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Co-Digestion of Ethiopian Food Waste with Cow Dung for Biogas Production

[1]Alemayehu Gashaw*, [2]Abile Teshita

[1]Department of Chemistry, Faculty of Natural and Computational Science, Bule Hora University, Bule Hora, Ethiopia

[2]Department of Biology, Faculty of Natural and Computational Science, Bule Hora University, Bule Hora, Ethiopia.

Corresponding author's email- alexgashaw@gmail.com

Fax +251464430355, Phone No. +251910788274

Abstract: *Now a day biogas production is one of the most promising renewable energy sources in Ethiopia. Anaerobic digestion is one of the effective ways of generating biogas. It is also a reliable method for treating food wastes such as cafeteria wastes, vegetable wastes etc. and cow dung and the digested slurry can be used as fertilizer to enhance the fertility of the soil. Co-digestion of food waste with cow dung or other feed stocks with low carbon content can improve process stability and methane production. Anaerobic co-digestion of food waste with cow dung is needed to enhance biogas production and very useful to treat these wastes. This review paper looks at the possibility of producing biogas from co-digestion of food waste with cow manure by optimizing the parameters that affect biogas production. Most literatures confirmed that the Co-digestion strategy substantially increased the biogas yields by 20-50% over the control.*

Key words: Co-digestion; Food waste; Biogas; Anaerobic digestion; Cow dung, Ethiopia

Introduction

The depletion of the world petroleum reserves and the increased environmental threat and security concerns has stimulated search for alternative sources to petroleum based fuels. Biogas, a flammable gas (for cooking and lighting), obtained from biogenic sources is being viewed as one of the best alternatives to petroleum- based fuel. It can also be used in modern waste management facilities where it can be used to run any type of heat engine to generate either mechanical or electrical power (Ofoefule *et al.*, 2013).

In recent years, the ever-increasing demands for energy, coupled with the shortage of fossil fuels almost all over the world have created a renewed interest for utilizing renewable energy sources (Kavitha and Joseph, 2007). The search for alternative renewable energy sources is needed not only for replacement of fossil fuels, but also meet environmental protection demands (Imri and Valeria, 2007). Petroleum is a widely used non-renewable source of energy which is bound to be exhausted in due course of time. Biogas generation and its utility as an alternative renewable source of energy is increasingly gaining attention, particularly among the developing countries (Abdulkareem, 2005).

Issues pertaining to global warming and climate changes are receiving unprecedented attention among the scientific as well as political spheres both at national and international levels.[5] Climate problems resulting from the green house effect, ozone depletion, etc. have all contributed to the recognition of the value of anaerobic digestion of organic wastes as an alternative renewable source of energy. Anaerobic digestion is a process carried out by microorganism in an oxygen free-environment; with generation of biogas mainly methane and hydrogen as its most significant products (Membere Edward *et al.*, 2012). In addition to serving as an alternative energy source, biogas generation through anaerobic digestion process also enables us to do away with organic wastes whose accumulation in the environment would otherwise lead to numerous health related problems. The organic wastes mainly consist of household food wastes, leftover food stuffs, agricultural, human and animal excrements (Alemayehu, et al., 2014).

Co-digestion has been defined as the anaerobic treatment of a mixture at least two different substrates with the aim of improving the efficiency of the anaerobic digestion process. Anaerobic co-digestion is reported to offer several benefits over digestion of separate materials, such as increased cost-efficiency, increased biodegradation of the treated materials, as well as increased biogas production. There is abundant literature about the utilization of co-digestion, such as co-digestion of organic fraction of municipal solid waste (OFMSW) and agricultural residues, organic solid wastes and sewage sludge or more specific wastes (Neczaj et al., 2012). Ethiopia has a large population of dairy and beef cattle, generating large amounts of surplus manure that can be used in biogas plants to produce renewable energy. However, the high water content, together with the high content in fibers, are the major reasons for the low methane yields when cattle manure is an-aerobically digested, typically ranging between 10 and 20 m^3 CH_4 per ton of manure treated (Tamrat, *et al.*, 2013).

Bio-methanation is the anaerobic digestion of biodegradable organic waste to produce biogas (principally composed of methane and carbon dioxide) in an enclosed space under controlled conditions of temperature, moisture, pH, etc (Prakash and Singh, 2013). Biogas so produced can be used for cooking purposes, light and electricity production and as an alternative vehicle fuel (Harris, 2008). Use of biogas for cooking purposes leads to substantial reduction in the amount of firewood consumption. This results in reduced deforestation thereby making significant contribution towards environmental protection. Besides, biogas generation is very economic in terms of labor requirement and provides organic residues that can be used as fertilizers. Presently, utility of biogas as a viable source of energy is seen to be taking root in many parts of the country. The aim of this review paper is to show the potential of biogas production from co-digestion of Ethiopian food wastes such as cafeteria wastes, vegetable wastes and fruit wastes with cow dung.

