the SPLP reveals excessive leaching of Cr above drinking water standards. Unrestricted reuse of FFs as earth-fill material could contaminate soil and water bodies. Leaching assessment and treatment measures are necessary before bulk reuse of FF for earth-fill and agricultural compost applications.

Keywords: Fine fraction; reuse; leaching; heavy metals

Introduction

The concept of LFM is referred to as the reclamation of decades-old dumps or landfill sites in an environmentally sound manner to expand its capacity and recovery of material and energy from previously deposited waste by burying them in the ground [1]. Previous investigations on LFM have revealed that landfill-mined material primarily comprises a mixture of combustible materials, non-combustible materials, and FF or soil-like-material [2,3]. Among all other components, FF is the predominant product of LFM, accounting for about 40–80 wt.% of the total mass of landfill-mined material [4]. Therefore, the reuse of FF serves as one of the decisive factors for the economic viability of LFM and aids in the circular economy [5]. There have been several feasibility studies on reusing FF as earth-fill material and compost [6]. However, the presence of excessive amounts of HMs is the primary concern that restrains the potential reuse of FF as earth-fill material and compost. Hence, bulk reuse of FF as earth-fill material and compost requires in-depth knowledge of their contaminant patterns and the leaching potential of HMs in different reuse scenarios [7,8].

The present study aims to investigate the reuse potential of FF (finer than 4.75 mm) retrieved from the LFM activity at Boragaon dumpsite located in the Assam state of India by assessing their total and leachable HMs content. The reuse feasibility of FFs as earth-fill material was assessed through three different laboratory batch leaching procedures, i.e., EN 12457-2, TCLP, and SPLP, to simulate different natural leaching scenarios [9,10,11]. On the other hand, the reuse potential of FFs as compost was evaluated on the basis of total HMs concentration. All of the obtained results were compared with the regulatory threshold limits (RTLs) of national and international regulatory authorities to classify the FF according to their environmental impacts.

Material and Methods

To determine the total environmentally available HMs content in the solid matrix of FF, a representative sample of FF was subjected to the US EPA 3050B acid digestion procedure [12]. As per the method, one gram of fine powder sample of FF was taken in a teflon beaker and digested on a hot plate with repeated additions of concentrated nitric acid (HNO_3) and 30% hydrogen peroxide (H_2O_2). Three standard batch leaching tests evaluated the leachability of HMs from FF under different reuse scenarios. The European Standard EN 12457-2 is a compliance test that provides information on the leaching of granular waste materials and sludges in normal water under experimental conditions to classify waste materials according to European criteria as well as to evaluate their valorization feasibility [9,13]. The US Environmental Protection Agency (USEPA) method 1311, designated as TCLP, is designed to simulate the leaching behavior of waste material for the worst-case scenario of co-disposal in municipal landfill condition, where water can move through the landfilled waste and into the groundwater, carrying the soluble materials along with it [10]. This test has been used as an environmental assessment tool for hazardous waste classification. The SPLP is a standard batch leaching test developed by USEPA (Method 1312) to simulate the leaching behavior of waste materials under acid rain conditions [11]. This method is often used in the laboratory to analogize the potential leaching of the waste materials in the natural environment, such as during land application. Following acid digestion and leaching experiments, the concentrations of metals and metalloids in the preserved samples were determined by atomic absorption spectroscopy.

Results and Discussion

The results of the total environmentally available HMs content in FF are compared with the RTLs of Indian standard for municipal solid waste (MSW) compost and presented in Figure 1 [14]. It can be inferred that the concentration of Cu and Cr exceeds the permissible limit for compost. This suggests that the FF does not adhere to the established restrictions for using as agricultural compost. If the FF is to be used as compost, the HMs level must be lowered.

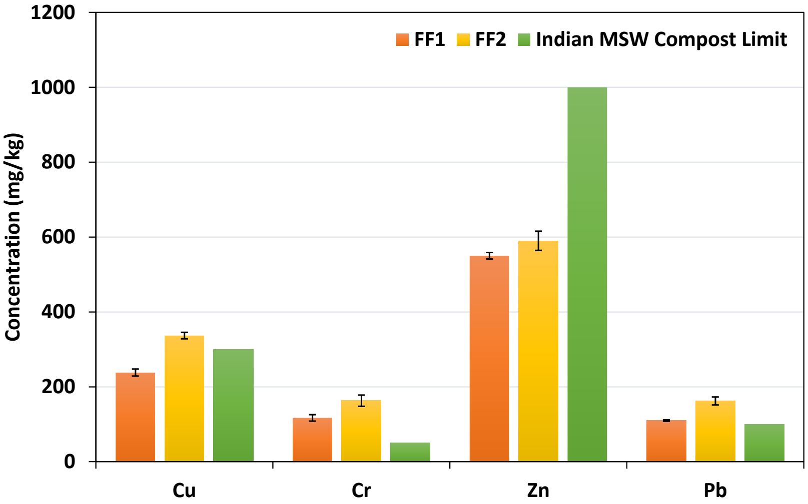

Fig.1. Total HMs concentration in FF compared with the Indian MSW compost limits.

The results of leachable HMs from EN 12457–2 batch leaching test are shown in Table 1 and compared with the RTLs of the European Union (EU) council decision (2003/33/EC) [13]. According to the EU regulations, the analysis of leachate composition is essential to estimate the acceptability as well as recycling possibilities of waste materials like the FF. Table 1 shows that all FF samples fell under the non-hazardous category as Cr content exceeded the inert limit value. This implies that the unrestricted reuse of FF may increase the Cr levels in the soil and groundwater beneath a thick earth-fill of FF if precipitation percolates through the body of the fill.

Table 1. EN12457-2 leaching test results (Mean ± SD; *n* = 3) for the FF in comparison with the RTLs.

Sample	Cu (µg/L)	Cr (µg/L)	Zn (µg/L)	Pb (µg/L)
FF1	138 ± 1.6	179 ± 7.1	311 ± 2.6	BDL
FF2	144 ± 6.4	242 ± 2.8	392 ± 6.2	BDL
EU Council Decision				
Inert	200	50	400	50
Non-hazardous	5000	1000	5000	1000
Hazardous	10000	7000	20000	5000

BDL - Below Detection Limit

The most essential consideration in the reuse of FF is whether the material is hazardous or not. The TCLP test is widely used to determine the possibility of releasing HMs from wastes and residues under simulated landfill conditions. As per the USEPA regulatory limits for Cr, and Pb, it can be observed from the Table 2, that the concentration of these HMs in the TCLP test is within the regulatory level as per stipulated standards. Other metals, such as Cu and Zn, were found to leach considerably during the TCLP test. However, there were no threshold limits established for these HMs as per USEPA. Hence, the FF can be classified as non-hazardous and thus does not need to be confined in hazardous waste landfills. However, as these FF samples are not inert, it is important to determine if the reuse of these non-hazardous wastes negatively influences the subsurface environment (soil and groundwater).

Table 2. TCLP test results (Mean ± SD; *n* = 3) for the FF in comparison with the RTLs.

Sample	Cu (µg/L)	Cr (µg/L)	Zn (µg/L)	Pb (µg/L)
FF1	153 ± 2.1	569 ± 17	570 ± 21.2	15.23 ± 0.4
FF2	168 ± 8.3	638 ± 18.5	1575 ± 24	22.07± 0.2
TCLP Limit	NSE	5000	NSE	5000

NSE - No Standard Established

The SPLP test results on the FF are presented in Table 3 and indicate that the Cr is the constituent of potential concern with respect to leachability as per the drinking water standards (DWS) [15]. The concentrations of Cr, which was the critical element of concern during the EN12457-2 batch leaching test, were also found to be several orders of magnitude higher than the DWS. Therefore, it is clear that uncontrolled disposal of FF in natural environments, as simulated by SPLP, is detrimental to the environment and can pose risk to ground and surface waters.

Table 3. SPLP test results (Mean ± SD; *n* = 3) for the FF in comparison with the RTLs.

Sample	Cu (µg/L)	Cr (µg/L)	Zn (µg/L)	Pb (µg/L)
FF1	142 ± 5.4	509 ± 11.3	356 ± 16.2	5.13 ± 0.2
FF2	160 ± 2.2	684 ± 8.5	427 ± 6.8	7.81 ± 0.3
IS 10500: 2012 Limit	1500	50	15000	10

Conclusions

In the present study, total and leachable HMs content in landfill-mined FF was assessed. The results were compared with the RTLs developed by various national and international regulatory agencies. The total concentration of Cu and Cr affects the reuse of FF as a compost material for agricultural applications. According to EN12457-2 and TCLP batch leaching test, FF samples were classified as non-hazardous. SPLP test show that the leaching of Cr from FF is above the RTLs of the DWS. Therefore, unrestricted reuse of FF does not appear to be feasible due to the possible contamination of subsoil and groundwater.

Acknowledgement

The assistance extended by Guwahati Municipal Corporation (GMC) officials and North East Enviro Tech Pvt Ltd (NEET) during the site visit and sample collection is gratefully acknowledged. We also thank the Department of Civil Engineering, IIT Guwahati, for providing the required facilities for analytical procedures.

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Improvement of Upstream SWM Supporting the Start Up Operation of Four New Sanitary Landfills in Indonesia

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ABSTRACT. This paper aims to demonstrate the necessary improvements in waste management facilities upstream of a new Sanitary Landfill in Malang City. The methodology consists of a waste balance and management model as well as comparison of four different 10-year development scenarios with the objective of increasing lifetime of this landfill. The study shows that National and Local Government targets on waste reduction and waste handling can be met with (1) strong emphasis on processing organic waste at household and neighbourhood levels and (2) revitalization and optimization of existing and additional upstream Material Recovery Facilities. The study concludes that the scenario preferred by the City's Waste Department leads to an increase in the landfill lifetime up to 18 years compared to the business-as-usual scenario of 15 years. The study recommends that the main upstream facilities be integrated into the waste management system under the responsibility of the municipal waste department.

