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Enhancing biogas production by anaerobic co-digestion of water hyacinth and pig manure

Gia tăng lượng khí sinh học từ đồng phân hủy yếm khí lục bình và phân heo

Research paper

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The characteristics of anaerobic batch co-digestion of water hyacinth (WH) with pig manure (PM) under seven mixing ratio 100%WH; 80%WH : 20%PM; 60%WH : 40%PM; 50%WH : 50%PM; 40%WH : 60%PM; 20%WH : 80%PM and 100%PM were investigated, each treatment was conducted in five replications with daily loading rate at 1 gVS.L^{-1}.day^{-1}. During the anaerobic digestion process of 60 days, maximum biogas production occurred in two periods, the first stage from 12 - 22 days and second stage from 30 - 35 days. The maximum daily biogas productions from each stage were 17.2 L.day^{-1} and 15.1 L.day^{-1}, respectively. The cumulative biogas production varied between 60 L (100%PM) and 360 L (60%WH : 40%PM). The results showed that the biogas yields of co-digestion 40 - 80%WH were higher from 34.6 to 56.1% in comparison with 100%PM and from 109 to 143% in comparison with 100%WH. When mixing with WH, treatments were received more methane and the methane contents were higher than 45% (v/v) that good for energy using purposes.

Nghiên cứu được thực hiện nhằm khảo sát khả năng gia tăng lượng khí sinh học khi tiến hành đồng phân hủy yếm khí lục bình (WH) và phân heo (PM) ở các tỉ lệ phối trộn khác nhau gồm 100%WH; 80%WH : 20%PM; 60%WH : 40%PM; 50%WH : 50%PM; 40%WH : 60%PM; 20%WH : 80%PM và 100%PM. Các nghiệm thức được nạp lượng nguyên liệu là 1 gVS.L^{-1}.ngày^{-1} và bố trí lặp lại 5 lần. Theo dõi quá trình phân hủy của các nghiệm thức trong 60 ngày ghi nhận có 2 khoảng thời gian lượng khí sản sinh nhiều nhất - giai đoạn 1 từ ngày 12 đến 22, giai đoạn 2 từ ngày 30 đến 35. Lượng khí sản sinh cao nhất tương ứng trong mỗi giai đoạn là 17.2 L.ngày^{-1} và 15.1 L.ngày^{-1}. Lượng khí tích lũy trong suốt thời gian thí nghiệm ghi nhận thấp nhất ở nghiệm thức 100%PM đạt 60 L, và cao nhất ở nghiệm thức 60%WH : 40%PM đạt 360 L. Năng suất khí sinh ra của các nghiệm thức phối trộn lục bình từ 40 đến 80% cao hơn từ 34,6 đến 56,1% so với nghiệm thức 100%PM và cao hơn từ 109% đến 143% so với nghiệm thức 100%WH. Hàm lượng mê-tan sinh ra từ các nghiệm thức có phối trộn lục bình ổn định trong khoảng > 45% đảm bảo nhiệt lượng cho nhu cầu sử dụng năng lượng.

Keywords: batch anaerobic co-digestion, biogas, mixing ratios, pig manure, water hyacinth

1. Introduction

Nowadays, the world strongly depended on fossil energy likes fuels, oil, petrol gas and coal. The burning process of fossil fuels emitted a huge amount of greenhouse gases that caused climate change. Therefore, there are many countries in the world focused on developing of renewable energy sources such as wind power, solar energy and biomass energy. In Vietnam, biogas - a potential renewable energy - was used more and more popular in rural areas because of low-cost and easy application (Chiem & Matsubara, 2012). The input for biogas production was varied including agricultural wastes, husbandry wastes, and industrial wastes (Bundhoo *et al.*, 2016; Nguyen & Fricke, 2015; Abbasi *et al.*, 2012). In the Mekong Delta (MD), biogas technology was used for treating husbandry wastes, especially pig manure (PM). However, most of farmers in MD doing their pig pressing in small scale and decentralize. As a result, it is often lacking of input substrates for biogas production when the farmers stop raising pig or start a new pig raising cycle. While, water hyacinth (WH) was abundant

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in MD due to their high density in canal system (Nam *et al.*, 2015). The development of WH in the river caused many negative effects on environment and water transport. Some researches proved that WH can be used for biogas production (Nguyen & Fricke, 2015; Ngan *et al.*, 2012; Gunnarsson & Petersen, 2007; Abdelhamid & Gabr, 1991). However, high content of lignocellulose and lignin in WH made it hard for decomposition (Harun *et al.*, 2011). Mixing PM and WH could balance C and N ratio and was beneficial for biological decay (Nam *et al.*, 2015; Ngan *et al.*, 2012). Thus, this study was done in order to find out the suitable mixing ratio between WH and PM for biogas production for application in case of shortage of PM.