Historical Background of biogas

Biogas is a mixture of gases, mainly methane and carbon dioxide, resulting from anaerobic fermentation of organic matter. In 1630 Van Helmont, a Belgian national, noted that the gas emanating from decaying matter is different from the constituents of air. It was Volta, an Italian national, who introduced biogas in a scientific setting. In 1776 he concluded that the amount of gas released is a function of the amount of decaying vegetation and that upon mixing with a certain proportion of air it becomes explosive. Afterwards, Dalton reported methane as a major proportion of biogas. Subsequently, Henry confirmed that town gas was similar to the gas which Volta studied. In 1808, Sir Humphrey Davy demonstrated the production of methane by the anaerobic digestion of cattle manure. Anaerobic digestion is a biological process that happens naturally when bacteria break down organic matter in the absence of oxygen. Then Beschamp, a student of Pasteur, discovered that biogas production was connected with microbial activity. In 1886 he discovered methanogens (Verma, 2002). Following the discovery of methane emissions from natural anaerobic habitats by Volta in 1776, people started using biogas as a fuel, basically for lighting. However, it took until the end of the 19th century to apply anaerobic digestion for the treatment of wastewater and solid wastes. The first digestion plant was reported to have been built at a leper colony in Bombay, India, in 1859. Anaerobic digestion reached England in 1895, when biogas was recovered from a sewage treatment facility to fuel street lamps in Exeter. The main purpose of anaerobic digestion is to reduce and stabilize solid wastes (Nayono, 2010). Biogas generation was introduced in Ethiopia in 1957/58 in the then Ambo Agricultural College, located 115km west from Addis Ababa. Human excreta served as the substrate used generation of the fuel (Mogues, 2009). . In October 1962, the first biogas floating drum digester or plant in Ethiopia was installed in the same college. This floating drum biogas system comprised of 7m^{3}digester which was charged with daily loading rate of about 100 liter of dung and water in a 1:1 ratio (Bilhat, 2009). During the period 1980 – 2000 more than 1000 biogas plants have been constructed in government institutions, private sectors and communities mostly for demonstration purposes (Mogues, 2009).

Raw materials for biogas fermentation such as cow or pig dung, poultry waste, water hyacinth, straw, weeds, leaf, human and animal excrement, domestic rubbish and industrial solid and liquid wastes are available in Ethiopia. Biogas production systems have several benefits, such as (a) eliminating greenhouse gas, (b) reduction of odor, (c) betterment of fertilizer, (d) production of heat and power. Usually efficiency of biogas plant varies with the type of digester, the operating conditions, and the type of material loaded into the digester. Operating temperature is an important factor influencing digester efficiency. Although higher temperature range produces greater quantities of biogas, an additional source of energy will likely be required to maintain the digester contents at a constant higher temperature. The content of biogas varies with the material being decomposed and the environmental conditions involved. Potentially, all organic waste materials contain adequate quantities of the nutrients essential for the growth and metabolism of the anaerobic bacteria in biogas production (Khan, *et al*., 2013).

Food wastes

Food waste is the single largest category of municipal solid waste in Ethiopia. Biogas plant operators know well the advantages of adding fat residues or food wastes to their biogas plants. Food wastes collected from restaurants are highly desirable substrates for anaerobic digesters. These substrates are reported to yield 80% of the theoretical methane yields in 10 days of digestion time provided the various parameters affecting biogas generation are monitored properly (Neves, *et al*.,2009).

Food waste has a potential for methane production depending on the type of food used. It can be digested rapidly making it a good source of material for anaerobic digestion. Optimization of methane generation from anaerobic systems is dependent on digester design and operation, although it has been stated that the feed stock is as important as the digester technology (Dearman and Bentham, 2007). High calorie food wastes like bread, pasta and rice are easily degraded by fermentative bacteria, which produce large amount of organic acids. Acid production lowers reactor pH inhibiting the methanogenic systems and limiting the generation of significant amount of methane (Dearman and Bentham, 2007). For instance, in Ethiopian higher institutions cafeteria wastes such as leftover of Injera, which is made of teff, contains 15% protein, 3% fat and 82% complex carbohydrates and has high calorie content. According to Alemayehu et al. (2014) the degradation of injera by fermentative bacteria produces large amounts of organic acids and lowers the reactor pH which in turn limits the generation of methane. Hence co-digestion of these wastes with cow dung regulates the fluctuation of pH occurs during digestion process.

Cow Dung

Mixing cow dung with organic wastes from industry and households has been successfully applied for biogas production. Co-fermentation offers economic and environmental benefits due to as it entails processing multiple waste streams in a single facility. There are three main advantages of using cattle dung for co-fermentation. Firstly, it is a good source for nutrients such as trace metals, vitamins and other compounds necessary for microbial growth. Secondly, it plays a role in neutralizing pH and improving buffering capacity. Thirdly, the high water content in dung helps dilute the concentrated organic wastes, which would be inhibitory and difficult to treat separately. Moreover, a high buffering capacity in manure makes the process more resistant to the effect of volatile fatty acids (VFAs) accumulation and thus avoids inhibition processes. Several studies have reported that the biogas process could be improved and stabilized by applying co-digestion strategy (Fang, 2010).