Keywords: *MRF, upstream SWM facility improvement, new SLF operation, Malang City, Indonesia.*

INTRODUCTION. From 2017-2022, an Accompanying Measures Consultancy (AMC) took place in parallel to the planning and construction of four new Sanitary Landfills (SLF) in Indonesia under the "Emission Reduction in Cities (ERiC) Program. This was implemented through the Indonesian Ministry of Public Works and Housing (MoPWH), funded by the German Kreditanstalt für Wiederaufbau (KfW), and the AMC financed by the Swiss State Secretariat for Economic Affairs (SECO). Several technical studies on upstream SWM were conducted during that time in the municipalities Malang and Jambi as well as in the Sidoarjo and Jombang regencies. The AMC experiences gained in Malang City are presented as a case study. The objective of this paper is to show case the necessary improvements in waste facilities upstream of the new SLF in Malang City (110 km²), which entered in operation in 2021 serving 845.000 inhabitants.

MATERIAL. The Presidential decree No. 97 of 2017 concerning National Policies and Strategies for the Management of Household Waste urges Local Governments to achieve in 2025 a performance of handling 70% of their waste generated and up to 30% of waste diversion prior to landfilling. According to Indonesian National Standard (SNI) 8632:2018, the existing waste generation in Malang is 667 tons/day in 2021. There is a split of responsibilities for waste management. During primary collection, e.g. by Citizens Associations, informal waste pickers and community-based activities in the different upstream facilities 19 % of the collected waste is diverted from landfilling, while during secondary collection and treatment under the responsibility of the City's Waste Department (DLH), only 2 % of waste diversion is achieved prior to landfilling.

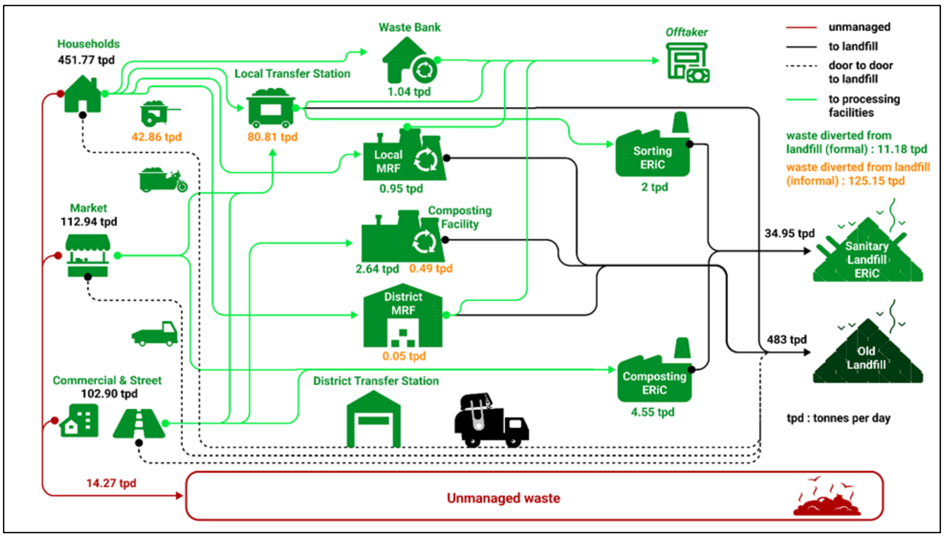

Figure 1: Waste Management Model for Malang City 2022

Figure 2: Typical Composting Facility

METHODS. In 2017, the AMC team proposed performance monitoring criteria to the Malang DLH. In 2021, they assessed progress against a baseline set in 2018. While waste handling stood at good 78.52% against the target of 70%, waste reduction with only 20.27% did not reach the 30% target due to low efficiency of upstream facilities. A performance analysing survey in and GIS tagging of all waste processing facilities upstream of the existing landfill followed in 2019/20, allowing their inclusion in a digital Waste Information System. In 2021/22, the analysis of existing waste generation and flow in primary and secondary collection as well as treatment before final disposal resulted in a waste balance chart. A performance assessment of upstream facilities, now including the sorting and composting plants of the new SLF in 2022 resulted in a Malang Waste Management Model (see Figure 1). With these tools, projections of waste management based on four scenarios in the next 10 years (2021-2031) were presented to DLH. With the focus on (a) increase of waste collection performance and (b) increase in waste diversion/treatment, projections were made for parameters like generation, collection, unmanaged waste, diversion prior to reach upstream facilities, total diversion incl. on new ERiC SLF, residual going to old landfill, residual going to cell(s) of new SLF with an available capacity of 715.000 cbm for cell 1 in following four scenarios: (1) Business-As-Usual (BAU); (2) collection rate at the end of 10 years is still below 100% and diversion rate in the 5th year reaches 30% by optimizing Standard Operation Procedures (SOP) and procuring new processing facilities; (3) collection rate in the 5th year reaches 100% with a diversion rate of 30% but by revitalizing and procuring new processing facilities; and (4) same collection and diversion like in scenario (3), but with an additional 30% composition of the organic waste now composted in households and upstream areas, resulting in some 88 tons/d by 2031. DLH preferred the fourth scenario with the overall intention to extend the lifetime of its SLF as much as possible and taking into consideration that land for additional waste processing facilities is scarce in the city. In this case, generation and collection would be 712 tpd by 2031. After 5 years (i.e. 2026) there would be no more unmanaged waste, diversion prior to upstream facilities would be 46 tpd, and total diversion before disposal 220 tpd. The old landfill would only be used until 2023. The new SLF cell 1 would be filled up in 2029 and cell 2 would be in use starting in 2030 with cell 3 to be operational in 2034 and serving until 2038. The speed of the use of the new SLF space is highly dependent on the upstream waste management system. With scenario 4, the lifetime of the SLF could be increased to 18 years compared to 15 years as per the BAU scenario. Above tools and methods can now be used by DLH for detailing strategies in their ongoing adaptation of the municipal overall long-term SWM Master Plan.

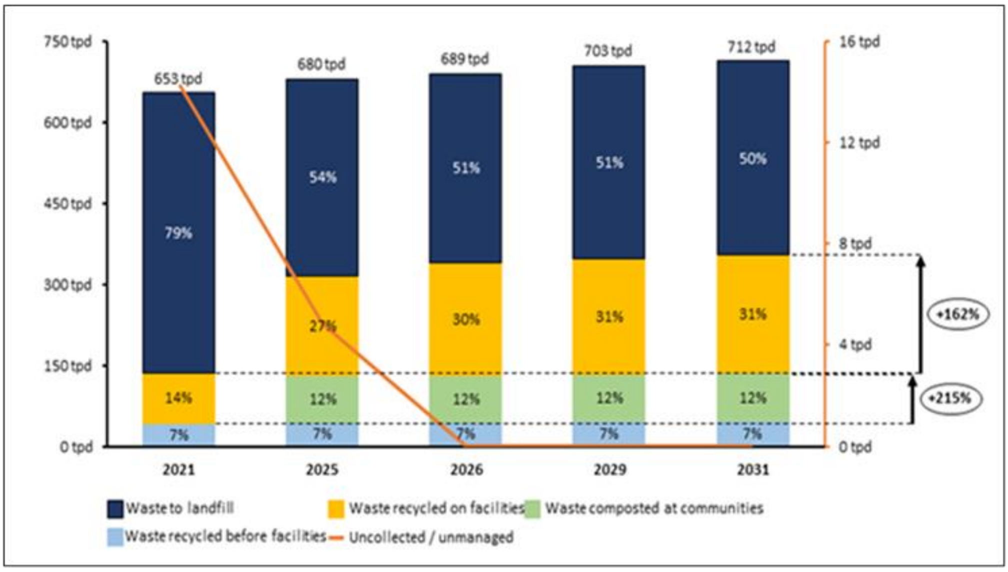

Figure 3: Malang City Waste Balance Projection 2021-2031, preferred scenario

RESULTS AND DISCUSSION. The performance analysis of 20 active upstream processing facilities revealed (not considering the 73 Local Transfer Stations) that they performed best when incoming waste from households, businesses and street sweep has already been separated at source. Overall, 70% of these facilities dealt with composting while 30% diverted animal feed. Staff ranged from 1 to 10 people, but not all workers had received training. Moreover, not all processes ran according to a technical/administrative SOP. For operational stability, financial support from DLH, from the lowest tier of local government on neighbourhood level and from private sector is necessary for maintenance but also for covering daily labour costs as their revenues from diverted materials are not sufficient yet and CSR agreements with facilities were increasing only slowly. In almost all facilities, sorting and composting area, recycling warehouse, transfer area, power supply and office were found. However, plastic crushing machines, organic waste choppers, pressing machines, sorting conveyor belts or black soldier fly farming were far less available. In terms of Health, Safety and Work Environment aspects, 8 facilities were quite good but 12 facilities needed an upgrade. In consequence, the DLH preferred scenario requires (a) its targets to be formally inserted into local policies, (b) high budget commitments especially during the transition period until 2031, (c) strong supervision and law enforcement, and (d) increasing institutional and human capacity for both the municipal regulator and operators. Table 1 shows the necessary increase of upstream facilities in order to achieve this scenario. Besides the investment in upstream facilities, this scenario requires the introduction of over 50.000 household (80 l) composter and ca. 35.000 communal composter (400 l) as non-permanent but easy to maintain equipment, adjustable to the availability of land on plots and in neighbourhoods. The following implementation strategies were discussed with DLH: (1) giving preference to revitalization of facilities (e.g. by fixing tools and machineries, sheltering against rainfall, using ramps for easier transfer of waste) and then optimization of SOP of facilities (e.g. by improving workflow and hours, division of tasks, increasing labor capacity) and (2) adapting storage/transport units. Based on the current practices and local conditions, DLH favoured closed armroll and dump trucks rather than compactor trucks. In addition, DLH intended outsourcing transport services to the private sector. The outcomes of this scenario and above strategies will also impact the sorting and composting plants of the new SLF, whose operation started since end of 2021 and are in a start-up phase. Simulations showed that by SOP optimization and with additional work shifts the sorting efficiency rate (percentage of sorted out recyclables from incoming mixed waste) could raise from currently 5.7% to 12.8%.

