EFFECT OF MIXING ON BIOGAS PRODUCTION FROM COW DUNG

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Abstract

Mixing in an anaerobic digester keeps the solids in suspension and homogenizes the incoming feed with the active microbial community of the digester content. The effect of mixing on anaerobic digestion of cow dung was evaluated in lab-scale experiment at 35 °C. The study was carried out at the biogas laboratory of Green Energy Knowledge Hub (GEKH) at Bangladesh Agricultural University, Mymensingh. The effect of continuous mixing (mixing for 5 min at 15 min interval at 100 rpm) on methane production was investigated in three lab-scale continuously stirred tank reactors. In addition to gas production and composition measurements various analyses were conducted periodically on the digester contents. In comparison to without mixing and ambient condition, biogas production was increased by 2.20 % and 18.85 %, respectively in the reactor with mixing. Methane productions in the reactor with mixing were improved by 3.21 % and 18.23 %, respectively in comparison to without mixing and ambient condition. The study thus indicated that mixing has no considerable effect on anaerobic digestion of cow dung. Further research should be aimed at studying the effects of mixing on a chemical and microbial level and on the different stages of anaerobic digestion.

Keywords: Anaerobic digestion, Mixing; continuously stirred tank reactor and biogas.

Introduction

Biogas production from biomass is attracting increased attention worldwide due to recent concern in climate change. Biogas can be produced from a wide range of biodegradable biomass crops as well as from a wide range of solid or liquid residues. Anaerobic digestion is a promising animal waste management option as it leads to the generation of methane which can be used as a renewable energy source. Over the past 25 years, anaerobic digestion processes have been developed and applied to a wide array of industrial and agricultural waste (Karim et al., 2005a). Bangladesh is one of the low energy consuming countries in the world. Currently natural gas is the main source for energy production in Bangladesh but the reserve of natural gas is low. So the country needs alternative energy sources. As an agricultural country Bangladesh has blessed with plenty of biomass which has been used for extracting energy by burning directly or making biogas. Animal manure being available in the rural areas can be used in biogas production. Currently there are about 91,350 biogas plants in Bangladesh (GEKH, 2016). Bangladesh Council of Scientific and Industrial Research (BCSIR) installed about 22,000 biogas plants from 1992 to 2003. Infrastructure Development Company Ltd. (IDCOL) also constructed about 22,000 small scale biogas plants through National Domestic Biogas and Manure Program (NDBMP) upto 2012. Grameen Shakti is the largest partner organization of IDCOL which installed about 12,000 small scale biogas plants across Bangladesh (Kabir et al., 2013). Biogas plants owner in Bangladesh encountered some technical problems in day to day operation in terms of mixing and temperature of digester content Most of the digesters are operated without mixing of substrate inside the digester in Bangladesh. Therefore, the domestic biogas plant owners facing the problem of crust formation of feed stock and clogging of the inlet port. Repair and maintenance of the digester is troublesome work, costly & risky. Digesters in our country are operated in ambient temperature condition where temperature fluctuates rapidly and affects the biogas production. Low temperature during winter also hampers normal biogas production.

The efficiency of anaerobic digesters is affected mainly by the retention time of the substrate in the reactor and the degree of contact between the incoming substrate and a viable bacterial population. These parameters are a function of the hydraulic regime (mixing) in the reactors. Thorough mixing of the substrate in the digester is required to distribute organisms uniformly throughout the mixture and to transfer heat, and is thus regarded to be essential in high-rate anaerobic digesters (Sawyer and Grumbling, 1960). It also prevents foam formation and enables lift from the fermentation substrate at high dry matter (DM) contents (Brehmer et al., 2012). Moreover, agitation aids in particle size reduction as digestion progresses and in removal of gas from the mixture. The importance of mixing in achieving efficient substrate conversion has been reported by many researchers (Casey, 1986; Lee et al., 1995; Smith et al., 1996; Karim et al., 2005b) though the optimum mixing pattern is a subject of much discussion. Mixing is usually accomplished with a variety of mechanical mixers, recirculation of digesters contents or recirculation of produced biogas using recirculation pumps (Karim et al., 2005b). Mechanical mixers are reported to be most effective in terms of power consumed per gallon mixed (Brade and noone, 1981). However, the internal fittings and equipment (required for mechanical mixing) are not accessible for maintenance purpose during digester operation. Therefore the long term reliability of operation is of paramount importance. Many researchers in the literature reported mixing achieved by biogas recirculation as most efficient for biogas production from anaerobic digesters (Lee et al., 1995; Kontandt and Roediger, 1977).

