Factors Affecting Biogas Production: A Review

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ABSTRACT

Biogas technology is also potentially useful in the recycling of nutrients back to the soil. Burning non-commercial fuel sources, such as dung and agricultural residues, in countries where they are used as fuel instead of as fertilizer, leads to a severe ecological imbalance, since the nitrogen, phosphorus, potassium, and micronutrients, are essentially lost from the ecosystem. Biogas production from organic materials not only produces energy, but preserves the nutrients, which can, in some cases, be recycled back to the land in the form of slurry. The organic digested material also acts as a soil conditioner by contributing humus.

Fertilizing and conditioning soil can be achieved by simply using the raw manure directly back to the land without fermenting it, but anaerobic digestion produces a better material. Chinese workers report that digested biomass increases agricultural productivity by as much as 30% over farm-yard manure, on an equivalent basis. This is due in part to the biochemical processes occurring during digestion, which cause the nitrogen in the digested slurry to be more accessible for plant utilization, and to the fact that less nitrogen is lost during digestion than in storage or comporting. This paper discusses several factors that affects biogas production which include among other things, temperature, pH, toxicity, Carbon/Nitrogen (C/N) ratio, loading rate, dilution and consistency of input, hydraulic retention time, agitation, additives**,** hydrogen partial pressure, and inhibitors.

(Keywords: biogas, nutrients, temperature, loading rate, inhibitors)

INTRODUCTION

The development of new methods of production and use of renewable energy sources that suit the economic and the geographical conditions of developing countries will be required to solve the problems of energy crisis and climate change [1]. Today, climate change is everyone's concern and is among the leading problems if not the only one linking the international community and drawing much attention. Fossil resources were given much attention in the past before climate change became a major concern. The time has come, where attention should now be shifted from fossil fuels to renewable energy sources.

The anaerobic bio digester process is not a new technique of converting waste material into usable product. However, there is a need for further investigation to improve the process especially in this era of climate change. Achieving solutions to possible shortages in fossil fuels and environmental problems that the world is facing today requires long-term potential actions for sustainable development [2].

Conventionally, the anaerobic digestion (AD) process should occur in a strict anaerobic environment with no free available oxygen. Such aerobic (oxygen presence) invasions can or may deteriorate the performance of the digestive system [3]. Under these conditions, (i.e. oxygen deficient environment), biogas is produced. Biogas is a combustible gas consisting mainly of methane and carbon dioxide. Carbon dioxide being one of the principal greenhouse gases, its concentration in the atmosphere is increasing expeditiously since the advent of industrialization [4].

BIOGAS

The term "biogas" is commonly used to refer to a gas which has been produced by the biological breakdown of organic matter in the absence of oxygen. Biogas is one of the products formed during the anaerobic digestion process, and consists of CO_2, CH_4, H_2S, H_2, H_2O and some traces of other substances depending on the composition of the substrate [5].

A. Methane Formation Pathways

The anaerobic digestion is characterized by a series of biochemical transformations caused by the degradation of organic matter. The whole process involves several distinct stages. i.e., hydrolysis, acidogenesis, acetogenesis and the final stage methanogenesis (Figure 1). In stage 1, fats, complex carbohydrate and proteins are hydrolysed to their monomeric form by enzymes. In stage 2, the monomers are further degraded into short chain acids and these short chain acids are converted to hydrogen, carbon dioxide and acetate and in the final stage which is stage 3, the intermediate products are converted to methane and carbon dioxide by methanogerns [6].

B. Factors for Optimum Performance

Anaerobic digester is a promising technology for treating waste and producing energy at the same time. Digestion is dependent on several factors for the well-being of a stable digester. Factors such as pH, temperature, organic loading rate, hydraulic retention time and carbon-to-nitrogen (C/N) ratio play a significant role during the bio-degradation of the solid material.

There are three temperature regions in which anaerobic digestion can be conducted, pychrophilic (10-20°C), mesophilic (20-45°C), and thermophilic (45-68°C) . The most common temperature ranges used to run anaerobic digesters are either mesophilic (with an optimum at 35°C) or thermophilic (with an optimum at 55°C) [5].

