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Original Research Article

Development of a Mini Cattle Dung Biodigester

***[1]Onoroh, F., [2]Agberegha, L.O. and [1]Towobola O.O.**

[1]Department of Mechanical Engineering, University of Lagos, Akoka, Yaba, Lagos, Nigeria.
[2]Department of Mechanical Engineering, Federal University of Petroleum Resources, Effurun, Delta state, Nigeria.
*fonoroh@unilag.edu.ng

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ABSTRACT

The escalating environmental challenges caused by livestock waste calls for urgent solutions. This research developed a mini biodigester for the production of biogas from cattle dung. The construction of the biodigester consists of a high-density polyethylene drum with slurry inlet and outlet pipe, type k temperature probes and a gas storage chamber. The digester was feed with 40.9 kg of slurry with a water to dungs ratio of 2:1 and the digester was observed for period of thirteen days while monitoring the temperature of the slurry and gas chamber and recording the mass of produced gas on a daily basis. Results shows a temperature range of 27 ℃ - 32 ℃ for the gas chamber and 27℃ - 30℃ for slurry, these temperature levels fell within the mesophilic range which is typically conducive for anaerobic digestion. Results obtained shows that a gestation period of five days is required for the production of biogas from cattle dung and a total volume of 1.5 m^3 of biogas was produced. Biodigesters help manage livestock waste more efficiently, reducing odors, and preventing runoff that can contaminate water sources.

1. INTRODUCTION

Livestock farming plays an essential role in global food production. It contributes about 12.9% of global calories and 27.9% of global protein consumed (Eckard et al., 2013). Yet it generates substantial quantities of organic waste in the form of dung (Parihar et al., 2019). As the world struggles with escalating environmental concerns, the potential for harnessing the energy embedded in organic waste through biogas production becomes increasingly significant (Biodun et al., 2021; Kasinath et al, 2021). Biogas is a renewable energy source primarily composed of methane which offers a sustainable solution for waste management and decentralized energy generation.

Biogas production from livestock dung aligns with broader sustainable development goals, contributing to reduced greenhouse gas emissions, improved waste management, and the creation of renewable energy resources (Triviño-Pineda et al., 2024; Ogbuewu et al., 2012). As the global community intensifies efforts to transition towards cleaner and more sustainable energy solutions, the investigation of biogas production from readily available agricultural waste emerges as a relevant avenue for exploration (Afridi et al., 2023).

The increasing global population and the intensified practices of livestock farming have strained the challenge of managing organic waste (dung) effectively. Inadequate disposal practices contribute to environmental pollution and resource wastage which brings forward the need for innovative and sustainable solutions. The absence of optimized biogas production systems tailored specifically for livestock dung poses a hindrance to efficient energy recovery from this abundant waste stream.

Farmhouses require heat and electricity which is often provided by burning Liquidified Petroleum Gas (LPG) and running electrical generators and this increases the cost of production of livestock due to increasing cost of LPG, diesel and Premium Motor Spirit (PMS). Even if the electricity is from the grid, high cost of electrical tariff will also affect the production cost. Hence, for sustainability, there is need for production of biogas for heating and electrical need at no extra cost from livestock dung waste.

Dere et al., (2017) research centers on biogas production from various feedstock and diverse waste materials. The composition of feedstock emerges as a crucial factor influencing biogas production, with methane yield largely dependent on the substrates employed. However, variations in total methane yield are observed, influenced by interactions among different wastes that impact their digestibility in the system. Their research finds out that the percentage of methane content in biogas from different fermentable materials is nearly consistent. Additionally, the research indicates that cotton wastes can be effectively treated aerobically and serve as a valuable biogas source. The study underscores the significant calorific and nutritive value of kitchen waste, enhancing microbial efficiency and potentially increasing methane production substantially. Owusu and Banadda, (2017) explore livestock waste-to-energy as a supplementary energy source with the potential to address both energy needs and waste management issues globally. The focus is on Uganda's capability to convert abundant livestock waste into energy. Using descriptive statistics, the study estimates that Uganda could generate enormous amount of biogas annually, representing 40% of the country's total energy consumption. Despite a target to install 100,000 biogas digesters by 2017, only half are operational. They recommends prioritizing biogas production to support Uganda's Rural Electrification Program. Egbere, (2010) examined biogas production from segregated municipal solid wastes using water and cow dung as inoculants in Jos Nigeria. Anaerobic digestion lasted 25 days at 37°C. Leaves proved most productive, generating 996 cm^3 of biogas, followed by the residue of food (52 cm^3), a mixture of segregates (36 cm^3), and paper (24 cm^3). Key bacteria involved were identified, with Streptococcus, Clostridium, Escherichia coli, Methanobacterium, and Methanococcus being most active. The findings suggest potential for utilizing municipal solid wastes as an energy source for biogas production on an industrial scale. Raja and Wazir, (2017) suggested that biogas, a simple and booming alternative energy source, holds great promise for rural communities. With abundant biomass resources worldwide and the introduction of efficient high-tech plants, smart biogas facilities are on the horizon. The study emphasizes the need to encourage and invest in biogas technology, particularly in remote rural areas where bio-waste is readily available. Kaur et al, (2022) underscored the crucial role of the power sector in developing economies and highlights India's abundant natural resources, particularly in agriculture. The study focused on estimating the potential for electrical energy generation through biogas production from livestock dung across all Indian states. The annual estimation reveals a substantial potential of 2633 million tons of livestock dung, corresponding to an annual biogas potential of 265,542 million m^3. This significant potential advocates for the implementation of distributed biogas plants, aiming to enhance India's power sector.