Table 1: Total number at end of 10-year period

Upstream Facilities	2019/20	2021-31
Local Material Recovery	4	42
Waste Bank	1	14
Composting Facility	14	32
Local Transfer Station	73	158
District Transfer Station	1	1
District MRF	1	14

Table 2: Adaptation of Storage/Transport Units

Total number of units	2019/20	2021-31
Closed Dust Bin 0.66 cbm	0	54
Armroll container 6 cbm	117	235
Pick Up 3 cbm	0	12
Armroll Truck 6 cbm	13	29
Armroll Truck 8 cbm	0	6
Dump Truck 6 cbm	19	5
Dump Truck 8 cbm	0	14
Compactor 10 cbm	12	6

Currently, the plant receives mixed waste from MRF and transfer stations, where recyclables have already been diverted once through waste pickers. Delivering waste from commercial and from door-to-door collection of household waste from middle-upper class households would be instrumental. Similar, the current 70% composting efficiency of the composting plant could reach 86% by delivering more market waste and directly collected green waste, e.g. from city parks. Once the targeted 30% of waste reduction prior to landfill is achieved, and with proper compaction, a lifetime of of over 5 years of SLF cell 1 could be realized. DLH also expressed interest in applying Waste-to-Energy (W-t-E) and Refused Derived Fuels (RDF) technologies to further reduce the flow of waste to their SLF. The closure of the still operating old landfill in the next 2 to 3 years will also impact on livelihood opportunities of some 170 waste pickers still working on this site. Their accommodation on the existing and the additional upstream facilities as well as in the sorting and composting plants of the new SLF should be part of the above-mentioned revitalization and optimization strategies.

CONCLUSION AND RECOMMENDATIONS. The preferred scenario serves DLH best to meet the prescribed waste management targets of Presidential Decree. To overcome the split of responsibility for primary and secondary collection, transport, and treatment of waste in the upstream, the study recommends that the main upstream facilities be gradually integrated into the waste management system under the full responsibility of the city's waste department DHL. Moreover, in both, primary and secondary, sub-systems strategies to encourage segregation of fractions, starting with small-scale trials should be formalized. This should be supported by volume- or quantity-based waste tariff introduction in commerce and markets. These measures call for a more intensive involvement of the many informal and private actors under the responsibility of DLH. In parallel to the technical studies, the AMC team has identified activities that have the potential to involve such actors for performance improvement in each sub-system. In addition, the AMC team also recommended to DLH: (1) conduct waste composition analysis per season; (2) make sure informal sector facilities and activities comply with health and safety provisions; (3) provision of DLH services at “shadow” i.e. not properly established and routinely served collection points; (4) increase staff training at MRF; and (5) prepare their own staff for supervision of eventually outsourced services.

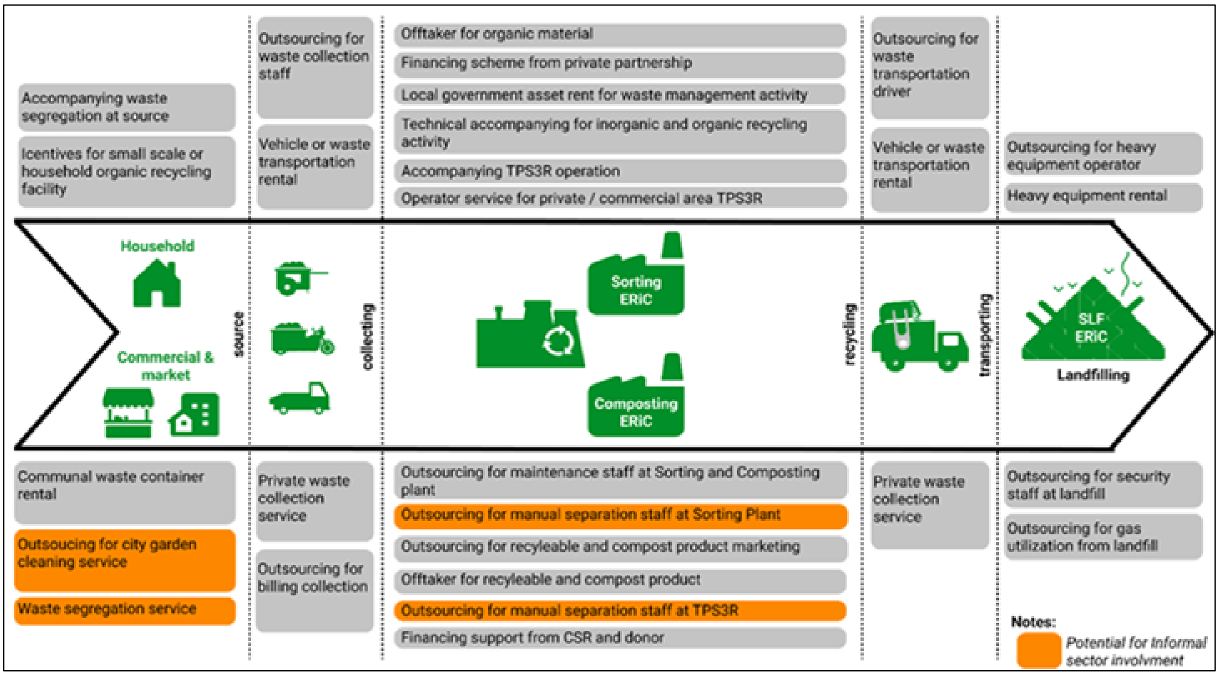

Figure 4: Potentials for the Involvement of Informal and Private Sector Actors

ACKNOWLEDGEMENTS.

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There are numerous opportunities for national/international academics and practitioners to support technical/governmental improvements in the upstream and for the operation of the new SLF in Malang but also in Jambi, Sidoearjo, and Jombang where overall condition are similar to those in Malang.

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Jawaharnagar Municipal Landill Leachate Treatment, Hyderabad, Telangana State

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The present study was undertaken at Jawaharnagar municipal landfill site of Greater Municipal Corporation of Hyderabad (GHMC), Telangana State, India in 2022 which generates 90,000 litres of leachate per day. The main objective of the leachate treatment was to remove organic compounds like color, suspended solids, ammonia and COD by coagulation-flocculation using polyaluminum chloride (PAC) as coagulant which has higher coagulant efficiency and relative low cost compared to the conventional coagulants. Jar test apparatus was used to conduct experiments for pH 7, rapid mixing speed 150 rpm for 3 minute, slow mixing speed 30 rpm for 20 minute and the settling time of 30 minute for different dosage of PAC (0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5 and 5.0 g/L). The highest percentage of removal of suspended solids, color, COD and ammonical nitrogen were observed as 97%, 96%, 60% and 37% with PAC optimum dose of 2.0 g/l. The results indicate that the PAC was effective in leachate treatment which is very much suitable for high toxicity of waste and economically feasible for Indian conditions. The treated water can be utilized for other purpose apart from drinking.

Keywords: Coagulant, Leachate, Polyaluminium chloride, Treatment.

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Electronic Waste Management

Facile recovery of CuO nanostructures from discarded Printed Circuit Boards: Evaluation of photocatalytic activity

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ABSTRACT. Discarded Printed Circuit Boards (PCBs) are secondary resources of high-purity copper, and precious metals. Therefore, recycling waste PCBs using environmentally friendly and suitable sustainable resource utilization techniques is in high demand. This research study focuses on the production of copper oxide nanoparticles from reclaimed copper via a facile precipitation route using alkaline medium to obtain a high added-value nano-product. XRD analysis confirmed the as-synthesized nanoparticles (NPs) were monoclinic CuO of crystallite size 19.23 nm. HRTEM analysis confirmed that the NPs were nearly round structures. The direct band gap is found to be 1.97 eV. The as-synthesized nanoparticles are investigated for their photocatalytic activity through the degradation of textile dyes. Hence e-waste can be utilized to produce nanomaterials with added values, thus reducing the problematic e-waste, and decreasing environmental problems.

Keywords: *Printed circuit boards; nano-product; CuO nanoparticles; Photocatalyst*

Introduction

Electrical and electronic equipment (EEE) has turned into an integral part of society due to the modern era's significant revolution in science and technology. The consumption of EEE is further increased worldwide due to the covid-19 pandemic. According to global e-waste monitor 2022, the worldwide generation of WEEE reached 41.8 million tonnes (Mt) in 2014, which increased to 44.7 Mt in 2016 and 53.6 Mt in 2019 and is expected to reach 74.7 Mt by 2030 and 110 Mt by 2050 [1,2]. It has been reported that only 17% of the generated e-waste is being recycled every year and 83% of treatment is unknown likely landfilled, traded or recycled in unauthorized recycling sectors in unhealthy environmental practices [3]. Among the metallic elements, copper contains the highest amount of PCB content, which can range from 10% to 30% by weight [4]. One potential choice to produce high-value products using recycled copper from WPCBs is to create nanoparticles, which is particularly significant given the current focus on research related to nanotechnology. Using nanomaterials derived from waste from industrial purposes in pollution removal not only addresses the issue of waste disposal but also assists in the management of natural resource depletion.

The monoclinic structure of CuO, a lower bandgap semiconductor, renders it highly reactive and its significant surface area offers notable potential in catalytic applications [5]. The prime focus of this research is to produce a nanostructure from electronic waste and to study its application as a simple, cost-effective and efficient photocatalyst. In the present study, a sustainable CuO nanoparticle recovery process from waste PCBs is investigated. CuO nanostructures are synthesized by a combination of precipitation and calcination. No chemical precursor, surfactant, substrate, template, particle size stabilizer is used for nanoproduct synthesis. Here PCB leached solution is used as precursor for copper source. Precipitation is achieved with sodium hydroxide. The nanoproduct is subject to various characterization techniques to confirm its phase, morphology and bandgap energy. Its photocatalytic activity is further explored for disintegration of textile dyes Methyl Orange, Crystal Violet, and Methylene Blue under visible light conditions. This approach to recovery is both cost-efficient and ecologically responsible.

Material and Methods

Materials and Chemicals

Computer motherboards from various manufacturers were obtained from a local supplier for the study, while all the chemicals used in the experiment were of analytical grade with high purity. Fisher Scientific was the source of pure ethanol, HNO_3 used in the experiment. Sodium hydroxide was obtained from Qualigens Fine Chemicals, India. In addition, double distilled water was used for the preparation of solutions and for washing the samples.

