EXPERIMENTAL INVESTIGATION ON THE EFFECT OF BIOGAS YIELD ENHANCEMENT THROUGH ANAEROBIC DIGESTION OF SWINE MANURE, CHICKEN FEATHERS, AND BIOFILM CARRIERS

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ABSTRACT *This study aimed to assess the biogas production and methane concentration resulting from anaerobic co-digestion of swine manure from slaughterhouses and backyard farms, as well as chicken feathers and biofilm carriers. Anaerobic digestion, a process performed in the absence of oxygen, stabilized organic waste and reduced greenhouse gas emissions. The anaerobic co-digestion of backyard swine manure and chicken feathers resulted in the highest biogas production, with 12.89 L and a methane concentration of 59.4%. The addition of biofilm carriers to backyard swine manure also produced substantial biogas, with 10.40 L and 56.9% methane. Meanwhile, the mono-digester of backyard swine manure produced 9.85 L with 59.3% methane. Biogas production and methane concentration from slaughterhouse manure were lower, with the mono-digester producing 6.93 L and a methane concentration of 47.6%. Results indicate that backyard scale swine manure is more favorable for biogas production and methane yield than slaughterhouse manure, and that the addition of chicken feathers enhances the results. The optimal mixture for anaerobic co-digestion was determined to be backyard swine manure and chicken feathers. This highlights the potential of anaerobic co-digestion to enhance biogas production and methane yield, as well as stabilize organic waste and reduce greenhouse gas emissions. The results of this study have important implications for the management of organic waste and the development of sustainable energy sources.*

Keywords: Anaerobic digestion, Biogas, Chicken Feather, Biofilm Carriers, Biogas Additives

INTRODUCTION

The transformation of the swine farming industry towards large-scale concentrated animal feeding operations has led to an increase in swine production efficiency and sanitary conditions [1,2]. In the Philippines, the swine sector encompasses both commercial and backyard swine farming operations. The commercial swine farming sector aims to produce high-quality and economically priced pork products, while backyard swine farming operations consist of smaller herds of no more than 20 adult equivalent animals and are easier to manage [3].

However, inadequate disposal of swine manure and other animal waste products can result in several negative impacts on the environment, including odor generation, attraction of vermin, toxic gas emissions, and groundwater contamination [4]. To mitigate these impacts, anaerobic digestion (AD) has been proposed as an environmentally friendly technology that integrates biogas production with sustainable waste management, and constitutes a crucial step in the swine manure treatment process [5]. Moreover, due to the large volume of swine manure produced in a limited area, traditional disposal methods such as land application can put pressure on the environment and represent a hindrance to the growth of swine farming and its associated economic activity [6]. AD is a microbial process that degrades organic matter in the absence of oxygen, resulting in biogas, primarily composed of methane (50-70%), carbon dioxide (30-40%), hydrogen sulfide, water vapor, and trace amounts of other gases. It is a biochemical treatment method that stabilizes a wide range of organic waste materials, such as complex lignocellulosic materials and food waste, while concurrently generating renewable energy, recovering fibers and nutrients for soil amendment, and reducing greenhouse gas emissions [7]. Biogas is a versatile and renewable energy source that can replace fossil fuels in energy generation for power and heat, as well as in gaseous vehicle fuel applications [8].

The addition of biofilm carriers to the interior of the AD reactors can increase biogas output. This is achieved by increasing the surface area of bacteria in contact with the microorganisms and biogas slurry, resulting in a more stable degradation process [9]. Biofilm carriers in AD reactors have the potential to enhance reactor performance by fostering microorganisms and augmenting the quantity of methane produced [10]. Chicken feathers, which make up 5-10% of broiler body weight, are one of the major solid waste products generated during poultry meat processing and are primarily comprised of keratins, proteins with high environmental persistence [11]. With its high protein content, poultry feathers represent an excellent raw material for biogas production [12].

In this study, a biogas production system through the anaerobic co-digestion of swine manure from backyard and commercial swine farming and slaughterhouse operations, with the addition of chicken feathers and biofilm carriers, will be developed. The impact of these additions on biogas production and methane content will be assessed to evaluate the feasibility of the proposed biogas production system. This study aims to provide a solution for the environmentally sustainable management of animal waste products in the swine farming industry and contribute to the generation of renewable energy.

