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Investigation of Biogas Generation from the Waste of a Vegetable and Cattle Market of Bangladesh

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Abstract

The results of a study on the type and quantity of solid wastes generated in a rural vegetable and cattle market, and biogas generation from the waste are presented in this paper. The market wastes were collected; individual items were separated and measured on both normal days and haat days. During a normal day, it was found that very insignificant amount of waste was generated. But on a haat day, a large amount of wastes was found to be generated. On average, the amount of easily biodegradable waste was 589 kg out of the total waste of 1004 kg on a haat day. Cow dung, fish waste, ginger, cursed lobe, guava, and banana leaf were the major biodegradable wastes. Other biodegradable wastes were goat dropping, bitter melon, pointed gourd, dhundul and brinjal. The total solids (TS) and volatile solids (VS) of the biodegradable portion of the market waste were determined and were found to be 17.94% and 13.87% respectively. Laboratory experiments were run in order to generate biogas in anaerobic digesters using the same composition of the market waste. They were placed in a large closed chamber and room heaters were used to maintain the temperature of the chamber at a constant value. Two types of experiments (batch and daily feed) were carried out in two phases. In the first phase of the experiments, 500 g and 750 g waste were added in 2.5 L digesters separately and inoculum was added to make the effective volume of 2.1 L for each digester. The experiments were operated for 46 days (hydraulic retention time – HRT) and the average temperature was found to be 34.7°C. In the second phase of the experiments, one single chamber reactor was initially fed with 750 g waste having the effective volume of 2.2 L. Another double chamber (two digesters connected in series) reactor was initially fed with 750 g waste having the effective volume of 2.7 L. Then a mixture of daily feed of 18.75 g waste and required volume of water was fed after dispensing equal volume of slurry from the reactor. The experiments were run for 40 days and the average temperature was 35.1°C. The results of the 1st phase of experiments revealed that the daily biogas generation rate was 0.273 and 0.389 m³/kg of VS added for the organic loading rate (OLR) of 0.83 and 1.24 g VS/L/d respectively for 40 days retention time. The results of the 2nd phase of experments revealed that for HRT of 40 days, the rate of biogas producton was 0.244 and 0.30 m³/kg of VS added for the single chamber reactor (OLR=1.18 g VS/L/d) and the double chamber reactor (OLR=0.96 g VS/L/d) respectively.

Keywords: Anaerobic digestion; Biodegradable waste; Biogas; Hydraulic retention time; Single chamber reactor; Double chamber reactor

Introduction

In Bangladesh, the collection and disposal of solid wastes of markets (bazaars) are done haphazardly. The practice mainly includes accumulation of solid wastes at different locations of a market by sweepers/cleaners irregularly, then loading the wastes in wheelbarrow or rickshaw van, and dumping the wastes on nearby road side/open area or into khal/river causing public annoyance and environmental pollution. This practice is aesthetically displeasing, and possesses a great threat to the environment by emitting greenhouse gases, polluting soil, surface water and groundwater, producing odorous gases and blocking the drains. When disposed on lands and waste dumps become dry, these are burnt to reduce the volume. The burning generates smokes and particulate matters polluting the surrounding air. A better waste collection, treatment and disposal system is necessary to improve the overall environment of a market. Waste reduction, reuse, recover, recycling and ultimate disposal of residual wastes are the key elements of an effective solid waste management plan. To improve the quality of life, the consumption of energy has been increasing rapidly worldwide causing high rate of depletion of fossil fuel. The use of fossil fuel as the primary source of energy has led to global warming and environmental pollution. In this backdrop, alternative sources of energy (water, sun light, biomass, wind etc.) have become the focus of attention worldwide. Energy recovery from solid wastes is gaining importance day by day. There are many technologies for producing energy from solid wastes such as anaerobic digestion, incineration, co-incineration

and refuse derived fuel [1]. Among them anaerobic digestion has become a promising technology particularly for recovery of energy from biodegradable organics. Anaerobic digestion of market wastes is a potential environment friendly technique which produces energy in the form of biogas [2-8] and the residue can also be used as fertilizer. Biogas is gaining popularity as a substitute for other fuels to save energy and to protect the environment. Successful dissemination of domestic biogas technology has occurred worldwide in countries where governments and institutions are involved in the subsidy system, in planning, design, construction, operation and maintenance of biogas plants. Several countries in Asia - China, India and Bangladesh particularly, have launched large-scale campaigns to popularize biogas technology. 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 [9,10]. Till April 2016, IDCOL has financed construction of over 42,800 biogas plants all over the country through its 43 partner organizations. It has a plan to install 60,000 biogas plants in Bangladesh by 2018. In recent years, community based biogas plants operated on kitchen waste have been established at Jahangirnagar University campus, Savar, Dhaka and Gaibandha Municipality with encouraging results [11,12]. 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 [10]. 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 the paper have undertaken a research project on solid waste management of rural markets of Bangladesh. As a part of the project, investigation on the type and quantity of solid wastes produced in a vegetable and cattle market was carried out, and the biogas generation from the wastes was quantified through laboratory scale reactors. This paper presents the results of the investigation.

