Obulisamy Parthiba Karthikeyan
Kirsten Heimann
Subramanian Senthilkannan Muthu
Editors

Recycling of Solid Waste for Biofuels and Bio-chemicals

Springer

Environmental Footprints and Eco-design of Products and Processes

Series editor

Subramanian Senthilkannan Muthu, SGS Hong Kong Limited,
Hong Kong, Hong Kong SAR

More information about this series at http://www.springer.com/series/13340

Obulisamy Parthiba Karthikeyan
Kirsten Heimann
Subramanian Senthilkannan Muthu
Editors

Recycling of Solid Waste for Biofuels and Bio-chemicals

Springer

Editors
Obulisamy Parthiba Karthikeyan
James Cook University
Townsville, QLD
Australia

Kirsten Heimann
James Cook University
Townsville, QLD
Australia

Subramanian Senthilkannan Muthu
Environmental Services Manager-Asia
SGS Hong Kong Limited
Hong Kong
Hong Kong

ISSN 2345-7651 ISSN 2345-766X (electronic)
Environmental Footprints and Eco-design of Products and Processes
ISBN 978-981-10-0148-2 ISBN 978-981-10-0150-5 (eBook)
DOI 10.1007/978-981-10-0150-5

Library of Congress Control Number: 2016942490

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer Science+Business Media Singapore Pte Ltd.

Preface

Global per capita solid waste generation has more than doubled over the first 15 years of this millennium and is expected to reach 2.2 billion tons per year by 2025, produced by 4.3 billion urban residents. As the human population is also forecasted to experience an unprecedented growth from currently ~7 to ~9 billion by 2050, the management of solid waste is becoming an increasingly pressing problem now and in near future. It is estimated that growing population will encounter food (~70 %), fuel (50 %), and freshwater (30 %) demands, resources that are already limiting in many regions of the world. Furthermore, vast ranges of chemical feedstock are also required to maintain current-day products and to meet their rates of production. The non-renewable and finite nature of the energy required for their production and destruction leads to an escalation of this spiral. Although waste generation is typically inversely correlated with level of income, developing nations forecast to produce significantly high amount of solid waste generation, as most of the expected population growth is to occur there. This places developing countries at an ever-increasing disadvantage concerning adequate infrastructure (including waste collection), accommodating growing costs of municipal solid waste management, and experiencing health issues and environmental pollution associated with current solid waste disposal practices, i.e., mainly open dumping. Moreover, globally, landfills are the third largest emitter of methane, a highly potent greenhouse gas, which is intolerable in view of climate instability (droughts and flooding) and warming global temperatures further placing immense pressure on providing food security, worldwide.

Yet, in spite of the looming threat to energy, food, and unpolluted freshwater security, globally mankind continues to dispose of on average ~1.3 billion tonnes of food waste, ~130 million tonnes of non-degradable fossil fuel-derived plastics, and 52 million tonnes of metals in landfills annually, despite the rising costs for solid waste management. Although the actual composition of municipal solid wastes are region- and income-influenced, with low-income nations having higher proportions of organic waste, their management costs for urban centers have been forecast to increase by ~80 % over the next decade to ~375 USD per annum, an increase expected to be four and five times higher in middle-income and developing nations, respectively. Significant municipal solid waste management cost increases together with the realization of wasted energy, and limits of non-renewable resources are, however, likely to sway the balance in favor of recycling approaches, which should become more cost-competitive and offer co-income development through the generation of renewable products produced in the various processes.

As municipal solid waste is complex in its composition, which varies with region and level of income, it is wise to investigate a variety of methods for recycling of solids wastes into renewable products, particularly fuel and energy. Given the above, the general undersupply of energy/fuel in developing nations, especially in rural and remote areas, offers another attractive incentive for vigorously facilitating appropriate waste recycling options in these areas. Economic (at least long term) and environmental sustainability are, however, key criteria for method implementation, irrespective of nation. In recognition of the growing problem of municipal solid waste management and finite resources of energy, this book presents strategies and case studies on waste to energy conversion options for a variety of wastes, as well as odor management arising from colocation in close proximity to residents.