A feasibility study by Nandiyanto et al, (2018) showed that biogas can be produced through the use of waste from dairy farming industry (cow's manure and cassava peel). The mass balance calculation showed that 1 kg of cow's manure combined with 0.30 kg of cassava peel waste could yield nearly 0.20 kg of biogas. Assuming 1700 kg of cow's manure per month, this process could produce over 300 kilograms of biogas, addressing environmental issues in dairy farming. However, the economic evaluation suggested that direct biogas conversion alone is not profitable. To enhance profitability, integrating biogas production with dairy farming, particularly fresh milk production, was found to be more profitable than either option alone. Given the dual benefits of profitability and environmental solutions, further development in this integrated approach is recommended. Matos et al, (2017) conducted a study to evaluate biogas production and potential from anaerobic bio digestion of dairy cattle manure in organic and conventional production systems. Bench biodigesters were used for 30 weeks, and the analysis included total solids, volatile solids, biogas production potential, and thermo tolerant coliform concentrations. The cumulative biogas production was 6.18 liter for cattle manure under organic production system and 11.15 liter for cattle manure under conventional production system. The average biogas production potential varied between the systems. Importantly, after bio digestion, thermo tolerant coliform concentrations were found to be below legal limits. Recebli et al, (2015) conducted an experimental study on a model biogas production unit at a breeding farm in Turkey, fermenting poultry and bovine (cow) manure in a 0.5 m^3 tank. The study, conducted during the summer, achieved daily biogas production rates of 6.33 m^3 and 0.83 m^3 from bovine (cow) and poultry manure, respectively. The estimated lower heating value of the biogas, with 62% CH_4 content, was 21,000 kJ/m^3. The study suggests that using biogas instead of natural gas for heating or energy systems could result in a cost saving of approximately $ 0.35/m^3.

Based on the reviewed literature, it appears that multiple studies have been conducted on biomass generation. Nevertheless, the current research provides a detailed description of the process and model of an animal dung biodigester that can be used for small-scale ranches and slaughterhouses to meet their energy needs while also promoting sustainable development.

2. METHODOLOGY

2.1. Design of the Biodigester

Figure 1 shows the schematic of the 3D and 2D views of the developed biodigester with the dimension h = 13.8 cm, H = 43 cm and Hd = 59 cm. The digester chamber is made of a high density polyethylene drum, HDPE, the slurry inlet and di-gestate outlet pipes material is made of poly vinyl choride, PVC. A flexible gas hose attached to the top of the gas chamber is connected to a tyre tube for storing the biogas produced. Table 1 detailed the specification of the biodigester.

The volume of the digester is a function of the daily feed rate and the hydraulic retention time defined by Equation (1) (Divyabharathi 2020):

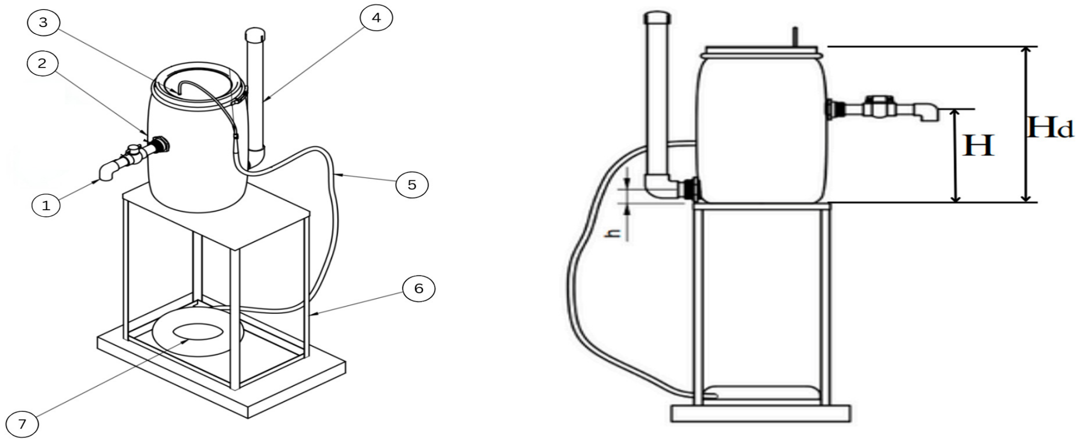
$$V_d = Q_i \times H_{RT} \tag{1}$$

Where V_d is the digester volume, m^3; $Q_i$is the daily feed rate, m^3/day and H_{RT} is the hydraulic retention time, days.