2. Materials and methods

2.1 Materials preparation

WH was collected in the canals in Camtho City, removed the root then sun-dried for 10 days. Before using for anaerobic digestion, it was chopped into the pieces of 10 ± 0.32 cm (n = 100). PM was taken from small pig farm in Tan Phu Thanh village, Chau Thanh district, Hau Giang province. PM was dried in cool place and mixed well before using for experiment.

2.2 Experimental design

The experiment was carried out in randomly design in batch digesters with 7 mixing ratios between WH and PM. The batch anaerobic digestion process was done in 21 L plastic reactors (Nam *et al.*, 2015). Each reactor contented 765 g VS based on the loading rate of 1 g $VS_{added}.L^{-1}.day^{-1}$ (suggested by Appels *et al.*, 2008) in the period of 45 continuous days. WH was pre-treated by biogas effluent in 5 days before loading into the reactors. All gas was collected and stored in an alluvium bag, then its volume and the composition were measured every day.

Table 1. The experiences design

Mixing ratio (%WH : %PM)	VS_{loaded} (g)		Total VS_{loaded}	C/N ratio
	WH	*PM*		
0 : 100	-	765	765	23.5
20 : 80	153	612	765	25.1
40 : 60	306	459	765	27.0
50 : 50	382.5	382.5	765	28.1
60 : 40	459	306	765	29.3
80 : 20	612	153	765	32.1
100 : 0	765	-	765	35.6

2.3 Analytical methods

The temperature, pH, redox potential of the fermented liquid was measured directly everyday by pH/ORP meter (HM-3IP-DKK TOA, Japan). Biogas volume was determined by drum-type gas volume meter (TG 02, Ritter, Germany). The methane and carbon dioxide content in biogas was determined by gas chromatography (GC 2014 AT Shimadzu, Japan). The VS content of the fermented liquid when starting and ending the experiment also recorded for VS reduction calculation.

2.4 Data processing

Data were analyzed by One-way ANOVA and Duncan post-hoc test for multiple comparisons. An alpha (α) level of 0.05 was used to determine the statistical significance of all analysis. Data were checked and transformed as appropriate to meet the normality and variance homogeneity requirements prior to statistical analysis. The analysis was performed by using the statistical software IBM SPSS 20.0.

3. Results and discussions

3.1 Temperature, pH, redox and alkalinity

The results showed that temperature of all reactors fluctuated from 29.1 - 31.1°C (Figure 1a), the temperature in all reactors containing mixed PM - WH had the temperature higher than the ones containing pure PM. However, the difference was not high (lower than 0.5°C). The temperature in range of mesophilic temperature and the temperature was suitable for biological decomposition (Ngan *et al.*, 2012).

Figure 1b illustrated that pH of substrates in all reactors ranged from 5.2 - 7.2, the more WH added the more pH reduced and the lowest was recorded in 100% WH reactors at pH of 5.46. The result was similar to the findings by Ye *et al.* (2013). pH levels of the substrates mixed WH and PM (0 : 100; 20 : 80; 40 : 60; 50 : 50; 60 : 40 and 80 : 20) were in range of 6.2 - 8.5 that suitable for the activity of methanogen batteries (Chandra *et al.*, 2012).

During anaerobic digestion process, redox of all reactors was highly fluctuated from -313 to -94 mV (Figure 1c); redox value lower than zero indicated the reduction process and it is a good indicator for the anaerobic digestion. When the redox value is smaller than -200 mV, it is easier for converting organic matter to methane. In this study, redox value at most of the time was lower than -200 mV.

Figure 1d showed that the alkalinity of substrate in all reactors ranged from 733 - 3,307 mg $CaCO_3$/L, the alkalinity of 100%WH substrate was lower than the one of others. The alkalinity ranged from 1,000 - 3,000 mg $CaCO_3$/L was suitable for methanogen batteries' activity (Ren *et al.*, 2004).

