CO-DIGESTION OF PIG MANURE AND HOUSEHOLD ORGANIC WASTE IN DOMESTIC BIOGAS DIGESTER

Đến tòa soạn 10-3-2021

Nguyễn Phạm Hồng Liên, Huỳnh Trung Hải
Trường Đại học Bách Khoa Hà Nội

TÓM TẮT

ĐỒNG PHÂN HUỶ CHẤT THẢI CHĂN NUÔI HEO VÀ CHẤT THẢI RẮN SINH HOẠT TRONG HẦM BIOGAS QUY MÔ HỘ GIA ĐÌNH

Hầm biogas hộ gia đình ở nông thôn Việt Nam đã chứng minh hiệu quả xử lý chất thải chăn nuôi nhất định, đồng thời tạo ra nhiên liệu khí sinh học cho các hộ gia đình. Để đánh giá hoạt động của hầm biogas xử lý chất thải nuôi heo cũng như khả năng xử lý kết hợp với chất thải sinh hoạt từ các hộ gia đình, nghiên cứu đã thực hiện trên hầm biogas trong thực tế có thể tích 6m^3. Khảo sát được thực hiện trong 3 giai đoạn chạy tại đó, giai đoạn 1 và giai đoạn 2 hầm biogas chỉ xử lý phân lợn ở các tải trọng khác nhau, và ở giai đoạn 3, chất thải sinh hoạt hữu cơ được bổ sung để tăng tải trọng hệ thống lên 10% so với chế độ 2. Kết quả cho thấy, hầm hoạt động ổn định trong 60 ngày khảo sát ở giai đoạn 3, không chỉ cho lượng khí sinh ra cao hơn 58% mà còn có năng suất sinh khí riêng (m^3 mê tan/kgVS) cao hơn 39% so với chế độ không bổ sung chất thải rắn. Nước thải sau xử lý có hàm lượng COD trung bình 1588 mg/L, cần được xử lý trước khi thải ra môi trường.

Từ khoá: *chất thải chăn nuôi, chất thải rắn sinh hoạt, đồng phân huỷ yếm khí, hầm biogas*.

1. INTRODUCTION

With the development of animal husbandry in recent years in Vietnam, domestic biogas digester has proven to be an effective and attractive technology for many households to treat livestock waste. Producing methane by anaerobic digestion of agricultural organic residues, especially animal manure is a promising way for not only producing clean energy but also solving environmental problems. The biological reaction occurring during anaerobic digestion in the biogas digester can reduce the organic content of waste material by 30-60 percent and produce biogas for household utilization.

The common raw materials used for biogas digester are organic waste, e.g. human excreta, animal manure, and vegetable crop residues. Due to the high organic matter content in domestic solid waste, it can be an active raw material for anaerobic digestion. According to the 2016 Vietnam environmental report, the amount of MSW generated annually in the countryside was about 7 tons million. Most of the amount of domestic solid waste is disposed to landfill. Direct landfilling of domestic organic waste was known to create lasting detrimental impacts on the environment (P.H.L. Nguyen *et al.*, 2007). Thus, the utilization of the waste produces biogas by using biogas plant treating animal manure was studied.

Anaerobic co-digestion of organic fraction of domestic solid waste and animal manure in a proper ratio could reach high methane yield and the best biodegradability (Hailin Tian *et al.*, 2014). Moreover, anaerobic co-digestion of different organic materials enhances the stability of the anaerobic process because of better carbon to nitrogen (C/N) balance (El-Mashad and Zang, 2010; Mshandete *et al.*, 2004).

The aim of this research was to investigate the performance of domestic biogas digester treating pig manure and the feasibility of anaerobic co-digestion of pig manure and organic fraction of MSW using this system.

