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Biogas generation from the wastes of a vegetable market in two types of reactors under daily feed condition

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Abstract

Bioenergy derived from biomass is expected to play a major role in the future energy system. This paper presents the results of two sets of laboratory experiments on biogas generation from the wastes of a rural vegetable market of Bangladesh in a single chamber and a double chamber reactors under daily feed condition. The daily average composition of easily biodegradable wastes of the market was used as the substrate for biogas generation. The major biodegradable wastes were cow dung, cauliflower stick, papaya and potato. The average total solids (TS) and volatile solids (VS) concentrations of the substrate were found to be 18.90% and 15.10% respectively. The experimental setups were placed in a closed chamber containing a room heater. It was operated at 35°C to maintain a favorable condition for anaerobic digestion of the substrate. In the first setup, 1000 g wastes and 1100 mL inoculum were added initially to the single chamber reactor. In the second setup, the double chamber reactor (bottom interconnection) was initially fed with 1000 g wastes (500 g in each chamber) and 550 mL inoculum was added to each chamber. Both the reactors were operated simultaneously for 67 days. To maintain the hydraulic retention time (HRT) as 40 days, from the 2nd day of operation, each reactor was fed daily with a mixture of 25 g wastes and 27.5 mL of tap water after dispensing 50 mL of slurry from the reactor. The results of the experiments revealed that the temperature varied from 33 to 36°C and it did not affect the rate of biogas generation. For the organic loading rate (OLR) of 1.89gVS/L.d, the daily stable biogas generation rate was 0.32 and 0.25 m^3/kg of VS added for the single chamber reactor and the double chamber reactor respectively. The performance of the single chamber reactor was better than that of the double chamber reactor.

Keywords: Anaerobic digestion, biodegradable waste, biogas, hydraulic retention time, single chamber reactor, double chamber reactor, organic loading rate.

1. Introduction

Increasing energy demand has led to excessive depletion of fossil fuels, significant emission of pollutants and climate change. It is an urgent task to secure clean alternative energy sources to ensure sustainable development. Major transformations are underway for the global energy sector, from growing electrification to the expansion of renewables, upheavals in oil production and globalization of natural gas markets. Oil markets are entering a period of renewed uncertainty and volatility, including a possible supply gap in the early 2020s. In power markets, renewables have become the technology of choice, making up almost two-thirds of global capacity additions to 2040. This is transforming the global power mix, with the share of renewables in generation rising to over 40% by 2040, from 25% today, even though coal remains the largest source and gas remains the second-largest [1].During 2017-2023, renewables are forecast to meet more than 70% of global electricity generation growth, led by solar PV and followed by wind, hydropower, and bioenergy. Hydropower remains the largest renewable source, meeting 16% of global electricity demand by 2023, followed by wind (6%), solar PV (4%), and bioenergy (3%) [2].The wide distribution of biomass provides rich sources of raw materials, while the significant

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development in bioenergy conversion technology improves its competitiveness. Bioenergy, which is used to produce biofuel, heat, and electricity, may be generated via various routes such as thermo-chemical, biological, and bio-electrochemical processes. Anaerobic decomposition of biodegradable solid wastes such as cowdung, poultry drops, food, fruit and vegetable wastes offers a viable method of generating methane gas (a source of energy) and nutrient rich digestate (a source of natural fertilizer).

