Thai Environmental Engineering Journal Vol. 39 No. 1 (2025) : 59-68
www.eeat.or.th

Study on Biogas Production from Broiler Manure by GAC-dosed Anaerobic Biological Treatment System for Renewable Energy

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Article History; *Received: 18 December 2024, Accepted: 10 April 2025, Published: 30 April 2025*

Abstract

The rising consumption of chicken has led to an expansion in poultry farming, resulting in increased accumulation of Broiler Chicken Manure. If not properly managed, this can lead to pollution and the spread of diseases. While Broiler Chicken Manure is often used as organic fertilizer, it emits nitrogen gases, contributing to odor problems. However, anaerobic digestion of Broiler Chicken Manure can produce biogas, offering an effective alternative energy source that helps reduce pollution and greenhouse gas emissions. This study investigates the biogas production potential of two types of Broiler Chicken Manure: Broiler chicken manure and Broiler Chicken Breed, Breeding period 45 and 440 days, respectively, with rice husk used as bedding material. The study focuses on two main aspects: 1) comparing the efficiency of biogas production from Broiler chicken manure and Broiler Chicken Breed, manure collection time, and the effect of mixing with rice husk, and 2) examining the impact of different mixing ratios of additive 4 type including Iron particles-A (Fe-A) with a size of <75µm, Iron particles-B (Fe-B) with a size of 75-180µm, Activated carbon powder-A (GAC-A) with a size of <75µm, Activated carbon powder -B (GAC-B) with a size of 75-180µm (Fe-A, Fe-B, GAC-A, GAC-B) at concentrations of 5, 10, and 20 mg/l. The results showed that Broiler Chicken Manure, with a 1:4 water-to-manure ratio and mixed with rice husk, had a methane production potential of up to 55 m^3/ton. The highest biogas production was achieved with GAC-B at 5 mg/l, showing a 59.98% increase in biogas potential.

Keywords : Broiler chicken manure; Rice husk; Ferric Oxide; Anaerobic treatment; Biogas; Renewable energy

Introduction

Broiler chicken manure has gained increasing attention due to the rising demand for chicken meat, which has increased by 50% in recent years [1]. Broiler chicken is an essential protein source suitable for all age groups, and this increased demand has led to the growth of poultry farming. However, improper management of the resulting manure can lead to the spread of diseases, air pollution, and environmental degradation. While chicken manure is often used to produce organic fertilizers, these fertilizers release a significant amount of nitrogen (N), which leads to odor issues [2].

Numerous studies have highlighted that broiler chicken manure, when subjected to anaerobic digestion (AD), is highly efficient in producing biogas and can be converted into renewable energy. This biogas can serve as a direct fuel substitute for fossil fuels, contributing to circular economy models for energy and utilities, while being environmentally friendly by reducing pollution, greenhouse gas emissions, and environmental impacts. The optimal chemical oxygen demand (COD) for biogas production from chicken manure is around 54,000 mg/L [3], producing between 50-100 m^3 of biogas per ton of manure. In Thailand, rice husk is often used as bedding material for chickens, resulting in mixed manure that includes rice husk. Rice husk, a lignocellulosic material, contains cellulose, lignin, and hemicellulose, making it suitable for biofuel production. Lignocellulosic materials have a high carbon content and are not easily biodegradable through anaerobic digestion, due to the slow degradation rate and low methane production. Although pretreatment can improve biogas production, such processes may not be economically viable due to the limitations of cellulose hydrolysis. However, rice husk can act as a co-substrate, improving the C/N ratio of nitrogen-rich materials like chicken manure and helping to prevent rapid acidification during anaerobic digestion [4].

Studies have also shown that biogas production and methane yields from chicken manure fermentation decrease when ammonia nitrogen (TAN) concentration reaches 6,000 mg/L, necessitating the use of large amounts of water for dilution to restore the process, which is costly. Co-fermentation of chicken manure with materials like corn stover or rice straw can adjust the C/N ratio to mitigate ammonia toxicity. Chicken manure has high ammonia nitrogen and sulfur content, which can disrupt biogas production. To prevent ammonia from exceeding toxic levels (1.1 g/L), water must be added to dilute it [5].

