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Assessing the Viability of Biogas Production from Various Domestic Animal Dungs for Meeting Household Energy Demands

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ABSTRACT

This laboratory experiment examines pig, cattle, and poultry waste biogas generation over various detention times. From 0 to 60 days, biogas production (L/Kg) was measured every 5 days. The patterns for each waste type provide valuable insights into anaerobic digestion dynamics. In pig waste, longer detention times consistently increased biogas production. Extended anaerobic digestion maximised biogas production, with the highest yield of 1.21 L/Kg at 60 days. Biogas production from cattle waste peaked at different detention times. At 45 days, biogas production was highest at 0.92 L/Kg, suggesting optimal times. As detention times increased, poultry waste biogas production peaked at 0.98 L/Kg at 50 days.

We found that longer detention times increased biogas production for all waste types. Peak production timing depends on waste characteristics and microbial activity. The findings help optimise anaerobic digestion by understanding biogas generation dynamics in agricultural waste. The experiment shows livestock farming can produce renewable energy and manage waste sustainably.

Keywords: Biogas yield, Renewable energy, Animal waste, Anaerobic digestion, Detention time

Introduction

Biogas technology stands at the intersection of sustainable waste management and renewable energy, offering a versatile solution that aligns with the principles of a greener and more sustainable future. The adoption of biogas technology contributes significantly to environmental sustainability. By diverting organic waste from landfills, it helps reduce methane emissions, a potent greenhouse gas. Furthermore, the use of biogas as a clean and renewable energy source contributes to mitigating climate change and promoting a circular economy (IPCC, 2014).

In the pursuit of sustainable and renewable energy solutions, biogas has emerged as a promising and environmentally friendly alternative (Weiland, 2010). Biogas is a combustible gas composed primarily of methane (CH4) and carbon dioxide (CO2) produced through the anaerobic digestion of organic materials. This process involves the microbial decomposition of biodegradable waste in the absence of oxygen, resulting in the generation of a valuable energy resource. Biogas technology harnesses this natural process for various applications, offering a range of benefits including waste management, renewable energy production, and reduction of greenhouse gas emissions (Angelidaki & Ellegaard, 2003; Weiland, 2010).

The core of biogas technology lies in the anaerobic digestion process, where organic materials such as agricultural residues, animal manure, sewage sludge, and organic household waste undergo microbial degradation. Microorganisms break down complex organic compounds into simpler molecules, releasing methane and carbon dioxide as byproducts. The efficiency of the process depends on factors such as substrate composition, temperature, pH, and retention time (Weiland, 2010).

Biogas is primarily composed of methane (50-70%), carbon dioxide (30-50%), and trace amounts of other gases such as hydrogen sulfide, ammonia, and water vapor (Weiland, 2010). The high methane content makes biogas a valuable fuel for various applications, including cooking, heating, electricity generation, and transportation (Weiland, 2010; IPCC, 2014).

The objective of this study is to assess the viability and efficacy of utilising various types of animal excrement for the production of biogas, with the aim of addressing the energy needs of households in a sustainable manner. The study entails a thorough examination of the production of biogas from various sources, including cattle, poultry, and pig dung. It does not take into account key factors such as methane yield, digestate quality, and overall energy efficiency. The study's findings provide significant contributions to the understanding of biogas as a renewable energy option for residential use, effectively addressing concerns related to environmental sustainability and energy security.

Literature Review

As the global demand for sustainable energy solutions intensifies, the exploration of alternative sources such as biogas from domestic animal dungs gains prominence. This literature review delves into the existing body of research on assessing the viability of biogas production from different domestic animal dungs and its potential in meeting household energy demands.

Numerous studies have investigated the feasibility of biogas production using domestic animal dungs as feedstock. A study by Mata-Alvarez et al. (2014) emphasizes the potential of anaerobic digestion in centralized biogas plants, with a focus on co-digestion achievements using manure and organic wastes. The authors highlight the importance of understanding the synergies between various types of organic waste, shedding light on the complexities of the anaerobic digestion process. To assess the viability of biogas production from different domestic animal dungs, a comparative analysis of methane yield is crucial. Smith et al. (2014) contribute insights into the methane emissions from agriculture, forestry, and other land-use practices. Their findings underscore the variations in methane production among different sources of organic waste, including animal manure, emphasizing the need for targeted research on maximizing methane yield for household energy purposes.

