VOL. 05 NO. 9,
AUGUST, 2024
E-ISSN 3026-958X
P-ISSN 3027-1169

African Scholar Publications & Research International
www.africanscholarpub.com

Journal of Science Innovation & Technology Research (JSITR)

Analyzing Biogas Production from Sheep Dung and Poultry Droppings Using Microbial Electrolysis Cells

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Abstract

Biogas is considered a renewable energy source with several advantages, including reducing greenhouse gas emissions, decreasing dependence on fossil fuels, and utilizing livestock manure and crop straw. Our research involved using sheep dung and poultry droppings in equal proportions in two digesters for experimental analysis. The digester was systematically filled with an appropriate volume of inoculum and raw sheep dung. Semi-continuous feeding was initiated with sheep dung alone for 90 days. Data obtained during this period was used as a reference period (control). The above procedure was repeated using poultry droppings separately. The results showed that poultry droppings produced a higher cumulative biogas production of 17,490 ml/week in 90 days than sheep dung. This research has been proven to be effective. Additionally, the biogas from poultry droppings had a high calorific value of 14.12 kcal/m^3, with 0% carbon monoxide and an excitingly high 16.46% methane content. Before anaerobic digestion at 30°C, sheep dung had a pH value 9.79, while poultry droppings measured 9.16 at 29°C. These findings strongly indicate the suitability of poultry droppings for biogas production. However, poultry droppings showed exceptional potential and merit in methane production, making them a compelling substitute for kerosene and coal for domestic applications.

Keywords: Anaerobic digestion, Biogas, Digester, Sheep dung, Poultry droppings

Introduction

The current primary use of fossil fuels for producing electricity contributes significantly to greenhouse gas (GHG) emissions and global warming. With a projected 93% increase in worldwide net electricity generation by the year 2040, the consequences of not addressing this issue could be severe, exacerbating environmental

issues if we continue to rely solely on fossil fuels (Yaqoob *et al.,* 2021).

Biomass is becoming increasingly crucial as a renewable energy source capable of producing biofuels, bioelectricity, and heat. In recent years, the generation of bioelectricity from biomass has significantly increased (Ardebili, 2020).

Properly managing agricultural waste can transform it into a valuable resource for biomass energy. This approach can address the global energy crisis, enhance agricultural production, protect the environment, and reduce carbon emissions (Liu *et al.,* 2023).

The microbial process of anaerobic digestion of organic substrates involves four main steps: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. This process results in the production of biogas and digestate. The main output, biogas, combines methane and CO_2 with small quantities of hydrogen sulphide (H_2S), moisture, and some trace gases (Kapoor *et al.,* 2020).

Frankowski & Czekała, (2023) in their study revealed that plant biomass, with its diverse applications, is a cornerstone of bioenergy production. The choice of substrates and technologies is not just crucial, but it carries the weight of the entire process. It is this decision that will determine whether the expected results can be achieved. Cost and accessibility of substrates are key considerations. Hence, the increasing use of waste and residues is a testament to the gravity of these decisions.

Anaerobic digestion of lignocellulosic wastes, such as agricultural residues, doesn't fully utilize their material and energy recovery potential in the form of biogas. Due to the recalcitrance of lignin, a significant portion of the organic matter remains in the digestate (Antoniou *et al.,* 2019).

Throughout human history, microorganisms and microbial technologies have been constant companions (Hey, 2023). As energy needs continue to rise and waste production increases, there is a greater demand for eco-friendly and intelligent solutions (Bibri *et al.,* 2024). Microbial technologies have played a pivotal role in the waste treatment process since the inception of industrialization (Marandola *et al.,* 2024).

