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Ammonia Removal of Chicken Manure by Vacuum Stripping Technique for Sustainable Biogas Production in Chicken Farm

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Abstract

The objective of the research was to examine how the temperature, agitation rate, and duration of pretreatment process of chicken manure (CM) affect the efficacy of ammonia removal and biogas production. The CM was pretreated through vacuum thermal stripping in various conditions and subsequently anaerobic digested using biochemical methane potential (BMP) test. The findings indicated that vacuum thermal stripping technique was successful in removing ammonia from the CM. However, the potential for ammonia removal was also influenced by the conditions used in the pretreatment process. Pretreatment at 120°C with agitation at 50 rpm for 4 hr showed the highest ammonia removal (68.69%), which was significantly greater than pretreatment at 50°C and 85°C (23-44%). However, pretreatment at high temperature could lower biogas yield of pretreated CM samples. The biogas yield of CM sample pretreated at 120°C (272-277 NmL/gVS$_{added}$) was lower than that of pretreatment at 50°C and 85°C (484-517 NmL/gVS$_{added}$). When using the vacuum thermal stripping technique for application in biogas system, it is important to ensure that the conditions are appropriate for both removing ammonia and producing biogas.

Keywords : ammonia removal; chicken manure; vacuum stripping technique; biogas production; chicken farm

Introduction

A challenge for chicken farm owners that desire to manage their waste through anaerobic digestion (AD) process for generating biogas is due to a large amount of nitrogen especially in the form of organic and ammonia nitrogen in chicken manure (CM). Significant nitrogen content in CM could be toxic to the biogas system, lower the biogas yield, and subsequently lead to process failure [1, 2]. To mitigate this issue, substantial amounts of water is usually used for dilution to obtain a total solids (TS) content of 0.5-3.0% for efficient AD of the CM [3]. However, using large amounts of water for dilution affects sustainability of the process, creates extensive amount of wastewater, and requires large size of reactor for AD.

Pretreatment which aims at ammonia reduction would help to lessen ammonia toxic effect of the nitrogen rich material resulted in biogas production improvement in high solids content biogas system or dry AD or solid-state AD (SS-AD) [4]. The vacuum stripping technique could be one of the promising techniques for ammonia removal. Under vacuum condition at high temperature, the ammonia mass transfer increases and ammonia evaporation can improve.

Therefore, the overarching goal of this study was to investigate the feasibility of vacuum stripping pretreatment on biogas production improvement from CM. The specific objectives were (i) to evaluate the effects of pretreatment conditions, including temperature, agitation rate, and time, on ammonia removal efficiency, and (ii) to examine the biochemical methane potential (BMP) of the pretreated substrate.

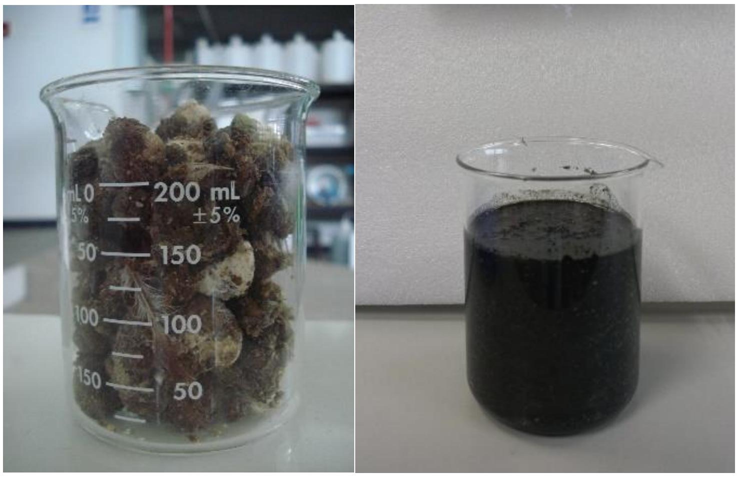
Materials and Methods

Chicken manure and seed inoculum

The CM and seed inoculum were obtained from anaerobic channel digester of R.P.M Farm & Feed, Chiang Mai, Thailand (Figure 1). The separated feathers and eggshells were used to prepare the CM. After being prepared, the CM was stored at 4°C until needed for further use, whereas the seed inoculum was filtered to remove the inert sludge. It was then incubated at 35±2°C for 7 d before being used. The dry matter (DM) content of the CM was 39.7%, the volatile solids (VS) content was 68.4% of the DM and the ammonia (NH_3) content was 1.7% of the DM.

