Research Article

Enhancing biogas production in anaerobic co-digestion of fresh chicken manure with corn stover at laboratory scale

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Abstract
Anaerobic digestion (AD) is one of the renewable technologies and a good alternative for the management of livestock manure. The present study focuses on co-digestion of fresh chicken manure (FCM) with corn stover (CS) experiments for biogas production. The objective of this study is to evaluate the effect of corn stover in the production of biogas and methane content by co-digestion. The mixing ratios of co-digestion of FCM with CS were 1:1, 1:2, and 2:1. The total solids for co-digestion were 8% for all ratios. The results showed that the ratio of 2:1 produced the highest biogas yield (46.7 m^3/ton of slurry) and 53.2% of methane purity. The pH fluctuated around a range of 5.2 to 7.9 due to different stages of anaerobic digestion as a result of microbe's activity.

Keywords Fresh chicken manure · Corn stover · Anaerobic digestion · Biogas · Methane content

1 Introduction

Biogas is a renewable form of energy composed of methane (CH_4) as the major composition (50–75%) followed by carbon dioxide (CO_2) with a concentration of 25–45% and other gaseous traces (~ 7%) produced from the decomposition of organic matters through anaerobic digestion process [1–3] Anaerobic digestion (AD) is a well-known process in converting waste to renewable energy, especially in a country like Malaysia which has different kinds of waste and biomass that can be utilized for this process. Massive waste has been produced from agriculture for livestock subsector specifically from chicken with the highest recorded number of 308.3 million [4]. The abundance of chicken farms leads to many problems, whether it is a closed or open system, such as unpleasant odor, health problem, and increasing of flies in the neighborhood area [5]. Chicken manure is basically composed of carbohydrate, proteins, lipids, and fiber based on the type of feeds of the chickens [6]. The previous study stated that poultry droppings have C/N ratio around 7 with 80% of volatile solids (% of TS) [6]. Proteins content in the chicken usually causes attraction to the flies to lay their eggs. Therefore, this manure can be utilized in AD to produce biogas which can be converted to electricity and used as cooking gas [7].

Agricultural waste, specifically from plant-based material, is increasing in these recent years due to food demand from both human and animals. To date, the wastes such as wheat straw, corn stover, and rice straw are either burned, fermented or used as animal feeds. However, if burned is preferred, the environment can be harmful as the lignocellulosic waste could release toxic gases due to the presence of heavy metals [8]. Therefore, one of the potential treatments for these wastes is through anaerobic digestion. Corn stover (CS) has a

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high quantity of lignocellulosic material [9] that contains high carbon but shallow nitrogen content which is less suitable as sole feedstock in AD. However, the biogas production can be enhanced when CS co-digested with high nitrogen feedstock to balance the C/N ratio such as animal manure (chicken, cow, and swine) [10, 11]. Co-digestion also provides more stable C/N ratio, pH, and maximizing utilization of the different types of wastes. Previously studies that investigated the co-digestion of chicken manure with corn stover or kitchen waste are reported by these studies [9, 12]. They figured out that co-digestion of chicken manure with corn stover in the range of 16–25 for C/N ratio was ideal for high methane yield. However, when kitchen waste was present, better methane yield was produced due to its higher biodegradability. But still, corn stover still has a good potential due to high carbon and presence of trace elements that can aid the anaerobic digestion.

One of the ways to overcome inhibition of ammonia or VFA accumulation in mono-digestion of chicken manure is by co-digestion process which is cost-effective and practical. Moreover, co-digestion could elevate the balance of macro- and micronutrients, decrease the inhibitory compounds, and excel the buffer capacity [13, 14]. The cost-effectiveness could be reached due to less usage of chemicals, electricity, additives, and catalyst to upgrade the methane content. As an example from the previous study by Hagos et al. [15], the digestion of two wastes in one digester at the same period could save the water usage, maximize the space of the digestion area, and lower the building cost. The presence of co-feedstock could enhance the size availability of feedstock for small-scale digester, especially for household application as single feedstock could lead to insufficient source [16]. The main key in optimizing the anaerobic co-digestion (AcoD) is choosing the suitable co-feedstock by looking into their characteristics and properties and also good mixing ratio to provide a better synergistic effect [17, 18]. The abundance of corn stover in Malaysia leads to utilizing it as one of the potential feedstocks in biogas production.