The microbial electrolysis cell (MEC) comprises an anode, an anion exchange membrane, a hydrogen-evolving cathode, and an electrolyte containing microorganisms (Dwivedi et al., 2022). For MECs to function correctly, the cathode chamber must be a meticulously controlled anaerobic environment utterly devoid of oxygen to facilitate the chemical production of hydrogen (Varanasi et al., 2019). At the heart of an MEC lies a microbial anode and a cathode that facilitates hydrogen evolution like conventional methods (Rousseau et al., 2020). Electrohydrogenesis aids in the anaerobic oxidation of organic compounds within the anode chamber (Veeramalini et al., 2024).

According to Naik et al. (2021) despite the popularity of solar and wind energy, their high initial costs and dependence on sunlight and wind availability are significant drawbacks. However, there is a promising alternative in the form of lignocellulosic materials, such as agricultural residue. These materials represent a vast, untapped source of energy. Importantly, the production of biofuels from these agricultural wastes is not just a theoretical possibility, but a feasible and practical approach to sustainable global development.

Biogas, as a renewable energy source, offers significant benefits such as reducing greenhouse gas emissions, lessening our reliance on fossil fuels, and using livestock manure and crop straw (Huang *et al.,* 2022). Livestock manure is a significant source of greenhouse gas emissions, particularly methane and nitrous oxide. However, the production of biogas through anaerobic digestion of manure, often in conjunction with other organic waste, offers a compelling solution. This method not only mitigates emissions but also provides a sustainable alternative to fossil fuels, a crucial step in our collective efforts to adopt eco-friendlier practices and combat climate change (Møller *et al.,* 2022).

Silwadi et al. (2023) studied the influence of dry solid mass fraction, pH, and temperature on biogas production from the digestion of specific types of manure. The findings revealed that biogas production followed a trend, peaking at a solid mass fraction of 0.16 for chicken manure.

Studies conducted by González et al. (2021), the anaerobic co-digestion of sheep manure and potato waste was examined under both batch and semi-continuous conditions. The research included conducting biochemical methane potential tests for the different substrates and evaluating co-digestion at high-solid content. The study found that the reactors demonstrated stable performance under mesophilic conditions, operating the specified conditions for the process with an organic loading rate (OLR) ranging from 3.5 to 4.0 kg VS/m^3 with a hydraulic retention time of about 20 days. This stability was observed under the specific conditions of the process, which included a mesophilic environment and an OLR within the specified range. It was observed that increasing the OLR of semi-continuous reactors led to a decrease in methane yield and degradation efficiency. The methane-specific production ranged from 196 to 467 mL CH4/g VS for the sheep manure system and co-digestion.

In a recent paper, Mohammed et al. (2022) investigated the enhancement of biogas production from cow, sheep, and poultry manure in a two-phase experiment. The experiment occurred in a 2000 mL digester soaking in a soothing 37°C warm water bath. The ratio of animal manure to water used was 1:1, with a Hydraulic Retention Time (HRT) of 12 days. Gas production was measured using the volumetric water replacement method. In the initial phase, the experiment tested various pH levels, and three different set-ups were prepared with pH values of 6.5, 7, and 7.5. The results indicated that pH significantly impacted biogas yield, with pH 7 resulting in the highest biogas production and pH 6.5 resulting in the lowest. These findings have practical implications for biogas production, particularly in optimizing pH levels for maximum yield. The current research focuses on generating biogas using sheep dung and poultry droppings.

The recent review by Das et al. (2023) comprehensively analyses microbial communities in anaerobic waste digestion. It discusses essential processes such as hydrolysis, acidogenesis, acetogenesis, and methanogenesis, emphasizing the use of molecular techniques to understand microbial communities and improve biogas production efficiency. The review also explores practical methods and upcoming trends in microbial-based biogas production, highlighting the confidence-boosting practicality of these methods and the reassurance they bring for process optimization and innovation through synthetic biology and microbiome exploration.

Sharma et al. (2024) emphasized the potential of Microbial electrolysis cells (MECs) for sustainable power generation through biohydrogen production and wastewater treatment. MECs combine Microbial Fuel cell (MFC) and electrolysis to produce biohydrogen and are considered a clean and effective method for biohydrogen production. However, challenges such as high production costs, internal resistance, methanogenesis, and biofouling hinder the effective scale-up of MECs.

