International Journal of Renewable Energy and Environmental Sustainability
Volume. 10, Number 2; April-June, 2025;
ISSN: 2837-3391| Impact Factor: 8.56
https://zapjournals.com/Journals/index.php/ijrees
Published By: Zendo Academic Publishing

EMPIRICAL INVESTIGATION OF THE COWDUNG YIELD AND PERFORMANCE EVALUATION OF A 20 M^3 FIXED-DOME DIGESTER

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Article Info

Keywords: Biodigester, biogas, cow-dung, fixed-dome, anaerobic digestion

DOI

10.5281/zenodo.15781739

Abstract

Environmental concerns regarding the indiscriminate disposal of biodegradable waste coupled with access to clean and sustainable energy sources have been a major challenge confronting the globe. This study aimed to empirically quantify cowdung yield and characterize a 20 m^3 fixed-dome biogas digester for heat generation. Empirical analysis of cowdung yield was performed by feeding three cows with different feeds for four weeks, and dried cowdung was fed into a digester for biogas production. The digester characteristics were determined experimentally by the computation of some equations . The produced biogas was characterized using a gas analyzer and was used for water-boiling test (WBT) analysis. The results of the analyses show an optimum daily cowdung yield of 31.9±773 kg. Similarly, the plant characteristics show the capacity of the mixing chamber (2.674 m^3) and digester (20 m^3) with a total biogas production of 75.098 m^3 after a retention period of 4 weeks at an average temperature of 42 ^{0}C and pH of 8.4 when a ratio of 1:5 (cowdung 2666.6 kg : water 10666.4 L) was used. Thus, for a dilution factor of 1:5, 1-kg cowdung produces 0.028 m^3 of biogas.

1.0 INTRODUCTION

One of the global challenges that requires urgent attention is access to clean energy. Fossil fuels are estimated to contribute 82% to the global energy mix by 2023 and are expected to drop to 38% by 2050 (Blackmon, 2023) (Energy 2050: Insights From the Ground Up, 2016). However, these finite resources are exhaustible and questionable from an environmental viewpoint. The recent rise in sea levels, flooding, climate change, and global warming are all consequences of anthropogenic activities resulting from the burning of fossil fuels. Scientists and engineers across the globe are keenly investigating alternatives to fossil fuels and; hence , renewable energy. These alternative energies, including wind, biomass, solar photovoltaic, solar thermal, geothermal, and tidal energy, are renewable sources of energy that can be replenished at a higher rate and consumed, as well as being

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more environmentally friendly. Of these renewables, one of the most abundant and widely available is biomass (Popp et al., 2021) (Jekayinfa et al., 2020). Biomass energy is the energy produced by living organisms, mainly plants and animals, that can be processed to generate heat, fuel, and electricity. Domestic utilization of biomass resources such as wood, animal dung, and crop residues for heating and cooking purposes predates the era of the industrial revolution. However, improper waste disposal, coupled with the need for clean energy, necessitates the search for efficient waste-to-energy conversion technologies. One of the most efficient ways to use agricultural, municipal, and industrial organic waste is through biogas production. Biogas is a renewable energy resource produced from organic waste via anaerobic digestion. The biodigester is a physical structure commonly known as a biogas plant. Because various chemical and microbiological reactions occur in the biodigester, it is also known as a bioreactor or anaerobic reactor (Erraji et al., 2023)**.** The main function of this structure is to provide anaerobic conditions. The chamber should be air- and water-tight and can be made of various construction materials and in different shapes and sizes. In an attempt to modernize its agricultural sector, provide energy access, provide environmental protection, and improve sanitation, for instance, the Chinese government constructed more than 7 million digesters in the 1980s (Deng et al., 2017). Unfortunately, almost half of the digesters were abandoned due to technical know-how regarding monitoring and maintenance of the systems, inadequate data, insufficient feedstock, and difficulty in handling raw straw feedstock (Puntos de Inflexión Ecológica, n.d). In Nigeria, the first biogas plant was constructed at Usmanu Danfodiyo University in Sokoto in the 1980s, with an installed biogas capacity of 425 liters per day (Dangoggo and Fernando, 1986) (Akinbami et al., 2001). Subsequently, there was an increase in the number of biogas digesters constructed across the country. Nevertheless, owing to the large amount of organic waste generated annually (approximately 542.2 million tons), the number of installed digesters was not encouraging. Several factors, including a lack of sufficient processing expertise and inadequate technology awareness, were reported to be responsible for the drawbacks (Biodun et al., 2021). This study aimed to empirically quantify cowdung yield and characterize a 20 m^3 fixed-dome biogas digester constructed at Sokoto Energy Research Center, Usmanu Danfodiyo University, Sokoto.