Co-digestion of different substrates and sewage sludge could be beneficial due to dilution of inhibitive substances, improved nutrient content (ammonium nitrogen, potassium, phosphorus, calcium, magnesium) and synergistic effect between the treated materials resulting in better degradation of both (Neczaj, *et al.*, 2012). Co-digestion of food waste with animal manure or other feedstocks with low carbon content can improve process stability and methane production. Co-digestion with other wastes, whether industrial (glycerin), agricultural (fruit and vegetable wastes) or domestic (municipal solid waste) is a suitable option for improving biogas production (Zhang, *et al.*, 2006). . It was observed from the study that co digestion of vegetable and fruit waste with cow dung decreases the digestion time because of cow dung increases the methanogenic activity in the digester (Prakash and Singh, 2013). Food waste is a desirable material to co-digest with dairy manure because of its high biodegradability.

According to Tamrat, et al., (2013) co-digestion of three mix ratios (75:25, 50:50 and 25:75) of rumen fluid inoculated Cow manure with organic kitchen waste was performed and biogas productions from the biodegradation of organic matter were compared with pure cattle manure and organic kitchen waste as the controls. As the result indicated, the co-digestions of the three mixes showed improved biogas production rates and achieved higher cumulative biogas production than the two pure samples. More balanced nutrients in co-digestion would support microbial growth for efficient digestion, while increased buffering capacity would help maintain the stability of the anaerobic digestion system. Co-digestion substantially increased the biogas yields by 24 to 47% over the control (Tamrat, et al., 2013). Co-digestion has in comparison with single anaerobic fermentation several advantages.

- increased biogas production with single fermentation of wastes comparison
- minimal green house gases producing
- disposition of wastes, which occupy large planes
- contamination’s restraint of ground waters
- destruction of pathogenous germs in raw waste
- smell removal
- digested waste is perfect bio-organic fertilizer.

Biogas

Biogas is a colorless, 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 (Khan, *et al*., 2013). This gas originates as a result of bacterial action in the process of bio-degradation of organic material like biomass, manure or sewage, municipal solid wastes, green wastes and energy crops under anaerobic conditions (Ilaboya, *et al*., 2010). . CH_4 gas is considered as a valuable fuel. This gas is called by several other names such as marsh gas, gobar gas, sewage gas, swamp gas and digester gas depending on where it is produced (Sagagi, *et al*., 2009).

Biogas Composition and Characteristics

The composition of biogas largely depends on the type of substrate used for its formation. Generally, biogas consisted of methane (50-70%), carbon dioxide (30-40%) and hydrogen, nitrogen as well as hydrogen sulphide (Rahmat, *et al.*, 2014).

Biogas is a renewable energy source produced by a large number of anaerobic microbial species that ferment the organic matter under controlled temperature, moisture and pH conditions. Biogas is about 20 percent lighter than air and has an ignition temperature in the range of 650°C to 750°C.

It burns without smoke and is non-toxic. It is also an odorless and colorless gas that burns with clear blue flame similar to liquefied petroleum gas (LPG) (FAO, 1996). LPG gas is also principally composed of methane and carbon dioxide. Methane produces more heat than kerosene, wood, charcoal and cow-dung chips (Karki, et al., 2005) Table 1 summarizes a typical approximate composition of biogas.

Table 1: A typical composition of biogas (Bilhat, 2009)

Substance	**Percentage**
Methane	50 – 70
Carbon dioxide	30 – 40
Hydrogen	5 – 10
Nitrogen	1 – 2
Water vapor	0.3
Hydrogen sulphide	Traces

Anaerobic Digestion

The biological break down of organic materials can be classified into two major groups: anaerobic (without oxygen) and aerobic (with oxygen). 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 (Hassan, 2003**.** The organic dry matter can be divided into proteins, fats and carbohydrates all of which have different degradation characteristics. For example, leftover foods consisting of cooked foods, such as meat, fish, rice, bread, noodle and vegetable are mainly composed of protein, starch, sugar and fat. These food wastes contain highly biodegradable organic matter and thus result in higher methane production (Lin et al., 2011) Typically, between 40% and 60% of the organic matter present in the feedstock is converted to biogas and microbial biomass (Juanga, 2005; Ros and Zupancic, 2003). .

The conversion of complex organic compounds into methane and carbon dioxide requires different groups of micro organisms and is carried out in a sequence of four stages: hydrolysis, acidogenesis, acetogenesis and methanogenesis. During the hydrolysis stage, organic substrate is converted into smaller components which are subsequently converted into volatile fatty acids (VFAs), ethanol, CO_2 and H_2 by acidogenic bacteria. Acetogenic bacteria then convert these fermentation products into acetic acid, CO_2 and H_2. Finally methanogenic bacteria use hydrogen and acetate (most important substrate) and produce methane and carbon dioxide. Figure 1 depicts the sequence of bacterial actions during anaerobic digestion (Balasubramaniyam et al., 2008).

