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Enhancement of Biogas Yield by Optimizing Key Factors: A Review

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***Abstract---* Biogas production through an anaerobic digestion process can solve both the problem of waste disposal and environmental pollution which is prevailing all over the world. But it has certain limitations such as it has low degradation rate, high solid retention time, lower biogas production which makes it unattractive for commercial use. This paper reviews effects of various process parameters such as agitation, ammonia nitrogen concentration, accumulation of volatile fatty acid and buffering capacity, pH, temperature, feedstock characteristics as biogas production optimization. From literature, it has been found that optimizing these process parameters and operating biogas plants at this optimum value results in enhance biogas production.**

***Keywords---* Biomass, Agitation, Volatile fatty acids, Buffering capacity**

I. INTRODUCTION

The generation of waste ever increases globally because of population blast and urbanization. Dumping or Burning of such a big volume of waste creates air pollution and groundwater contamination. These problems of both, waste disposal and environmental pollution can be resolved to a certain extent by biogas production via anaerobic digestion. Energy generation through anaerobic digestion is one of the promising technologies for sustainability and pollution mitigation. But anaerobic digestion process has certain limitations such as lower degradation rate, higher retention time, and lower biogas production. In order to resolve these issues and to optimize biogas production, the various researcher investigates the effect of agitation, ammonia nitrogen concentration accumulation of volatile fatty acid and buffering capacity, pH, temperature, substrate characteristics on biogas production. If we operate the biogas digester at its optimum process parameter then we definitely improve anaerobic digester performance.

II. FACTORS AFFECTING BIOGAS PRODUCTION:

2.1 Effects of Agitation

Agitation is necessary for uniform distribution of organic material & microbial population, is to make a close connection between bacteria and biowaste, is to prevent the accumulation of material on the bottom of the digester and uniform distribution of temperature inside the digester. If agitation is not carried out at regular intervals, there is a scum formation inside the digester. If organic materials are in the scum layer, they are unavailable for microorganisms, thus reducing the degradation rate and hence the biogas production. The agitation can be achieved through a mechanical stirrer, pneumatic stirrer, or with the help of a hydraulic stirrer. The agitation helps in the reduction in particle size and removal of gas from a mixture of slurry. Chen et al. (1990) investigated that higher methane yield was obtained in a non-mixing/agitated digester compared to a continuous stirrer digester. They used municipal solid waste and wastewater as feed material in both cases. Stroot et al. (2001) investigated that continuous agitation was not helpful to improve performance of anaerobic digestion and it inhibits biogas production at a higher organic loading rate. They also found that nominal agitation helps in improving biogas generation for organic loading rate ranges from 3.5 to 9.4 g VS/L d at a temperature of 37º C and a hydraulic holding time of 20 days. They observed that reduction in agitation speed also helps in improving the performance of unstable digester.

Kim et al. (2002) investigated that lowest biogas was produced at low and increased organic loading rate in continuous stirred biogas reactor while the intermittent minimally mixed reactor produces maximum biogas at temperatures of 35º C and 55º C. Ong et al. (2002)