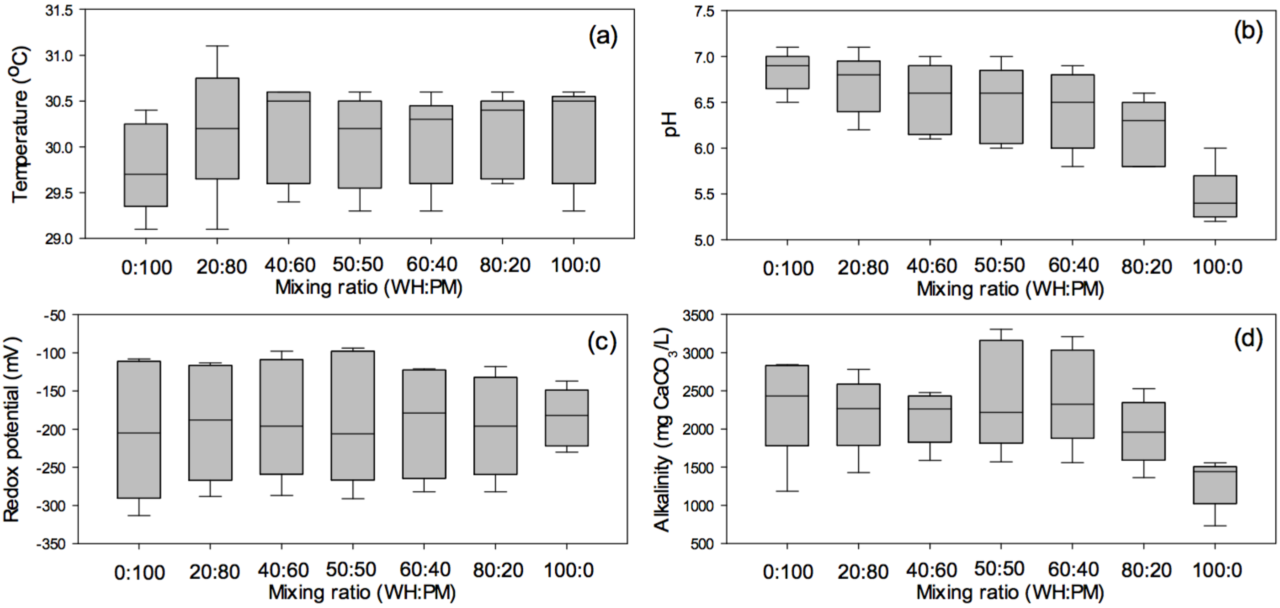

Figure 1. The variation of temperature (a), pH (b), redox potential (c) and alkalinity (d)

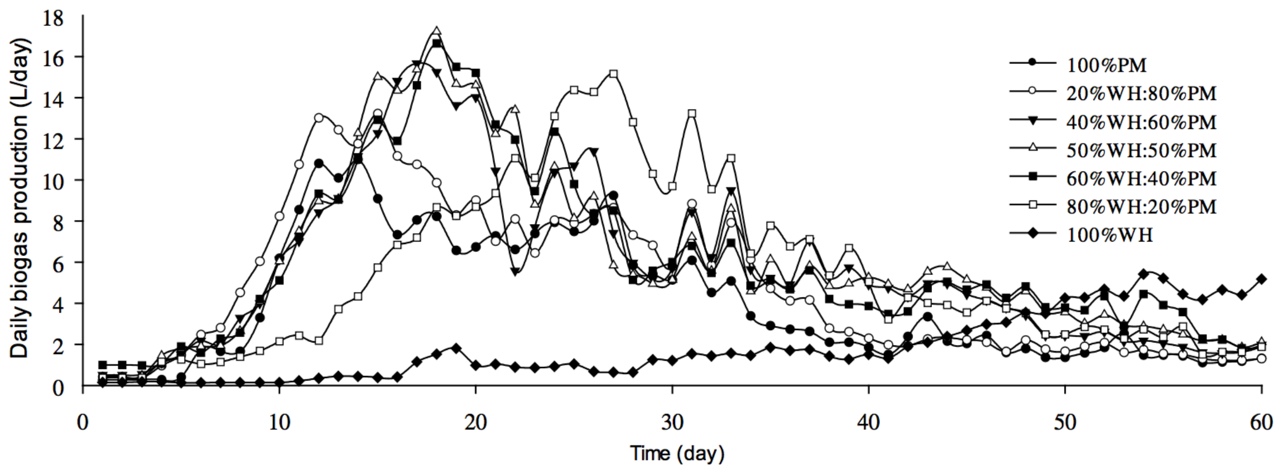

Figure 2. Daily biogas production of WH : PM treatments

3.2 Daily biogas productions

Figure 2 showed that there were two periods produced more biogas than others. The first period from the day 12 to 22 with the highest production at 17.2 $L.day^{-1}$ in reactor of 50%WH : 50%PM and the second period from the day 30 to 35 at 15.1 $L.day^{-1}$ in reactor of 80%WH : 20%PM (Figure 2). The reactors that mixed PM and WH produced biogas quickly than the pure PM and pure WH; the WH reactors produced biogas slower than the PM reactors. While 20%, 40%, 50%, 60%WH reactors produced more biogas from the day 12 to 22, the reactor of 80%WH generated more biogas from the day 24 to 34. After 35 days, daily biogas production was gradually reduced until 60 days. The reactors with more PM reduced daily biogas production stronger than the one with more WH.

