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Review

Co-digestion of municipal organic wastes with night soil and cow dung for biogas production: A Review

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Currently, biogas production is one of the most promising renewable energy sources and it represents a very promising way to overcome the problem of waste treatment. Biogas, which is principally composed of methane and carbon dioxide, can be obtained by anaerobic fermentation of biomass such as manure, night soil, sewage sludge and municipal solid wastes. Furthermore, the solid residuals of fermentation (the digested slurry) might be reused as fertilizer, to enhance the fertility of the soil. The huge amount of waste generates in the urban areas especially organic fraction of municipal solid waste or simply municipal bio-waste, which is used as feedstock for biogas production; represents an environmentally sustainable energy source since it improves solid waste management while simultaneously providing an alternative clean energy source. The primary advantages of biogas technology is the use of organic wastes with a low nutrient content to degrade by co-digesting with different substrates in the anaerobic bioreactors, and the process simultaneously leads to low cost production of biogas, which could be vital for meeting future energy needs. This review clearly indicates that co-digestion of municipal organic waste with night soil and cow dung is one of the most effective biological processes to treat a wide variety of solid organic wastes and the use of these wastes for biogas production. In addition, this review briefly discussed the factors affecting biogas production and analytical methods.

Key words: Biogas, anaerobic digestion, municipal solid waste, pretreatment.

INTRODUCTION

Energy is one of the most important factors to global prosperity. In today's energy demanding lifestyle, the need for exploring and exploiting new sources of energy which are renewable, sustainable as well as eco-friendly is inevitable. The over dependence on fossil fuels as primary energy source has led to global climate change, environmental pollution and degradation, thus leading to human health problems. In the year 2040, the world as predicted will have 9 to 10 billion people, which must be provided with energy and materials. The majority of people in developing countries do not easily and steadily have access to advanced forms of energy such as electricity; therefore, they entirely depend on solid forms of fuels like firewood to meet their basic energy needs for cooking and lighting. At the same time, over 60% of the total wood in developing countries is used as wood fuel in

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form of either charcoal, especially in the urban areas or as firewood mostly in the rural areas. This has resulted in depleting forests at a faster rate than they can be replaced. Biogas is a well-established fuel that can supplement or even replace wood as an energy source for cooking and lighting in developing countries. Currently, as the fossil-based fuels become scarce and more expensive, the economics of biogas production is turning out to be more favorable. Biogas is a readily available energy resource that significantly reduces greenhouse-gas emission compared to the emission of landfill gas to the atmosphere (Aremu and Agarry, 2013).

One of the burning problems faced by the world today is management of all types of wastes and energy crisis. Rapid growth of population and uncontrolled and unmonitored urbanization has created serious problems of energy requirement and solid waste disposal. Vegetable market wastes contribute to a great amount of pollution; hence, there has been a strong need for appropriate vegetable waste management systems. Vegetable wastes that comprise of high fraction of putrescible organic matter cause serious environmental and health risks (Dhanalakshmi and Ramanujam, 2012). For instance, Ethiopia produces a plenty of fruits and vegetable wastes and generates a solid waste of 0.4 kg/capita/day in Addis Ababa only. Therefore, it becomes necessary to develop appropriate waste treatment technology for vegetable and other organic wastes to minimize greenhouse gas emission (http://www.un.org/esa/dsd/susdevtopics/sdt_pdfs/meetings2010/icm0310/2b-2_Tessema.pdf).

Biological conversion of biomass to methane has received increasing attention in recent years. There are many technologies such as incineration and refuse derived fuel etc., for producing energy from solid wastes. Among them anaerobic digestion has become a promising technology particularly for recovery of energy from organic fraction of solid wastes. Many research works are being carried out for treating various types of organic solid wastes using anaerobic digestion process (Tamilchelvan and Dhinakaran, 2012). It has become a major focus of interest in waste management throughout the world. Anaerobic Digestion is potential environment friendly technique produce energy in the form of biogas and residue which can be used as soil conditioner. It is known that organic waste materials such as vegetables contain adequate quantity of nutrients essential for the growth and metabolism of anaerobic bacteria in biogas production (Dhanalakshmi Sridevi and Ramanujam, 2012).

Waste is one of the most promising options for the production of biofuels which act as an alternative source of energy. This would also help in the treatment of wastes which is becoming a nuisance to the community (Singhal et al., 2012). Municipal waste is the abandoned materials which have been thrown away after use in daily life in the urban area. It generally composed of residential waste, institutional waste and hospitals wastes. Due to the increasing growth of urban population in the world this municipal waste is getting high concerns from the management perspective. Municipal solid waste (MSW) contains a significant fraction (30 to 50%) of organics (Tchobanoglous et al., 1993). On the other hand, Uddin and Mojumder (2011) revealed that, the amount of municipal waste generated in six major cities of Bangladesh is about 7690 tons daily. These wastes mainly composed of about 74.4% organic matter, 9.1% paper, 3.5% plastic, 1.9% textile and wood, 0.8% leather and rubber, 1.5% metal, 0.8% glass and 8% other waste. Therefore, this huge portion of municipal waste being organic can contribute to the production biogas. It can be a useful resource if this organic fraction could be used for power generation. Municipal solid waste landfills generate biogas and leachate. Due to the amount of waste, biogas production represents a very promising way to solve the problem of waste treatment. Furthermore, the solid residuals of fermentation might be reused as fertilizers. Landfill gas is water saturated gas mixture containing about 40 to 60% methane, with the remainder being mostly carbon dioxide (CO_2). Landfill gas also contains varying amounts of nitrogen, oxygen, water vapor, sulfur and a hundreds of other contaminants (Asgari et al., 2011; Ramanathan et al., 2013; Otaraku and Ogedengbe, 2013).

