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Review: Factors Affecting Biogas Production

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Abstract: Bioenergy, a renewable energy holds a promising solution to the most pressing problems of energy crises and waste treatment, disposal and thereby creating a circular economy. There is a need to exploit biogas potential to the fullest to enhance its productivity and utilize it for heating, cooling, generating electricity and also for transportation. Valorisation of the municipal solid waste (MSW), agricultural non-fodder waste, sewage sludge, animal waste, etc., for energy production (biogas), material recovery (fertilizers) and waste elimination (waste treatment) attracts the attention of the researchers. This research review highlights the crucial parameters like pH, temperature, OLR, HRT, etc. affecting the biogas productivity and provide insights to run the digesters at optimum conditions thus optimizing the biogas yield.
Keywords: Biogas, Bio-energy, Anaerobic Digestion, Co-digestion

I. INTRODUCTION

The increasing energy demand due to population growth and industrialization has led to depletion of conventional sources of energy. Hence, this has paved way to explore the new and renewable sources of energies like solar, wind, tidal, biogas, etc. Biogas among all the other energy sources can be easily available option for energy generation which would help to solve dual problems of energy demand and waste management. Biogas energy is being exploited to generate energy for the automobile transportation. This paper explores the potential factors affecting the rate of biogas production and suggests the appropriate conditions to accelerate and optimize the gas yield.

A. Background

Biogas contains high methane content (40–70%) that can further be upgraded to natural gas quality (75–99% methane content). This upgraded biogas can be injected into a natural gas grid or can be used as a transport fuel (Mittal, Ahlgren, & Shukla, 2018). The heating value of biogas and natural gas is 17.99- 20.64 MJ/Nm3 and 33.5 MJ/Nm3 respectively which is approximately 60% lesser than natural gas LHV, although pure methane has a LHV (35.8 MJ/Nm3) which is equivalent to natural gas which can be obtained by enrichment of biogas (Wyman & Goodman, 1993; Mataalvarez, Mace, & Llabres, 2000).

MNRE (Ministry of New and Renewable Energy) is implementing the 'New National Biogas and Organic Manure Programme with the help of State nodal departments viz.: Khadi and Village Industries Commission KVIC, Mumbai and Biogas Development and Training Centre for dissemination of biogas technology. This programme has set a target to set up at least 2.55 Lacs biogas units which will generate approximately 8.40 Lacs m3/day of biogas by the end of 2020 in capacity range of 1- 25m3/day (MNRE, 2018). Government of India has announced several support schemes like the National Biogas and Manure Management Program (NBMMP), waste to energy scheme and off -grid biogas power generation program (Shukla, 2007; MNRE, 2018).

Researchers have reported its advantages being better digestibility, enhanced biogas generation/bio-methane yield due to availability of additional nutrients and more efficient usage of the organic waste (Agunwamba, 2001; Mshandete & Parawira, 2009; Parawira, Mutro, Zvauya, & Mattiasson, 2004). In addition to these advantages it also helps in eliminating groundwater and soil contamination, emission of harmful air pollutants like furans, dioxins and methane (which are a precursor GHG) (Kumar & Bohara, 2014; Mittal, Ahlgren, & Shukla, 2018). The nitrogen rich slurry a by-product of biogas plant is more effective than the raw biomass manure which can be used as liquid fertilizer. The use of these fertilizers would not only curtail the farmer's expense on buying the fertilizer but also increase the quality of yield by adopting organic farming practices.

According to PIB report (2016), Indian waste basket accounts for about 62 million tonnes of waste every year. 50% of 62 million tonnes of waste i.e. around 31 million tonnes is biodegradable organic waste with 4% average annual growth rate. (Swaminathan & Mathangi, 2018). Biogas can prove to be a boon to villagers and also the urban population as biogas can supplement LPG energy. This would not only help the people but also government who is struggling on the amounts of subsidy on the LPG gas. This could actually help in saving the cost for cooking in every house which would amount to saving of Rs. 800-900/- on the monthly expenditure and in addition to this it would solve the waste disposal problem. Presently, waste disposal generally takes place by dumping, landfilling or incineration. All these techniques however, are not eco-friendly ways of managing our solid waste. Thus, utilization of organic waste to create energy can be a viable, cost-effective & eco-friendly solution.

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The main problem associated with biogas is its low heating value (LHV) (17.99 – 20.64 MJ/Nm3) and difficulty in maintaining anaerobic conditions, limiting its wide applicability. Apart from this, presence of inhibitory substances like ammonia, sulfide, light metal ions, heavy metals, and organics, etc. disrupts the biogas production. Thus further studies to enhance the biomethanation and process optimization can help to enhance the gas production. (Wyman & Goodman, 1993; Mataalvarez, Mace, & Llabres, 2000).