Weiland (2010) provides a comprehensive review of biogas production, elucidating the factors that influence the efficiency of the anaerobic digestion process. The author discusses substrate composition, temperature, pH, and retention time as critical parameters affecting biogas yield. Understanding these factors is essential in optimizing biogas production from various domestic animal dungs for household energy needs. The dual benefits of waste management and energy security are evident in the utilization of biogas from domestic animal dungs. Angelidaki and Ellegaard (2003) explore the concept of co-digestion of manure and organic wastes in centralized biogas plants. The study emphasizes the role of biogas technology not only in producing renewable energy but also in efficiently managing organic waste, aligning with sustainable waste management practices.

Assessing the viability of biogas production also involves considerations of economic feasibility and technological innovations. A critical review by Appels et al. (2011) discusses the challenges and potential advancements in anaerobic digestion for global bio-energy production. The authors emphasize the importance of continuous research and development to enhance the economic viability of biogas technology, making it a more accessible and attractive solution for meeting household energy demands. Microbial communities play a pivotal role in the anaerobic digestion process, influencing biogas production efficiency. Recent research by Sundberg et al. (2013) investigates the microbial community dynamics in anaerobic digestion systems. Understanding the microbial consortia involved in the degradation of different domestic animal dungs provides insights into optimizing anaerobic digestion for enhanced biogas yields.

Assessing the economic viability of biogas production from various domestic animal dungs requires a comprehensive evaluation of the associated costs and benefits. A study by Jha and Kalamdhad (2018) provides a techno-economic assessment of biogas production from animal manure. The authors emphasize the importance of considering factors such as capital costs, operational expenses, and revenue streams, offering valuable insights for scaling biogas systems for household energy needs. To holistically evaluate the viability of biogas production, environmental impacts must be considered. Life cycle assessment (LCA) methodologies offer a systematic approach to analyzing the environmental footprint of biogas systems. Guo et al. (2018) conducted an LCA of biogas production from different organic waste sources, providing valuable information on the overall sustainability and environmental benefits of utilizing biogas for household energy demands.

The success of biogas production for household energy also hinges on supportive policy and regulatory frameworks. A study by Mondal et al. (2017) examines the policy landscape for promoting biogas technology in developing countries. Understanding the regulatory environment is crucial for identifying barriers and opportunities for the widespread adoption of biogas systems, particularly those utilizing domestic animal dungs. Continuous advancements in biogas technology contribute to its viability for household energy applications. Kothari et al. (2014) provide an overview of recent innovations in biogas production, including advancements in reactor design, pretreatment techniques, and integration with other renewable energy systems. These innovations are essential for enhancing the efficiency and applicability of biogas technology, particularly in the context of diverse domestic animal dungs.

Biogas Generation Process

The generation of biogas involves several key stages, each contributing to the overall efficiency and effectiveness of the process. According to Weiland (2010), Appels et al. (2011) and Angelidaki & Ellegaard, (2003), the primary stages in biogas generation:

1. Substrate Preparation:

At this stage, the organic material, also known as the substrate, is collected and prepared for the anaerobic digestion process. This can include various feedstocks such as agricultural residues, animal manure, organic wastes, and energy crops.

2. Anaerobic Digestion:

The heart of biogas generation is the anaerobic digestion process. This stage occurs in a controlled environment without the presence of oxygen. Microorganisms break down complex organic compounds in the substrate into simpler molecules, producing methane (CH4) and carbon dioxide (CO2) as byproducts.

3. Biogas Collection:

The biogas produced during anaerobic digestion is collected from the digester. The composition of biogas typically includes methane (50-70%), carbon dioxide (30-50%), and trace amounts of other gases such as hydrogen sulfide, ammonia, and water vapor.

4. Gas Storage and Upgrading (Optional):

Biogas can be stored for later use or undergo upgrading processes to remove impurities, particularly carbon dioxide, to increase its methane content. Upgraded biogas is often referred to as biomethane and can be injected into natural gas grids or used as a vehicle fuel.

Review on Biogas Generation from Poultry Waste

Poultry farming generates substantial amounts of organic waste, presenting an opportunity for sustainable energy production through anaerobic digestion. This literature review explores research findings on biogas generation from poultry waste, emphasizing the generation potentials and implications for renewable energy utilization.