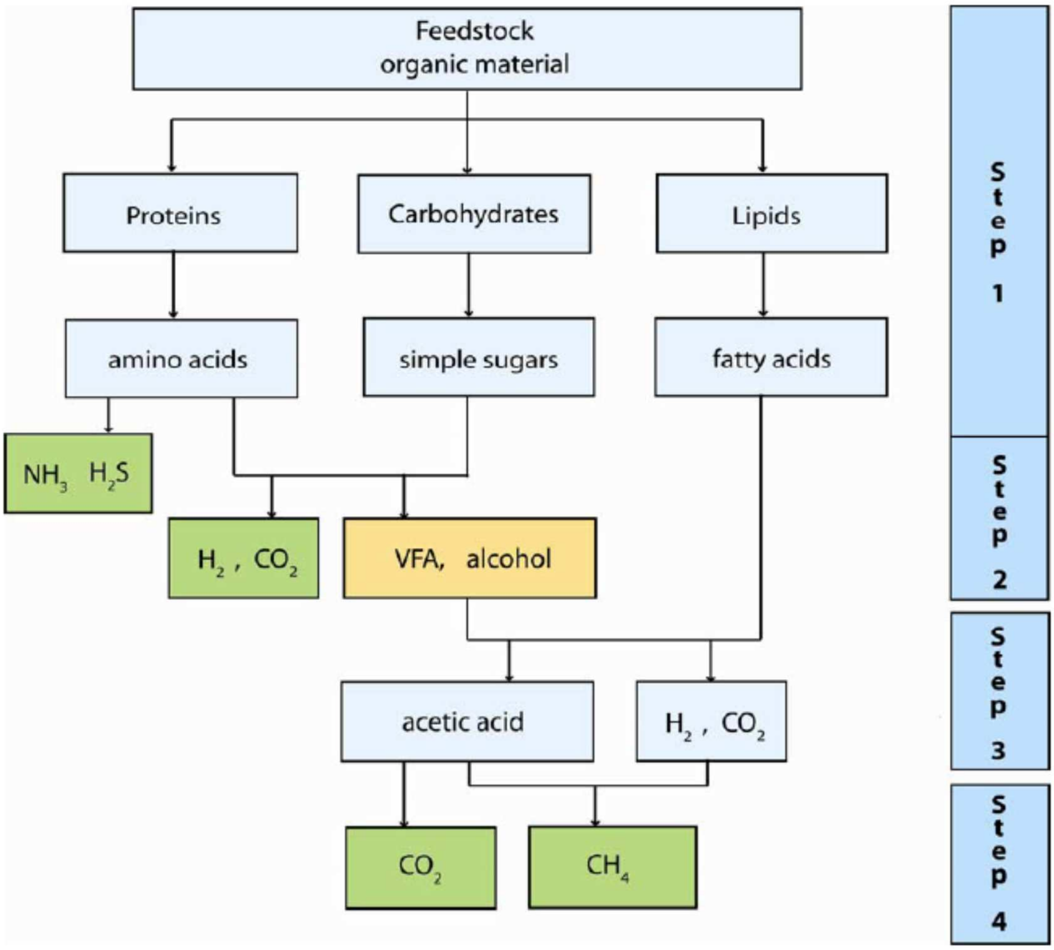


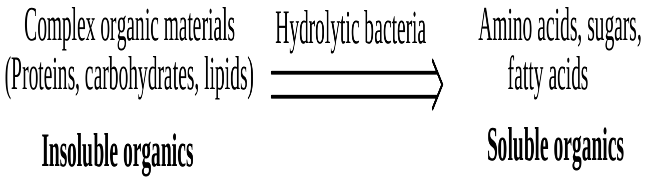
Figure 1: Anaerobic digestion of organic material. Step 1: Hydrolysis, Step 2: Acidogenesis, Step 3: Acetogenesis, and Step 4: Methanogenesis. VFA: Volatile fatty acids (Lomborg, 2009).

Biochemical Reaction and Microbiology

The chemistry of digestion process in the production of biogas involves hydrolysis, acidogenesis or acetogenesis and methanogenesis.

Hydrolysis

Hydrolysis is a slow process that depends on the nature of the particulate matter and size of organic matter. For complex substrates with a high solid content, hydrolysis is usually the slowest step and hence the rate limiting step in the overall anaerobic digestion process (Lomborg, 2009). Hydrolysis converts complex organic matters such as carbohydrates, proteins and lipids into soluble organic molecules such as sugars, amino acids and fatty acids by the action of extracellular enzyme, i.e. cellulase, amylase, protease and lipase. Hydrolytic bacteria, which hydrolyze the substrate with these extracellular enzymes, are facultative anaerobes (Blatt, 2009). Proteins are broken down into amino acids, small peptides, ammonia and CO_2 while polysaccharides are generally converted into sugars. There are three main hydrolytic bacteria: the proteolytic bacteria produce an enzyme known as protease for the breakdown of proteins and peptides into ammonia and amino acids, the lipolytic ones generate lipase enzyme for the breakdown of saponifiable lipids into fatty acids and glycerol, and cellulolytic bacteria create hydrolase enzymes for the breakdown of polysaccharides into sugars. Most of these microorganisms are obligate anaerobes and few of them are facultative. The degradable polymeric substrates found in solid waste include lignocellulose, proteins, lipids and starch (Veeken *et al.*, 2000). Hydrolytic microorganisms excrete hydrolytic enzymes, converting biopolymers into simpler and soluble compounds as shown below in Figure 2.



