Effect of Operational Parameters on Biogas Production using Tomato Waste as Substrate and Cow Dung as Inoculating Medium

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Abstract: ***A balanced and self-inoculated system that could maintain the optimal acidogenic-methanogenic microbial ratio for the consistent production of biogas was developed using cow dung as mixed microbial culture. This was attained by maintaining the system in mesophilic phase (28-34 ^{0}C) and neutral pH in a 50 L scale digester for 10 days during which the reactor was treated as the batch digester and analyzed for biogas production. A cumulative gas production of 27.5 L was observed and the gas attained flammability form the 4th day of experiment. Thedigester was next fed with tomato wastes in a semi continuous manner and observed for gas production. Parameters influencing the gas production such as OLR (organic loading rate), pH, and hydraulic retention time (HRT) were optimized during the process. The average gas production was optimum for HRT of 24 days and moderate for 20 days but the digester turned acidic at HRT of 16 days with volatile solid (VS) concentration 8 % W/V and OLR of 5 Kg VS/m^3 day.***

Keywords: Biogas, microbial culture, mesophilic phase, inoculum and methanogens

1. Introduction

Waste disposal in assorted form and depletion of conventional fossil fuels have collectively become the major problem in India which could not be solved despite many initiatives by the government. In India, the estimate of fruit and vegetable waste distribution in the food supply chain was nearly 15% during the agricultural production, around 9% during storage, around 25 % during processing and packing, 10% was during distribution and 7% during consumption stages [2].So the waste disposal was highly segregated and distributed which is also a consuming effort in maintaining cleanliness and conducting waste and disposal management. These problems can together be addressed by installation of local and disintegrated biogas plants in confined localities of both rural and urbanized societies. Biofuels have been considered to be clean fuels and recognized as the significant alternative for replacing the continually depleting conventional fossil fuels. Application of novel biodegradation techniques for gasification and liquefaction of biomass into value added fuels has been the topic of vital importance in current research. Out of the conventional methods used for gasification, biodegradation has been found to be advantageous over physical methods. Apart from the energy, bio digester produces organic fertilizer and soil conditioner.

Anaerobic digestion is the process in which the organic and degradable substrates are subjected to microbial action which under mesophilic or thermophilic conditions produces organic acids and gas rich in methane and carbon dioxide. Biogas produced in the digester on an average constitutes 50-75 % of methane by volume, upto 25-50 % of CO_2,0-10 % N_2, 0-1 % H_2, and0-3% H_2S[11]. The process is mainly comprised of 4 stages of digestion[12] which include i. Hydrolysis in which undissolved volatile components are cracked into monomers and the complexity of the process increases with degree of cross linkage in the structure [12]. ii. Acidogenesis is the process in which hydrolyzed monomers are further degraded into volatile fatty acids such as acetic acid, propionic acid, butyric acid and valeric acid and alcohols, small amounts of CO_2 and H_2. Iii. Acetogenic phase results in the production of acetic acid H_2 from the higher order fatty acids. This process has considerable importance as the higher partial of H_2isrequired for the survival of methanogens[12]. Iv. Methanogenic phase constitute the production of methane by methanogens.

2. Related Work

Nature and composition of the substrate, temperature, pH, OLR and HRT significantly affects the biogas production and degree of digestion in the anaerobic reactor. P. Vishwanath et al. [1]used versatile and mixed form of substrates composing mixture of tomato, jack fruit, pineapple wastes, orange peels with oil in various proportions in pilot scale studies at 60 liters capacity for various HRTs in the range of 8-24 days, TS content in the range 4-10 % by mass/volume of and obtained the biogas yield of 0.6 l/g VS added with maximum concentration of 59% methane by volume. In his work critical observation was that 60% of the total gas production was within first 12 hours of feeding. BVelmurgan et al. [2] used fruit and vegetable wastes such as banana stem, ladies finger, cabbage in 2 L scale using inoculums from bio methane plant at Chennai for OLR 2.25 kg VS/ m^{-3}day $^{-1}$ and recorded 0.595 (L/g of VS added) biogas with 65% methane concentration. H. Bouallagui et al.[3] used tubular reactor (18 L) for treating arbitrary fruit and vegetable wastes using OLR 4 -5 kg VS/ m^{-3}day $^{-1}$, HRT 20 days and 6 % TS content and obtained 0.69 (L/g of VS added) biogas. The degradation efficiency was 75 %. Azadehbabaee et al. [4] conducted pilot plant study in 70 L scale on degradation of vegetable waste at 25 days HRT and by varying OLR in the range 1.4 -2.75 kg VS m^{-3}day $^{-1}$ and recorded biogas production of 0.396 L/g VS added with 65 % methane concentration. Imalfa et al. [5]