Objectives of the study

In Zamfara state, there are extensive sheep and poultry farms. There is a need to explore the economic benefits of utilizing waste from these farms more effectively. Considering the environmental consequences of the ongoing reliance on fossil fuels, there is a growing interest in developing alternative renewable fuels. This study proposes the conversion of sheep dung and poultry droppings in a modified continuous flow reactor to produce biogas as an alternative renewable energy source. The environmental benefits of this conversion are significant, offering a promising solution to reduce pollution and combat climate change. Converting these abundant and underutilized wastes into biogas could meet rural communities' energy needs and reduce environmental pollution from these wastes.

METHODOLOGY

Design

The biogas plant was designed in two ways: analytically and solidly. The analytical design, achieved using reliable formulae from the literature, ensured the security of the process. The solid biogas plant, designed using Google Sketch-up solid tools, utilized parameters from the analytical phase. The mixer, electrochemical container, and digester were designed to show all their components in a clear and comprehensive manner.

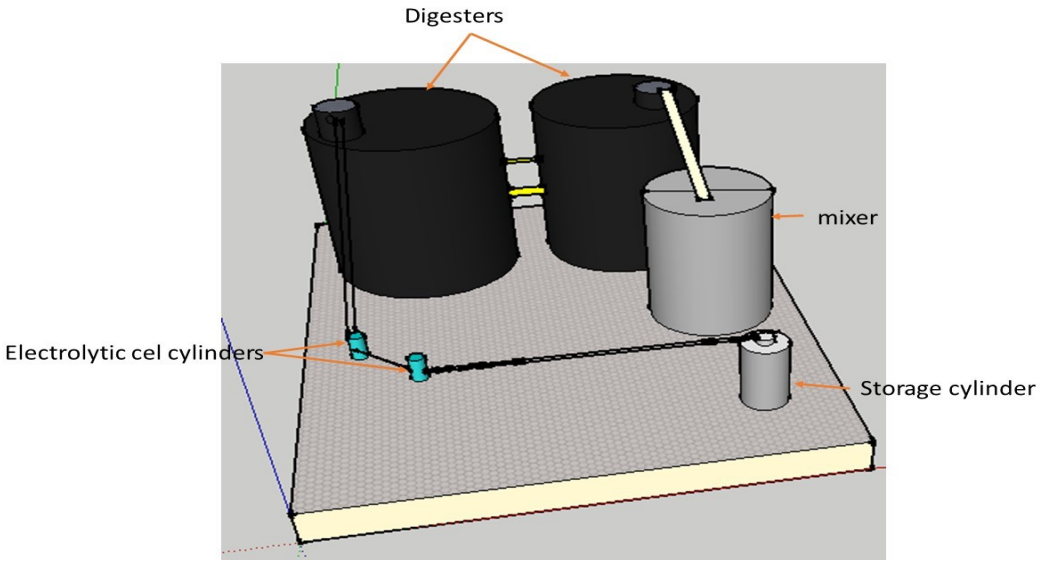


Figure 1: Designed Digester plant

Fabrication

Mixer

Its body was fabricated using a steel drum coupled with a mixing shaft at the centre of the drum.

Digester

Due to its cost-effectiveness and durability, the digester was fabricated using 5 mm galvanized steel sheets. The fabricated digester was coated with black auto-based paint and was pressure-tested.

Assembling

The mixer was connected to the two coupled fabricated digesters using 75x5 mm galvanized pipes as an inlet and outlet to the soak away. The pressure gauge, the stirrer and the liquid level were assembled on the digester. The biogas outlet pipe was connected at the top of the digester using an inch galvanized pipe to two 400 ml and 100 ml flasks containing microbial electrolytic cells, potassium hydroxide and potassium permanganate, which play a crucial role in the purification of biogas. These were connected to the moisture trap, and finally, the gas was collected in a storage cylinder equipped with a weighing balance. After that, the gas was channelled into the generating set via the gas carburettor to generate electricity.



