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Augmentation of Biogas Production Efficiency Under Different Feeding Interval of Waste Products

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ABSTRACT

Biogas originates from bacteria in the process of biological breakdown of organic material under anaerobic conditions. Biogas can be produced from biodegradable substrates such as agricultural waste, cow dung, municipal waste, plant material, sewage, green waste or food waste. The study was conducted to augment biogas production efficiency under different feeding interval. The objectives were measured biogas production, estimate major components (Ambient Temperature, pH, CH_4, CO_2), measure the biogas production efficiency under different ambient temperature and pH. Two digesters were installed to digest cow dung, where one set-up was used for digestion of cow dung by regular feeding and other set-up was used for digestion by 4-day interval feeding. The digester was made up of PVC of 7.5 m^3 capacity while gas holding capacity was 2 m^3. 50kg cow dung and 50 L water was used at 1:1 ratio for regular feeding. In 4-day interval, 200 kg cow dung and 200 L water was used at 1:1 ratio. The digesters were operated at ambient temperature 25-35^{0}C. The pH ranges from 6.5-7.5. The ambient temperature and pH maintained good range for gas production. The overall biogas yield for feeding in 4-day interval was 34% higher compared to regular feeding as well as there was a significant difference from regular feeding. The methane yield was 28% more in 4-day interval feeding. 48 kg of cow dung would be necessary to produce 1 m^3 of biogas in praxis as usual and 32 kg feeding in 4-day interval. In both setups, the digesters could produce enough biogas to cover daily theoretical demand (0.8-1.6 m^3) for preparing 2 meals for the average family size in Bangladesh.

Introduction

Biogas, as a renewable energy source, is gaining importance in today's era of global warming and depleting sources of fossil fuels. Biogas is produced by anaerobic digestion (digestion in the absence of oxygen) of organic material which can be available from various wastes such as agro industrial waste, urban and rural wastes, human and animal waste and aquatic plants (Gutiérrez *et al.,* 2017). According to national and international policies in order to protect environment regarding renewable sources of energy, biogas is one of the best alternatives to reduce waste and pollution and getting energy (Mcdonald, 2008). Other benefits are improving waste management (for manure wastes) for forest health, timber stand improvement or implementation of best manure management practice, reducing odor and flies for livestock operation, improving local air quality by reducing emissions of volatile organic compounds (VOCs), producing steady revenue source for the developer through electricity sales lease agreements for farmers, co-producing heat and other value-added products for new agricultural markets such as fertilizer or soil amendment from biochar or digestate, promote economic development by creating jobs and tax revenues, economically revitalizing agriculture and rural communities, improving local grid support, reducing catastrophic wildfires for urban and forest interface, improve forest health, watershed and timber stand, reduce costs of forest management, reduce risks and improve public health and safety (Yebo *et al.,* 2011; Zerihum, 2015).

Bangladesh especially rural villager is facing severe energy crises due to increase in population, inadequate development of energy infrastructure, lack of power generation and high investment cost etc. In that context, biogas technology is one of the best means can provide gas to the largest number of rural people. Despite of

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huge potential of local feed stocks, only few numbers of biogas plants have been deployed till date in Bangladesh (Kabir *et. al*., 2013). Besides, most of these plants (mostly fixed dome type) are unable to produce the expected amount of biogas as most of the digesters of these plants are made locally and they don't have any scheme for monitoring and controlling of operating conditions (like temperature, pH, bacterial population in digester, mixture of different substrate, hydraulic retention time, total solid (TS), periodic agitation, periodic loading and unloading of substrate etc.) (Demirbasa and Balat, 2009). A plenty of substrates for biogas production are available in Bangladesh. Cowdung is being major practiced substrates in Bangladesh, Apart from Cowdung, any biodegradable components: kitchen waste, agricultural waste, food waste, marketed organic waste can also be used as co-substrates for biogas production. These substrates used in the biogas digester can reduce the CH4 and CO2 emission. So generation of energy from the alternative sources has become the crying need for Bangladesh. In this study, an analysis has done focusing the impacts of different factors by producing biogas by PVC digester under different feeding interval. Daniel *et al*. (2016) found that a larger amount of biogas was produced after feeding in the reactors fed less frequently (once per day and every second day), whereas the amount remained constant in the reactor fed more frequently (every 2 h), indicating the suitability of the former for the flexible production of biogas.

The specific objectives of this study are to: (i) measure biogas production under different feeding condition; and (ii) measure the biogas production efficiency under different temperature and pH.

Materials and Methods

Experimental site and period

The experiment was conducted in the Animal Research Farm under the Department of Surgery & Obstetrics as well as Livestock and Poultry Vaccine Research and Production Center under Department of Microbiology & Hygiene of Bangladesh Agricultural University, Mymensingh. The experiment was designed in February, 2017. Experiment set up and data were collected during April, 2017 to August, 2017. The schematic diagram of the experimental procedure is presented in Fig. 1.