Anaerobic digestion (AD) is one of the most effective techniques for converting organic waste into renewable energy, primarily in the form of biogas or methane [4-5]. This biological treatment process occurs in the absence of oxygen, utilizing bacteria capable of producing biogas, a clean fuel primarily composed of methane (CH_4) and carbon dioxide (CO_2) (Reynolds, J., & Richards, A. (1996). Factors affecting anaerobic digestion include organic matter concentration, pH, temperature, alkalinity, volatile fatty acids, and nutrients. Rice husk, which is commonly used in poultry farming in Thailand, degrades slowly under anaerobic conditions due to its high lignin content and carbon sources, making it unsuitable for efficient anaerobic digestion when present in concentrations higher than 30% [4]. Ferric oxide particles have been employed to enhance the anaerobic digestion process and accelerate the breakdown of organic matter, resulting in higher biogas production [6].

In anaerobic digestion, trace elements are crucial for the growth and metabolism of microorganisms, particularly in the methane production (methanogenesis) stage. Iron (Fe) is the most abundant trace element in the system and plays an essential role in electron transport and the acceleration of chemical reactions involved in methane production. A lack of iron can limit the efficiency of the digestion process and reduce methane production. Supplementing iron and other trace elements in AD processes has been shown to significantly increase biogas production rates and improve process stability. Iron supplementation stimulates the growth of methane-producing bacteria and enhances the efficiency of anaerobic digestion systems [7]. The optimal ratio for adding ferric oxide is 20 mL per liter, which can increase natural gas production by up to 1.6 times [8].

This study focuses on assessing the potential for biogas production from broiler chicken manure through anaerobic digestion, with the addition of trace elements such as ferric oxide to improve the biogas yield. The economic and environmental viability of this process, in terms of reducing greenhouse gas emissions and providing a sustainable alternative to fossil fuels, will be evaluated. Biogas can be used directly as fuel, replacing fossil fuels, and it can also be converted into electricity, reducing energy costs for organizations and countries. Furthermore, this process helps mitigate organic waste accumulation and is environmentally friendly. Future research may explore the conversion of natural gas into biomethane or hydrogen to increase its value further.

Materials and Methods

1. Preparation of Chicken Manure Samples. The chicken manure samples were divided into two types: (1.1) Broiler Chicken Manure and (1.2) Broiler Chicken Breed Manure The Different periods of these animals

differ significantly, resulting in variations in the properties of their manure. These differences can influence characteristics such as moisture content and ammonia levels.

2. The manure was extracted as a manure solution. The manure-to-water ratios used for extraction were 1:2, 1:4, and 1:6 using a mixer with a speed range of 300-450 RPM for 5 minutes. The condition mentioned is a process to completely separate the manure and rice husk, based on an experiment conducted in a laboratory.

3. BMP Testing Under Experimental Conditions (2.1) A study on the biogas production efficiency of broiler chicken manure was conducted by comparing broiler chicken manure with broiler chicken breed manure, considering the time of manure collection and the differences between mixing and not mixing rice husk. (2.2) The study also examined the biogas production efficiency of broiler chicken manure with different mixing ratios of four types: Fe-A (<75µm), Fe-B (75-180µm), GAC-A(<75µm), and GAC-B (75-180µm) at concentrations of 5, 10, and 20 mg/l using the BMP equation. The addition of iron at the nanoparticle level (10 ppm) helps improve the efficiency of biogas and methane production. The research hypothesis was based on testing at the nm level, which is smaller in size and has a larger surface area. Additionally, if carbon particles are included as a component, it can help reduce the required concentration of iron [8].

$$\text{BMP (ml/gCOD}_{\text{removal}}) = \frac{\text{(ml Methane)}}{\text{gCOD removal}} = \frac{\text{Biogas(l)} \times \text{Methane(\%)}}{\text{(COD influence-COD effluence)}(\frac{\text{mg}}{\text{L}})} \quad (1)$$

$$\text{BMP (ml/gVS}_{\text{removal}}) = \frac{\text{(ml Methane)}}{\text{gVS removal}} = \frac{\text{Biogas(l)} \times \text{Methane(\%)}}{\text{(VS influence-VS effluence)}(\frac{\text{mg}}{\text{L}})} \quad (2)$$

4. Analysis of Experimental Parameters. The parameters of the experimental samples, as shown in Table 1, were analyzed both before and after the BMP test, including pH, VFA, Alkalinity, BOD, COD, TKN, Ammonia, TS, VS, SS, TP, and Iron, using the methods outlined in the *Standard Methods for the Examination of Water and Wastewater* (24th edition, 2023).