Vacuum stripping unit

The vacuum stripping pretreatment process was controlled by a control panel, which regulated the temperature, agitation speed, and time of the 10 L stainless steel vacuum stirrer reactor (30 cm height and 20 cm diameter). The reactor was equipped with an impeller connected to a 120 W motor to offer agitation up to 200 rpm, and covered with a heating plate to heat the contents from 30°C to 150°C. In addition, it was connected to a particle trap and a vacuum pump to ensure efficient operation (Figure 2).



(a) (b)

Figure 1 The physical characteristics of (a) chicken manure (b) seed inoculum

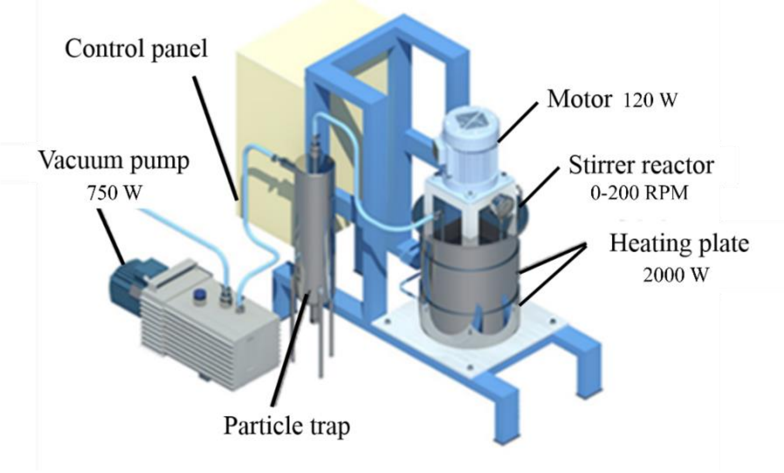


Figure 2 Vacuum stripping unit

Vacuum stripping pretreatment study and BMP test

This study aims to evaluate the optimal pretreatment conditions for ammonia removal in the CM using a two-level full factorial design of experiment and the Central Composite Design (CCD). In the pretreatment process, the reactor containing 2 kg of CM was heated at temperatures ranging from 50-120°C, agitated at a rate of 50-100 rpm, and exposed to a vacuum for 1-4 hr. The total kjeldahl nitrogen (TKN), total solids (TS), volatile solids (VS) and ammonia (NH_3) were measured from the sample both before and after undergoing pretreatment. The pretreated sample that showed the highest level of ammonia removal was chosen for further investigation. Both pretreated and non-pretreated samples were diluted with water in ratios of 1:2 and 1:5 (w/v) and subjected to BMP test followed by modified VDI4630 [6]. To study the effect of ammonia dilution on biogas production rate. It can be used to develop wet or dry biogas production systems for chicken farms.

The batch BMP test was done in triplicate with a 1,250 ml bottle (working volume 400 ml). In each bottle, 300 ml of inoculum seed and 100 ml of the CM sample were added before being sealed with a rubber stopper. To create an anaerobic environment, nitrogen gas was purged into the bottles for a period of three minutes. The bottles were subsequently placed in a temperature-controlled room (35±2°C). Biogas production was measured using pressure meter (KIMO Mode MP120, France) and the volume of biogas produced was calculated and reported under standard temperature and pressure condition as the biogas yield (NmL/gVS_{added}). In addition, the composition of the biogas was observed using a portable gas detector (Gas data Model GFM406, UK) when the relative gas pressure inside the bottles exceeded 300 mbar. The standard method [5] was employed to evaluate the parameters of pH, VS, volatile fatty acid (VFA), and alkalinity (Alk) in the samples before and after the BMP test.

Statistical analysis

The data is presented as mean values and their corresponding standard deviations. One-way ANOVA was used to analyze the data, and Tukey test was employed to determine significant differences among the means at a 95% confidence level.

