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Anaerobic co-digestion of biodegradable municipal solid waste with human excreta for biogas production: A review

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Abstract: Biogas, which is principally composed of methane and carbon dioxide, can be obtained by anaerobic fermentation of biomass like: manure, sewage sludge, municipal solid waste. Biogas production represents a very promising way to overcome the problem of waste treatment. Furthermore, the solid residuals of fermentation might be reused as fertilizers. This review clearly indicates that co-digestion of organic waste is one of the most effective biological processes to treat a wide variety of solid organic waste products and sludge as well as biogas production. The prime advantages of this technology include (i) organic wastes with a low nutrient content can be degraded by co-digesting with different substrates in the anaerobic bioreactors, and (ii) the process simultaneously leads to low cost production of biogas, which could be vital for meeting future energy-needs.

Keywords: Biogas, Methane, Municipal Solid Waste, Co-Digestion

1. 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 overdependence 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 – 10 billion people and 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 such as cooking and lighting. At the same time, over 60% of the total wood in developing countries is used as wood fuel in 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).

Achieving solutions to possible shortage in fossil fuels and environmental problems that the world is facing today requires long-term potential actions for sustainable development. In this regard, renewable energy resources appear to be one of the most efficient and effective solutions. Biogas has globally remained a renewable energy source derived from plants that use solar energy during the process of photosynthesis. Being a source of renewable natural gas, it has been adopted as one of the best alternatives for fossil fuels after 1970's world energy crisis. Biogas is a colourless, flammable gas produced via anaerobic digestion of animal, plant, human, industrial and municipal wastes amongst others, to give mainly methane (50-70%), carbon dioxide (20-40%) and traces of other gases such as nitrogen, hydrogen, ammonia, hydrogen sulphide, water vapour etc. It is smokeless, hygienic and more convenient to use than other solid fuels. Biogas production is a three stage biochemical process comprising hydrolysis, acidogenesis/acetogenesis and methanogenesis (Ofoefule *et al*., 2010).

Ethiopia produces a plenty of fruits and vegetable wastes and generates a solid waste of 0.4kg/c/day in Addis Ababa only. Therefore, it becomes necessary to develop appropriate waste treatment technology for vegetable wastes to minimize green house gas emission (Addis Ababa city SWMS, 2010). 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 putrecible organic matter cause serious environmental and health risks (Dhanalakshmi and Ramanujam, 2012).

Biological conversion of biomass to methane has received increasing attention in recent years1. There are many technologies such as incineration and refuse derived fuel (RDF) 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. 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 and Ramanujam, 2012).

Waste is one of the most promising options for the production of biofuel which act as an alternative source of energy. This would also help in the stabilization of wastes which is becoming a nuisance to the community. In recent years, biogas formation from municipal solid waste, food manufacturing waste, waste activated sludge has been reported (Singhal *et al*., 2012).

Municipal solid waste (MSW) generation is significantly increasing in Ethiopian urban areas and started creating enormous waste disposal problems in the recent past. In Ethiopia, MSW management is the duty of the local municipalities. The anaerobic digestion is an attractive option for energy generation from the putrescible fraction of MSW as well as for reducing the disposal problem. It has reduced environmental impact, especially with respect to the greenhouse effect and global warming (Yusuf and Debora, 2011).

Municipal solid waste (MSW) contains a significant fraction (30–50%) of organics. It is the waste generated in a community with the exception of industrial and agricultural wastes. Hence MSW includes residential waste (e.g., households), commercial (e.g., from stores, markets, shops, hotels etc), and institutional waste (e.g., schools, hospitals etc). Paper, paper board, garden and food waste can be classified in a broad category known as organic or biodegradable waste (Tchobanoglous *et al*., 1993). . It can be a useful resource if this organic fraction could be used for power generation. Beside, rapid exhaustion of conventional energy sources has necessitated the search for alternate energy sources. Present municipal solid waste landfills generate biogas and leachate. Due 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 40-60% methane, with the remainder being mostly carbon dioxide (CO2). Landfill gas also contains varying amounts of nitrogen, oxygen, water vapor, sulfur and a hundreds of other contaminants (Asgari et al., 2011).

Generally cow dung is used to generate biogas, but human excreta have the potential to produce biogas as it contains similar matter to cow dung. Additional water and cow dung is not normally required when the biogas digester is connected to a flush toilet that provides excreta, urine and flush water. Although human excreta can be used to produce biogas energy, which is of benefit to people, negative connotations are attached to it. 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' (hospitals, schools etc) 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 including human excreta from different sources 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 such as to improve biogas yield by controlling the carbon to nitrogen ratio (Yusuf and Debora, 2011). Cellulosic wastes are generally known to be poor biogas producers because of their poor biodegradability. One treatment method for improving the biogas production of various feedstocks is co-digesting them with animal and/or plant wastes.