1.1. Biogas technology in Bangladesh

Bangladesh is an agriculture-based country and faces huge energy crisis and environmental challenges. Production of biogas alleviates two major problems of Bangladesh– solid waste management and energy crisis at the same time. A total of 65,317 biogas plants operated on cattle dung and poultry droppings have been installed in Bangladesh till 2012 by IDCOL (Infrastructure Development Company Ltd.), BCSIR (Bangladesh Council for Scientific and Industrial Research), Grameen Shakti, NGOs and others [3, 4]. Till July 2019, IDCOL has financed construction of over 51,800 biogas plants all over the country through its 42 partner organizations. In recent years, community based biogas plants operated on kitchen wastes have been established at Jahangirnagar University campus, Savar, Dhaka and Gaibandha Municipality with encouraging results. In Bangladesh, biogas is currently being used mainly for cooking and lighting purposes in rural areas, and there have been some experiments on the use of biogas to generate electricity or drive irrigation water pumps [4]. The biogas plants have been constructed using bricks or concrete and a number of construction defects and operational problems exist [3]. Huge amount of biodegradable solid wastes (i.e. food waste, fish waste, slaughtered animal waste, animal feces, vegetable waste, fruit waste etc.) are generated in the markets of Bangladesh and can be used for biogas generation. However, in Bangladesh, no study on biogas generation based on market solid wastes has been reported in the literature. The authors of this paper have undertaken a research project "Investigation of Prospects for Sustainable Waste Management of Markets" to address the solid waste management problems of rural markets of Bangladesh. Two rural markets were selected - a large size market and a medium size market. The scopes of the study were to collect information on the prevailing technologies and practices of solid waste management, analyze the current situation and identify the major problems of the prevailing technologies and practices of solid waste management, test opportunities for anaerobic waste treatment at the two selected markets, investigate if the products of the waste treatment (biogas and digested slurry) are beneficial and can be sold to potential consumers, figure out activities associated with the handling, storage and processing of solid wastes at or near the point of generation, study sustainability of bio-digester with regard to operation and maintenance and other aspects, and recommend sustainable disposal procedure for non-biodegradable and hazardous solid waste.

As a part of the project, investigation on biogas generation based on the easily biodegradable solid wastes of a wholesale vegetable market was carried out in laboratory scale single and double chamber reactors under daily feed condition at high concentration of the substrate and controlled temperature. This paper presents the results of the investigation.

1.2. Anaerobic digestion process

Anaerobic digestion is a complex fermentation process brought about by the symbiotic association of different types of bacteria with ultimate products being mainly methane and carbon dioxide. It consists of a series of four metabolic processes namely hydrolysis, acidogenesis, acetogenesis, and methanogenesis shown in Fig. 1 [5]. The products generated by one group of bacteria serve as substrates for the next group. In a well-balanced anaerobic digestion process, all products of a previous metabolic stage are converted into the next one without significant buildup of intermediate products and no inhibition occurs. The overall results are nearly complete conversion of the anaerobically biodegradable organic matter into end products like methane, carbon dioxide, hydrogen sulfide and ammonia.

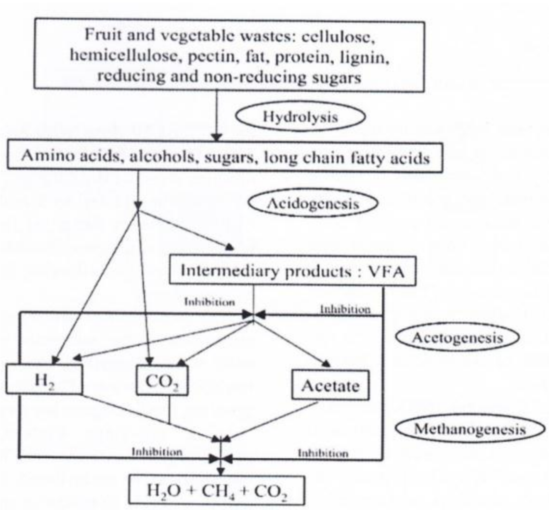

Fig. 1. Reaction scheme for anaerobic digestion of particulate organic material.

2. Materials and Methods

2.1. Selection of market and composition of wastes

Tekerhat Shangkardirpar bazaar (a large size market) of Rajoir upazilla of Madaripur district of Bangladesh was selected for the study. It consists of about 700 shops (400 are permanent) and a slaughter house. During haat days (Saturday, Wednesday), it acts as wholesale market of vegetables having about 200 temporary vegetable shops. There are about 200 carpentry shops, 5 restaurants and 6 tea-stalls in the bazaar. A field survey was conducted to acquire the composition of wastes produced on a haat day and a normal day. It was found that a total of 480 kg wastes were produced on a haat day of which 254 kg (53%) was biodegradable. On the normal days 152 kg wastes was produced of which 89 kg (58%) is biodegradable.

Cowdung, cauliflower stick, dry paddy straw, banana leaves, papaya, and potato were the major biodegradable wastes. Garlic and onion peel, paperboard and polythene were the major non-biodegradable wastes. The experiments were conducted using the daily average composition of easily biodegradable portion of the market wastes (48% of the total daily average wastes) as substrate (Table 1).

