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DEVELOPMENT AND PERFORMANCE EVALUATION OF A 20 L BATCH BIODIGESTER FOR BIOGAS PRODUCTION FROM COW AND PIG DUNG UNDER MESOPHILIC CONDITIONS

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ABSTRACT

Biogas technology has emerged as a pivotal solution for waste management, energy generation, and environmental conservation across the globe. This study focused on the development, and construction of a small-scale (20 L) biodigester system for biogas production using cow and pig dung at ratio 1:1 substrate-to-water and operating under mesophilic conditions (25–35 °C). The pH, COD, BOD and TS of cow dung and pig dung were 7.49 and 7.54; 3500 and 2000mg/L; 70 and 160mg/L; 27.7 and 46.2% respectively. The proximate analysis showed moisture content of 8.64% cow dung and 8.52% pig dung, crude fat 1.32 % cow dung and 3.58% pig dung, ash content of 18.62% pig dung and 22.52% cow dung. Nitrogen extract was 29.73% cow dung and 30.72% pig dung. The hydraulic retention time was 30 days and the total biogas produced was 2.180 m^3. The gas yield was dependent on the type of substrate and environmental temperature. The results depicted the suitability of using cow and pig dung as substrates for biogas production under natural temperature variations. The findings show that biogas from cow and pig dung is a viable and sustainable cooking fuel. Adopting this technology can reduce reliance on fossil fuels and lower the environmental and health risks associated with their use. Additionally, using inexpensive, locally available materials to build digesters makes this approach practical for resource-limited communities.

Keywords: Biogas, Animal Dung, Energy, Biodigester, Microorganisms

INTRODUCTION

In recent years, global concerns about energy security, rising fuel prices, and environmental pollution have prompted the search for sustainable, Eco-friendly alternatives to fossil fuels (Tolessa, 2024). Among these alternatives, biogas technology has emerged as an accessible and highly effective solution (Aransıola *et al.,* 2021). Biogas is a combustible gas primarily composed of methane and carbon dioxide, generated through the anaerobic digestion of organic matter such as agricultural waste, animal dung, food waste, and crop residues (Kulkarni *et al.* 2021).

Biogas generation operates on a biological process wherein microorganisms break down complex organic matter in an oxygen-free environment (Issahku *et al.* 2024). The process of anaerobic digestion (AD), in which organic matter is broken down by microorganisms in the absence of oxygen, is central to biogas generation. Cow dung is converted through anaerobic microbial processes into biogas, a combustible mixture mainly of methane (50-75%) and carbon dioxide (25–50%), while also producing nutrient-rich digestate that can be used as organic fertilizer. Studies indicate that this biogas can cut greenhouse gas emissions by up to 80% compared to firewood and provide a consistent, efficient cooking fuel with methane content of up to 70% (Gana and Sa'id, 2025).

Household air pollution from the incomplete combustion of traditional fuels causes about 3.2-3.7 million premature deaths each year, including deaths from respiratory infections, COPD, stroke, heart disease, and lung cancer. Unsafe household energy practices in low and middle income countries also lead to accidental kerosene ingestion and fire related injuries (WHO, 2022; UNICEF, 2021). In rural and semi-urban areas of Nigeria and across the African continent, biogas technology is gaining prominence due to its potential to provide clean, affordable, and sustainable energy while addressing waste management and environmental concerns (Tolessa, 2024).

Several critical parameters govern the performance and efficiency of a biodigester such as pH, temperature, C/N ratio, retention time, substrate composition, etc. The pH of the digester environment must be within an optimal range for the activity of methanogens. An imbalanced pH can halt the fermentation process. Biogas production is highly sensitive to temperature fluctuations. Mesophilic temperatures are ideal for rural biodigesters, allowing a stable environment for microbial activity. The Carbon/Nitrogen (C/N) ratio influences the nutritional balance for microorganisms. Adequate retention time allows for complete digestion of the substrate, yielding maximum gas and Animal waste, especially cow dung, is highly advantageous due to its balanced C/N ratio, rich microbial population, and abundance in rural areas (Adeleke *et al.,* 2025).

In Nigeria, and specifically in rural communities, agricultural waste, including cow dung and crop residues, often goes unused and is left exposed, creating unsanitary conditions. The recycling of waste has also become important due to its economic benefits (Jock *et al.* 2023). Meanwhile, the rising cost of fossil fuels (now reaching alarming levels of ₦1,200–₦1,800 per liter) has placed a significant financial burden on rural households and institutions. The resulting energy crisis has deepened poverty and limited access to clean cooking and lighting methods. Against this backdrop, small-scale biodigesters have emerged as an ideal solution for converting waste into energy (Alvarez *et al.,* 2024).