Experimental design

The experiment was designed to augment biogas production efficiency under different feeding interval. Two different feeding intervals were designed to compare the production efficiency of biogas.

Preparation of biogas plant

Two 7.5 m^3 PVC digesters imported from China were set up on 2 February 2017 with gas holding capacity of 2 m^3. Plastic pipe was used as inlet and water tank was used as outlet. PVC digester is rather flexible to maintain the gas production.

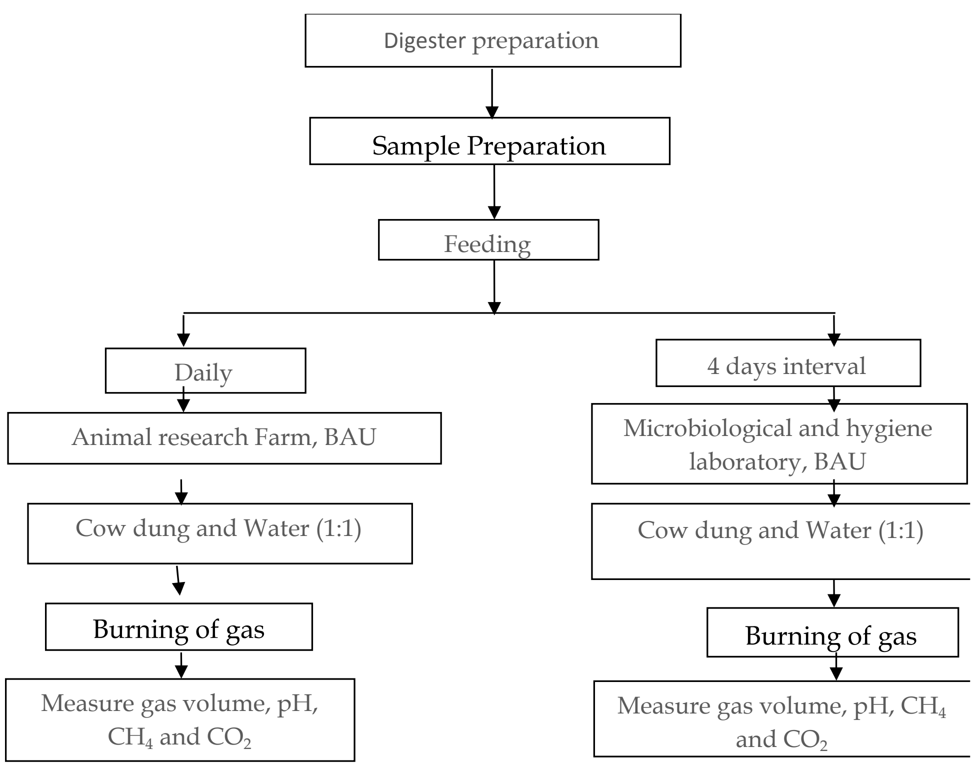

Figure 1. Schematic diagram of the experimental procedure

Sample Collection

Fresh cow dung was collected from Animal Research Farm daily for daily feeding and after 4-day for 4-day interval feeding. The sample was carefully collected and it was free from any contamination such as straw, waste feeds, urine and any other materials.

Sample Preparation

During the set up two digesters were fed simultaneously with fresh cow dung diluted with water in a ratio of 1:1, farm digester on daily basis with 50 kg and lab x digester once in 4-day with 200kg at once, with loading rate around 1.14 – 1.64 kg ODM (vs)/m^3d^{-1} digester volume and day, all over 5500 kg of cow dung were used for each of the digesters, with long hydrolic retention time of 55 days. The experiment was conducted over a period of 110 days. The optimum water content is likely to differ with different input materials depending up on the substrates chemical characteristics and bio-degradation rate (Valdes *et al.*, 1996).

Sample preparation for regular and 4-day interval feeding

For the preparation of sample, at first the cow dung was diluted with water properly. Then, the mixture was fed by the inlet pipe and the ratio of water and cow dung was maintained properly (Table 1).

Table 1. Amount and ratio of cow dung and water for feeding

Types of feeding	Types of feeding materials	Amount	Ratio
Regular feeding	Cow dung and water	50 kg, 50 L	1:1
Four days interval	Cow dung and water	200 kg, 200 L	

Experimental procedure

Two experimental set-ups were made to investigate the production of biogas from the anaerobic digestion of cow dung. Where one set-up was used to produce biogas on the basis of daily feeding and another for 4-day interval feeding. The digesters were connected with oven machine and gas meter. The gas formed in the digester passed through the pipe. Another plastic pipe was connected with a gas meter, gas suction machine and another plastic pipe was connected with the gas stove. That stove was used for burning the produced gas regularly.