Biogas is a mixture of colorless, flammable gases produced by anaerobic fermentation of organic waste materials such as animal, human excreta, agricultural and industrial wastes. These include human excreta, animal faeces, municipal sludge and garbage, abattoir waste, paper waste and waterweeds. Biogas produced by bacteria through the bio-degradation of organic material under anaerobic conditions. Natural generation of biogas is an important part of bio-geochemical carbon cycle. It can be used both in rural and urban areas. Biogas is useful as fuel to substitute firewood, cow-dung, petrol, LPG, diesel, & electricity; depending on the nature of the task, and local supply conditions and constraints. Bio-methanation process is one of the most essential processes for treating the Bio-degradable portion of any solid waste. The essential elements of a high rate biomethanation are complete mixing and uniform temperature with more or less uniform feeding of the substrate (Ramanathan et al., 2013; Otaraku and Ogedengbe, 2013).

In anaerobic digestion environmental factors such as substrate concentration, temperature, pH and metal ions have great influences on methane production. A high concentration of VFAs has been reported to inhibit methane production from VFAs by mixed anaerobic microorganisms. The optimum pH range for anaerobic digestion producing methane is 6.8–7.2. The growth rate of methanogens can be greatly reduced when the pH value is less than 6.6. An excessively alkaline pH can lead to the disintegration of microbial granules and subsequent failure of the digestion process. Therefore, a buffer is needed in the methane production process in order to provide the resistance to significant and rapid pH changes in the system.

Optimization of various process factors affecting biogas production is a complex process with a number of interactive controlling parameters. At industrial level, even a small improvement in the process, gives a better yield which may be beneficial commercially, making process optimization a major area of research in the field of industrial biotechnology [16]. Therefore, there is a need for optimization of accurate process parameters which, improves the production of the biogas significantly (Sajeena Beevi *et al*., 2014).

This review paper explores a suitable way to use organic waste such as human excreta, which served as useful raw material for biogas production by co-digestion of municipal biodegradable solid waste. It plays a vital role in creating good awareness of using biodegradable solid waste and human excrement for biogas production and soil conditioner especially in Ethiopia.

2. Anaerobic Digestion

Anaerobic digestion is a process of controlled decomposition of biodegradable materials under managed conditions where free oxygen is absent, at temperatures suitable for naturally occurring mesophilic or thermophilic anaerobic and facultative bacteria and archaea species, that convert the inputs to biogas and whole digestate. It consists in the 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), nitrogen (N_2) and hydrogen sulfide (H_2S). The significant amount of biodegradable components (carbohydrates, lipids and proteins) present in the microalgae biomass makes it a favorable substrate for the anaerobic microbial flora that can be converted into biogas rich in CH_4 (Steinmetz et al., 2013).

The anaerobic digestion process is characterized by a series of biochemical transformations brought on 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 acidogenenesis 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 themost 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).

3. 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: 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 polymeric components is the necessary first step in anaerobic digestion. In the first step (hydrolisis), 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 lingo-cellulosic material is a major factor, which influences the level of the carbon source required for biogas production (Asgari, 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 be used by methanogens. MSW contains a significant fraction of ligno-cellulosic material. The acidification of these materials influences the biogas yield (Asgari, 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 use and any dead bacterial remains constitute the digestate (Onojo et al., 2013; Dioha et al., 2013).

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/tone. 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).

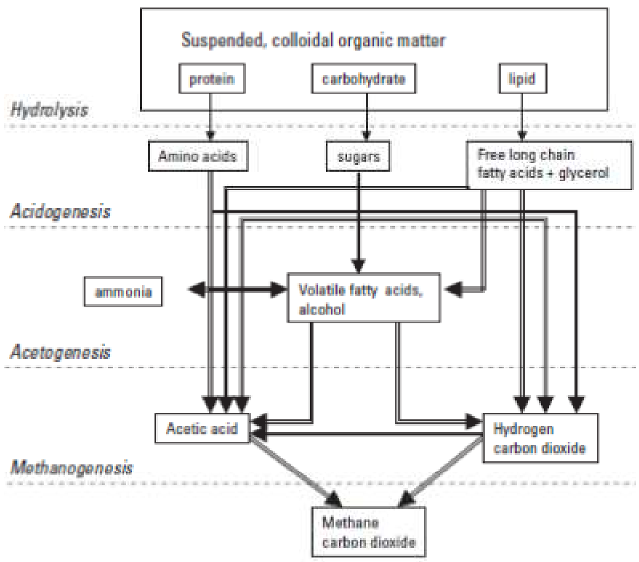

Figure 1. *Simplified schematic representation of the anaerobic degradation process (Lettinga et al., 1999).*

4. Factors Affecting Biogas Production/ Variation in Operational Parameters

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' results show that factors like temperature, pH, concentration of total solids, etc affect the production of the biogas.