METHODOLOGY*2.1 Biogas Digester Setup*

The four organic biomass materials used in this study included swine manure from a backyard scale farm, swine manure from a slaughterhouse, and a combination of swine manure and chicken feathers with biofilm carriers in both settings. The biogas digester setup consisted of three components: two 1.5 L bottles, one 10 L bottle, and a gas collector chamber containing water. The 1.5 L anaerobic digester was sealed airtight and connected to the 10 L gas collector chamber, allowing for the measurement of the amount of biogas produced through the water displacement method. The pH of the mixture was tested prior to loading it into the digester and monitored throughout the experiment using a pH meter.

To ensure a homogeneous mixture of microbes and biomass, the digester was mixed daily. The temperature and methane concentration were also monitored and recorded regularly. The temperature was measured using a Flir MR365 moisture meter and thermal imager, while the methane concentration was determined through gas analysis with a gas analyzer. The gas samples were collected using a 60 mL gas-tight syringe and analyzed under mesophilic temperature conditions to gather accurate readings.

Further, the results of this study provide valuable insights into the biogas production potential of different organic biomass materials and highlight the importance of monitoring the experimental parameters, including temperature, pH, and methane concentration, in the optimization of anaerobic co-digestion processes.

Experimental Material

2.2.1 Substrate for Biogas Production

The research study aimed to assess the feasibility of utilizing swine manure as a substrate for biogas production. To this end, swine manure was collected from two different sources: the City Slaughterhouse Plant located in Cugman, Cagayan de Oro City, and the AG Venture Piggery Farm in Pagatpat, Cagayan de Oro City. The swine manure was mixed with water in a 1:1 ratio, and this mixture served as the substrate for biogas production.

2.2.2 Additives Utilized

In order to optimize the biogas production process, the addition of biofilm carriers and chicken feathers was investigated as potential additives. A suitable biofilm carrier must possess a number of specific characteristics, including a large specific surface area, bio-affinity, stability, resistance to acids and bases, oxidation resistance, difficulty in biodegradation and aging, a light mass, and strong mechanical strength. Additionally, the carrier must be cost-effective and non-toxic to cells. A number of options for biofilm carriers exist, each with its own advantages and disadvantages [13].

In this study, the biofilm carrier utilized was of the K1 media type, which was used. This biofilm carrier measures 10mm by 7mm, with a surface area of 1000m2/m3, and was employed to assist in the nourishment of the microbes present in the slurry for biogas production.

The utilization of chicken feathers as a co-substrate additive was also assessed. The feathers were collected and immediately washed in a dilute soap solution, followed by a rinse with tap water. The washed feathers were then sun-dried, chopped into particle sizes ranging from 1mm to 4mm, and stored at room temperature until use. The resulting material