The effect of mixing in anaerobic digestion of animal manure was studied on a laboratory scale by Karim et al. (2005b), whom showed that mechanical, hydraulic and pneumatic accounted for 29%, 22% and 15% higher biogas yields compared to the unmixed digester. With increased DM content in the slurry, deposition of solids could be observed. They concluded that mixing is becoming prominent in digesters fed with thicker manure. Laboratory scale research of anaerobic digestion of sewage water demonstrated that in continuous mixing systems, higher impeller speeds rising from 140 rpm to 1000 rpm did not improve total gas yields and even a slight reduction in gas production occurred (Stafford et al., 1982). Kaparaju et al. (2007) concluded that in biogas digesters fed with manure and solid substrates, mixing is indispensable. The mixing intensity had a small effect on biogas yield and mixing schemes proved to have an effect on anaerobic digestion of manures. Karim et al. (2005a) found no effect in mixing anaerobic digester slurry by biogas recirculation.

Many researchers reported improved gas production by mixing and it prevents crust formation. But the contradictory findings reported in the literature as described earlier about the effect of mixing on the efficiency of anaerobic digesters bring the need of extensive research in mixing of digester contents. This research work is intended to evaluate the effect of mixing on gas production from cow dung at lab-scale.

Materials and Methods

Experimental site

The experiment was conducted at the biogas laboratory of Green Energy Khowledge Hub (GEKH) at Bangladesh Agricultural University.

Substrate collection

The main substrate used in this research work was cow dung. Fresh cow dung was collected from the dairy farm of the university. The cow dung was always collected from the same farm in order to ensure as uniform feed characteristics as practically possible.

Experimental set-up

The biogas test plants system (BTP2-control, UIT, Germany) consists of three digesters units, heating unit, agitation system, module SENSOcontrol and a gas analyzing unit. Every digester has a diameter of 27 cm and a height of 42 cm resulting in a maximum volume of 17.2 L with a net capacity of 15 L and is equipped with different heating systems. The agitator is connected with agitator shaft by a flexible coupling installed in the tank. On the shaft there are two stirring tools (propeller and stirrer) installed, which can be changed by height. The agitator (Allowed environmental temperature 5 – 40˚ C, 80 % RH) with stirrer can be adjusted by data logging and control module SENSOcontrol. Biogas generated in each digester was collected in a gas bag of capacity 10 L. Feed was prepared by diluting the manure with water, whenever necessary, to attain a consistent TS of 7.5 –10 %. The digester was fed from top of the reactor. The digester was fed daily by an amount of 500 ml influent and was discharged with the same amount considering 30 days HRT (Hydraulic Retention Time). Effluent was removed from bottom of the reactor. The reactor had one outlet at the bottom for sediment removal.

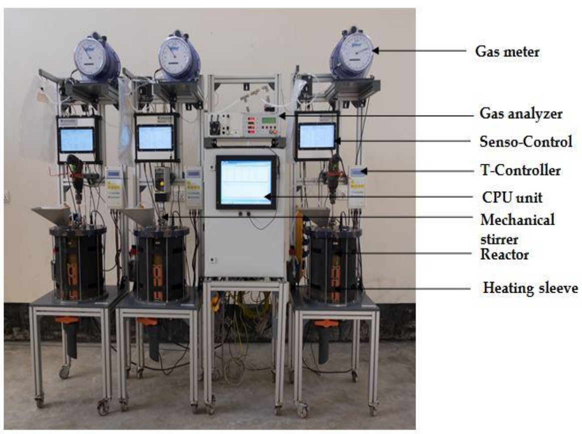

Fig. 1. Experiment set-up with Continuous stirred tank reactor (CSTR)