Even though previous studies have reported the co-digestion of chicken manure with corn stover, they mostly focused on the effect of C/N ratio, type of the AD condition, pretreatment, and microbial community [12, 19, 20]. However, additional studies are still required to complement the existing research by focusing on optimum condition for the FCM with CS and instead of using the usual chicken manure, the co-digestion can be done by using FCM. FCM used in this study is different with the usual chicken manure used in the other studies because of the way of the sampling. The sampling was done by retaining the FCM directly from the chicken without it touching the ground and mixing with the beddings and food. The FCM was still in liquid form which is good for anaerobic digestion as this process required stable water content.

The objective of this study was to determine the optimum ratio between FCM and CS by analyzing the effect of pH, quality, and quantity of biogas production.

2 Methodology

2.1 Feedstock and inoculum

Fresh chicken manure (FCM) was collected from a broiler chicken farmhouse in Dinding Broiler Breeder Farm, Perak, Malaysia, and kept at − 4 °C to avoid decomposition by microorganisms in the samples. Corn stover (CS) was obtained from Institut Pertanian, Perak, Malaysia. It was dried at 105 °C and ground into small pieces of approximately 1 mm. The drying purpose is to discard all the water content in the corn stover as well as to ease the grinding purpose as it cannot be ground in wet condition. Plus, drying of CS could enhance the microbial activity in degrading the lignocellulosic materials which are resistant to breakdown easily. There was a previous study by You et al. [21] in pretreatment of corn stover by using NaOH and CaO that required drying of the CS at 105 °C [22]. This pretreatment caused the hydrolytic microbes to outbreak the internal cellulose to ease the breakdown of organic matters into methane [23]. Based on this study, we can agree that drying at 105 °C gave a good effect in the present experiment and most probably was not toxic to the microbes. The properties of feedstock and inoculum are shown in Table 1. For inoculum, cow dung was used, which was obtained from cow farm in Kampung Gajah, Perak, Malaysia. Prior to usage in AD process, the inoculum was degassed at 37 °C for less than one week, to reduce the residual biodegradable organic material [24].

Table 1 Properties and characteristics of fresh chicken manure, corn stover, and inoculum

Parameter	FCM	CS	Inoculum
TS (%)	23.79 ± 0.17	87.95 ± 0.70	5.86 ± 1.49
VS (% of TS)	77.00 ± 0.20	98.30 ± 1.50	74.36 ± 0.52
C (%)	42.95 ± 0.07	22.15 ± 0.07	35.75 ± 6.12
H (%)	5.75 ± 0.07	6.00 ± 0.14	5.20 ± 0.10
N (%)	4.45 ± 0.21	0.51 ± 0.01	1.68 ± 0.18
S (%)	0.57 ± 0.04	–	0.27 ± 2.00
C/N ratio	9.66 ± 0.48	43.86 ± 0.47	21.12 ± 1.32
pH	5.41 ± 0.01	NA	6.33 ± 0.08
Protein	27.81 ± 1.33	3.15 ± 0.04	10.50 ± 1.15

FCM fresh chicken manure, *CS* corn stover, *NA* none analysis

2.2 Laboratory-scale digesters

The co-digestion tests were carried out in batch test by using fresh chicken manure and mixed with corn stover with ratios of 1:1, 1:2, and 2:1 and labeled as digesters A, B, and C, respectively. The total solid for all three digesters was 8%. The ratio of feedstock to inoculum was 1:3. The mixtures were loaded in 1.5-L soda bottles and put in an oven with temperature maintained at 30 °C. Biogas composition and volume were measured every 5 days for 60 days.

2.3 Analytical methods

Total solid (TS) and volatile solid (VS) of feedstock and inoculum were determined according to the APHA methods 2540 G [25]. Elemental compositions (C, H, N, S) of feedstock were measured by CHNS Analyzer (Perkin Elmer EA Series II CHNS/O 2400). The pH value of each sample (1 g) was analyzed potentiometrically in distilled water at a ratio of 1:10 (w/v) by using Mettler Toledo FG2-Kit FiveGo™ Portable pH meter. Crude protein was estimated by multiplying the value of nitrogen with 6.25 [26]. The physicochemical properties of feedstocks and inoculum are shown in Table 1.

Composition of biogas was analyzed by using a gas chromatography (GC-8AIT) equipped with thermal conductivity detector (TCD), and volume of biogas was determined by using water displacement method.