2. METHODOLOGY

2.1. Anaerobic digester

The research was conducted in a household biogas reactor in the suburbs of Hanoi. This digester is completely buried underground, consists of a reactor tank with an effective volume of 6m^3 and a displacement tank with a total volume of 2m^3. The inlet pipe is straight and ends at mid-level in the digester. The outlet is at the same level. The anaerobic condition was ensured by completely closing the reactor with several thin layers of mortar at the inside surface. The gas produced during digestion is stored under the dome. During gas, production slurry is pushed back sideways and displaced to the displacement tank. When gas is consumed, the slurry enters back into the digester from the displacement tank. This was to ensure the pressure in the digester remains constant. A gas sample was sampled for content measurement before reaching the wet gas meter. Fig. 1 represents the schematic diagram of an anaerobic digester

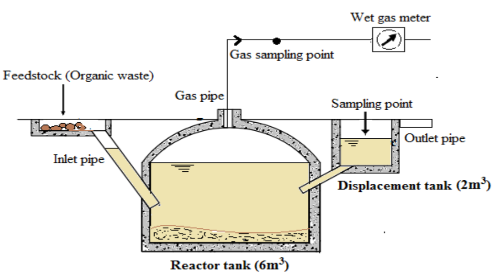

Figure 1. Schematic diagram of digester

Table 1. Composition of the MSW

No.	Composition of the MSW	% (Wet waste basis)
1	Vegetables	70÷74
2	Fruit waste	23÷25
3	Bone, shape of egg, etc.	2÷3
4	Rock, coal ash, plastic, etc.	1÷2

Table 2. Characteristic of PM and MSW (mean±SD)

Properties	PM		MSW
	Mode 1	Mode 2	
Total solid (TS) (%WW)	23.2±0.2	25.6±0.9	12.8±2.2
Volatile solid (VS) (%TS)	88.2±0.5	89.1±0.3	88.6±3.7
Total kjeldahl nitrogen (TKN) (mg/g TS)	32.2±2.5	34.1±1.2	20.4±4.8
Total organic carbon (TOC) (mg/ g TS)	554.8±9.7	576.2±12.1	580.6±85.0
C/N ratio	17.2	16.9	28.5

2.2. Feedstocks

Feedstocks are pig manure (PM) and organic fraction of domestic waste/municipal solid waste (MSW). MSW was collected from twenty households in Hanoi every two days and the weight of wastes range from 6 kg to 7kg on a wet waste basis. MSW was classified to remove visible inert fractions including plastic, rock, bone, etc. The remaining fraction was reduced size by a cutter to the particle size less than 5 mm diameter. PM was livestock waste of household and added directly into the digester. The composition of the MSW is given in Table 1 and Characteristic of PM and MSW is given in Table 2.

2.3. Operation modes

The experiment was conducted with a biogas digester in two modes: Mode 1 where PM digestion alone was applied with two periods corresponding to two organic loading rates and Mode 2 where co-digestion of PM and MSW was applied. The operation parameters of the biogas digester in Mode 1 (period 1 and 2) and Mode 2 (period 3) were described in Table 3.

Table 3. The operational parameters of biogas digester in model 1 and model 2

Operation parameters	**MODE 1**		**MODE 2**
	Period 1	**Period 2**	**Period 3**
Reactor volumes (m^3)	6		
Hydraulic retention time (day)	7		
Experimental duration (day)	14	21	60
Sampling frequency of effluent	Sampling was done for pH measurement every day and usually every two day or every four day for other parameters measurement (COD, NH_4^+ ,VFA, TS, VS, Alkalinity)		
Sampling frequency of gas	Everyday		
Feed stock	PM		PM and MSW
C/N ratio of feedstock	17.23	16.89	18.27
TS total of feedstock (%WW)	23.04	25.55	23.61
VS total of feedstock (%TS)	88.18	89.05	89.01
Feedstock loading (kg WW/d)	24	14	14 (PM) and 2.5 (MSW)
Organic loading rate (kg VS/m^3.d)	0.66	0.42	0.46
MSW:PM ratio (WW basis)	-		15:85

In mode 1, the digester received only pig manure as feedstock at the organic loading rate of 0.66 kg VS/ m^3.d (Period 1) and 0.42 kg VS/ m^3.d (Period 2). Feeding was conducted three times a day when the farmer gathered PM and flushed the floor (normally at 8 am, 11 am and 15 pm). The purpose of Mode 1 was to investigate of performance of biogas digester treating PM in terms of methane yield and characteristic of effluent. Moreover, Mode 1 is also controlled.

