Research article

Production and Quality of Biogas from Pilot Biodigesters using Cow Manure

LYTOUR LOR*
Faculty of Agricultural Engineering, Royal University of Agriculture, Phnom Penh, Cambodia
Email: llytour@rua.edu.kh

MACHITO MIHARA
Faculty of Regional Environment Science, Tokyo University of Agriculture, Tokyo, Japan

BUNTHAN NGO
Royal University of Agriculture, Phnom Penh, Cambodia

LYHOUR HIN
Faculty of Agricultural Engineering, Royal University of Agriculture, Phnom Penh, Cambodia

DYNA THENG
Faculty of Agricultural Engineering, Royal University of Agriculture, Phnom Penh, Cambodia

CHANMAKARA MEAN
Faculty of Agricultural Engineering, Royal University of Agriculture, Phnom Penh, Cambodia

BART FREDERIKS
United Nations Industrial Development Organization, Vienna, Austria

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Abstract Biogas systems are being applied at commercial pig farms and at starch processing plants to manage their wastes and produce biogas for generating electricity or heat for on-site use. The installation numbers are increasing in Cambodia. The data on potential biogas production quantity from different feedstocks as well as on biogas quality are required to design the biogas systems. The purposes of this study was to determine biogas production and biogas quality from dairy cow manure produced in pilot digesters, and to analyze the variation in biogas production and quality during the year of 2019 and 2020. Pilot bio-digesters were installed at the Biogas Technology and Information Center, a research unit located in the Royal University of Agriculture, to obtain these data, since it is easier to do the experiments with the pilot digesters than that with commercial ones. The experiments were conducted during the year of 2019. In the experiments, 3 identical floating drum bio-digesters were used. Each bio-digester has 1 m^3 of volume and has been supplied mixture of 5-10 kg of fresh manure from dairy cattle with 5-10 liters of water every day. The daily biogas production quantity was recorded using a gas flow meter attached to the outlet of each bio-digester; also the gas quality, such as methane, carbon dioxide, oxygen, and hydrogen sulfide was measured using a portable biogas analyzer. The average rate of biogas production was around 37 liters of biogas per kg of wet manure. Average percentage of methane was around 52%, and average concentration of hydrogen sulfide varied from around 390 ppm to 604 ppm. These two parameters are the main indicators of biogas quality.

Keywords biogas, floating drum digester, cow manure, methane, hydrogen sulfide

INTRODUCTION

Global warming is the worldwide concern which is caused by greenhouse gas emissions. In Cambodia, methane is a major greenhouse gas from animal production. Ministry of Environment

(2002) projected that methane emission from domestic livestock would be 545 Gg in 2020 compared to 303 Gg from rice production, 2 Gg from grassland burning, and 5 Gg from agricultural residue burning.

Recently in Cambodia, animal production has increased in all kinds of animals, especially commercial farms. In 2017, there were 83 commercial cattle farms, 653 pig farms with total number of cattle and pig 20,363 heads, and 742,771 heads, respectively (MAFF, 2018a). According to Prakas no. 549 of the Ministry of Agriculture, Forestry and Fisheries issued on December 12, 2018, all commercial animal farms are required to manage their waste properly, especially using biogas systems (MAFF, 2018)

Currently, some commercial farms and agro-processing plants have already installed biogas plants to treat their waste and convert biogas to electricity for use on farms. To design biogas systems, data on potential biogas production and quality from various feedstocks are required. These data are available in other countries but not in Cambodia. To obtain these data in local condition, the use of pilot digester is more appropriate since it is difficult to do on commercial biogas systems.

OBJECTIVE

The objectives of this study were (1) to determine biogas production and quality from dairy cow manure by pilot digesters and (2) to analyze the variation in biogas production and quality during the year of 2019 and 2020.