Digestion was done at ambient temperature. The digester temperature has also measured. During the investigation, the volume of the produced gas was measured with the help of gas meter. CO_2, CH_4 and gas temperature were also estimated by gas meter. The daily produced gas was burnt to reduce the environmental pollution. After burning, feeding was done in daily feeding digester and after 4-day interval feeding was done on 4-day interval basis digester. Proper mixing and dilution were done perfectly and always maintained the cow dung and water in 1:1 ratio. The pH values were monitored on 7 days intervals to determine the action of methanogens, which utilized the acids, CO_2 and hydrogen produced by non-methane producing bacterial using a litmus paper.

Major measuring component

Digester temperature and ambient temperature

The digester temperature and ambient temperature were measured by a digital thermometer, DT-2 model and this measurement was done regularly.

Gas volume

Many chemistry and physics experiments involve collecting the gas produced by a chemical reaction and measuring its volume. In the study the gas volume was measured with gas meter, BF-2000 regularly. Gas volume = Gas volume at the ending point of burning Gas volume at the starting point of burning. In the comparison of various statistical procedures, efficiency is a measure of quality of an estimator of an experimental design. The efficiency of gas volume was calculated in following way:

Efficiency of digester (%) = (Average volume/ Real gas volume) * 100

pH, CH_4 and CO_2

The pH was measured by litmus paper. The measurement was done weekly.
CH_4 were measured by gas meter and the measurement was done at the starting period of gas burning.
CO_2 was measured by the following formula-
$CO_2 = (100 - CH_4)$ %

Statistical analysis (Two *t* sample test)

Data regarding gas volume (m^3) were statistically analyzed by STATA 10.1 software package to examine the significant variation of 4-day interval feeding and regular feeding system. The data were analyzed by two *t* sample test.

Results

Relationship between different parameter in case of regular feeding

The Frequently Fed Digester (FFD) produced on average 20% more methane and had lower effluent concentrations of long-chain fatty acids. Greater daily fluctuations in acetate, pH and biogas production rate could explain the lower specific methane yield and β-oxidation (Svensson *et al*., 2018; Mulat *et al*., 2016).

Relationship between ambient temperature and gas volume in case of regular feeding

Figure 2 represents the relationship between ambient temperature and gas volume. Temperature plays a vital role in gas production. It is the main factor that affect the production. In high temperature the gas production is high and in low temperature the gas production is low. For this reason, in winter, the gas production volume is low in everywhere in the world (Yadvika *et al*., 2004; Kaparaju *et al.,* 2008).

Figure 2 shows that the highest gas volume 1.7 m^3 was production at 10th week higher temperature & the average temperature is 30.6°C. The lowest gas volume 0.6 m^3 is produced at 14th week at lower temperature about 27.8°C. That proves temperature plays satisfactory role in gas production.

The ambient temperature during trials was in range from 25-35°C, ideal for anaerobic digestion by mesophilic microbes and like the temperature condition in lab with 27-33. Most of the acid forming microorganisms grow under mesophilic conditions; however, for methanogens, a higher temperature is favorable. The biogas production increases by tenfold when raising the temperature from 10 to 25°C (Brown *et al.,* 1995; Rabiu *et al*., 2014).

Relationship between pH and gas volume in case of regular feeding

The substrate's acidity is measured by pH, which is an important parameter affecting the growth of microbes during anaerobic digestion (Kim *et al.,* 2006). For optimal performance of the microbes, the pH with in the digester should be kept in the range of 6.8 - 8.0. The pH value below or above this interval may restrain the process in the reactor since micro-organisms and their enzymes are sensitive to pH deviation (Ghaly *et al.,* 2000). A neutral pH is favorable for biogas production, since most of the methanogens grow at a pH range of 6.7 to 7.5 (Demetriades, 2008). Performance of gas volume is shown in relation with pH in Figure 3. A neutral pH is favorable for biogas production. The highest gas volume 1.7 m3 was produced at pH 7 at 10th week. That pH value was in ideal range. That favors the biogas production very much. So the reduction of biogas cannot be explained with pH.

