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ANAEROBIC DIGESTION: AN INCREASINGLY ACCEPTABLE TREATMENT OPTION FOR ORGANIC FRACTION OF MUNICIPAL SOLID WASTE

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Abstract- Anaerobic Digestion has been used for decades, primarily in rural areas, for the production of biogas for use as a cooking and lighting fuel. Anaerobic digestion of organic fraction of municipal waste is a relatively new concept that only in the past 20-30 years has found application in pilot and full scale. While anaerobic digestion of organic fraction of municipal solid waste is yet to be widely applied in underdeveloped countries, it can said to be well established in industrialised nation most especially Europe. This result is largely due to waste and energy policies in Europe (e.g., The Landfill Directive 1999). In Europe, Investigation reveals that as at the year 2016 there are 224 anaerobic digestion facilities with an accumulative capacity of 7,750,000 tonnes/year treating over 5% of the biodegradable organic fraction of municipal solid waste. Netherland and Switzerland have the largest capacity installed per capita. The current study shows that anaerobic digestion has become a well-established and accepted treatment option for the organic fraction of municipal solid waste. It has become a good alternative to incineration or landfill disposal due to its lower environmental impacts.

Index Terms- Municipal Solid Waste, Anaerobic Digestion, Waste Composition, Hydrolysis, Digestible Material

I. INTRODUCTION

Since it was established by Jan Baptista Van Helmont that flammable gases evolved from decaying organic matter in the 17th century and possible production of methane from cattle was demonstrated by Sir Humphry Davy in 1808 several advances and achievement has been made in applicability of anaerobic digestion (AD) processes in waste treatment [1]. According to Lusk and Moser, 1996, the Large scale application of anaerobic digestion began in 1859 with the first digestion plant established in Bombay, India [2]. The energy crisis of 1973 and 1979 triggered renewed interest in use of solid waste in methane production as an energy source with countries such as India responded to the crisis with marked expansion of anaerobic digestion with many community digesters using solid waste such as human, animal and kitchen waste to produce large volume of biogas.[3-5]. During the last years, anaerobic digestion of municipal solid waste has developed from a comparatively simple technique of biomass conversion, with the main purpose of energy production, into a multi-functional system that covers: treatment of organic waste and waste waters in a broad range of organics and substrate concentrations, improvement of sanitation and reduction of odours, energy production and utilization and production of high quality fertilizers.

Municipal solid waste (MSW) is the waste generated in a community with the exception of industrial and agricultural waste [6]. Hence MSW includes residential waste (households), commercial (e.g., from stores, markets, shops, hotels etc.) and institutional waste (e.g., schools, hospitals etc.). The organic fraction of MSW in most countries represents 70% of the waste composition and consists of paper, garden waste, food waste and other organic waste [7]. According to the World Bank by the year 2025 the world will annually generate about 201 million tonnes of municipal solid waste. [8].Therefore, treatment of these wastes in a green and sustainable manner such as anaerobic digestion technology is crucial. The anaerobic decomposition of organic materials yields principally methane (CH_4), carbon dioxide (CO_2) and a solid compost material that can be used as soil conditioner. This paper examines in depth anaerobic digestion process as one of the treatment options for organic fraction of municipal solid waste and its future.

II. ANAEROBIC DIGESTION OF ORGANIC FRACTION OF MUNICIPAL SOLID WASTE

Anaerobic biodegradation of organic fraction of municipal solid waste is the consequences of a series of metabolic interactions among various groups of microorganism. It occurs in three stages (hydrolysis, acidogenesis and methanogenesis) [9]. The first group of microorganism secretes enzymes that hydrolyses polymeric materials to monomers such as glucose and amino acids. These are subsequently converted by second group acetogenic bacteria to higher volatile fatty acids, H_2 acetic acid. At the last stage, the third group of bacteria, methanogenic, converts H_2, CO_2 and acetate to CH_4.[9]. The sequence of anaerobic digestion is described in Figure 1.