II. ANAEROBIC DIGESTION

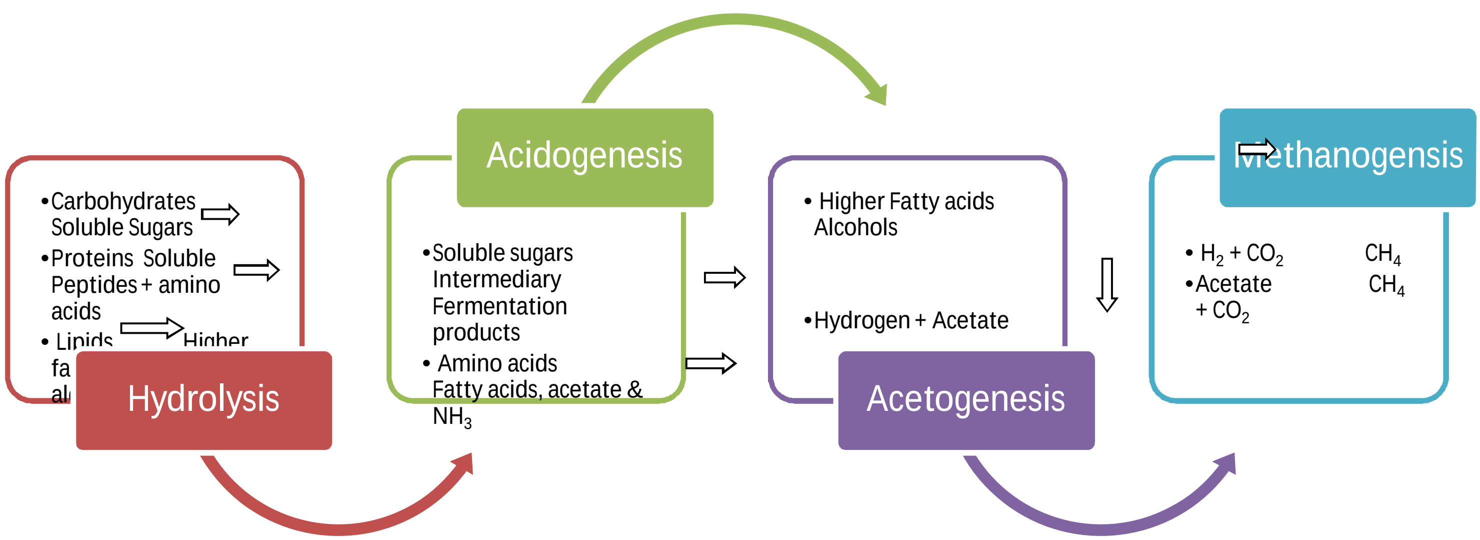
The anaerobic digestion takes place in absence of oxygen. The degradation of the organic materials happens in 4 steps presented graphically in Fig 1.

1. Hydrolysis 2. Acidogenesis 3. Acetogenesis 4. Methanogenesis

Biogas is a mixture of methane: 40-70%; CO_2: 25-40%; N_2: 0.5-3%; H_2: 1-10% with traces of H_2S. Initial phase of anaerobic digestion in acidic conditions and the final phase (Methanogenesis) take places under neutral conditions (Hobbs , Ward, & Pardo, 2007). Methanogenesis is critical step where the biogas is generated. This is a final stage and is the slowest biochemical conversion step (Seadi, et al., 2008).

Anaerobic Digestion Process

Fig. 1



A. *Factors affecting Biogas Production:*

There are several factors such as biogas potential of feedstock, inoculums, nature of substrate, pH, temperature, loading rate, hydraulic retention time (HRT), C:N ratio, volatile fatty acids (VFA), inhibitory substances, etc. influence the biogas production (Gashaw, 2014; Dioha, Ikeme, Nafi, Soba, & Yusuf, 2013).

1) *Temperature:* Temperature is an important factor for determining the efficiency of anaerobic digestion (AD) process. The process can be operated under three temperature ranges:

a) Thermophilic (40°-70°C)

b) Mesophilic (25°-40°C)

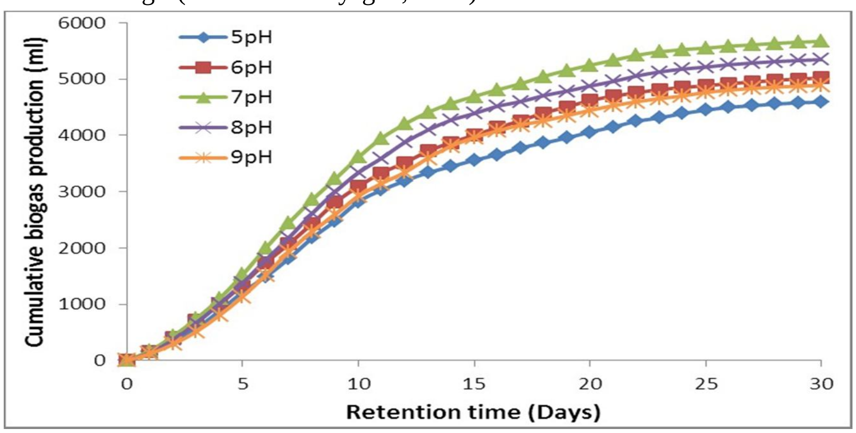
c) Psychrophilic (below 25°C)