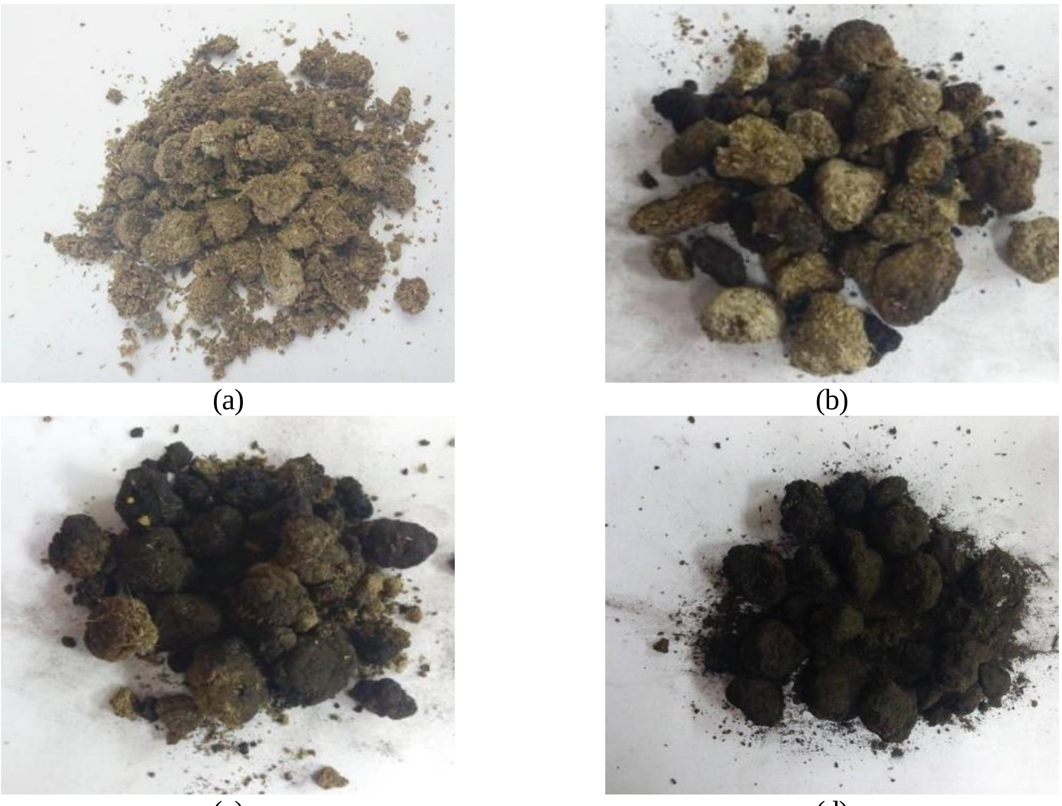
Results and Discussion

The physical characteristics of the pretreatment chicken manure were performed on the CM samples, which were presented in Table 1. The effect of different pretreatment conditions on ammonia removal efficiency was also studied and it was found that the temperature and time of vacuum pretreatment had a significant impact on ammonia removal. Additionally, Figure 3 illustrated the physical characteristics of the pretreatment chicken manure. The optimal pretreatment condition was found to be 120°C, 50 rpm for 4 hr, resulting in a maximum ammonia removal of 70% and the organic (VS) removal of 19.8%. As excessive heat can trigger the decomposition of organic matter during the process, leading to negative VS removal. Overall, it is important to carefully evaluate all the options and consider the long-term costs and benefits of each alternative energy source to determine the most effective and sustainable approach for conditioning the CM.

The BMP test for non-pretreated and pretreated CM at two different CM and water ratios (1:2 and 1:5 (w/v)) and the resulting biogas yields are shown in Table 2. It was found that pretreatment caused significant reduction on the biogas yield. This could be due to excessive heating and vacuum time resulted in significant drop in organic matter of the CM (19.8%). It was found that pretreatment caused a significant reduction in biogas yield at 95% confidence. It could be due to excessive heating and vacuum time. As a result, the organic matter in the CM decreased. According to the research by Raju *et al.* [7], thermal pre-treatment at 225°C for 15 min reduced the BMP of dewatered CM by 18%. However, the study also found that at lower temperatures, there were no significant changes in the BMP.