The composition of biogas largely depends on the type of substrate. Human excreta or night soil based biogas contains 65-66% CH_4, 32 to 34% CO_2 by volume and the rest is H_2S and other gases in traces while the biogas composition for municipal solid waste is composed of 68 to 72% CH_4, 18 to 20% CO_2, and 8% H_2S (Elango et al., 2007). Biogas is a colourless, flammable gas produced via anaerobic digestion of animal, plant, human, industrial and municipal wastes amongst others, to give mainly methane and carbon dioxide. It is smokeless, hygienic and more convenient to use than other solid fuels. Biogas production has three stages of biochemical process comprising hydrolysis, acidogenesis/acetogenesis and methanogenesis (Ofoefule et al., 2010). Since cow dung has enormous bacterial population and municipal solid waste (MSW) and night soil, contains a relatively large amount of organic matter which decomposes by the actions of microorganisms under anaerobic conditions (Igoni et al., 2008), it is better to co-digest municipal organic wastes with these wastes for optimizing the buffer capacity of digester and hence increase biogas production and obtain excellent soil conditioner.

Therefore, this review paper explores a suitable way to use organic waste such as night soil and cow dung, which served as useful raw material for biogas production by co-digestion of municipal biodegradable solid waste.

WASTES OTHER THAN MSW FOR BIOGAS PRODUCTION

Other raw materials for biogas fermentation such as cow

Table 1. Average composition of biogas from different organic residues (Salomon and Lora, 2007).

Gases	Percentage (%)
Methane (CH_4)	40-75
Carbon dioxide (CO_2)	25-40
Nitrogen (N)	0.5-2.5
Oxygen (O)	0.1-1
Hydrogen sulphide (H_2S)	0.1-0.5
Ammonia (NH_3)	0.1-0.5
Carbon monoxide (CO)	0-0.1
Hydrogen (H)	1-3

or pig dung, poultry waste, water hyacinth, straw, weeds, leaf, human excrement, domestic rubbish and industrial solid and liquid wastes are available in Ethiopia. Some people may view the biogas produced from human excreta as dirty and not fit to be used, especially for cooking. Despite the negative connotations, countries like China have been using biogas produced from human excreta wherever possible (Sibisi and Green, 2005).

In Ethiopia, some organizations' toilets have been connected to biogas digesters by a local NGO working to improve the social conditions of the people. Some public toilets have also been connected to biogas digesters and the gas generated has been used for lighting inside and outside the toilets for safer public use. This reflects a growing trend towards using human excreta for biogas generation. In many instances, the generation rate of animal waste types varies significantly in nature and in situation of relative abundance of a particular animal waste; the need for combining animal waste (night soil and cow dung) with different biodegradable wastes may become imperative in biogas generation. Hence, the implications of combining or co-digesting animal wastes for biogas production need to be properly assessed for successful implementation of such anaerobic process. Co-digestion was used by researchers to improve biogas yield by controlling the carbon to nitrogen ratio (Yusuf et al., 2011). One treatment method for improving the biogas production of various feedstocks is co-digesting them with animal manure and/or plant wastes.

Anaerobic digestion

Anaerobic digestion, also known as biomethanation, is a biochemical degradation process that converts complex organic materials into simpler constituents in a series of metabolic interactions that involve a wide range of microorganisms that catalyze the process in the absence of oxygen. The organic fraction of almost any form of biomass, including sewage, sludge, food wastes, animal wastes and industrial effluents can be broken down through anaerobic digestion (Alemayehu and Abile, 2014). Anaerobic digestion consists of biochemical degradation of complex organic matter resulting in the biogas production, which has as main constituent methane (CH_4), and carbon dioxide (CO_2), and trace amounts of hydrogen (H_2), ammonia (NH_3) and hydrogen sulfide (H_2S) as shown in the Table 1. The significant amount of biodegradable components (carbohydrates, lipids and proteins) present in the biomass makes it a favorable substrate for the anaerobic microbial flora that can be converted into biogas rich in CH4 (Sialve et al., 2009).

Mechanism of biogas production

The anaerobic digestion process is characterized by a series of biochemical transformations brought by different consortia of bacteria: firstly, organic materials of the substrate-like cellulose, hemicellulose, and lignin must be liquefied by extracellular enzymes, and then is treated by acidogenic bacteria; the rate of hydrolysis depends on the pH, temperature, composition and concentration of intermediate compounds. Then soluble organic components including the products of hydrolysis are converted into organic acids, alcohols, hydrogen and carbon dioxide by acidogens. The products of the acidogenesis are converted into acetic acid, hydrogen and carbon dioxide. Methane is produced by methanogenic bacteria from acetic acid, hydrogen and carbon dioxide and from other substrates of which formic acid and methanol are the most important. The process is catalyzed by a consortium of microorganisms (inoculum) that converts complex macromolecules into low molecular weight compounds (methane, carbon dioxide, water and ammonia) (Fantozzi and Buratti, 2009).

Processes of biogas production

Many microorganisms affect anaerobic digestion, including acetic acid-forming bacteria (acetogens) and methane-forming bacteria (methanogens). These organisms promote a number of chemical processes in converting the biomass to biogas. There are four key biological and chemical stages of anaerobic digestion as shown in Figure 1: hydrolysis, acidogenesis, acetogenesis and methanogenesis (Onojo et al., 2013).

In most cases, biomass is made up of large organic polymers. For the bacteria in anaerobic digesters to access the energy potential of the material, these chains must first be broken down into their smaller constituent parts. These constituent parts, or monomers, such as sugars, are readily available to other bacteria. The process of breaking these chains and dissolving the smaller molecules into solution is called hydrolysis. Therefore, hydrolysis of these high-molecular-weight