Anaerobic Digestion Process

A consortium of microorganisms working synergistically accomplishes the anaerobic digestion of organic matter in the absence of oxygen with ultimate products being carbon dioxide and methane. The general process of anaerobic digestion is a series of four metabolic processes like enzymatic hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Figure 1) and each metabolic stage is assisted by a series of microorganisms. A brief description of the processes is given below.

1. First, large protein macromolecules, fats and carbohydrate polymers (such as cellulose, hemicellulose, starch, pectin, and lignin) are broken down through hydrolysis by extracellular enzymes to amino acids, long-chain fatty acids, and sugars before being taken up by acidogenic bacteria. The rate of hydrolysis is a function of pH, temperature, composition, particle size of the substrate and concentrations of intermediate products [13].

2. After that, soluble organic components including the products of hydrolysis are fermented to form three, four, and five-carbon volatile fatty acids (such as lactic, butyric, propionic, and valeric acid), alcohols, hydrogen, and carbon dioxide by acidogens.

3. In acetogenesis, bacteria consume these fermentation products and generate acetic acid, carbon dioxide, and hydrogen.

4. Finally, methane is produced by methanogenic bacteria from the acetic acid, hydrogen, and some of the carbon dioxide as well as directly from other substrates of which formic acid and methanol are the most important [13]. Three biochemical pathways are used by methanogens to produce methane gas. The pathways along with the stoichiometries of the overall chemical reactions are:

a. Acetotrophic methanogenesis: $CH_3COOH \rightarrow CO_2 + CH_4$

b. Hydrogenotrophic methanogenesis: $CO_2 + 4 H_2 \rightarrow CH_4 + 2 H_2O$

c. Methylotrophic methanogenesis: $4 CH_3OH + 6 H_2 \rightarrow 3 CH_4 + 2 H_2O$

Methanol is shown as the substrate for the methylotrophic pathway, although other methylated substrates can be converted. Sugars and sugar-containing polymers such as starch and cellulose yield one mole of acetate per mole of sugar degraded. Since acetotrophic methanogenesis is the primary pathway used, theoretical yield calculations are often made using this pathway alone. From the stoichiometry above, it can be seen that the biogas produced would theoretically contain 50 percent methane and 50 percent carbon dioxide. However, acetogenesis typically produces some hydrogen, and for every four moles of hydrogen consumed by hydrogenotrophic methanogens, a mole of carbon dioxide is converted to methane. Substrates other than sugar, such as fats and proteins, can yield larger amounts of hydrogen and acetate can be biochemical substrates for a number of other products as well. Therefore, the overall biogas yield and methane content will vary for different substrates, biological consortia and digester conditions. Typically, the methane content of biogas ranges from 40-70 percent (by volume).

For healthy methanogenesis to occur, anaerobic conditions are essential. The digesters used must be well sealed which allows the biogas to be collected for energy conversion and eliminates methane and carbon dioxide emissions during the anaerobic digestion process. In addition to methane and carbon dioxide, small amount of hydrogen sulfide and ammonia are produced. The most important nutrients for bacteria are carbon and nitrogen, and must be provided in the proper ratio. Otherwise, ammonia can build up to levels that can inhibit the microorganisms.

