Current Trends in Biomedical Engineering & Biosciences
ISSN: 2572-1151

Review Article
Volume 7 Issue 4 - August 2017
DOI: 10.19080/CTBEB.2017.07.555719

Curr Trends Biomedical Eng & Biosci

Sustainable and Cost-Effective use of Organic Waste

Salah Elhaggar[1]* and Hala Omar[2]

[1]*Mechanical Engineering Department, The American University in Cairo, Egypt*

[2]*Mechanical Engineering Department, The American University in Cairo, Egypt*

Submission: February 12, 2017; **Published:** August 24, 2017

***Corresponding author:** Salah Elhaggar, Mechanical Engineering Department, The American University in Cairo, Parcel 8, 74 S El-Teseen St, NEW CAIRO, Cairo, Cairo Governorate 11835, Egypt, Email: elhaggar@aucegypt.edu

Abstract

The rapid population, industrialization, urbanization and change in consumption patterns have contributed to an increase in the amount solid waste generation. A large portion of generated waste is organic waste. Organic wastes are animal and plant based materials as well as degradable carbon such as paper, cardboard and timber. Traditional waste management techniques such as incineration and/or land filling are very expensive and lead to depletion of natural resources. With the growing concerns over environmental issues and escalating costs related to waste management, there has never been a greater need for sustainable and cost-effective methods to recycle organic wastes than there is today. This paper reviews different simple, sustainable and cost-effective methods to utilize organic wastes. It focuses on composting and biogas techniques and also briefly summarizes briquetting and animal fodder. These technologies not only reduce the amount of disposed organic wastes, but also conserve natural resources, protect the environment and public health, produce useful products, and create job opportunities.

Keywords: Sustainability; Organic waste; Composting; Biogas; Briquetting; Animal fodder

Introduction

Industrialization, urbanization and population growth coupled with changes in consumption patterns and growth in resource consumptions have led to scarcity of natural resources and generation of huge amounts of wastes. According to World Bank report in 2012, 1.3billion tons of municipal solid waste (MSW) was generated per year by 3billion urban residents all over the word, which will increase to 2.2billion tons by 2025 [1]. MSW mainly consists of food waste, paper and paperboard, yard trimmings, wood, plastic, metal, and glass. However, its composition differs depending on regions and countries in which it is collected. Around 15billion tons of waste, like crops residues and animal manure, is generated worldwide annually from the agricultural sector [2]. Egypt generates around 20.5million tons of MSW per year [3]. In Pakistan a study by the Ministry of Environment and Urban Affairs revealed that 1.9 to 4.29kg of waste are generated per household per day [4]. India generates around 50million tons of MSW every year [5]. The largest component of municipal solid waste is organic material especially in developing countries. Organic wastes are animal and plant based materials as well as degradable carbon such as paper, cardboard and timber. According to Wong et al. solid waste constitutes 30 to 55% of food by weight in different countries [6], in Egypt it constitutes 60% [7], and in India 50% [6].

Proper solid waste management is costly. For example, Asian countries only spent 25billion US dollars on solid waste management, which is expected to rise up to 50 billion US dollars annum by 2025 [5]. Traditionally, wastes are disposed of either through land filling and/or incineration. Incineration is a process in which solid waste is burnt and converted to ash. The main benefit of incineration is to considerably reduce the amount of solid waste. Also, the solid waste and/or ash produced from incineration are usually land filled. Land filling process requires durable and puncture resistant material to be used as a liner, usually polyethylene, high-density polyethylene and polyvinyl chloride. It also needs coverage for the landfill, a leachate collection system, biogas collection system as well as a storm water drainage system. These practices require high capital and running costs and most importantly contribute to the depletion of natural resources [3,8-10]. Many countries have drafted and adopted several environmental protections laws and regulations. Yet, in many developing countries these disposal techniques and environmental protection procedures are a burden and not properly implemented. Instead, most of the wastes generated are either burnt or end up in open, public and random dumpsite or water canals, which contribute to the heath, ecological and environmental problems especially in rural areas. There has been growing awareness that the natural resources are finite leading to increasing calls for development of sustainable solutions [11-13].