Plate 1: A cross-section of the assembled constructed Digesters, Mixer and other gas collection cylinder

Samples

Precise and meticulous, the samples of sheep dung and poultry droppings, were collected from Kaura Namoda Local Government Area of Zamfara state. The rumen contents of sheep, containing all the required microbes, were collected fresh from the Kaura Namoda abattoir in an airtight container and stored at a temperature of 4^{o}C. Maintaining precision in the collection process is crucial to ensure the success of the biological methane potential assays. These assays were conducted following the method outlined by Hafner et al. (2020).



Plate 2: Sheep Dung

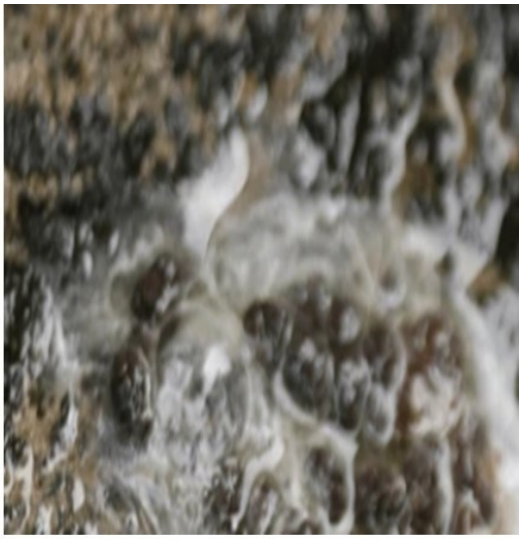


Plate 3: Poultry Droppings

Experimental Set-up

The reactor was filled with an appropriate volume of inoculum and raw sheep dung in a systematic manner. Semi-continuous feeding was initiated with sheep dung alone for 90 days. Data obtained during this period was used as a reference period (control). The above procedure was repeated using poultry droppings, separately. Co-digestion of a simple mixture of the various substrates was achieved in twelve batches at a feed ratio of 2:1 (w/w) and 1:1 (w/w), respectively. During each run, a minimum of 1 hydraulic retention time (HRT) was maintained, and the organic loading rate (OLR) was changed when only steady-state conditions characterized by a constant gas production rate were achieved.

Analytical methods

pH: This was carried out using the hydrogen ions concentration meter adopted from the SMEWW procedure (Sandoval *et al.,* 2022 & Tumialán *et al.,* 2024). Total Dissolved Solids (TDS): This was analysed by adopting the procedure reported in Badamasi et al. (2024).

Chemical Oxygen Demand (COD) was determined for each of the samples in triplicate using the methods adopted from SMEWW (Zelinski *et al.,* 2023).

Trace Elements (heavy metals) determination: This was determined using the atomic absorption spectrophotometric (AAS) method, as reported by Kassim et al. (2022).

The ash, proteins, and lipid content of the fresh and dried samples were analyzed using the official methods outlined by the Association of Official Analytical Chemists (Yisa *et al.,* 2023).
The ammonia content of the sample was detected by an electrical conductivity cell (Chang *et al.,* 2021). Ammonium– nitrogen (NH+4 —N) was measured by flow injection analysis after steam distillation into dilute sulfuric acid (Zhang *et al.,* 2020).
Volatile fatty acids (VFA) concentrations and methane content in biogas were analyzed using gas chromatography with a flame ionization detector (Al-Sulaimi *et al.,* 2022).
Total solids (TS), volatile solids (VS) and suspended solids would be determined according to the Standard Methods (Johnravindar *et al.,* 2022).

RESULTS

Component Composition of the Cumulative Biogas Produced

Table 1 presents the component composition of the produced biogas and its respective calorific values for each sample (Sheep dung and Poultry droppings).