Process Parameters: Within all the biological processes, keeping the constancy of the living conditions is important. A change in temperature or substrates or substrate concentration can result a shutdown of biogas production. The microbial metabolism process depends on many parameters or factors [8]. A mass of parameters should be taken into consideration and be controlled for an optimum fermenting process. (Deublein, 2008) [9].

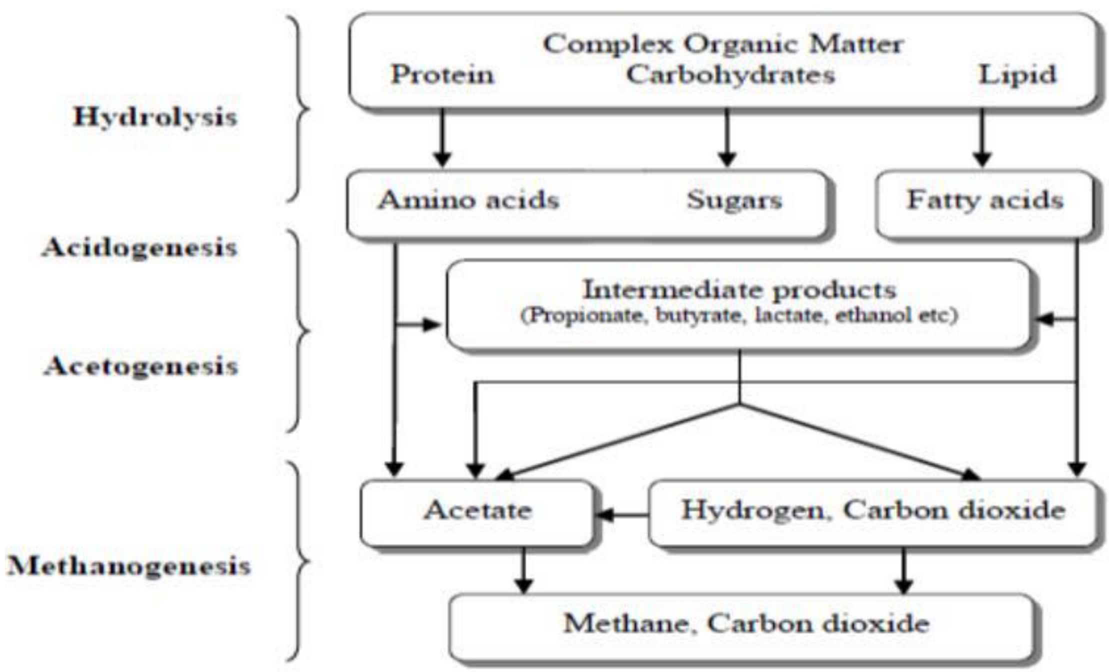

Figure 1: Anaerobic Digestion Pathways of Organic Degradable Substrate [7].

Type of Substrate: During the anaerobic process, substrates play an important role which determines the rate of the anaerobic degradation. Microorganism metabolism will shut down if important components of a substrate runs out [8]. Therefore, it is always important to feed possibly lacking substance like carbohydrates, fat, proteins, mineral substance as well as the substrate (Beublein, 2008) [9]. Intermediate products of the decomposition of substrates can also inhibit degradation. For example, the degradation of fats will increase the concentration of fatty acids, which limits further degradation (Deublein, 2008).

Specific Surface of Material: The material surface should be as big as possible to support a biochemical reaction. The material surface is associated with the square of particle size. It is recommended that comminution of biomass can increase the surface of material. Bigger specific surface leads to higher biogas yield though a relationship is not linear (Deublein, 2008) [9].

Carbon/Nitrogen (C/N) Ratio: The relationship between the amount of carbon and nitrogen present in organic materials is expressed by the carbon/nitrogen (C/N) ratio. A suitable C/N ratio plays an important role for the proper proliferation of the bacteria for the degradation process [10]. Depending upon the relative richness in carbon and nitrogen content, feed material can be classified as nitrogen- or carbon-rich. 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) [11]. To meet this requirement, constituents of feedstock are chosen in such a way to ensure a C/N ratio of 25:1 to 30:1 and concentration of dry matter as 7-10%. 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 [7].