Chapter "Prospects of Biomethanation in Indian Urban Solid Waste: Stepping Towards a Sustainable Future" provides a succinct overview of urbanization and waste statistics globally and for developing nations such as India. As India is predicted to be the nation with the highest population growth, emphasis is placed on hurdles that impede sustainable solid waste management and regionalized examples are provided for common undesired practices such as illegal dump sites, failed implementations including reasons why, and successful ones. It briefly introduces process technologies and their advantages and disadvantages for managing solid wastes. The focus of this chapter is biomethanation (anaerobic digestion) of solid waste. Therefore, this chapter describes the different stages of microbial degradation of organic wastes and parameters that influence the digestion process, including operational parameters and anaerobic digester types. This chapter closes in detailing efforts undertaken by the Indian government to enable an organic waste to energy program and describes anaerobic digester types designed for volumes of organic waste generated in rural and suburban locations around India aiming to service the immediate need for energy of these communities and larger projects for energy generation between 5 and 7 MW funded by the Indian government. This chapter concludes that biomethanation is a sustainable solution for reducing organic wastes, which requires assistance through government funding, policies, private and public sectors, and education/participation by the public for implementation.

Chapter "Status and Prospects of Municipal Solid Waste to Energy Technologies in China" reviews municipal solid waste (MSW) management to energy strategies applied in China, the world's largest developing country. It strategically compares global advances with the current status in China. China's MSW management has to cope with rapid urbanization accompanied by a large increase in MSW generation due to improved living standards, which also result in sharply rising energy demands. MSW management has only recently been adopted in China (over the last 30–40 years) and is characterized additionally by large scales and rapid increase in waste generation. This chapter provides a concise treatment of factors influencing waste classification in different regions of China and the implementation of a zero-waste hierarchy aiming to reduce MSW through separating waste for recycling, reuse, and waste to energy types at the source. With landfilling representing around 70 % of the countries MSW management strategy, technical differences between the four main types are summarized. As energy generation from waste is the driver of China's MSW strategy, this chapter discusses the combined heat to power generation approaches at landfills and regional deployment of particular incinerator types. It discusses government responsibility for managing MSW, policies, and regulations, as well as economics and incentives for waste to energy approaches.

Chapter "GHGs Emissions and Sustainable Solid Waste Management" focuses on greenhouse gas (GHG) emissions emanating from waste management practices and impacts on climate. It provides an introduction on greenhouse gas emissions and climate consequences and highlights the flow on effects of increased urbanization and waste generation of the global population. It reviews zero-order and first-order models for waste generated GHG emissions and applies these to case studies of Panama and Thailand and Chennai, India, respectively. Based on the case studies, it is concluded that zero-order models are inaccurate compared to first-order models; however, zero-order models can provide estimates in situations were solid waste management data sets are not available. It reviews life cycle analyses to evaluate effects of solid waste management options on GHGs emissions. It is demonstrated that source reduction and recycling have significant GHG emission savings. For solid waste management of OECD countries, it is shown that mechanical biological treatments and incineration coupled with waste to energy recovery are the most promising approaches for reducing GHG emissions. Pyrolysis of waste materials and the production of biochar and renewable energy are identified as another promising approach for lowering GHG emissions from the agricultural sector. It evaluates landfill gas collection for case studies in Thailand, mechanical biological treatment in China and Nigeria, and gasification, landfill gas, and anaerobic digestion technologies in Indonesia. It is shown that all test methods yield significant reductions in GHG emissions. This chapter concludes that skilled human resources, technical capacities, and enforcement of national policies are the main obstacles for the implementation of GHG emission-conscious solid waste management practices, particularly in developing nations.