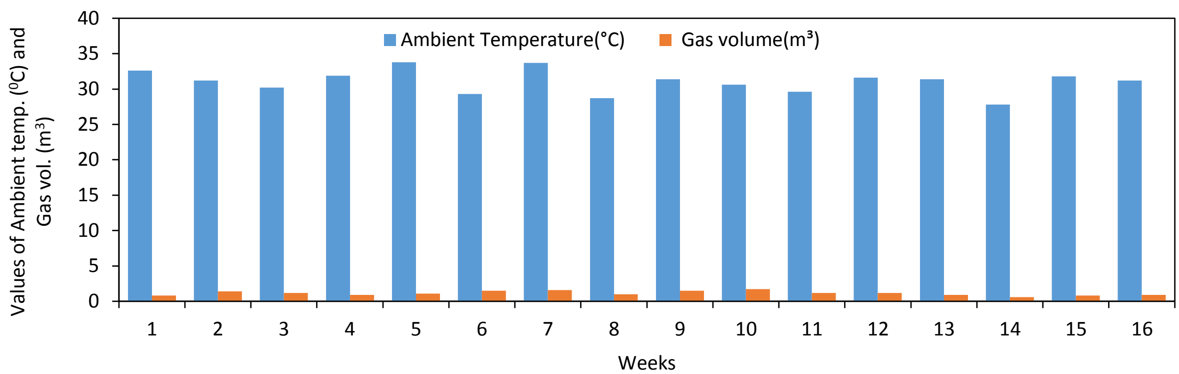

Figure 2. Relationship between ambient temperature and gas volume in case of regular feeding

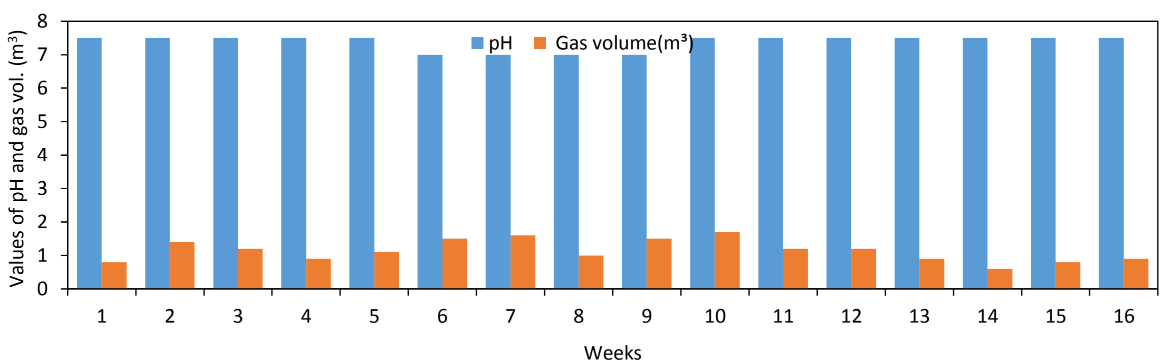

Figure 3. Relationship between pH and gas volume in case of regular feeding

Relationship between ambient temperature and CH_4 in case of regular feeding

Temperature is a critical parameter influences CH_4 production. To evaluate the overall potential of anaerobic digestion, the methane fermentation must be understood; and the fermentation temperature, loading rate, and retention time to optimize the anaerobic system must also be determined. Since methane fermentations are a biological process, temperature should affect the rate of reactions taking place. Specific temperature would be optimum for respective groups of bacteria. Ramaraj and Unpaprom (2016) found that the temperature was increased the biogas production and methane was also increased, however the high amount of biogas production rate and methane content was observed in the digester operated at 35 °C. Figure 4 shows that at first week the highest amount of CH4 57.5% was produced at 32.6°C. Ambient temperature regulates the digester temperature and helps in CH4 production. The Figure 3 shows that a strong correlation between ambient temperature and CH4. are prevailed.

Relationship between ambient temperature and CO_2 in case of regular feeding

In biogas, CO_2 is produced when methanogenic bacteria break down simple organic compounds, through the process of fermentation. The two main components of biogas are CH_4 and CO_2, products of the conversion of simple organic compounds by methanogenic bacteria. Since CO_2 can be readily measured in the field, the balance is usually considered to be CH_4. Thus high levels of CO_2 are indicative of poor methane content and therefore a lower energy value (Scott and Minott, 2003). Thus, CO_2 is dependent on ambient temperature. Figure 5 shows the relationship between ambient temperature and CO_2. Figure 5 shows that at first week low CO2 produced was 42.5%. CH4 and CO2 are related together. If CH4 increase then CO2 reduce. For this reason, CO2 is dependent on temperature and there is a correlation between temperature and CO2 and low CO2 production is good for biogas production. The Figure shows the relation perfectly.

Relationship between different parameter in case of 4-day interval feeding

Relationship between ambient temperature and gas volume in case of 4-day interval feeding

Temperature is the most important factor affecting biogas production. In order to find simple ways to maintain temperatures, it is important to understand the main driving factors influencing digester temperature is environmental temperature. If the environmental temperature falls then the digester temperature also fall. On the other hand, reduce the biogas production. Figure 6 represent the relationship between ambient temperature and gas volume. Figure 6 shows that the highest gas volume 2.3 m3 was production at 2nd week and the average temperature is 28.4°C. The lowest gas volume 0.6 m3 is produced at temperature about 31.1°C. Due to an unknown reason the high temperature produced lower gas volume. The reduction was started gradually from 9th week and the last 2 weeks the increasing of gas production was started.