METHODOLOGY

Experimental Procedure

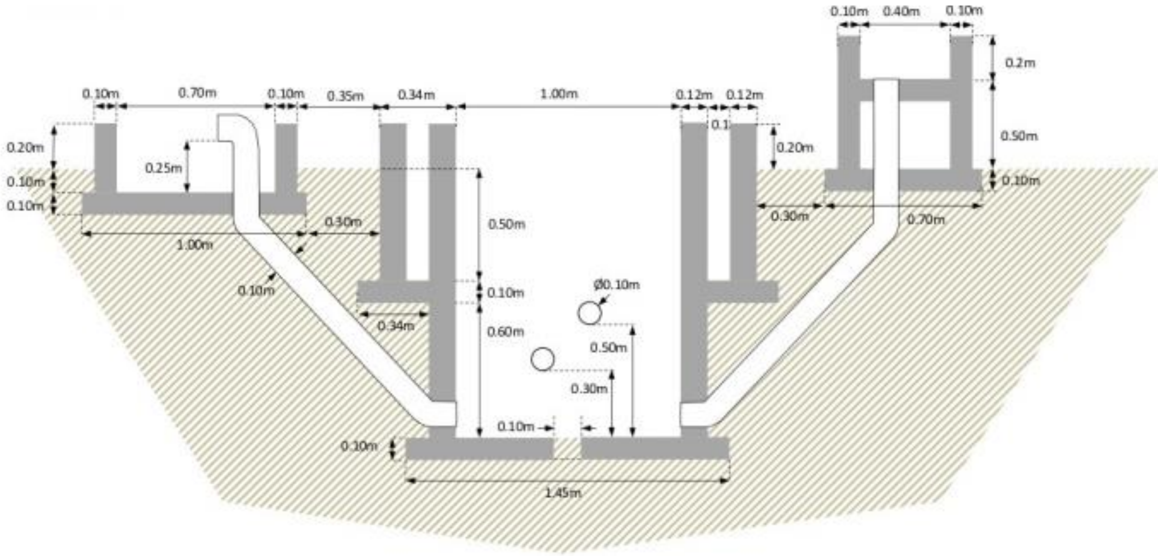
The experiment was conducted in 2019 and early 2020. Fresh cow manure was collected from dairy cattle farm located on the campus of the Royal University of Agriculture. The ratio of manure to water was 1:1 to bring down the percentage of DM to around 10% in the mixture (Farouk et al., 2017). The mixture was thoroughly mixed and solid pieces of grass were removed before feeding into the digesters to avoid sludge build up in the digesters. Daily manure used was 5kg/day or 10kg/day (fresh manure). At the beginning feeding rate of 5kg/day was used to start up the digester and then was increased to 10kg/day. Ground water was used to mix with the manure.

Table 1 Amount of feedstock and water used

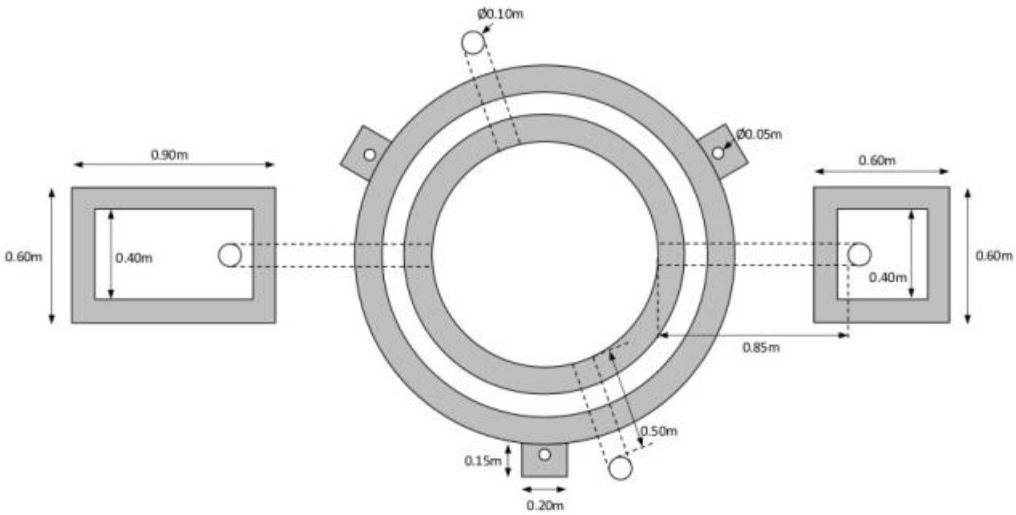
Digester	Mass of Feedstock (kg)	Mass of Water (liter)	Mix Ratio	Remark
Digester 1	5 to 10	5 to 10	1:1	- 25 February to 11 March 2019, 8kg/day of cow manure used - 12 March to 29 July 2019, 10kg/day of cow manure used - 30 July 2019 to 31 January 2020, 5kg/day of cow manure used
Digester 2	10	10	1:1	
Digester 3	10	10	1:1	

Three floating drum biodigesters of identical design were used, see Fig. 1. This design was selected because it would ease the modification of the digester for various experiments. It is equipped with two sampling pipes on the sides of the digester from which substrate can be extracted for analysis. Each biodigester has a total volume of 1m^3. The hydraulic retention time was around 47 days, which depends on daily feeding rate of 5 kg or 10 kg, to ensure complete anaerobic digestion of the feedstock.

The duration of data collection was shown in Table 2. Digester 1 was started up in December 2018 and started to produce stable biogas in February 2019 and the daily biogas production was recorded. It took longer than 1 month before the digester started to produce biogas. After the low biogas production was observed for Digester 1, it was opened in September 2019 to make sure that there was no sludge building up in the digester. The digester 1 was restarted up again and began producing biogas in October 2019. Digester 2 and Digester 3 was completed the construction and started up in July 2019. During long holidays such as Cambodian New Year in April and Pchum Ben in September and Water Festival in November, data was not collected daily.