Table 1: Cumulative biogas production Yield

Samples	A	B
First Month Cum. biogas Yield	7982 ml	8051 ml
Second Month Cum. biogas Yield	778 ml	6280 ml
Third Month Cum. biogas Yield	Retention Time	3159 ml
Fourth Month cum. biogas Yield	Retention Time	Retention Time
Total cum. biogas Yield	8,760 ml	17,490 ml

Key: Sample A = Sheep dung; Sample B = Poultry droppings

Table 1 shows that Sample A initially yielded a promising cumulative biogas production of 7982 ml in December 2023 during summer. However, there was a significant decline in January 2024, the winter season, with only 778 ml of biogas produced. This decline underscores the need for further research and understanding of the factors influencing biogas production. Subsequently, a retention period was noticed in the following months, February 2023 and March 2024. On the other hand, Sample B exhibited a biogas production of 8051 ml in the first month (December 2023), which continued until the third month, yielding a cumulative biogas production of 3159 ml. Biogas production ceased in the fourth month, March 2024. Further analysis indicated that Sample B had an overall cumulative biogas production of 17,490 ml, while sheep dung exhibited a cumulative biogas production of 8,760 ml.

Component Composition of the Percentage Biogas Produced and Calorific Values

The results from the analysis of the component composition of the generated biogas, along with their corresponding calorific values for each sample, can be found in Table 2 for (Sheep dung and Poultry droppings).

Table 2: Substrate composition and calorific values

Samples	Composition					Caloric Value (kcal/m^3)
	CO (%)	CO_2 (%)	CH_4 (%)	H_2 (%)	O_2 (%)	
A	0.05	0.32	0.06	0.00	26.29	0.05
B	0.00	1.58	16.46	0.42	22.72	14.12

The data from Table 2 indicates that Poultry droppings biogas is a high-energy source. It contains a significantly higher 1.58% carbon dioxide (CO_2) content, 80% more than sheep dung. However, it also has a notably higher percentage of methane gas (CH_4) at 16.46%. Additionally, poultry droppings biogas contains 0.42% hydrogen gas (H_2), but the oxygen gas (O_2) rate is relatively low at 22.72% compared to sheep dung. It is also worth noting that poultry droppings biogas has a high calorific value of 14.12 kcal/m^3, significantly higher than the 0.05 kcal/m^3 calorific value of sheep dung.

pH values and Temperature readings on biogas production

Table 3 displays the pH values for biogas samples A and B, produced from sheep dung and poultry droppings. The table also includes the corresponding temperatures measured before the anaerobic digestion and after the experiment.

Table 3: pH values from biogas samples

Sample	pH Before Anaerobic Digestion	Temp. Before Anaerobic Digestion (ºC)	pH After experiment	Temp. After Experiment (ºC)
A	9.79	30	7.22	30
B	9.16	29	9.34	29

Table 3 shows that sample A underwent a remarkable transformation in pH levels before and after anaerobic digestion at 30°C. Samples A had a pH of 9.79, indicating a neutral state. However, after the experiment, the pH of sample A plummeted to 7.22, marking a shift to a highly acidic state. This significant change in pH levels underscores the profound impact of anaerobic digestion on sample A. In contrast, the pH of sample B was 9.16 at 29°C before digestion, categorizing it as slightly acidic. After the experiment, the pH of sample B was reduced to 9.34 at 29°C, maintaining its classification as slightly acidic according to the pH scale.