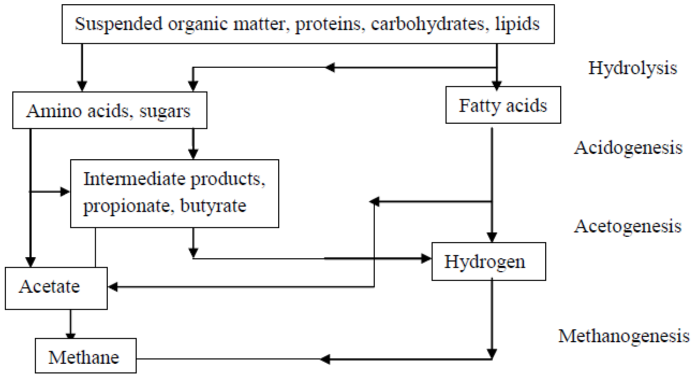

Figure 1. Steps and sequence of anaerobic digestion of organic fraction of municipal solid waste.

2.1 Hydrolysis/liquefaction

This is the first stage in anaerobic digestion of organic fraction of municipal solid waste (OFMSW). Fermentative bacteria convert the insoluble complex organic matter, such as cellulose, into soluble molecules such as sugars, amino acids and fatty acids. The complex polymeric matter is hydrolyzed to monomer, e.g., cellulose to sugars or alcohols and proteins to peptides or amino acids, by hydrolytic enzymes, (lipases, proteases, cellulases, amylases, etc.) secreted by microbes. [10, 11]. The hydrolytic activity is of significant importance in high organic waste and may become rate limiting. Some industrial operations overcome this limitation by the use of chemical reagents to enhance hydrolysis. The application of chemicals to enhance the first step has been found to result in a shorter digestion time and provide a higher methane yield [12].

2.2 Acetogenesis

In the second stage, acetogenic bacteria, also known as acid formers, convert the products of the first phase to simple organic acids, carbon dioxide and hydrogen. The principal acids produced are acetic acid (CH_3COOH), propionic acid (CH_3CH_2COOH), butyric acid ($CH_3CH_2CH_2COOH$), and ethanol (C_2H_5OH). The products formed during acetogenesis are due to a number of different microbes, e.g., s*yntrophobacter wolinii*, a propionate decomposer and s*ytrophomonos wolfei*, a butyrate decomposer. An acetogenesis reaction is shown in equation (1).

$$C_6H_2O_2 \rightarrow 2C_2H_5OH + 2CO_2 ------------ (1)$$

2.3 Methanogenesis.

In the third stage (methanogenesis methane is produced by bacteria called methane formers (also known as methanogens) in two ways: either by means of cleavage of acetic acid molecules to generate carbon dioxide and methane, or by reduction of carbon dioxide with hydrogen [7]. The methanogenic bacteria include *methanobacterium, methanobacillus, methanococcus and methanosarcina*. Methanogens can also be divided into two groups: acetate and H_2/CO_2 consumers. *Methanosarcina spp. and methanothrix spp*. (also, methanosaeta) are considered to be important in anaerobic digestion both as acetate and H_2/CO_2consumers. The methanogenesis reactions can be expressed as follows in equations (2), (3) and (4).

$$CH_3COOH \rightarrow CH_4 + CO_2 ----------(2)$$

$$2C_2H_5OH + CO_2 \rightarrow CH_4 + 2CH_3COOH --------(3)$$

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O ------------- (4)$$

III. ANAEROBIC DIGESTION SYSTEM

Generally, the overall anaerobic digestion technology process can be divided into four stages: Pre-treatment, waste digestion, gas recovery and residue treatment. Most digestion systems require pre-treatment of waste to obtain homogeneous feedstock. According to De Baere, 2006, anaerobic technologies for treatment of organic fraction of municipal solid waste treatment can be categorise into: batch systems which can either exist as one or two stage system, one stage continuous system (low solids or high solids) and two stage continuous system (dry-wet and wet-wet). Batch reactors are used where the reactor is loaded with feedstock at the beginning of the reaction and products are discharged at the end of a cycle. The other type of reactor used, mostly for low solids slurries, is continuous flow where the feedstock is continuously charged and discharged. Batch reactors are loaded with feedstock, subjected to reaction, and then are discharged and loaded with a new batch. There are three types of batch systems - single stage batch system, sequential batch system and an Upflow Anaerobic Sludge Blanket reactor.
Single-stage digesters are simple to design, build, and operate and are generally less expensive. The organic loading rate (OLR) of single-stage digesters is limited by the ability of methanogenic organisms to tolerate the sudden decline in pH that results from rapid acid production during hydrolysis. Two-stage digesters separate the initial hydrolysis and acid-producing fermentation from methanogenesis, which allows for higher loading rates but requires additional reactors and handling systems. Worldwide, about 90 percent of the installed AD capacity is from single-stage systems and about 10 percent is of two-stage systems.