Rise in temperature aids increased gas production but results in lesser methane content and increased percentage of CO_2 leading to lower heating value of biogas. Hence, the optimum temperature was found to be 32°-35°C for efficient and continuous biogas production (Al Mamun & Torii, 2015). The operating temperature ranges are much debated as some researchers prefer mesophilic and others thermophilic for the anaerobic treatment. It has also been reported that the anaerobes are most active in the mesophilic and thermophilic ranges (Desai & Madamwar, 1994; Zennaki, Cadi, Lamini, Aubinear, & Boulif , 1996).

Insulating the digester with insulating material can help retain desired temperature. Digester coated with charcoal has been observed to have improved biogas production by 7-15% in KVIC model (Al Mamun & Torii, 2015; Anand & Singh, 1993). Maintaining the temperature to 40°C can help reduce the retention time in digester by 40% (Desai & Madamwar, 1994).

Thermophilic conditions (> 45°C) were reported to better than mesophilic conditions (25–40°C) as higher temperature helps reduce pathogens and also eliminate odour problem (Sahlström, 2003; Johansen, et al., 2013; Moset, Poulsen, Wahid, Hojberg, & Moller, 2015).

2) *pH:* pH plays a pivotal role in the operation as the pH changes at different stages of the anaerobic digestion. pH and temperature are interdependent. The optimum pH which helps to enhance biogas yield lies between 6.5-7.2 (Sunny & Joseph, 2018). The pH changes when total VFA concentration exceeds 4 g/l and glucose is inhibited for fermentation (Siegert & Banks , 2005; Nazmi, Korres, & Murphy, 2009). The concentration of VFA and acetic acid should be < 200 mg/l for maintaining optimum level of pH (Yadvika , Sreekrishnan, Kohli, & Rana , 2004; Gashaw, 2016). The pH within the digester can be maintained within the range of 6.5- 7.2 by determining adequate organic loading rate. If the process leads to a decrease in the pH of the substrate inside the biodigester then it can be controlled by addition of lime or recycled filtrate (Al Mamun & Torii, 2015). The graph (Graph: 1) shows that the biogas productivity is affected by change in pH with respect to the retention time. Thus, we can interpret that the optimum pH for enhanced biogas production lies in the neutral range i.e. 7.0. Researchers comprehended that when pH is in the methanogenic range then it valorizes the methane content in the biogas which is more than 60%. They observed that the pH of the effluent leachate of CSTR digester was in the range of 7.75-8 at a loading rate of 1.4 kg VS/m3.d and COD of 2150 mg/l (Babaee & Shayegan, 2011).



Graph 1: pH Vs Biogas Production (Sunny & Joseph, 2018)

3) *Feedstock:* All the biodegradable waste containing carbohydrates, fats, proteins, cellulose and hemicelluloses can be used as feedstock in bio-digesters (Weiland, 2010). Table 1 shows the theoretical COD and the potential biogas yield from different types of nutrients in the substrates. The productivity differs due to varied biochemical structure and rate of its biodegradability. The Biochemical oxygen demand (BOD), Chemical oxygen demand (COD), volatile solids (VS) content, C:N ratio and presence of inhibitory substances present in the feedstock influence the productivity of biogas (Babaee & Shayegan, 2011; Kwietniewska & Tys, 2014). From the below table 2, it is evident that kitchen waste and MSW containing organic fraction municipal solid waste (OFMSW) and slaughterhouse waste which is characterised by high moisture content and high biodegradability having greater potential for high methane yield as compared to the other feedstock. Agricultural waste on the other hand is composed by lignocellulosic material which may lead to poor degradability hence pre-treatment of lignocellulosic materials can enhance the productivity thereby reducing the HRT (Jingura & Kamusoko, 2017). The biogas production in case of Jatropha curcas press cake was 60% higher as compared to cattle waste and the methane content was found to be 66% (Jingura & Kamusoko, 2017). Studies on Jatropha curcas which is used to extract biofuels is reported to only 30% oil of the total biomass subjected to biofuel extraction process. The 70% left out deoiled cake combined with buffalo dung has showed an increase in biogas production having 71.74% methane content (Pal, Vanerkar, & Satyanarayan, 2015). Chandra et al., 2012 studied the lignocellulosic agricultural waste (wheat straw) with and without pre-treatment gave 111.6 % and 87.5% biogas yield respectively (Jingura & Kamusoko, 2017; Chandra, Takeuchi, & Hasegawa, 2012).