Table 1 Results of analyses performed on the pre-treated and non-pretreated CM

Item	Temp (°C)	agitation rate (rpm)	Time (hr)	DM (%)	VS (%DM)	NH_3 (g/kgDM)	TKN (g/kgDM)	NH_3 removal (%)	VS removal (%)
1	50	50	1	45	72	10.26	47.42	37.99	4.94
2	120	50	1	84	51	5.48	54.58	66.87	-25.30
3	50	100	1	49	71	9.39	57.35	43.25	3.96
4	120	100	1	62	72	10.22	64.93	38.21	5.50
5	50	50	4	48	71	10.38	37.32	37.25	3.81
6	120	50	4	94	55	5.18	42.29	68.69	-19.82
7	50	100	4	47	71	9.34	49.44	43.56	4.39
8	120	100	4	82	65	8.60	55.14	48.01	-4.28
9	85	75	2.5	57	68	10.34	55.28	37.49	-0.47
10	85	75	2.5	73	66	10.07	47.52	39.12	-3.39
11	85	75	2.5	66	66	9.61	58.32	41.92	-3.40
12	85	75	2.5	62	69	10.75	47.83	35.01	0.31
13	27.8	75	2.5	44	71	10.05	53.06	39.28	3.17
14	142.1	75	2.5	77	65	8.22	49.60	50.30	-4.57
15	85	34.1	2.5	60	67	11.49	51.57	30.56	-1.77
16	85	116	2.5	53	69	10.48	42.82	36.64	1.06
17	85	75	0.05	44	72	10.67	51.24	35.54	4.53
18	85	75	4.9	63	69	11.80	73.91	28.69	0.95
19	85	75	2.5	67	66	10.09	56.10	39.05	-3.01
20	85	75	2.5	59	65	9.97	55.21	39.73	-5.65
non-pretreated CM				40	68	16.55	52.16	-	-



(a) (b) (c) (d)

Figure 3 Physical characteristics of pretreatment chicken manure (a) CM pretreated of 50°C (b) CM pretreated of 85°C (c) CM pretreated of 120°C and (d) CM pretreated of 142°C

Table 2 Biogas yield from CM of non-pretreated and pretreated samples at different dilution rates

Samples		Biogas yield (NmL/gVS_{added})	Biogas yield efficiency (%)
CM: water (1:2) %w/v	CM non-pretreated	469^{A} ±28	-
	CM pretreated 50°C 100 rpm 4 hr	484^{A} ±15	3.3
	CM pretreated 85°C 75 rpm 2.5 hr	495^{A} ±31	5.7
	CM pretreated 120°C 50 rpm 4 hr	272^{B} ±5	-42.0
CM: water (1:5) %w/v	CM non-pretreated	492^{A} ±21	-
	CM pretreated 50°C 100 rpm 4 hr	517^{A} ±4	5.1
	CM pretreated 85°C 75 rpm 2.5 hr	517^{A} ±14	5.2
	CM pretreated 120°C 50 rpm 4 hr	277^{B} ±12	-43.6

The vacuum stripping technique allowed for an increase in biogas yield (Table 2) by 3.3% to 5.7% for CM pretreated 50°C to 85°C, respectively, compared to chicken manure without pretreatment. Increasing the water diluted from 1:2 %w/v to 1:5 %w/v resulted in and increase in biogas production by 5.1% and 5.2%. But the CM pretreated 120°C 75 rpm 4 hr: water (1:2) %w/v and the CM pretreated 120°C 75 rpm 4 hr: water (1:5) %w/v were no significant differences in biogas yields ($P<0.05$). However, there was a significantly lower difference of biogas production compared to other experiments. The results revealed that overheating period during manure conditioning can have an impact on the biogas potential of the substrate. It is recommended that the pretreatment CM at high temperature should heating time less than 4 hours to avoid negative effects on biogas potential. These results indicate that factors related to CM pretreatment to reduce water scarcity for biogas production of chicken farms. It was shown that the pretreatment of chicken manure can reduce water dilution.

In Table 2, the specific biogas yields achieved from the pretreated CM under these conditions (85°C 75 rpm 2.5 hr and 50°C 100 rpm 4 hr in a dilution ratio of 1:5 (w/v) were 517±4 and 517±14 NmL/gVS_{added}, respectively. Lower temperature treatment of CM may be beneficial in biogas yield because it can help to preserve the microbial population that is responsible for breaking down the organic matter. This finding was in close agreement with Konkol *et al.* [8], which reported that extracting excess nitrogen from chicken manure through water extraction within a temperature range of 20°C to 60°C resulted in a notable enhancement of biogas production, ranging from 16% to 45%, when compared to untreated manure.