Poultry waste, comprising manure and bedding materials, is rich in organic matter. The composition of poultry litter includes nitrogen-rich elements, cellulose, and other organic compounds, making it an ideal substrate for anaerobic digestion (Ghosh and Henry, 2007). The efficient breakdown of these components during anaerobic digestion is crucial for maximizing biogas yields. Anaerobic digestion is a well-established process for converting poultry waste into biogas. Studies, such as that by Masse et al. (2011), delve into the microbial processes involved in anaerobic digestion of poultry litter. The research highlights the importance of optimizing conditions such as temperature and retention time to enhance biogas production efficiency.

Poultry waste has demonstrated significant biogas generation potentials. In a study by Zupancic et al. (2016), the authors assessed the biogas potential of poultry litter through batch experiments. The results indicated substantial methane yields, emphasizing the viability of poultry waste as a valuable feedstock for renewable energy production. Various factors influence the biogas production potential from poultry waste. Ghosh and Henry (2007) outline the impact of litter moisture content, carbon-to-nitrogen ratio, and microbial activity on biogas yields. Understanding these factors is essential for designing and operating efficient biogas systems. The utilization of biogas generated from poultry waste aligns with renewable energy goals. Poultry farms can benefit from on-site energy production, reducing reliance on external energy sources (Angelidaki and Ellegaard, 2003). Additionally, the utilization of biogas contributes to waste management and mitigates environmental impacts associated with untreated poultry waste.

Review on Biogas Generation from Pig Waste

Pig farming operations generate substantial amounts of organic waste, predominantly in the form of pig manure. This literature review explores research findings on biogas generation from pig waste, focusing on generation potentials and the implications for sustainable energy production. Pig waste is characterized by a high organic content, including manure, urine, and bedding materials. The organic composition, rich in volatile solids and nutrients, makes pig waste an excellent candidate for anaerobic digestion (Bauer and Slepicka, 2012). Understanding the characteristics of pig waste is essential for optimizing the biogas production process.

Anaerobic digestion is a widely studied process for converting pig waste into biogas. Bauer and Slepicka (2012) conducted research on the anaerobic digestion of pig manure, emphasizing the importance of temperature control and digester design for efficient biogas production. The study provides insights into the microbial processes involved in the degradation of pig waste. Numerous studies have explored the biogas generation potentials of pig waste. A study by Bonmatí et al. (2010) investigated the methane production from pig slurry through anaerobic digestion. The research demonstrated substantial biogas yields and highlighted the significance of optimizing operating conditions for enhanced methane production.

Several factors influence biogas production from pig waste. Research by Wu et al. (2010) delves into the impact of influent concentration, hydraulic retention time, and organic loading rate on biogas yields. Understanding these factors is crucial for designing and operating efficient anaerobic digestion systems for pig waste. Utilizing biogas generated from pig waste aligns with sustainability goals in agriculture. The on-site production of renewable energy from pig waste offers potential economic benefits for pig farmers while addressing environmental concerns related to untreated waste management (Hao et al., 2018). The integration of biogas systems into pig farming operations contributes to a circular and sustainable approach to waste and energy management.

Review on Biogas Generation from Cattle Waste

Cattle farming is a significant contributor to the agricultural sector, and the management of cattle waste presents an opportunity for sustainable energy production through anaerobic digestion. This literature review explores research findings on biogas generation from cattle waste, focusing on its generation potentials and implications for renewable energy production.

Cattle waste, primarily in the form of manure, is characterized by its rich organic content and nutrient composition. The mix of solid and liquid components, including feces and urine, provides an ideal substrate for anaerobic digestion (Abbasi et al., 2012).

Understanding the unique characteristics of cattle waste is crucial for optimizing biogas production. Anaerobic digestion is a well-established method for converting cattle waste into biogas. Research by Demirel and Scherer (2008) provides insights into the microbial processes involved in the anaerobic digestion of cattle manure. The study emphasizes the significance of temperature control, pH levels, and hydraulic retention time for maximizing biogas yields from cattle waste.

Studies have explored the biogas generation potentials of cattle waste, highlighting its viability as a renewable energy source. A study by Hassan et al. (2018) assessed the methane production potential of cattle dung through laboratory experiments. The findings emphasized the substantial biogas yields achievable from anaerobic digestion of cattle waste, underscoring its potential for clean energy generation. Various factors influence biogas production from cattle waste. Abbasi et al. (2012) investigated the impact of substrate characteristics, temperature, and organic loading rate on biogas yields. The study provides valuable insights into optimizing anaerobic digestion parameters for efficient biogas production from cattle waste. The utilization of biogas generated from cattle waste aligns with renewable energy goals and offers additional benefits. Research by Hafner et al. (2019) explored the potential of integrating biogas production into existing cattle farming operations. The study highlighted the economic and environmental advantages, emphasizing the potential for sustainable waste management and energy self-sufficiency.