Table 1: Theoretical COD, Biogas yield from various nutrient sources

Nutrients source	Theoretical COD [gO_2 g-1]	Biogas [ml g-1 VS]	CH_4 %	CH_4 [ml g-1 VS]	Biogas [ml g-1 COD]	CH_4 % [ml g-1 COD]
Carbohydrates	1.13	750	50	375	664	332
Proteins	1.6	800	60	480	500	300
Fats	2.03	1390	72	1001	685	493

Source: (Schmidt, McCabe, & Harris, 2018)

Table 2: Potential methane yield from various substrates

Feedstock substrate	Methane yield (ml-CH_4/g VS)	References
Cow dung	242-399	(Kougias & Angelidaki, 2018)
Pig manure	107-438	(Kougias & Angelidaki, 2018)
Poultry manure	322-355	(Kougias & Angelidaki, 2018)
Fish waste	390	(Sejahrooda, et al., 2019)
Fruit Vegetable waste	153-342	(Kougias & Angelidaki, 2018)
Rice straw	279-280	(Kougias & Angelidaki, 2018)
Kitchen waste	541-683	(Kougias & Angelidaki, 2018)
Organic fraction of municipal solid waste (OFMSW)	300-570	(Kougias & Angelidaki, 2018)
Sewage sludge	250-350	(Popescu & Jurcoane, 2015)
Slaughterhouse waste	550-1000	(Popescu & Jurcoane, 2015)
Microalgae	285-359	(Kougias & Angelidaki, 2018)
Maize silage	232	(Popescu & Jurcoane, 2015)
Napier grass	220	(Yodthongdee, Weerayutsil, & Khuanmar, 2019)

4) *Biochemical oxygen demand (BOD) and Chemical oxygen demand (COD):* Biochemical oxygen demand is the measure of oxygen required by the microbes to decompose the organic material. Higher the BOD, more rapid the organic degradation. COD is the measure of all organic and inorganic biodegradable matter present in the sample. COD value of organic waste can help predict the theoretical methane yield from the substrate (Kwietniewska & Tys, 2014). For 0.5 l/gm of COD removed, methane production will approximately equal to 0.35 l/g (Angelidaki & Sanders, 2004).
5) *Carbon/ nitrogen ratio:* C/N ratio plays an important role to determine the suitability of organic matter (OM) for anaerobic digestion. High C/N ratio indicates low nitrogen content for microbial growth and as a result methanogens uptake the nitrogen for protein production thereby leading to carbon wastage which ultimately leads low biogas yield (Aworanti, Agarry, & Ogunleye, 2017; Chandra, Takeuchi, & Hasegawa, 2012). Whereas, low C/N ratio can lead to accumulation of ammonia, nitrogen which may cause inhibition in the anaerobic digestion process (Aworanti, Agarry, & Ogunleye, 2017; Gerardi, 2003). Gerardi have reported that C/N ratio of 25:1 was optimum for good biogas production (Gerardi, 2003). The optimum range of C/N for proper functioning of bi-digester was found to be 20-35:1 (Kwietniewska & Tys, 2014). Higher temperatures require higher C/N ratio to lessen the possibility of ammonia inhibition (Wang, Nges, Nistor , & Liu, 2014). Typical C/N ratios were recorded for few feedstocks: chicken manure 15:1, grass silage 25:1, cattle manure 13:1and rice husks 47:1 for obtaining maximum biogas yield (Dioha, Ikeme, Nafi, Soba, & Yusuf, 2013). The optimal C/N ratio ensures better methane yield.

