Journal Majelis Paspama
Volume 4 Number 02, 2026 (No 178-187)
E.SSN 2987-1379 (Online)

Design and Construction of a Biogas Digester for Producing Methane from Cow Dung

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ABSTRACT

The increasing demand for renewable energy and the need for sustainable waste management necessitated this study on the design and construction of a biogas digester for producing methane from cow dung. The objectives were to design a mini floating-drum biogas digester, construct and operate the system using cow dung as substrate, evaluate its performance based on biogas volume and methane content, and assess the digested slurry as organic fertilizer. The digester was constructed using locally available materials and consisted of a digestion chamber, inlet and outlet pipes, a water-jacket seal, and an inverted floating drum as gas holder. The system was charged with cow dung slurry mixed at a 1:1 ratio with water and operated under ambient conditions for a retention period of 30 days. Results showed that biogas production commenced on day 3 and reached a peak between day 14 and day 18. A total cumulative biogas yield of 1.26 m³ was recorded, with an average daily production of 0.042 m³. Gas analysis revealed a methane content of 61.4%, carbon dioxide 34.8%, and trace amounts of hydrogen sulfide, hydrogen, nitrogen, oxygen, and water vapor. The methane content was sufficient for combustion, confirming the biogas as methane-rich. The digested slurry obtained was odorless and suitable for use as organic fertilizer. The study concluded that the floating-drum biogas digester is effective for converting cow dung to methane and organic fertilizer under local conditions. The design is simple, cost-effective, and can be adopted by small-scale farms and households for waste management and renewable energy generation. It is recommended that further work focus on gas purification and scale-up for community use.

Keywords: Biogas, Methane, Cow dung, Anaerobic digestion, Floating-drum digester, Organic fertilizer

INTRODUCTION

Energy remains a fundamental requirement for socio-economic development, yet access to clean, affordable, and sustainable energy is still a major challenge in Nigeria. The overdependence on fossil fuels such as petrol, diesel, and liquefied petroleum gas has led to environmental degradation, high energy costs, and energy insecurity, especially in rural communities. Consequently, there is a growing shift toward renewable energy technologies that are eco-friendly and economically viable. Biogas technology, which involves the anaerobic digestion of organic wastes to produce methane-rich gas, has been identified as a practical solution for decentralized energy supply. Cow dung is one of the most abundant and effective substrates for biogas production due to its high microbial load and biodegradability. In Nigeria, where cattle rearing is widespread, large volumes of cow dung are generated daily from abattoirs and farms but are often underutilized or disposed of improperly. The design and construction of a biogas digester therefore offers dual benefits of waste management and renewable energy generation, making it relevant to Engineering practice.

Several studies have investigated the design, fabrication, and performance of biogas digesters using cow dung as primary feedstock. Agede and Nwokolo (2025) developed a 60-litre cost-effective bio-digester using cow dung obtained from Lafia Abattoir and reported an average biogas yield of 0.50 m^3 per day with methane content of 60–65%. Their design emphasized simplicity, use of locally available materials, and safety, making it suitable for household application in Nigeria.Similarly, Hassan and Garba (2022) constructed a laboratory-scale digester using 750 ml plastic bottles to manage abattoir waste through biogas production from cow dung. The study observed that biogas generation commenced on the fourth day of fermentation, peaked on day 17, and averaged 172.33 cm^3 in the third week, confirming the viability of cow dung for short retention-time digestion.On digester fabrication, Akindele et al. (2022) designed and fabricated a 6.8-litre biogas digester and evaluated it using blends of cow dung and chicken droppings. The system produced 506.8 ml of biogas in the first 7 days, with gas analysis showing 58.79% methane, 36.92% CO_2, and trace amounts of H_2S, confirming anaerobic conditions. The study highlighted the influence of temperature on daily production rates.Co-digestion has also been explored to improve gas yield. Shagal et al. (2020) studied the co-digestion of cow dung and kitchen waste and noted enhanced biogas production and purification potential compared to mono-digestion of cow dung alone. Torbira and Saturday (2021) modified a fixed-dome digester for cow dung and reported improved structural stability and gas holding capacity, addressing leakage issues common in rural installations.Recent innovations in digester configuration were reported by Olugbemide et al. (2026), who evaluated a vertical plug-flow digester using cow dung co-digested with Hura crepitans leaves. The study recorded significant methane yield and high-quality digestate suitable as organic fertilizer, supporting the circular economy concept.Kusmiyati et al. (2024) reviewed present and future innovations in biogas production from cow dung and identified pre-treatment, digester insulation, and stirring mechanisms as key factors influencing methane content and retention time. Mhlanga et al. (2023) also confirmed that co-digesting cow dung with food waste increases volatile solids degradation and total biogas volume compared to cow dung alone. In community applications, Malik et al. (2020) successfully operated a community-based biogas plant using food waste and cow dung, demonstrating scalability beyond laboratory setups. Earlier work by Mohammed (2015) established baseline data for biogas production from cow dung and food waste mixtures, showing that cow dung provides buffering capacity and microbial seeding that stabilize the digestion process.