Fresh wastes were collected once per week and were cut into small pieces (maximum dimension of 4 mm). Then the pieces were mixed thoroughly to obtain a uniform mixture and it was preserved in a refrigerator. Feeding of the digesters was done with this sample only for the next 7 days. During the whole project duration, the TS (Total solids) and VS (Volatile Solids) of the substrate were determined for several times.

Table 1. Composition of wastes fed into the reactors of Shangkardirpar bazaar.

Item	Amount (g)	% of Total Biodegradable Wastes
Cauliflower Stick	556	27.8
Banana Leaves	133	6.6
Turnip Stick	178	8.9
Vegetable Stick	35.5	1.8
Pepper	35.5	1.8
Tomato	20	1.0
Ginger	20	1.0
Potato Peel	100	5.0
Tuberose Stick	100	5.0
Brinjal	22	1.1
Cataract (Potol)	22	1.1
Cow dung	778	38.9
Total	2000	100

2.2. Experimental setup

In order to generate basic data on biogas generation with high concentration of substrate in the reactors, two sets of laboratory experiments were run in semi-continuous feeding mode (one-time daily feeding). Each reactor was provided with suitable arrangements for feeding, biogas collection and draining of residues. The experiments were conducted in a closed chamber made of Thai Aluminium placed on a wooden table and an electrical room heater was placed inside the chamber to limit the fluctuation of temperature. In the first setup, one single chamber reactor was operated in semi-continuous feeding mode. The room heater was set at 35^{o}C. The single chamber reactor was a 5 L capacity plastic container and it was loaded initially with 1000 g wastes. Then 1100 mL inoculums (collected from a field biogas plant) was added to make the effective volume of 2 L. Water displacement method using an inverted cylinder was practiced to measure the generated biogas (Fig. 2).

Fig. 2. Expermental setup of the daily feed single chamber reactor.

In the second setup, two plastic containers connected in series, each having a capacity of 1.5 L, were used as the double chamber reactor. The interconnection was made near the bottom so that solids accumulated at the bottom of the inlet container could move easily to the outlet container. Each container was fed initially with 500 g wastes and 550 mL inoculum to make the effective volume of the reactor of 2 L. Water displacement method of biogas measurement was used for each chamber (Fig. 3).

Fig. 3. Experimental setup of the daily feed double chamber reactor.

2.3. Operation of anaerobic digesters

Both the reactors were operated simultaneously from 31st May 2017 to 6th August 2017 (total 67 days of operation). As the optimum HRT was found to be 40 days from the batch studies conducted earlier [6], daily feeding was calculated based on this. Accordingly, from the 2nd day of operation, 50 mL of slurry was taken out from each reactor and then 50 mL mixture consisting of 25 g wastes and 27.5 mL of tap water was added to the reactor daily at a particular time. The biogas production in each chamber and the temperature within the enclosure were recorded daily.

2.4. Methods of measurement

The TS and VS of the wastes were determined according to the APHA Standard Methods [7]. The biogas generated in each chamber was measured daily by water displacement method by inserting its gas outlet tube into an inverted measuring cylinder filled with water and placed in a water jar. The inverted cylinder was refilled as and when required. The temperature within the closed Thai Aluminum chamber was measured by a thermometer. The temperature was also displayed on the heater. The pH of the slurry taken out form each reactor was measured time to time with a pH meter (Model No.WTW Multi 3500i).

3. Results and Discussion

The TS and VS of the biodegradable portion of the market wastes were determined three times and the results are presented in Table 2.

Table 2. TS and VS contents of biodegradable wastes of Shangkardirpar bazaar.

Sl. No. of Measurement	TS (% of Raw Wastes)	VS (% of Raw Wastes)
1	17.94	13.87
2	16.99	13.83
3	21.76	17.61

The average of the three measurements is found to be 18.90% for TS and 15.10% for VS. Calculations for all the experiments were based on these average values. The variations in TS and VS measurements were due primarily to sampling cowdung from the stomach of slaughtered cow and actual cowdung.