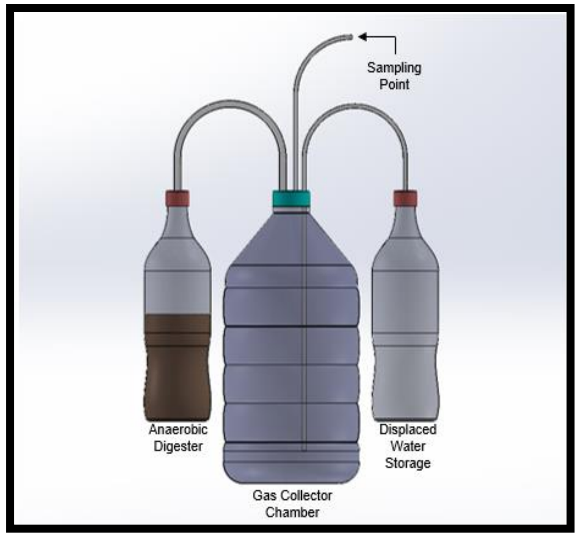

Figure 1: Schematic Diagram of the digester setup

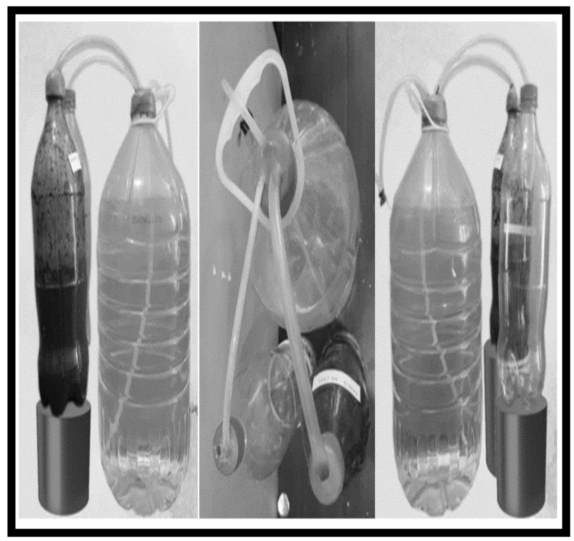

Figure 2: Actual experimental set-up of the system*2.2*

Figure 3: Actual photos of biofilm carriers and chicken feathers

was added directly to the slurry.

By utilizing these additives, the research aimed to determine if their addition would result in an improvement in biogas production yields.

RESULTS AND DISCUSSION

1.1 *Biogas Production*

The results of the cumulative biogas production experiment provide valuable insights into the performance of various anaerobic co-digestion systems. The observation that the highest biogas yield was obtained from the BSFM and CF system supports the findings of previous studies which have shown that feathers can serve as a valuable substrate for biogas production. The addition of feathers to the BSFM system effectively increased biogas production, likely due to the efficient degradation of the feathers in the presence of appropriate microbial populations. The addition of biofilm carriers to the BSFM system also showed the potential in enhancing biogas production by providing a supportive environment for microorganisms to thrive.

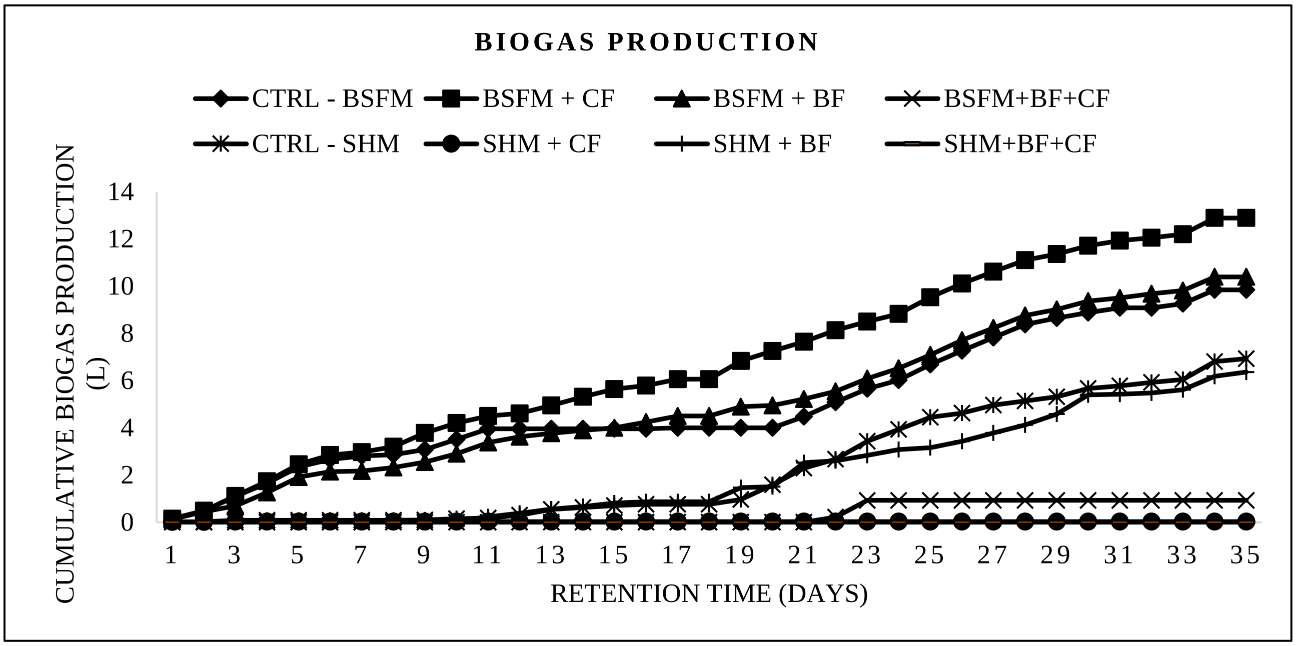

Figure 4: Variation of biogas production during the anaerobic co-digestion process: cumulative biogas production