3.1 Significant Operating Parameters in Anaerobic Digestion Process

In general, the optimal conditions for anaerobic digestion of organic matter are near-neutral pH between 6.8 –7.4, constant temperature (thermophilic 55^{o}C - 70^{o}C and mesophilic 37^{o}C), and a relatively consistent feeding rate [13, 14]. Imbalances among the different microorganisms can develop if conditions are not maintained near optimum. The most common result of imbalance is the buildup of organic acids which suppresses the methanogenic organisms adding to even more buildup of acidity [15]. Acid buildup is usually controlled naturally by inherent chemical buffers and by the methanogens themselves as they consume acids to produce methane. These natural controls can break down if too much feed is added and organic acids are produced faster than they are consumed, if inhibitory compounds accumulate, or if the feed stream lacks natural pH buffers such as carbonate and ammonium.
Solid concentrations higher than about 40 percent total solid (TS) can also result in process inhibition, likely due to the reduced contact area available to the AD microorganisms. The TS content

of OFMSW typically ranges from 30-60 percent, thus some water may need to be added [16]. Higher temperatures result in faster reaction kinetics which, in practice, translates to smaller reactors needed to process a given waste stream. However, the micro-organisms themselves are adapted to relatively narrow temperature ranges. Mesophilic and thermophilic microbes are adapted to roughly 30 - 40°C and 50 - 60 °C respectively. The most important nutrients for bacteria are carbon and nitrogen, but these two elements must be provided in the proper ratio. Otherwise, ammonia can build up to levels that can inhibit the microorganisms. The appropriate carbon/nitrogen (C/N) ratio is highly important because it reflects the nutrients level of a digestion substrate [13]. It depends on the digestibility of the carbon and nitrogen sources; therefore, the appropriate C/N ratio for organic MSW may be different from that for other feedstocks such as manure or wastewater sludge. Information on typical C/N ratio of some digestable material is shown in Table 1.

Table. 1. Typical C/N ratio of some digestable material.

S/N	Raw material	C/N Ratio
1	Human excreta	8
2	Chicken dung	10
3	Pig dung	18
4	Sheep dung	19
5	Cow dung	24
6	Duck dung	8
8	Elephant dung	43
9	Goat dung	12
10	Maize straw	60
11	Rice straw	70
12	Wheat straw	90
13	Water hyacinth	25
14	Municipal solid waste	40
15	Saw dust	>200

Source :[17].

IV. PRESENT AND FUTURE TREND OF ANAEROBIC DIGESTION.

In recent times, developed nations came under pressure to explore AD market because of two significant reasons: High energy prices and stringent environmental regulations, especially controls on organic matter going to landfills as well as further expansion of landfills. Because of environmental pressures, many nations have implemented or are considering methods to reduce the environmental impacts of waste disposal. In developing countries, china and India are ahead. In India the family size biogas programme initiated by the National Biogas and Manure Management Programme (NBMMP) in 2009-2010 installed family size anaerobic digesters which helped in waste management and energy generation. Indian has over 12 million installed family AD digesters while Indonesia and Cambodia have smaller biogas programme which reflects in the less than 1000 system found in each of the country. Over 19 million anaerobic digesters are currently installed in china and more than 25 million household are currently using biogas the produced biogas [18, 19]. Figure 1 is a world distribution of AD systems.