Method of synthesis of CuO Nanoparticles

The metal fraction recovered from waste PCBs of computer motherboards was subjected to nitric acid leaching in a 100 ml three-neck flat bottom flask, equipped with magnetic stirring and thermocouple setup, heated on a hotplate. The leaching process was carried out using 3 M HNO_3, at a temperature of 30° C, for a period of 2 h, with a pulp density of 50 g/L and stirring speed of 500 rpm. The resulting leaching solution was filtered and then magnetically stirred. 1 M NaOH solution was added while continuous stirring until pH of solution reached 8.5. A curdy blue precipitate was collected by centrifugation, washed several times to eliminate impurities, and dried in oven at 70° C for 12 h. The dried powder was then ground and calcined at 400° C for 4 h in a muffle furnace. After calcination, the black powder was collected and subjected to various characterization methods.

Results and Discussion

1. XRD, FTIR

The powder x-ray diffraction pattern performed to understand the composition of the prepared sample is shown in **Error! Reference source not found.(a)**. The peaks observed were in agreement with the monoclinic CuO phase centered at the base (JCPDS 89-5899). Notably, the dominant peaks at 2θ values of 35.5° and 38.9° corresponded to the (-111) and (200) planes, respectively, which were distinctive peaks of pure monoclinic CuO [6]. No impurity peaks of Cu, $Cu(OH)_2$, Cu_2O or $Cu(NO_3)_2$ were seen in the XRD pattern, which confirmed the formation of pure CuO. The average crystallite size calculated from Debye-Scherrer's formula was 19.23 nm.

Error! Reference source not found.(b) illustrates the FTIR infrared radiation spectrum which exhibits several bands at 527, 595, 1050, 1630, 3439 cm^{-1}. The spectrum displayed three absorption peaks at 527, 595, and 1050 cm^{-1} which corresponds to the Cu-O bond stretching mode. These peaks confirm the formation of pure monoclinic CuO nanoparticles (NPs) [7,8]. The absorption peaks observed at 1630 and 3436 cm^{-1}, which were of low and high intensity respectively, can be attributed to H-O-H bending and O-H bond stretching vibrations. These vibrations arise due to the presence of water molecules adsorbed on the surface of Cu-O [9].

2. SEM, TEM, UV-DRS analysis

The surface morphology of CuO NPs prepared was revealed through high resolution-scanning electron microscopy, as seen in **Fig. 5.** (a) FESEM image, (b) Tauc plot, (c) Particle size distribution plot, (d) TEM micrograph of obtained CuO nanoparticles**(a).** The image shows uniform distribution of nearly spherical CuO NPs. Furthermore, the EDX spectrum confirms the presence of [Cu] and [O] peaks, providing evidence for the formation of CuO.

Tauc's formula was used to calculate the bandgap energy of CuONPs [10], resulting in a value of 1.97 eV as shown in **Fig. 5.** (a) FESEM image, (b) Tauc plot, (c) Particle size distribution plot, (d) TEM micrograph of obtained CuO nanoparticles**(b)**. This value is higher than the reported bandgap energy of bulk CuO (1.8 eV) [11]. The increase in the bandgap energy of CuO NPs is attributed to the occurrence of quantum confinement effects, which is a typical phenomenon observed in nanoparticles due to their reduced size [12].

Fig. 5. (a) FESEM image, (b) Tauc plot, (c) Particle size distribution plot, (d) TEM micrograph of obtained CuO nanoparticles**(d)** presents transmission electron microscopy image which demonstrates the spherical morphology of the particles. The particle size distribution of the synthesized NPs is depicted in **Fig. 5.** (a) FESEM image, (b) Tauc plot, (c) Particle size distribution plot, (d) TEM micrograph of obtained CuO nanoparticles**(c).** The analysis shows that the particle size ranges between 19.75-41.84 nm, while the average particle size is determined to be 19.973±6.036 nm.

3. Photocatalytic activity assessment

The photodegradation of textile dyes Methyl Orange, Crystal Violet, and Methylene Blue were conducted under visible light irradiation using 1 mg CuO NPs acting as a catalyst. **Error! Reference source not found.** displays the UV-visible absorption spectrum of the degradation of the dyes at various time intervals. Under visible radiation, the primary absorption peak of the dye solution gradually diminishes in the presence of

CuO NPs, as was observed in **Error! Reference source not found.(a-c).** Methyl orange, crystal violet, and methylene blue showed a degradation of 13.53, 17.2, and 82.57%.

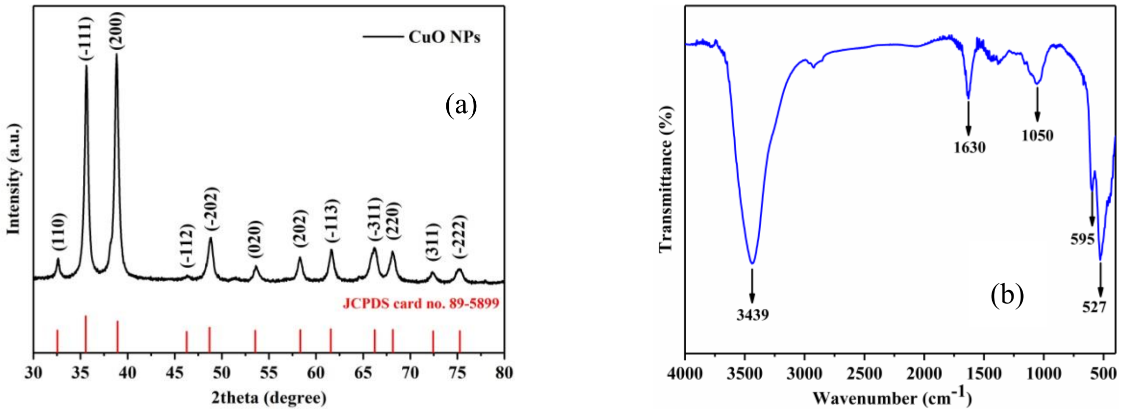

Fig. 4. (a) XRD pattern, (b) FTIR of synthesized product

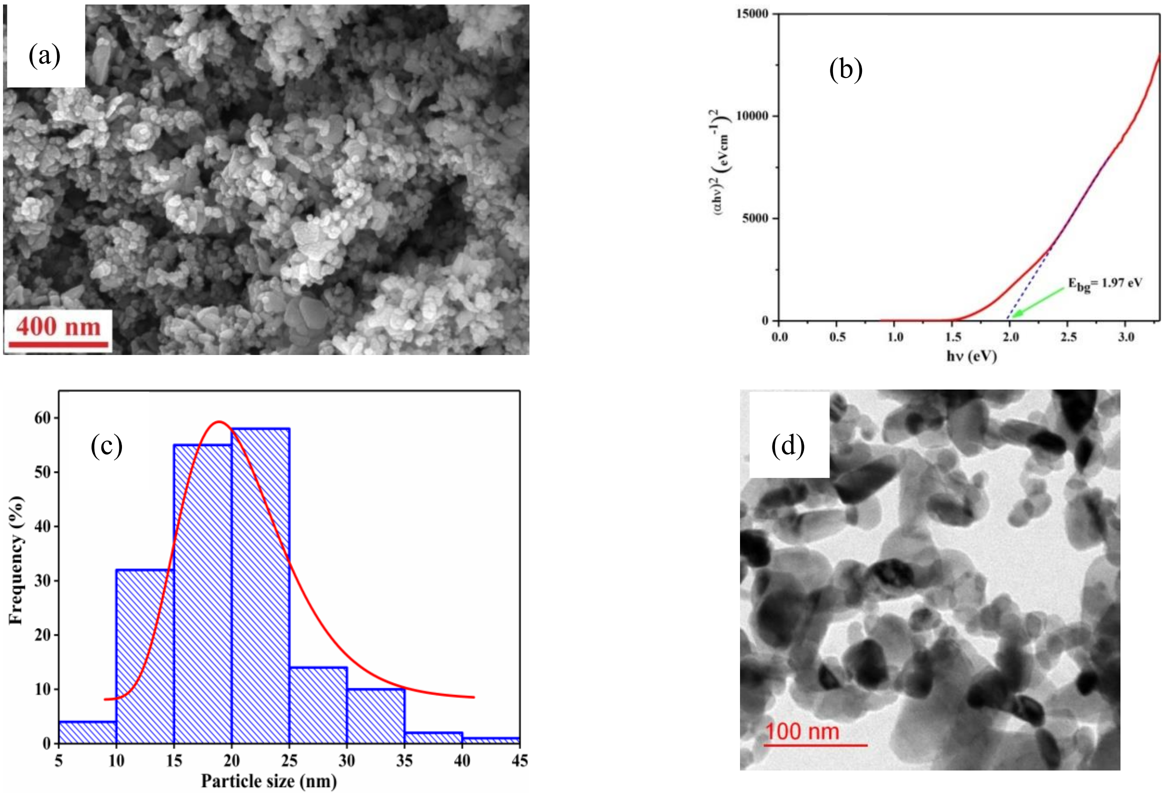

Fig. 5. (a) FESEM image, (b) Tauc plot, (c) Particle size distribution plot, (d) TEM micrograph of obtained CuO nanoparticles

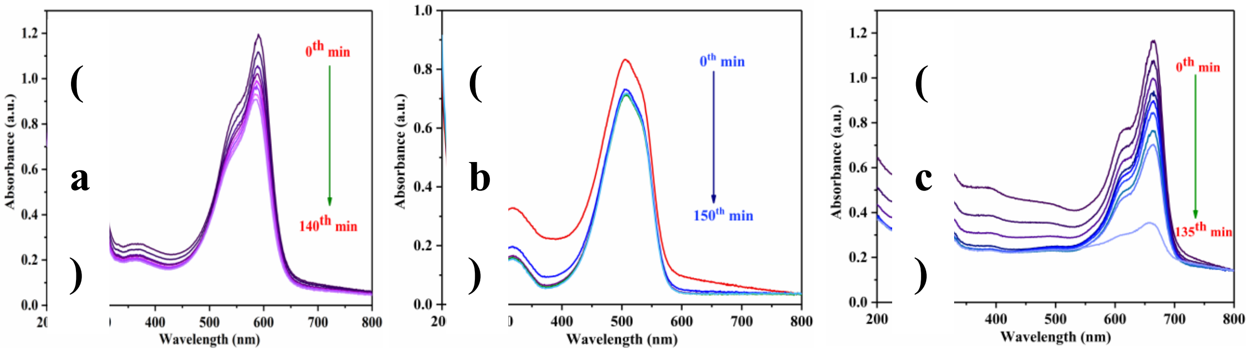

Fig. 6. UV-visible spectra of degradation of Crystal Violet (a), Methyl Orange (b), and Methylene Blue (c)

Conclusions

This study presents a method for the recovery of copper as copper oxide from waste PCBs of computer motherboards, which provides an opportunity for cost-effective and environmentally safe and sustainable development. XRD, FTIR, and SEM confirmed the formation of high purity CuO nanoparticles. The TEM image showed that the synthesized nanostructures were nearly-round spheres. The optical bandgap energy of the nanomaterials is found to be 1.97 eV. The CuO NPs exhibited good photocatalytic degradation of textile dyes, making them a potential photocatalytic decomposer of organic pollutants in wastewater.