DISCUSSION

The findings highlighted in Table 1 demonstrate that sheep dung and poultry droppings yielded cumulative biogas production of 8,760 ml and 17,490 ml, respectively. The biogas production from sheep dung was notably high in the first week due to the rapid microbial activity triggered by favourable temperature and pH conditions, this is line with investigation from Liu et al. (2022). This first week is a crucial period in biogas production, as it sets the pace for the rest of the process. Sheep dung had a retention time of 56 days, a key factor

influencing biogas production, while poultry droppings continued to produce biogas for up to 90 days. Poultry droppings yielded a higher biogas output with a cumulative production of 17,490 ml compared to sheep dung, in line with findings from Siyal et al. (2023). This suggests that poultry droppings can be a valuable feedstock for biogas production when digested alone, as also observed by Bhatnagar et al. (2022). However, the lack of biogas production from poultry droppings in the first week can be attributed to its slightly acidic pH of 9.16, another critical factor influencing biogas production.

Notably, no production occurs under a pH scale that is not conducive to methanogens, which are a type of archaea responsible for producing biogas through a process called methanogenesis (Harirchi *et al.,* 2022). Moreover, the retention time for sheep dung and poultry droppings substrates was found in the fifth and eighth weeks. Sheep dung had a retention time of eight weeks at a temperature of 33°C, falling within the mesophilic temperature range. Production of biogas from the substrate ceased in the eighth week due to a decrease in pH to 7.22, indicating highly acidic conditions. As a result, the bacteria responsible for biogas production could not act on the substrate, which similar to the findings of Nwuche et al. (2023).

The poultry droppings, left at room temperature (29°C) for 13 weeks, fell within the psychrophilic temperature range (<30°C). This temperature range was unsuitable for biogas production, as the bacteria responsible for this process could not function, as per Obileke et al. (2021). The pH of the substrate also changed to 6.43, indicating a slightly acidic environment that could have hindered microbial activity.

The result presented in Table 2 indicates that biogas from sheep dung have a low calorific value of 0.05 kcal/m^3. This was because it has 0.00% hydrogen gas and a shallow percentage composition of 0.06% methane gas, a combustible fuel. However, sheep dung low methane gas yield was found in the vegetable waste class with high fiber, cellulose content, and low glucose content (Zhang *et al.,* 2022). In addition, biogas from sheep dung has a percentage composition of 0.05% of carbon monoxide, a potent gas that seriously threatens the environment and human health. The presence of this toxic gas in sheep dung contributed to the low calorific value, in agreement with Inna et al. (2024). The biogas produced from poultry droppings obtained a high calorific value of 14.12 kcal/m^3 due to the high percentage composition of 16.46% methane gas and 0.42% hydrogen gas, which are combustible fuels. Also, it has the advantage of 0.00% of carbon monoxide, which is toxic in the environment and follows Mattiuzzi & Lippi, (2020).

CONCLUSION

The combination of poultry droppings resulted in a high yield and a total cumulative biogas production of 17,490 ml. The sheep dung and mixture showed early production at a mesophilic temperature range of 30^{o}C - 40^{o}C. It was discovered that the biogas yield is influenced by both the pH value and the room temperature. Biogas obtained from poultry droppings had a high calorific value of 14.12 kcal/m^3, attributed to the high percentage of methane (CH_4) and hydrogen gases (H_2). Before anaerobic digestion at 30^{o}C, the sheep dung pH value was 9.79, while for poultry droppings at 29^{o}C, it was 9.16. These findings indicate that poultry droppings

and sheep dung are suitable substrates for biogas production. Importantly, poultry droppings exhibit outstanding potential and merit in methane production, making it a reliable and efficient alternative to kerosene and coal for domestic use, with its capabilities surpassing those of sheep dung and establishing its superiority in biogas production. The research underscores the immense potential of poultry droppings and sheep dung for biogas production, offering a promising avenue for renewable energy. It further delves into the long-term sustainability, economic viability, scalability, and practical implications of using these substrates in various conditions. Additionally, it underscores the importance of conducting a comprehensive life cycle assessment to understand biogas production's environmental impact and resource efficiency from these substrates.

Acknowledgements

The authors would like to acknowledge the support of the Tertiary Education Trust Fund (TETFUND) for allocating the Research Grant (IBR, 2024) through Federal Polytechnic Kaura Namoda, Zamfara State, Nigeria.

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