studied the biogas production in batch digestion from the substrates of pre-treated cow dung, lemon grass and poultry manure which gave highest average biogas production of 7.3 L/day.Jin Young-Jung et al. [13] experimented on piggy waste for anaerobic digestion in a pilot plant scale and observed an average methane production of 0.32 m^3 CH4/kg CODremoved in a two stage process.

3. Objective

A novel self-mixing configuration of digester gas collector assembly was designed. The design is next constructed and observed for the robustness in terms of self-inoculation, self-buffering abilities and extreme operating parameters. The results are next to be used to fix the limits for operating the anaerobic digestion in terms of pH, temperature, OLR and VS composition.

4. Experimentation and Methodology

4.1 Digester setup

In the experiments, 50 L digester setup with 45 L slurry working volume was used. The digester was an inverted vessel having provision for an inlet ‘U’ shaped 4 inch ID pipe as shown in the figure (Fig. 1) which has longer arm outside the digester while the shorter end was projected inside towards the top end. Another 4 inch pipe takes a U turn from the tank bottom which was provided to act as an outlet to the digester. Pipe of size (1 or ¾ or ½ inch) has been considered based on the required rigidity which in turn depends on the length of pipe required inside the digester. The pipe was used to transfer the accumulated gas on the surface of the liquid in the digester to the separate gas collector. Pipe was introduced from the bottom in order to reduce the efforts of making the dome top as gas proof. Instead the bottom was made liquid sealed which was much simpler. This also reduces the wear and tear of the digester wall due to the fluctuations achieved in the pressure of the gas inside the container.

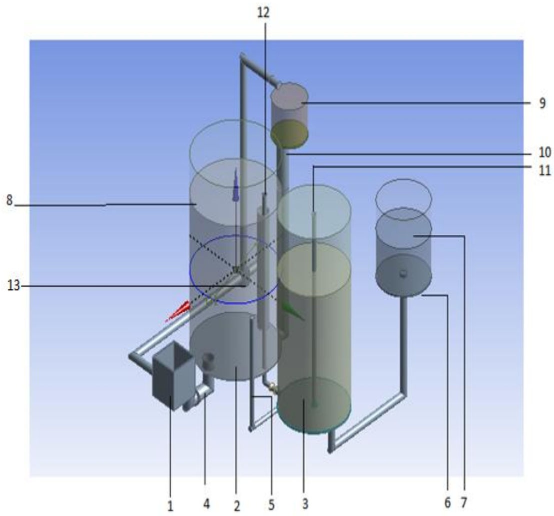

Figure 1: Experimental setup

1 - Mixing tank, 2- Digester, 3- Gas collector, 4- Sludge outlet, 5- Gas sample to the burner, 6- Siphon tank, 7- water level, 8- Slurry level, 9- Feed tank, 10- Feed inlet pipe, 11- Gas inlet to the collector, 12- Gas outlet and 13- slurry pump.

4.2 Working

Feed was introduced into the mixing tank where it encounters a part of underflow sludge from the reactor outlet and was fed to the digester. Sample of the outlet sludge was periodically taken to monitor the parameters such as VS, pH, temperature etc. Gas produced above the slurry level was passed to the gas collector on opening the gas valvewhile keeping the slurry and sludge valves closed which pushes down the water level in the gas collector down due to which water was displaced into the siphon tank through the connecting tube. Required pressure of outlet gas without disturbing the pressure of the reactor can be achieved by closing the valve V1 and simultaneously maintaining corresponding level of water in thesiphon tank and then opening the remaining gas valves.Siphon tank was calibrated to know the amount of water collected in it periodically and addingcorresponding water head to obtain the volume gives periodical gas production. If periodical mixing of the constituents are required, then closing all gas valves andsimultaneously opening outlet sludge valve results in the bottom denser sludge to be collected in the mixing tank which was subsequently pumped to the feed introducing tank. This denser slurry was introduced at the top of the slurry surface by overflowing through the u shaped feedinlet pipe which makes the slurry inter mixing simplifiedcompared to the conventional digester designs.