Collectively, these studies confirm that cow dung is a reliable substrate for biogas generation, and that digester design, substrate ratio, temperature, and retention time are critical parameters affecting methane yield. However, most existing digesters are either laboratory-scale or require modifications for durability, cost, and ease of operation at the community level in Nigeria. This gap justifies the present study, which focuses on the design and construction of a practical biogas digester specifically optimized for producing methane from cow dung under local conditions.

Biogas Gas-Grid Injection

Upgrading biogas to biomethane is essential for injecting it into existing natural gas grids or using it as vehicle fuel, since raw biogas contains 40–75% CH_4 and 15–60% CO_2 along with impurities that make it unsuitable for direct grid use. After purification to ≥95% CH_4, biomethane meets natural gas quality standards and can be injected with minimal updates to infrastructure. However, cleaning and upgrading biogas accounts for a considerable share of total biomethane production costs, which remains a barrier for small and medium-scale plants.

Biomethane injection is gaining policy attention globally because it enables fossil fuel displacement in hard-to-electrify sectors without major new infrastructure investment. The IEA notes that net growth in global biogas/biomethane will come from biomethane owing to its versatility and the opportunity to use natural gas grids and equipment. In Europe, the 2024 Gas Package mandates the right to inject biomethane into grids, and regulators are developing “reasonable time limits” for grid connection to accelerate market access.

Key technical requirement

Biomethane for grid injection typically requires >95% CH_4, low CO_2, H_2S <5 mg/m³, and controlled O_2 levels to prevent corrosion. Differences in oxygen tolerance across countries — e.g., 0.5% mol/mol in Denmark vs. 0.001% mol/mol in France — still create cross-border trade barriers

Objectives of the Study

The main aim of this study is to design and construct a functional biogas digester for the production of methane from cow dung. The specific objectives are to:

1. Design a mini biogas digester plant suitable for anaerobic digestion of cow dung, taking into account material selection, sizing, and safety considerations.
2. Construct and operate the designed digester to produce methane-rich biogas using cow dung as the primary feedstock.
3. Evaluate the performance of the biogas digester by determining the volume and methane content of biogas produced from cow dung.
4. Produce organic fertilizer in the form of digested slurry as a by-product of the anaerobic digestion process for agricultural use.

METHODOLOGY

Design of the Biogas Digester

The three most common and widely adopted biogas digester designs are the fixed-dome digester, the plastic covered-lagoon digester, and the floating-drum digester. For this study, the floating-drum digester was selected as the design for the construction of a biogas digester for producing methane from cow dung. The floating-drum design was chosen because it is simple in construction, easy to operate, and allows for direct visual monitoring of gas production through the movement of the drum. It also provides constant gas pressure, which is essential for domestic applications, and can be fabricated using locally available materials, making it cost-effective and reproducible for small-scale use in Nigeria (Figure 1). The digester will be designed to accommodate cow dung as the sole substrate, with provisions for inlet, digestion chamber, gas holder (floating drum), gas outlet, and slurry outlet. Design calculations will consider digester volume, hydraulic retention time, organic loading rate, and expected methane yield based on standard biogas production rates from cow dung.