Biofilm carriers have been shown to play a significant role in improving reactor productivity by maintaining the microbial populations required for efficient biogas production [14]. The combination of biofilm carriers and feathers, however, did not produce the desired results in the SHM system. This can be attributed to the low biodegradability of feathers and the potential for ammonia inhibition during the anaerobic degradation of feathers [15].

It is noteworthy that the pH level and temperature of the substrate played a crucial role in biogas production. The pH of the BSFM substrate was within the optimum range for the digestion process, which contributed to the efficient degradation of organic matter and biogas production. On the other hand, the pH of the SHM substrate was below the optimal range, which may have hindered microbial activity and biogas production. The inconsistent temperature reading in the SHM system may also have contributed to the irregular biogas generation observed.

The results of this study highlight the importance of considering various factors in the design and optimization of anaerobic co-digestion systems for biogas production. The use of feathers and biofilm carriers as substrates, as well as maintaining optimal pH and temperature conditions, can significantly enhance biogas production. The findings of this study are valuable for the development of sustainable and efficient biogas production systems using anaerobic co-digestion

3.2 Methane Yield

The daily methane concentration curve of the digestion trials is depicted in Figure 5. The average methane content of the control digesters, BSFM and SHM, was found to be 41.87% and 26.82%, respectively. The addition of chicken feathers (CF) to the backyard scale farm swine manure (BSFM+CF) resulted in an average methane content of 42.1%, whereas the average methane content of the slaughterhouse swine manure (SHM) with CF was 24.81%. The presence of biofilm carriers (BF) in the digesters, BSFM+BF and SHM+BF, resulted in average methane contents of 41.93% and 27.44%, respectively. The co-digestion of backyard scale farm manure (BSFM), chicken feathers (CF), and biofilm carriers (BF) (BSFM+CF+BF) and the co-digestion of slaughterhouse manure (SHM), chicken feathers (CF), and biofilm carriers (BF) (SHM+CF+BF) resulted in average methane contents of 38.55% and 13.44%, respectively. The results indicate that the co-digestion of backyard scale farm manure (BSFM) with chicken feathers (CF) and biofilm carriers (BF) results in significantly higher methane content compared to the control digesters. On the other hand, the digestion of slaughterhouse manure (SHM) had a longer startup time to produce methane, which highlights the imbalances in the process. The pH level of the slurry upon loading was measured, and the pH of the slaughterhouse slurry was 6.14, which is below the optimal pH range for methanogens, close to neutral. As methanogenesis is a rate-

