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A Comprehensive Review Operating Parameters Affected the Biogas Production in Anaerobic Digestion Process

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***Abstract*-Due to increases the environmental problems, energy crisis and fear of depletion of fossil fuels have all inspired investment in the development of alternative energy sources. The researchers emphasized more on the production of biogas from organic waste. Producing the renewable energy from biodegradable waste helps to overcome the energy crisis and solid waste management, which is done by anaerobic digestion. Municipal solid waste (MSW) management is becoming a serious issue in all over the world. Environmental issues start to arise when these wastes are not properly disposed and manage. Anaerobic digestion (AD) is one of the technologies to convert that waste into useful form of energy and reduce the environmental problems. Therefore there is a need to study critically the operating parameters like temperature, pH, C: N ratio, OLR (organic loading rate), Retention time etc so that one can get the maximum output with limited input. To fulfill the need, the present paper deals with the review of various operating parameters and their effects on AD.**

***Keyword:* Anaerobic digestion, Biogas, Organic waste, operating parameters.**

I. 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. Biogas is a well-established fuel that can supplement or even replace fossil fuel as an energy source for cooking and lighting in 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 [1].

Municipal solid waste (MSW) generation is significantly increasing in Indian urban areas and started creating enormous waste disposal problems in the recent past. Municipal solid waste (MSW) contains a significant fraction (30–50%) of organics. 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 [2]. 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. 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.

Anaerobic digestion is regarded as one of the oldest and the most efficient techniques in waste management in the history of mankind. Rapid increase in the amount of wastes involves poor processing and its improper treatment leads to environmental crisis, acidification of oceans affecting marine life and also loss in biodiversity, thereby destroying the ecosystem. Anaerobic digestion hence holds the key role in eliminating waste by biodegrading it in the presence of micro-organisms [3]. In anaerobic digestion environmental factors such as substrate concentration, temperature, pH, OLR (organic loading rate) and C:N have great influences on methane production. Optimization of various process factors affecting biogas production is a complex process with a number of interactive controlling parameters. Therefore, there is a need for optimization of accurate process parameters which, improves the production of the biogas significantly [4]. 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 [5].

Biogas is a combustible mix of gases produced by Anaerobic Digester (AD) or fermentation of biodegradable materials such as but not limited to biomass, manure or sewage, municipal waste, green waste and energy crop. AD is a microbiological process of decomposition of organic matter, in which oxygen is absent, a norm to many natural environments and widely applied at present to produce biogas in airproof reactor tanks, commonly named as digester. Biogas contains methane (CH_4) and carbon dioxide (CO_2) with traces of hydrogen sulphide (H_2S) and water vapour. It is an eco friendly fuel which can be used as automotive fuel and used for electricity generation. It protects the earth's natural resources and reduces the pollution rate by significantly lowering greenhouse effect and methane emissions [6].

1.1 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 (CH4) and carbon dioxide (CO2), and trace amounts of hydrogen (H2), nitrogen (N2) and hydrogen sulfide (H2S). 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 CH4 [7].

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 the most important. The process is catalyzed by a consortium of microorganisms (inoculum) that converts complex macromolecules into low molecular weight compounds (methane, carbon dioxide, water and ammonia) [8].

1.2 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 [9]. 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. 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 [5].

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.

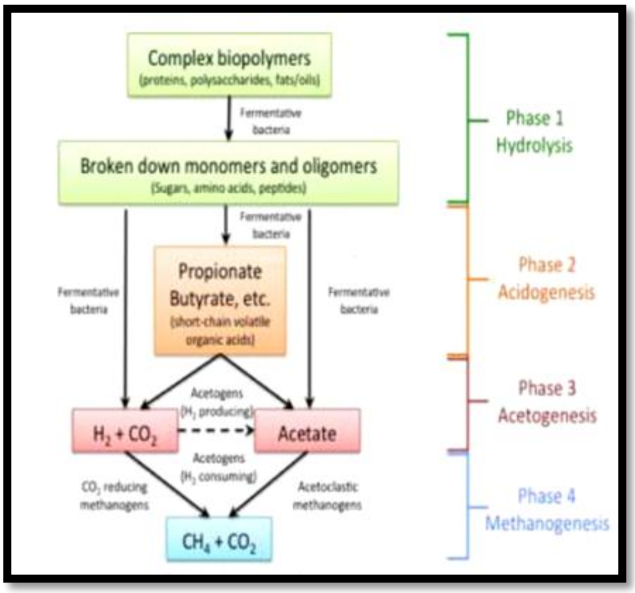

Fig. 1: Stage of Anaerobic digestion [5]

II. 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 [10].

2.1 Operating Temperature

Operating temperature is a essential factor which determines the performances of the AD reactors because it is an important condition for the survival and optimum flourishing of the microbial association. Bacteria have two optimum ranges of temperature, termed as mesophilic and thermophilic temperature optimum [11]. Mesophilic digesters have very good output efficiency while operated in the temperature range of 25-40 degree Celsius and thermophilic digesters have a range of 50-65 degree Celsius.