The concept of sustainability has emerged during the United Nations Conference on Human Environment in 1972. The term "sustainable development" gained popularity after the publication of Brundtland Report, 'Our Common Future', by the World Commission on Environment and Development (WCED). This report defined sustainable development as the "development that meets the needs of the people today without compromising the ability of future generations to meet their own needs" [14]. Since then, there have been substantial efforts to define and implement the concept of sustainability. Therefore, waste reduction and recycling has been encouraged in different forms. The aim of this paper is to present different cost-effective and efficient recycling techniques of organic waste with an emphasis on composting, biogas technologies and a brief summary of briquetting and animal fodder.

Composting

Composting is the process of deliberately breaking down or decomposing complex organic matters into simple substances that can then be used as plant nutrients via aerobic fermentation by bacteria. This process occurs in nature, called rotting, but slowly. The objectives of composting are to accelerate and create optimum conditions for the naturally occurring decomposition process to take place. Composting is a sustainable and environmentally viable solution to biologically transform huge amounts of organic wastes into useful product using microorganisms.

In the composting process organic waste with certain oxygen and moisture content is digested by bacteria and is converted into soil conditioner. The most important factors that influence the decomposition process of organic wastes include:

a) Carbon to nitrogen (C: N) ratio

b) Moisture content

c) Temperature and

d) Oxygen

C: N ratio

The most important nutrients that microorganisms require for the decomposition of organic matter are carbon (C) and nitrogen (N). Studies showed that the optimum C: N ratio is 30: 1. However, C: N ratios between 26 and 35 [15] and 20 and 40 [16] were also reported. If the C: N ratio is low (i.e. the carbon content is low) nitrogen is lost in the form of ammonia as microbes have not enough energy (carbon) to consume nitrogen. If the C: N ratio is too high, the decomposition process will take longer [7-16]. Other nutrients such as phosphorus, potassium, sulfur, and micronutrients are also essential for microbiological growth.

Moisture

A minimum moisture level is required in compost pile as microorganisms live on water and also keeps nutrients in solution so that microbes can consume them. Studies showed that the ideal moisture content is 40% to 60% [3-16]. If the moisture content is higher than 60% compost piles will emit odors. If the moisture content is lower than 40% the microbial activity slows down and become dormant [7]. Water can be added to compost piles manually or maintained by open loop control of water [17]. Some studies suggest the use of moisture absorbent to adjust the initial moisture content for successful composting [16,18].

Temperature

The composting process involves two populations of bacteria that results into two temperature ranges: mesophilic and thermophilic. The initial compost temperature stage (mesophilic) ranges from 20 to 45 °C. When thermophilic bacteria takes over, the temperature rises to 50 to 70 °C. During the bacterial activity heat is generated at the center of the compost pile then temperature cools to ambient temperature as organic matters are consumed. When the temperature decrease the pile should be turned to introduce un-decomposed material at the center of the pile. The high temperature is a sign of vigorous microbial activity and this high temperature is important to kills weeds, ailing microbes, and diseases including Shengella and Salmonella [16]. The ambient temperature is affecting the composting process; in fact, in winter the process is slower compared to during spring and summer.

Oxygen

Composting is an aerobic fermentation process; therefore, it requires continuous oxygen supply. Oxygen can be supplied by (a) simply turning the piles (natural composting), (b) having perforated pipes in the compost pile to distribute air uniformly (passive composting), or (c) equip pipes with blowers to force air flow into the compost piles (forced aeration).

Composting Process

Composting is one of the most popular techniques used to recycle organic waste. The composting process consists of: (1) adding microorganisms and feedstock to organic waste to ensure a C: N ratio of 30: 1, (2) continuous supply of oxygen, and (3) water to keep moisture content of 40% to 60%. The compost pile generates heat, water and carbon dioxide during the process. At the end soil amendments is produced from different organic material, which normally would be wasted. Compost can then be adjusted by adding natural rocks such as phosphate (source of phosphorus), feldspar (source of potassium), dolomite (source of magnesium), etc. to produce organic fertilizer for organic farming [7].