Chapters "Recent Advances of Anaerobic Digestion for Energy Recovery" and "Anaerobic Digestion of Solid Waste: A Focus on Microbial Community Structures" review treatment of organic waste by anaerobic digestion in detail. The process, i.e., the degradation phases occurring stepwise in the degradation process, is introduced in detail, as are system and system efficiencies and improvements, incorporation of efficiency monitoring through process analytical technologies, and details molecular tools to evaluate the microbial community, the latter being one of the drivers for system performance and management. As the efficiency of the anaerobic digestion process is strongly influenced by temperature, type of feedstock, pH level, retention time, carbon to nitrogen (C/N ratio), and volatile fatty acid (VFA) concentration, these factors are discussed. With regard to temperature, the review identifies that a phase-separated system (e.g., thermophilic followed by mesophilic conditions) would be beneficial for achieving higher biogas production. Anaerobic digestion systems are introduced with regard to feedstock applicability, advantages, and draw backs and are divided into wet/low residual solid reactors and dry/high residual solid systems. Regardless of the system, hydrolysis efficiency is identified as the rate limiting step. These chapters discuss mechanical, ultrasonic, thermochemical, and microbial/enzymatic pretreatments and their efficiencies in increasing the bioavailability of complex organic matters to microbes and phase-separated system approaches to increase biogas yields. Chapter "Recent Advances of Anaerobic Digestion for Energy Recovery" introduces anaerobic digestion systems and identifies phase-separated systems to improve the efficiency of the process. Retention time directly impacts on efficiency, the pros and cons of upflow anaerobic sludge blanket, expanded granular sludge bed reactors, attached growth reactors, membrane reactors, and hybrid models. Ultimately, however, the microbial community composition governs the efficiency of the entire complex process, which is the focus of Chapter "Anaerobic Digestion of Solid Waste: A Focus on Microbial Community Structures" for the different phases. As such, monitoring of changes to these would benefit models that can then be used to calculate efficiencies. Both chapters detail several molecular techniques suitable for obtaining these detailed inputs for improving process efficiencies. In addition, Chapter "Anaerobic Digestion of Solid Waste: A Focus on Microbial Community Structures" presents techno-economic outcomes of a pilot- and industrial-scale case study and for the anaerobic digestion of food waste, which in both cases proved profitable.

Chapter "Recycling of Livestock Manure into Bioenergy" reviews the outcomes of anaerobic digestion of pig, cattle, and poultry manure and details changes in the microbial communities at different stages of the process. The details of animal head production per country are detailed based on 2013 data, with manure production being calculated. The literature is reviewed with regard to meso- and thermophilic cattle manure biogas production under single feed with cofeeding conditions and a two-phase system operating a pretreatment step at 68 °C and a formal methane yielding phase at 55 °C. For single mesophilic pig manure digestion, the review suggests applying grass silage to pig manure ratio of 1:1, resulting in reduced lag times and increased biogas yields. For chicken manure due to the high ammonia levels, ammonia-stripping is recommended, as the study shows that continuous stirred tank reactors can then be operated under both meso- and thermophilic conditions. Under high ammonia, the mesothermic anaerobic digester showed a much more resilient microflora, as the system recovered after inhibition in contrast to the thermophilic one. This chapter closes in providing a proposed chicken manure anaerobic treatment path, providing potential energy yields for sustainable electricity and thermal heat generation.

Indonesia and Malaysia are the biggest palm oil producers, globally, and the negative environmental and ecological impacts have been discussed for a long time, in particular when considering production of biodiesel from palm oil. This approach has now been suspended, as palm oil has a myriad of applications for products fetching a much higher market value. In this light, Chapter "Anaerobic Digestion of Palm Oil Mill Residues for Energy Generation" presents a review of energy generation of palm oil mill effluent using anaerobic digestion. To describe the palm oil mill effluent characteristics, this chapter introduces the reader first to palm oil production pathway, before introducing the palm oil mill effluent treatments. It presents an evolutionary perspective from treatment of effluents in open lagoon pond systems with a primary focus on treatment of the wastewaters to meet requirements for discharge to more advanced and controlled anaerobic systems aiming to provide renewable energy as an additional benefit to treatment of wastewaters for discharge purposes. This chapter details benefits of biogas recovery and puts in perspective the importance of emission trading schemes, i.e., provided through the Kyoto Protocol until 2012, for modernization of anaerobic digestion approaches for bioenergy recovery from oil palm mill effluents in developing nations.