Inhibitors: The concentration of the inhibitors, the composition of the substrate and the adaptation of the bacteria to the inhibitor are all matters that influence the decision of the inhibition process. Commonly inhibitors include oxygen, sulfur compounds, organic acids, nitrate, ammonium, ammonia, and heavy metals Deublein, 2008) [9].

Temperature: Temperature is one of the most important factors influencing the anaerobic process especially in methane production. Compared to the operating temperature, the variation in temperature has much more influence the methane-forming bacteria. Furthermore, it affects not only the methane-forming bacteria but also volatile acid-forming bacteria (Gerardi, 2003). Maintaining the optimal digester temperature is the most important problem during anaerobic process.

Most digesters installed in the field lack mechanisms for temperature control and removal of dissolved oxygen. Hence, efficiency of these digesters is reported to be low, particularly during the winter months. There are different temperature ranges during which mesophillic and thermophilic bacteria are most active causing maximum gas yield [12]. Generally, mesophillic bacteria are most active in the temperature range 35-40°C and thermophilic bacteria in the range 50-60°C. Choice between the mesophilic and thermophilic fermentations is governed by the natural climatic conditions in which the plant is located. Though, it is possible to create conditions for thermophilic fermentation by external heat, but such a method is generally uneconomical.

Length of fermentation period is linked with the digester temperature. The methanogens are inactive in extreme high and low temperatures, while the optimum temperature is 35°C [10]. When the ambient temperature decreases to 10°C, gas production virtually stops. Satisfactory gas production takes place in the mesophilic range (30-40°C). Proper insulation of digester helps to increase gas production during the cold weather.

When the digester operates at a temperature of 15°C it takes nearly a year for the digestion cycle to complete. However, if the temperature is approximately 35°C, the cycle can be easily completed in less than a month. When the digester temperature is maintained at 25°C, it takes approximately 50 days for digestion of cattle waste. But, if the temperature ranges between 32 and 38°C, digestion is complete within 28 days. Mahanta et al. [13] carried out experiments to analyze the effect of temperature variation on anaerobic fermentation of cattle wastes. Smith et al. [14] suggested that at low temperature, biogas plants with some design modifications could also function quite effectively as in a warm climate.

The average minimum ambient temperature in north-eastern India falls below 13.5°C during the winter season, which lasts for about 4-5 months in a year [15]. Further, temperatures during the day and night differ significantly in this region. The bacteria cannot survive under such extreme temperature variations as well as at low temperature. To overcome such problems, a biogas digester with design modification has been proposed. Laboratory experiments at IIT Guwahati [16] show that for a given capacity, a digester under controlled temperature provides a significantly larger biogas production compared to a digester without controlled temperature.

Cultivation, Mixing and Volume Load: To avoid the failure of start-up phase of the plant, a careful but intensive mixing of the reactor is chosen (Deublein, 2008) [9]. The volume load depends on the residence time, the organic dry matter in the substrate and the temperature. If the substrate contains more than 12% solids, gas production is impaired. However, a too low load causes economically loose [9].

Dilution and Consistency of Input: All waste materials fed to a biogas plant consist of solid substance—volatile organic matter and non-volatile matter (fixed solids)—and water. During anaerobic fermentation process, volatile solids undergo digestion and non-volatile solids remain unaffected. According to a finding by The Energy and Resources Institute (TERI) [17], fresh cattle waste consists of approximately 20% total solid (TS) and 80% water. TS, in turn, consists of 70% volatile solids and 30% fixed solid.

For optimum gas yield through anaerobic fermentation, normally, 8-10% TS in feed is required [17]. This is achieved by making slurry of fresh cattle dung in water in the ratio of 1:1. However, if the dung is in dry form, the quantity of water has to be increased accordingly to arrive at the desired consistency of the input (i.e., ratio could vary from 1:1.25 to even 1:2). If the dung is too diluted, the solid particles will settle down into the digester and if it is too thick, the particles impede the flow of the gas formed at the lower part of the digester. In both cases, gas production will be less than optimum [17]. It is also necessary to remove inert materials such as stones from the inlet before feeding the slurry into the digester. Otherwise, the effective volume of digester will decrease.