(a)



(b)

Fig. 1 Drawing of the pilot digester (a) side view (b) top view

From July to early August 2019, the biogas composition was measured once every two weeks. It was done daily since late August 2019 when the air injection experiment was conducted on Digester 2 to remove H_2S.

Daily biogas production was measured by using gas counter which was attached to the outlet end of the pipe. To avoid direct emission of methane into the atmosphere, it was burned by using a biogas stove after passing through the gas counter.

For the quality of the biogas produced, contents of methane, carbon dioxide, oxygen, and hydrogen sulfide were measured using a portable gas analyzer. The gas analyzer, Geotech Biogas 5000, was regularly calibrated to ensure its accuracy in measuring. At the beginning, the biogas quality was measured weekly. Later on, it was measured daily since there was a need to test hydrogen sulfide removal using air injection into gas holder of the digesters. The content of hydrogen sulfide before and after the air injection need to be measured daily.

Table 2 Duration of Data Collection

Digester	Duration of data collection	Remark
Digester 1	February 2019 to January 2020	-In September 2019, the digester was opened since the low biogas production was observed. After new startup, the digester started produce biogas in October 2019. -24 February to 11 March 2019, 8kg of manure per day
Digester 2	July 2019 to January 2020	
Digester 3	July 2019 to January 2020	

RESULTS AND DISCUSSION

Production of Biogas

During the monitoring, the average daily biogas production of digester 1, digester 2, and digester 3 were 238 L/day, 426 L/day, and 371 L/day, respectively. The average daily biogas production of the digester 1 was the lowest since it was fed mostly only 5 kg of cow manure per day. The average daily biogas production of digester 1 was only 71 L/day in February 2019. At that time, it was the beginning of biogas production after it was started up in December 2018. The daily biogas production of digester 1 and digester 2 were similar. The two digesters were constructed at the same time and fed 10 kg of cow manure daily. The fluctuation of average biogas production in each month may have been caused by quality of animal feed and weather conditions. Matos et al. (2017) reported that biogas production potential from dairy cattle manure raised under organic production system is lower than that of the conventional one which supplement commercial feed in the animal diet. Daily biogas production is higher in summer than in winter as reported by Choudhury et al. (2019) during evaluation of hydrogen sulfide scrubbing systems on two US dairy farms.

Table 3 Average daily biogas production of each digester (L/day)

	Digester 1				Digester 2				Digester 3			
Month	Avg (L/day)	Min (L/day)	Max (L/day)	Std (L/day)	Avg (L/day)	Min (L/day)	Max (L/day)	Std (L/day)	Avg (L/day)	Min (L/day)	Max (Lday)	Std (L/day)
Jan-19												
Feb-19	71	55	90	15								
Mar-19	159	67	223	42								
Apr-19	290	251	512	77								
May-19	253	184	300	25								
Jun-19	250	152	302	34								
Jul-19	251	178	316	33	467	417	523	38	428	200	517	125
Aug-19	192	133	596	92	466	158	544	68	354	123	501	101
Sep-19					375	104	500	99	375	104	500	99
Oct-19	411	175	652	133	453	276	599	70	416	259	579	80
Nov-19	199	66	549	123	409	146	494	73	302	227	419	52
Dec-19	179	24	367	80	390	126	497	107	306	176	429	76
Jan-20	204	98	350	71	423	227	719	108	415	299	664	79
Average	223				426				371			

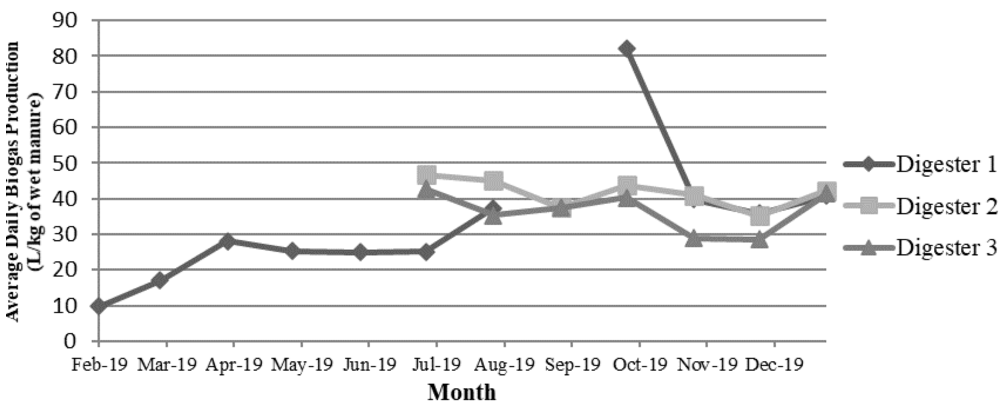


Fig. 2 Average daily biogas production per kg of wet manure (L/kg)