2.0 METHODOLOGY

2.1 Materials

Some of the materials used in this research include cow-dung, Guinea-corn husk (konon dawa), beans husk (kowa), chaff (dussa), groundnut shell (rugugi), weighing balance, solar dryer, biodigester, biogas compressor, gas analyzer, biogas burner, stop watch, flexible horse pipe, pot, pH meter, digital data logger, and gas flow-meter.

2.2 Methods

2.2.1 Feedstock (cow-dung) Production

Three different species of cows (Gudali, Yakana, Rahaje) were caged and fed four different animal feeds; Guinea-corn husk (konon dawa), beans husk (kowa), chaff (dussa), and groundnut shell (rugugi) at different concentrations (1-12 kg) for 4 weeks. Twenty kilograms (20 kg) of each feed were weighed and fed to the animals (cows), and the daily leftover feed were weighed and subtracted from the recorded amount . Wet cowdung was weighed using a weighing balance before dryness was performed using a passive tent solar dryer. The dried cow dung was weighed using a weighing balance and stored for biogas production.

2.2.2. Digester feeding

The dried feedstock (cowdung) was weighed and placed into the mixing chamber of the digester. An appropriate quantity of water at a ratio of 1:5 was added to produce the slurry, which was later fed into the digester via the digester inlet. The slurry samples were taken to the laboratory for pH and temperature analyses using a pH meter and digital data logger, respectively. The same procedure was repeated until the digester was completely filled with a known concentration of the slurry at a retention period of 4 weeks (Erraji et al., 2023).

2.2.2.1 Mixing Chamber Characteristics

The mixing chamber is an integral part of the fixed-dome biogas plant. In this study, a masonry structure with a gate valve as a delivery channel was used as a mixing chamber (plate 1. The total volume of the chamber was computed using equation 1.

Volume = b*l*h**..eqn 1**

where b = breadth, l = length, and h = height.

2.2.2.2. Digester Characteristics

This is an air- and water-tight physical structure where various chemical and microbiological reactions occur.

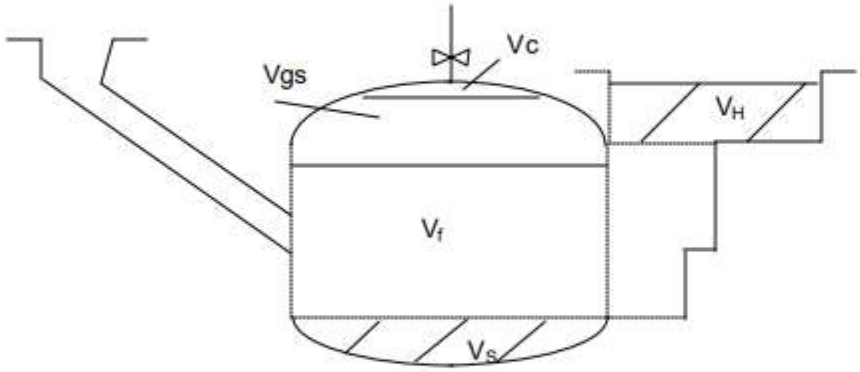

Figure 1: Schematic view of a fixed-dome digester.

The volume of the digester was calculated using equation 2, as shown in fig. 1 (Mukumba et al., 2017).

Total volume of digester = $V_c+V_{gs}+V_f+V_s$ ....**eqn 2**

Where: V_c = volume of the gas collecting chamber, V_{gs} = volume of the gas storage chamber, V_f = volume of the fermentation chamber, and V_s = volume of the sludge layer.

2.2.3 Biogas Production and Characterization

After the retention period, a biogas flow-meter (BF2008-4) was used to evaluate the amount of biogas generated, and the biogas composition was analyzed using a biogas analyzer (xund XD-B-HP).

2.2.4 Water Boiling Test (WBT)

A water boiling test (WBT) was conducted to determine the quantity of biogas required to raise 1 kg of water to 100 ^{0}C. The test was conducted in a controlled laboratory environment. The Bunsen burner was connected to the biogas source using a pipe hose, and a pipe valve was used to control the gas flow. A measured volume of water was placed on the burner and ignited with a match. The gas flow rate was measured using a flow meter, and a digital data logger was used to measure the temperature of the water. The time for water boiling was recorded.