In general, the optimal conditions for anaerobic digestion of organic matter are near-neutral pH, constant temperature (thermophilic or mesophilic), and a relatively consistent feeding rate. Imbalances among the different microorganisms can develop if conditions are not maintained near optimum. Imbalances occur if too much feed is added, if inhibitory compounds accumulate, or if the feed stream lacks natural pH buffers. Solid concentrations higher than about 40 percent total solids can also result in process inhibition, likely due to the reduced contact area available to the microorganisms. Higher temperatures result in faster reaction kinetics. However, the microorganisms themselves are adapted to relatively narrow temperature ranges. Mesophilic and thermophilic microbes are adapted to roughly 30-40°C and 50-60°C respectively.
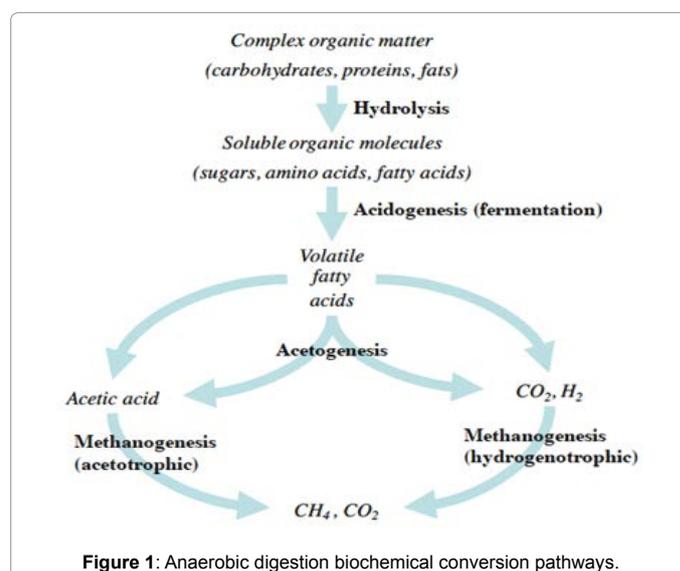

Figure 1: Anaerobic digestion biochemical conversion pathways.

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 [14]. The overall results are nearly complete conversion of the anaerobically biodegradable organic matter into end products like methane, carbon dioxide, hydrogen sulfide and ammonia.

Materials and Methods

Selected market and composition of waste

Madbarer Char bazaar (a large size market) of Shibchar upazila of Madaripur district of Bangladesh was selected for the study. It consists of both permanent and temporary shops (about 1500 nos.) including open spaces for cattle and goat market. This market is usually functional twice a week – on haat days (Sunday and Thursday). On Thursday, the haat is usually the largest. Cows and goats are sold only on that day. Large amount of vegetables are sold on both Sunday and Thursday. Twenty restaurants are operated only on the haat days and 7-8 tea stalls serve on other days of the week. On non-haat days, milk, fishes and very limited amount of vegetables are sold. Not much commodities are sold on other five days of the week.

Two labors were appointed to collect, separate, store and measure the wastes on two consecutive haat days. They collected all the wastes produced in a whole day and separated each item and kept them in different sacks. Figure 2 shows collection of wastes by two labors in a plastic bucket. The amount of individual item was measured using an electronic weighing scale after the hat was over. The composition of the wastes is shown in Table 1. From Table 1, it is found that the amount of wastes generated on Thursday was about 25% greater than those on Sunday. On the haat day, the average amount of easily biodegradable waste was found to be 644 kg out of the total waste of 1054 kg. About 61% of the waste generated was biodegradable. Cow dung, fish waste, ginger, cursed lobe, guava, and banana leaf were the major biodegradable wastes. Goat droppings, bitter melon, brinjal, dhundul, and pointed gourd were the minor biodegradable wastes.

Experimental setup

In order to generate basic data on biogas generation, experiments were run in two phases. In the first phase, batch reactors were operated and in the second phase, daily feed reactors were operated. The same composition of the easily biodegradable portion of the market waste was used in both the phases. Daily average composition of the biodegradable wastes was determined on the basis of the average waste generation on the haat days per week. Experiments were conducted using this daily average composition. At the onset of the experiments, the TS (Total solids) and VS (Volatile Solids) of the biodegradable wastes were determined. The biodegradable wastes were cut into small pieces (maximum dimension of 4 mm) before feeding a reactor (anaerobic digester). A glass bottle of 2.5 liter capacity was used as batch reactor for biogas generation. Two batch reactors were set up in the Environmental Engineering Laboratory of BUET in the first phase of the experiments. The effluent of the biogas plant of Jahangirnagar University was used as the liquid of the digester to ensure the abundance of active microbes for biogas generation. The digester was placed in a closed chamber made of Thai Aluminium and two electrical room heaters were placed inside the chamber to maintain a constant temperature. The heaters were operated alternatively. Biogas was collected in a gas holder using water displacement method. The experimental setup is shown in Figure 3. In the second phase of the experiments, two daily feed reactors - one

Figure 2: Collection of wastes from matbarer char market.