6) *Total and volatile solids and their particle size:* Solid content are the total amount of fermentable substrate present in a unit volume of slurry. Higher level of dry solids especially lignocellulosic content affect the hydrolysis process (Nazmi, Korres, & Murphy, 2009). The optimum level solid content for improving the productivity was found to be 7-9%. (Zennaki, Cadi, Lamini, Aubinear, & Boulif , 1996). Total solids (TS) encompass both organic as well as inorganic matter. The percentage of volatile solids (VS) present in the substrate is directly proportional to the methane yield. (Moody, Burns, Haan, & Spajic, 2009). It is recommended that 8% TS resulted better biogas yield. Baserja reported that the biogas production increased to 0.46 m^3/ (m^3 day) at 37°C and 0.68 m^3/ (m^3 day) at 55°C respectively. It was observed that when TS content decreases below 7% system becomes unstable whereas above 10% TS content the digester becomes overloaded hindering its performance (Baserja, 1984). The size of the particle influences the overall fermentation of the organic matter in the digester. Smaller particle size enhances greater adsorption on the substrate resulting in increase in the microbial activity leading to greater biogas yield. Crushing of the feedstock into smaller & uniform particle size can significantly reduce the volume of the digester without compromising on the quantity of biogas produced.
7) *Moisture Content:* The moisture content of the substrate affects the process of anaerobic digestion. The highest methane yield has been reported at 60-80% humidity (Gashaw, 2016). The experimental comparison between 70% and 80% moisture content showed that maximum biogas was produced in former i.e. 83 ml CH_4/ gm dry matter as compared to later i.e. 71 ml CH_4/ gm dry matter (Gashaw, 2016; Khalid, Arshad, Anjum, Mahmood, & Dawson, 2011).
8) *Organic Loading Rate (OLR):* The amount of organic matter subjected to the digester volume with respect to time or the biological conversion capacity of the substrate is termed as organic loading rate (OLR). The gas production is mainly influenced by the OLR. The OLR is directly proportional to the amount of volatile solids to be loaded in the digester which also influences the biogas yield. Lesser the OLR, higher the methane produced. The higher concentration VFA's indicates that the reactor is overloaded. In an experimental study on manure performed in Pennsylvania on 100 m^3 biogas plant, the loading rates varied from 346- 1030 Kg VS/day. It was observed that the gas yield increased steadily from 67- 220 m^3/day. They investigated that at an optimum feeding rate the gas production increases, but beyond the optimum feeding rate the biogas production remains constant. Studies suggests that a daily OLR of 16 Kg VS/ m^3 of digester volume generated 0.04 – 0.074 m^3 of gas/Kg of dung fed. In a pilot scale studies for 1 m^3 biogas plant, it was observed that its OLR was 24 Kg dung/ m^3digester/day. (Yadvika , Sreekrishnan, Kohli, & Rana , 2004; Gashaw, 2016). OLR of 2.91 Kg VS m^3/day is required for generation of 0.36 m^3/Kg VS. According to the rule of thumb, OLR should be between 0.5- 3 Kg VS m^3/day. For CSTR digester the OLR is 1-6 Kg COD/ m^3 reactor vol/ day. (Gashaw, 2016).
9) *Hydraulic retention time (HRT)* is the time for which the biodegradable matter remains inside the reactor. HRT is influenced by the temperature inside the digester, the type of the feedstock and the technologies applied. The HRT in case of mesophilic digester is 10- 40 days and thermophilic is of 14 days. Too short retention time might leave the bacteria getting washed out of the digester without they getting multiplied thus leaving the digester coming to standstill state and longer retention time would increase the volume of the reactor. Thus in order to reduce the retention time and reactor volume, the optimum loading rate is to be maintained for optimizing the methane gas generation. 2-3 weeks of time is considered optimum for lignocellulosic material to degrade and generate biogas (Qi, Aldrich, Lorenzen, & Wolfaadt, 2005; Nazmi, Korres, & Murphy, 2009). Studies of treating a co-digested cattle waste, poultry waste and cheese whey (2:1:3) gave highest biogas production of 2.2 l/day having 62% methane content with an HRT of 10 days and OLR of 6 g TS/ l (Al Mamun & Torii, 2015; Desai & Madamwar, 1994).
10) *Co-digestion:* Studies have revealed that digester performance can be enhancement by co-digestion supplying the necessary missing nutrients to micro-organism to increase their efficiency. Yusuf reported using co-digested substrate can improve biogas yield by controlling the carbon to nitrogen ratio (Yusuf, Debora, & Ogheneruona, 2011). Using co-digestion of leftover foods, vegetable wastes, fruit and cow manure can help improve biogas technology (Deressa, Libsu, Chavan, Manaye, & Dabassa, 2015). Co-digestion of feedstock as compared to single substrate waste treated anaerobically have shown encouraging results to enhance cumulative biogas yield (Narayani & Gomathi , 2012; Prakash & Singh, 2013; Otun, Ojo, Ajibade, & Babatola, 2015; Aworanti, Agarry, & Ogunleye, 2017). Researchers studied co-digestion of cattle manure with food waste, cow dung with fruit waste, food waste and vegetable waste, pig/swine manure with grass silage and grass clippings and chicken droppings/manure with Cymbopogon citratus, water hyacinth and municipal sewage sludge and found encouraging results to improve the productivity (Aworanti, Agarry, & Ogunleye, 2017; Prakash & Singh, 2013; Otun, Ojo, Ajibade, & Babatola, 2015; Quiroga, Castrillon, & Nava, 2014; Owamah, Alfa, & Dahunsi, 2014; Matheri, Belaid, Seodigeng, & Ngila, 2016; Xie, Wu, Lawlor, Frost, & Zhan, 2012; Imam, Khan, Sarkar, & Ali, 2013; Borowski, Domanski, & Weatherley, 2014). The non-edible agricultural waste of oil seeds like citronella, jatropha, mustard oil cake, mahua, soya sludge, neem and pongamiaare can be