In mode 2 (period 3), co-digestion of municipal solid waste and pig manure was conducted in the same digester. MSW was added into the digester every two days. Feeding of MSW was conducted in the morning at 8 am when PM was fed. In this mode, the performance of biogas digestion was investigated. The purpose of mode 2 was to investigate the feasibility of anaerobic co-digestion of MSW and PM at the same digester in terms of methane production and system stability to further applications.

2.4. Sampling and analysis

During experiments, PM and MSW were sampling every week and the samples were grinded to archive the average particle size less than 2 mm for analysis of total solids (TS), volatile solids (VS), total Kjeldahl nitrogen (TKN), and total organic carbons (TOC). The TS and VS was analyzed according to SMEWW 2540B:2012 and SMEWW 2540E:2012 respectively. The TKN and TOC of the waste samples were measured according to TCVN 6498: 1999 and TCVN 6644: 2000, respectively. The effluents of the digester were sampled periodically for measurement of pH (pH meter- HORIBA B212) and analysis of volatile fatty acid (VFA), total solids (TS), volatile solids (VS), Ammonium-nitrogen (NH_4^+), Alkalinity, according to standard method (APHA, 2017), chemical oxygen demand (COD) according to TCVN 6491 (1999). Daily gas production was determined by RITTER wet gas meter (Germany). The biogas samples were collected periodically and immediately analyzed for the content of methane and carbon dioxide using the SHIMADZU portable gas analyzer (Japan).

3. RESULTS AND DISCUSSION

3.1. Biogas production

The measurement of biogas production is of fundamental importance to assess the performance of biogas plants treating organic waste. In this study, the variation of daily biogas production and specific biogas yield by the time were shown in Figure 2. The average daily biogas production is 0.83; 0.57 and 0.9 m^3 methane/day respectively in periods 1,2, and 3 respectively; corresponding to average specific biogas yields of 0.21; 0.23, and 0.32 m^3 CH_4/kg VS/day.

When comparing period 1 and period 2 (same feedstock pig manure but different organic loading rates), it can be seen that at the higher organic loading rate in period 1 (OLR of 0.66 kgVS/m^3.day), average daily biogas production was higher but the specific biogas yield was slightly lower than period 2 (OLR of 0.42 kgVS/m^3.day). It indicates that a high organic loading rate will result in high daily biogas production but it can give a slightly smaller percentage conversion of volatile solids to biogas.

In period 3, adding 2.5kg MSW per day means to increase of organic loading rate from 0.42 kg VS/m^3.day (in period 2) to 0.46kg VS/m^3.day (in period 3) - approximately 10% increase in organic loading rate. The behavior of digester in this period in terms of biogas production was interesting. A significant rise in both daily biogas production and specific biogas yield was observed. The behavior of digester in this period in terms of biogas production was interesting. A significant rise in both daily biogas production and specific biogas yield was observed. The daily biogas production reached the value of 0.9 m^3 CH_4/day, equivalent to a 58% increase from period 2; the specific biogas yield increased approximately 39% compared to period 2. Furthermore, both biogas production and specific biogas yield were also higher than that in period 1 when OLR was much higher at 0.66 kgVS/m^3.day. It implicates that co-digestion showed benefits in terms of biogas production.