Wukari Local Government Area in Taraba State, North-East Nigeria is an agrarian, livestock rearing community with abundant cattle dung, making it well suited for biogas production. Heavy reliance on firewood, charcoal, and kerosene has led to deforestation and indoor air pollution, highlighting the potential of cow and pig dung-based biogas as a sustainable alternative cooking fuel. Biogas technology helps mitigate emissions by capturing methane from organic waste and reducing reliance on biomass, providing both climate and health benefits. Therefore, clean cooking should be prioritized in climate finance agendas because of its environmental, health, and socio-economic advantages. The study aims to develop and evaluate the performance of a batch biodigester for biogas production using cow and pig dung as primary feedstocks under mesophilic conditions.

MATERIALS AND METHODS

Materials

Materials required for this research were sourced locally and the include, an improvised 20L (High-density polyethylene jerrycan) biodigester system, PVC pipe, gas storage bag (Tyre tube), epoxy resin, silicone sealant, and rubber gaskets, water, cow and pig dung.

Methodology

Physicochemical and Biological Analysis of Feedstock

Cow dung was obtained from the animal farm, Federal university and pig dung was collected from a pig farm in Wukari town. The samples were pretreated by removal of the unwanted non-biodegradable materials such as stones, gravels and broken bottles. In addition, the dungs were sun dried for 5 days at an average temperature of 28.5°C the dried samples were pulverized and sieved to further removed impurities. The sieved dungs were stored for characterization and anaerobic digestion experiments. The biochemical oxygen demand (BOD), chemical oxygen demand (COD) and total solids (TS) are not expressed directly for solid materials in their raw form**.** They were evaluated based on a testable sample prepared from solids**,** usually as a slurry while the pH organic carbon, nitrogen content and carbon/nitrogen ratio were determined on the dried samples. The elemental composition of the cow and pig dung were determined using X-ray fluorescence (XRF).

Proximate Analysis of Feedstock

Proximate analysis was carried out according to the procedure of Association of Official Analytical Chemist (A.O.A.C., 2019) for moisture, ash content, crude fibre, fat content, crude protein content and carbohydrate content.

Biodigester Design

A bench scale biodigester capable of handling 20 L of feedstock for the production of biogas was designed by adopting the methods prescribed by Okwu *et al.,* 2020 and Mungwe, 2021. Cylindrical shape and biodigester volume was based on the substrate input quantity and chosen retention time. The operating volume of digester (V_o) was improvised and theoretically determined based on substrate input quantity (S_d) and chosen retention time (RT) .

$$V_o = S_d \, X \, RT = m^3 \quad (1)$$

The retention time is interval time during which the biomass remains decompose in the digester. Normally, the retention time for anaerobic digestion of cow dung and pig dungs at mesophilic temperature is between 20-40 days. However, 30 days was adopted in the design of the biodigester. Substrate input rate is given as:

$$S_d = \frac{\text{Total substrate added}}{Time\ (days)} - \frac{\text{Total volumef Biomass (B) + Water (W)}}{Time\ (days)} = m^3/\text{day} \quad (2)$$

Usually, the total volume of the biogas is always higher than the operating volume. Therefore, operating volume of 75% of the total volume was chosen. This is to give room for the expansion in volume of the slurry during fermentation. Therefore, the volume is:

$$V_T = \frac{V_o}{0.75} = m^3 \quad (3)$$

An airtight batch anaerobic biodigester was constructed using the appropriate tools at the Mechanical Engineering workshop, Federal University Wukari, Nigeria. The biodigester consists of digestion chamber, gas and digestate outlet pipes and feedstock inlet. The biodigester construction was carried out by strict compliance with the design parameters calculated.

Biogas Production

Ten kilograms (10 kg) each biomass (cow dung and pig dung) was measured using digital weighing balance and mixed with equal amount (10 L) of water to obtained the feedstock (1:1 w/v). The dilution of the biomass was to enable bacteria move freely in the bio-digester. The feedstock was homogenized for easy digestion. Ten kilograms (10 kg) of each feedstock mixed with 10 L of water was fed into each bio-digester through the top opening and closed after charging, airtight condition of the digestion process was ensured. The feedstock occupied 75% of the biodigester volume leaving a clear space of 25% for biogas production. The digester and its content were allowed to digest at mesophilic conditions (25-35 °C) and biogas was collected after 21 days (Mapantsela *et al.*, 2024).