Sl. No.	Item	Quantity of Waste Generated on Thursday (kg)	Quantity of Waste Generated on Sunday (kg)
1	Cursed lobe	50	38
2	Bitter melon	9	7.5
3	Brinjal	5	5.5
4	Lemon	7.2	8
5	Pointed gourd	6.3	5
6	Dhundul	6.3	5.5
7	Garlic and onion peel	45	48
8	Ginger	163	148
9	Guava	41	35
11	Banana leaf	30	32
12	Fruit branch of banana tree	137	110
13	Crown of pine apple	18.5	12
14	Other leaves	56	63
15	Cow dung	200	90
16	Fish waste	150	120
17	Coconut peel	234	200
18	Goat droppings	15	7
	Total	**1173 kg**	**935 kg**
	Biodegradable Portion	**731 kg**	**557 kg**

Table 1: Composition of solid wastes generated in matbarer char market during haat days.

single chamber reactor and one double chamber reactor (two reactors connected in series) were set up in the Environmental Engineering Laboratory of BUET. A plastic container fitted with an inlet tube at the mid height and an outlet tube near bottom on the opposite side of the container was used as the single chamber reactor. Two plastic containers were connected with a tube near the bottom and an inlet tube was fitted to the first container at the middle while an outlet tube was attached near the bottom of the second container to make the double chamber reactor. Other arrangements were the same as those in the first phase of the experiments. The experimental setups are shown in Figure 4.

Operation of anaerobic digesters

In the first phase, the experiments were started on the 18th August, 2016 and ended on the 2nd October, 2016 (total 45 days of operation).
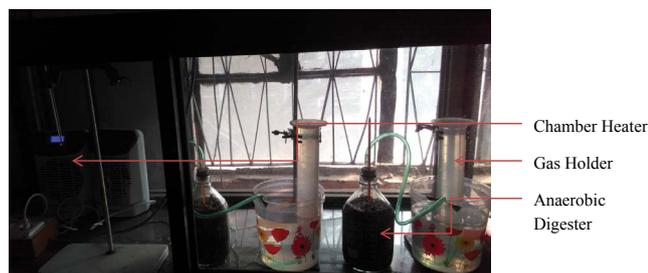
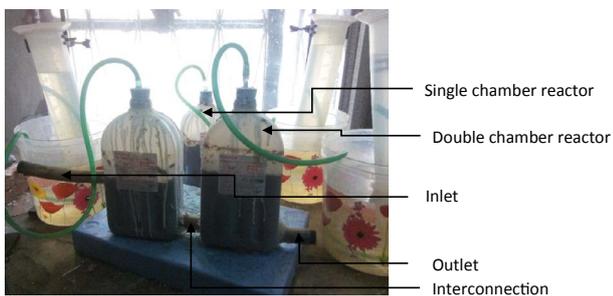**Figure 3:** Setup of batch reactors in environmental engineering laboratory.

Figure 4: Setup of daily feed reactors in environmental engineering laboratory.

In this phase, 500 g and 750 g of the waste were added in two 2.5 L digesters separately and the amount of liquid added was 1500 mL for 500 g waste and 1400 mL for 750 g waste to make the effective volume of 2.1 L. The temperature of the chamber and the volume of gas generation were recorded daily during the experiments. The pH of the contents of the digesters was sometimes measured. Gas leakage from the digester was sometimes not realized, and when this problem was understood/ encountered, remedial measures were taken immediately. The experiments of the second phase were started on the 25th October, 2016 and ended on the 18th December, 2016 (total 53 days of operation). In the single chamber reactor, 750 g waste and 1500 mL inoculum were added at the start of the experiment. Each container of the double chamber reactor was loaded with 375 g waste and 1000 mL inoculum at the beginning of the experiment. The data of the 1st phase experiments revealed that the optimum retention time was 40 days. Hence, 18.75 g of waste was mixed with 37.5 mL of water to prepare the daily feed for the single chamber reactor. From the 2nd day of the operation, this mixture was fed at a time every day through the inlet of the reactor after taking out 55 mL slurry from the reactor through the outlet. For the double chamber reactor, the daily feed consisted of a mixture of 18.75g waste and 50 mL water. The first chamber of the reactor was fed daily with this mixture once after taking out 67.5 mL slurry from the second chamber. The temperature within the Thai Aluminum chamber and the volume of gas generation of each reactor were recorded daily during the experiments. On the 3rd December, 2016, the heater was out of order and the experiments were continued at the ambient temperature up to the end.

Methods of measurement

The biogas generated was measured daily by water displacement method using an inverted measuring cylinder filled with water and placed in a water jar. The inverted cylinder was refilled as and when needed. The temperature within the closed Thai Aluminum chamber was measured by a thermometer. The temperature was also displayed

on the heater. The TS and VS of the wastes, and pH of the content of the reactor were determined according to the APHA Standard Methods [15].