used as a feed to generate biogas (Pal, Vanerkar, & Satyanarayan, 2015). Co-digestion of grass silage with slurries was found to enhance digestion process thereby also reducing the inhibitory effect of ammonia and H_2S (Sterling , Lacey , Engler, & Ricke, 2001; Nazmi, Korres, & Murphy, 2009). Co-digestion of cow dung with grass (5:2) showed 53% VS removal with a methane yield of 0.268 m^3 CH_4/ kg VS added (Lehtomaki, Huttunen, & Rintala, 2007; Nazmi, Korres, & Murphy, 2009). Prakash and Singh studied effects of using co-digested waste of cow dung (CW) + vegetable waste (VW) and CW+ Fruit waste (FW) in different ratios. They have suggested 1:1 ratio for CW+ VW and 2:1 ratio for CW+ FW for enhancing the productivity (Aworanti, Agarry, & Ogunleye, 2017; Prakash & Singh, 2013). Studies of using cowdung, sewage, chicken waste and pig manure in equal proportion gave the highest biogas yield (Aworanti, Agarry, & Ogunleye, 2017; Sebola, Tesfagiorgis, & Muzenda, 2015). It was also observed that chicken gizzard/ chicken rumen can be used as inoculum to maximize the biogas production. (Aworanti, Agarry, & Ogunleye, 2017; Aragaw, Andargie, & Gessesse, 2013; Ogunleye, Aworanti, Agarry, & Aremu, 2016). However, kinetic mathematical modelling aspect and thermodynamic properties of biogas generation also needs to be studied (Aworanti, Agarry, & Ogunleye, 2017). Co-digestion of several substrates, for example, banana and plantain peels, spent grains and rice husk, pig waste and cassava peels, sewage and brewery sludge, among many others, have proved to improve the methane yield to more than 60% as compared to that in mono-substrate digestion process yield. (Ezekoye & Okeke, 2006; Illori, Adebusoye, Lawal, & Awotiwon, 2007; Adeyanju, 2008; Babel, Sae-Tang, & Pecharaply, 2009). Co-digested food waste with dairy manure in a two-phase digestion system conducted at laboratory scale demonstrated that the gas production rate (GPR) of co-digestion has been increased by 0.8 - 5.5 times compared to dairy manure mono-digestion (Mashad & Zhang, 2007). A study on biogas production from co-digestion of a 60: 40 wt % of cattle dung and sinews gave a maximum biogas production of 3.3 L/day at 33 days after a 20-day period of inactivity (Paulchamy, Dharmaraj, & Laxmanan, 2008). The tomatoes and cattle dung was co-digested, a 20 days minimum retention period yield 62% biomethane content at 40°C. (Aworanti, Agarry, & Ogunleye, 2017). Lignocellulosic material can actively undergo biodegradation at 30-60°C (Usman, Olanipekun, & Ogunbanwo, 2012; Aworanti, Agarry, & Ogunleye, 2017).

11) *Agitation:* Studies have revealed that agitation of the substrate inside the bio-digester helps to enhance biogas production (Aworanti, Agarry, & Ogunleye, 2017; Santosh, Sreekrishman, Kohli, & Rana, 2004). Stirring the slurry helps to mix the feedstock without settling down and forming a scum in the digester. Slow mixing of the substrate was found to improve the biogas yield (Baier & Schmidheiny, 1997). The digester were subjected to 30, 40, 50, 60 and 70 rpm agitation speed and it was observed that 30 rpm speed gave highest amount of biogas (i.e. 6.285 dm3/gm) having 58% CH_4 content and followed by 40, 50, 60, 70 rpm having biogas yield of 6.003, 5.720, 5.438 and 5.044 dm3/gm and CH_4 content of 57.1%, 55%, 50% and 48% respectively. (Aworanti, Agarry, & Ogunleye, 2017). Researchers investigated that the biogas production will increase by 15% for stirred digester compared to unstirred (Muthanna & Muhul, 2006). Studies have suggested an increase of 10 to 30% in biogas yield with agitation (Karima, Hofmanna, Klassonb, & Al-Dahhana, 2005). An increase of 7% in biogas yield was reported with intermittent mixing as compared to continuous mixing (Kaparaju, Buendia, Ellegaard, & Angelidakia, 2008). Thus, a moderately agitated digester can be employed for maximizing the generation of biogas.
12) *Pre-Treatment/ Inoculum:* Pre-treatment of the substrate helps to increase the degradability of the feedstock. It breaks the complex organic molecules into the simpler ones which can be readily degraded by the micro-organisms. The methods of pre-treatment can be physical, chemical or biochemical. The substrate derived from agricultural waste, poultry waste, MSW, etc. needs pre-treatment as they contain lignin, cellulose, hemicellulosic complex substances which can be broken down to simpler forms for better digestion. The pre-treatment of ligno-cellulosic material have proved to increase the biogas production also reducing the HRT (Chandra, Takeuchi, & Hasegawa, 2012; Jingura & Kamusoko, 2017). An addition of nickel (Ni), cobalt (Co), molybdenum (Mo), selenium (Se) and sulfate nutrients resulted in an 40% higher yield and reduced VFA concentration (Gunaseelan & Nallathambi, 1997; Nazmi, Korres, & Murphy, 2009). The ideal combination of nutrients for the hydrolysis and acidogenesis is C:N:P:S of 500:15:5:3 and that for Methanogenesis is 600:15:5:3 (Dieterich, 2008; Nazmi, Korres, & Murphy, 2009). Addition of NH_4Cl to Bermuda grass gave 96% methane yield (Gunaseelan & Nallathambi, 1997). An experimental study of chicken dropping without/ with pre-treatment showed encouraging results in pre-treated feedstock leading enhance biogas productivity. The biogas generation without and with pre-treatment were 20 m^3/ one ton of fresh waste and 64.4 m^3/ one ton of fresh waste (Elasri & Afilal, 2016).