Loading Rate: Loading rate is defined as the amount of raw materials fed per day per unit volume of digester capacity. It is an important parameter that affects gas yield. If the plant is overfed, acids will accumulate, and methane production will be inhibited since micro-bacteria cannot survive in acidic situations. Similarly, if the plant is underfed, the gas production will also be low because of alkaline solution, which is also not a favorable condition for anaerobic bacteria.

The effect of daily and alternate day loadings on biogas yield was also studied [18]. It was found that a 50 kg charge on daily basis and 100 kg charge on alternate day basis produced 2.9043 and 2.9285 m^3 of gas, respectively. Also, for a particular size of plant, there is an optimum feed of charge rate that will produce maximum gas and further quantity of charge will not proportionately produce more gas. According to Moharao [19], a daily loading rate of 16 kg of volatile solids per m^3 of digester capacity produces 0.04-0.074 m^3 of gas per kg of raw dung fed. He further recommended loading rates for plants working on night soil ranging from 1.04 to 2.23 kg of volatile solids per m^3 of digester capacity [20].

Higher loading rates are recommended only in cases where mean ambient temperature is high. Srivastava and Chynoweth [21] developed a mathematical model to describe gas yield as a function of organic loading rate corresponding to two different digester designs, viz. a continuously stirred tank and non-mixed vertical flow reactor. Analysis of the digester operation with the help of the model indicated that optimum gas yield could be achieved by selecting a digester design and an operating technique that will increase solid conversion through longer solids and micro-organisms retention. Pre-treatment of feed was identified as one of the contributing factors for increasing the biogas yield.

Disintegration: Disintegration is the destruction of the cell structure, sometimes even of the cell walls with higher energy impact. It is hard to define if disintegration is suitable for normal biomass fermentation plant for its plenty of advantages and backwards. Today, it is mainly used for swage gas production (Deublein, 2008) [14].

Hydraulic Retention Time: Hydraulic retention time (HRT) is the average period that a given quantity of input material remains in the digester to be acted upon by the methanogens. In a cattle-dung plant, the retention time is calculated by dividing total volume of the digester by volume of input added daily. From the results of experiments at IIT Guwahati, it is observed that the rate of gas generation is initially high and then, gradually, declines as the digestion approaches completion [27]. Thus, the time required for 70-80% digestion is considerably less than that needed to achieve complete digestion.

HRT is chosen to achieve at least 70-80% digestion. Langrage [22] suggested that HRT depends upon the interior temperature of the digester— higher the temperature of the digester lower the retention time. HRT varies between 20 and 120 days, depending upon the design and operating temperature of the digester. For digesters operating in countries of tropical region such as India, HRT is usually taken as 40-60 days and in countries of colder region such as China, digesters are designed for HRT of about 100 days [23]. Boodoo et al. [24] studied the effects of different retention times employed in the anaerobic fermentation of slurry from cattle kept on slatted floors and those fed primarily by sugarcane and its by-products.

Hydrogen Partial Pressure: An undisturbed process between the hydrogen producing acetogenic bacteria and hydrogen consuming-methanogenics is quite narrow. A well-balanced hydrogen concentration is required during the process, because methanogenics need enough hydrogen for methane production while the hydrogen partial pressure should be low enough to prevent the acetogenic bacteria from surrounding too much hydrogen and consequently stop the hydrogen production. The optimal hydrogen partial pressure depends on the species of bacteria and substrates (Deublein and Steinhauser, 2008).

Toxicity: Mineral ions, heavy metals and detergents are some 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 from 50 to 200 mg/l stimulates the growth of anaerobic microbes, whereas, its concentration above 1500 mg/l produces toxicity. Similarly, heavy metals such as copper, nickel, chromium, zinc, lead etc., in small quantities are essential for the growth of bacteria but their higher concentration has toxic effects [19]. 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 [19].