Results and Discussion

The TS and VS of the biodegradable portion of the market waste were found to be 17.94% and 13.87% respectively. The batch experiments of the 1st phase were run for 46 days with 500 g and 750 g waste in two reactors. The variation in the quantity of daily gas production in the reactors and the daily average temperature within the Thai Aluminum chamber with time are shown in Figure 5. The results of the 1st set of experiments reveal that for each digester, the gas production per day was very high during the initial few days of operation and then fluctuated for the remaining days. The relatively high quantity of gas production in each digester during the initial few days can be attributed to the biodegradable organic matter of the added liquid and the amount of readily biodegradable organic matter (cow dung) added to the digester. Variability in the biodegradation processes of the components of the waste was the main reason for fluctuation in the daily gas production. After the first three days, the variation in daily gas production was small for 750 g waste up to about 39 days of operation and then gas production reduced to low values in general. But the daily gas production reduced to low values for 7 days after the initial high values. Undetected leakage and gas collection problem might be the reasons of this poor performance. Then the daily gas production increased significantly for 9 days. After about 20 days of operation, the daily gas production of 500 g waste was low and the fluctuation was insignificant. The highest gas production per day was 1700 mL for 500g waste, and 3100 mL for 750 g waste. The daily average temperature varied from 32-36°C and it is revealed that this small variation in the temperature has no effect on the rate of gas generation. The pH of the reactors was measured at the end of the experiments and was found to be 7.6 for 500 g waste and 7.7 for 750 g waste indicating favorable condition for microorganisms. It can be assumed that the pH was in favorable range judging the rate of the gas production throughout the experiments.

The cumulative gas production with time curves for the digesters are shown in Figure 6. The nature of the curve for 750 g waste appears to be reasonable. Although the curve for 500 g waste appears reasonable for the first 3 days corresponding to generation of high amount of biogas, later the production rate reduced abruptly – the reason appears to be gas leakage from the digester which could not be detected. Additional sealing of the reactor was done and the rate of gas production increased
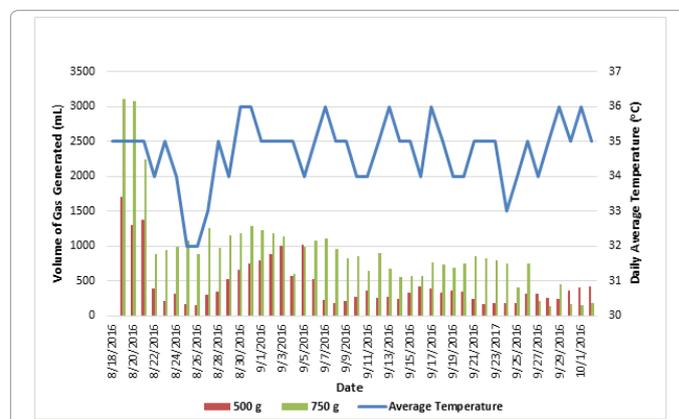

Figure 5: Variation in daily gas production and temperature in the first phase of experiments.

which is reflected in the nature of the curve. The total gas production for 45 days of operation was about 20.6 L for 500 g waste and 41.6 L for 750 g waste. It reveals that this higher waste concentration was more favorable for biogas generation.

The experiments of the second phase were operated on daily feed basis with 750 g waste as initial substrate and run for 53 days. The variation of the daily gas production in each system (single chamber and double chamber) with time and the daily average temperature with time are depicted in Figure 7. From the results of the 2nd phase of experiments, it is observed that the gas production per day was very high during the first two to three days owing to availability of high amount of easily biodegradable organic matter (cow dung). Then a sharp drop was noticed in the daily gas production and it fluctuated for 10 to 11 days. After that a more or less stable condition was obtained and continued as long as the average daily temperature was within 32–38°C. When the temperature dropped suddenly to 22-25°C, the daily gas production rapidly decreased to low values. Sudden drop of the closed chamber's temperature came as a shock to the microorganisms resulting in slow down of their metabolic activity greatly and the gas production was negligible. It should be noticed that the daily gas production was generally higher for double chamber in comparison with that of the single chamber. Greater retention time and prevention of short circuiting of daily added feed are the reasons for the higher rate of gas generation. Under favorable conditions, the average daily gas production was 635 mL for single chamber and 780 mL for double chamber. About 23 percent higher gas production was achieved under stable condition. The cumulative gas generation in the single chamber and double chamber with days of operation is presented in Figure 8. In general, the trend of the curves appears to be reasonable. The initial part of the curves is steeper and then the slope decreases up to 13 days of operation. After that both the curves become straight lines revealing stable rate of gas generation up to 40 days of operation. The slopes of the straight lines are different – higher value for double chamber and lower value for single chamber. Then the slope of each curve decreases due to sudden drop of the temperature within the closed chamber. The cumulative gas production for 40 days was 39.1 L for