Thermophilic digesters permit higher loading rates and generate higher methane production, substrate decomposition and pathogen destruction. The higher temperature squeezes the required retention time by speeding up the reactions of degradation of organic material. The thermophilic anaerobic bacteria are easily influenced by toxins and small changes in environment and need some time to undergo redox population. The systems are less suitable for commercial application because they need subsidiary energy input for self-heating purpose. Mesophilic AD reactors employ powerful microbial consortia which have high tolerance towards environmental changes and have better stability and easy to maintain. These systems don't need any additional energy input for heating. But they have disadvantage of longer retention time and low rate of biogas formation. However, these are more suitable for commercial scale plants as they are easy to operate and maintain and have lower investment cost [12].

2.2 PH Value Range

The pH value plays an important part as the micro-organism i.e. the methanogens are highly sensitive to acidic environmental conditions. As an acidic environment inhibits their growth and methane production. 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. The biogas generation is highly affected by the parameters like its pH value range, optimum operating temperature, retention time, loading capacity and the composition of the organic waste used. It has been experimentally proved that the biogas production yield and the degradation efficiency is said to be higher for the substrates having an optimum range value of pH 7 comparing with other pH range values. On the other hand increasing the pH value more than 7.5 and towards 8 can lead to proliferation of methanogens which inhibits acetogenesis process. In order to keep the pH value in an equilibrium condition, a certain amount of buffer solution is added to the system such as CaCo3 or lime. Although the optimum PH value should be maintained between 7.5 to 8, in order to obtain higher yield of biogas [6].

2.3 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 [13].

2.4 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. Retention time or "residence time" in the AD systems is the amount of time a feedstock resides in an anaerobic digester. It is calculated in terms of no. of days (n) as in the case of the following equation.

No. Of days (n) = Operating volume (V) / Flow rate (Q)

It is the average time required for the organic material residing in a digester to decompose considering the COD or chemical oxygen demand of the influent or the particles residing in and also the BOD or biological oxygen demand of the liquid waste materials. The longer is the retention time period; the better is the degradation of the organic matter [14]. Retention time also depends on the operating temperature and content of the solid waste material of an AD system. The retention time for dry systems or highly solid wastes are usually more than that of wet system or liquid type waste. The residence time for a digester is designed in a way keeping in mind the microbial communities present in the digester that operate at different rates and at different times.

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 [15].

2.5 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.

2.6 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.

2.7 Organic Loading Rate (OLR)

Loading rate is another essential parameter in the anaerobic digestion process. It is determined by the measure of the amount of volatile solids in a biological AD system which can be feasible as an input in the system. Gas production rate is highly dependent on loading rate. Methane yield is found to increase with reduction in loading rate. Based on pilot plant studies (1 m3 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 [15].

The loading rate of a system should never be high as it may result in a low or average biogas production. The overloading of a system usually happens due to the presence of degrading or inhibiting substances in the system such as insoluble fatty acids which can cause hindrances in the path of biogas production. High loading in simple words causes increase in the amount of acidogenic bacteria which stimulates PH fall and hence results in the elimination of methanogenic bacteria or methane producing micro-organisms hence causing the system to crash.

2.8 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 [15].

2.9 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 [15]. 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.

2.10 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. 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. 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 [13].

2.11 Composition of the Waste

This is another parameter considering the content of the food waste or its composition which may affect the anaerobic digestion in a different way. The content of the organic material generally depends on the time of year, cultural habitat, environmental conditions, abiotic and biotic factors and also the region [2]. It is important to know the composition in order to predict the course and rate of the reaction also keeping in mind the amount of biogas yielded.

The rate of methane production or the bio-methanization potential is dependent upon four major concentrations which are- lipids, proteins, carbohydrates and cellulose. The AD systems having high lipids content usually have high biomethanization efficiency but due to its complex structure, it requires a high retention time period. The retention time period is the least in the case of proteins followed by carbohydrates and cellulose [8]. However systems having an excess of proteins or lipids content may have inhibitory factors due to the accumulation of ammonium and nitrogen respectively which greatly affects the bio-methanization yield.