The major challenge of traditional composting process is that it is slow, it can take from three to six month to produce high quality compost. Hence, studies are still needed to produce high quality and cost effective compost in short period of time. Some research has been conducted to accelerate the degradation process via shredding and frequent turning, forced aeration and mechanical turning, use of mineral nitrogen compounds,

How to cite this article: Salah E, Hala O.Sustainable and Cost-Effective use of Organic Waste. Curr Trends Biomedical Eng & Biosci. 2017; 7(4): 555719. DOI: 10.19080/CTBEB.2017.07.555719.

effective and cellulolytic microorganism, use of worms, addition of fungal and bacterial cultures [4,6,19,20], but some of these methods are still disputable.

Biogas

Biogas technology is a biological method for degrading and stabilizing organic, biodegradable raw materials in special plants under controlled condition. It is based on microbial activity that occurs in oxygen-free (anaerobic) conditions and results in two end-products: (1) biogas and (2) digestion residue known as digestate. Biogas is a mixture of methane and carbon dioxide. Methane is the component chiefly responsible for a typical calorific value of 21–24MJ/m^3 or around 6kWh/m^3 [21]. Biogas is a clean, efficient and renewable source of energy that can be used as a substitute for natural gas or liquefied petroleum gas. The digestate can be utilized as a fertilizer because of its high nutrition content available to plants [22].

During the anaerobic fermentation process several different microbial degradation steps occurs as follows:

I. Hydrolysis stage in which microorganisms excrete hydrolytic enzymes that decomposed complex organic matter (polymers) like carbohydrates, proteins and lipids, into smaller units (monomers and dimers).

II. Acidogenesis stage in which hydrolysis products are then converted into methanogenic via acidogenic (fermentative) bacteria. In this process, simple sugars, amino acids and fatty acids are degraded into acetate, carbon dioxide and hydrogen (70%) as well as into volatile fatty acids (VFA) and alcohols (30%)

III. Methanogensis stage in which methanogenic bacteria produce methane and carbon dioxide. Methanogenic bacteria degrade acetate to produce methane also this bacteria convert hydrogen and carbon dioxide into methane.

There are different designs of biogas digesters that have been developed including

a) Chinese fixed dome digester,

b) Floating drum digester, and

c) Bag digester.

Chinese fixed dome digester

Chinese fixed dome digester was first developed in China in 1936 and is also known as “drum less digester” [23]. It consists of a fixed (non-movable) dome (or well) made out of concrete, which sits on the top of the digester to collect generated gas. A feed tank takes raw material and forces it to move to the fermentation reservoir to be digested. When the gas production starts, the slurry expands and overflows into the overflow tank to store digestate. The digester design is simple and does not have any moving parts making it easy to construct and operate. It is usually built underground making it well insulated but difficult to access for cleaning or maintenance purposes. In this method methane is pushed out of the fermentation reservoir by the pressure of newly produced methane. Hence, the gas pressure coming out of the digester is subject to large fluctuations making it difficult to use in applications requiring constant energy supply [24].

Floating drum digester

Floating drum digester was first developed in India in 1956 by Jashu [23]. It consists of a cylindrical dome shaped digester made of stainless steel. Unlike fixed dome digester, the dome is moveable and floats to collect gas generated. If biogas is produced the drum moves up, if gas is consumed the gasholder sinks back. The drum has a guiding frame to prevent it from tilting. Similar to the fixed dome digester, the pressure of the gas coming out of the floating drum digester cannot be maintained at a specific value. However, the design is easy to maintain due to the presence of the movable part. The lifetime of the drum is shorter and more expensive compared to fixed dome digester [23].

Bag digester

The most common type of bag digester is plastic bag digester and was developed by Union Industrial Research Laboratories in Hsinchu, Tawian. The reactor is made out of Red Mud Plastic (RMP), which is a mixture of PVC and red mud generated from the production of aluminum [25]. Another type of bag digester is the balloon digester. In this arrangement, the digester is made of plastic or rubber like. The advantage of this design is that the skin of the balloon is thin and flexible so the skin slightly moves resulting into agitation of fermentation slurry. This is favorable for digestion process. Bag digesters seem to be a competitive option in terms of cost. However, research is still needed to study its durability as well as its potential for increasing its performance.