The total mass of slurry can be expressed as Equation (2):

$$m_s = m_f + m_w \tag{2}$$

F. Onoroh et al. / Nigerian Research Journal of Engineering and Environmental Sciences
9(2) 2024 pp. 689-695



Part list 1: 2-inch di-gestate outlet pipe with elbow and valve 2: A 60 Liter high density polyethylene with lever-lock closing ring drum 3: ¼ inch brass pipe fitting 4: 3inch slurry inlet pipe with elbow and valve. 5: ¼ inch flexible gas outlet tubing 6: Metal frame stand 7: Gas reservoir tube

Figure 1: Model of a biodigester

Table 1: Biodigester specification

Component	Size
Digester volume	60 litres
Sludge inlet pipe	2-inch diameter, 0.8m length
Sludge outlet pipe	2-inch diameter, 0.35m length
Gas hose	10 mm diameter, 1.55m length
Gas hose to tube	10 mm diameter, 0.27m length
Gas hose for testing	10 mm diameter, 0.38m length
Storage tube	16-inch diameter
Valves	2 inch and 10 mm ball types

Where m_s is the total mass of slurry; m_f mass of dungs; and m_w mass of water respectively in kg.

The mass of water can be expressed as a fraction of the mass of dungs. According to Divyabharathi, (2020), the optimum ratio is expressed as Equation (3):

$$m_w = 2m_f \tag{3}$$

The volume of the slurry can be obtained using Equation (4) (Divyabharathi 2020):

$$V_s = \frac{m_s}{\rho_s} \tag{4}$$

Where V_s is the Volume of m^3, and ρ_s is the density of slurry, kg/m^3. The amount of biogas and the electrical generation capacity can be obtained using the gross theoretical potential of biogas B_{GT} expressed as Equation (5) (Kaur et al, 2022):

$$B_{GT} = M_{gr} \times T_S \times A_C \times B_g \tag{5}$$

Where B_{GT} is the gross theoretical potential of biogas, m^3/day; M_{gr} is the gross cumulative amount of procurable/collectable dung, kg/day; T_S is the total solid content, %; A_C is the availability coefficient and B_g is the biogas quantity generated, m^3/kg. Where the gross cumulative amount of procurable/collectable dung, is obtained using Equation (6):

$$M_{gr} = P_O \times D_d \tag{6}$$

Where P_O is the animal population and D_d is amount of dung/day, kg. The approximate values for total solids is 25%, availability coefficient and biogas quantity generated for large and small animals are

70% and 20% respectively while quantity of biogas generated are 0.6 for large animals and 0.4 for small animals (Kaur et al, 2022).

The quantity of methane components in produced biogas depends on the kind of dung used and microbial population in the anaerobic digestion process (Neethu et al, 2019). Several related works show that the methane component in average biogas recovered is 50%-70% from the anaerobic digestion of cattle dung and 40% to 50% from the anaerobic digestion of small animal dung. Electrical energy production from biogas can be obtained using Equation (7) (Kaur et al, 2022):

$$e_g = E_g \times m_b \times \eta \qquad (7)$$

Where e_g is the quantity of electricity generated, kWh; E_g is the biogas in terms of calorific value, kWh/m^3; and m_b = quantity of biogas produced, m^3 and η is the overall conversion efficiency. For large turbine system the efficiency value is generally taken between 35% and 42% and plants operating with small generators, the efficiency value is about 25% (Kaur et al, 2022). The quantity of heat obtained from biogas is estimated using Equation (8):

$$\dot{Q} = \dot{v} \times C_v \qquad (8)$$

Where $\dot{Q}$ is the quantity of heat, kJ; $\dot{v}$ is the volume biogas, m^3 and C_v is the calorific value for methane gas, kJ/m^3.