single chamber and 44.6 L for double chamber. Based on the data of the batch reactors presented in this paper, it is found that for 40 days of hydraulic retention time (HRT), the daily average biogas generation per unit volume of the reactors were 0.225 and 0.482 m^3/m^3 for organic loading rate (OLR) of 0.83 and 1.24 g VS/L/d respectively. The corresponding rates of biogas producton were 0.273 and 0.389 $m^3/$kg of VS added. For the daily feed reactors having HRT of 40 days, the stable rate of daily biogas generation per unit reactor volume was 0.289 m^3/m^3 for both the single chamber and double chamber reactors. The stable rates of biogas production were 0.244 and 0.30 m^3/kg of VS added for the single chamber reactor (OLR=1.18 g VS/L/d) and the double chamber reactor (OLR=0.96 g VS/L/d) respectively. The double chamber reactor was more productive than the single chamber reactor because short circuiting of fresh feed could not occur in case of the double chamber reactor. For batch studies, Bouallegui et al. [4] reported biogas generation rate of 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. In case of daily feed reactor, Babaee and Shaygen [6] obtained biogas generation rate in the range of 0.30 – 0.47 m^3/kg of VS added for vegetable wastes with OLR in the range 1.4-2.75 g VS/L/d with HRT of 25 days. They also reported biogas generation rate of 0.26-0.47 m^3/kg of VS added for OLR in the range of 0.3-1.6 g VS/L/d for fruit and vegetable waste and municipal solid wastes from literature. Sridevi et al. [7] conducted daily feed two phase studies (acidogenic, HRT=2 days and methanogenic, HRT=15-25 days) with OLR varying from 1.5-4.5 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 [8] reported the biogas yield from a mixture of vegetable wastes in the range of 0.36–0.90 m^3/kg of VS added from literature. The results obtained from the present study agree well with those reported in the literature.

Conclusion

The composition of a rural market wastes was determined and experimental investigation of biogas production from the biodegradable portion of the market wastes was conducted using batch reactors and daily feed reactors. Based on the results of the study, the following conclusions can be made:
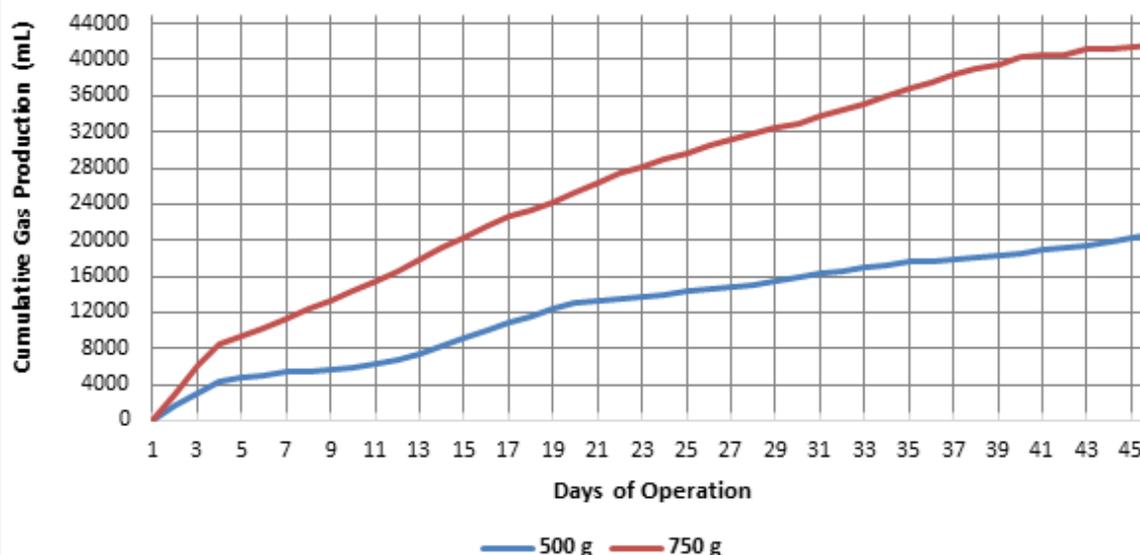