Experimental consideration

Reactor 1 (R_1) was operated with stirring, reactor 2 (R_2) was operated without stirring and reactor 3 (R_3) was operated on ambient condition without stirring. The temperature of reactor 1 and reactor 2 was maintained at 35 °C by T-controller and temperature of reactor 3 varied between 26.9 – 33 °C as it was operated at ambient condition. The reactor (R_1) was stirred for 5 minutes at 15 minutes interval at 100 rpm. The temperature of the fermenting substrate, gas quality and biogas temperature are measured continuously in every digester. Samples of fermenting substrate were taken on a weekly basis and analyzed for TS, VS, pH, ammonium (NH_4-N) and volatile fatty acids (VFA) content in the biogas laboratory.

Measurement of different parameters

Gas volume was measured by a drum meter. Biogas composition (CH_4, CO_2, H_2S, O_2) was auto analyzed by a gas analyzing unit (SSM 6000 LT, PRONOVA, Germany). pH was continuously monitored in the CSTR. VFA and alkalinity was measured by the method developed by Møller and Ward (2011), TS and VS was measured according to standard method (APHA, 1998). Ammonium was measured by a photometer (NOVA 60**,** Memmert, Germany) according to manufacturer procedure.

Data analysis

After finishing all the experiments, accumulated data in the CPU (central processing unit) of CSTR were collected and analyzed with the help of MS excel 2010.

Results and Discussion

Laboratory scale anaerobic digesters were operated to evaluate the effect of mixing on biogas production. Feedstock characteristics are presented in table 1. These include C/N ratio, total solids content, the volatile solids content, volatile fatty acids, pH, alkalinity, and ammonium.

Table 1. Feedstock Characteristics

Characteristics	
C/N ratio	25
TS (%)	16.57 %
VS (%)	14.34 %
pH	7.16
VFA	6732.48 mg/l
Alkalinity	29.92 mg/l
NH_4-N	1650 mg/l

Effect of mixing and ambient condition on biogas production

The performance of all reactors in terms of biogas production during different phases of the experiment is presented in Fig. 2. Daily gas volume for all the reactors was not varied considerably. During the start-up period the gas production was low. Throughout the 30 days retention period the approximate gas production in the reactor 1 (with stirring) was 9.76 L/day, in the reactor 2 (without stirring) was 9.55 L/day and in the reactor 3 (ambient condition) was 7.92 L/day . Total gas volume from R_2 (without stirring) was 286.5 L. Gas production from R_1 (with stirring) was 292.8 L which is 2.20 % higher than R_2. Gas production from R_3 (ambient condition) was 237.6 L which is 17.06 % less than R_2 and 18.85 % less than R_1. Reactor 1 and 2 was maintained at 35 °C temperature and temperature of the reactor 3 varied between 26.9 – 33 °C. Methanogens are very sensitive to temperature changes as a result the gas production from the reactor 3 was low. Methane content of the reactors during the experimental period is presented in Fig. 4. The produced biogas during the experimental period contained 48.4 – 57.41 % methane in both digesters. The highest percentage of methane (57.41 %) was recorded in case of mixing. Abdel-Hadi and El-Azeem (2008) also found highest concentration of methane in case of mixing. Daily methane production profile is presented in Fig. 5. Average methane production in the reactor 1 (with stirring) was 5.32 L/day, in the reactor 2 (without stirring) was 5.16 L/day and in the reactor 3 (ambient condition) was 4.36 L/day. Cumulative methane production is presented in Fig. 6. Methane production profiles followed the same trend as biogas production. Total methane production from R_2 was 154.90 L. Methane production from R_1 was 159.87 L which is 3.21 % higher than R_2. Methane production from R_3 was 130.73 L which is 15.60 % less than R_2 and 18.23 % less than R_1.