Scheme 1. General illustration of hydrolysis reaction during anaerobic digestion (Juanga, 2005).

When the substrate is hydrolyzed, it becomes available for cell transport and can be degraded by fermentative bacteria in the acidogenesis step.

Acidogenesis

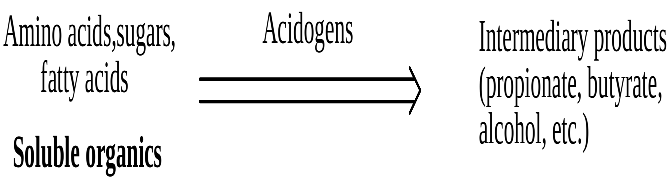
In the acid-forming stage, soluble compounds produced through hydrolysis or discharged to the digester are degraded by a large diversity of facultative anaerobes and obligate anaerobes through many fermentative processes (Gerardi, 2003). In this stage, the products of the hydrolysis such as sugars, long-chain fatty acids and amino acids are converted into acetate, other volatile fatty acids (VFAs), alcohols, hydrogen and carbon dioxide. Acidogenesis leads to different products including glucose. Equations 1-3 in Scheme 2 show the conversion of glucose to acetate, ethanol and propionate, respectively (Parawira, 2004).

$$C_6H_{12}O_6 + 2H_2O \longrightarrow \underset{\text{Acetic acid}}{2CH_3COOH} + 2CO_2 + 4H_2 \qquad (1)$$

$$C_6H_{12}O_6 \longrightarrow \underset{\text{Ethanol}}{2CH_3CH_2OH} + 2CO_2 \qquad (2)$$

$$C_6H_{12}O_6 + 2H_2 \longrightarrow \underset{\text{Propanoic acid}}{2CH_3CH_2COOH} + 2H_2O \qquad (3)$$

Scheme 2. Conversion of glucose to intermediary products



Scheme 3. General illustration of acidogenesis reaction.

Acetogenesis

In acetogenesis, the acetate forming microorganisms convert alcohols, volatile fatty acids such as butyric acid, propionic acid and valeric acid other than acetic acid to CO_2, hydrogen and acetic acid (Zamudio Canas, 2010). Zamudio Canas, E.M., (2010). In other words, acetogenic organisms are the vital link between hydrolysis/acidogenesis and the methanogenesis in anaerobic digestion. Acetogenesis provides hydrogen and acetate which are the two main substrates for the last step in the methanogenic conversion of organic material. Both acidogenesis and acetogenesis produce the methanogenic substrates: acetate and H_2/ CO_2. The products from acetogenesis are then the substrates for the last step of anaerobic digestion, which is called methanogenesis (Lomborg, 2009).

$$CH_3CH_2COOH + 2H_2O \longrightarrow CH_3COOH + 3H_2 + CO_2 \qquad (4)$$

Propanoic acid

$$CH_3CH_2CH_2COOH + 2H_2O \longrightarrow 2CH_3COOH + 2H_2 \qquad (5)$$

Butanoic acid

$$CH_3CH_2CH_2CH_2COOH + 2H_2O \longrightarrow 2CH_3COOH + 2H_2 \qquad (6)$$

Valeric acid

Scheme 4. Volatile fatty acid degradation.

Methanogenesis

During methanogenesis, acetate and H_2/CO_2 are converted to CH_4 and CO_2 by methanogenic bacteria. The methanogenic bacteria are able to grow directly on H_2/CO_2, acetate and other one-carbon compounds, such as formate and methanol (Arthurl and Brew-Hammond, 2010). In the normal anaerobic digesters, acetate is the precursor for up to 70% of total methane formation while the remaining 30% originates from H_2/CO_2. Moreover, the interaction between hydrogen and acetate, catalyzed by homoacetogenic bacteria, also plays an important role in the methane formation pathway. Hydrogenotrophic methanogenesis functions better at high hydrogen partial pressure, while aceticlastic methanogenesis is independent of hydrogen partial pressure. Methanogenic bacteria are more sensitive to changes in temperature than other organisms present in the digester. This is due to the faster growth rate of the other groups, such as acetogens, which can achieve substantial catabolism even at low temperature (Parawira, 2004). At higher temperatures, the acetate oxidation pathway becomes more favorable (Fang, 2010). The following methanogenic groups are important for the formation of methane.

Group 1: Hydrogenotrophic Methanogens

The hydrogenotrophic methanogens use hydrogen to convert carbon dioxide to methane (Equation 7). By converting carbon dioxide to methane, these organisms help to maintain a low partial hydrogen pressure in an anaerobic digester that is required for acetogenic bacteria (Sagagi, 2009).

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O \qquad (7)$$

Group 2: Acetotrophic Methanogens

The acetotrophic methanogens or acetoclastic bacteria "split" acetate into methane and carbon dioxide (Equation 8). Some hydrogenotrophic methanogens use carbon monoxide to produce methane (Equation 9).

$$4CH_3COOH \longrightarrow 4CH_4 + 4CO_2 \quad (8)$$

$$4CO + 2H_2O \longrightarrow CH_4 + 3CO_2 \quad (9)$$

The acetotrophic methanogens reproduce more slowly than the hydrogenotrophic methanogens and are adversely affected by the accumulation of hydrogen. Therefore, the maintenance of a low partial hydrogen pressure in an anaerobic digester is favorable for the activity of not only acetate-forming bacteria but also acetotrophic methanogens. Under a relatively high hydrogen partial pressure, acetate and methane production are reduced (Gerardi, 2003).