Comparative Studies on Biogas Generation Potentials of Poultry, Pig, and Cattle Waste

The management of organic waste from poultry, pig, and cattle farming has gained attention as a potential source for sustainable biogas production. This literature review explores comparative studies that investigate and compare the biogas generation potentials of waste from poultry, pig, and cattle farming, shedding light on the unique characteristics and efficiency of anaerobic digestion across these livestock sectors.

Each type of livestock waste—poultry, pig, and cattle—possesses distinct characteristics based on the animals' digestive systems, diets, and waste compositions. Poultry waste is typically rich in nitrogen, while pig waste has a balanced carbon-to-nitrogen ratio, and cattle waste contains a mix of solid and liquid components (Bauer and Slepicka, 2012; Ghosh and Henry, 2007; Abbasi et al., 2012). Understanding these differences is crucial for optimizing anaerobic digestion processes. Several studies have investigated the efficiency of anaerobic digestion for biogas production across different livestock waste types. Bauer and Slepicka (2012) explored the anaerobic digestion of pig manure, emphasizing the importance of temperature control and digester design. Ghosh and Henry (2007) conducted research on the methane production potential of poultry litter, highlighting the significance of litter moisture content and carbon-to-nitrogen ratio. Abbasi et al. (2012) investigated biogas recovery from cattle manure, emphasizing the role of temperature and organic loading rate. Comparative assessments of these studies provide insights into the efficiency variations among poultry, pig, and cattle waste digestion processes.

Comparative studies, such as that conducted by Hassan et al. (2018), directly compare the biogas generation potentials of poultry, pig, and cattle waste. The research assessed the methane production potential of these livestock wastes through laboratory experiments, providing quantitative data on their respective biogas yields. Such studies contribute valuable insights into the comparative performance of anaerobic digestion across different livestock sectors. Understanding the factors influencing biogas production from poultry, pig, and cattle waste is essential for optimizing anaerobic digestion systems. Wu et al. (2010) investigated the impact of influent concentration, hydraulic retention time, and organic loading rate on biogas yields, providing a comparative analysis across these waste types. Comparative studies contribute to the broader implications of integrating biogas production into sustainable agriculture. The potential economic and environmental benefits of waste-to-energy systems vary across poultry, pig, and cattle farming operations (Hafner et al., 2019). Comparative assessments help identify the most effective strategies for waste management and renewable energy production within each livestock sector.

The results by Kamen et al. (2019), of the biogas productions from cow, pig and poultry dung showed that appreciable quantity of biogas can be obtained from the dung of these three domestic animals which if explored in large scale will be of great economic benefit and help to combat environmental pollution. The result showed that cow dung had the highest biogas yield of 107cm3/150g dry dung, followed by the poultry dung with the yield of 83.1cm3/150g dry dung and lastly pig dung having the yield of 79cm3/150g dry dung. a comparative study by Soom et al. (2016), indicated that piggery feaces gave the highest yield of biogas (1.07 L/kg), followed by cattle dung (0.71 L/kg), with poultry wastes the least (0.42 L/kg) all under direct sunlight. This study shows that piggery droppings are the best substrate for biogas production and the best yield result when the process is carried out under direct sunlight.and was collected between 15-40 days of the detention time.

Laboratory Set-Up for Biogas Generation Experiment

Materials:

i. Anaerobic Digester:

ii. Livestock Waste Samples:

iii. Temperature Control:

iv. Gas Collection System:

Methods:

i. Preparation of Livestock Waste:

a) Collect representative samples of poultry, pig, and cattle waste.

b) Shred or blend the waste to facilitate microbial digestion.

ii. Anaerobic Digester Setup:

a) Prepare the anaerobic digester according to the chosen design.

b) Inoculate the reactor with the anaerobic sludge or inoculum.

iii. Temperature and pH Control:

a) Maintain the desired temperature and pH levels within the digester.

b) Monitor and adjust as needed during the experiment.

iv. Gas Collection:

a) Connect the gas collection system to the digester to capture and measure biogas production.

b) Ensure airtight seals to prevent gas leakage.

This study was carried out to compare the rate of and amount of gas produced from six different animals' dung under anaerobic conditions. ***1-kilogram*** dry weight of each animal's dung was weighed out under anaerobic conditions in the laboratory and with temperature of between ***27-30^{O}C*** (room temperature)**.** The detention period is 60 days.