Relationship between pH and gas volume in case of 4-day interval feeding

In the anaerobic digester, pH condition is important parameter because affects bacteria activity to destroy organic matter to biogas. pH optimum has range 6.5–8.2 (Speece, 1996). At pH 7, biogas formed was more bigger than pH 6 and pH 8. The measured pH values for the digester mostly ideal in range of *6.5*-7.5. The variable pH does not hamper so much of biogas production because of the ideal range of pH. Figure 7 shows the relation between pH and gas volume. The Figure shows the ideal pH for gas production. The highest gas was produced during 2nd week with pH 7. The reason for declining productivity for 4-day interval feeding cannot be explained with pH, hence the measured values were with 7-7.5 within the ideal range for anaerobic digestion.

Relationship between ambient temperature and CH_4 in case of 4-day interval feeding

The biogas produced contains usually 50-65% methane, (World Energy Council, 1994). However, the proportions of methane keep on varying with the duration and extent of biomethanation over retention time. It is also important to determine the composition of the other gases in order to keep track of the quality of the gas as well as assessing its green house effects. There is a good relationship between ambient temperature and CH_4. Figure 8 represents the relationship between ambient temperature and CH_4. Figure 8 represent the relationship between ambient temperature and CH_4 in case of 4-day interval feeding. The highest CH_4 was produced at first week. In case of low temperature methane production reduces due to the reduction of the activity of methanogenic bacteria. So the Figure shows that there is a correlation between ambient temperature and CH_4.

Relationship between ambient temperature and CO_2 in case of 4-day interval feeding

Methane and carbon dioxide are the two main constituents of biogas. Biogas also contains traces of nitrogen, hydrogen, oxygen and hydrogen sulphide. One of the reasons of poor combustion is the presence of carbon dioxide in the biogas. Percentage of carbon dioxide in biogas varies with the ambient temperature (Saiful, 1996). Figure 9 represent the relationship between ambient temperature and CO_2.

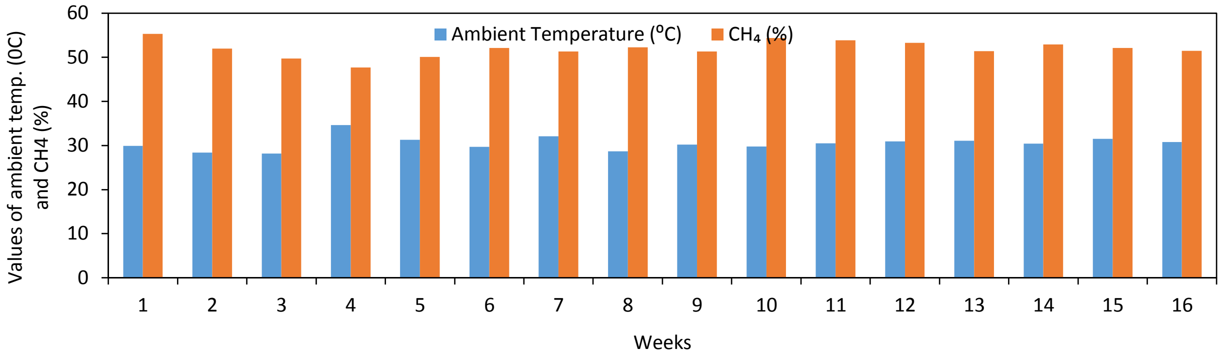

Figure 4. Relationship between ambient temperature and CH_4 in case of regular feeding

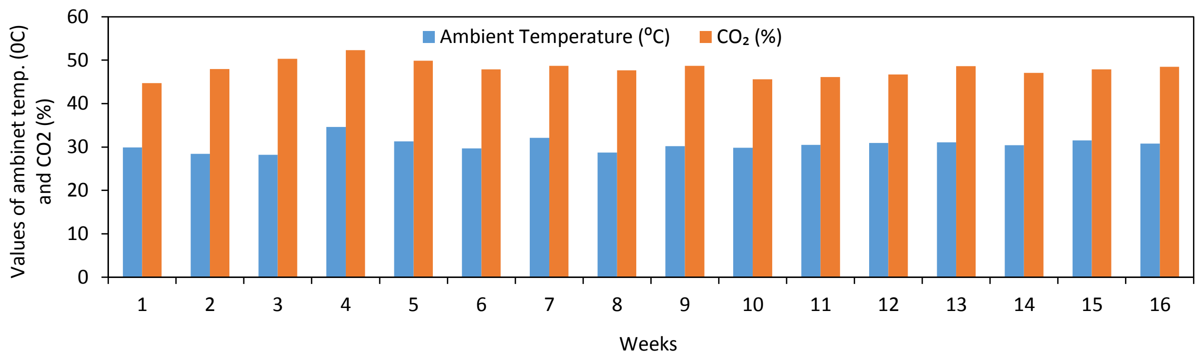

Figure 5. Relationship between ambient temperature and CO_2 in case of regular feeding