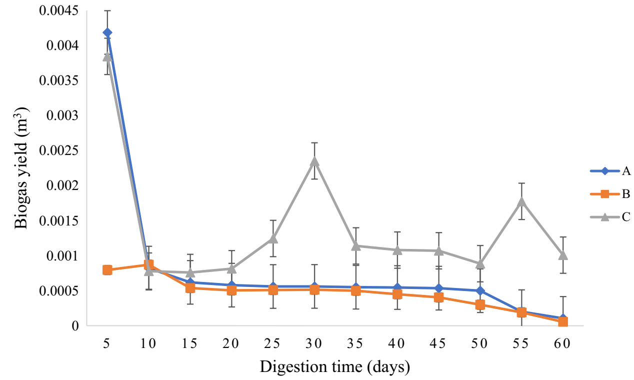

Fig. 1 Biogas yield from co-digestion of FCM/CS at 5-day interval

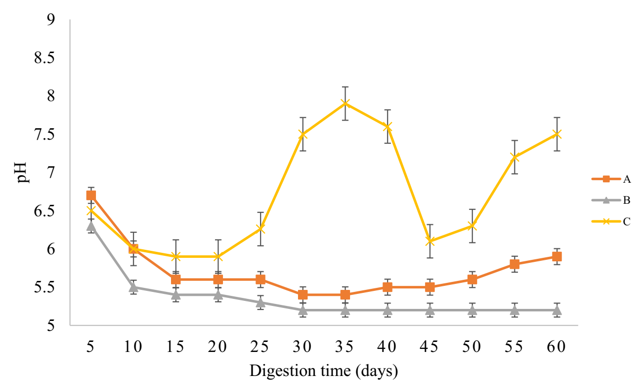

Fig. 2 pH of the co-digestion of FCM/CS at five-day interval

3 Results and discussion

Table 1 shows the properties of FCM, CS, and inoculum used in this study. FCM contained lower total solids (TS) compared to CS due to the presence of higher moisture content supported by the slurry physical appearance of FCM. C/N ratio of CS was higher than FCM due to lower nitrogen content, which can stabilize the C/N ratio when co-digested with FCM. The pH of FCM showed acidic condition due to high nitrogen content in the form of uric acid and undigested protein [27].

3.1 Comparison of biogas production (volume) at different CM/CS combinations

Figure 1 shows the accumulation of biogas for three digesters of FCM-to-CS ratio (1:1, 1:2, and 2:1). At the beginning of AD process, biogas production was high for digesters A and C with amounts of 0.82 L/day and 0.76 L/day, respectively. For digester B, the biogas yield was very low compared to other digesters due to the presence of high content of corn stover which caused the microbes to take a longer time to break down the lignocellulosic materials [7, 15], which led to low degradation of organic matter and thus production of lower quantity of biogas. The biogas yield was found to be fluctuated along the 60 days, especially for digester C, as it increased drastically on day 30, and it was then decreased with constant volume and increased again on day 55 by 51%. The fluctuation of biogas yield was due to the metabolism of microbes and effect from fluctuation of pH in the digestion process [29]. The fluctuation of pH (Fig. 2) can be seen clearly for digester C as the pH was in the range of 7.2–7.5 on days 30 and 55. Furthermore, the biogas yield was also increased on the same day. However, when the pH was too high approaching 8, the biogas yield dropped drastically as it was not in the optimum range of pH for AD process. Final pH values for all digesters A, B, and C were 5.9, 5.2, and 7.5, respectively, which showed digester C had better digestion as it contained more chicken manure which could act as buffer to stabilize the pH. Overall, digester C showed the highest total of biogas production per slurry (47m^3/ton) followed by digesters A (24 m^3/ton) and B (16 m^3/ton).

3.2 Comparison of biogas composition at different CM/CS combinations

The composition of biogas for co-digestion of FCM with CS for 60 days of digestion is shown in Fig. 3. In early stages of digestion on day 5, carbon dioxide was the major content with traces of amounts of hydrogen gas in each digester. All digesters of FCM to CS (A, B, and C) showed similar trends. The methane started to yield on day 15 with amount of nearly 3% for all three digesters and kept increasing until it reached the peak on day 45 for digester B and day 35 for digester C, while for digester A (Fig. 3a), the methane yield was almost constant around 10% and finally increased to 16% on day 60. For digester B (Fig. 3b), methane yield dropped after day 45 and kept stable until the end of the digestion which produced only a maximum of 17% of methane. This result was most probably due to the high amount of nitrogen gas (~ 42%), which was contributed by the nitrogen origin (4–5%) in chicken manure. Plus, the lignocellulosic materials could also be the reasons for the low methane yield acidic condition (Fig. 2) within the range of 5.2–6. This acidic condition was probably due to the accumulation of volatile fatty acid (VFA) generated from ammonia inhibition which originated from high nitrogen content in the chicken manure [17–19]. For digester C (Fig. 3c), the methane yield dropped on day 40 and started to increase back and remained constant until day 60. This fluctuation was probably due to the instability of the microorganisms and decrease in pH (6.1–6.3). These results showed that co-digestion with higher composition of corn stover than chicken manure could cause slow digestion process due to lignocellulosic materials that cause difficulties for microbes to digest which suggested that AD process for this feedstock should be longer than 60 days to obtain a better result in terms of biogas yield and methane content. Li et al. [12] reported that their co-digestion of chicken manure with corn stover was carried out for more than 70 days, which obtained 77% of methane yield and proved that corn stover needs a longer digestion time to break down the lignin materials.