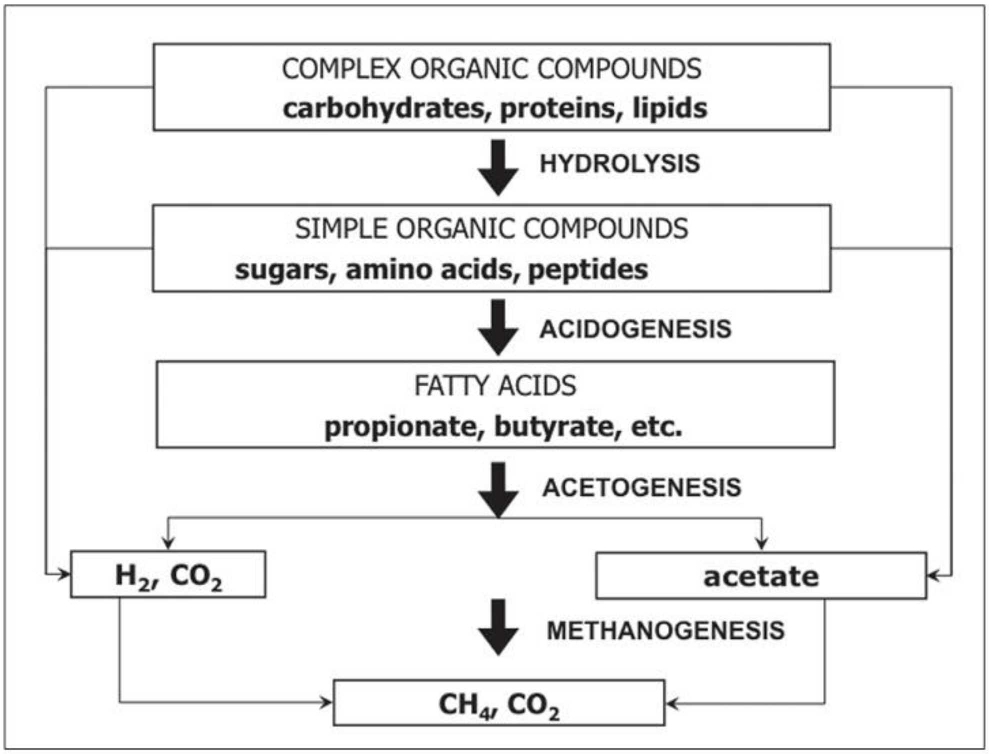

Figure 1. Simplified schematic representation of the anaerobic degradation process (Lettinga et al., 1999).

polymeric components is the necessary first step in anaerobic digestion. In the first step (hydrolysis), is a process of breakdown of organic matter into smaller products that can be degraded by bacteria. Ligno-cellulosic material constitutes the major organic fraction of MSW. Hydrolysis of ligno-cellulosic material is a major factor, which influences the level of the carbon source required for biogas production (Asgari et al., 2011). Through hydrolysis the complex organic molecules are broken down into simple sugars, amino acids, and fatty acids. Acetate and hydrogen produced in the first stages can be used directly by methanogens. Other molecules, such as volatile fatty acids (VFAs) with a chain length greater than that of acetate must first be catabolised into compounds that can be directly used by methanogens. MSW contains a significant fraction of ligno-cellulosic material. The acidification of these materials influences the biogas yield (Asgari et al., 2011).

The biological process of acidogenesis results in further breakdown of the remaining components by acidogenic (fermentative) bacteria. Here, VFAs are created, along with ammonia, carbon dioxide, and hydrogen sulfide, as well as other byproducts. The process of acidogenesis is similar to the way milk sours. The third stage of anaerobic digestion is acetogenesis. Here, simple molecules created through the acidogenesis phase are further digested by acetogens to produce largely acetic acid, as well as carbon dioxide and hydrogen. The terminal stage of anaerobic digestion is the biological process of methanogenesis. Here, methanogens use the intermediate products of the preceding stages and convert them into methane, carbon dioxide and water. These components make up the majority of the biogas emitted from the system. Methanogenesis is sensitive to both high and low pH and occurs between pH 6.5 and pH 8. The remaining, indigestible material, the microbes cannot be use and any dead bacterial remains constitute the digestate (Onojo et al., 2013; Dioha et al., 2013).

FACTORS AFFECTING BIOGAS PRODUCTION

The performance of biogas plant can be controlled by studying and monitoring the variation in parameters like pH, temperature, loading rate, agitation, etc. Any drastic change in these can adversely affect the biogas production. So, these parameters should be varied within a desirable range to operate the biogas plant efficiently. Most researchers showed that factors like temperature, pH, concentration of total solids, etc affect the production of the biogas. Various factors such as design of digester, inoculums, nature of substrate, pH, temperature, loading rate, retention time, C:N ratio, volatile fatty acids (VFA), can also influence the biogas production (Dioha et al., 2013).

Temperature

Temperature inside the digester has a major effect on the biogas production process. There are different temperature ranges during which anaerobic fermentation can be carried out: psychrophilic (<30°C), mesophilic (30 to 40°C) and thermophilic (50 to 60°C). However, anaerobes are most active in the mesophilic and thermophilic temperature range. The length of fermentation period is dependent on temperature (Yadvika et al., 2004). The methanogenic bacteria, which facilitate the formation of biogas, are very sensitive to temperature changes and the optimum temperature for the bacteria to operate is between 33 to 38°C. Temperatures below this slow down the biogas production process, while a higher temperature than necessary kills the biogas producing bacteria. This is why the structure for biogas production is generally built underground, to keep the temperature as constant as possible (Sibisi and Green, 2005). Nevertheless, sharp increases of temperature should be avoided because they can cause a decrease in bio-methane production due to the death of specific bacteria strains, particularly sensitive to temperature changes. To keep constant the temperature during biomethane production tests, it is needed to submerge the reactors in a water bath kept at the selected temperature or to incubate them in a thermostatically controlled room (Esposito et al., 2012). The slurry temperature values were monitored in determining the rate of digestion and retention of the process, since temperature is very important. The temperature affects the rate of digestion, due to the outside walls of the digester surface make direct contact with the atmosphere, hence the digester walls absorb or loose heat depending on the temperature gradient between the digester and its immediate environment (Ukpai and Nnabuchi, 2012).

pH

pH is another important parameter affecting the growth of microbes during anaerobic fermentation. pH of the digester should be kept within a desired range of 6.8 to 7.2 by feeding it at an optimum loading rate. The amount of carbon dioxide and volatile fatty acids produced during the anaerobic process affects the pH of the digester contents. For an anaerobic fermentation to precede normally, concentration of volatile fatty acids, acetic acid in particular should be below 2000 mg/l (Yadvika et al., 2004). pH values below 6.0 to 6.5 inhibit the methane bacteria activity. To avoid drops in pH chemicals are added to the organic substrate to supply a buffer capacity. Sodium bicarbonate, sodium hydroxide, sodium carbonate and sodium sulphide are the most used chemicals (Esposito et al., 2012). Process instability due to ammonia often results in volatile fatty acids (VFAs) accumulation, which leads to a decrease in pH and thereby declining concentration of FA. The interaction between FA, VFAs and pH may lead to an ‘‘inhibited steady state’’, a condition where the process is running stably but with a lower methane yield. Control of pH within the growth optimum of microorganisms may reduce ammonia toxicity. Reducing pH from 7.5 to 7.0 during thermophilic anaerobic digestion of cow manure also increased the methane production by four times. It should also be noted that both methanogenic and acidogenic microorganisms have their optimal pH. Failing to maintain pH within an appropriate range could cause reactor failure although ammonia is at a safe level (Chen et al., 2008).