Floating-Drum Biogas Digester Design

The floating-drum biogas digester designed for this study operates on the principle of anaerobic digestion of cow dung to produce methane. The system is fed by mixing cow dung with water in a ratio of 1:1 to form slurry, which is introduced through the inlet pipe into the digestion chamber. Inside the digester, the slurry undergoes anaerobic decomposition. The digestion chamber maintains three distinct layers: a layer of digested biosolids settles at the bottom, an active liquid effluent occupies the middle layer where microbial activity occurs, and the generated biogas collects at the top. The floating drum, which serves as the gas holder, rises as biogas accumulates and falls as gas is withdrawn for use, thereby maintaining relatively constant gas pressure.This design was adopted for the construction of the biogas digester because it allows for continuous feeding of cow dung, ensures easy monitoring of gas production through drum movement, and can be fabricated from locally available materials. The effluent discharged from the outlet pipe is rich in nutrients and will be collected as organic fertilizer, ensuring complete utilization of the cow dung.

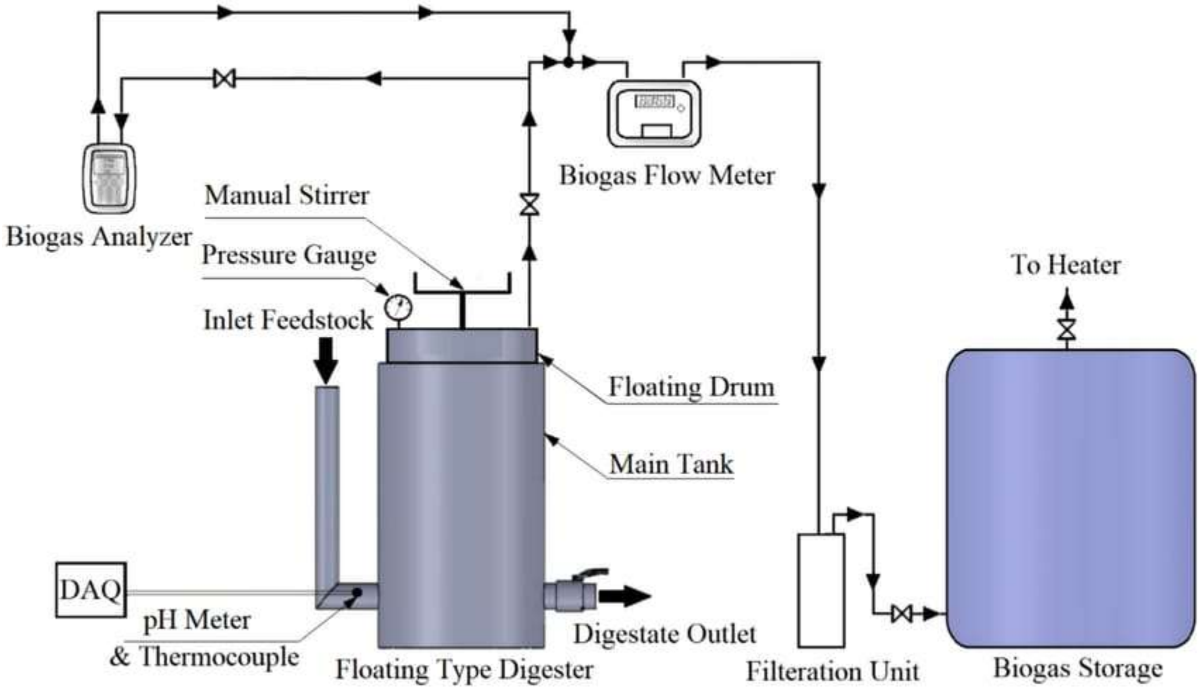

Figure 1: Selected Design for the Biogas Digestion System

Gas Holder Mechanism and Construction Considerations

In the floating-drum biogas digester designed for producing methane from cow dung, the gas holder consists of an inverted drum mounted over the digestion chamber and sealed with a water jacket. The water jacket, located outside the digester, serves as a gas seal to prevent biogas leakage while allowing the drum to move freely.As anaerobic digestion of cow dung proceeds, biogas accumulates under the drum, causing it to rise due to increasing gas pressure. To ensure stability of the floating drum and prevent it from tilting or falling off as it rises, a controlled weight such as bricks or metal pieces is placed on top of the drum. This added weight also helps to maintain adequate gas pressure for end use.To reduce construction cost, a flexible balloon gas holder can be considered as an alternative to the floating drum. However, practical challenges are commonly encountered with this option, particularly in achieving an airtight seal at the attachment point between the balloon and the digester body, which may lead to gas leakage and reduced efficiency. Therefore, for this study on the design and construction of a biogas digester for producing methane from cow dung, the conventional floating-drum gas holder with water seal is adopted to ensure reliability, ease of maintenance, and consistent gas pressure delivery.

Figure 2: Cow Dung Substrate

Figure 2 shows the cow dung substrate used as feedstock in the design and construction of the biogas digester for producing methane. The cow dung was collected fresh from abattoirs and cattle farms to ensure high microbial content and degradability. Prior to charging into the digester, the cow dung is mixed with water in a ratio of 1:1 to form a slurry, which facilitates anaerobic digestion and enhances biogas yield. The use of cow dung as substrate aligns with the research aim of converting animal waste to methane and organic fertilizer through an efficient digester system.