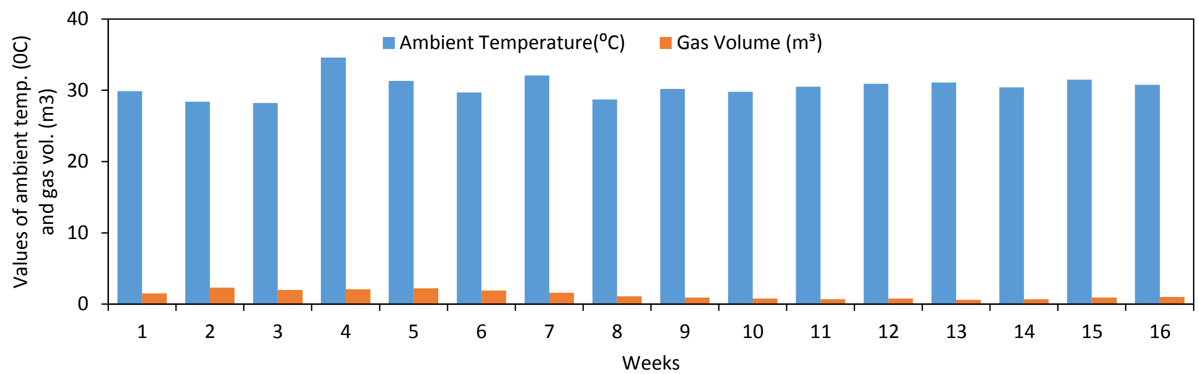

Figure 6. Relationship between ambient temperature and gas volume in case of 4-day interval feeding

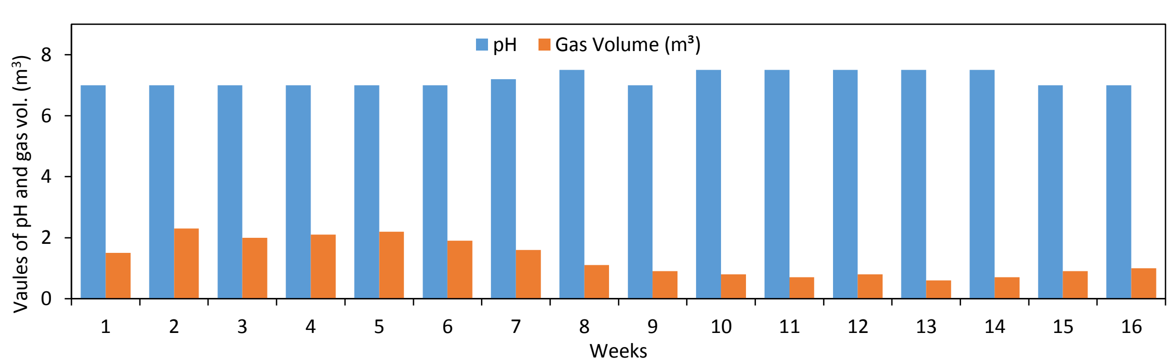

Figure 7. Relationship between pH and gas volume in case of 4-day interval feeding

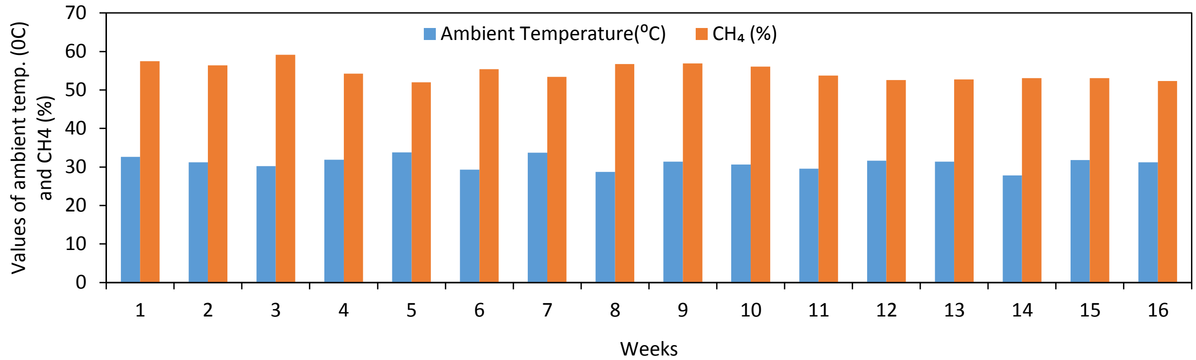

Figure 8. Relationship between ambient temperature and CH_4 in case of 4-day interval feeding