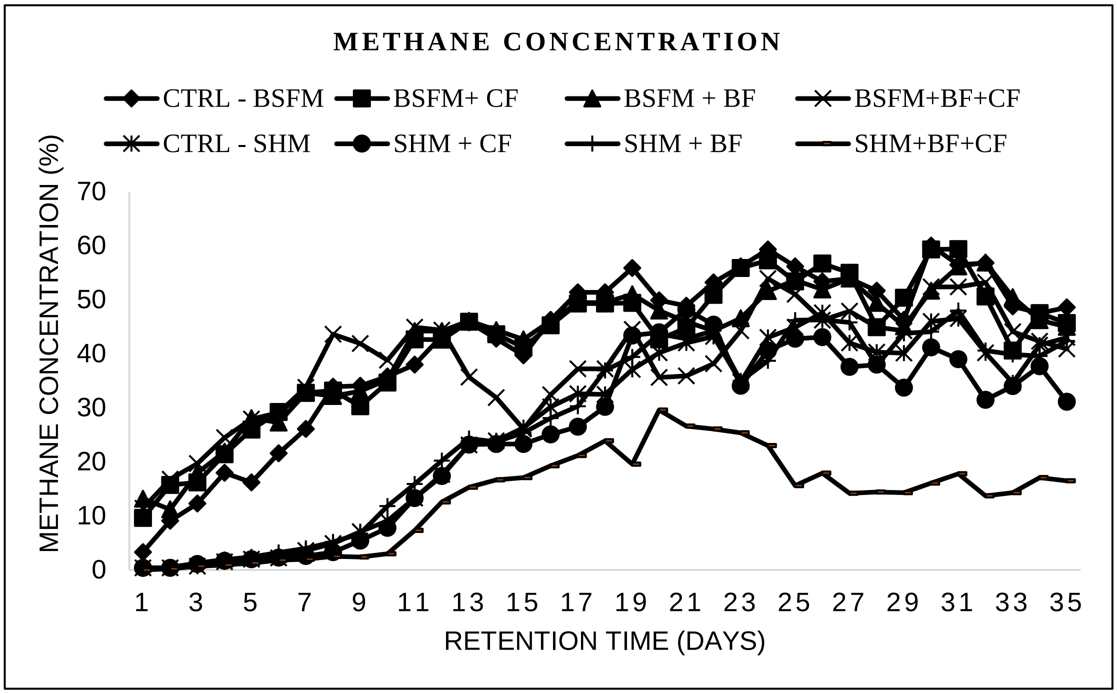

Figure 5. Variation of biogas production during the anaerobic co-digestion process: methane content

limiting phase, maintaining the pH of the reactor close to neutral is crucial for biogas digestion processes [16].

Fluctuations in the daily methane concentration were primarily due to fluctuations in pH, which is difficult to monitor in a batch digester. [17] have emphasized that the pH level is not constant throughout the process.

3.3 Correlation of CH_4 Content and Biogas Volume

By further elaborating on the findings presented in Figure 4, the strong positive correlation between CH_4 content and biogas volume in digesters containing BSFM and CF or BF is an important outcome of this study. These results highlight the potential of incorporating poultry waste products in swine manure-based biogas systems, as the CH_4 production appears to be significantly influenced by the addition of these waste materials. The R-squared values of 0.6598 and 0.635 further indicate the strength of this relationship, demonstrating that the majority of the variation in CH_4 content can be explained by the biogas volume produced.

It is also noteworthy that the mono-digestion of BSFM and SHM showed positive correlations between biogas volume and methane quality. This suggests that the methane quality can be improved through the optimization of the mono-digestion process. The R-squared values of 0.5742 and 0.630 indicate that the increase in biogas volume is significantly associated with the improvement in methane quality, making these results valuable for practical applications in the biogas industry.

In contrast, the negative correlation observed in the BSFM with additives is an unexpected outcome. Further investigation is required to understand the reasons behind this negative relationship and to determine the optimal conditions for improving biogas production in such systems. The zero correlation between SHM with additives and biogas volume highlights the need for a more detailed understanding of the complex interactions between different types of waste products and their impact on biogas production.

The results of this study provide valuable insights into the relationship between CH_4 content and biogas volume in various biogas systems, which can inform the optimization and design of practical biogas systems. Further research is needed to fully understand the impact of different waste materials and operational conditions on biogas production.

3.4 Calorific Value

The calorific value of biogas, as a renewable energy source, is of great importance for its potential applications. Biogas production through anaerobic digestion of organic matter can produce methane, which serves as the primary source of energy. The calorific value of biogas, expressed as the lower heating value (LHV), is a measure of the energy content of the gas and is directly proportional to its methane content. The LHV of raw biogas with a CH_4 concentration of approximately 60% has been estimated to be approximately 30 MJ/kg.

However, through purification processes, the CH_4 concentration can be increased to 90%, resulting in an LHV of 45 MJ/kg. The study presented in Figure 5 demonstrates the comparison of calorific values of biogas produced from different digesters. The highest LHV was observed in the digester derived from backyard scale farm manure (CTRL-BSFM) with an average value of 11.09 MJ/kg. This was