Group 3 Methylotrophic Methanogens

The methylotrophic methanogens grow on substrates that contain the methyl group ($–CH_3$). Examples of these substrates include methanol (CH_3OH) (Equation 10) and methylamines [$(CH_3)_3–N$] (Equation 11). Group 3 methanogens produce methane directly from methyl groups and not from CO_2.

$$3CH_3OH + 6H^+ \longrightarrow 3CH_4 + 3H_2O \quad (10)$$

$$4(CH_3)_3N + 6H_2O \longrightarrow 9CH_4 + 3CO_2 + 4NH_3 \quad (11)$$

The use of different substrates by methane-forming bacteria results in different energy gains by the bacteria. For example, hydrogen-consuming methane production results in more energy gain for methane-forming bacteria than acetate degradation (Gerardi, 2003).

Factors Affecting Biogas Production

The factors affecting the biogas production are mainly caused by the characteristics of the feedstock and operating condition of the process. In order for anaerobic reactors to perform at their best, they should be operated under steady state conditions. The parameters that can often determine the performance of the digester include pH, temperature, solids retention time (SRT), volatile fatty acids (VFA) and organic loading rates (Choorit and Wisarnwan, 2007). These factors can either enhance or inhibit the performance of the anaerobic digestion by influencing parameters such as specific growth rate, degradation rates, biogas production or substrate utilization. The operational and environmental parameters of the process obviously affect the behavior, performance and eventually the fate of the microbial community in anaerobic digesters. An understanding of the parameters that can adversely affect the digestion process is critical because even small changes in conditions can disturb or permanently damage microbial interactions and performance.

pH

The pH value of the digester content is an important indicator of the performance and the stability of an anaerobic digester. In a well-balanced anaerobic digestion process, almost all products of a metabolic stage are continuously converted into the next breaking down product without any significant accumulation of intermediary products such as different fatty acids which would cause a pH drop (Nayono, 2010).

Many aspects of the complex microbial metabolism are greatly influenced by pH variations in the digester. Although acceptable enzymatic activity of acid forming bacteria can occur at pH 5.0, methanogenesis proceeds only at a high rate when the pH is maintained in the neutral range (Nayono, 2010). Most anaerobic bacteria including methane forming bacteria function in a pH range of 5.5 to 8.5, (Fang, 2010) but optimally at a pH of 6.8 to 7.6, and the rate of methane production may decrease if the pH is lower than 6.3 or higher than 7.8 (Gerardi, 2003). Significant changes in alkalinity or pH are introduced in an anaerobic digester by substrate feed or the production of acidic and alkali compounds, such as organic acids and ammonium ions, respectively, during the degradation of organic compounds in the digester. Alkalinity in an anaerobic digester is also derived from the degradation of organic-nitrogen compounds, such as amino acids and proteins, and the production of carbon dioxide from the degradation of organic compounds. When amino acids and proteins are degraded, amino groups (and hence ammonia) are released and alkalinity is produced.

The pH in anaerobic digestion may be adjusted by a slow addition of chemicals such as sodium bi-carbonate, potassium bi-carbonate, calcium carbonate (lime) and calcium hydroxide (quick lime). Because methanogenic bacteria require bicarbonate alkalinity, chemicals that directly release bicarbonate alkalinity are preferred. Sodium bicarbonate and potassium bicarbonate are more preferred due to their desirable solubility, ease of handling, and minimal adverse impacts. Lime may be used to increase digester pH to 6.4, and then either bicarbonate or carbonate salts (sodium or potassium) should be used to increase the pH to the optimum range (Gerardi, 2003).

Cow dung is also used to facilitate the bacterial growth in the digester and thus hasten the biogas generation. It plays a role in neutralizing pH and improving buffering capacity by making the process more resistant to the effect of VFA accumulation and thus avoids inhibition processes. It also helps to maintain a stable and reliable digestion performance and yields good quality fertilizer (Fang, 2010).

Temperature

Temperature is one of the most important factors affecting microbial activity within an anaerobic digester and methane production is strongly temperature dependent. Fluctuations in temperature affect the activity of methane-forming bacteria to a greater extent than the operating temperature (Sibisi and Green, 2005).

The effect of temperature on the first stages of the digestion process (hydrolysis and acidogenesis) is not very significant. The second and third stages of decomposition can only be performed by certain specialized microorganisms (acetogenic and methanogenic bacteria) and these are much more sensitive towards temperature change. With a digester temperature of approximately 35°C, the cycle can be easily completed in less than a month (Mahanta *et al*., 2005). Therefore, fluctuations in temperature may be advantageous to certain groups and disadvantageous to other groups. However, an important characteristic of anaerobic bacteria is that their decay rate is very low at temperatures below 15°C. In the mesophilic range, the bacterial activity and growth decreases by one-half for each 10°C drop below 35°C. Thus, for a given degree of digestion to be attained, the lower the temperature, the longer is the digestion time (Saleh and Mahmood, 2004). . The temperature ranges over which anaerobic digestion (AD) can take place are summarized in Table 2.