Effect of mixing and ambient condition on pH

The measured pH values for the anaerobic digestion of cow dung in all digesters at experimental intervals are shown in Fig. 7. The pH is known to influence enzymatic activity, because each enzyme has a maximum activity within a specific and a narrow pH range. The pH of the digestion liquid material and its stability as well comprises an extremely important parameter, since methanogenesis only proceeds at high rate when pH is maintained in the neutral range. During the experiment pH remained stable around 6.5 throughout this period. pH of the reactor 2 (without mixing) and reactor 3 (ambient condition) was slightly higher than the reactor with mixing which may be due to the fact that as the digester was not mixed, the added feed was concentrated at a particular region in the digester. This feed was converted to acetic acid by acetogens at a rate faster than the consumption of acids by methanogens, resulted in higher pH. VFA (Volatile fatty acids) levels were slightly

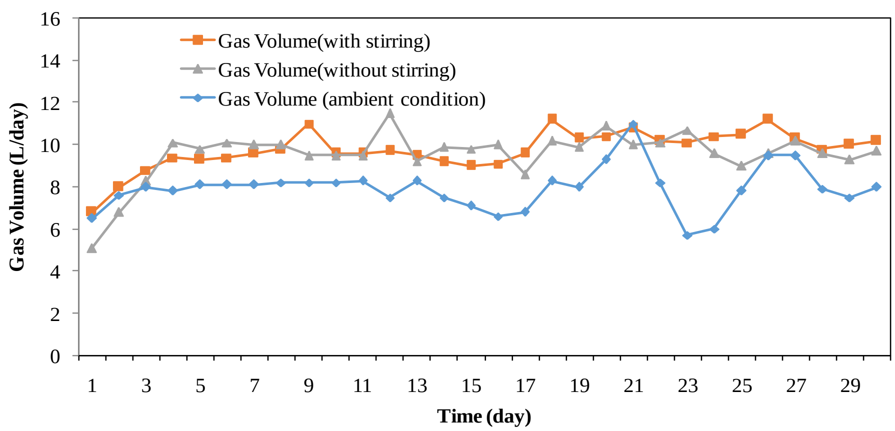

Fig. 2 – Daily gas production profile at different condition

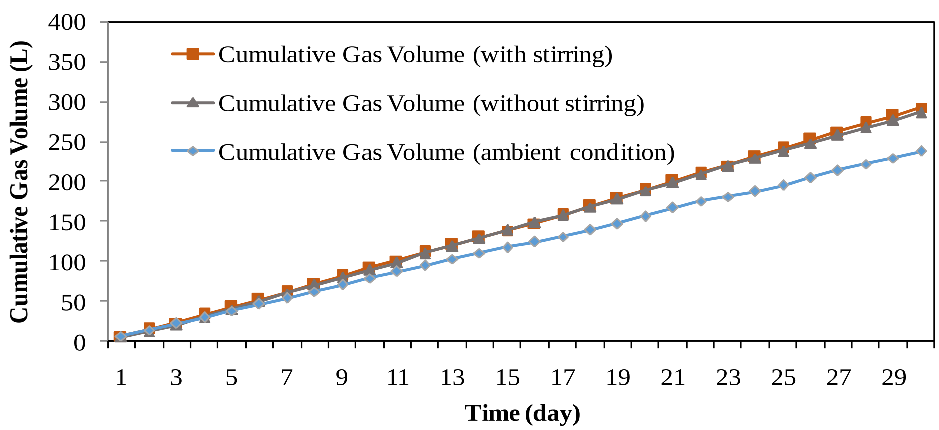

Fig. 3. Cumulative gas production

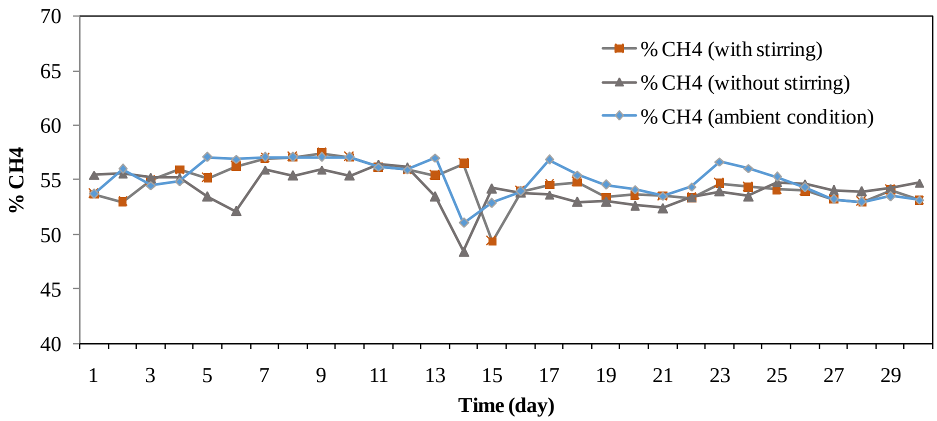

Fig. 4 – Methane content profile at different condition

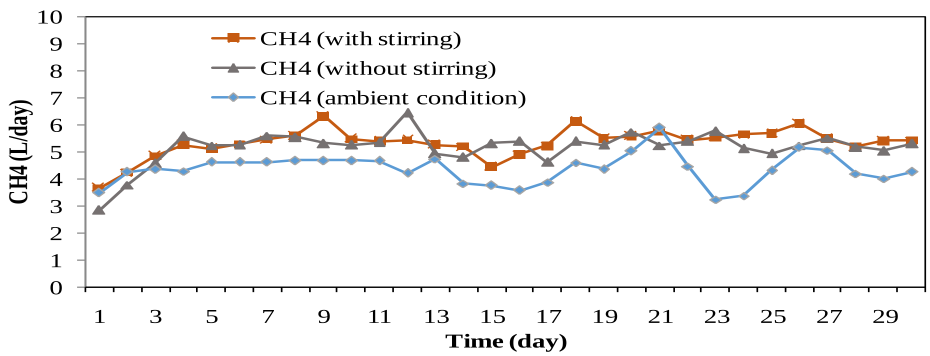

Fig. 5 – Daily methane production profile at different condition

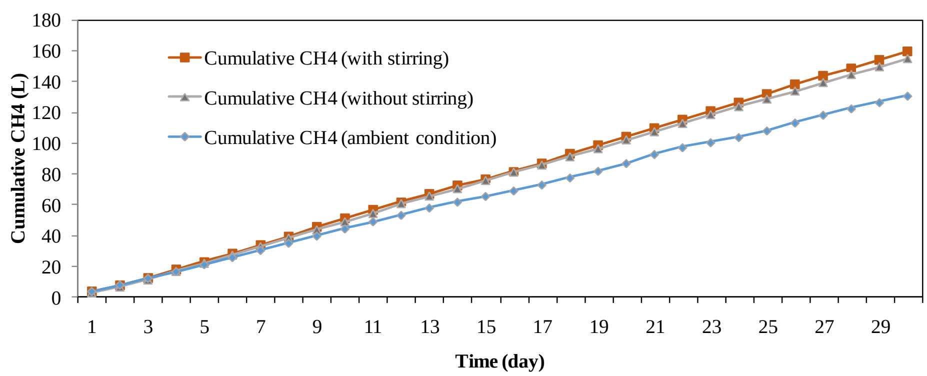

Fig. 6. Cumulative methane production

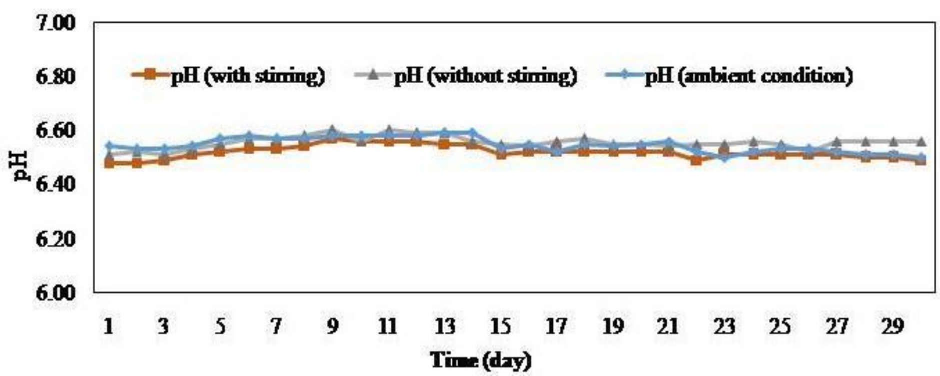