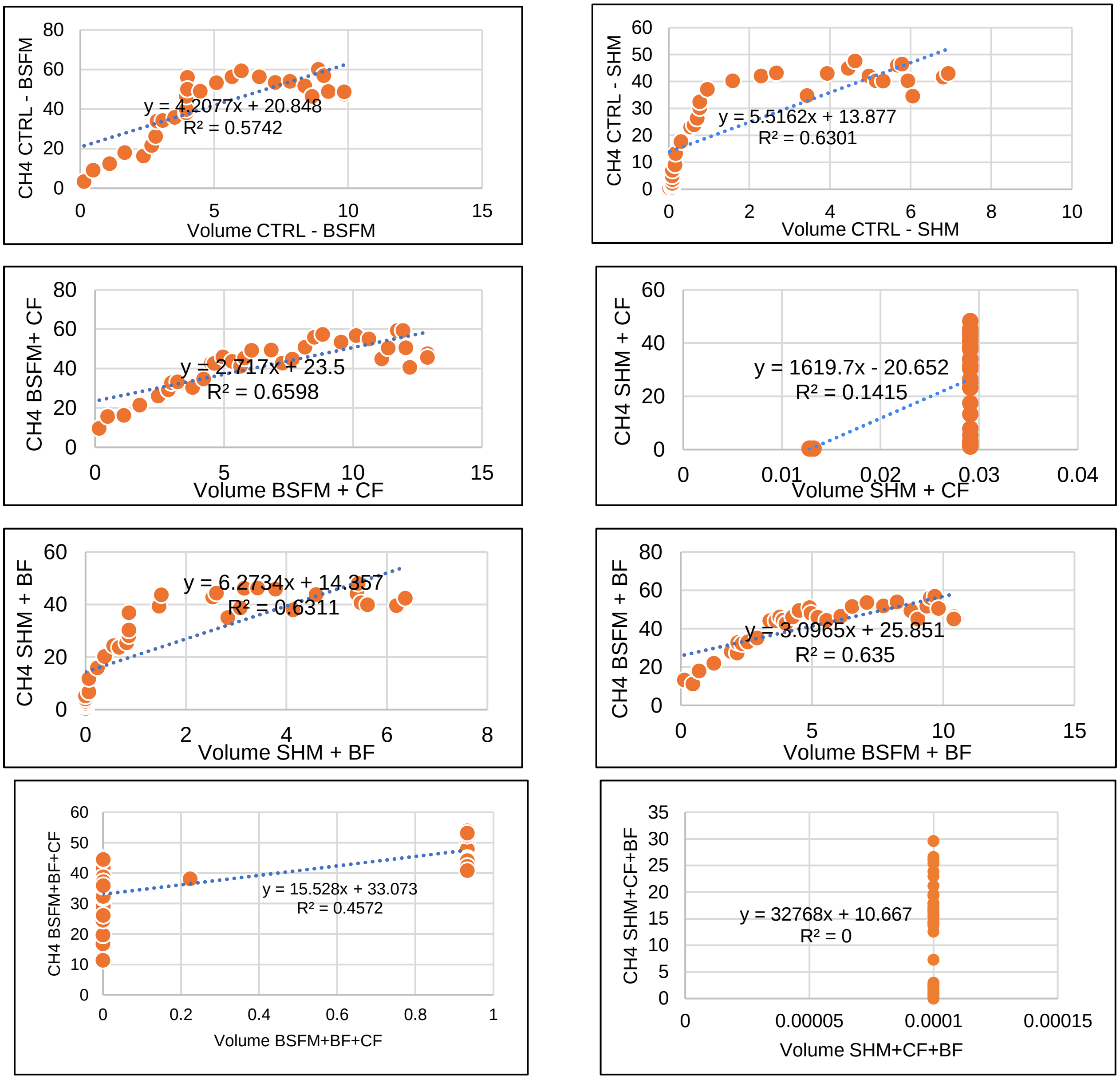

Figure 6. Correlation between CH_4 and biogas volume

followed by the BSFM+CF and BSFM+BF digesters with average LHV values of 10.93 MJ/kg and 10.92 MJ/kg, respectively. The digester utilizing a mixture of backyard scale farm manure, chicken feathers, and banana leaves (BSFM+CF+BF) had the lowest LHV of 9.86 MJ/kg. On the other hand, the lowest LHV values were observed in the digesters utilizing slaughterhouse manure, with an average of 6.45 MJ/kg for CTRL-SHM, 6.63 MJ/kg for SHM+BF, 5.91 MJ/kg for SHM+CF, and 2.79 MJ/kg for the mixture of all three.