After the fermentation process were completed, the samples' chemical characteristics were examined as depicted in the table 3. This time, there was no indication that ammonia had a detrimental effect on bacteria, resulting in VFA and Alk values that were within the acceptable range for microbes that produce biogas. For a general stable fermentation process, it is assumed that the ratio of VFA/Alk should not exceed 0.4. In this study, the ratios of VFA/Alk were between 0.12 to 0.16, and thus the fermentation process can be regarded stable. The VS removal efficiency was found to range from 17.7-41.4% and 20-36.8% at a dilution rate of CM: water (1:2) %w/v and (1:5) %w/v, respectively.

Table 3 Chemical analysis of samples after BMP test

Parameters		pH	VS (mg/L)	VFA ($mgCH_3COOH/L$)	Alk ($mgCaCO_3/L$)	VS removal (%)
CM: water (1:2) %w/v	Non-pretreated	7.2±0.0	18,713±202	863±38	6,883±395	37.2±0.7
	50°C 100 rpm 4 hr	7.3±0.1	19,032±532	975±80	7,721±157	41.4±1.6
	85°C 75 rpm 2.5 hr	7.5±0.1	26,843±705	1,544±178	11,474±354	40.7±1.6
	120°C 50 rpm 4 hr	7.4±0.1	39,967±875	1,175±65	9,982±21	17.7±1.8
CM: water (1:5) %w/v	Non-pretreated	7.0±0.0	15,750±350	513±23	4,137±230	24.6±1.7
	50°C 100 rpm 4 hr	7.1±0.1	16,307±498	726±56	4,454±270	27.6±2.2
	85°C 75 rpm 2.5 hr	7.3±0.1	19,757±215	846±161	6,142±58	36.8±0.7
	120°C 50 rpm 4 hr	7.2±0.1	26,807±289	765±77	6,122±63	20.0±0.9

Conclusions

Using vacuum stripping as a pretreatment method on CM had a significant effect in removing ammonia and producing biogas. The reduction of ammonia content through vacuum stripping can improve the stability of the biogas production process by preventing the buildup of toxic substances that can inhibit the growth of microorganisms involved in the biogas production. Moreover, the use of waste heat to power the vacuum stripping process can further improve the efficiency and sustainability of the production system by reducing the cost of pretreatment of CM. By adopting such integrated approaches, farms can optimize the use of resources, minimize waste, and reduce their environmental impact, while also generating renewable energy from CM. Moreover, the use of waste heat to power the vacuum stripping process can further improve the efficiency and sustainability of the production system by reducing the cost of pretreatment of CM. By adopting such integrated approaches, farms can optimize the use of resources, minimize waste, and reduce their environmental impact, while also generating renewable energy from CM.

Acknowledgements

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References

[1] McCarty, P. L. 1964. Anaerobic waste treatment fundamentals. Public Works (95). 107-112.

[2] Salminen, E. and Rintala, J. 2002. Anaerobic digestion of organic solid poultry slaughterhouse waste – a review. Bioresource Technology. 83(1): 13-26.

[3] Bujoczek, G., Oleszkiewicz, J., Sparling, R. and Cenkowski, S. 2000. High Solid Anaerobic Digestion of Chicken Manure. Journal of Agricultural Engineering Research. 76(1): 51-60.

[4] Chaitanoo, N., Aggarangsi, P. and Nitayavardhana, S. 2021. Improvement of solid-state anaerobic digestion of broiler farm-derived waste via fungal pretreatment. Bioresource Technology. 332: 125146.

[5] APHA. 1998. Standard methods for the examination of water and wastewater, 20th edition. American Public Health Association/ American Water Works Association/ Water Environment Federation, Washington DC.

[6] Ingenieure, V. D. 2006. VDI 4630: Fermentation of organic materials-Characterisation of the substrate, sampling, collection of material data, fermentation tests. In V. D. Ingenieure (Ed.), VDI Handbuch Energietechnik (pp. 44-59). Berlin: Beuth Verlag GmbH.

[7] Raju, C. S., Sutaryo, S., Ward, A. J. and Møller, H. B. 2013. Effects of high-temperature isochoric pre-treatment on the methane yields of cattle, pig and chicken manure. Environmental Technology. 34(2): 239-244.

[8] Konkol, I., Swierczek, L. and Cenian, A. 2023. Chicken Manure Pretreatment for Enhancing Biogas and Methane Production. Energies 2023. 16(14): 442.