4.3 Inoculum

Self-inoculating system was developed using cow dung slurry (4:5 by volume in water) as mixed microbial culture by maintaining it for 10 days in the anaerobic and mesophilic conditions. During the time, batch performance of the digester for biogas production was conducted. When pH was consistent after 10 days, digester itself was used forconducting semi continuous study on vegetable wastes.

4.4 Analytical Methods

pH was measured using microcontroller Bench top (Systronics 9101 ATC). Temperature was measured using thermometer by sampling at various levels. Total solids (TS) and volatile solids (VS) were estimated using the methods proposed for waste water treatment [20]. Gas production was observed by the rise of liquid level in the siphon of gas collector. The height recorded in the siphon was liquid displaced by the occupied gas which in turn gives pressure in the gas collector.The excess volume of the liquid in the siphon gives volume change in the gas collector. Applying ideal gas assumption, the change in quantity of gas produced at any time was obtained.

4.5 Feed Stocks and Properties

Cow dung was used alone for the preparation of digestion inoculum during batch study. Tomato wastes of the following properties as shown in the table (Table 1) were studied for anaerobic digestion during semi continuous study.

Table 1: Typical substrate composition

Parameter	*Cow Dung*	*Tomato waste*
Moisture content (% w/w)	86.48	73.665
Total Solids (% w/w)	13.52	26.33
Volatile Solids (% VS/TS)	81.71	94.68
pH	7.1	4.6
Tmeperature°C	30	30

5. Results and Discussion

5.1 pH variation

pH is one of the most influential parameter in biogas production. pH in an anaerobic digester is the balance of competitive effect of production of VFA that was responsible for acidic nature and production of free ammonia and hydroxyl ions are responsible for basic nature. Higher pH > 7.6 would inhibit methanogenic activity whereas lower pH < 6.3 would hamper biogas production. So balanced rates of production should maintain the necessary pH (6.5 to 7.6)[14] for the optimal activity of methanogens. Alkalinity of digester in the range 1500 and 5000 mg/L[15] would retain the self-buffering capacity of digester despite the disturbances in the input pH.

5.1.1 Batch Experiment Results

During batch observations, pH was maintained in the optimal range of methanogens as shown in the figure (Fig. 2). During the ninth and 10th days of operation, pH was stably fluctuating in the neutral range. It may be described by attaining self-buffering capacity. Thus the digester operated in semi continual mode.

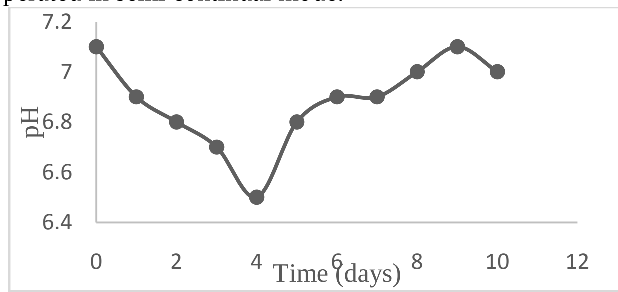

Figure 2: pH variation of digester slurry in batch process

5.1.2 Semi continuous experiment results

During the semi continuous study, digester was fed with tomato waste of pH 4.3 and was operated at lower OLR of 1.6 Kg VS/m^3 day and sustained the pH change that was self-buffering (Fig. 3). pH drastically reduced to 5.7 when the operation was at OLR of 5 Kg VS/m^3 day and HRT was 16 days as shown in the figure.

Pallavi et al. [14] operated the thermally hydrolysed sludge in the mesophilic range 37-42 °C and SRT 15 and 20 days and the digester performed in pH 6.5 -7.0 in the first 30 days of operation. Alkaline treatment enhanced the pH and was maintained in the optimal range for the remaining days of experiment.