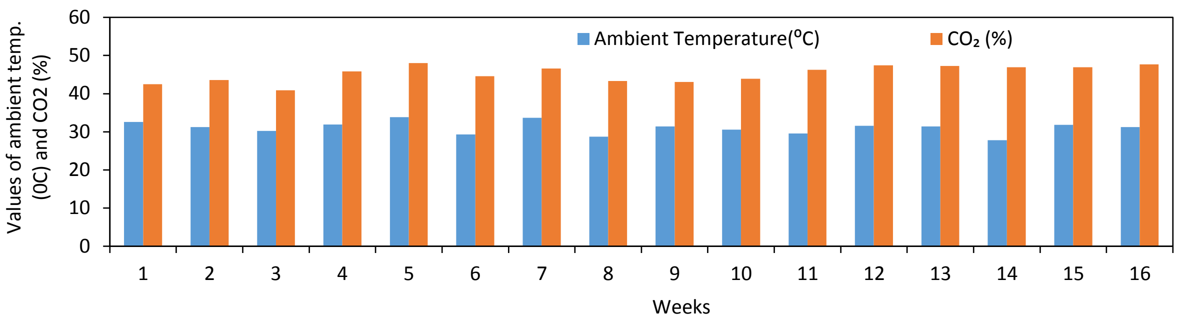

Figure 9. Relationship between ambient temperature and CO_2 in case of 4-day interval feeding

Figure 9 shows the relationship between ambient temperature and CO_2 in case of 4-day interval feeding. Highest CO_2 was produced at 4th week. High CO_2 is not good for biogas production.

Comparison between different parameters in regular feeding vs. 4-day interval feeding

Comparison between different parameters in regular vs. 4-day interval feeding were done considering temperature and pH values as same because the differences among them were negligible, and all other conditions were exactly same.

Comparison of gas volume in regular feeding vs. 4-day interval feeding

From Figure 10, it is undoubtedly 4-day interval feeding generated 48% more biogas comparing with regular feeding. However, after 6th week the trend has changed for inappropriate dilution and feeding. The production of gas in lab digester again increased from 14th week. Observing the total biogas production during the period of 110 days, the performance of 4-day interval feeding digester was higher, with all over 95 Nm^3 or 34%more than regular feeding with 63 Nm^3. When converting the biogas yield per ton of substrate, the yield achieved by 4-day interval feeding was about 32 Nm^3/t and 2l Nm^3/t for regular feeding. However, animal research farm that also represents the common practice in Bangladesh by daily semi continues feeding, was 40% lower. With obtained results, 48kg of CM would be necessary to produce 1 m^3 of biogas in praxis as usual and 32kg feeding in 4-day' intervals. Bruun (2019) found that biogas from cow manure with 1 kg produced as much as 40 liters of biogas, while chicken dung with the same amount produced 70 liters. Biogas has a high energy content which is not less than the energy content of the fuel fossil.

Figure 11 shows that the yield of CH_4 production is 24% higher in 4-day interval feeding than the regular feeding. So, 4-day interval feeding is good in compare to regular feeding. It increases the combustion efficiency. It also reduces the labor cost for feeding and save time for producer.

Comparison of CO_2 production in regular feeding vs. 4-day interval feeding

Figure 12 shows that the concentration of CO_2 is higher in case of regular feeding. The high percentage of CO_2 reduces the combustion of biogas. So, the low percentage of CO_2 is good for biogas production. 4-day interval feeding shows low CO_2 concentration that is also good for burning.

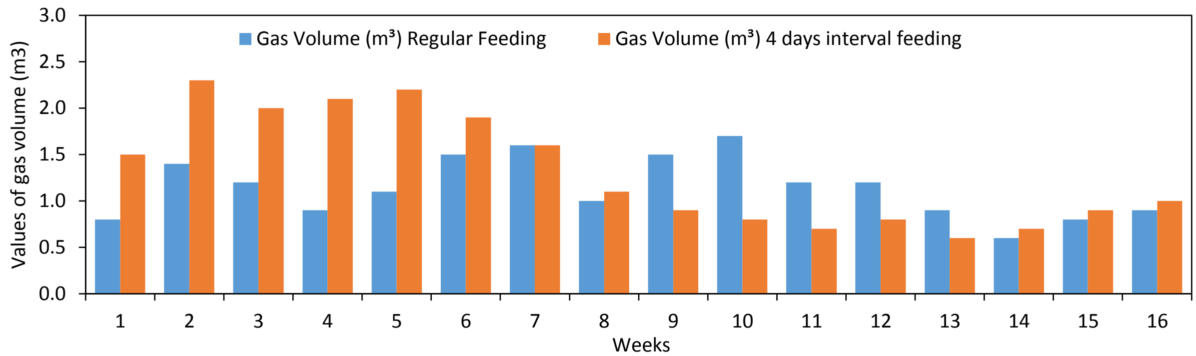

Figure 10. Comparison of gas volume in regular feeding vs. 4-day interval feeding