investigated the effect of Continuously stirring, intermittent stirring (0.5-hour stirring and 5.5hour break) and without stirring on anaerobic digester. They used cow dung as feed material in all three digesters. They found that non-agitated digester produces higher biogas (up to 28.4%) compared to the continuously agitated digester. However, there was no change in biogas quality weather continuously or intermittent stirring was used. Karim et al. (2005) found that agitation did not improve the performance of anaerobic digesters when digester was fed with the manure of total solid concentration of below 5%. However, agitation plays an important role in anaerobic digestion, when digesters were fed with the manure of a total concentration of 10-15%. Deublein et al. (2008) reported that anaerobic bacteria are very reactive to agitation intensity and they may not live in an extreme agitation intensity. Kaparaju et al. (2008) investigated the effects of minimal agitation (10 min before feeding/discharge) and alternate agitation (2hr break before feeding/discharge) using diluted cow dung as a substrate. They observed minimal agitation increases biogas yield by 12.5 % while alternate agitation increases biogas yield by 1.3 %. Kowalczyk et al. (2013) investigated that discontinuous agitation generates additional biogas in the beginning compared to continuous agitation. They used three lab-scale digesters with a capacity of 22 liters. They carried out two experimental studies for the investigations. In the first one, they used corn cob left over and cow dung as substrate. The stirring intensity for fermenter one was two hours which was followed by a one-hour break, digester two was agitated with seven hours stirring and one-hour break while digester three was agitated continuously. For the second experimental study, the researcher uses maize silage and cow dung as input organic material. For the Second experimental study digester, 1 was agitated for 10 minute and 230-minute break. Digester 2 was agitated for 10 minutes and break for 50 minutes. The digester 3 was agitated continuously. In starting days, they found that biogas production increased up to 20 % compared to the continuous stirred digester. Afterward, biogas generation was reduced and altered in a span of ±10% compared to the continuous stirred digester. Aworanti et al. (2017) investigated the impact of stirring intensity on co-digestion of cattle dung, pig dung, and poultry dung (mixed animal dung) with pineapple fruit left out and chicken-gizzard as an inoculum. For this research work, they vary the stirring speed from 30 to 70 rpm in an interval of 10. They found that digester with 30 rpm stirring speed produces the fastest biogas with the highest accumulation yield on 35th day and it remained constant till 70th day which was followed by 40, 50, 60, and 70 rpm speed. They also found that with agitation, biogas generation starts from the first day for all speed while without agitation, biogas generation starts from the fifth day. Without agitation cumulative biogas production was 4.7882 dm^3/gm of slurry with methane percentage of 46 %, while its corresponding value with mixing intensity of 30,40,50,60,70 rpm was 6.2853 6.0028,5.7203, 5.4379 and 5.0443 dm3/gm with a methane content of 58%, 57.1%, 55%, 50%, and 48% respectively. Thus, they concluded that as agitation speed increases from 30 to 70 rpm, biogas production increases from 5.3 to 31.3 %. Bambang et al. (2017) investigated the effects of stirring intensity on the methanogenesis step of two-step anaerobic fermentation of palm oil mill left over. The acidogenesis and methanogenesis stages are physically separated and they used continuously stirred two-stage digester of two-liter capacity in this study.

They maintained a pH value of 7 ± 0.2 and a temperature of 55ºC inside the digester. To investigate the effect the researchers of the study vary the speed from 50, 100, 150, 200 rpm and found that the corresponding value of biogas was 52.46 ± 5.52, 58.87 ± 6.27, 57.23 ± 12.06, and 44.29 ± 14.56 L/kg-VS respectively. Thus, they concluded that a moderate speed of 100 rpm generates maximum biogas. Karivama, et al. (2018) reported that the efficiency of anaerobic fermentation is not enhanced through continuous stirring and high-intensity stirring mixing. They also found that intermittent stirring and low-intensity stirring was beneficial to increase process stability and anaerobic fermentation.

2.2 Effects of Ammonia Nitrogen Concentration:

Ammonia is essential for the growth of bacteria but its excess amount results in failure of the process. The biogas production from the nitrogen-rich substrate like cow manure, Piggery waste, organic fraction of municipal waste, poultry waste, meat processing waste, dairy waste, etc results in the release of ammonia, causes inhibition of the anaerobic digestion process. The biogas production can be maximized by increasing organic loading. But this practice in the case of protein-rich substrates results in the accumulation of free ammonia nitrogen. Accumulation of ammonia not only results in process instability but also causes environmental pollution. Therefore, the biogas digester operator needs to be monitor ammonia inhibition in order to ensure process stability. Some studies suggest that adjustment C/N ratio was effective to mitigate the effect of ammonia inhibition. McCarty and McKinney