Acknowledgement

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A Review on Improved Collection Approach for Small IT and Telecommunication Equipment Waste in India Under Circular Economy

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Booming information technology (IT) around the globe, India in particular, has shown tremendous growth after the digital revolution and digitization of the economy and education system. The increasing market of electrical and electronic equipment (EEE) creates a significant E-waste generation problem. Due to lack of E-waste collection and the involvement of the informal sector create havoc in the systematic E-waste management approach. This article gives insights into the circular economy (CE) in E-waste to streamline formal E-waste collection and increase methodological treatment options. Small IT and telecommunication equipment waste is one of the untouched sectors in E-waste. However, it could have significant recovery potential for precious and rare earth elements under urban mining and can help to achieve CE. As the collection system is one of the essential factors in the integrated waste management hierarchy, the article will discuss existing E-waste collection practices and innovative methods for improved E-waste collection in India. The generation of small IT and telecommunication equipment waste majorly belongs to the secondary generators (local repair shops) of E-waste. The primary waste generator or EEE consumers practiced repairing and replacing damaged/exhausted components at local repair shops instead of buying new items. This practice led to irregularity and disturbed streamlining in E-waste management. Multiple case studies and best practices were reviewed in the small IT and telecommunication equipment sector to address such irregularity. This will help to compare and adopt the best collection approach considering the Indian scenario. However, there is limited research on CE in E-waste; this limitation will be addressed through this article by creating a value chain. Considering multiple scenarios, targeting secondary waste generators under extended producer's responsibility can be an effective approach for regular collection in comparison with the primary waste generator. Finally, varying collection approaches could be different based on the market and consumption or waste generation patterns. In conclusion, the E-waste management system should be focused on the best collection approach for improving collection efficiency.

Keyword: Circular economy; E-waste; Small IT and telecommunication equipment; Electrical and electronic equipment.

E-waste Hazards: Encourage the Need for Green Electronics

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With rapid advancement in technology, electronic waste (e-waste) or Waste Electronic and Electrical Equipment (WEEE) are an emerging danger. The e-waste poses crucial contamination problems the eco-system. The primary cause behind unrestrained electronic waste around the globe is the speedy advancement of innovation. Low production cost of electronic gadgets is also play an important role in increase of e-waste. Because to this, exceptionally large amounts of e-waste must be discarded each and every year whose disposal is a main issue. To handle this problem of e-waste, reducing and recycling of waste play a vital role. These techniques also help in configure the circular economy. This paper sums up the data of e-waste generated worldwide with special reference to India, along with focusing on the advantages of recycling. This paper also highlights the impact of e-waste on the eco-system and how green electronics could be one of the practical solutions to this.

Keywords: E-Waste, Electronic scrap, WEEE, Green electronics.

Evaluating WEEE Generation, Disposal Decision and Consumer Preferences in Support of Reverse Logistics for a Circular Economy in Hong Kong

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The growth in the waste electrical and electronic equipment (WEEE) is a growing issue in Hong Kong and mechanisms for the proper management of e-waste are urgently needed. Drawing on the circular economy (CE) as a solution for the city's WEEE challenge is a promising approach: the concept bears relevance for the city's waste management hierarchy, constitutes an established approach for managing post-consumer waste streams and helps conserving virgin resources. Given the value of discarded electronics due to function and inherent metals, CE approaches such as repair, refurbishment and remanufacturing combined with a reverse logistics mechanism can strengthen system soundness and stakeholders' responsibilities.

One comprehensive mechanism in this context is the Producer Responsibility Scheme for WEEE (WPRS), which has been gradually implemented in Hong Kong since 2016. Yet, detailed statistics on WEEE generation at the household level and how physical and psychological factors influence the consumer preference regarding the disposal decision and reverse logistics for CE are absent. The study aims at estimating WEEE generation in Hong Kong's households and evaluate consumer's preferences regarding the End-of-life management of electronics. Herein, particular focus is set on residents' attitude towards reverse logistics for WEEE and other mechanisms and patterns related to the CE's R-principles. The main hypothesis of this study is that product-specific, physical and psychological factors are positively related with consumer willingness to support CE approaches in WEEE management.

In terms of materials and methods, the study will use survey data from two waves in 2022 covering over 5,000 households. Additionally, models on the estimation of EEE marketisation and respective WEEE generation will be adopted to complete and extrapolate survey data. Particular focus will be put on the consumption of white and brown goods commonly used in Hong Kong, i.e. air-conditioners, refrigerators, washing machines, televisions, monitors, laptops, mobile phones and, tablets/iPads. To explore consumer preferences for existing disposal channels and contrast these with actual behaviour patterns, the theory of planned behaviour (TPB) will be employed. The TPB's core elements of attitude, subjective norms and awareness of consequences in regard to the WPRS and the circular economy concepts will be verified via the partial least square path modelling (PLSPM) approach.

The study is limited to certain types of EEE from households, but will develop framework for future research on other types of electronics from schools, universities, offices and other public institutions may also be carried out. In sum, the findings will provide a fundament for future research on material flow analysis, value chain analysis and life cycle analysis of WEEE management by e-waste traders in Hong Kong as well as offer CE policy recommendations for policy-makers.

Keywords: Circular Economy, WEEE generation, Disposition decision, Reverse logistics.

A Green Slurry Electrolysis to Recover Valuable Metals from Waste Printed Circuit Board (WPCB) in Recyclable pH-Neutral Ethylene Glycol

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The continuous growth of e-waste necessitates an efficient method to recover their metal contents to improve their recycling rate. The successful recovery of the metallic component from Waste Electrical and Electronic Equipment (WEEE) can generate great economic benefits to incentivize the industrial recycling effort. In this study, we report the use of slurry electrolysis (SE) in pH-neutral ethylene glycol (EG) electrolyte to extract and recover the metallic component from waste printed circuit broad (WPCB) powder. The system operates at room temperature and atmospheric pressure, and the electrolyte can be recycled multiple times with no signs of chemical degradation. The EG electrolyte system can oxidize the metallic component without triggering anodic gas evolution, which allowed us to incorporate a reticulated vitreous carbon (RVC) foam anode to maximize the capture and oxidation of the metal content. The system demonstrated up to 99.1% Faraday efficiency for the cathodic metal deposition and could recover Cu from the WPCB powder in a selective manner of 59.7% in the presence of 12 other metals. The SE reaction system was also scalable and displayed no compromises on the Cu recovery selectivity. With the ability to leach and recover metallic content from WPCB in a mild and chemically benign condition, the SE system displayed much promise to be adapted for industrial-scale metal recovery from WPCB.

Keywords: Slurry electrolysis, Ethylene glycol, Waste printed circuit broad (WPCB), Reticulated vitreous carbon.

Effect of Magnetised Nutmeg Seed Shell-Based Biochar on the Bioleaching of Printed Circuit Boards

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ABSTRACT: One of the numerous extraction techniques being utilized to recover metal resources from e-waste is the bioleaching approach. The study focused on the enhancement of bioleaching of Cu using modified biochar. Nutmeg seed shells (NSS), which is an agricultural waste are utilized as a substrate for the synthesis of biochar. Biochar is then coated with magnetized Fe particles with the help of plant extract which is proved for the presence of reducing and capping agents required for the reduction of magnetic iron nanoparticles from ferric and ferrous salt. This composite is used to improve the bioleaching process by enhancing electron transfer because of its rich functional groups, developed pore structure, and substantial specific surface area. Due to the enhanced properties of magnetic biochar (FeNSSB), it is growing in popularity among researchers. characteristics and composition helping bioleaching processes and microbial growth. After adding biochar, the static bioleaching experiment that lasted 7 days to observe the effect of composite in the leaching rate of copper (Cu). Furthermore, biochar with magnetic property served as an excellent physical medium to promote electron transfer, increasing the ability of bacteria to oxidize thus increase the effect of Cu leaching in M9 medium with sucrose as carbon source

Keywords: *Nutmeg seed shell, Biochar, Magnetisation, Electronic waste, Bioleaching*

Introduction

E-waste is the solid waste stream that is rising the fastest globally since the advent of the information age (Wang et al., 2016). As per the Central Pollution Control Board's report, the e-waste generated in India amounted to 1.71 million metric tons, whereas the global e-waste generation reached 59.40 million metric tons. Synergetic effect of nutmeg seed shell-based biochar on bioleaching of e-waste. Bioleaching is a cost-effective, secure, and environmentally responsible approach for recovering metal from electronic waste compared to other traditional processes (Kadivar et al., 2021). Utilising microorganisms to transfer metals from e-waste is known as bioleaching. Despite the fact that bioleaching has many benefits, it still faces significant challenges, most notably the poor metal recovery yield and slower metal dissolution rate, which might limit its widespread application. Research demonstrates that utilising a catalyst such activated carbon, biochar, or modified carbon nanotubes increases the bioleaching efficiency and helps to overcome the challenges that impede the bioleaching process. Biochar's distinctive porosity structure created an environment for microorganisms to live in while retaining a wealth of nutrients. This study have looked into the enhanced effect of biochar on the bioleaching by bacteria found in old e-waste printed circuit boards from waste clock momentum is selected for this study which have copper in high quantity. Utilisation of biochar and biochar with magnetic property as bioleaching activator is analysed in this study.