The results of the study as shown in Figure 7 indicates a strong correlation between the CH_4 composition and the LHV of biogas. As the CH_4 concentration increases, the LHV also increases, thus demonstrating the importance of purification processes in enhancing the energy output of biogas. The findings of this study contribute to the understanding of the energy content of biogas and provide valuable information for the development of sustainable biogas production technologies.

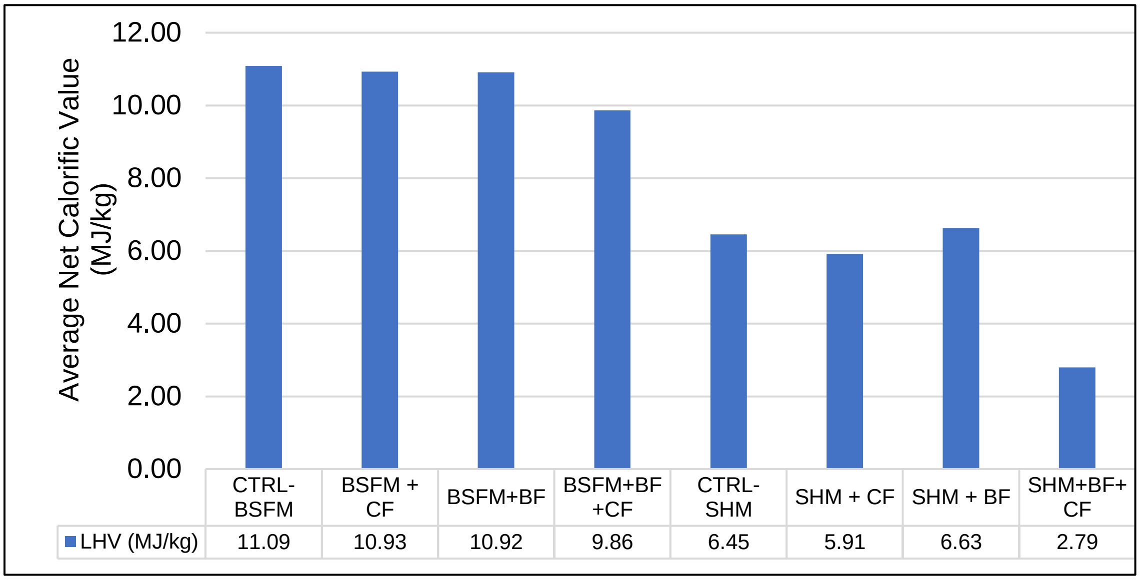

Figure 7. Average Net Calorific Value of the Anaerobic Digestion Process

CONCLUSIONS

The results of the study provide valuable insights into the utilization of chicken feathers and biofilm carriers as additives for anaerobic co-digestion of swine manure. The use of chicken feathers as an additive has been shown to significantly increase biogas and methane production in backyard scale farm swine manure digesters compared to the utilization of slaughterhouse swine manure alone. The findings are consistent with previous studies that have reported an increase in biogas production through the co-digestion of livestock waste and organic waste. The study's results also highlight the importance of considering the composition of the feedstock in determining the efficacy of biogas production. The utilization of chicken feathers and biofilm carriers as additives in backyard-scale farm swine manure digesters has been shown to produce elevated levels of biogas and methane compared to the utilization of slaughterhouse swine manure alone. The results indicate that the utilization of chicken feathers and biofilm carriers may be most effective in backyard-scale farm swine manure digesters that have a high content of readily biodegradable organic matter.

The study's findings also have implications for the sustainable management of chicken feathers and biofilm carriers, which are often considered waste materials. The results of the study demonstrate that chicken feathers can be utilized as a valuable resource for biogas production, providing a potential solution for the sustainable disposal of these waste materials. The findings also suggest that the utilization of biofilm carriers as an additive in anaerobic co-digestion can improve biogas production, thereby providing a more sustainable method of managing this waste material.

In conclusion, the results of the study provide valuable insights into the utilization of chicken feathers and biofilm carriers as additives for anaerobic co-digestion. The findings demonstrate that the utilization of chicken feathers and biofilm carriers can improve biogas production and provide a sustainable solution for the management of these waste materials. Further research is needed to determine the optimal conditions for the co-digestion of chicken feathers and biofilm carriers with swine manure, as well as to investigate the potential utilization of these additives in other waste streams.

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