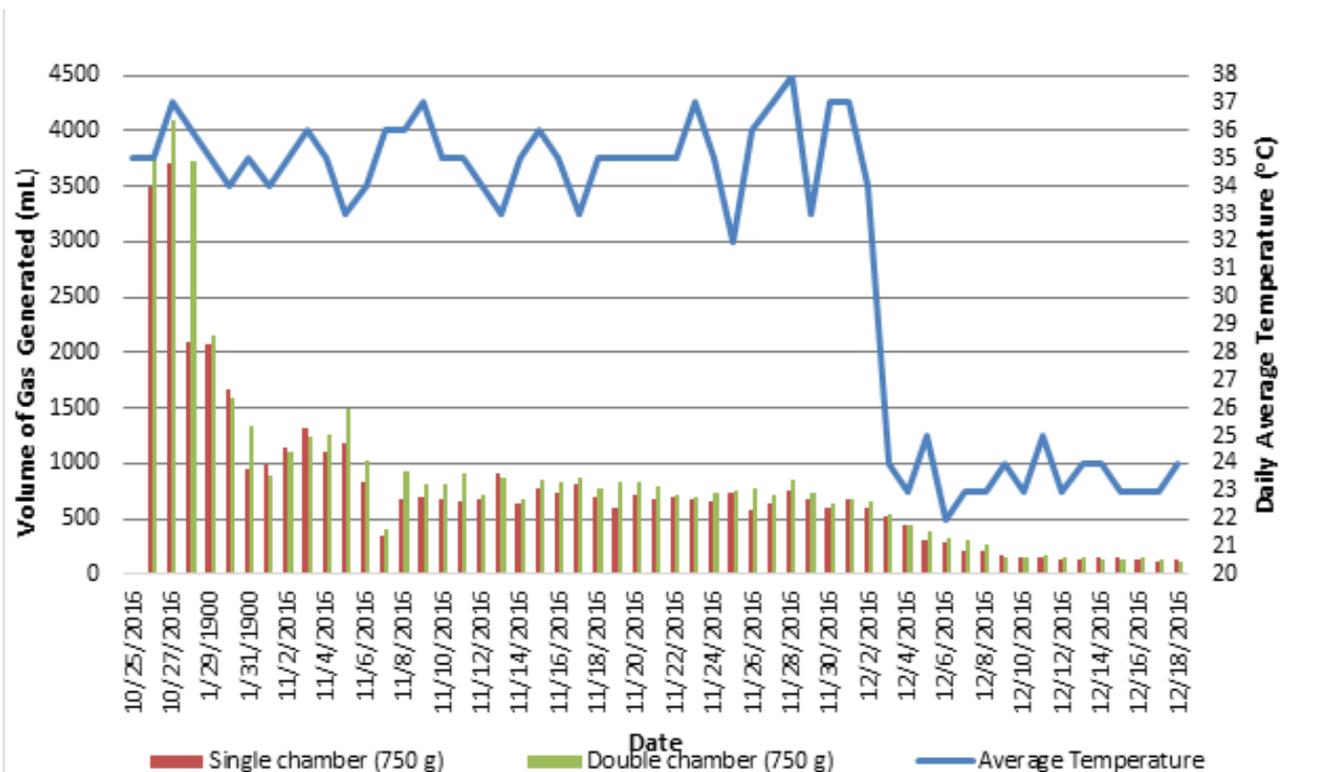**Figure 6:** Cumulative gas production with time during the first set of experiments.

Figure 7: Variation in temperature and daily gas production in the second set of experiments.
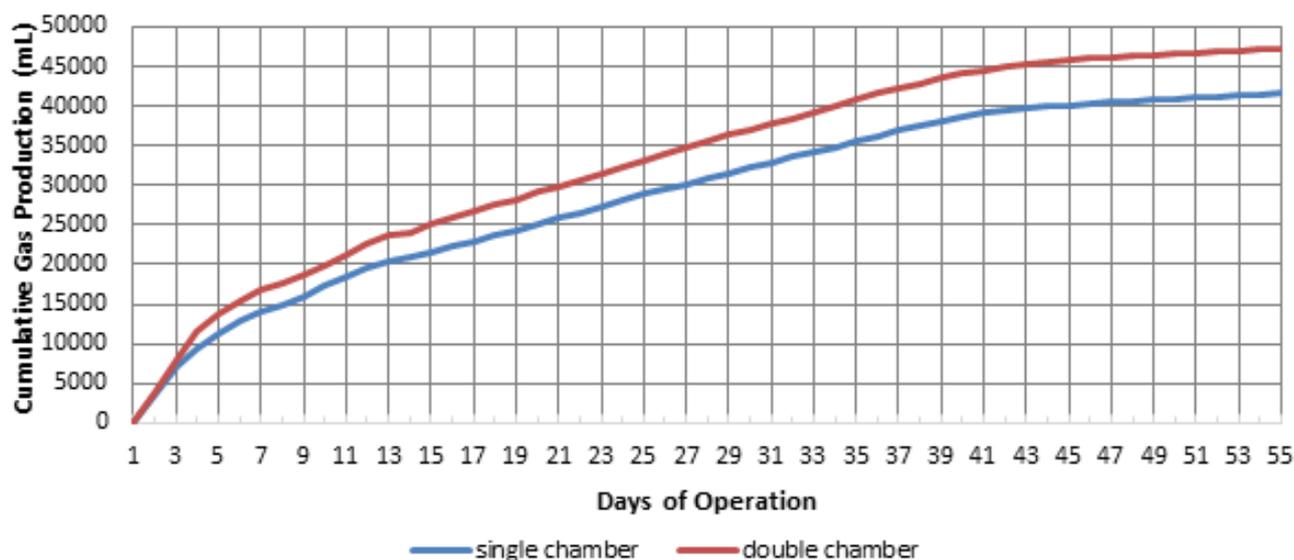