(1961) investigated that the threshold limit for free ammonia nitrogen level is 150 mg/L. If the free ammonia nitrogen content exceeds beyond this limit then the anaerobic digestion process may be inhibited. Kayhanian (1999) reported that the effect of ammonia inhibition can be resolved by adjusting C/N proportion and also found that in the case of organic proportion of municipal leftover, carbon to nitrogen proportion of 27-32 is sufficient for its degradation. Ho and Ho (2002) investigated some approaches to alleviate the effect of ammonia accumulation on thermophilic anaerobic fermentation of piggery wastewater. For this purpose, the researcher investigates the effects of pH adjustment and various approaches like organic left over, natural zeolite, and humic acid addition to mitigate the effect of ammonia accumulation. They found that organic left over and humic acid was not effective to mitigate the effect with and without pH adjustment but the mixing of 10-20 g/L of zeolite was most effective without pH adjustment (pH 8.1) than with pH adjustment (pH 6.5). Chen et al. (2008) investigated that ammonia accumulation is reduced to a considerable extent by dilution of feedstock to a solid concentration of 0.5 to 0.3. But the disadvantage of dilution is that it decreases gas production because less organic matter is available for degradation. Kotsopoulos et al. (2008) examined the impact of zeolite concentration of 0,4,8 and 12 g/L on anaerobic digester using pig waste and maintained digester at the thermophilic condition. They observed that zeolites dose of 8 and 12 g/L increased CH_4 generation significantly. However, they also observed that when zeolite doses were added then total ammonia concentrations decrease slightly. Lin et al. (2009) investigated the effect of microwave radiation to reduce ammonia concentration of cooked plant wastewater at a positive hydrogen ion concentration of 11. For this, they conducted experiments under various pH, radiation time, and with and without aeration. They found that aeration was not effective to reduce ammonia concentration. They also found that when wastewater was exposed to 750 W radiation at 10 minutes then the ammonia concentration decreases from 5000 mg/L to 350 mg/L at a positive hydrogen ion concentration of 11. But major disadvantages of these methods are microorganisms can be destroyed and the cost of power consumption is high. Zeshan et al. (2012) carried out a simulation study using biodegradable waste material and identifies that C/N of 32 was most effective to minimize the effect of ammonia inhibition. They also found that the C/N ratio of 27 was less effective. Kougias et al. (2013) investigated the effects of different concentration of zeolite such as 5 and 10 g/L on anaerobic digestion of poultry manure. They used swine manure as an inoculum and found that 10 g/L zeolite addition was most effective, increases methane production by 109.75% compared to digester without zeolite addition. They also found that zeolite also reduced volatile fatty acid concentrations in the digester and increases the process stability of the anaerobic digestion process. Cho et al. (2014) investigated the effects of applying ultrasonic waves (frequencies 28 and 40 kHz) on livestock wastes to the decreases ammonia concentration. For, this they conducted an experimental study at varied pH (10-12), temperature (30-72º C), and duration (5-60 minute). A higher ammonia elimination rate was observed at 28 kHz and at pH 11 for about 15 minutes. They concluded that ultrasonic treatment helps in increasing solubilization and ammonia elimination rate was observed at 28 kHz and at pH11 for about 15 minutes. They concluded that ultrasonic treatment helps in increasing solubilization and thereby increasing hydrolysis rate. The ammonia inhibition problem arises because of the large concentration of proteinaceous biowaste, which is present mostly in the form of domestic food left over. The proteinaceous material when undergoing hydrolysis reaction may result in ammonia inhibition. Depending on the temperature, pH condition maintained inside the digester, a proportion of this total ammonia nitrogen is available as free ammonia nitrogen inside the digester.

2.3 Effects of Accumulation of VFA and Buffering Capacity:

The degradation of organic matter at the acidogenesis stage results in the generation of VFA. The VFA is produced in the form of three acids namely propionic acid, butyric and acetic acids. Both propionic acid and butyric acid cannot be directly converted into CH_4, so it is first degraded into acetic acid and then transformed again into CH_4. The acetic acid is directly transformed into CH_4 as methanogenic bacteria can act directly only with acetic acids. The volatile fatty acid is considered as a food for methanogens but if its value increases beyond a certain limit then digesters will experience problems. The accrual of volatile fatty acids arises when more acid is produced than consumes during the second stage of anaerobic digestion. The imbalance between different microbial groups results in process failure. Accumulation of volatile acid results in a drop in pH value and continuously drop in pH value results in failure of process. It is an indicator of the health of anaerobic digester.

Buffering capacity is also known as alkalinity. To enhance digester stability and to control pH value, alkalinity is important. It is achieved by a number of substrates and is obtained by carbonate, bicarbonate, and hydroxide, etc. Neutral pH value is required to carry out anaerobic digestion and for methanogens, bio carbonate is the main source of carbon, therefore bio carbonate alkalinity is of great importance (Altamira, 2008) The anaerobic degradation of amino acids, protein also results in accumulation of alkaline concentration in the digester. In this process, the amino acid is released which will produce ammonia. The produced ammonia will further react with carbon dioxide which will produce ammonium bicarbonate. Hill et al. (1987) found that VFA higher than 2000 mg per liter or a proportion of propionic acid to acetic acid higher than 1.4 results in process failure. Marchaim and Krause (1993) found that the proportion of propionic to acetic acid higher than 1.4 shows an indication of organic overloading. According to Gerardi (2003) alkalinity is prevailing in form of bio carbonate in the digester which is in balance form with the carbon dioxide at a given pH value. According to Gonzales-Fernandez and Garcia-Encina (2009) accumulation of volatile fatty acid can be occurred due to organic overloading, changes in the temperature and it inhibit the digestion process due to its toxicosis effect (Mechichi and Sayadi, (2005)) Luo et al. (2015) carried out two experimental study one with biochar and other without biochar using glucose anaerobic digesters. They reported that the first system produces methane 86.6% higher compared to without biochar system. This is because biochar improves buffering capacity of anaerobic digesters. Sunyoto et al. (2016) also found that mixing of biochar in a biowaste material increases hydrogen and methane production by 31.0 % and 10.0 %. Cooney et al. (2016) reported that biochar has acted as a packing material that facilitates the growth and retention of methanogenesis-rich biofilms. This helps in improving the performance of the anaerobic digester.