Table 2: The three main temperature intervals used in anaerobic digestion (Seadi *et al.*, 2008).

	Temperature range (ºC)	**Optimum temperature(ºC)**
Psychrophilic	**< 25**	**15**
Mesophilic	**25 – 42**	**35**
Thermophilic	**43 – 70**	**55**

Nutrients

Nutrients are one of the most important environmental factors in biological process in general and anaerobic digestion in particular. Nutrient needs for anaerobic biological treatment process may be grouped as macronutrients and micronutrients. Macronutrients are nitrogen and phosphorus that are required in relatively large quantities by all bacteria. Micronutrients (K, Mg, Ca, Fe, Na, Cl, Zn, Mn, Mo.) are required in relatively small quantities by most bacteria. The inorganic nutrients are critical in the conversion of acetate to methane (Huy, 2008).

The bacteria in anaerobic digestion process require elements such as nitrogen, phosphorous, sulphur, calcium, magnesium, iron, nickel, cobalt, zinc, manganese and copper in trace amount for better growth. Although these elements are needed in extremely low concentrations, the lack of these nutrients has an adverse effect upon the microbial growth and performance (Fang, 2010). The macro-nutrients concentration in the cell should be around 10^{-4} M. The micro-nutrients such as nickel, cobalt and copper, on the other hand, are required in smaller amounts. Most nutrients can be inhibitory if present in high concentrations. Sulfide and phosphate can decrease the metal ions bioavailability (the extent to which a nutrient can be used by the bacteria) by precipitating them. Methane forming bacteria have relatively high internal concentrations of iron, nickel and cobalt (Saleh and Mahmood, 2004).

The relationship between the amount of carbon and nitrogen present in organic materials is expressed by the carbon/nitrogen (C/N) ratio. Optimum C/N ratios in anaerobic digesters are 20 – 30. It is generally found that during digestion, micro-organisms utilize carbon 25 to 30 times faster than nitrogen, i.e. carbon content in feedstock should be 25 to 30 times of the nitrogen content. To meet this requirement, constituents of feedstock are chosen in such a way as to ensure a C/N ratio of 25:1 to 30:1 and concentration of organic dry matter to total solid as 70-95 percent. Even in situations where C/N ratio is close to 30:1, the biomass can undergo efficient anaerobic fermentation only if waste materials are also biodegradable at the same time (Mahanta et al., 2005).

A high C/N ratio is an indication of rapid consumption of nitrogen by methanogens and results in lower gas production. On the other hand, a lower C/N ratio causes ammonia accumulation and pH values exceeding 8.5, which are toxic to methanogenic bacteria (Adelekan and Bamgboye, 2009). As a result, optimum C/N ratios of the digester materials can be achieved by mixing materials of high and low C/N ratios. To this end, organic solid waste is mixed with sewage or animal manure.

Retention (residence) 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).

Volatile Fatty Acids (VFA)

The stability of the AD process is reflected in the concentration of intermediate products like the VFA. The VFA are intermediate compounds with a carbon chain of up to six atoms (acetate, propionate, butyrate, lactate etc.) produced during acidogenesis. In most cases, AD process instability will lead to accumulation of VFA inside the digester, which can also lead to a drop of pH-value (Veeken *et al.*, 2000). When lipids like fats and oils are present in excess in food wastes, there may be accumulation of volatile fatty acids**.** Accumulation of long chain fatty acids (LCFAs) that result from lipid hydrolysis is reported to lead to failure of the system. LCFAs have been reported as inhibitory to microorganisms even at low concentrations**.** The ratio of the concentration between VFA and total alkalinity is an important factor that can show the stability of the system. VFA to alkalinity ratio of 0.1 to 0.3 show good stability of anaerobic digestion. For instance, animal manure has a surplus of alkalinity, which means that cow manure buffer capacity is able to overcome the effect of volatile fatty acids produced due to the presence of excess lipids in food waste. In addition volatile solids are a measure of the amount of digestible organic material in a feedstock. That is, materials with high volatile-matter content produce more biogas if digested properly (Thouars, 2007).

The presence of high lipid content leads to increased VFA concentration in the digester which, in turn, severely inhibits the AD process. For properly proceeding digestion, the concentration of VFAs should not exceed

250mg/l but the maximum tolerable value at which methane production can be achieved is at VFA concentration up to 6000mg/l (Seadi, 2008).

Particle Size

Particle size exerts less influence on gas production relative to temperature or pH of the digester contents. Large particle size of the feedstock will result in clogging of the digester thereby making difficult for the microbes to carry out the digestion function. The hydrolysis rate has been found to be directly related to the amount of substrate surface available. The surface of the particulate substrate has been reported to be a key factor for the hydrolysis process. Also, the rate of hydrolysis of particulate organic matter is determined by the adsorption of hydrolytic enzymes to the biodegradable surface sites and an increase in biodegradability results in an increase in adsorption sites for enzymes. Thus, reduced particle size could increase hydrolysis rate and shorten digestion time (Huy, 2008). Physical pretreatment such as grinding, mashing and shredding the wastes could significantly reduce the volume of digester required, without decreasing biogas production (Yadvika et al., 2004).