Material and Methods

Materials: Nutmeg seed shell is the agricultural waste used as the substrate in this study to assess its capability to enhance bioleaching process. Nutmeg waste was collected from the Angamaly-Kalady region of Kerala, India and washed with double-distilled water and then dried in a hot air oven at 105°C to a constant weight. Dried NSS were crushed, sieved to 105µm, and stored in an air-tight polyethene zip lock cover. All the chemicals used for the experimental work are of analytical grade and purchased from Sigma Aldrich and Loba chemi.

NSS biochar preparation: NSS dried in an oven to dry at 105°C, ground and sieved through a 106 µm sieve. NSSB prepared in a muffle furnace at 500°C for 4 hrs then cooled and washed. The pH was neutralised using 0.1 M HCL. Biochar is then dried at 105°C and stored.

Preparation of biochar with magnetic property: One gram of $FeCl_3 \cdot 6H_2O$ and 3 g of $FeCl_2 \cdot 4H_2O$ in 100 ml of water at 70°C at 500 rpm for 1 hour. Five milliliters of NSS extract are added to this solution and stirred the whole solution at 70°C at 500 rpm for 2 hours then NaOH solution is added to make the pH to 10. Two gram of biochar is added to this solution and stirred at 70°C at 500 rpm for 1 hours. Composite is precipitated by diluted HCl and then separated by a magnet and dried at 70°C.

E-waste bioleaching: Two-stage e-waste bioleaching is carried out by first culturing the microbes and then added with electronic waste with biochar (Figure 1). M9 medium with Molasses (10 mL /L)(**M9M**), M9 medium with Sucrose:4g/L (**M9S),** 9K medium with 44.7 g/L of ferrous sulphate (**9KF)** were used as bioleaching medium for this study. 100 mL culture media with 10 mL of inoculum (microbes isolated from old e-waste cutured in nutrient broth) with 1g of biochar (B) or biochar with magnetic property (FB) prepared from nutmeg seed shell with 1g/100 mL of powdered e-waste is cultured at 30°C with 150 rpm. Periodical analysis of samples for copper concentration in bio-leachate done by using atomic absorption spectroscopy (AAS).

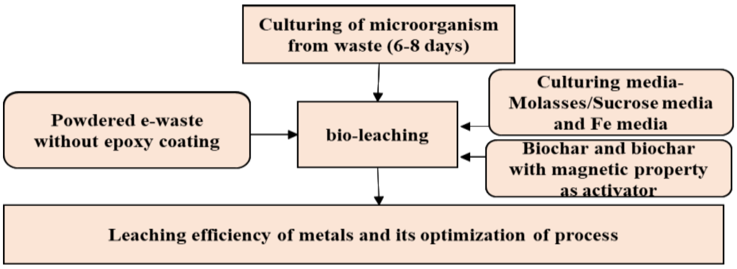

Fig 1: Bioleaching of e-waste

Results and Discussion

Characterisation:

FESEM analysis: The morphology of the NSS biochar with and without magnetic property were investigated by FESEM microscopy. NSS biochar holds micropores of size ranging from 1.559- 8.887 µm (Figure 2a) and even nanopores of 238 nm (Figure 2b). Carbonation of material makes more surface area and pore size to the material. The FESEM micrographs of the NSS biochar with magnetic property shows surface changes compared to biochar (Figure 2c,d).

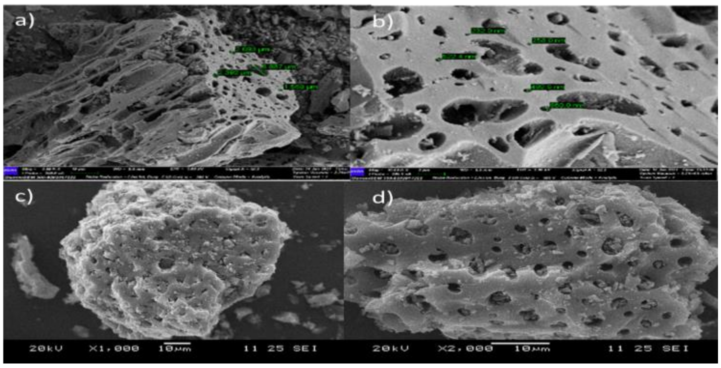

Figure 2: a) NSS biochar with micropores (2K magnification) b) FESEM image for thermally treated NSS powder with nanopores (10 K magnification) c*) NSS biochar with magnetic property (1K magnification) d) FESEM image for NSS biochar with magnetic property (2 K magnification)*

Powder XRD patterns are analysed at the 2θ range of 10° - 80° using monochromatic Cu Kγ radiation of wavelength 0.1540598 Å generator voltage of 45 kV. The peaks were observed at the (2θ) value of 22.679, 28.508, 43.044 and 47.422, which corresponds to iron, lead, copper, and cobalt, respectively (Figure 3a). NSS, NSSB and FeNSSB also analysed using XRD. In the case of NSS biochar, the XRD pattern has a shift in some of the peaks, and in that 2θ = 29.369º, which is assigned to lattice plane of 104, which indicates the presence of $Ca_6C_6O_{18}$ which is calcite (Ahmad et al., 2020) (Figure 3b,c). In FeNSSB, Fe peaks were found at 2θ range of 30.31°, 35.71° and 63.056° represents correspond to the lattice plane (022), (131) and (044) magnetised iron (Figure 3d). Hashemi et al. (2020) and Shagholani et al. (2015) show similar results for magnetised iron particles.

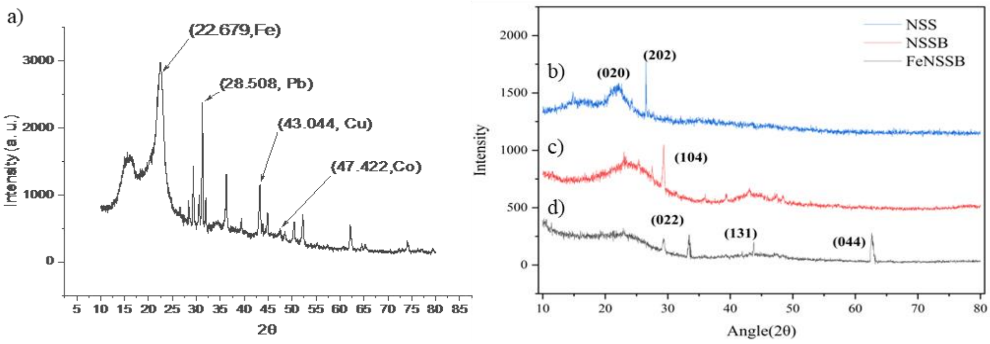

Figure 3: a) XRD of e-waste powder b) XRD of NSS c) NSSB d) FeNSSB

E-waste pretreatment for epoxy coating removal: PCB have epoxy coating which will creat microbial growth inhibition thus to enhance the bioleaching efficiency the epoxy caoting should be removed before the bioleaching process. NaOH (5 N) with a soak time of 8 h and a reaction time of 5 min in a bath sonicator could easily remove the epoxy coating from PCB (figure 4) (Senophiyah-Mary et al., 2018). After the removal of epoxy coating from the e-waste, it is grinded and sieved to achieve a size range of 106 **µ**m. Characterisation of e-waste leachate can be carried out by ICP-OES (Inductively coupled plasma optical emission spectrometry) by qualitative determination of metals which is shown in table 1. Analysis shows copper, iron, nickel, and lead concentrations are high in the waste PCB (chemical-leaching using acids).

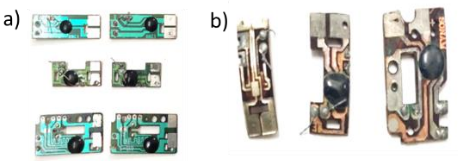

Figure 4: a) e-waste (Clock PCB) with epoxy coating b) e-waste after removal of epoxy coating

Table 1: ICP-OES analysis of chemically leached metals from e-waste

ELEMENT	WAVE LENGTH	CONCENTRATION (MG/L)	ELEMENT	WAVE LENGTH	CONCENTRATION (MG/L)
Au	242.794 nm	0.0	Cr	267.716 nm	3.8
Hg	184.887 nm	1.0	Cu	324.754 nm	718.2
Ag	328.068 nm	0.1	Fe	238.204 nm	185.0
Al	396.152 nm	7.5	Mn	257.610 nm	3.7
Cd	214.439 nm	2.1	Zn	213.857nm	5.8
Co	238.892 nm	30.6	Ni	230.299 nm	140.8
Pb	220.353 nm	521.3			

Bioleaching of e-waste: The amount of copper is analyzed by AAS with and without activator for different culture medium is shown in figure 5. Cu leaching is always greater when biochar composites with magnetic properties are used as an activator rather than conventional biochar under similar conditions and a rapid leaching of Cu metal from e-waste is happened in case of 9K medium with ferrous sulphate. The unique porosity structure of biochar produced a habitat for microorganisms to live in while preserving an abundance of nutrients. Additionally, biochar can be a great physical medium for encouraging electron transport, which will increase the capacity of bacteria to oxidise. The use of biochar may also be useful in reducing precipitation during bioleaching, hastening the breakdown of electronic waste and the release of metal elements.

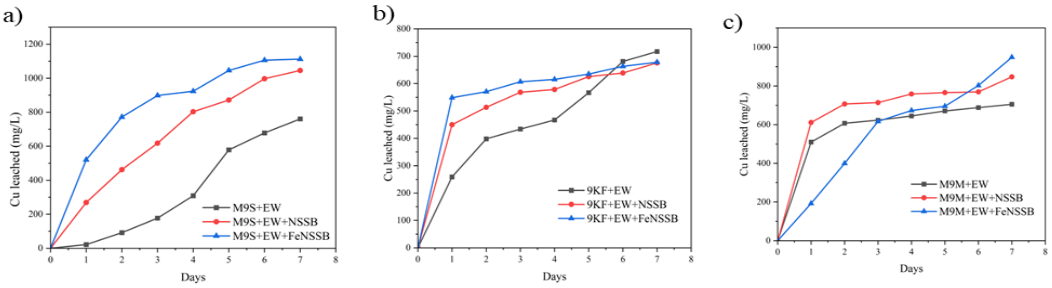

Figure 5: a) Bioleaching of e-waste with 9K medium with ferrous sulphate b) Bioleaching of e-waste with M9 medium with molasses as carbon source c) Bioleaching of e-waste with M9 medium with sucrose as carbon source

Conclusions: The bioleaching of e-waste enhancement using different microbial medium and using biochar and biochar with magnetic property as an activator is analysed in this study. Biochar is sysnthesised based on agricultural waste- nutmeg seed shell. Cu leaching under the stimulation of biochar composite with magnetic property is increased in all case compare to the normal bioleaching condition and normal biochar as an activator. The inclusion of biochar may also be effective in preventing precipitation from developing during bioleaching, hence accelerating electronic waste breakdown and metal element release. This work demonstrates that biochar-composite-enhanced bioleaching may be an effective and advantageous method for recovering metal resources from electronic wastes.