13) *Inoculum:* The inoculum helps in reducing the start-up time of the digester. The seeding of the digester is found to accelerate the rate of biogas formation. Researchers have found that the feed to inoculum ratio affected the performance of biogas digester. It was reported that 80% biogas was obtained during the first ten days of digestion period when seeded with inoculum (Ahamed, Raiyan, Hossain, Rahman, & Salam, 2016).
14) *Inhibitors:* Ammonia (NH_3), carbon dioxide, Long Chain Fatty Acids (LCFA), H_2S are most common inhibitory substances present in the substrate in the anaerobic digestion process. It has been observed that methanogens are more sensitive to toxic material as compared to other group of bacteria. Methanogens are affected more by short chain fatty acids. The ammonia concentration of less than 200mg/l has been found to be suitable for biogas generation as nitrogen acts a nutrient, hence C:N ratio of 30:1 has been determined to improve biogas productivity thereby supplying proper nutrients to micro-organisms for the microbial activity (Chen, Cheng, & Creamer, 2008; Liu & Sung, 2002). The inhibitory effect of ammonia mainly influences the methanogenic phase of digestion process (Calli, Yenigun, Mertoglu, & Inanc, 2005). Poultry waste, swine waste, high proteinaceous sludge is rich in NH_3 (Kougias & Angelidaki, 2018; Kougias, Fotidis, Zaganas, Kotsopoulos, & Martzopoulos, 2017; Fotidis, Kougias , Zaganus, Kotsopoulos, & Martzpoulos, 2014; An, et al., 2017). The free ammonia (NH_3) is responsible for inhibitory effect and not the ammonium ion (NH_4^+) (Kougias & Angelidaki, 2018). A study on ammonia inhibition suggests that the concentration of 1.77-14 g/l of total ammonia nitrogen can reduce the biogas yield by almost 50% (Kougias & Angelidaki, 2018; Chen, Cheng, & Creamer, 2008). The ammonia inhibition is influenced by the pH and temperature. The change in pH and temperature can lead to disturb the process dynamics which will lead to operate the digesters under inhibited steady conditions leading to around 30% loss in the biogas yield. Long Chain Fatty Acids (LCFA) is present in the agricultural residues, food waste, olive oil wastewater, slaughterhouse waste, etc. which act as inhibitory substances in the process of anaerobic digestion. It is reported that thermophiles are more sensitive to LCFA than mesophiles (Chen, Cheng, & Creamer, 2008; Hwu & Lettinga, 1997).

III. CONCLUSION

The efficiency of the anaerobic digester is dependent on the combination of all the factors like pH, temperature, co-digestion that are discussed in details in this review. The efficiency of the digester can be enhanced by optimizing each factors and thus synergizing the overall process of anaerobic digestion.

1) The optimum operating temperature is 32- 35°C, pH range lies between 6.5- 7.2, C/N ratio of 25:1, TS should be 7-9%, co-digested substrate has potential to enhance biogas by 25- 100% as compared to mono-digested substrate.
2) Pre-treatment changes the chemistry of the substrate thereby making it readily available to the micro-organisms for treatment.
3) Agitation aids the digestion process without letting the slurry from settling down. Inoculum helps to reduce the start-up time of the digester helping it generate the biogas at a faster pace than usual.
4) OLR is directly dependent on the amount of volatile solids loaded in the digester. OLR also depends on the type of feedstock as the different feedstock has different characteristics, hence different rate of biodegradability.

Thus, we understand that all the factors discussed in the paper are interdependent and there is a need to establish correlations between them to create a synergy to optimize the biogas productivity. Biogas will play a crucial role to help mitigate the energy crises and climate change issues hence enhancement and upgradation technologies in biogas to convert it to BIO-CNG plugin models which are economically viable source of energy generation can prove to be revolutionary in the energy starving nations which can come to rescue the developing and under developed countries of the world.