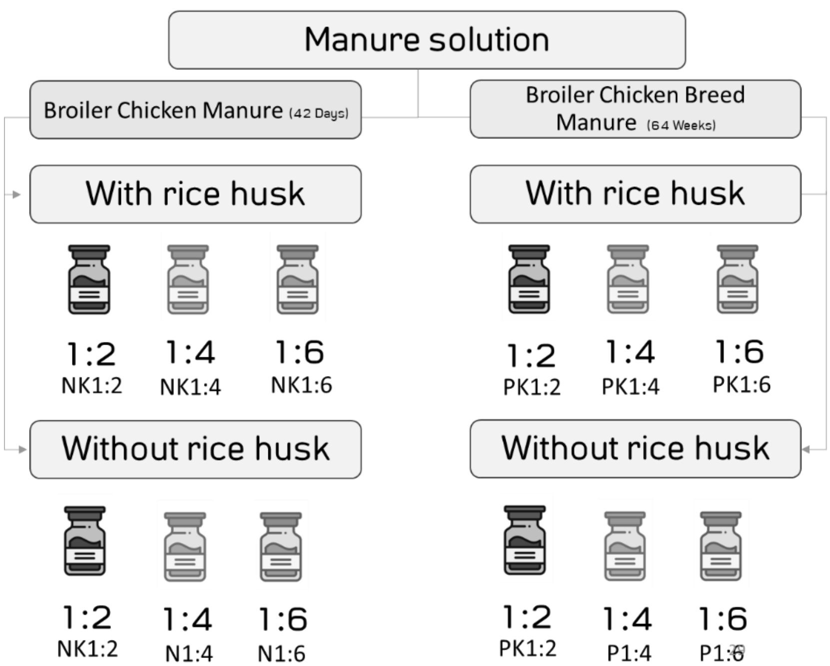

Figure 1 The manure solution were divided into two types: (1.1) Broiler Chicken Manure and (1.2) Broiler Chicken Breed Manure

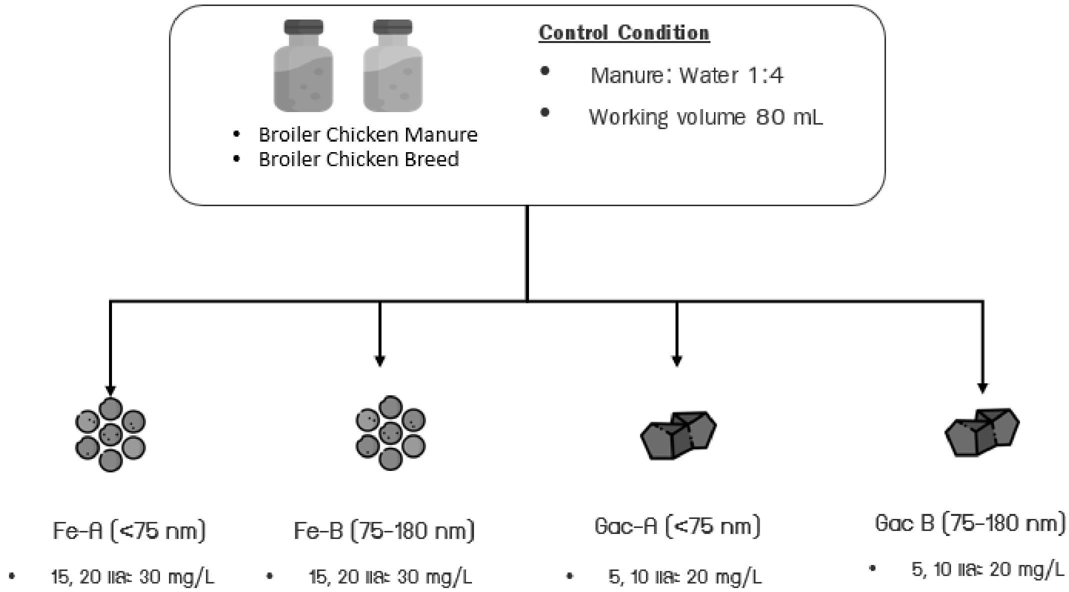

Figure 2 Shows the proportions of additive materials at different ratios

Results and Discussion

1. Study on the Biogas Production Efficiency of Broiler Chicken Manure. The comparison of biogas production efficiency between Broiler Chicken Manure and Broiler Chicken Breed Manure, considering different manure collection periods and the differences between mixing and not mixing rice husk.