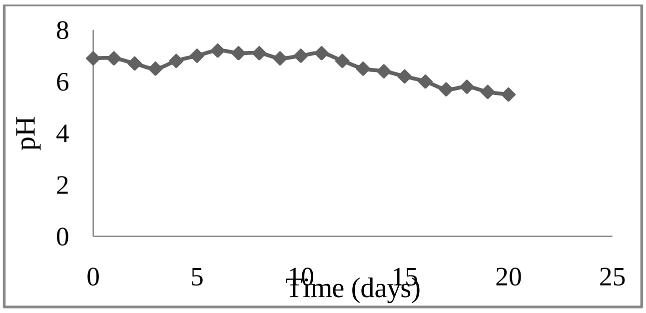

Figure 3: Change in pH of the digester slurry with time in semi continuous process

Thus pH control during digestion process were reported often reported by many researchers. Jin-Young Jung et al. [13] conducted two stage anaerobic digestion, and had to control the pH of acidogenic digester for maintenance in the range of 6-7 during the initial days of operation for enhanced gas production of s 0.32 m^3 CH_4/kg COD removed. Adrian et al.[17] studied the digestion of mixed agricultural wastes and wheat bran and observed the pH of 5-7 in the first 50 days of operation using wheat bran and 6-7 using mixed agricultural waste. A.E. Ghalay et al. [16]operated the digester in two stage process and observed for the effect of pH control, without any pH control he observed the operation of second stage digester reaching neutral pH in the initial stages of operation. However the pH lowered to below 4 in the 20th day of operation.

5.2 Temperature Variation

Temperature was an important parameter influencing the digestion rate and efficiency. It also indicates the digestion progress in the reactor. Mesophilic digestion in the range of 30- 45 °Cis easy and convenient to operate the anaerobic digester.

5.2.1 Batch Experiment Results

In the batch reactor, temperature was recorded as shown in [Fig. 4]. The substrate temperature was 28 °C during the feeding and was consistently rising with time indicating the progress of anaerobic digestion which is exothermic process [18].

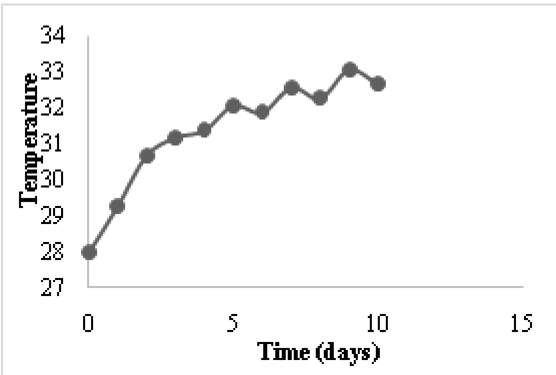

Figure 4: Change in temperature of the digester slurry with time in batch process

5.2.2 Semi Continuous Experiment Results

During the semi continuous operation, temperature was fluctuating within 30 °C-34°C and was highest in the second week of operation. Phenomenon can be explained as the increase in the digestion rate and gas production enhanced the reaction and hence temperature increased during first week of operation. However further increase in the substrate input increased VFA production rate compared to methanogen activity which resulted in the highest temperature record.But due to severe VFA accumulation from the end of second week along with increase in feed input at temperature 28 ^{o}C in combined effect led to lowering of temperature to 30 ^{o}C that signifies the VFA accumulation (Fig. 5).

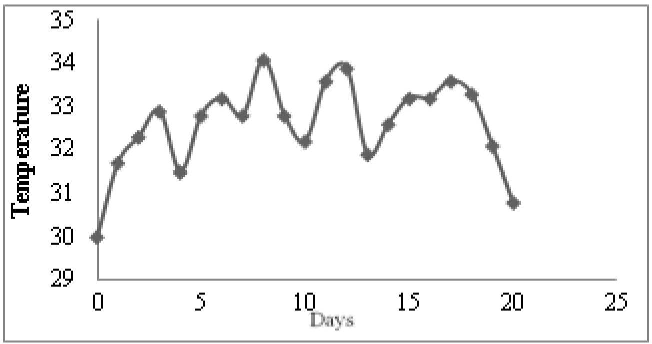

Figure 5: Change in temperature of the digester slurry with time in semi continuous process

A.E. Ghalay et al. [16]similarly conducted two stage digestion and observed the temperature fluctuations in the range 34 to 37 during 50 days of operation. Adrian et al [17] conducted the digestion of wheat bran and mixed agricultural waste and observed temperature to be varying in 30-40 ^{o}C and fall to below 30 ^{o}C after 50 days of operation.