The variations in the daily gas generation and temperature with time in the single chamber reactor are presented in Fig. 4. From this Fig., it is seen that a large volume of gas (over 3L) was produced on the first day of operation. Then it rapidly decreased to a low value of 750 mL within 6 days of operation. After that, the gas generation fluctuated, sometimes rapidly, over a period of 39 days. Then the fuctuation was smaller and a relatively stable rate of gas production of about 1200 mL/d (0.32 m^3/kg of VS added) was achieved during the last week of operation. The temperature fluctuated in between 33 and 36°C except for 3 days due to disruption of power supply. During that period, the ambient temperature varied from 26 to 31°C. It appears that the temporary drop of the ambient temperature about 7°C for 3 days had no effect on the gas production. The pH varied in the range of 7.1 – 7.6 indicating favorable condition for biogas production.

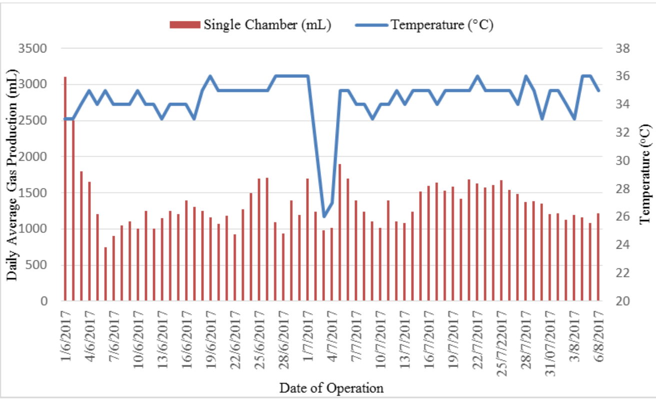

Fig. 4. Variations in temperature and daily gas production with time in the single chamber reactor.

The variations in gas generation in the inlet chamber and outlet chamber of the double chamber reactor and the ambient temperature with days of operation are depicted in Fig. 5. From this Fig., it is seen that huge amount of gas was produced in the 1st day in the inlet chamber compared to that of the outlet chamber. In general, high fluctuation in the gas generation was observed in both chambers, but the fluctuation was more prominent in the outlet chamber and the gas generation was more or less stable in the inlet chamber for the last six days of operation. Variable amount of substrate transfer through the interconnector was the main reason for the high fluctuation in the gas generation in each chamber. The temperature varied between 33 and 36°C except low values (26 to 31°C) for 3 days due to disruption of power supply. It apperas that the drop of the ambient temperature about 7°C for a few days did not affect the gas generation. Fig. 6 presents the comparison between the daily total gas production in the single chamber reactor and the double chamber reactor. It is found that gas generation in the double chamber reactor was generally much higher compared to that of the single chamber reactor for the first 23 days of operation. After that the gas generation pattern wasgenerally reversed and the stabilized gas generation was 1200 mL/d (0.32 m^3/kg of VS, 0.60m^3/m^3/d) for single chamber reactor and 950 mL/d (0.25 m^3/kg of VS; 0.48 m^3/m^3/d) for the double chamber reactor during the last 7 days of operation at the OLR of 1.89g VS/L.d. Improper transfer of susbtrate through the interconnector was probably the reason of lower volume of gas generation in case of the double chamber reactor compared to the single chamber reactor. No advantage was gained by using the double chamber reactor compared to the single chamber reactor.Velmurugan & Ramanujam studied anaerobic digestion of vegetable wastes in a fed-batch reactor with a HRT of 30 days and an OLR of 2.25 g/L.d [8] and found the biogas yield as 0.59 L/g VS added. They also reported methane yield in the range of 0.15-0.732 L/ g VS added for vegetable, fruit and mixture of fruit and vegetable wastes. Bouallegui et al. [9] conducted batch studies using fruit and vegetable wastes, and obtained the methane generation rate as 0.16 m^3/kg of VS added for OLR of 1.06 having HRT of 47 days and 0.26 m^3/kg of VS added for OLR of 0.9 g VS/L/d with HRT of 32 days.