III. 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 1000m3 of gas (containing 50- 70 percent methane) can be produced from 1000m3 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 ft3) of gas will release an amount of energy equivalent to lighting a 25-watt bulb for about 6 hours. 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 [11].

IV. CONCLUSION

The conversion of biomass into biogas can have many advantages to the ecosystem and to the existing life. Conversion has led to the decrease of greenhouse gases and also helps in the reduction of soil, water and air pollution. Biogas can be produced from the co-digestion of municipal biodegradable solid waste with other organic substance. 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. Important among the factors are the pH, temperature and more importantly, the C/N ratio that controls the pH value of the slurry. It is almost impossible to evaluate the performance of anaerobic digester by one or two parameters only. Each parameter is interconnected with each other. Higher temperature regime undoubtedly increases the reaction rate but requires high operational cost as compared to mesophilic system. Optimum OLR is highly dependent on the type of substrate used in the reaction. As the conventional ponding system requires longer HRT, the development of high rate anaerobic digester reactor aims to lessen the HRT and increases the process efficiency. This parameter also closely related to the type of substrate used in the process. The optimum C: N ratio as suggested by previous researchers is between 20 - 30 to higher biogas production. However, one must consider all of the above factors and other factor such as pH value, the optimum pH value is 6.9-7.2 consider for higher biogas production.

REFERENCES

[1] M .O. Aremu & S. E. Agarry "Enhanced Biogas Production from Poultry Droppings Using Corn-Cob and Waste Paper as Co-Substrate" International Journal of Engineering Science and Technology (IJEST), (2013), 5(02), 247- 253.

[2] M.O.L. Yusuf & A. Debora "Ambient temperature kinetic assessment of biogas production from co-digestion of horse and cow dung" Res. Agr. Eng. (2011), 57(3), 97–104.

[3] L N Itodo & EB Lucas "The Effect of Media Material and its Quality on Biogas Yield" Nigerian Journal of Renewable Energy 3, (1992). Nos. 1 and 2 pp. 45-49.

[4] B Sajeena Beevi & P. P Jose "Optimization of Process Parameters Affecting Biogas Production from Organic Fraction of Municipal Solid Waste via Anaerobic

Digestion”. International Journal of Environmental, Ecological, Geological and Mining Engineering, (2014), 8(1), 43-48.

[5] M. Asgari & K Safavi “Landfill Biogas production process”, International Conference on Food Engineering and Biotechnology, IPCBEE, (2011) 9(2011).

[6] B. Garba & A. Zuru “Effect of slurry concentration on biogas production from cattle dung”. Nigeria journal of Renewable Energy. (1996). 4(2): 38-43.

[7] S Perazzoli & R. Steinmetz “Biogas production From Microalgae Biomass”. III Simposio Internacional Sobre Gerenciamento De Resíduos Agropecuários E Agroindustriais, (2013), 12 A 14 São Pedro – Sp.

[8] F. Fantozzi & C. Buratti, “Biogas production from different substrates in an experimental Continuously Stirred Tank Reactor anaerobic digester”. Bioresource Technology, (2009) 100, 5783–5789.

[9] O.J Onojo & G.A Chukwudebe “Estimation Of The Electric Power Potential Of Human Waste Using Students Hostel Soak-Away Pits”. American Journal of Engineering Research (AJER), (2013), 02(09), 198-203.

[10] J. Dioha & C.H. Ikeme “Effect of carbon to nitrogen ratio on biogas production”. International Research Journal of Natural Sciences, (2013),1(3), 1 -10.

[11] S.K. Nayak & B.P. Pattanaik “Experimental investigation on performance and emission characteristics of a diesel engine fuelled with mahua biodiesel using additive”. Energy procedia. (2014), 54; 569-579.

[12] Y Godliving & S. Mtui “Trends in Industrial and Environmental” Biotechnology Research in Tanzania, African Journal of Biotechnology, (2007), Vol. 6 No. 25 pp 2860-2867.

[13] A. Khalid & M. Arshad “The anaerobic digestion of solid organic waste. Waste Management”, (2011), 31, 1737–1744

[14] G. Esposito & L. Frunzo “Bio-Methane Potential Tests to Measure the Biogas Production From The Digestion and Co-Digestion of Complex Organic Substrates”. The Open Environmental Engineering Journal, (2012),5, 1-8.

[15] Yadvika & Santosh “Enhancement of biogas production from solid substrates using different techniques–a review”. Bioresource Technology, (2004)