Moisture

High moisture contents usually facilitate the anaerobic digestion; however, it is difficult to maintain the same availability of water throughout the digestion cycle. Initially, water added at a high rate is dropped to a certain lower level as the process of anaerobic digestion proceeds. High water contents are likely to affect the process performance by dissolving readily degradable organic matter. It has been reported that the highest methane production rates occur at 60 to 80% of humidity. Methanogenesis processes during anaerobic digestion at different moisture levels, that is, 70 and 80%. However, bioreactors under the 70% moisture regime produced a stronger leachate and consequently a higher methane production rate. At the end of the experiment, 83 ml methane per gram dry matter were produced at the 70% moisture level, while 71 ml methane per gram dry matter were produced with the 80% moisture (Khalid et al., 2011).

Retention time

The hydraulic retention time (HRT) is the theoretical time that the influent liquid phase stays in the digester, while the solids retention time (SRT) is generally the ratio between solids maintained in the digester and solids wasted in the effluent. The required retention time for completion of the AD reactions varies with differing technologies, process temperature, and waste composition (Zamudio Canas, 2010; Alemayehu and Abile, 2014). The conversion of organic matter to gas is more closely related to SRT rather than HRT. The retention time for wastes treated in mesophilic digester ranges from 10 to 40 days. If the retention time is too short, the bacteria’s in the digester are washed out faster than they can reproduce, so that fermentation practically comes to a standstill. The longer a substrate is kept under proper reaction conditions, the more complete its degradation will become. But the reaction rate will decrease with increasing residence time. The dis-advantage of a longer retention time is that a large reactor size is needed for a given amount of substrate to be treated (Hassan, 2003). Although, a short retention time is desired for reducing the digester volume, a balance must be made to achieve the desired operational conditions, for example, maximizing either methane production or organic matter removal (Zamudio Canas, 2010).http://trace.tennessee.edu/utk_gradthes/676Digesters operating in the thermophilic range requires lower retention times. For instance, a high solids reactor operating in the thermophilic range has been reported to require a retention time of 14 days. The degradability of food waste was approximately 20 to 30% higher than that of bio-waste. This has been attributed to the higher concentration of digestible fat in food waste. To achieve higher biogas amount or conversion efficiency of organics with food waste a relatively long digestion time of around 6 days has been reported; as compared to about 3 days with bio-waste (Nayono, 2010).

Particle size

Though particle size is not that important a parameter as temperature or pH of the digester contents, it still has some influence on gas production. The size of the feedstock should not be too large otherwise it would result in the clogging of the digester and also it would be difficult for microbes to carry out its digestion. Smaller particles on the other hand would provide large surface area for adsorbing the substrate that would result in increased microbial activity and hence increased gas production. According to Yadvika et al. (2004), out of five particle sizes (0.088, 0.40, 1.0, 6.0 and 30.0 mm), maximum quantity of biogas was produced from raw materials of 0.088 and 0.40 mm particle size. Large particles could be used for succulent materials such as leaves. However, for other materials such as straws, large particles could decrease the gas production. The results suggested that a physical pretreatment such as grinding could significantly reduce the volume of digester required, without decreasing biogas production.

Pretreatment

Feedstocks sometimes require pretreatment to increase the methane yield in the anaerobic digestion process. Pretreatment breaks down the complex organic structure into simpler molecules which are then more susceptible to microbial degradation. Yield from MSW varies due to the heterogeneous nature of MSW. Theoretically, estimated values of biogas based on stoichiometry vary between 150 and 265 m^3/ton of waste. The household waste after source separation yields 494 m^3 of methane per ton of solid waste. Although landfill sites are the sources of methane, the landfill gas needs to be purified to increase the methane concentration. To increase the biogas yield, also presorting and pretreatment are usually conducted. Hence, it has been reported that in a biomethanation process, 30% of the total expenditure is incurred in presorting and pretreatment (Asgari et al., 2011).

Organic loading rate (OLR)

Gas production rate is highly dependent on loading rate. Methane yield is found to increase with reduction in loading rate. As study carried out in Pennsylvania on a 100 m3 biogas plant operating on manure, when OLR was varied from 346 to 1030 kg VS/day, gas yield increased from 67 to 202 m^3/day. There is an optimum feed rate for a particular size of plant, which will produce maximum gas and beyond which further increase in the quantity of substrate will not proportionately produce more gas. According to Yadvika (2004), a daily loading rate of 16 kg VS/m^3 of digester capacity produced 0.04 to 0.074 m^3 of gas/kg of dung fed. A lab-scale digester operating at different OLRs produced a maximum yield of 0.36 m^3/kg VS at an OLR of 2.91 kg VS/ m^3/day. Based on pilot plant studies (1 m^3 capacity), maximum gas yield was observed for a loading rate of 24 kg dung/m^3 digester/day although percent reduction of VS was only 2/3rd of that with low loading rate (Yadvika et al., 2004).

Agitation

Stirring of digester contents needs to be done to ensure intimate contact between microorganisms and substrate which ultimately results in improved digestion process. Agitation of digester contents can be carried out in a number of ways. For instance daily feeding of slurry instead of periodical gives the desired mixing effect. Stirring can also be carried out by installing certain mixing devices like scraper, piston, etc. in the plant. Gas recirculation has also been found to enhance mixing and thus gas production (Yadvika et al., 2004).