Result

Table 1. Biogas production from 3 animal waste

Detention time (days)	Pig (L/Kg)	Cattle (L/Kg)	Poultry (L/Kg)
0	0.00	0.00	0.00
5	0.12	0.15	0.02
10	0.08	0.33	0.09
15	0.06	0.36	0.18
20	0.06	0.64	0.40
25	0.20	0.70	0.59
30	0.22	0.76	0.66
35	0.49	0.81	0.71
40	0.55	0.89	0.86
45	0.99	0.73	0.92
50	1.10	0.71	0.98
55	1.21	0.67	0.82
60	1.00	0.59	0.78

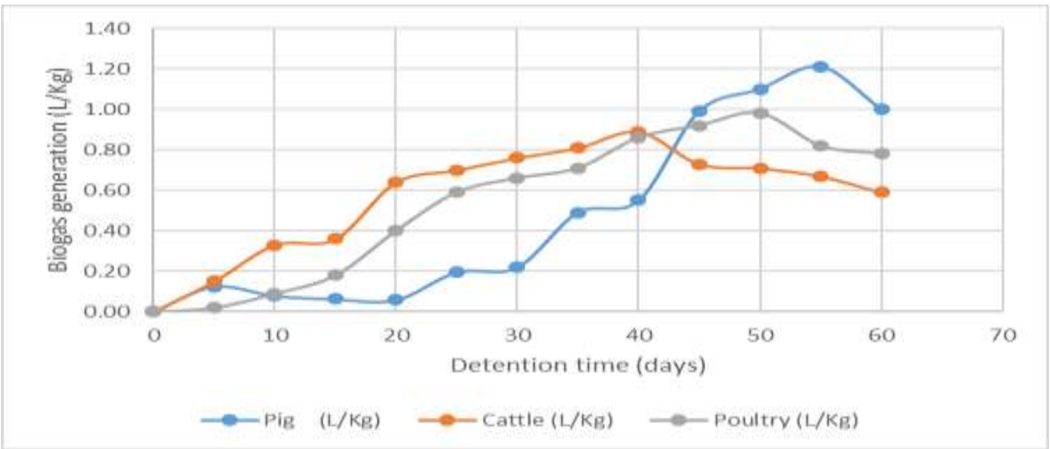

Figure 1. Graph showing the results for the biogas production

The results provided represent the biogas generation in L/Kg (liters per kilogram) for different types of livestock waste (pig waste, cattle waste, and poultry waste) over a range of detention times (days). Each value corresponds to the amount of biogas produced per unit of waste (per kilogram) at specific time intervals.

The biogas generation starts at 0.00 L/Kg, indicating no biogas production initially.

As the detention time progresses, biogas production increases, reaching a maximum of 1.21 L/Kg. Similar to pig waste, the biogas generation starts at 0.00 L/Kg. Biogas production increases over time, reaching a maximum of 0.89 L/Kg. As with the other waste types, the biogas generation starts at 0.00 L/Kg. Biogas production increases with detention time, reaching a maximum of 0.98 L/Kg. For all three types of livestock waste, there is an initial period with no biogas production, possibly representing the start-up phase of anaerobic digestion.

Biogas production increases with longer detention times, suggesting that prolonged digestion periods lead to higher gas yields.

Each type of waste reaches a peak biogas production, and the values fluctuate over the detention times.

Implications:

These results provide insights into the potential biogas production from different livestock wastes over specific detention times.

The variation in biogas production could be attributed to the differences in the composition of the wastes, microbial activity, and environmental conditions within the anaerobic digestion system.

The data suggests that certain waste types might have higher biogas generation potentials compared to others.

The results might be influenced by factors such as waste composition, temperature, pH levels, and the efficiency of the anaerobic digestion process.

It would be valuable to compare these results with other parameters such as volatile solids content, methane content in biogas, and overall system efficiency.

In summary, the presented results indicate the dynamic nature of biogas generation from pig, cattle, and poultry wastes over a range of detention times, offering valuable information for

Conclusion

Overall, the results indicate a positive correlation between longer detention times and increased biogas production for all waste types. The specific timing of peak production varies, emphasizing the influence of waste characteristics and microbial activity. The findings contribute to the understanding of biogas generation dynamics in agricultural waste, providing insights for optimizing anaerobic digestion processes. The experiment underscores the potential for sustainable waste management and renewable energy production in livestock farming contexts.

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