2.2. Test Rig

This research developed an anaerobic biodigester for animal dung. The biodigester contains the slurry inlet and di-gestate outlet pipes, gas collection hose and connectors and biogas storage chamber. The HDPE drum was made airtight with the use of silicon gum and properly latched. The biodigester was tested using cattle dung mixed with water to form a slurry in the ratio of one part dung to two part of water on mass basis to ensure an even microbial action, 40.9 kg of slurry was ingested into the biodigester. The experiment lasted for a period of thirteen days while monitoring the temperatures of the slurry and the gas chamber with a UT320D mini dual K/J temperature meter through a type K thermocouple probe inserted into the slurry and gas chamber respectively. In order to prevent the digester from going sour due to imbalance of bacteria and methanogens, a fresh batch of slurry was added on day 7. A Globetrek International weighing scale was used to record the mass of the storage tube. The produced biogas was collected and stored in a tube. The di-gestate or by-product of the anaerobic digestion can be utilized as an organic fertilizer. Figure 2 shows the experimental setup of the biogas production plant.

Figure 2: Biogas production test rig

3. RESULTS AND DISCUSSION

3.1. Plot of Temperature against number of Days

Figure 3 shows a plot of the temperature distribution inside the gas chamber and slurry against number of days. The gas chamber temperature and slurry temperature were recorded using UT320D mini dual K/J temperature meter at an interval of 24 hours. Clearly the temperature of the gas chamber ranged between 27℃ to 32℃ and 27℃ to 30℃ for the slurry. The point where the gas chamber temperature spiked to 32℃ was due to the digester setup relocation outdoor and the drop in slurry temperature was due to the addition of a new batch of slurry on day 7. These temperature levels fall within the mesophilic range which is typically conducive for anaerobic digestion.

3.2. Plot of Digested Volume of Biogas against number of Days

Figure 4 shows the volume of biogas produced against number of days. The mass of the biogas generated was recorded using Globe trek International weighing scale and converted to volume the density relation. The readings of biogas production was taken on a daily basis. From the graph, it can be observed that a gestation period of five days is required for the production of biogas since no significant volume of gas was recorded. It can be inferred that the hydrolysis, acidogenesis and acetogenesis stages of biogas production is approximately five days. On the 7th day of the experimentation, there was a spike in biogas produced. The spike was due to the addition of 14 kg of slurry to the system and exposing the digester to solar radiation. These have two profound effects on the biogas production. Firstly, there was a reduction in the gas chamber volume and secondly an increase in gas temperature with a resultant increase in gas pressure. A total volume of 1.5 m^3 of biogas was produced in the thirteen days of the experiment. The hydraulic retention time usually varies from 10 to 30 days on the temperature and level of microorganism population for biodegradation. Thus, high yield in the recorded time could be attributed to some microbial activities that have commenced in a holding tank in the slaughter house.

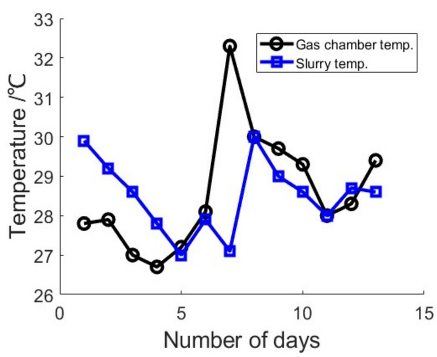


Figure 3: Temperature of gas chamber and slurry vs number of days

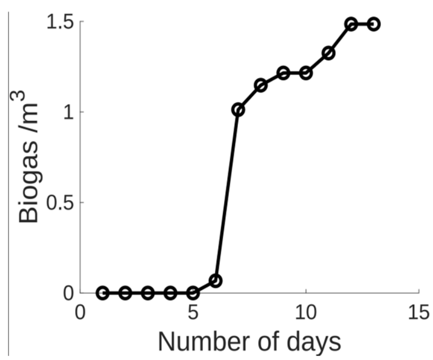


Figure 4: Plot of biogas produced against number of days

4. CONCLUSION

Inadequate disposal of livestock dung contribute to environmental pollution and resource wastage which brings forward the need for innovative and sustainable solutions. Biogas production from livestock dung aligns with broader sustainable development goals, contributing to reducing greenhouse gas emissions, improved waste management, and the creation of renewable energy resources. Thus, a fixed dome anaerobic biodigester was designed and experimentally tested. The construction consists of a high-density polyethylene drum with slurry inlet and outlet pipe, type K temperature probes and a gas storage chamber. The digester was feed with 40.9 kg of slurry with a water to dung ratio of 2:1 and the digester was observed for a period of thirteen days while monitoring the temperature of the slurry and gas chamber and recording the mass of produced gas on a daily basis. Results show a temperature range of 27℃ - 32℃ for the gas chamber and 27℃ - 30℃ for the slurry, these temperature levels fell within the mesophilic range which is typically conducive for anaerobic digestion. Results obtained show that a gestation period of five days is required for the production of biogas from cattle dung and a total volume of 1.5 m^3 of biogas was produced. Biodigesters help manage livestock waste more efficiently, reducing odors, and preventing runoff that can contaminate water sources.

5. ACKNOWLEDGEMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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