Toxicity

Mineral ions, heavy metals and detergents are among the toxic materials that inhibit the normal growth of pathogens in the digester. Small quantity of mineral ions (e.g., sodium, potassium, calcium, magnesium, ammonium and sulphur) also stimulates the growth of bacteria, while very heavy concentration of these ions leads to toxic effects. For example, presence of NH_4^+ ions in the concentration range of 50 to 200 mg/l stimulates the growth of anaerobic microbes, whereas its concentration above 1500 mg/l produces toxicity (FAO, 1996). Similarly, heavy metals such as copper, nickel, chromium, zinc, lead etc., in small quantities are essential for the growth of bacteria but are toxic at higher concentration. Detergents including soap, antibiotics, organic solvents etc. also inhibit the activity of methane producing bacteria and hence addition of these substances in the digester should be avoided (Mahanta, 2005).

i. Salts

All microorganisms require salts to function. The salts contain essential building blocks for the microorganisms, such as sodium, potassium, and chlorine. These substances are available in many substrates and do not need to be added to the biogas process separately. However, some waste has a high salt concentration or results in the release of excess salt, which can inhibit the microorganisms in the biogas production process. Too much salt causes the cell to pump out water and lose both form and function (Sulaiman *et al*., 2009; Schnurer and Jarvis, 2010). Some organisms can adapt to high salt concentrations if they are allowed to adjust slowly. They often form so-called osmolytes: compounds that help them maintain their function, even in the presence of salt. Organisms that can handle relatively high salt concentrations are called halotolerant, and those that grow even better at high salt concentrations are called halophiles. The most extreme forms of halophile grow best at salt concentrations above 20%-30% sodium chloride (> 3.4mol/L-5.1mol/L) and this group also includes some methane producers. Examples of materials that could lead to increased salt concentrations in biogas processes are wastes from the food and fisheries industries, or different types of protein-rich materials that lead to the release of ammonia.

ii. Ammonium (NH_4^+) and Ammonia (NH_3)

Ammonia and ammonium ion result from the anaerobic biological degradation of nitrogenous matter, mostly in the form of proteins and urea. Ammonia forms ammonium ions in the substrate, the extent of this depending on the pH value. Ammonia has an inhibiting effect, and with larger concentrations can even be toxic, while ammonium is innocuous. Its inhibiting effect is predominantly due to the species whose concentration depends on the pH value (Deublein, 2008). When hydrogen ion concentration in the solution is sufficiently high then the equilibrium is shifted to the left and ammonium ions are the main constituents of the mixture. At higher pH values this equilibrium shifts towards dissolved ammonia gas in solution. This is shown in Equation 12 below.

$$NH_4^+ \rightleftharpoons NH_3 + H^+ \qquad (12)$$

Among the four types of anaerobic microorganisms, the methanogens are the least tolerant and the most likely to cease growth due to ammonia inhibition. As ammonia concentrations were increased in the range of 4051–5734 mg L^{-1}, acidogenic populations in the granular sludge were hardly affected while the methanogenic population lost 56.5% of its activity. 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 (Chen et al., 2008)**.**

Pre-treatments

Pretreatment enhances sludge digestion and the rate and quantity of biogas generated, thereby reducing the retention time requirement from 15 to 25 days to approximately 7 days. Pretreatment methods may also be applied to increase the digestibility of the organic solids and increase the efficiencies of anaerobic digesters. Thermal, chemical, biological and mechanical processes, as well as combinations of these, have been studied as possible pretreatments cause the lysis of or disintegration of sludge cells permitting the release of intracellular matter that becomes more accessible to anaerobic microorganisms (Subramani and Ponkumar, 2012). Over the past few decades, numerous experimental pre-treatment methods have been developed to enhance the anaerobic digestion of municipal sludge**.** Commonly, the material is pre-treated before it enters the biogas digester.

There are many reasons for such pre-treatment:

1. To remove materials that cannot be degraded and/or that disrupt the process. This pre-treatment may involve tearing up and removing plastic materials that are not broken down in the process or removing sand or cutlery from food waste that wear down grinders and shredders and sink to the bottom of the digester.
1. To concentrate the organic material content, i.e. thickening.
1. To increase the availability of organic matter, namely a reduction of particle size or increasing the solubility (Sibisi and Green, 2005).

Conclusion

Organic food wastes co-digested with cattle manure improved the biogas potential compared to cattle manure alone. The co-digestion of more than one waste is good for skyrocating the amount of biogas yield and decreasing waste disposal in the environment, which in turn minimizes the green house gas emitted and plays a significant role in minimizing health problems human beings faced due to the unintended stay of wastes in the environment. Several factors affecting biogas production discussed in the paper should be optimized for good biogas yield. In addition, pretreatment method is applied to increase the digestibility of the organic solids and increase the efficiency of anaerobic digesters.

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