2.4 Effect of Concentration of Positive Hydrogen Ion

It plays an important and predominant role in the anaerobic digestion process. As reported in the literature, reduction in pH value results in operational problems of biogas reactor. Adjustment of pH value up to optimum leads to an increase in biogas yield and quality. The optimum pH value for acidogenesis bacteria differs from methanogenesis bacteria. During the acidogenesis stage acetic acid, propionic acid, lactic acid is generated. Low pH value may cause inhabitation of acidogenesis. pH value affects the chemical equilibrium of ammonia, hydrogen sulfide, and volatile fatty acid which are responsible for the inhibition of anaerobic digestion. Karki and Dixit (1984) reported that methanogenic bacteria cannot survive at a pH value greater than 8.5 and it creates toxic effects inside the digester. Mosey et al. (1989) reported that the ideal pH for methanogens lies in the span of 6.8-7.6 and observed that growth of methanogenic bacteria was retarded below a pH value of 6.6. Arshad et al. (2011) reported that the optimum pH value for hydrolysis and acidogenesis lies in the range of 5.5 to 6.5. Khalid et al. (2011) reported that the optimal pH value for anaerobic fermentation lies in the span of 6.8 to 7.4. Rajagopal et al. (2013) reported that at higher pH values free ammonia concentration dominates and is responsible for inhibition than ammonium ion (NH_4). Wang et al. (2014) reported that a methanogenic bacteria could not be survived below a pH value of 6.5.

2.5 Effects of Temperature

The degradation takes place faster at higher temperatures. The thermophilic anaerobic digester is much faster and produces more biogas than the mesophilic digester. However, biogas generation remains same in both the cases. Thermophilic fermentation is most effective in terms of organic load and retention time because of the higher temperature involved in it but it is rarely used in actual practice as too much power is required to obtain desired hotness inside the fermenter. Proper insulation of anaerobic digester helps in maintaining desired temperature and biogas production in the winter. Therefore, in cold climatic conditions or in areas of temperature changes, its effect is minimized by increasing insulation (Kalia, 1988) or by the use of heaters to maintain desired temperatures (Lichtman, 1983). Lund et al. (1996) reported that when the average surrounding temperature is 30º C or less, then the dome temperature of the fermenter remains greater than 4º C above the surrounding temperature. Vindis et al. (2009) reported that thermophilic anaerobic digester (55º C) gives a better result than mesophilic digester (35º C). They used maize as a substrate in their investigation. They also reported that better biogas quality was produced in the thermophilic digester and it was four times faster than thermophilic digester.

2.6 Effect of Carbon Nitrogen Concentration:

Carbon and nitrogen both are essential for the growth and survival of microorganisms. The excess carbon concentration will lead to more carbon dioxide formation and results in decreases in pH value, while the excess concentration of nitrogen will result in the accumulation of ammonia and an increase in pH value which is harmful to microorganisms. A higher or lower C/N ratio will negatively affect anaerobic digester performance. C/N ratio of 30 means that in the organic substrate, there are 30 grams of carbon for each 1 gram of nitrogen. The optimum carbon to nitrogen proportion can be obtained in the digester by adding a high carbon/nitrogen percentage substrate with a low carbon/nitrogen percentage substrate. The optimal value of the C/N ratio varies from substrate to substrate but its optimum values lie in the span of 20-30 [35]. Carbon nitrogen proportion of some frequently used material is given in table-1.0

Table:1.0 Carbon Nitrogen Ratio of Different Substrate [42]