C:N ratio

It is necessary to maintain proper composition of the feedstock for efficient plant operation so that the C:N ratio in feed remains within desired range. It is generally found that during anaerobic digestion microorganisms utilize carbon 25 to 30 times faster than nitrogen. Thus, to meet this requirement, microbes need a 20 to 30:1 ratio of C to N with the largest percentage of the carbon being readily degradable. Waste material that is low in C can be combined with materials high in N to attain desired C:N ratio of 30:1. Some studies also suggested that C:N ratio varies with temperature. Use of urine soaked waste materials is particularly advantageous during winter months when gas production is otherwise low (Yadvika et al., 2004; Alemayehu et al., 2014). The unbalanced nutrients are regarded as an important factor limiting anaerobic digestion of organic wastes. For the improvement of nutrition and C/N ratios, co-digestion of organic mixtures is employed. Co-digestion of fish waste, abattoir wastewater and waste activated sludge with fruit and vegetable waste facilitates balancing of the C/N ratio. Their greatest advantage lies in the buffering of the organic loading rate, and anaerobic ammonia production from organic nitrogen, which reduce the limitations of fruit and vegetable waste digestion (Khalid et al., 2011).

The C/N ratio of 20 to 30 may provide sufficient nitrogen for the process. According to Khalid et al. (2011) a C/N ratio between 22 and 25 seemed to be best for anaerobic digestion of fruit and vegetable waste, whereas, the optimal C/N ratio for anaerobic degradation of organic waste was 20 to 35. The variation of the C/N values can affect the pH of a slurry. The increase in carbon content will give rise to more carbon dioxide formation and lower pH value, while high value of nitrogen will enhance production of ammonia gas that could increase the pH to the detriment of the micro-organisms (Dioha et al., 2013).

Ammonia concentration

It is generally believed that ammonia concentrations below 200 mg/L are beneficial to anaerobic process since nitrogen is an essential nutrient for anaerobic micro-organisms since bacteria could not thrive in substrate that contained ammonia concentrations above 200 mg/L. A wide range of inhibiting ammonia concentrations has been reported in the literature, with the inhibitory total ammonia nitrogen concentration that caused a 50% reduction in methane production ranging from 1.7 to 14 g/L. The significant difference in inhibiting ammonia concentration can be attributed to the differences in substrates and inocula, environmental conditions (temperature, pH), and acclimation periods (Chen et al., 2008). Methanogen bacteria was the least tolerant and the most easily killed to ammonia inhibition among the four anaerobic microorganisms in four step biogas production there were hydrolysis, acidogenesis, aceto-genesis, methanogenesis. Changing ammonia into ammonium was depended on pH condition. Ammonium was less toxic than ammonia. Ammonium disturbed bacterial activity just in high concentration. Concentration of ammonium of 1,500 to 10,000 mg/L was inhibition start for bacterial growth, whereas that of 30,000 mg/L was toxicity concentration (Sumardiono et al., 2013).

ANALYTICAL METHODS AND THEIR DETERMINATION

TS and VS contents are measured according to Standard Methods

Ts and Vs

To measure total solids (TS) a certain amount of the sample is taken and then poured into a weighted empty (W1) and dried crucible. Then in order to desiccate the sample completely, the crucible containing the sample is put in the furnace set in 105°C. The crucible containing the dried sediment was weighted (W2). The following equation was used to measure the TS value (L-1) (Afazeli et al., 2014).

$$\text{TS (mg L}^{-1}) = \frac{w_2 - w_1}{v} \qquad 1$$

For measuring the volatile suspended solids (VSS), the crucible containing the sample (W1) used for measuring the TS value is kept in the furnace set at 550°C for 2 h (Alemayehu et al., 2014) in order to create ash. Crucible containing the weighted ash (W2) is prepared and the following equation was used to measure the volatile suspended solids concentration (Afazeli et al., 2014). High values of volatile solids are favorable for anaerobic digestion (Samuel et al., 2012).

$$\text{VS (mg L}^{-1}) = \frac{w_2 - w_1}{v} \qquad 2$$

Chemical oxygen demand and biological oxygen demand

Organic matters are usually quantified as BOD (Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand) while inorganic matters are mainly quantified as sulfate, chloride, ammonium, heavy metals and others (Lee and Nikraz, 2014). Chemical Oxygen Demand (COD) is the amount of oxygen consumed by the organic compounds and inorganic matter which were oxidized in waste. Biological Oxygen Demand (BOD) is the amount of oxygen consumed by the organic and inorganic compounds which were oxidized by biological-oxidation effect in a certain condition (Pujar et al., 2014). As BOD is predominantly a biochemical parameter, it generally reflects biodegradability of organic matter in substrate thus making BOD:COD ratio a good indicator of the proportion of biochemically degradable organic matter to total organic matter (Kjeldsen and Christophersen, 2001; Kjeldsen et al., 2002). It is anticipated that BOD and COD value decrease over time most likely attribute to a combination of reduction of organic pollutants that are leaching in the landfill.

BOD:COD ratio is a good indicator for degrees of both biological and chemical decompositions that are taken place in the landfill and can be taken as an indicator of degradation of organic matter in landfill. Relatively, substrate COD strength has significant effect on the ultimate amount of biogas yield, as well as the methane content (Ghani and Idris, 2009). COD gives a precise estimation of the organic (degradable) material content of a given sample (Curry and Pillay, 2012). COD is determined by adding a strong chemical oxidizing agent to the substrate in an acidic medium (Pisarevsky et al., 2005). Therefore, higher values of COD are favorable for anaerobic digestion (Samuel et al., 2012).

TKN (total Kjeldahl nitrogen)

The total Kjeldahl nitrogen (TKN) indicates the nitrogen content of a feedstock. Monitoring TKN content of feedstocks can be important because a change from nitrogen-poor to nitrogen-rich feedstock mixtures can cause severe process instabilities. The reason for this is that nitrogen-rich feedstocks will lead to ammonia accumulation in the digester which can cause ammonia inhibition (Drosg, 2013; O'Dell, 1993).

Co-digestion

Co-digestion is a waste treatment method in which different wastes are mixed and treated together. It is also termed as ‘‘co-fermentation’’. Co-digestion is preferably used for improving yields of anaerobic digestion of solid organic wastes due to its numeral benefits. For example, dilution of toxic compounds, increased load of biodegradable organic matter, improved balance of nutrients, synergistic effect of microorganisms and better biogas yield are the potential benefits that are achieved in a co-digestion process (Fang, 2010). Co-digestion of an organic waste also provides nutrients in excess, which accelerates biodegradation of solid organic waste through bio-stimulation. Additionally, the benefits of co-digestion are the facilitation of a stable and reliable digestion performance and production of a digested product of good quality, and an increase in biogas yield. It has been observed that co-digestion of mixtures stabilizes the feed to the bioreactor, thereby improving the C/N ratio and decreasing the concentration of nitrogen. The use of a co-substrate with a low nitrogen and lipid content waste increases the production of biogas due to complementary characteristics of both types of waste, thus reducing problems associated with the accumulation of intermediate volatile compounds and high ammonia concentrations (Khalid et al., 2011). The feasibility and benefits of the anaerobic co-digestion of sewage sludge and organic fraction of municipal solid waste are dilution of potential toxic compounds, improved balance of nutrients, synergistic effects of microorganisms, increased load of biodegradable organic matter and better biogas yield (Jereb, 2004).