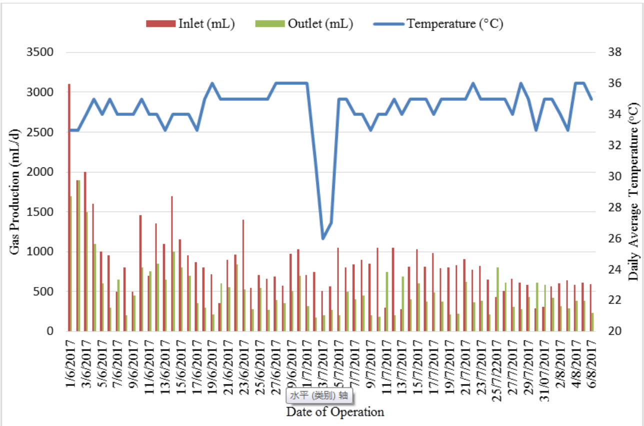

Fig. 5. Variation in temperature and daily gas production in inlet and outlet chambers with time.

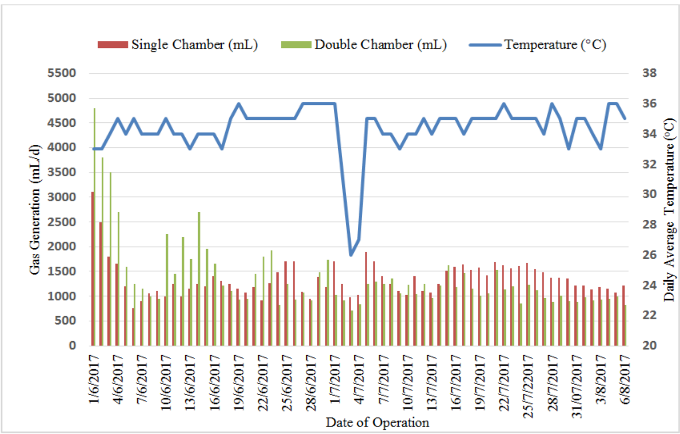

Fig. 6. Comparison of daily gas production between the single chamber and the double chamber reactors with time.

For vegetable wastes Babaee and Shaygen [10] obtained biogas production rate from 0.30 to 0.47 m^3/kg of VS added for OLR from 1.4 to 2.75 g VS/L.d with HRT of 25 days in case of daily feed reactor. They also reported biogas generation rate of 0.26-0.47 m^3/kg of VS added for OLR in the range of 0.30-1.6 g VS/L/d for fruit & vegetable waste and municipal solid wastes from literature review. Sridevi *et al.* [11] conducted daily feed two phase studies (acidogenic, HRT=2 days and methanogenic, HRT=15-25 days) with OLR varying from 1.50-4.50 g VS/L.d and found biogas production in the range of 0.24-0.72 m^3/kg of VS added. Patil and Deshmukh [12] reviewed past literature on biogas yield from mixture of vegetable wastes and found it in the range of 0.36–0.90 m^3/kg of VS added. In case of batch reactors, Jalil *et al.* [13] reported average biogas generation rate of 0.27 and 0.39 m^3/kg of VS input for OLR of 0.83 and 1.24 g VS/L.d respectively for 40 days HRT for a market wastes. For the same HRT, they found the stable rate of biogas producton as 0.24 and 0.30 m^3/kg of VS added for single chamber reactor (OLR=1.18 g VS/L/d) and the double chamber reactor (OLR=0.96 g VS/L/d) respectively. For the market wastes of the present paper, Jalil *et al.* [14] obtained the stable biogas generation as 0.22 and 0.26 m^3/kg of VS added for single chamber reactor and double chamber reactor respectively for OLR of 1.42 g VS/L.d and 40 days HRT. The results of the present study are generally in good agreement with the data obtained from the past studies.

4. Conclusion

Based on the results of the present study, the following conclusions can be made:

- About 48% of the wastes generated in the market were easily biodegradable. Cow dung, cauliflower stick, dry paddy straw, banana leaves, papaya, and potato were the major easily biodegradable wastes.
- The TS and SS contents of the easily biodegradable portion of the market wastes were 18.90% and 15.10% respectively.
- Under daily feed condition at favorable temperature, the stable biogas generation rate was 0.32 m^3/kg of VS added and 0.25 m^3/kg of VS added for single chamber reactor and double chamber reactor respectively for OLR of 1.89 g VS/L.d and 40 days HRT. Drop of operating temperature by a few degree centigrade for a few days did not affect the rate of biogas generation.
- The performance of the single chamber reactor was better than that of the double chamber reactor.

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