Table 1 Properties of Extracted Broiler Chicken Manure and Broiler Chicken Breed Manure

Parameter	Average value of this research		Ref Data	Ref
	Broiler Chicken Manure	Broiler Chicken Breed Manure		
pH	7.40	7.53	6.94-7.29	[2],[3]
COD (mg/L)	116,133	104,133	53,500 -	[3]
Alkaline (mg/L as CaCo3)	25,969	45,689	-	
VFA (mg/L as CH3COOH)	4,444	6,111	-	
TKN (mg/L as N)	20,300	15,400	-	
Ammonia (mg/L as NH3)	1,400	840	≤5,000	[10]
TS (%V/V)	65%	70%	70 – 75%	[2],[3]
VS (%V/V as Dried)	75%	71%	60 – 80%	[7]

Table 1 presents the properties of Broiler Chicken manure and Broiler Chicken Breed manure, compared to poultry manure from other research studies. Broiler Chicken Breed manure, which is stored for a longer period, shows a higher pH value of 7.53, due to the increased release of ammonia. In contrast, Broiler Chicken manure and poultry manure from other research studies had pH values ranging from 6.94 to 7.29. This higher pH is a result of the ammonia produced during the extended storage of the manure, as ammonia is a basic compound that increases the pH.

Regarding Chemical Oxygen Demand (COD), Broiler Chicken manure had a COD value of 116,133 mg/l, and Broiler Chicken Breed manure had 104,133 mg/l. These values are approximately twice as high as those reported in other studies. This difference is mainly due to the bedding material used in the farms. In Thailand, rice husk, which contains lignin, is commonly used as bedding material. Lignin is a complex compound that is resistant to decomposition which some chemical for test COD, and when mixed with manure, it increases the COD value. In contrast, other studies abroad often use rice straw or sawdust, which have lower lignin content and therefore lower COD values.

The higher COD values indicate that both types of manure have significant potential for biogas production, as a higher COD correlates with more organic matter available for microbial digestion in anaerobic conditions. According to previous research, a gas yield of 1,270 mg/l per gCOD was observed, suggesting that Broiler Chicken and Broiler Chicken Breed manure can effectively produce biogas. However, while rice husk increases the COD, its lignin content can also slow down the degradation process in anaerobic digestion, which may slightly affect the overall gas yield. This phenomenon is supported by studies on lignin-rich materials, which often show slower biogas production rates due to the resistance of lignin to microbial degradation [4].

After analyzing the properties of both types of manure, it was found that both Broiler Chicken manure and Broiler Chicken Breed manure have high dryness due to the presence of rice husk as a component, and the manure is not regularly removed from the poultry houses. This results in the need to improve the moisture content to an appropriate level by adding water. The next step was to determine the suitable water mixing ratio.

From the experimental results in Table 2, it was found that the water mixing ratios of 1:2, 1:4, and 1:6, both with and without separating the rice husk, affected the COD values and the potential toxicity in the anaerobic digestion system of the manure. The COD values decreased as the water content increased in the higher ratios, which corresponds to the reduction of organic and inorganic substances in the manure extract. Separating the rice husk from the manure also significantly reduced the COD values. Additionally, this reduction in COD resulted in better decomposition during the subsequent anaerobic digestion process [8, 9].

Table 2 Average composition of different water mixing ratios

Substrates (Manure mixture ratio by weight)	Broiler Chicken manure					Broiler Chicken Breed manure				
	With Rice husk			Without Rice husk		With Rice husk			Without Rice husk	
	1:2 (NK1:2)	1:4 (NK1:4)	1:6 (NK1:6)	1:4 (N1:4)	1:6 (N1:6)	1:2 (PK1:2)	1:4 (PK1:4)	1:6 (PK1:6)	1:4 (P1:4)	1:6 (P1:6)
pH	7.4	8.65	8.64	6.55	6.47	7.53	6.29	6.68	7.25	7.23
COD (mg/L)	116,133	24,080	18,440	23,800	16,000	104,133	49,587	30,680	15,600	13,100
Alkaline (mg/L as CaCo3)	6,589	5,730	3,220	4,268	4987	4,876	3,425	2,120	2,864	3,879
VFA (mg/L as CH3COOH)	4,444	6,334	4,083	2,927	2,511	6,111	8,000	5,330	1,025	1,239
TKN (mg/L as N)	20,300	2,600	2,500	1,500	1,197	15,400	2,200	1,064	712	663
Ammonia (mg/L as NH3)	1,400	705	465	272	119	1,167	633	362	182	85
TS (mg/L)	259,000	148,280	65,360	36,987	34,330	220,000	173,420	67,380	33,000	27,320
VS (mg/L)	195,000	106,260	44,660	27,674	15,000	156,000	147,720	55,760	24,420	20,020
C/N Ratio	5.7	9.3	7.4	15.9	13.4	6.8	22.5	28.8	21.9	19.8
Ammonia (g/L) as NH3)	1.4	0.7	0.46	0.27	0.19	1.1	0.63	0.36	0.18	0.085
VFA/Alkaline	0.7	1.1	1.3	0.7	0.5	1.3	2.3	2.5	0.4	0.3