Average daily biogas productions per kg of wet manure were 33 L/kg, 42 L/kg, and 36 L/kg in digester 1, digester 2, and digester 3, respectively; see Fig. 2. The mean biogas production of the three digesters was 37 L/kg of fresh manure. After opening for checking in August 2019, the digester was restarted and began to produce biogas in early October 2019. In October 2019, the rate of biogas production was highest, around 80 L/kg of wet manure, due to the change of feedstock from cow to pig manure which yield higher biogas production rate from the same mass. Aremu and Agarry (2012) reported a little higher biogas production from pig manure than cow manure in Lithuania. Matulaitis (2015) found higher methane content in biogas produced from pig manure than from cattle one.

Quality of Biogas

Table 4 Biogas composition

	Digester 1					Digester 2					Digester 3				
Month	CH_4 (%)	CO_2 (%)	O_2 (%)	H_2S (ppm)	Bal (%)	CH_4 (%)	CO_2 (%)	O_2 (%)	H_2S (ppm)	Bal (%)	CH_4 (%)	CO_2 (%)	O_2 (%)	H_2S (ppm)	Bal (%)
Jul-19	48.8	35.0	1.1	410.5	14.6	50.7	35.3	0.3	446.5	13.8	50.9	35.6	0.2	503.0	13.4
Aug-19	48.2	36.2	0.6	410.0	14.6	51.2	38.3	0.3	273.1	10.1	51.3	38.6	0.3	265.4	10.1
Sep-19						51.1	41.6	0.4	115.6	6.1	51.1	41.6	0.4	115.6	6.1
Oct-19	51.9	38.4	0.1	751.7	9.7	49.4	40.2	0.2	169.7	10.2	49.0	39.0	2.0	242.6	9.9
Nov-19	52.5	39.3	0.1	692.4	8.1	50.0	40.6	0.1	299.6	9.3	50.4	41.3	0.1	584.6	8.2
Dec-19	55.4	42.2	0.2	722.0	2.2	54.9	41.9	0.1	740.3	3.1	54.6	41.3	0.0	936.1	2.3
Jan-20	54.3	43.3	0.1	637.5	2.8	53.2	42.4	0.2	693.3	4.2	53.8	43.3	0.1	897.5	2.7
Average	51.8	39.1	0.4	604.0	8.7	51.5	40.0	0.2	391.2	8.1	51.6	40.1	0.4	506.4	7.5

The average percentage of methane in digester 1, digester 2, and digester 3 were 51.8%, 51.5%, and 51.6% respectively; see Table 4. Abubakar and Ismail (2012) reported that average methane in biogas from cow dung from slaughterhouse in Malaysia was 47% which is similar to these results. Choudhury et al. (2019) reported average methane content of 64.1±0.2% in biogas of US dairy farms. Methane content fluctuates according to digester conditions and quality of feedstock. Average percentages of carbon dioxide in the three digesters were around 40%, while average percentage of oxygen was less than 1%. The average hydrogen sulfide varied from around 390 ppm to 604 ppm. The average highest concentration of 936.1 ppm was in the digester 3 in December 2019. Mean hydrogen sulfide in biogas from dairy farms in the US was 450±42 ppm (Choudhury et al., 2019). It is suitable for use with gas heating boiler and combined heat and power (CHP) systems (Allegue and Hinge, 2014; Petersson and Wellinger, 2009). To use with engine, it is recommended that hydrogen sulfide should be reduced to 100 ppm to 250 ppm (Bioclean, 2020).

CONCLUSION

The average daily biogas production of the pilot digesters, each with $1m^3$ working volume, varied from 223 L/day to 426 L/day when feeding with 5 kg to 10 kg of cow manure per day and mixed with water using 1:1 ratio. The average rate of daily biogas production was around 37 L/kg of wet cow manure.

The biogas contained on average 51.6% methane, 39.7% carbon dioxide, 0.3% oxygen, 500ppm hydrogen sulfide, and other gases was around 8.1%. Average percentage of methane was lower than the one reported in US dairy farms, which was around 64%. However it was similar to the one in Malaysia which was around 47%. The average hydrogen sulfide varied from around 390 ppm to 604 ppm. It is suitable to use with gas heating boiler and combined heat and power (CHP) systems.

However, it is not suitable to use with gas engine without pre-treatment system which is used to reduce hydrogen sulfide concentration in the biogas to 100 ppm to 250 ppm.

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