A case study on the benefits of leachate recirculation in BioReactor Landfill (BRL) is presented in Chapter "Landfill Bioreactor Technology for Waste Management". It is demonstrated that leachate recirculation positively affects waste stabilization reducing required times by >90 % and thereby reducing the risk of environmental impacts through accidental leachate leakage, which typically increase with the time required for the stabilization process to complete. This chapter details leachate recirculation also increase volumes of biogas produced, making biogas recovery economically attractive. Primary areas of consideration are that no landfill will equal another, and, as such, leachate recirculation specifics must be designed with the waste composition in mind. The case study presents a leachate recirculation waste stabilization laboratory assessment using a trickle bed reactor. Predicted outcomes are based on modeling on biogas yields and production times for landfills characterized by low biodegradable wastes.

Ammonia–nitrogen contents and removal are key issues in bioreactor landfill operations, significantly influencing monitoring requirements and affecting reclamation. Chapter "Biotransformation of Nitrogen in Landfills" focuses on laboratory- and field-scale application case studies for using novel mechanisms such as SHARON (Single reactor system for high activity ammonia removal over nitrite), ANAMMOX (Anaerobic Ammonium Oxidation), CANON (Complete Autotrophic Nitrogen removal Over Nitrite), and OLAND (Oxygen Limited Autotrophic Nitrification and Denitrification) for the removal of ammonia-nitrogen. With a total nitrogen removal of 84 % and ammonia–nitrogen removal efficacy of 71 % at nitrogen loading rate of 1.2 kg N/m^3/day over 147 days, a combined process of SHARON–ANAMMOX yields promising results for waste nitrogen management of leachates in bioreactor landfills, although full-scale in situ operation still needs to be demonstrated and the effect of environmental parameter fluctuation on the combined processes still require further research.

In addition to waste management and renewable energy issues, both being pressing problems for mankind, the economical production of renewable hydrocarbons for conventional combustion engines also needs urgent attention. Chapter "Biofuel Production Technology and Engineering" discusses butanol production from organic waste using fermentation by Clostridia bacteria and its use as a potential hydrocarbon additive/replacement of conventional fossil fuel-derived petroleum. While some *Clostridium* wild-type species can hydrolyze lignocellulose directly, these are not the strains capable of the acetone–butanol–ethanol (ABE) producing pathway, making them unsuitable for the renewable butanol biofuel market. This chapter introduces mathematical models that can simulate potential outcomes of different processes. For example, it is shown that in a three-stage continuous stirred tank reactor, decreasing dilution rates led to a 120 % improvement on butanol yields but also resulted in lower productivity. It remains to be seen which factor, butanol yield and ease of purification or productivity, governs production cost. This chapter highlights the need for a system-integrated approach for evaluating the suitability and economics of the ABE process under different configurations for the production of butanol from organic municipal solid waste.

Chapter "Fast Pyrolysis of Agricultural Wastes for Bio-fuel and Bio-char" deals with another approach of managing solid waste, fast pyrolysis of waste, which yields liquid biofuel, which can also be used for the production of chemicals, and an additional product, biochar. This chapter discusses reactor types for fast pyrolysis the properties, challenges, and opportunities for the bio-oil and biochar, the current status of fast pyrolysis applications, and the energy and economics of the process. Configuration, differences, and application advantages/disadvantages are discussed for bubbling fluidized bed, circulating fluidized bed, rotating cone, augur, and ablative reactors, and novel configurations, such as vacuum pyrolysis, fixed bed, entrained flow reactors, microwave pyrolyzer, plasma, and solar reactors. The most marketable reactor designs are bubbling fluidized bed, circulating fluidized bed, and auger reactors, with fluidized bed reactors producing higher bio-oil yields compared to auger reactors. Bio-oil properties are summarized against engine performance and fuel standard criteria for combustion engines. Although bio-oil is more suitable industrial burners, due to the high acidity, viscosity, oxygen and water contents, and heterogeneity of contributing compounds, it can still be used in pilot-ignited medium-speed diesel engines, provided, due to the corrosiveness of bio-oil, injector and fuel pumps are made of stainless steel. Following a brief description of bio-oil-derived chemicals and benefits of biochar applications in agriculture, this chapter explores upgrading technologies for the production of renewable fuels, providing a summary of companies using fast pyrolysis technology for drop-in fuel production from bio-oil.