Biogas challenges

Many types of organic waste can be utilized to produce biogas. However, the amount of biogas generated strongly depends on the waste composition and biodegradability. According to Moller et al, the highest biogas yield can be achieved from lipids (1.01Nm^3 CH_4/kg of Volatile Solids), followed by proteins (0.5Nm^3 CH_4/kg of Volatile Solids), and carbohydrates (0.42Nm^3 CH_4/kg of Volatile Solids) [26]. The degradability is also important as it defines the amount of material used during the process [27]. Although lignocellulosic is abundant, accounts for 50% of the biomass worldwide or 200 billion tons per year, and have high carbohydrate content, it degrades at very low rates [27]. Therefore, studies are still needed to develop a cost-effective initial pretreatment step to convert the raw material to an amenable form to microbial and enzymatic degradation. Some pretreatment methods were suggested including physical treatments like milling, physicochemical, chemical and biological treatments [28-32] yet, these treatments are not always efficient

How to cite this article: Salah E, Hala O.Sustainable and Cost-Effective use of Organic Waste. Curr Trends Biomedical Eng & Biosci. 2017; 7(4): 555719. DOI: 10.19080/CTBEB.2017.07.555719.

and in some cases chemical agents can inhibit microbial activity [33].

Another challenge facing biogas production is lack of full understanding and control of the complex microbial activity occurring during the process. As previously mentioned anaerobic digestion process involves a synchronized action of different groups of microorganisms with different metabolic capabilities. Hence, more studies are needed to understand the microbial communities and their function in connection with different aspects of anaerobic degradation to be able to optimize the anaerobic digestion process [27].

Another important limitation to the spread of the biogas technology is lack of financial capabilities to invest in biogas plants among poor farmers in rural areas remain one of the biggest challenges. Even though biogas plants are considered a cheap source of energy it requires a capital cost that could be high for many farmers. Experience in countries such as Nepal and Vietnam has shown that government support as well as subsidies helps increase the number of biogas plants constructed [20,27].

Other Utilizations of Organic Wastes

Animal fodder

An easy and cost-effective way to utilize organic waste is to produce animal fodder. Several developing countries are confronted with deficiency of animal foodstuffs, which causes reduction in animal production. To overcome this deficiency, raw material for animal foodstuff is imported at inherent high cost. Hence, transforming agricultural wastes into animal foodstuffs can help in overcoming this deficiency. This is done via mechanically and chemically treating agricultural waste to turn tough and big material into an easily digestible form [7].

Mechanical treatment consists of chopping, shredding, grinding, moistening, soaking in water and streaming under pressure. However, mechanical methods require high capital and running cost, which make them not widely spread. Chemical treatment of agricultural waste with urea or ammonia was proven to be more feasible. It is reported that good quality animal fodder can be obtained by injecting ammonia or urea to the mass of waste [7,34,35]. The treated waste is then covered with a 2mm thick polyethylene wrapping material for 2 weeks in summer and 3 weeks in winter. Finally, the treated material is uncovered and left for 2 to 3 days to release all remaining ammonia before using it as animal feed [7].

Briquetting

Briquetting consists of collecting combustible material like agricultural waste that are not useable due to lack of density and compressing them into solid fuel of a convenient shape that can be burned like wood and charcoal. Agricultural waste has two main disadvantages that prevent it from being directly used as fuel. The first problem with agricultural waste is that it burns rapidly and it is difficult to maintain a steady fire for a long period. The second problem is that agricultural waste has a form and structure that is not suitable to be used in traditional coal pots and stoves. To overcome these issues the briquetting process involves the following steps:

I. Reducing the size of organic waste material by chopping, crushing or shredding,

II. Drying the raw material usually by subjecting it to sun rays

III. Mix raw material with a binding material like natural or synthetic resins, tar, animal manure, or sewage mud to produce feed stick.

IV. Compacting material using compaction or extrusion techniques

Briquetting is a very attractive method to recycle agricultural waste as it is an easily, understandable technology and simple to operate. In the briquetting process unused material is compressed to form relatively high-density solid fuel to be used for domestic and/or industrial applications. Briquettes are also easy to use, transport and store. Briquetting will help decrease the volume of waste causing many environmental disasters and produce efficient solid fuel of high thermal value. It was reported that some developing countries including India, Thailand, and some places in Africa have tried substituting fuel wood and coal with fuel briquettes to overcome the firewood shortage and farm waste disposal problems [7].