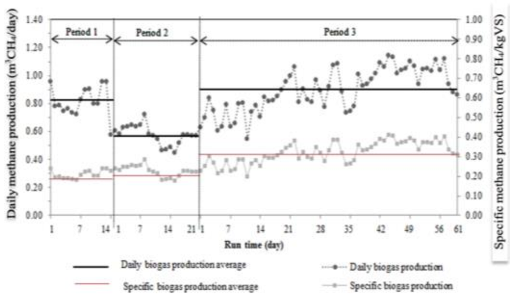

Figure 2. Daily methane production and specific methane production in three period

The behavior of digester in this period in terms of biogas production was interesting. A significant rise in both daily biogas production and specific biogas yield was observed. The daily biogas production reached the value of 0.9 m^3 CH_4/day, equivalent to a 58% increase from period 2; the specific biogas yield increased approximately 39% compared to period 2. Furthermore, both biogas production and specific biogas yield were also higher than that in period 1 when OLR was much higher at 0.66 kgVS/m^3.day. It implicates that co-digestion showed benefits in terms of biogas production.

The anaerobic digestion of MSW by co-digestion with other organic substrates shows several advantages in terms of process stability and economical feasibility (Mata-Alvarez J., 2003). Co - digestion in a proper ratio helped improve the specific biogas production compared to the digestion of PM alone by improvement of C/N ratio, as reported by others author (Hailin Tian *et al.*, 2014; Mohammad Nazrul Islam *et al.*, 2012). In another word, PM could provide a buffering capacity for MSW or MSW could reduce the ammonia nitrogen concentration during anaerobic digestion of household biogas reactor.

3.2. Effluent characteristics

The stability of digester performance was also investigated through effluent characteristic examination. Table 4 shows wastewater charactersitic in terms of COD, VFA, pH, NH_4^+, Alkalinity, TS, VS.

Table 4. The value of parameters of effluent digestate

Parameter	Period 1			Period 2			Period 3		
	Max	**Min**	**Average**	**Max**	**Min**	**Average**	**Max**	**Min**	**Average**
VFA (mg/l)	129	266	225±58	214	118	157±39	233	75	149±49
NH_4^+ (mg/l)	718	868	763±63	980	812	913±64	994	630	834±93
sCOD (mg/l)	830	1161	992±154	1341	1034	1188±133	2005	928	1588±320
Alkalinity (mg $CaCO_3$/l)	3085	3925	3511±360	4955	3890	4469±400	4333	2040	3399±665
Total solid (mg/l)	3121	3614	3417±223	4315	3756	4160±204	8543	5593	7036±1001
Volatile solid (mg/l)	1066	1242	1168±73	1465	1163	1311±108	5627	2060	3577±979

The pH value is a very important indicator for evaluating the stability of an anaerobic digestion system (Liu, C. F *et al.*, 2008; Shi, X.S *et al.*, 2014), and its variation also depends on the buffering capacity of the system. The pH of effluent in the period 1 and 2 were stable between 7.0 - 7.1. In period 3, the pH value range from 6.9-7.0, slightly lower than period 1 and 2. The addition of MSW into the digester slightly dropped the pH values of the system but it is still quite stable within the appropriate range.

As shown in Figure 4, alkalinity was at a good level of 3085 mg/l to 4955 mg/l in periods 1 and 2. It dropped significantly at the first two weeks of period 3 when MSW started to be added but it returned to the same level of period 2 (more than 3000 mg/L) after that. It showed the adaptation of the system to new material in terms of alkalinity.