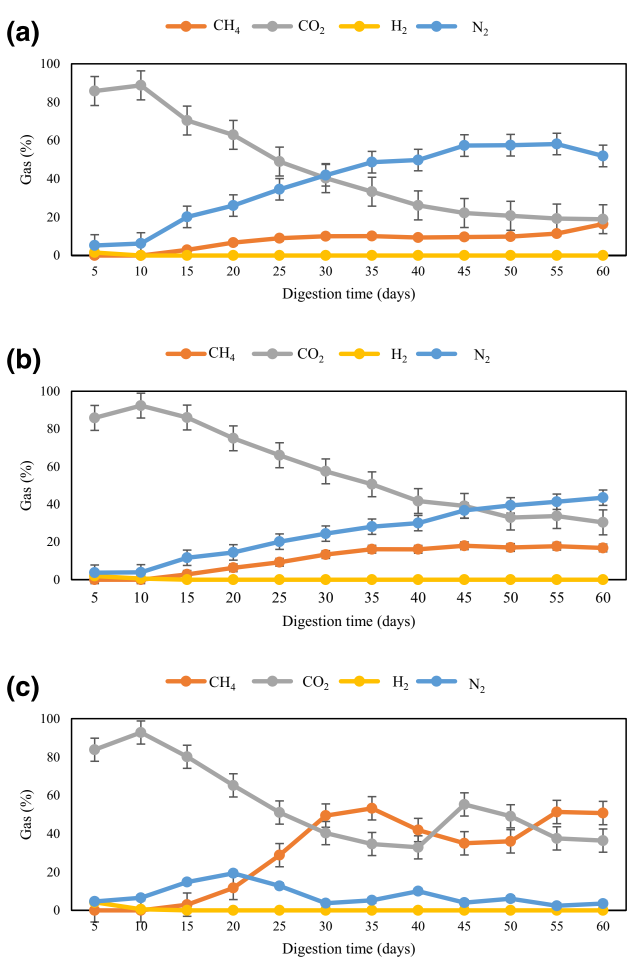

Fig. 3 Composition of biogas for 60 days from co-digestion of FCM/CS **a** 1:1, **b** 1:2 and **c** 2:1

3.3 Effect of C/N ratio in methane production

The C/N ratio is one of the critical parameters in anaerobic digestion process [15, 20]. A high C/N ratio could result in low biogas yield due to rapid nitrogen degradation by microbes, while a very low C/N ratio could cause inhibition of microbial community, especially methanogens [15, 21]. For this study, the C/N ratios for digesters A, B, and C were 19, 20, and 17, respectively. Based on Fig. 3, as the number of passed days increased, the nitrogen also increased for digesters A and B, mainly due to high nitrogen content in chicken manure. The nitrogen content was the highest for digester A because the CS was insufficient to balance the C/N ratio of the AD process which caused least methane content with a maximum value of 16% on day 60. As for digester B, high C/N ratio (20) resulted in a low methane production due to high production of carbon dioxide contributed from higher content of corn stover and rapid nitrogen degradation by the microbes [21, 22]. However, for digester C, it did not produce a high amount of nitrogen gas but produced the highest methane content (53%). This probably was due to nutrient balance and stable C/N ratio which was 17 [35]. This result was in line with the previous study by Zhang et al. [28] who found that the highest methane content was produced from co-digestion of chicken manure and corn stalks with C/N ratio of 17.39. From these results, it can be concluded that the co-digestion process favored C/N ratio below 18 for chicken manure with corn stover.

4 Conclusion

Biogas production could be improved by co-digestion of FCM with CS in suitable ratios with balanced C/N ratio for 60 days of digestion period. The pH conditions were acidic along the digestion period for digesters A and B, while for digester A, the pH was better and in favored range. The maximum methane yield (53%) was generated from digester C, while 16% and 17% were produced from digesters A and B. The optimum value for C/N ratio was suggested around 16 – 18 for co-digestion of FCM with CS. Furthermore, higher composition of FCM than CS is recommended based on the quality and quantity of the biogas which were 46.7 m^3/ton and 53%, respectively. However, when the amount of corn stover increases, the retention time must be increased (more than 60 days) due to high lignocellulosic materials that could cause difficulties for microbes to digest.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interest.

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