The high initial COD values of both types of manure make them suitable for use in anaerobic digestion processes because COD values greater than 2,000 mg/l are ideal for biogas production without the need for additional energy to heat the reactor to stimulate decomposition [8]. The gas production rate per COD value in this study was 1,270 mg/l per gCOD for Broiler Chicken Breed manure mixed with water at a 1:4 ratio (PK1:4). This value indicates good biogas production efficiency from the manure and helps dilute the toxicity within the system [10].

It was also found that mixing ratios greater than 1:4 result in ammonia concentrations that do not reach toxic levels in the system. According to research, ammonia levels in anaerobic digestion systems should not exceed 1.1 g/L to avoid toxicity [5]. This adjustment allows for a 30% reduction in water use costs compared to the 1:6 ratio. Additionally, the rice husk mixture eliminates the need for a pre-treatment system, reducing construction costs by at least 30% and increasing COD values while maintaining an appropriate C/N ratio.

This research is based on farms in Thailand, where rice husk is commonly used as bedding material due to its abundance, availability, and low cost. However, rice husk contains lignin, which reacts with the chemicals used to measure COD, resulting in higher values. This leads to higher potential for biogas production from manure that contains rice husk as a component.

An appropriate C/N ratio can reduce the impact of ammonia and increase methane production efficiency. Research has shown that increasing the C/N ratio helps reduce ammonia impacts. For C/N ratios between 20 and 32, which align with the study by, the ideal C/N ratio for anaerobic digestion of chicken manure is between 23 and 25, as it promotes effective decomposition and reduces ammonia nitrogen concentrations. An excessively high C/N ratio may lead to lower methane production because microbial growth tends to focus on protein use instead of carbon degradation in nutrients [11].

Samples with VFA/Alkaline values exceeding 0.3 [14] indicate instability in the system and are often associated with acid accumulation due to organic overload or insufficient buffering capacity. The optimal value should not exceed 0.3 to ensure efficient biogas production. It is necessary to adjust the organic loading rate, modify the C/N ratio, or add buffering agents to maintain system balance. Particular attention should be given to the C/N ratio, as it plays a crucial role in microbial activity and the overall stability of the anaerobic digestion process.

The findings from this research indicate that Broiler Chicken Breed manure has a C/N ratio ranging from 19.8 to 22.5, which is within the optimal range. The longer rearing period results in greater ammonia release than Broiler Chicken manure, making Broiler Chicken Breed manure more likely to produce higher methane quantities. This is expected to be most pronounced in the PK1:4 sample. The experimental sample PK1:4 (Broiler Chicken Breed manure mixed with water at a 1:4 ratio and containing rice husk) demonstrated strong potential for biogas production when considering both the COD, C/N ratio, and the volume of biogas produced, which reached 55 m^3/ton. This finding is consistent with previous research [1], where poultry manure typically produces biogas volumes ranging from 50 to 100 m^3/ton, as shown in Figure 3.

Figure 4 illustrates that the methane production efficiency of the PK1:4 sample is only 15%, which is approximately twice as low as the P1:6 sample, which has the highest methane production at 34%. The key factor behind this discrepancy is the presence of rice husk in the PK1:6 sample. Rice husk is composed of lignin and cellulose, which are more challenging to break down biologically compared to other organic materials [4] As a result, the degradation process in the PK1:6 sample takes longer, leading to reduced methane production within the same time frame. This extended degradation time also results in a slower accumulation of biogas compared to samples with easier-to-degrade materials.

Furthermore, the lower water mixing ratio in PK1:4 results in higher ammonia concentrations in the system. Ammonia, particularly in high concentrations, can be toxic to the microbial communities responsible for anaerobic digestion. Studies have shown that elevated ammonia levels can inhibit the activity of methanogenic bacteria, thereby slowing down the biogas production rate. In this study, the higher ammonia concentration in the PK1:4 sample likely contributed to the observed decrease in methane production efficiency. Additionally, the higher ammonia levels can disrupt the microbial metabolic processes, resulting in slower anaerobic digestion reactions and lower overall methane yield. These findings underscore the importance of balancing water mixing ratios and feedstock composition in optimizing methane production in anaerobic digestion systems [5].