Conclusion

Organic waste constitutes a large portion of generated wastes. Traditional methods to dispose of organic wastes like incineration and land filling are expensive and require large lands causing a huge economic burden on some countries, especially developing countries. Therefore, it is essential to improve and develop cost-effective technologies to recycle organic waste into useful products. This review clearly indicates that composting and anaerobic digestion is effective biological techniques to treat a wide variety of organic wastes. Composting transforms organic wastes into bio-fertilizers and soil conditions minimizing chemical fertilizer demand. Anaerobic digestion transforms organic fertilizer into biogas, which is a clean, efficient and renewable source of energy that can be used as a substitute for natural gas or liquefied petroleum gas. Research is still needed to fully understand, control and optimize the complex microbial activity occurring during these processes.

In addition to the individual efforts and researches in applying and improving waste recycling techniques, it is essential that research institutes, environmentalists, policy makers, society and business community collaborate together to implement these sustainable and cost-effective waste management techniques, especially in developing countries. These ideas need to be studied by academic institutions and research centers. The business community needs to implement these techniques and

How to cite this article: Salah E, Hala O.Sustainable and Cost-Effective use of Organic Waste. Curr Trends Biomedical Eng & Biosci. 2017; 7(4): 555719. DOI: 10.19080/CTBEB.2017.07.555719.

create new types of industries. The government needs to support these concepts by developing and reinforcing strict rules and/or laws that prohibit land filling and incineration to make these industries more appealing to entrepreneurs. It is imperative that the proposed solutions utilize available and obtainable technologies and be compatible with social and environmental norms of each country. These technologies not only reduce the amount of disposed organic wastes, but also conserve natural resources, protect the environment and public health, produce useful products, and create job opportunities.