Other Factors Affecting Biogas Yield

Agitation: Agitation or mixing of digester contents significantly helps to ensure intimate contact between micro-organisms, which leads to improved fermentation efficiency. Coppinger [25] suggested that effect of varying degrees of mixing of digester contents improves biogas production. The major problem associated with the different designs of biogas plant such as KVIC, Deenabandhu, etc., is that a thick layer of scum formation appears at the top of the digester which blocks the gas from coming out of the upper free portion of the digester. Thus, no gas is available at the utility point. The effects of recirculation of gas to break the scum formation were investigated by Mahanta et al. [24]. They found that recirculation of gas improves the biogas yield. A recent experiment at IIT Guwahati showed that recirculation of gas increases the biogas production by three times [27]. The gas production with circulation is much more than that without recirculation at the same pH value.

Additives: Additives can play an important role in biogas yield. Addition of 5% commercial charcoal to cattle dung slurry on dry weight basis raised the yield by 17 and 35% in batch and semi-continuous processes, respectively. Madamwar and Mithal [26] performed two sets of experiments: one at controlled temperature of 38°C and the other at ambient temperature of 15°C to find the impact of adding pectin to cattle dung slurry as feed on biogas yield. Pectin not only enhances gas yield but also imparts process stability during the periods of fluctuating temperature. The impact of adding inert materials such as vermiculite, charcoal and lignite bovine excreta as feed on biogas yield has also been reported [27]. These additives increased biogas yield by 15-30%. Pebbles, glass marbles and plastic mesh when suspended in digester slurry reportedly led to an increase in the gas yield by 10-20%. Prasad [28] studied the effects of adding bagasse, Gulmohar (Delomix ragia) leaves, wheat straw, groundnut shells and leguminous plant leaves as additives to cattle dung on the biogas yield, gas composition and extent of bio-degradation. These additives were separately mixed with cattle dung in the ratio of 1 part (oven dry) to 10 parts of fresh dung containing 19.2% of TS on weight basis. Anaerobic fermentation was carried out under batch process in bottles in laboratory at ambient temperature between 30 and 32°C for 9 weeks. The volume of biogas generated in 24 h was measured every day and gas composition analyzed periodically. It has been concluded that addition of additives is advantageous for obtaining high gas yield [28].

pH: The optimal pH range can be divided into two groups, 5.5-6.5 for acidogens and 7.8-8.2 for methanogens. It is important to adjust the pH-value in the optimal range because anaerobic performance is affected by a slight pH changes away from the optimum. For the combined cultures pH ranges from 6.8 to 7.4 will be the ideal (Deublein, 2008). In the low pH environment, the activity of methanogens will be reduced, result in the accumulation of acetic acid and hydrogen. With higher partial pressure of hydrogen, propionic acid-degrading bacteria will be inhibited which causes the accumulation of VFA, which slows down the production of acetic acid making the pH drop further. Finally. the biogas process fails (Khanal, 2008).

Nutrients (C/N Ratio): The C/N ratio of the substrate should be within the range of 16:1-25:1. Due to the fact that not much biomass is developed with the anaerobic process, the need for nutrients is very low. Just as too low C/N ratio causes an increase in ammonia production and an inhibition of methane production, too high a C/N ratio causes negative influence in protein formation and a decline in the energy and structural metabolism of the microorganisms. It is necessary to keep a balanced composition of C/N ratio (Deublein, 2008).

CONCLUSION

Biogas is a multilateral renewable energy source that can replace conventional fuels to produce heat and power; it can also be used as gaseous fuel in automotive applications. Biomethane (upgraded biogas) can also substitute for natural gas in chemicals production. Recent evaluations indicate that biogas produced via anaerobic digestion (AD) provides significant advantages over other forms of bio energy because AD is an energy-efficient and environmentally friendly technology.

In comparison with fossil fuels, AD technology can reduce GHG emissions by utilizing locally available sources. In addition, the by-product of this technology, called digestate, is a high-value fertilizer for crop cultivation and can replace common mineral fertilizers. This work examined various factor that affect biogas production which include temperature, pH, toxicity, Carbon/Nitrogen (C/N) ratio, loading rate, dilution and consistency of input, hydraulic retention time, agitation, additives**,** hydrogen partial pressure, and inhibitors.

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