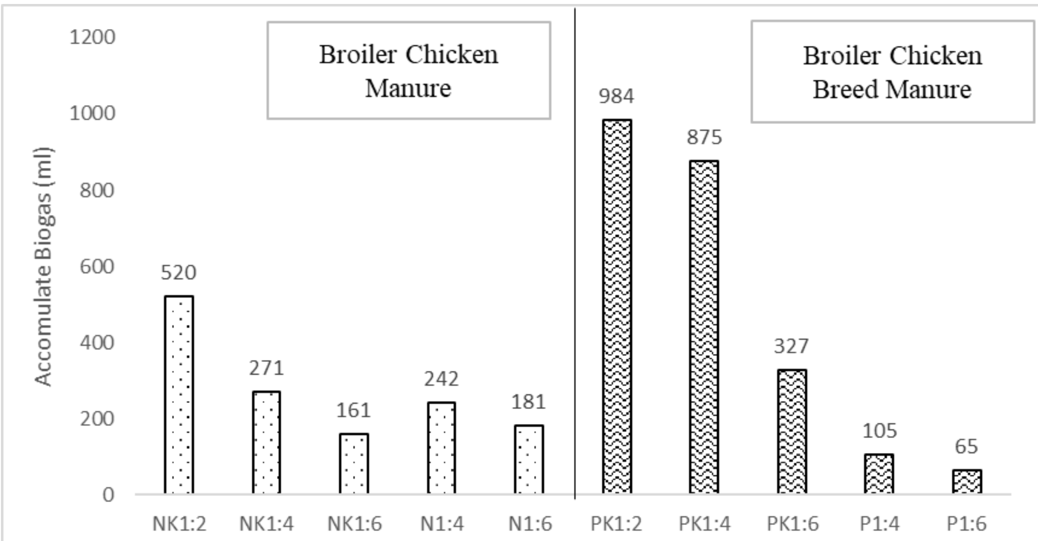

Figure 3 Biogas production from experimental with different water mixing ratios, with and without rice husk as a component

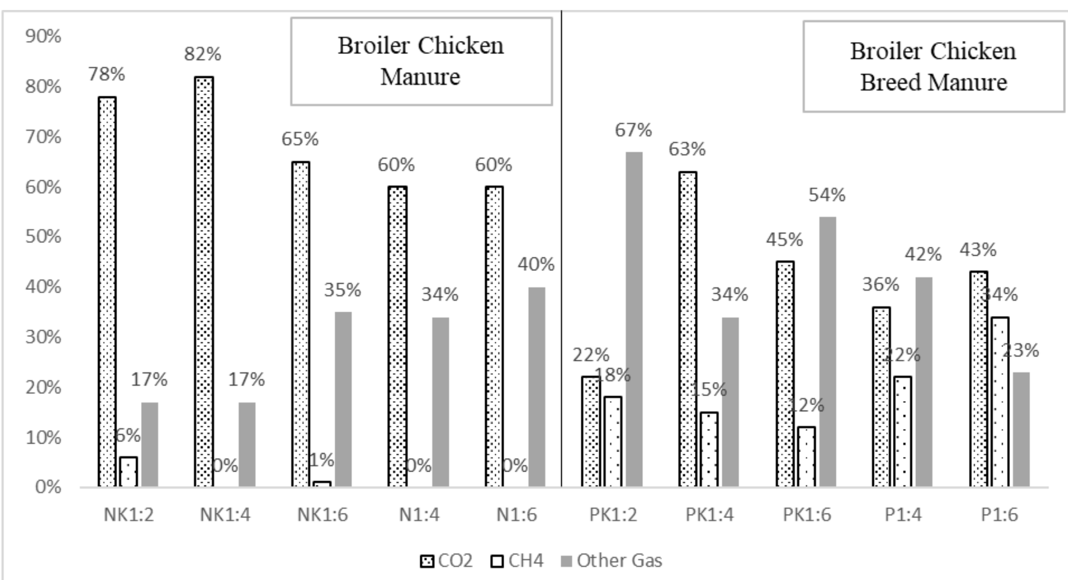

Figure 4 Study of the methane production efficiency of two types of broiler chicken manure at different mixing ratios

The experiment in section 1 led to the subsequent experiment aimed at enhancing methane production efficiency in the PK1:4 sample.