Biowaste	Carbon %	Nitrogen %	C/N Percentage
Chicken waste	45	3.0	15
Pig dung	7.8	0.65	13
Horse dung	10	0.42	24
Cow dung	7.3	0.29	25
Sheep manure	16	0.55	29
Stalks of soy and bean Left over	41	1.3	32
Potato stalks	40	1.2	22
Tree leaves Left over	41	1.0	41
Lucerne	48	2.6	18
Corn cobs	40	0.75	56
Rice straws Left over	42	0.63	67
Barley straws Left over	42	0.75	56
Wheat straws Left over	46	0.53	87
Different herbs	15	0.6	25

2.7 Effects of Feedstock Characteristics:

Different feedstock has different biogas potential and it depends upon proteins, lipids, carbohydrates, lignocellulose content of biomass. The quality of biogas and the rate of biogas production depends upon the types of feedstock that undergo anaerobic degradation. The conversion rate of biogas production is faster with carbohydrates and proteins but it has a lower biogas yield. The biodegradability of lipids is slow so it requires a longer time to degrade but produces the highest biogas. The substrates rich in carbohydrates are food and organic wastes from agricultural-based industries while lipids-rich substrates are food waste, waste coming from dairies, slaughterhouses, or fat refineries. Chen et al. (2008) found that anaerobic fermentation of protein-rich substrate results in a risk of ammonia accumulation inside the digester which would inhibit the digestion process. According to Cuetos et al. (2010) the substrate rich in proteins nitrogen is animal waste and meat processing waste. These wastes have high organic concentration but have low carbon to nitrogen proportion. According to Esposito et al. (2012) animal dung, sewage sludge left over from aerobic wastewater treatment plant, dairy wastes, food left over, agricultural left over, meat and fish industries waste, certain energy crops, municipal organic solid waste are a very common material used for anaerobic fermentation. Sun et al. (2014) reported that anaerobic digestion of lipid-rich substrates may result in a reduction in positive hydrogen iron concentration, hindrance of long-chain fatty acids, and sludge floatation. This may lead to operational problems. Paritosh et al. (2017) reported that anaerobic digestion of carbohydrate-rich substrates could result in unfavorable C/N ratios which may inhibit anaerobic digestion due to rapid acidification and limited nutrients.

Percentage Concentration of CH_4 from Anaerobic fermentation of different biowaste is listed in table-2.0

Table 2.0 Percentage of CH_4 from Anaerobic Fermentation of Different Substrates [47] [48]

Substrates	Methane Percentage (%)
Cattle dung	50-60
Pig dung	60
Poultry Left over	68
Sheep manure	65
Horse dung	66
Grass	84
Wheat straw Left over	78.5
Dried leaves Left over	58
Barley straw Left over	77
Beet leaves Left over	84.8
Corn silage Left over	54.5

III. 3.0 CONCLUSION:

From the literature review and by studying various research papers it has been concluded that

(i) Minimal or intermit agitation has a positive impact on biogas production and reduces the possibility of scum formation in the digester, while continuous stirring reduces the performance of anaerobic digestion. Stirring intensity and duration greatly affect anaerobic digester performance. So, biogas production can be optimized by a selection of intermittent agitation or minimal agitation.

(ii)The threshold limit for free ammonia nitrogen is 150 mg/L. If the free ammonia nitrogen level exceeds beyond this limit then the anaerobic digestion process is inhibited.

(iii)Accumulation of ammonia nitrogen concentration inside the digester inhibits the digestion process and may arise due to the digestion of nitrogen and protein-rich substrates. From literature review and study carried out by different researchers, it is concluded that the problem of accumulation of ammonia can be resolved and optimized by dilution of substrates, adjusting C/N ratio, mixing zeolite and through different treatment like ultrasonic and microwave.

(iv)Total VFA greater than 2000 mg per liter or a proportion of propionic acid to acetic acid greater than 1.4 results in process inhibition. Accumulation of VFA may occur in the digester due to overloading of organic material and results in a drop in pH value inside the digester. This may even cause process failure. The problem of volatile fatty acid can be resolved and the process can be optimized by maintaining alkalinity inside the digester or avoiding overloading of organic material.

(v) The optimum pH, Carbon to nitrogen proportion lies in the span of 6.8-7.6 and 20- 30 respectively.

(vi)The biogas production in the thermophilic temperature range (50- 60^{o} C) is faster, effective in terms of holding time and biowaste loading rate than the mesophilic temperature range (40-50^{o} C).

(vii)By studying various research papers, it has been found that biogas production depends on the lipid, protein, carbohydrate, and lignocellulose content of biomass.

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