Further research studies on start-up time for biogas generation, the effects of substrate/ inoculum ratio, agitation speed, OLR, HRT needs to be carried out to improve the efficiency and productivity of biogas plant. The study on kinetics modelling to evaluate the biomethanization process, cumulative biogas production can be simulated to design an efficient biodigester for enhancing the productivity (Aworanti, Agarry, & Ogunleye, 2017). Process optimization research can accelerate the production of biogas (Sajeena, Jose, & Madhu , 2014). Although, organic material having easy availability, biogas has faced barriers in commercialization due to difficulty in maintaining the optimum operational conditions. There is a need to explore a standardized plug-in models of biodigesters based on different feedstocks. Kitchen waste based compact biogas plant will serve to green energy in kitchen thereby reduce the waste reduction at source. Looking from the microbiological perspective novel molecules can be generated from the bacteria present in biogas plant. Novel products like polysaccharides, bioplastics, chemicals (biosuccinic acid, hexanol, lactic acid, etc.) can be recovered from the digesters (Kougias, Fotidis, Zaganas, Kotsopoulos, & Martzopoulos, 2017). Slurry and sludge produced as a result of anaerobic digestion can be utilized as a bio-fertilizer.

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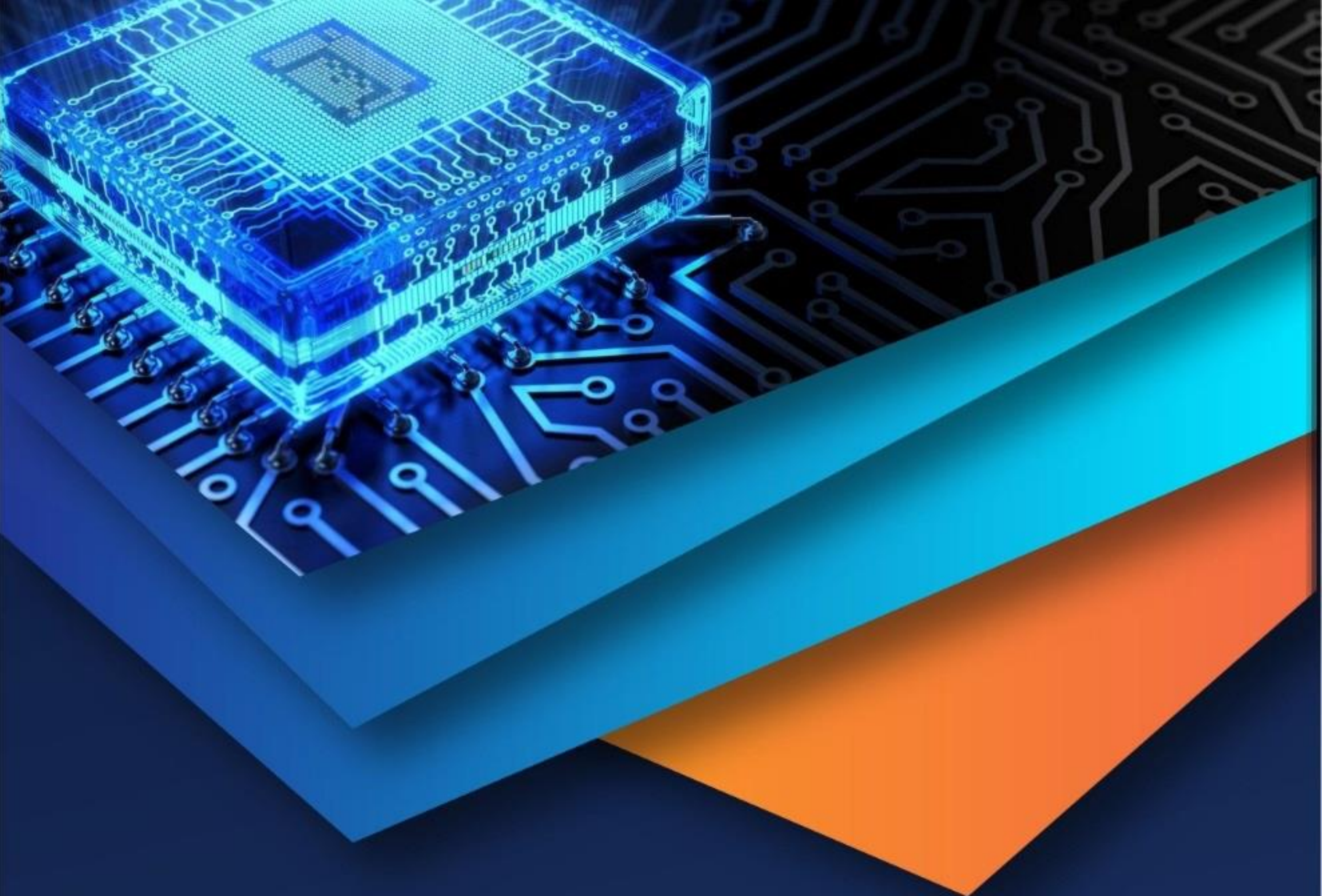

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