2. The biogas production from Broiler Chicken Breed manure with different mixing ratios of 4 types: Fe-A, Fe-B at 15, 20, 30 mg/l and GAC-A, GAC-B at 5, 10, 20 mg/l.

The biogas production potential from 45-day-old Broiler Chicken Breed manure at a manure-to-water ratio of 1:4, combined with iron scales Fe-A, Fe-B, GAC-A, and GAC-B at the difference specified concentrations, was tested. It was found that biogas production began within 24 hours and increased until day 37, where gas production stabilized as shown in the figure. In the Broiler Chicken Breed GAC-B experimental group at 5 mg/l, the accumulated biogas volume reached a maximum of 1,727 milliliters, with a maximum methane content of 60%, which is approximately 30% higher than the control group. When comparing the composition of biogas produced from different substrates, as shown in Table 3, the results indicate that The biogas volume in each experiment did not increase significantly. However, what made the experiment interesting was that the addition of only 5 mg/l of GAC-B resulted in a rapid increase in methane production, reaching up to 60%. This led to a more than 50% reduction in the digestion time, to just 17 days compared to the control group. This effect is due to the carbon content of GAC, which helps absorb ammonia and reduce toxicity. Additionally, the presence of Fe contributes to enhancing bacterial activity and helps absorb H_2S The shape and size of the iron particles have an impact on biogas production in this system by optimal biogas production occurred when 5 mg/l of GAC-B was added [12, 13].

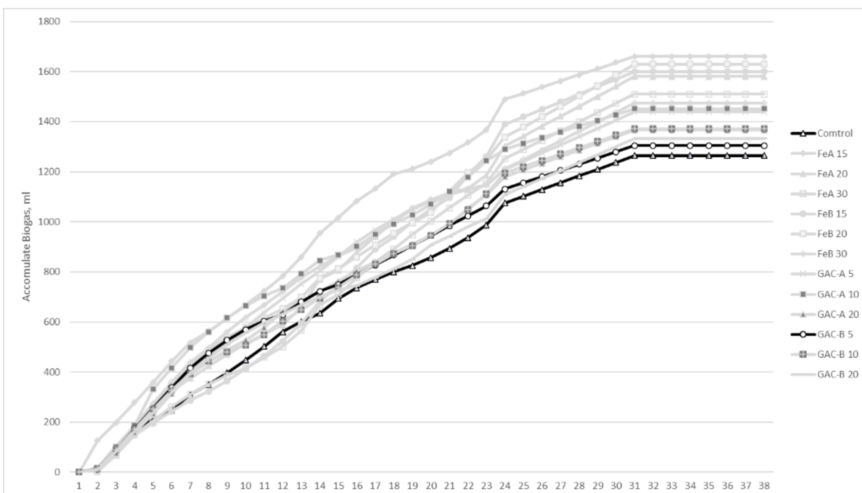

Figure 5 shows the cumulative biogas production (a) and cumulative methane production (b) after the addition of iron particles (Fe-A, Fe-B) at concentrations of 15, 20, and 30 mg/l, and GAC-A, GAC-B at concentrations of 5, 10, and 15 mg/l

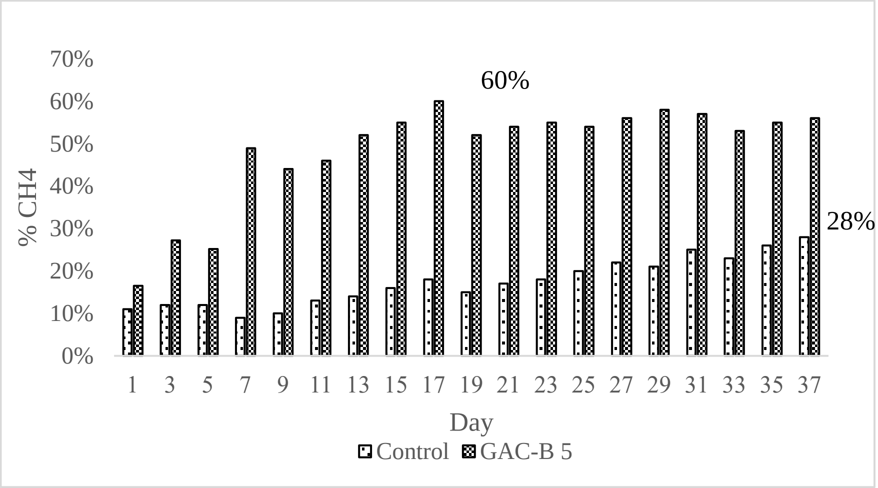

Figure 6 shows the duration of methane production (% CH_4) between the control group and the experimental group with the addition of GAC-B at 5 mg/l