5.3 Gas Production

Biogas production was influenced by the factors such as HRT, OLR, VS concentration, Temperature and pH of the digester slurry. An optimum collection of parameters would maintain the balance in acedogenic, acetogenic and methanogenic activities and give good gas yield and higher methane concentrations.

5.3.1 Batch Experiment Results

During the batch study, only cow dung was used as substrate with an objective to prepare self-inoculated system with self-buffering capacity. Figure [Fig. 6] illustrates change in gas production with time. Maximum production of 4.5 L was observed in the 8th day of installation [**Fig.** 6]. The production was stable thereafter and the digester was treated with tomato wastes for semi continuous study.

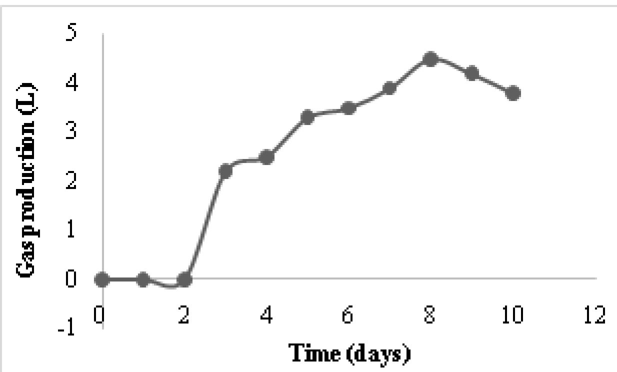

Figure 6: Change in gas production with time in batch process

5.3.2 Semi Continuous Experiment Results

During the semi continuous study, the tomato wastes with pH 4.3 were subjected to anaerobic digestion for three weeks at different OLRs that resulted in gas production as shown in the figure 7.

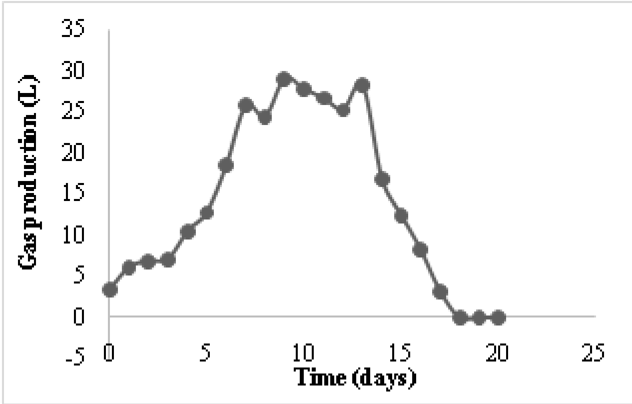

Fig.7. Change in gas production with time in the semi continuous process

Table 2. Results summary

Duration	HRT	OLR (Kg VS/m^3 day)	VS fraction (w/w)	Average gas production (L/day)	Specific production (L/g VS /day)
1st Week	25	1.6	0.04	9.414	0.13
2nd Week	20	3.5	0.07	26.87	0.17
3rd Week	16	5	0.08	5.84	0.026

High OLR with pH 4.3 resulted in higher Volatile Fatty Acid accumulation and pH fell drastically to 5.8 on 18th day of semi continuous operation. Gas production was entirely terminated and yet the digester was active which could be illustrated by the consistent temperatures above 30 ^{0}C in the digester even though the temperature of ambience reached 23- 25 ^{0}C. Simular case has been encountered in the experiments conducted by BerlianSetarous et al.[9] on 200 liters batch digester which has turned sour (pH < 6) after 3rd week of installation and it got stabilized to neutral and attained self-buffering capacity after the 9th week of installation.

6. Conclusion

Anaerobic digestion of cow dung was conducted in a pilot plant scale and observed for batch production of biogas for two weeks during which the digester achieved inoculum rich characteristics and self-buffering capacity. The digester was next observed in a semi continuous mode for biogas production using tomato wastes at various HRT, Volatile Solid concentrations and OLR. Maximum specific gas production of 0.17 L/g VS/ day was noted during the second week of continuous operation and the digester turned acidic under heavy load of 5 OLR at 16 days HRT and 8 percent Volatile solid concentration. The studies signify that pH of the feed substrate not only influences the gas production and composition but also fixes the limits of operational parameters such as HRT and OLR. Thus using vegetable waste such as tomato waste, efficient biogas production can be achieved if optimum process conditions are maintained in a semi continuous digester.

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