Chapter "The Energy and Value-Added Products from Pyrolysis of Waste Plastics" presents advancements made in the pyrolysis of plastic waste for the generation of energy and value-adding coproducts. Although renewable fuel yields of 80 % with similar characteristics as diesel are possible under catalytic pyrolysis conditions, challenges still exist in converting plastic waste to renewable fuel, activated char for the remediation of industrial waste waters, heat storage, metal removal, etc. Based on a case study of the Kingdom of Saudi Arabia, these challenges are identified as high temperatures and retention times, catalyst cost, and performance improvements, which require improvement to make the pyrolysis of plastics more environmentally and economically favorable.

Chapter "Turning Food Waste into Biofuel" reviews waste to energy conversion of food waste, as the annually generated food waste amounts to ∼1.3 billion tonnes or 1/3 of wastage of the overall human food production, representing a gross underutilization of energy-rich organic resources. Food waste is a valuable resource for bioenergy (methane, hydrogen, ethanol), bioplastics, and high-value bioproducts (organic acids and enzymes), but given the global challenges of meeting the future energy demands of the rapidly growing human population, this chapter places emphasis on techniques suitable for renewable fuel production (direct and microbial transesterification to biodiesel, production of ethanol via enzymatic pretreatment and microbial fermentation primarily by the yeast *Saccharomyces cerevisiae*, and microbial hydrogen and methane production). Review of life cycle analyses of bioethanol, biohydrogen, and methane production determined that greenhouse gas emissions are reduced by more than 50 %, but the processes are not sufficiently mature for incorporation into waste management. Particularly, evaluation of coproduct generation potential is required for economic sustainability.

Chapter "Solidification and Stabilization of Tannery Sludge" presents results on solidification and stabilization of tannery wastewater sludge from the leather industry, a process required to minimize adverse environmental impacts of the hazardous tannery agent chromium(III). Hazardous chromium(III)-containing wastewaters when treated produce hazardous primary and secondary sludge, with disposure in secure landfills. Increasing environmental safeguarding and space constraints in India make secure landfilling of this sludge is problematic. Data obtained for short- and long-term leaching tests show that chromium can be successfully encapsulated in a cement–lime sludge mixture, allowing the materials obtained to be utilized as alternatives to conventional construction materials, rather than requiring deposition in secure landfills.

Odor complaints from municipal solid waste management sites are a common complaint by nearby residents, and perception by the public often leads to problems in choosing sites. Therefore, odor management is as critical as management of solid wastes. Chapter "Odour Pollution from Waste Recovery Facilities" reviews odor compounds generated by MSW treatment using anaerobic digestion, incineration and refuse to fuel conversions, and odor control technologies. It summarizes odor measurement regulations in different countries, standards, and assessment strategies, i.e., how assessment needs to be conducted for different odor sources, e.g., point sources such as stacks and plumes, and area sources such as ponds. Odor treatment technologies discussed are biofilters packed with either organic or synthetic materials, wet scrubbers, and thermal or chemical oxidation, which are all equally effective. This chapter concludes that potential downstream environmental impacts of these odor control technologies require additional research.

As detailed, this book presents a solid background and method review for students and researchers in the municipal solid waste to energy conversion field. Additionally, synthesised details on current limitations to technologies and case study afford a great data reference for experts in the field of “solid waste management.”

Townsville, Australia Obulisamy Parthiba Karthikeyan
Townsville, Australia Kirsten Heimann
Hong Kong Subramanian Senthilkannan Muthu

Contents