RESULTS AND DISCUSSION

Physical and Biological Properties of Feedstock

The physical and biological characterization of the cow and pig dung is presented in Table 1. The parameters determined were pH, COD, BOD and Total solids.

Table 1: Physical and Biological Properties of Feed Stock

Properties	Samples	
	Cow Dung	Pig Dung
pH	7.49	7.54
COD (mg/L)	3500	2000
BOD (mg/L)	70	160
Total Solid, TS (%)	27.7	46.2

The pH value of cow dung is 7.49 and pig dung, 7.542 all fall within the typical of 6.8 to 7.5 for methanogenic activities (Adeleke et al., 2025). This minimizes risks of acidification during acidogenesis or inhibition of methane formation, promoting stable digestion without the need for significant pH adjustment. The chemical oxygen demand (COD) is higher in cow dung (3500 mg/L) than pig dung (2000 mg/L), indicating higher availability of organic matter for digestion, thus higher potential for biogas production from cow dung. In contrast, **t**he biochemical oxygen demand (BOD) is higher in pig dung (160 mg/L) than cow (70 mg/L). This suggests a larger fraction of readily biodegradable organics in pig dung and could lead to faster initial hydrolysis and acidogenesis in pig dung but might require careful monitoring to avoid volatile fatty acid accumulation. In biogas production, Total Solids (TS) play a crucial role because they determine how efficiently microbes can break down the material to produce gas. They are the dry matter in the dung (organic matter or volatile solids and inorganic matter or ash). Pig dung has higher TS (46.2%) than cow dung (27.7%) and the higher TS the more materials are converted and the more biogas production (Orhorhoro *et.al*. 2017). Generally, the values obtained for the TS in both dung slurry are higher than the widely accepted typical ranges used in biogas of 16–20% for cow dung and 18–25% for pig dung (). However, the TS depends on factors like animal diet, water added, and handling method (Jeppu *et al*, 2021).

The chemical composition of the feedstock is summarized in Table 2. The XRF analysis revealed the presence of major inorganic oxides in both cow dung and pig dung such as CaO, SiO_2, K_2O, Al_2O_3, and trace elements like MnO and ZnO. These elements play significant roles in the anaerobic digestion process by influencing microbial activity, buffering capacity, and overall biogas yield.

Table 2: Chemical Composition of Feed Stock

Components	Samples	
	Cow Dung (wt%.)	Pig Dung (wt%)
SiO_2	28.865	30.063
V_2O_5	0.040	0.084
CrO_3	0.026	0.031
MnO	1.300	0.373
CaO	38.238	24.373
Al_2O_3	5.344	5.452
MgO	1.083	0.000
K_2O	8.547	12.799
TiO	1.316	1.476
ZnO	0.155	0.248

The high concentration of CaO (38.238%) in cow dung indicates strong buffering capacity within the digester system. CaO helps stabilize pH by neutralizing excess acids produced during acidogenesis, thereby maintaining favorable conditions for methanogenic microorganisms (Wang *et al.* 2024). This supports continuous methane production and prevents process failure due to acidification. The presence of SiO_2 in cow dung (28.865%) and pig dung 30.063%) is associated with indigestible mineral matter. Silica does not directly contribute to biogas production, its high concentration reflects the fibrous and soil-related content of the feedstock, which may reduce overall biodegradability (Angelidaki *et al*. 2011). Higher SiO_2 and CaO contents in cow and pig dung usually come from a mix of diet, soil contamination, and animal physiology/management rather than the animals producing (Provolo *et al.* 2018). The K_2O was also detected in significant amounts, particularly in pig dung (12.799%). Potassium is an essential nutrient that enhances microbial metabolism and enzyme activity, thereby improving the efficiency of anaerobic digestion. The presence of Al_2O_3 and trace metals such as MnO and ZnO are beneficial in small quantities, as these elements act as cofactors in enzymatic reactions required for microbial growth and methane formation. Generally, substrates rich in essential minerals enhance biogas production by supporting microbial consortia and maintaining stable digestion conditions (Aworanti *et al.* 2023).

Proximate Analysis of Feedstock

The results of proximate nutritional composition of the oil sample are presented in Table 3. The moisture, ash, crude fat, crude protein, crude fibre and nitrogen extract were determined.