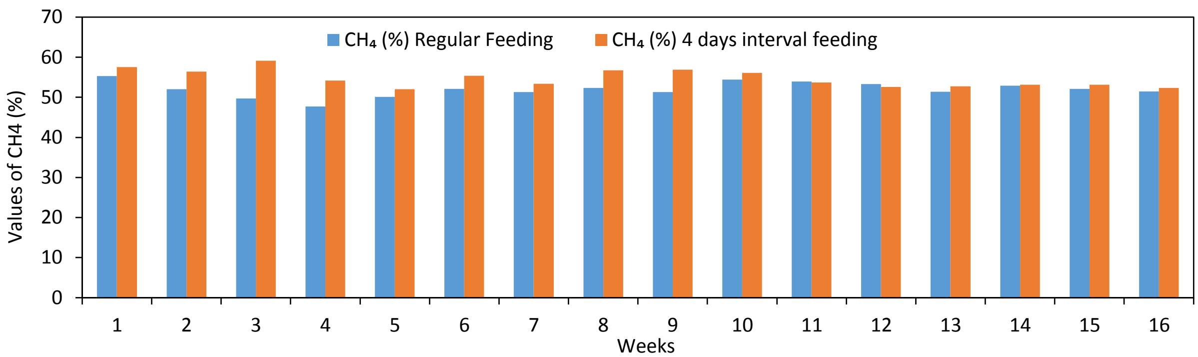

Figure 11. Comparison of CH_4 production in regular feeding vs. 4-day interval feeding

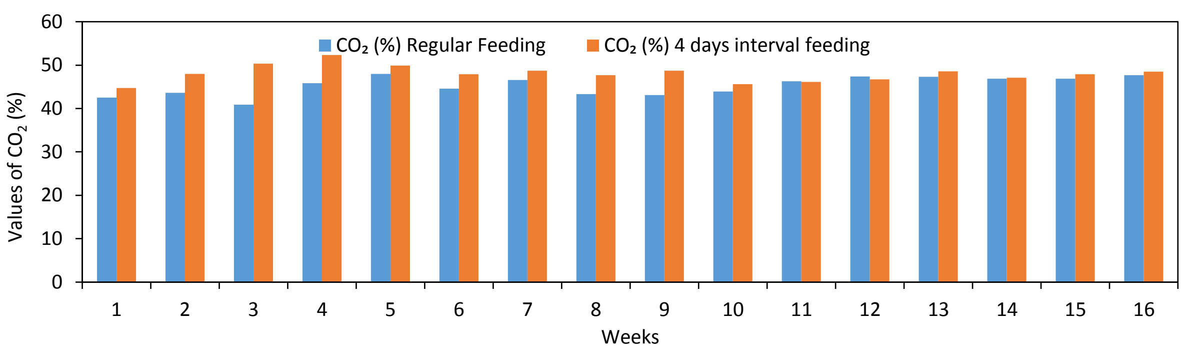

Figure 12. Comparison of CO_2 production in regular feeding vs. 4-day interval feeding

Conclusion

The results were discussed about gas production in case of regular feeding and 4-day interval feeding. It was found that overall biogas yield for 4-day interval feeding was 34% higher which was statistically significant, and 48 kgs of CM would be necessary to produce 1 m^3 of biogas in praxis as usual and 32 kgs feeding in 4-day interval The gas production was observed under the ambient temperature. In case of high temperature, the gas production was high and at low temperature gas production was low and there was a significant difference between regular feeding and 4-day interval feeding. The experiment also expressed the pH and the pH (7-7.5) showed the standard range for gas production. The ambient temperature was found much effective for gas production. The CH4 (54.7) production was higher in 4-day interval feeding than the regular feeding. The low methane content in biogas was affected by the amount of impurities in the biogas. The CO2 (45.3) was lower in 4-day interval feeding. It can be recommended that augment biogas production under different feeding interval of waste products can be adopted through training, extension services among the farmers level before introducing this system at farmers level and further experiments are necessary for more understanding. Government could concern about this topic for reducing methane emission and also solving the crisis of energy.

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Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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