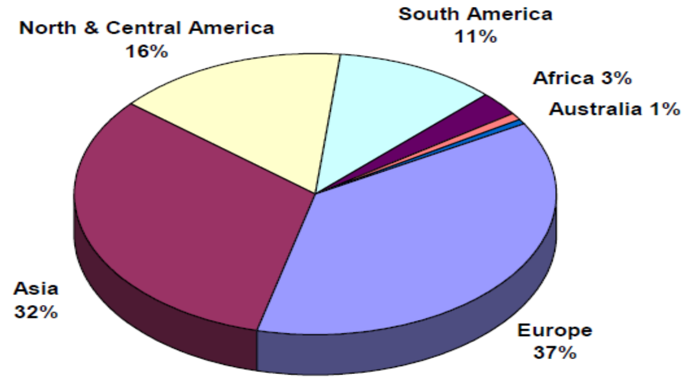

Figure 1. World geographical distribution of industrial anaerobic plants [20].

Europe leads in large centralized AD systems. The most commonly installed anaerobic digestion technology are Kompogas, Valorga, RosRoca, BTA, DRANCO, Citec and Linde. These technologies operate either in mesophilic or thermophilic temperature range. As at the year 2014, Cumulative percentage of mesophilic and thermophilic capacity are 67 and 33% respectively. Europe started AD with three plant with a total capacity of 120,000 tons per year in 1990 but presently, anaerobic digestion capacity in Europe is growing to a total of 290 plants and a digestion capacity of almost nine million tons per year in 2015. From 1990-2014, installed capacity of AD systems has increased in most European countries. Netherlands and Switzerland which are early starters in the application of AD technology have reached levels of 53,000 and 48,000 tonnes per year of installed capacity per million inhabitants respectively. other countries such as France and Spain have also recorded significant increase of installed capacity as indicated in Figure 2[21, 22].

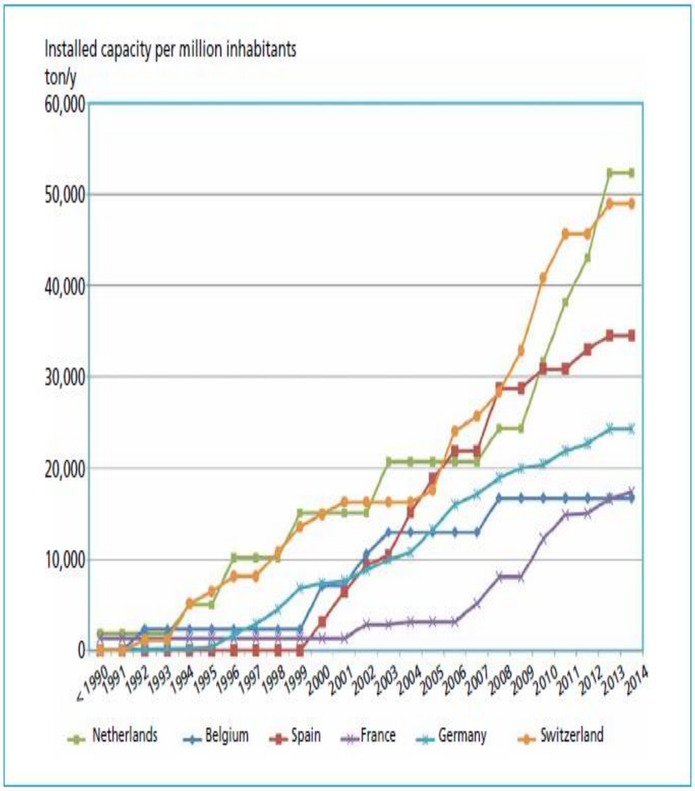

Figure 2: Increase in capacity per million inhabitants per country [21].

A large variation exists in the number of anaerobic digesters installed in Developing Countries. While the AD of organic fraction of municipal solid waste as centralised high technology will continue to increase in developed countries in coming years, the appropriate technology is still struggling in developing nations most especially in Africa. This is due to insufficient knowledge and information available on challenges, opportunities, technical and operational feasibility. If the applicability of AD must advance there is the need for necessary legal frame work that will drive it to the next level of advancement.

V. CONCLUSIONS

The anaerobic digestion of municipal solid waste is a rapidly growing field. The technology has become an increasingly acceptable way of managing organic fraction of municipal solid waste due to it several benefits to the environment which includes potential to reduce environmental impact of waste disposal while capturing biogas energy. While it’s extend of applicability have reached advanced level in developed nations it is still a growing technology in developing nations. Nevertheless, it will continue to be an easy and environmentally friendly green technology for managing municipal solid waste.

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