Table 3: Proximate Composition of Feedstock

Samples	%Moisture Content	%Ash	%Crude Fat	%Crude Protein	%Crude Fiber	% Nitrogen Extract
Cow dung	8.64	22.52	1.32	11.56	26.29	29.63
Pig dung	8.52	18.62	3.58	21.28	17.28	30.72

The moisture content of cow dung and pig dung were 8.64 and 8.52% respectively. This indicates that cow dung is slightly wetter and easier to form into a pumpable slurry than pig dung. The ash for cow dung was 22.52% and 18.62% for pig dung. Ash content represents the inorganic mineral content in the substrate. High ash content indicates higher mineral composition but lower combustible organic matter (Orhorhoro *et al.* 2017). The crude protein content was 11.56% for cow dung and 21.28% for pig dung. Crude protein reflects nitrogen content, which supports microbial growth but may lead to ammonia inhibition if excessive. Nitrogen-rich substrates such as pig manure enhance microbial activity but may cause ammonia inhibition at high levels (Herrera *et al.* 2026). The higher protein content in pig dung indicates greater nitrogen content and rapid microbial activity but may require careful control to prevent ammonia toxicity. The crude fibre in cow dung and pig dund were 26.29% and 17.28% respectively. Crude fiber consists mainly of lignocellulosic materials that degrade slowly during anaerobic digestion. Higher fiber content slows down digestion due to the resistant nature of lignin (Guimaraes and Maia 2023). therefore, the high fiber content in cow dung suggests slower but sustained biogas production, while pig dung, with lower fiber content, is likely to decompose faster. The crude fat was 1.32% in cow dung and 3.58% in pig dung. Crude fat contributes significantly to energy content, as lipids yield higher methane during digestion. Moderate fat levels enhance methane production, while excessive fat can cause inhibition by forming scum layers. Lipid-rich substrates improve methane yield but may cause operational challenges at high concentrations (Kulkarni *et al.* 2021). The nitrogen free extract (NFE) were 29.63% and 30.72% for for cow dung and pig dung respectively. The NFE represents readily available carbohydrates that are easily degraded by microorganisms and substrates with higher readily degradable carbohydrates enhance microbial activity and biogas production (Ejigboye *et al.* 2025). The higher NFE in pig dung indicates that it contains more readily digestible organic matter, leading to faster biogas production compared to cow dung.

Biodigester Design
The Summary of design parameters for the development of 20 L capacity biodigester for biogas production using cow dung and pig dung feedstock is presented in Table 4.

Table 4: Design Parameters of a Bench Scale Bio-Digester

Design Parameters	Capacity/Description
Digester configuration	Rectangular
Basis of Biodigester design	20 kg/per batch substrate
Substrate input quantity	0.0180 m^3/day
Operating volume (V_o)	0.018 m^3
Total volume of digester (V_T)	0.020 m^3
Height to diameter ratio (h:d) of biodigester	2:1
Material of construction	Height Density polyethylene

The geometry of the biodigester was chosen as rectangle for ease of operation, maintenance and to promote good mixing of the content. In addition, high density polyethylene was used as material for the development of an improvised biodigester due to it relatively hardness to be able to withstand the weight and pressures of the substrates and corrosive nature of some products associated with biogas such as CO_2 and H_2S (Olanipekun *et al.,* 2024).

Biogas Production
The biogas production was monitored at an interval of 5 days for 30 days of retention time. The gas yield increases as retention time increased as presented in Table 5. The biogas produced from cow dung was more than pig dung and cumulative biogas from the two dungs at 30 days was 2.18m^3. The biogas generation intensifies between the 20–30 days and this could be due to the establishment of a stable microbial population and enhanced breakdown of complex organic matter (Adeleke *et al*. 2025).

Table 5: Biogas Production Over Retention Time of 30 Days

Retention Time (days)	Temperature (°C)	Biogas Production (m^3)		Cumulative Biogas Yield (m^3)
		Cow Dung	Pig Dung	
5	27	0.050	0.038	0.088
10	25	0.075	0.067	0.230
15	28	0.125	0.110	0.465
20	29	0.245	0.230	0.940
25	35	0.282	0.268	1.490
30	30	0.365	0.325	2.180

CONCLUSION
This study evaluated the performance of a batch biodigester using cow and pig dung for biogas production under mesophilic conditions in Wukari, Nigeria. Biogas yield increased significantly, reaching a cumulative volume of 2.81 m³ with peak production occurring between Days 25 and 30. The results confirm that both substrates are effective for biogas generation. The locally constructed, low-cost biodigester proved suitable for household-scale energy production, highlighting the potential of biogas as a reliable renewable alternative to firewood and charcoal in rural communities.

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