Figure 3: Biogas Construction for Methane Generation from cow Dung.

Figure 3 illustrates the constructed floating-drum biogas digester designed for producing methane from cow dung. The setup consists of an inlet pipe for feeding cow dung slurry, a main digestion chamber where anaerobic decomposition occurs, and an inverted floating drum that serves as the gas holder. A water jacket around the digester provides a seal to prevent gas leakage while allowing vertical movement of the drum. As methane-rich biogas is generated from the cow dung, it collects under the drum, causing the drum to rise. The stored gas is then withdrawn through the gas outlet pipe for use, while the digested slurry is discharged through the outlet pipe as organic fertilizer. This arrangement demonstrates the complete design and construction concept for converting cow dung to methane and bio-fertilizer

RESULTS AND DISCUSSION

The floating-drum biogas digester designed and constructed for this study was charged with cow dung slurry prepared at a 1:1 ratio of cow dung to water. The system was operated under ambient temperature conditions of 28–32°C for a retention period of 30 days.

Biogas Production

Biogas generation commenced on day 3 of digestion, indicated by the upward movement of the floating drum. Daily gas production increased steadily and peaked between day 14 and day 18, with an average daily yield of 0.042 m³. The cumulative biogas produced over the 30-day retention period was 1.26 m³. Table 4.1 presents the daily biogas yield.

Table 4.1: Daily Biogas Yield from Cow Dung Over 30-Day Retention Period

DAY	BIOGAS YIELDS(m3)
1	0.000
2	0.000
3	0.008
4	0.015
5	0.021
6	0.027
7	0.032
8	0.036
9	0.039
10	0.042
11	0.045
12	0.048
13	0.052
14	0.058
15	0.061
16	0.064
17	0.062
18	0.059
19	0.054
20	0.048
21	0.041
22	0.038

DAY	BIOGAS YIELDS(m3)
23	0.035
24	0.032
25	0.028
26	0.025
27	0.021
28	0.018
29	0.014
30	0.011

Total cumulative biogas yield: 1.260 m^3
Average daily yield: 0.042 m^3/day
Peak production period: Day 14 – Day 18

Methane Content

Gas analysis of the biogas collected showed an average methane (CH_4) content of 61.4%, carbon dioxide (CO_2) content of 34.8%, and trace gases including hydrogen sulfide (H_2S) making up the balance. The methane content was sufficient for combustion, as confirmed by the blue flame test.

Table 2: Typical Composition of Biogas Produced from Cow Dung and Associated Chemical Reaction

Component	Chemical formula	Percentage Range.	Average value(%)	Remark
Methane	CH_4	55-70	61.4	
Carbon Dioxide	CO_2	30-45	34.8	
Hydrogen Sulfide	H_2S	0.1-0.5	0.3	
Hydrogen	H_2	0-1	0.5	
Nitrogen	N_2	0-3	1.5	
Oxygen	O_2	0-1	0.2	
Water vapor	H_20	1-5	1.3	
Ammonia	NH_3	Trace	0.1	

Calorific Value of Biogas: 21 – 25 MJ/m^3, depending on methane content. At 61.4% CH_4, calorific value ≈ 22.1 MJ/m^3.