Various factors such as biogas potential of feedstock, design of digester, inoculums, nature of substrate, pH, temperature, loading rate, hydraulic retention time (HRT), C:N ratio, volatile fatty acids (VFA), etc. influence the biogas production (Dioha et al., 2013).

4.1. 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 (30–40°C) and thermophilic (50–60 °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 33-38 °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 ambient and slurry temperature values were monitored in determining the rate of digestion and retention of the process, since temperature is very important. The ambient 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).

4.2. 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 6.8–7.2 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 proceed normally, concentration of volatile fatty acids, acetic acid in particular should be below 2000 mg/l (Yadvika et al., 2004). pH values below 6.0-6.5 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).

4.3. 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 60–80% of humidity. Methanogenesis processes during anaerobic digestion at different moisture levels i.e., 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).

4.4. 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).

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 bacterias 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 disadvantage 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).

Digesters operating in the thermophilic range require 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 – 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).

4.5. 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 (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.

4.6. 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.

4.7. 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 m^3 biogas plant operating on manure, when OLR was varied from 346 kg VS/day 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 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 m3/kg VS at an OLR of 2.91 kg VS/ m3/day. Based on pilot plant studies (1 m^3 capacity), maximum gas yield was observed for a loading rate of 24 kg dung/m3 digester/day although percent reduction of VS was only 2/3rd of that with low loading rate (Yadvika, 2004).

4.8. Hydraulic Retention Time (HRT)

HRT is the average time spent by the input slurry inside the digester before it comes out. In tropical countries like India, HRT varies from 30–50 days while in countries with colder climate it may go up to 100 days. Shorter retention time is likely to face the risk of washout of active bacterial population while longer retention time requires a large volume of the digester and hence more capital cost. Hence there is a need to reduce HRT for domestic biogas plants based on solid substrates. It is possible to carry out methanogenic fermentation at low HRT's without stressing the fermentation process at mesophilic and thermophilic temperature ranges (Yadvika, 2004).

4.9. 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).

4.10. 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 25–30 times faster than nitrogen. Thus to meet this requirement, microbes need a 20–30:1 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, 2004).

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 20–30 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 20–35.

4.11. 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 microorganisms. A wide range of inhibiting ammonia concentrations has been reported in the literature, with the inhibitory TAN 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).

4.12. Chemical Oxygen Demand/Nitrogen Ratio

COD is amount of oxygen needed for waste material in the water that can be oxidized through a chemical reaction. COD/N ratio of substrate is necessary parameter to produce biogas optimally. The COD/N range of 350/7 – 1000/7 is the optimal range for anaerobic digestion. If more or less than the range, microbial growth in the digester will be hampered. So, adjustment of COD/N of substrate was needed to be done. Proteins, amino acids and urea are nitrogen source needed by microbe to build cell structures. Biogas produced at COD/N ratios of 500/7 and 600/7 were in nearly equal amount. Whereas, biogas produced at COD/N ratio of 400/7 is less than that of 500/7, 600/7, and 700/7.

Bacteria could not thrive in substrate that contained ammonia concentrations above 200 mg/L. 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, acetogenesis, 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 1,500-10,000 mg/L was inhibition start for bacterial growth, whereas that of 30,000 mg/L was toxicity concentration (Sumardiono et al., 2013).

5. Analytical Measurements

TS and VS contents are measured according to Standard Methods.

6. 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).

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

For measuring the volatile suspended solids (VS), the crucible containing the sample (W1) used for measuring the TS value is kept in the furnace set at 550°C for 2 hours 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):

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

7. 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. 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).

8. Biogas Production and Use

The production of methane during the anaerobic digestion of biologically degradable organic matter depends on the amount and kind of material added to the system. The efficiency of production of methane depends, to some extent, on the continuous operation of the system. As much as $1000m^3$ of gas (containing 50- 70 percent methane) can be produced from $1000m^3$ of volatile solids added to the digester when the organic matter is highly biodegradable (e.g., night soil or poultry, pig, or beef-cattle faecal matter) for a period of 30 days. Combustion of about 30litres (1 ft^3) of gas will release an amount of energy equivalent to lighting a 25-watt bulb for about 6 hours. In general, lower gas-production rates result when the wastes are less biodegradable (Onojo et al., 2013).

Among the many potential uses of digester gas are hot-water heating, building heating, room lighting, and home cooking. Gas from a digester 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).

9. Conclusion

Biogas can be produced from the co-digestion of municipal biodegradable solid waste with human excrement. This technology has tremendous application in the future for sustainability of both environment (treatment of wastes) and agriculture, with the production of energy 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, volatile matter, mineral concentrations 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.

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