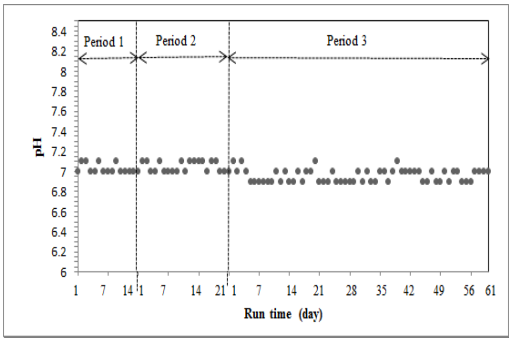

Figure 3. The variation of pH

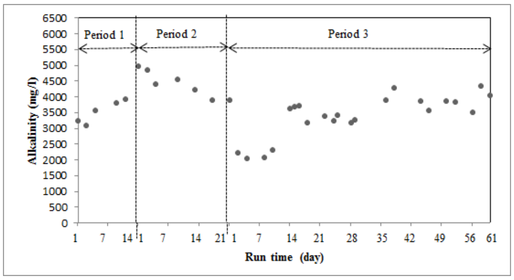

Figure 4. The variation of alkalinity

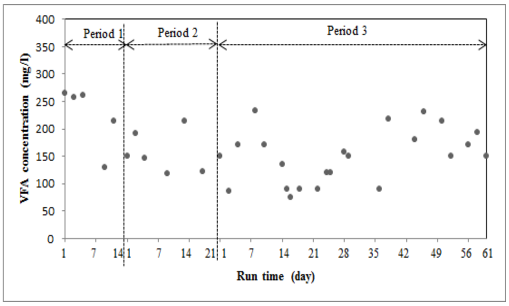

Figure 5. The variation of Volatile fatty acid

The VFA values can also be used as another indicator for the evaluation of fermentation status and the results are shown in Figure 5. The total VFA values range from 75 mg/l to 266 mg/l. It was reported that the fermentation process was slightly inhibited when the VFA concentration was above 4000 mg/l and the composition of biogas changed obviously with the VFA concentration over 6000 mg/l (Siegert *et al.*, 2005). VFA inhibition is observed in terms of a great drop in the reactor's pH value. Meanwhile, pH values in the three periods were quite stable; its variation was not inconsiderable. Therefore, it can be stated that the anaerobic process was stable and not inhibited by VFA for all three periods.

The NH_4^+ values of the three periods range from 630 mg/l to 930 mg/l. The effluent ammonium nitrogen is quite high because PM is rich in nitrogen concentration (Braun. R *et al.*, 1981; Yin.D *et al.*, 2014). Moreover, when operated biogas digester, most of the urine that is high in ammonia nitrogen concentration of animals had been added into the digester. Ammonia nitrogen inhibition has been observed to commence at a concentration of 1500 - 3000 mg/l at a pH value of 7.6. Thus, ammonia inhibition was not observed in this research. Average ammonium nitrogen in period 2 is slightly higher than that in period 1 possibly because of different influent characteristics and that of period 3 is higher than both period 1 and 2 because MSW was added.

In terms of COD and TS, VS of effluents, Tables 5 shows that the concentration of these parameters increases slightly in period 3. The result obtained in this work were higher than the previous finding where conducted at the similar system and modern farm-size digesters (T.H.Nguyen *et al.*, 2012; D.T. Vu *et al.*, 2008). The average sCOD in period 2 and 3 was higher than that in period 1 possibly because of higher TOC content in the feedstock as shown in Table 2. In period 3, there was a significant increase for both effluent soluble COD and TS. Particularly sCOD increased about 60% and 34 %; TS increased about 105% and 66% compared to period 1 and 2 respectively. Therefore, when MSW was added, digester liquid effluent characteristic was not improved in terms of sCOD and TS. There would be a need for wastewater treatment whenever MSW is added to the system or not.

4. CONCLUSIONS

According to the results presented in this paper, it is concluded that co-digestion at MSW: PM ratio of 15:85 (WW based) and the total organic loading rate of 0.46 kgVS/m^{3}day could increase the daily biogas yield of 58% and specific biogas yield of 31% in comparision with digestion of PM without MSW.

Anaerobic co-digestion of MSW and PM in a household digester is a possible solution for treating organic household waste in a rural area Co-digestion can be applied for increasing biogas production.

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