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Construction and Demolition Waste

Binder Testing of Mixed Plastics-Polymer Modified Bitumen for Asphaltic Wearing Course

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ABSTRACT. This paper reports an experimental study on the use of recycled mixed plastics, derived from municipal solid waste, in polymer-modified bitumen for infrastructural applications such as construction and maintenance of roads, carparks and airfield pavements. The objective of this study is to evaluate the binder properties and performance for asphaltic wearing course to produce optimized asphalt mixtures. The laboratory works performed include binder testing on penetration, softening point, dynamic shear, short-term ageing, rotational viscosity and storage stability. Based on the binder test results, a suitable range of mixed plastics contents by mass of binder is recommended to be used in the asphalt mixtures.

Keywords: *Binder testing; mixed plastics; polymer-modified bitumen; asphaltic wearing course*

Introduction

According to Shah et al. [1], global plastic production has increased steadily over the past decades with the average growth rate of plastics at 8.70% from 1951 to 2021 annually, increasing from 1.7 million tonnes to almost 300 million tonnes today. The annual plastics waste generation in Singapore has risen rapidly over the past twenty years: from 546,537 tonnes in 2001 to 1,001,000 tonnes in 2022 making up about 13.6% of total municipal solid waste (MSW) generated i.e. 7,385,000 tonnes in 2022; with 944,000 tonnes of waste plastics discarded and only 57,000 tonnes recycled, the annual recycling rate remained very low at 6% [2]. Due to the widespread usage of plastic products and their non-biodegradable nature, the proper end-of-life management of these materials has been demanding and challenging. The main obstacles in plastic recycling are the need for sorting, the non-homogeneity nature and contamination of plastic waste with food waste. This project shall be the first of its kind to study direct usage of MSW mixed plastics as raw materials without the need for waste sorting. The use of MSW mixed plastics in bituminous mixtures can significantly reduce the need of taking up precious space in the landfill and eliminate the emission of toxic pollutants from incineration. It could also enhance the properties of bituminous mixtures and lead to environmental and economical improvements.

Materials and Methods

Laboratory tests were performed to determine the optimal mixed plastics composition with reference to a conventional binder (control binder). The five types of recycled plastic waste investigated were low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polystyrene (PS) and polyethylene terephthalate (PET). Five binder formulations comprising one control/conventional bitumen of Pen Grade 60/70 with 0 wt% mixed plastics and four mixtures (MP-PMB-A; MP-PMB-B; MP-PMB-C; MP-PMB-D) with 92.5 wt% Pen 60/70 bitumen and 7.5 wt% mixed plastics content were studied, with LDPE, HDPE, PP, PS and PET making up the 100 wt% concoctions. The samples were prepared at a mixing temperature of 180 ± 5 °C and a shearing rate of 3,500 rpm for an hour followed by continuous blending at 2,000 rpm for four hours, after which they were cured at room temperature till the date of testing. A series of standard test methods with the corresponding required specifications in Table 1 were adopted for the optimization of mixed plastics blend in binder form.

Table 1. Binder tests.

Test description	Standard method	Required specifications
(a) Penetration @ 25°C, dec.mm	ASTM D5	60 to 70 dec.mm for Pen 60/70
(b) Softening point (temperature), °C	ASTM D36	47 to 56°C for Pen 60/70
(c) Rheological properties by dynamic shear rheometer, kPa	ASTM D7175	Min 1.0 for un-aged sample Min 2.2 for aged sample, at design temperature
(d) Short-term ageing by rolling thin film oven (RTFO) test	ASTM D2872	N.A.
(e) Rotational viscosity, Pa.s	ASTM D4402	Max 3.0 Pa.s

(f) Storage stability by differences in top and bottom of sample after 72 hours at 180°C	BS EN 13399	Max 5°C by ring and ball test

ASTM – American Society for Testing and Materials; BS EN – British Standard implementation of European Standard

Results and Discussion

Based on preliminary studies, four binder samples of 7.5 wt% mixed plastics content with varied polymer compositions (MP-PMB-A to MP-PMB-D) were tested for comparison with the control Pen 60/70 binder sample as reference.

Penetration value

As shown in Figure 1(a), the penetration values of binder samples with 7.5 wt% mixed plastics ranging from 35 to 39 dec.mm were lower than that of the control Pen 60/70 binder sample. A lower penetration value indicates a stiffer binder which provides higher resistance against deformation or rutting but reduced resistance towards cracking.

Softening point

A higher softening point (temperature) implies greater resistance to materials softening hence increased resistance to deformation under high temperature exposure. From Figure 1(b), all binder samples with 7.5 wt% mixed plastics content recorded higher softening temperatures than the control Pen 60/70 binder sample.

Dynamic shear modulus

Dynamic shear modulus quantifies the visco-elastic behaviour of binder samples, thus providing useful insights on the resistance to rutting. For performance grade standard, the minimum values of dynamic shear modulus before and after short-term ageing by rolling thin film oven (RTFO) test at 76 °C are 1 kPa and 2.2 kPa, respectively. The trends observed in Figures 1(c) and 1(d) were consistent, with binder samples of 7.5 wt% mixed plastics content exhibiting up to 300% improvement compared to control Pen 60/70 binder sample. The MP-PMB-C binder sample recorded the best dynamic shear modulus performance for both conditions before and after short-term ageing by RTFO test.

Dynamic viscosity

Dynamic viscosity characterizes the flowability of binder samples at specific temperatures. Figure 1(e) shows significant increase in viscosity at 135 °C compared to 165 °C for all the binder samples. Despite such increase with a drop in temperature from 165 °C to 135 °C, the viscosity of all binder samples remained below the maximum value of 3 Pa.s for performance grade standard.

Storage stability

The softening point (temperature) was also used to evaluate the storage stability of binder samples. The difference in softening temperature between the top and bottom fractions should not be more than 5 °C. A large difference in softening point indicates segregation in binder storage which may result in phase separation when binder is stored at a high temperature for a long period of time. From Figure 1(f), the difference in softening temperatures for all binder samples with mixed plastics were greater than 5 °C after 72 hours. Thus, it is recommended not to store the plastic modified binder for over 24 hours or a modification in materials handling and storage of binders containing mixed plastics is required to achieve a good homogeneity prior to mixing for asphalt production.

Visual inspection

In addition, visual observation was made for the blending process of Pen 60/70 bitumen with mixed-plastic waste using a high shear mixer as shown in Figure 2. Plastic particles were found on the mixer head during the blending process for all mixed plastics binder samples. This could be attributed to the higher melting temperatures of PS (240 °C) and PET (265 °C) compared to LDPE (120 °C), HDPE (150 to 180 °C) and PP (160 °C) as well as the use of mixed-plastic waste in loose flakes form, causing plastic particles to agglomerate during high shear mixing. This is consistent with reported observations by Ma et al. [3] and Grady [4] in which plastics with lower melting points such as LDPE, HDPE and PP could form a thin film to increase the adhesion among asphalt, plastics and aggregates; whilst plastics with higher melting temperatures such as PS and PET were usually applied as aggregates substitution.

Discussion based on reported literatures

Based on a critical literature review by Wu and Montalvo [5], the major types of recycled waste plastics such as LDPE, HDPE, PP, PS and PET were found to yield conflicting performance measures. Hence, additional research is needed to fully understand the effects of various plastics on the performance of asphalt road pavements, as well as potential environmental and economic impacts this process could implicate. Another area where further study is required includes methods to improve the compatibilization between asphalt and recycled waste plastics.

Xu et al. [6] stated that the performance of modified asphalt is highly dependent on multiple factors such as waste sources, waste plastic dosages, blending conditions and pre-treatment methods for waste plastics. They considered the use of chemical methods such as additives and functionalization as an effective way to provide better interactions between waste plastics and the binder as well as to achieve a higher utilization rate of waste plastics. It was also emphasized that the optimal proportions of materials used in the blends are still unclear and should be explored further.

Fonseca et al. [7] studied the influence of waste plastics on the workability and mechanical behaviour of asphalt mixtures; and observed that although the addition of waste plastics reduced workability, the asphalt mixtures retained satisfactory handling conditions. They reported that the incorporation of various types of waste plastics as a bitumen extender can improve certain mechanical properties such as elasticity and resistance to fatigue and permanent deformation. They suggested further works in this area to obtain a full understanding of the long-term behaviour, environmental impact and life cycle analysis of the asphalt mixtures.

Conclusions

The findings from this study indicate that recycled mixed plastics derived from municipal solid waste can be potentially used as a binder in polymer-modified bitumen for asphaltic wearing course in infrastructural applications. Based on the binder testing on penetration, softening point, dynamic shear, short-term ageing, rotational viscosity and storage stability, mixed plastics contents containing higher proportions of LDPE and PP are recommended to be used in the asphalt mixtures. Proposed further research works include asphalt performance tests, field trials involving on-site performance monitoring and environmental tests as well as life cycle assessment of the asphalt road pavements.