Overall Chemical Reaction for Anaerobic Digestion of Cow Dung

The conversion of organic matter in cow dung to biogas occurs in four stages and is summarized by the overall reaction:

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$$

For complex organic waste like cow dung, the generalized Buswell equation is used

$CcHhOoNnSs + yH_2O \rightarrow xCH_4 + (c-x)CO_2 + nNH_3 + sH_2S$

Where:

$x=81(4c+h-2o-3n-2s)$

$y=41(4c-h-2o+3n+2s)$

For cow dung: The high cellulose and volatile solids content gives a theoretical methane yield of 0.24–0.30 m^3 CH_4/kg VS added

Organic Fertilizer Output

After digestion, 18.5 kg of digested slurry was discharged from the outlet pipe. The slurry was odorless, dark in color, and had reduced viscosity compared to the fresh cow dung feedstock, indicating effective degradation of organic matter.

Discussion

The onset of biogas production on day 3 confirms that cow dung contains adequate methanogenic bacteria to initiate anaerobic digestion without external seeding. This agrees with the findings of Hassan and Garba (2022) who reported gas production from cow dung starting on day 4. The peak production period between day 14 and day 18 corresponds to the exponential phase of microbial activity, after which substrate depletion caused a gradual decline in daily yield.The average methane content of 61.4% obtained from the constructed digester falls within the 55–70% range reported for well-functioning cow dung digesters by Akindele et al. (2022) and Agede and Nwokolo (2025). This indicates that the floating-drum design provided suitable anaerobic conditions and gas retention for methane enrichment. The relatively constant gas pressure maintained by the floating drum also facilitated consistent flame quality during testing.The production of odorless, nutrient-rich digestate confirms the dual benefit of the system. The digested slurry can serve as organic fertilizer, supporting the circular economy objective of converting waste to useful products. Minor challenges observed included slight scum formation at the top of the digester, which was mitigated by periodic manual stirring through the inlet pipe. Overall, the results validate that the designed and constructed floating-drum biogas digester is effective for producing methane from cow dung under local conditions. The system is simple to operate, uses locally available materials, and achieves the objectives of waste management, renewable energy generation, and fertilizer production.

CONCLUSION

This study successfully achieved the design and construction of a floating-drum biogas digester for producing methane from cow dung. The digester, fabricated from locally available materials, effectively provided anaerobic conditions for the decomposition of cow dung slurry prepared at a 1:1 ratio with water. The system commenced biogas production on day 3 of operation and attained peak yield between day 14 and day 18 of the 30-day retention period. A cumulative biogas volume of 1.26 m^3 was obtained with an average daily yield of 0.042 m^3. Gas analysis confirmed that the biogas was methane-rich, with a methane content of 61.4%, which falls within the acceptable 55–70% range for cow dung digesters. This methane content was sufficient to sustain a stable blue flame during combustion tests, validating the performance of the digester for energy generation.In addition to biogas, the process yielded 18.5 kg of odorless, nutrient-rich digestate, confirming the dual benefit of the system as a waste-to-energy and waste-to-fertilizer technology. The low levels of oxygen 0.2% and nitrogen 1.5% in the gas indicated that the water-jacket seal effectively maintained anaerobic conditions with minimal air leakage. The results demonstrate that the four objectives of this research were met:

1. A mini floating-drum biogas digester was successfully designed for cow dung.
2. The digester was constructed and operated to produce methane-rich biogas.
3. Performance evaluation showed satisfactory biogas volume and methane content.
4. Organic fertilizer was produced as a valuable by-product.

The study therefore concludes that cow dung is a viable feedstock for decentralized biogas production, and the floating-drum design is simple, cost-effective, and suitable for adoption by small-scale farms and rural households in Nigeria. Minor challenges such as scum formation were managed by periodic stirring. For improved efficiency and wider application, it is recommended that future work incorporate a simple gas scrubbing unit to remove hydrogen sulfide and scale up the digester volume for community-level energy supply.

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