Modes of digestion

Batch and continuous digesters

In AD process technology, there are two main different types of digesters for producing biogas: storage technique (batch) and flow technique (continuous or semi-continuous feeding). The most commonly used one is the flow technique. But, batch-type digesters are the simplest to build. In the batch process, the substrate is put in the reactor at the beginning of the degradation period and sealed for the complete retention time, after which it is opened and the effluent removed. The operation consists of loading the digester with organic materials and allowing it to digest. The retention time depends on temperature and other factors. Once the digestion is complete, the effluent is removed and the process is repeated. In the continuous process, fresh material continuously enters the tank and an equal amount of digested material is removed. There are distinct stages of digestion throughout the batch process whereas equilibrium is achieved in the continuous process. Unlike batch-type digesters, continuous digesters produce biogas without the interruption of loading material and unloading effluent. They may be better suited for large-scale operations (Hassan, 2003). Semi-continuous operation is the feeding method that is done usually once or twice a day. The sludge is also removed at the same time interval. This mode of operation is suitable when there is steady flow of organic matter (Rugvichaniwat, 2003).

Biogas plants

In many countries worldwide, biogas plants are in operation producing biogas from the digestion of manure or other biomass. In addition, small scale biogas plants are successfully utilized to displace woody fuels and dung in many developing countries. In conclusion, biogas plants have proven to be an effective and attractive technology for many households in developing countries. Under the right conditions a biogas plant will yield several benefits for the end-users, the main benefits are:

1. Production of energy for lighting, heat, electricity.
2. Improved sanitation (reduction of pathogens, worm eggs and flies).
3. Reduction of workload (less firewood collecting) and biogas stoves have a better cooking performance.
4. Environmental benefits (fertilizers substitution, less greenhouse gas emission).

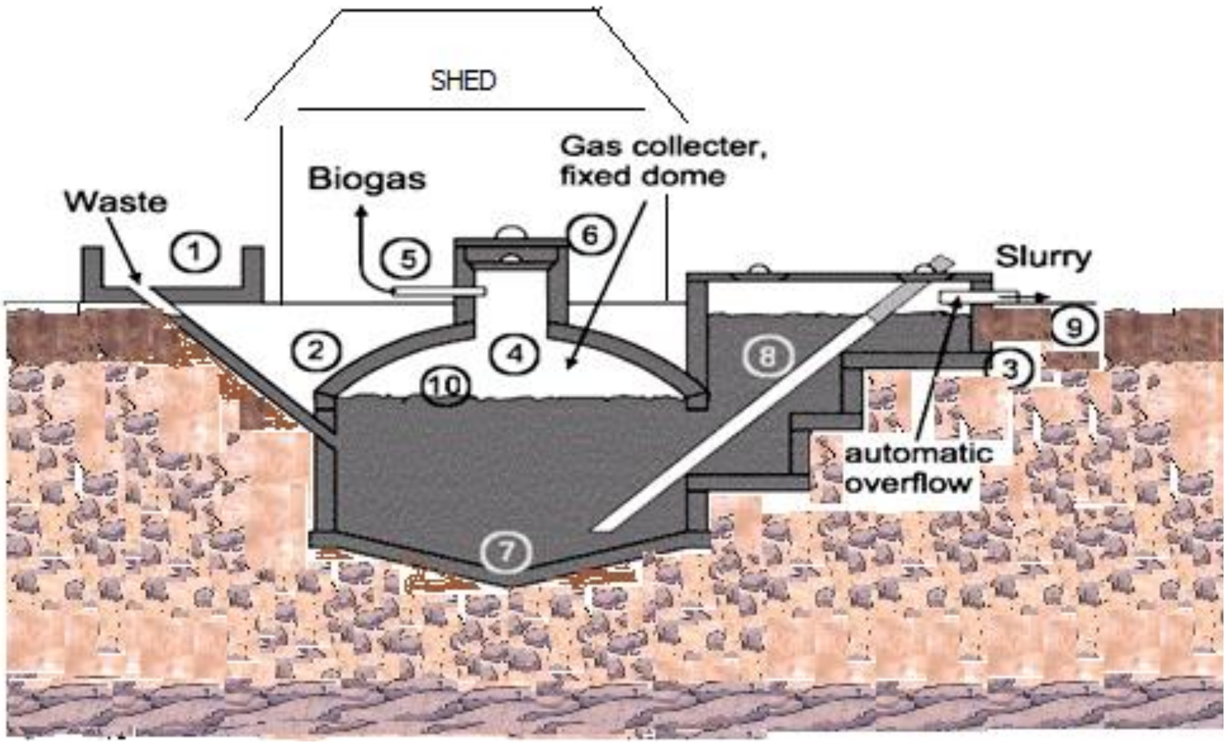

Figure 2. Fixed dome plant Nicarao design. 1. Mixing tank with inlet pipe and sand trap. 2. Digester. 3. compensation and removal tank. 4. Gas holder. 5. Gas pipe. 6. Entry hatch, with gastight seal. 7. Accumulation of thick sludge. 8. Outlet pipe. 9. Reference level. 10. Supernatant scum, broken up by varying level (GTZ, 1999).

5. Improved indoor air quality (less smoke and harmful particle emission of a biogas stove compared to wood or dung fuels).
6. Economic benefits (substitution of spending on expensive fuels) and fertilizer.

Consequently, biogas plants are of great benefit to the end-users and the environment. In developing countries like Ethiopia there are several digesters in operation, the most familiar is the fixed dome digester. In addition, the floating dome digester and bag digester are found in many developing countries (Balasubramaniyam et al., 2008).