Conclusions

The potential for biogas production from broiler chicken manure and broiler chicken breed manure was tested by adding activated carbon mixed with iron scale. The results indicated that iron scale of the type GAC-B, at a concentration of 5 mg/l, was the most effective in enhancing biogas production, particularly for broiler chicken breed manure. This concentration was found to be optimal due to the role of sulfate levels, which influence the selection of iron scale concentration in the system. The iron scale helps prevent sulfate formation in the system, reducing toxicity. Additionally, the addition of iron scale was found to outperform the addition of granular activated carbon in increasing biogas production capacity. It also accelerated the production of methane, increasing its production rate by up to two times, leading to a reduction in the required size of the reactor and cutting investment costs by up to 30%.

Acknowledgments

The research project titled “Study on Biogas production from broiler manure by GAC-dosedAnaerobic Biological Treatment System for Renewable Energy” was supported by the National Nanotechnology Center (NANOTEC), National Science and Technology Development Agency (NSTDA), for the synthesis of the additive (iron scale).

References

[1] AVEC. 2016. Annual report 2016. Association of Poultry Processors and Poultry Trade in the EU countries.

[2] Fuchs, W., Wang, X., Gabauer, W., Ortner, M., & Li, Z. 2018. Tackling ammonia inhibition for efficient biogas production from chicken manure: Status and technical trends in Europe and China. Renewable and Sustainable Energy Reviews. 86: 186-199.

[3] Miles, D. M., Logan, J. W., Arora, S., & Jenkins, J. N. 2016. On-farm resources and renewable energy in broiler chicken production: Brinson farms case study. International Journal of Poultry Science. 15(2): 41-47.

[4] Haider, M. R., Zeshan, Yousaf, S., Malik, R. N., & Visvanathan, C. 2015. Effect of mixing ratio of food waste and rice husk co-digestion and substrate to inoculum ratio on biogas production. Bioresource Technology. 190: 451-457.

[5] Xu, Y. and Li, Y. 2015. Ammonia inhibition on anaerobic digestion: Effects and mitigation strategies. Bioresource Technology. 179: 191-197.

[6] Abdelsalam, E., Samer, M., Attia, Y. A., Abdel-Hadi, M. A., Hassan, H. E., & Badr, Y. 2017. Influence of zero valent iron nanoparticles and magnetic iron oxide nanoparticles on biogas and methane production from anaerobic digestion of manure. Energy. 120: 842-853.

[7] Baek, G., Kim, J., & Lee, C. 2019. A review of the effects of iron compounds on methanogenesis in anaerobic environments. Renewable and Sustainable Energy Reviews. 113: 1-14.

[8] Feng, Y., Zhang, Y., Quan, X., & Chen, S. 2014. Enhanced anaerobic digestion of waste activated sludge by the addition of zero valent iron. Water Research. 52: 242-250.

[9] Holm-Nielsen, J. B., Al Seadi, T., & Oleskowicz-Popiel, P. 2009. The future of anaerobic digestion and biogas utilization. Bioresource Technology. 100(22): 5478-5484.

[10] Wang, L., Aziz, T. N., & de los Reyes, F. L. III. 2013. Determining the limits of anaerobic co-digestion of thickened waste activated sludge with grease interceptor waste. Water Research. 47(11): 3835-3844.

[11] Wang, X., Lu, X., Li, F., & Yang, G. 2014. Effects of temperature and carbon-nitrogen (C/N) ratio on the performance of anaerobic co-digestion of dairy manure, chicken manure, and rice straw: Focusing on ammonia inhibition. PLOS ONE. 9(5): e97265.

[12] Ortner, M., Rameder, M., Rachbauer, L., Bochmann, G., & Fuchs, W. 2015. Bioavailability of essential trace elements and their impact on anaerobic digestion of slaughterhouse waste. Biochemical Engineering Journal. 99: 107-113.

[13] Al Mamun, M. R., & Torii, S. 2015. Removal of hydrogen sulfide (H_2S) from biogas using zero-valent iron. Journal of Clean Energy Technologies. 3(6): 428-435.

[14] Chen, Y., Cheng, J. J. and Creamer, K. S. 2008. Inhibition of anaerobic digestion process: A review. Bioresource Technology. 99(10): 4044-4064.