Acknowledgements

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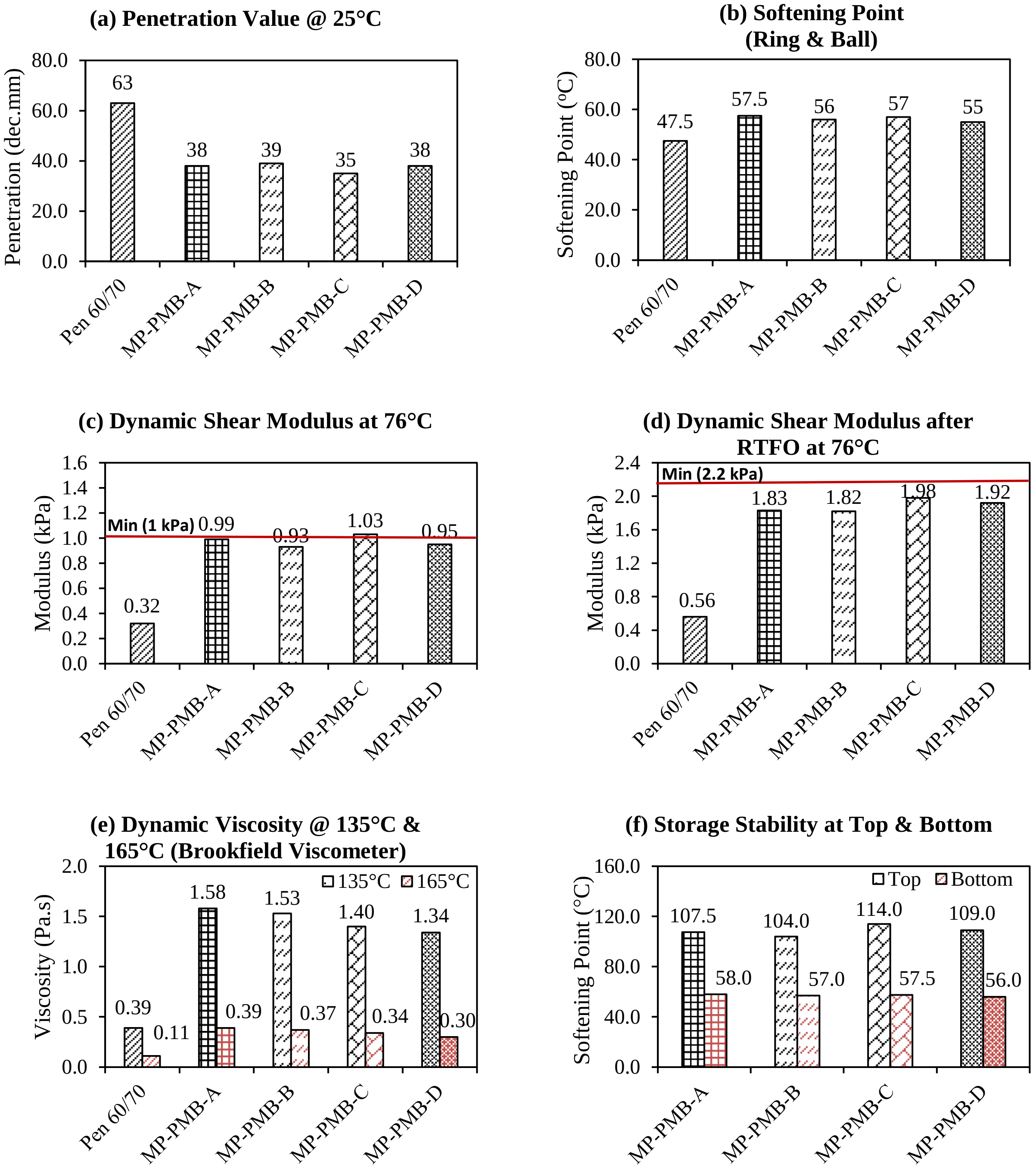

Fig.1. Binder test results.

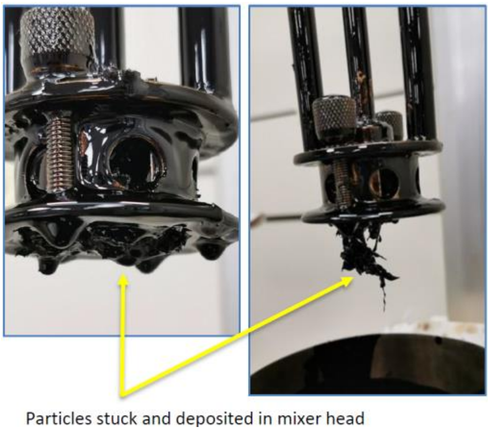

Fig.2. Visual observation during the preparation of mixed plastics binder samples.

Prediction of Illegal Dumping by Using Geographically Weighted Regression

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Construction waste, also called construction and demolition (C&D) waste, is the solid waste generated from various construction activities. When it is generated at source, C&D waste is often a mixture of multifarious compositions including inert materials (e.g., concrete, brick, tile, asphalt, stone, soil, glass, and gypsum) and non-inert materials (e.g., steel, timber, plastic, textile, paperboard, and vegetation). Understanding their specific compositions is critical for the subsequent waste management decision-making, e.g., reuse, recycling, or landfilling. However, in real-life practice, this is often an onerous task by segregating and weighting their proportions respectively. This research aims to contribute method that can predict the compositions of a C&D waste dump by combining computer vision, big data, and machine learning. The method requires three inputs, i.e., the surface image, weight, and volume of a C&D waste dump. Firstly, the surface image is leveraged for identifying waste composition types based on the computer vision technique. Then, the weight and volume are used for inferring the most possible quantity combination of identified composition types using a big data-enabled probability analysis. Lastly, the method is verified by using a large construction waste disposal data set collected from Hong Kong. Applying this method, the detailed waste composition type and respective amount can be accurately and swiftly derived. The method not only supports waste disposal facility operators to decide optimal treatment schemes, but also assist construction site managers to make appropriate waste management plans. Future research is recommended to transfer our method to other solid waste domains to enable its beneficial applications.

Keywords: Construction and demolition waste, Waste management, Composition prediction, Computer vision, Big data.

Construction & Demolition Waste Challenges – An Analysis using the Analytical Hierarchy Process

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In a developing country like India, Construction & Demolition (C&D) waste generation is very high, amounting to 150 million tonnes per annum. 35% - 40% of the global C&D waste comprises the waste generated by the Indian subcontinent. In spite of the Indian government having issues the C&D Waste Management Rules, 2016, only 1% of the total C&D waste is recycled. As the Indian construction industry is forecasted to grow at the compound annual growth rate (CAGR) of 10%, the utilization or reuse of recycled C&D waste is absolutely necessary to achieve the sustainable development goals (SDGs). Thus, there is a need for a greater reuse and recycling of C&D waste for substitution of raw materials in construction sector; further, improper disposal of C&D waste is adding to environmental pollution and loss of economy. Moreover, C&D waste often integrates with the municipal solid waste (MSW) stream to increase the burden on landfills. So, identification of criteria which are preventing proper management of C&D waste is an absolute essential to find a foolproof solution to the issue. The study has been done to assess the major parameters which pose as challenges to C&D waste management. Additionally, the analytical hierarchy process (AHP) has been used to compute the degree of threat being imposed by the parameters to identify the most critical parameter. This is done to curb the identified problem at the very root. Furthermore, it would help create more effective strategies to overcome the challenges of C&D waste management.

Keywords: C&D Waste, Sustainability, Waste management, India, AHP.

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O·PARK2

Organic Resources Recovery Centre Phase 2

Overall Project Introduction

Environmental Protection Department · AJA Joint Venture

01 Vision

To combat global warming, China officially proposed the "30 · 60" decarbonization goal in 2020. In response to the national strategy, Hong Kong has also proposed to strive to achieve carbon neutrality by 2050. The Hong Kong Government announced in 2021 the Waste Blueprint for Hong Kong 2035, setting out the vision of **"Waste Reduction · Resources Circulation · Zero Landfill"**. To achieve the goal of **"Zero Landfill"**, the Government will continue to develop waste-to-energy facilities, with a view to progressively replacing the disposal of municipal solid waste in landfills. This includes the expansion of the organic resources recovery centres to raise food waste treatment capacity, alleviate pressure and odour problem of landfills, and lower greenhouse gas emissions.

The Organic Resources Recovery Centre Phase 2 (O·PARK2) will convert food waste into electricity and fertiliser with anaerobic digestion technology to recycle food waste into renewable energy. At the same time, O·PARK2 is the **most advanced low-carbon construction project in Hong Kong** currently. During construction, the contractor applied low-carbon construction techniques and offsetting the remaining carbon emissions by purchasing carbon credits, so as to achieve carbon neutrality during construction. In operation, O·PARK2 will generate electricity with biogas, providing renewable energy for Hong Kong and reducing electricity generation by fossil fuels. In addition, it will reduce organic waste to be disposed of at landfills, helping cut down on carbon emissions.

02 Project Introduction

O·PARK2 is a representative green project implemented under **Design, Build, and Operation (DBO) mode**. The project is constructed by Alchmex International Construction Limited (Alchmex) in conjunction with the Jardine Engineering Corporation Limited and Agrivert Limited (AJA Joint Venture). After careful consideration by Environmental Protection Department (EPD), the project was located in **Sha Ling, North District**, covering an area of 2.5 hectares. O·PARK2 is the **second organic resources recovery centre** in Hong Kong. At the same time, O·PARK2 as a pilot project actively explores carbon neutrality during construction period.

03 Major Systems of O · PARK2

O · PARK2 CONSISTS OF THE FOLLOWING SEVEN MAJOR SYSTEMS:

① **Food Waste Reception and Pre-treatment System** Automated recording, efficient sorting, and retaining as many organic substances as possible

② **Anaerobic Digestion System**
Biological digestion, biogas production, and digestate recycling

③ **Biogas Purification and Storage System**
Collection by piping, dehumidification and desulfurization, storage for power generation

④ **Granulation System**
Centrifugal dehydration, digestate granulation, high-quality fertilizer production

⑤ **Combined Heat and Power System**
Biogas-to-electricity, heat recycle, self-consumption and surplus electricity exported to power grid

⑥ **Centralized Air Pollution Control System**
Enclosed operation of key equipment and facilities, negative pressure, removal of odorous compounds

⑦ **Wastewater Treatment System**
Green innovative wastewater treatment, water-recycling and energy-saving

Waste-to-Energy

Client	Environmental Protection Department
Employer's Representative	AECOM
Contract Type	Design, Build, Operation
Contractor	AJA Joint Venture
Design and Build	Commenced in 2019
Operation	Scheduled for commissioning in 2024, 15-year operation period

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