Figure 8: Cumulative biogas production during the second phase of experiments.

1. About 61% of the waste generated in the market was biodegradable. Cow dung, fish waste, ginger, cursed lobe, guava, and banana leaf were the major biodegradable wastes.

2. The TS and SS contents of the biodegradable portion of the market wastes were 17.94% and 13.87% respectively.

3. The average biogas generation rate was 0.273 and 0.389 m³/kg of VS added for OLR of 0.83 and 1.24 gVS/L/d respectively for 40 days HRT in case of batch reactors.

4. For HRT of 40 days the rate of biogas production was 0.244 and 0.30 m³/kg of VS added for the single chamber reactor (OLR=1.18 g VS/L/d) and the double chamber reactor (OLR=0.96 g VS/L/d) respectively.

5. Leakage of anaerobic reactors must not occur to obtain accurate data on biogas generation.

Acknowledgement

References

1. Sultan Z (2015) Waste to energy-solution for tomorrow's energy.

2. Mata AJ, Cecchi F, Ilabres P, Pavan P (1992) Anaerobic digestion of the Barcelona central food market organic wastes: plant design and feasibility study. Bioresour Technol 42: 33-43.

3. Gunaselan NV (1997) Anaerobic digestion of biomass for methane production: A review. Biomass and Bioenergy 13: 83-11.

4. Boullagui H, BenCheikh R, Cheikh RB, Hamdi M (2005) Bioreactor performance in anaerobic digestion of fruit and vegetable wastes. Process Biochemistry 40: 989-995.

5. Boullagui H, Touhami Y, Marouani L, Hamdi M (2003) Mesophilic biogas production from fruit and vegetable waste in tubular digester. Bioresour Technol 86: 85-90.

6. Babaee A, Shayegan J (2011) Effect of organic loading rates (OLR) on production of methane from anaerobic digestion of vegetable waste, Linköping-Sweden.

7. Sridevi VD, Rema T, Srinivasan SV (2015) Studies on biogas production from vegetable market wastes in a two-phase anaerobic digester. Clean Techn Environ Policy 17: 1689-1697.

8. Patil VS, Deshmukh HV (2015) Anaerobic digestion of vegetable waste for biogas generation. Int Res J Environ Sci 4: 80-83.

9. http://www.idcol.org/notice/86e1c7700f88b15452435d90c762ec68.pdf

10. Hamid MR, Haque MN, Rouf MA, Islam MS (2013) Dissemination of domestic biogas plants in Bangladesh - current state, problems faced and barriers. International Journal of Scientific & Engineering Research 4: 1-4.

11. No Authors Listed (2016) Personal Communication with Dr. Khabir Uddin on Installation of Biogas Digester for Disposing Solid Waste and Piloting of Waste Collection System at Jahangirnagar University, Savar, Dhaka, Bangladesh.

12. No Authors Listed (2012) Waste to Biogas -The natural choice for the future, Progress Report, 2012. Practical Action Bangladesh, Dhaka.

13. Veeken BA, Kalyuzhnyi S, Scharff H, Hamelers B (2000) Effect of pH and VFA on hydrolysis of organic solid waste. J Environ Engg 126: 1076-81.

14. Kubler H, Hppenheidt K, Hirsch P, Cottar A, Nimmrichter R, et al. (2000) Full scale co-digestion of organic waste. Water Sci Technol 41: 195-202.

15. APHA (1998) Standard methods for the examination of water and wastewater. American Public Health Association, Washington DC.