Fixed dome digester

The fixed dome digester (Figure 2), whose archetype was developed in China, is the most popular digester and is relatively inexpensive. It is simple, has no moving parts and has therefore a long lifespan, up to 20 years. The plant is suitable for cold climates because the most part is beneath the ground level. Therefore, the plant is protected against low temperatures occurring during night and in cold seasons. The temperature within the digester is lower during day time and higher during night time. This is beneficial for the methanogenic bacteria and consequently for the biogas production. The level of slurry in the digester depends on the loading rate, gas production and consumption. During gas production slurry is pushed back sideways and displaced to the compensation tank. When gas is consumed slurry enters back into the digester from the compensation tank. As a result of these movements, a certain degree of mixing of slurry of different ages is obtained; therefore this design approaches a mixed digester reactor.

Floating drum digester

Floating-drum plants (Figure 3) consist of a digester and a moving gasholder. The gasholder floats either direct on the fermentation slurry or in a water jacket of its own. The gas collects in the gas drum, which thereby rises. If gas is drawn off, it falls again (Sasse, 1988). The ideal situations for a community based biogas digester recommends a central collection area for the plant substrate, be it animal manure, excrete or food/vegetable waste. The operation of a floating dome digester is not that different from a fixed dome digester. The produced gas is collected in a movable steel drum, the gasholder. The steel drum is guided by a guide frame. When gas is consumed the drum sinks. Slurry is pushed out of the digester after the digestion (Singh et al., 1987). In contrast to the fixed

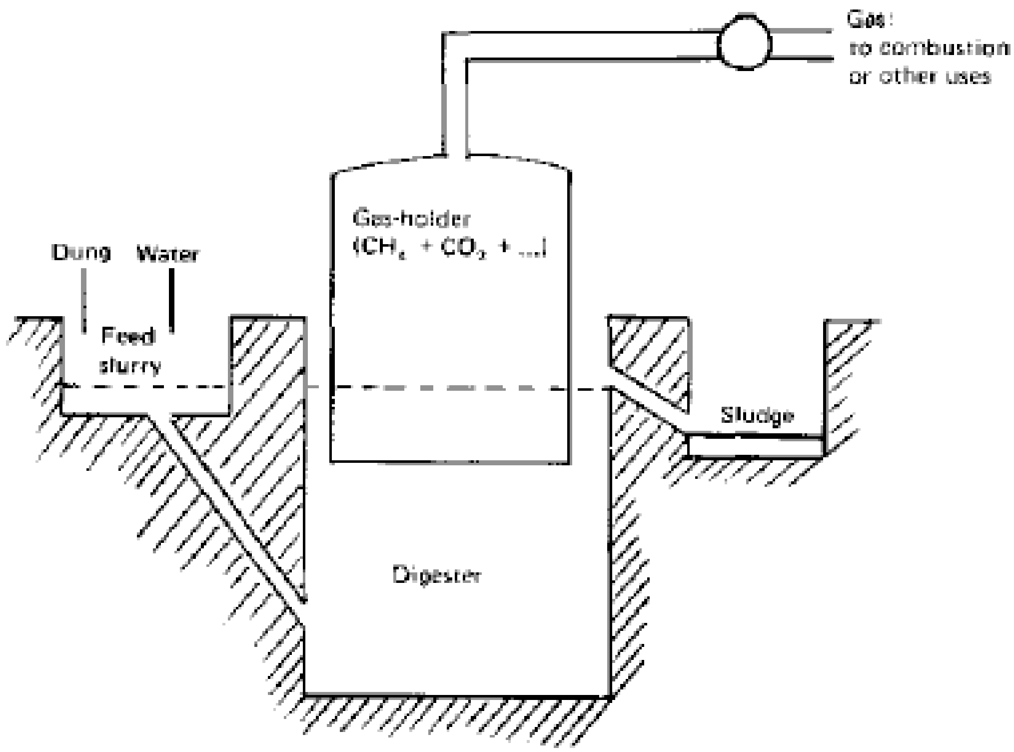

Figure 3. Floating-drum plant.

dome digester, a floating drum digester is not a mixed reactor. But some mixing take place due to removal of gas produced at the bottom of digester. A low cost option is to use a balloon as a gas holder instead, which is attached to the digester. Its disadvantage is the susceptibility to physical damage.

Bag digester/ balloon plants

A balloon plant (Figure 4), also referred to as a bag digester, is a plastic or rubber bag combining the gas holder and digester. This is a plug-flow type reactor. Gas is collected in the upper part and manure in the lower part; the inlet and outlet are attached to the skin of the bag. The bag digester was developed to solve the problems experienced with brick and metal digesters. These bags have a limited life span of 3 to 5 years. In China red mud bags, a byproduct from the production of aluminum has been successfully used since 1983. It has advantages such as low cost and simple technology. It also has disadvantages like, short life-span, susceptible to physical damage, hard to repair, need for high quality plastic (Balasubramaniyam et al., 2008).

Deenbandhu model

The Deenbandhu model was developed by Action for Food Production (AFPRO), New Delhi, India, in 1984. The word deenbandhu means ‘friend of the poor’. Until now, this model is the cheapest among all the available models of biogas plant. This model is designed on the basis of the principal of minimization of the surface area of a biogas plant to reduce its installation cost without sacrificing the functional efficiency. The design consists of two spheres of different diameters, joined at their bases. The structure thus formed acts as the digester or fermentation chamber, as well as the gas storage chamber. The digester is connected with the inlet pipe and outlet tank. The upper part above the normal slurry level of the outlet tank is designed to accommodate the slurry to be displaced from the digester with the generation and accumulation of biogas (Singh and Sooch, 2004). The main feature of this digester is the fixed underground digester chamber, constructed with a layer of bricks by making an additional layer of cement mortar forming the roof above. In colder climate like the lower regions of Himalaya the deenbandhu fixed model is ideal because the digestion chamber is underground providing good insulation against the cold (http://www.grassrootindia.com/deenbandhu.html). Therefore, the deenbandhu digester (Figure 5) needs to be adapted to lower temperatures (Singh et al., 1987).