References

1. Hoornweg D, Thomas L (1999) What a waste: solid waste management in Asia. The World Bank.
2. Donkin SS, Doane, Perry H, Cecava, Michael J (2013) Expanding the role of crop residues and biofuel co-products as ruminant feedstuffs. Animal Frontiers 3(2): 54-60.
3. Elfeki M, Tkadlec E (2015) Treatment of municipal organic solid waste in Egypt. Red, Journal of Materials and Enviromental Science 6(3): 756-764.
4. Ali U, Khalid A, Mahmood T, Aziz I (2013) Accelerated biodegradation of solid organic waste through biostimulation. Proceedings of the Pakistan Academy of Sciences 50(1): 37-46.
5. Sarkar S, Pal S, Chanda S (2016) Optimization of a vegetable waste composting process with a significant thermophilic phase. Procedia Environmental Sciences 35: 435-440.
6. Wong JWC, Fung SO, Selvam A (2009) Coal fly ash and lime addition enhances the rate and efficiency of decomposition of food waste during composting. Bioresour Technol 100(13): 3324-3331.
7. Haggar El S (2007) Sustainable industrial design and waste management: cradel-to-cradle for sustainable development. Elsevier Academic Press, USA.
8. Haggar El, Salah M (2009) Industrial Solid Waste Utilization and Disposal. In: Nemrow N, Agardy F, Sullivan P, Salvato J, (Eds.), Environmental Engineering: Environmental Health and Safety for Municipal Infrastructure, Land Use and Planning, and Industry, (6th edn), John Wiley & Sons Hoboken, New Jersey, United States Inc, USA, pp. 1-81.
9. Tammemagi H (1999) Waste Crisis: Landfills, Incinerators, and the Search for a Sustainable Future. Oxford University Press.
10. Nemerow, Nelson L (1995) Zero Pollution Industry: Waste Minimization Through Industrial Complexes. John Wiley & Sons Hoboken, New Jersey, USA.
11. O'Riordan T (2004) Environmental science, sustainability and politics. Transactions of the Institute of British Geographers 29 (2): 234-247.
12. Tudor T, Adam E, Bates M (2007) Drivers and Limitations for the Successful Development and Fuctioning of EIP (Eco-Industrial Parks) A Literature Review. Ecological Economics 61(2-3): 199-207.
13. Dunn B, Steinemann A (1998) Industrial Ecology for Sustainable Communities. Journal of Environmental Planning and Management 41(6): 661-672.
14. (1987) World Commission on Environment and Development: Our Common Future. Oxford University Press: New York, USA.
15. Kumar S (2011) Composting of municipal solid waste. Critical reviews in biotechnology, 31(2): 112-136.
16. Misra RV, Roy RN, Hiraoka H (2016) On-farm composting methods. Rome, Italy: UN-FAO.
17. MacGregor ST, Miller FC, Psarianos KM, Finstein MS (1981) Composting process control based on interaction between microbial heat output and temperature. Appl Environ Microbiol 41(6): 1321-1330.
18. Lu Y, Wu X, Guo J (2009) Characteristics of municipal solid waste and sewage sludge co-composting. Waste Management 29(3): 1152-1157.
19. Salinas Martínez A, De los Santos Córdova M, Soto Cruz O, Delgado E, Pérez Andrade H, et al. (2008) Development of a bioremediation process by biostimulation of native microbial consortium through the heap leaching technique. J Environ Manage 88(1): 115-119.
20. Sadik MW, El Shaer HM, Yakot HM (2010) Recycling of agriculture and animal farm wastes into compost using compost activator in Saudi Arabia. J Int Environmental Application & Science 5(3): 397-403.
21. Bond T, Michael RT (2001) History and future of domestic biogas plants in the developing world. Energy for Sustainable development 15 (4): 347-354.
22. Ward AJ, Hobbs PJ, Holliman PJ, Jones DL (2008) Optimisation of the anaerobic digestion of agricultural resources. Bioresour Technol 99(17): 7928-7940.
23. Ramatsa MI, Esther TA, Daniel MM, Robert H (2014) Design of the bio-digester for biogas production: A review, Proceedings of the World Congress on Engineering and Computer Science, San Francisco 2.
24. Rajendran K, Aslanzadeh S, Taherzadeh M (2012) Household Biogas Digesters-A Review. Energies 52911-2942.
25. Nijaguna BT (2006) Biogas technology. New Age Internationa006C.
26. Møller HB, Sommer SG, Ahring BK (2004) Methane productivity of manure, straw and solid fractions of manure. Biomass and bioenergy 26(5): 485-495.
27. Horváth IS, Tabatabaei M, Karimi K, Kumar R (2016) Recent updates on biogas production-a review. Biofuel Research Journal 3(2): 394-402.
28. Chandra RP, Bura R, Mabee WE, Berlin DA, Pan X, et al. (2007) Substrate pretreatment: The key to effective enzymatic hydrolysis of lignocellulosics?. Adv Biochem Eng Biotechnol 108: 67-93.
29. Taherzadeh MJ, Karimi K (2008) Pretreatment of lignocellulosic wastes to improve ethanol and biogas production: a review. Int J Mol Sci 9(9): 1621-1651.
30. Yang B, Wyman CE (2008) Pretreatment: the key to unlocking low-cost cellulosic ethanol. Biofuels Bioproducts and Biorefining 2(1): 26-40.
31. Hendriks ATWM, Zeeman G (2009) Pretreatments to enhance the digestibility of lignocellulosic biomass. Bioresource technology 100(1): 10-18.
32. Jin S, Chen H (2006) Superfine grinding of steam-exploded rice straw and its enzymatic hydrolysis. Biochemical Engineering Journal 30(3): 225-230.
33. Kabir MM, Rajendranb K, Taherzadeh MJ, Horváth IS (2015) Experimental and economical evaluation of bioconversion of forest residues to biogas using organosolv pretreatment. Bioresour Technol 178: 201-208.
34. Abou Hussein SD, Sawan OM (2010) The Utilization of Agricultural Waste as One of the Enviromental Issues in Egypt (A case Study). Journal of Applied Sciences Research 6(8): 1116-1124.
35. Huber JT, Foldager J, Smith NE (1979) Nitrogen distribution in corn silage treated with varying levels of ammonia. Journal of Animal Science 48(6): 1509-1515.

How to cite this article: Salah E, Hala O.Sustainable and Cost-Effective use of Organic Waste. Curr Trends Biomedical Eng & Biosci. 2017; 7(4): 555719. DOI: 10.19080/CTBEB.2017.07.555719.

DOI: 10.19080/CTBEB.2017.07.555719