Fig. 7. Variation of pH at different condition

Table 2. Bioslurry characteristics of different reactors

Reactor	Time	VFA mg/l	NH4-N mg/l	TS (%)	VS (%)	TS reduction (%)	VS reduction (%)
	1st week	1484.09	950	3.97	2.91	53.51	55.84
R_1	2nd week	1395.10	1000	4.20	3.22	50.82	51.14
	3rd week	737.09	2250	5.23	4.24	38.76	35.66
	4th week	1306.95	850	4.78	3.73	44.03	43.40
	1st week	1118.61	900	4.03	3.03	52.81	54.02
R_2	2nd week	1295.74	850	4.09	3.17	52.11	51.90
	3rd week	530.42	1550	5.70	4.62	33.26	29.89
	4th week	1383.53	850	5.05	3.91	40.87	40.67
	1st week	812.34	850	4.28	3.33	49.88	49.47
R_3	2nd week	923.34	900	4.34	3.45	49.18	47.65
	3rd week	894.55	1150	5.49	4.53	35.71	31.26
	4th week	1096.59	850	4.81	3.78	43.68	42.64

higher in R_1 (with stirring) than in R_2 (without stirring) and R_3 (ambient condition). Ammonium nitrogen level during third week of the experiment was higher and resulted in lower TS (Total solids) and VS (Volatile solids) removal (Table 2).

Effect of mixing and ambient condition on TS and VS reduction

The volatile solids (VS) reduction and total solids (TS) reduction for all reactors is presented in Table 2. Average total solid reduction for R_1, R_2 and R_3 was 46.78 %, 44.76 % and 44.61 % respectively. Average volatile solids reduction for R_1, R_2 and R_3 was 46.51 %, 44.12 % and 42.75 % respectively. Reflecting the higher gas production, the volatile solids reduction were higher in the mixed reactors. TS reduction and VS reduction of all reactors was lower during third week of the experiment which may be due to the higher values of ammonium. Mixing had no discernible effect on pH, ammonium content or volatile acids concentration and biogas production. Results from this work comply with the result obtained by Neelakantan et al. (1975).

Conclusion

Lab-scale experimental results showed that mixing had improved biogas production by 2.20 % and 18.85 %, respectively than unmixed reactor and the reactor at ambient condition. Reactor with mixing at fixed temperature increased gas production considerably than reactor at ambient condition without mixing. The difference in the performance of mixed reactor and unmixed was not considerable. In long term operation of digester, crust formation in reactor is a common problem. Crust formation hampers effective reactor operation and biogas formation. Mixing can be an engineering approach to solve this problem. However, it would be interesting to examine if the mixing patterns inside the digesters changed with the applied physical changes in the mixing conditions or not**.** The effects of mixing on the digestion process cannot be appropriately evaluated in the laboratory, future mixing studies should be performed on field digesters. Further research should be carried out to investigate the effects of mixing on a chemical and microbial level and on the different stages of anaerobic digestion. The above experiment was conducted for one HRT (Hydraulic Retention Time). So in future a two HRT study should be carried out for better performance of mixing effect.

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