Biogas application

Biogas is “gas rich in methane, which is produced by the

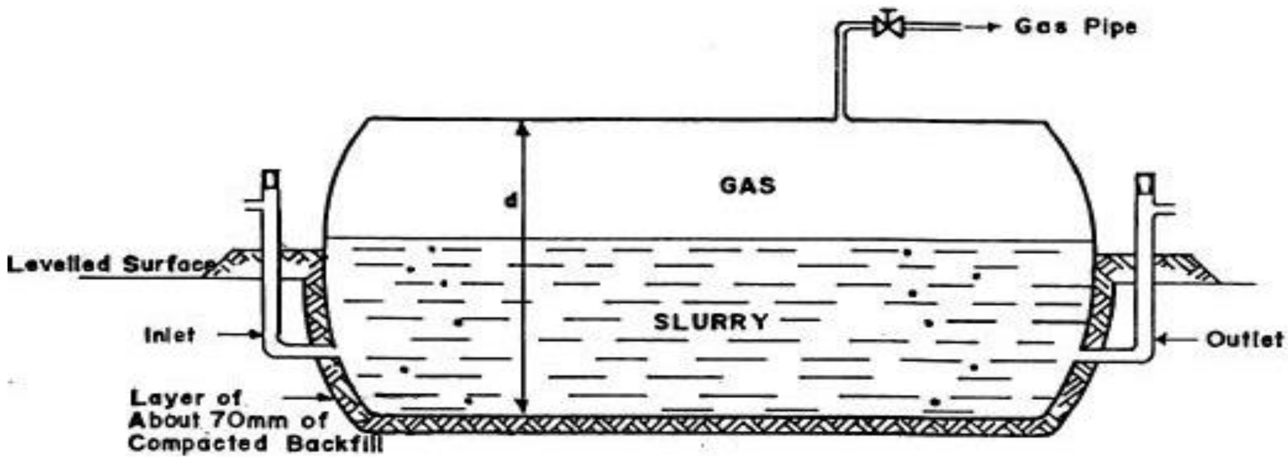

Figure 4. Bag digester (Singh et al., 1987).

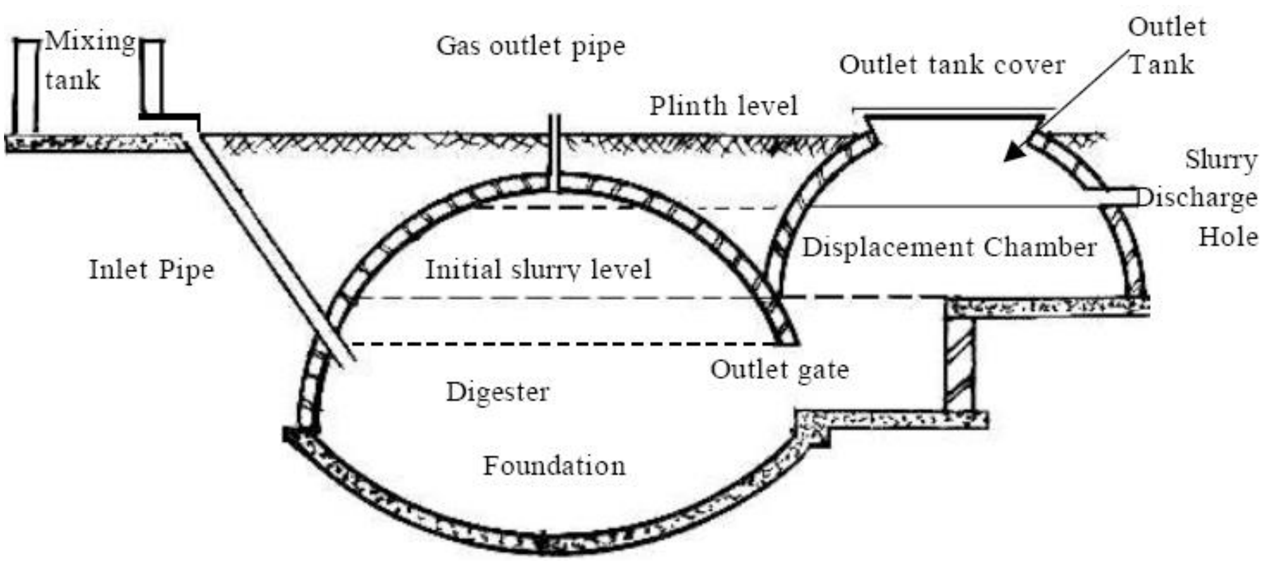

Figure 5. Deenbandhu digester (Singh et al., 1987).

fermentation of animal dung, human sewage or crop residues in an air tight container". A vast amount of literature already exist on the applications and benefits of anaerobic digestion processes with special emphasis focused initially on anaerobic digestion of municipal solid waste for bio-energy production almost a decade ago (Membere Edward et al., 2012). Among the many potential uses of gas are hot-water heating, building heating, room lighting, and home cooking. Biogas can be used in gas-burning appliances if they are modified for its use. Conversion of internal-combustion engines to run on digester gas can be relatively simple; thus the gas could also be used for pumping water for irrigation. Past experiences have shown that where methane is generated in significant quantities in rural areas of developing countries, its use is primarily for lighting and cooking (Onojo et al., 2013).

CONCLUSION

Biogas technology has tremendous application in the future for sustainability of both environment (treatment of wastes) and energy with the production of fertilizer as an extra benefit. Biogas production depends on various parameters that affect the yields of the gas from different substrates. Prominent among the factors are the pH, temperature and more importantly, the C/N ratio that controls the pH value of the slurry. The total solids and volatile matter, are among the factors affecting biogas yields. Similarly, formation of volatile fatty acids beyond a particular range hinders the methane production. Loading rate and solid concentration should be properly balanced and continuously maintained. Production of biogas will enhance clean environment through the killing of the pathogens, during anaerobic digestion and thus producing fertilizer very rich in NPK. Biogas finds application in cooking, lighting, electricity generation amongst other uses.

Abbreviations

VFAs, Volatile fatty acids; **HRT,** hydraulic retention time; **SRT,** solids retention time; **OLR,** organic loading rate; **TS,** total solids; **VSS,** volatile suspended solids; **BOD,** biochemical oxygen demand; **COD,** chemical oxygen demand; **TKN,** total Kjeldahl nitrogen.

Conflict of interests

The author has not declare any conflict of interest.

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