3.3 Cumulative biogas production, biogas yield, methane content and VS reduction

The results showed that cumulative biogas after 60 days of 40%WH, 50%WH and 60%WH reactors was highest at 341.8 L, 350.5 L and 358.7 L, respectively. The 80%WH reactor had the biogas volume of 330 L that was lower than the ones of 50% and of 60% reactors, but was significant higher than the ones of 20%WH reactor (286 L), of 100%PM reactor (190 L) and of 100%WH reactor (102 L) ($p<0.05$). The statistic analytical results showed that when WH increased from 40% to 60% in loading component, biogas production was higher than other mixing ratio treatments ($p<0.05$). When the mixing ratio was higher than 60%WH or lower than 40%WH, the cumulative biogas was reduced in comparison with reactors of 40 to 60%WH. The reactors of 100%WH caused pH dropped to 5.2 - 5.4 and inhibited the methanogenic bacteria. Thus biogas productions of these reactors were lower than others. VS reduction of all treatment ranged from 37.8 - 55.7% after 60 days; mixing PM and WH made the decomposition process more quickly than 100%WH and 100%PM.

Table 2. Cumulative biogas production, biogas yield, VS reduction and methane content

Treatments (%WH : %PM)	Cumulative biogas production (L)	VS reduction (%)	Biogas yield ($L.kgVS^{-1}_{degraded}$)	Methane content (%)
0 : 100	$190^{d} \pm 24$	45.2	$549^{c} \pm 37$	$50.45^{ab} \pm 6.21$
20 : 80	$286^{c} \pm 24$	50.7	$738^{b} \pm 45$	$52.93^{a} \pm 4.48$
40 : 60	$342^{ab} \pm 24$	55.7	$803^{ab} \pm 66$	$53.05^{a} \pm 0.96$
50 : 50	$351^{a} \pm 24$	55.6	$825^{ab} \pm 30$	$52.85^{a} \pm 1.82$
60 : 40	$359^{a} \pm 24$	54.8	$857^{a} \pm 59$	$53.00^{a} \pm 3.37$
80 : 20	$330^{b} \pm 24$	53.1	$812^{ab} \pm 50$	$45.28^{b} \pm 4.51$
100 : 0	$102^{e} \pm 24$	37.8	$353^{d} \pm 86$	$29.55^{c} \pm 6.88$

Note: The number in the same column with the same letter (a, b, c, etc.) was not significant different in ANOVA, Duncan test of 5%

Biogas yields of all treatment ranged from 353 - 857 $L.kgVS^{-1}_{degraded}$. Biogas yields of 40 - 80% WH reactors were not significant different ($p>0.05$), but different from 100%WH and 100%PM reactors. Mixing PM and WH increased biogas yield from 34.6 to 56.1% and from 109 to 143% in comparison with 100%PM and 100%WH, respectively. In case of treatment 100%WH, pH drop is the reason inhibiting methanogen then leads to low biogas yield. The results showed that mixing WH with PM can be applied with 40 - 80%WH and all these treatments was not different at biogas production ($p>0.05$).

The methane contents of all treatment ranged from 29.6 - 53%. The mixing ratio from 20 to 60% produced significant higher methane than that of 80%PM and of 100%PM ($p<0.05$), but the methane contents from treatments of 0 : 100 and of 80 : 20 were not significant different ($p>0.05$). The previous research of Ngan *et al*. (2012) showed that methane content higher than 45% can be used for household's cooking. Therefore, methane content of all WH mixed treatments were good for energy using and the biogas can be used for replacing fossil fuel.

4. Conclusions

During the anaerobic fermentation process, temperature, pH, redox potential and alkalinity were in optimizing range for biogas production. The daily biogas production separated to two stage: the 1st stage from day of 12th to 22nd and the second stage from day of 30th to 35th. Mixing WH to PM from 40% to 60% can produced more biogas and increase biogas yield. Mixing treatments of WH and PM can increase biogas production from 34.6% to 56.1% and from 109% to 143% in comparison to treatment of 100%PM and 100%WH, respectively. Biogas quality from all treatments can be used for cooking.

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