3.0 RESULTS AND DISCUSSION

3.1 Feedstock (cowdung) Production

Table 1 presents the results of the feed experiment conducted within a period of 1 month. From the results, a total yield of cowdung (31.9±7.73 kg) was obtained at an optimal feed concentration of chaff (9.8±1.851 kg), beans husk (3.9±1.539 kg), groundnut shell (3.7±1.578 kg), and Guinea corn husk (3.7±1.617 kg).

Table 1: Result of Optimal Feed Concentration

FEEDS	CONCENTRATION (Kg)
Chaff (Dussa)	9.8±1.851
Bean husk (Kowa)	3.9±1.539
Groundnut shells (Rugugi)	3.7±1.578
Guinea corn husk (Konon dawa)	3.7±1.617
Weight of the Dung (wet)	36.1±8.52
Weight of the Dung (dried)	31.9±7.73

Results = MEAN±Standard deviation

A significant reduction was observed from wet (36.1±8.52 kg) to dry (31.9±7.73 kg) dungs, which might be due to the loss of water molecules during drying. Similarly, the result also shows a high affinity of the cows to the chaff feed. This is because the feed (chaff) was an industrial-based product that was well developed and branded.

However, not much difference was observed in their urge to use the remaining three feeds, which might be due to their being raw and devoid of any industrial treatment.

Plate 1: Weighing and feeding of the biogas digester.

3.2 Digester Feeding

The average pH and temperature of the slurry were 8.4°C and 42 ^{0}C respectively. The pH level was slightly basic, and methanogenic bacteria were reported to thrive well between pH values of 7 and 8.5 (Sommer & Husted, 1995). The slurry temperature (42 ^{0}C) is slightly high, which might be due to the hot climatic conditions. Several researchers have reported optimal slurry temperatures 22-40^{0}C (Adamma C. E. et al., 2023) (Kayode Latinwo & Enahoro Agarry, 2015) ("Production of Biogas Using Water Waste Products (Water Hyacinth and Cow Dung)," 2023) (HAO et al., 2012) (Nekhubvi & Tinarwo, 2022) (Kibona Enock et al., 2018). The mixing chamber had a total capacity of 2.674m^3~2,674 L which was calculated using equation 1 with height (0.84 m), length (1.84 m), and breadth (1.69 m). To ensure adequate mixing of the slurry, half of the chamber (1337 L) was used. This implies that for half the volume of the chamber, eight times the mixing was required with cowdung (334.2 kg) and water (1337 L) to achieve a ratio of 1:5. This result corroborates the results of (Haider et al., 2015) (KeChrist et al., 2017) (Zare et al., 2019) (S. Octiva et al. (2018) used food waste, rice husk, empty fruit bunches (EFB), and palm oil mill effluent (POME). The volume of the digester was found to be 20 m^3~20000 L using equation 2. Hence, 2/3 (13,333 L) of the digester was fed with the slurry, whereas the remaining 1/3 was left for gas collection, as reported by Suheang and Puthaty (2021). Thus, for a dilution factor of 1:5, both water (10,666.4 L) and cow dung (2,666.6 kg) must make up 13,333 L. At the end of the experiment, a total of 75.098 m^3 of biogas was obtained after a retention period of 4 weeks.

Biogas produced per 1kg dung (m^{3}kg^{-1}) = $\frac{Total\ biogas\ produced\ (m3)}{Total\ amount\ of\ cow-dung\ (kg)}$ .....**equation 3**

In this research, a dilution factor of 1:5 was used, which implies that by applying equation 3, 1 kg of cowdung produces 0.028 m^3 of biogas. This result is slightly lower than the result from the research conducted by Nwaukwu, (2014). This result is in congruence with the result of ("Production of Biogas Using Water Waste Products (Water Hyacinth and Cow Dung)," 2023). The slight variation might be due to the differences in the nature of feedstock and weather conditions (Sari, 2022) (Xu et al., 2010). Similarly, since the average daily dung production was 31.9±7.73kg, it infers that an approximately 70-day supply of dung was required to have 2666.6 kg for a single experiment that generates ~75.098 m^3 of biogas. However, one of the advantages of a fixed-dome digester is its ability to accommodate continuous feeding (Budiman, 2020) (Mtamabari Simeon Torbira & Ebigenibo Genuine Saturday, 2021) (Obileke et al., 2023) (C. S. et al., 2023). Consequently, after the initial bulk feeding, subsequent feeding can be continued with less feedstock.

Table 2: Results of water-boiling test

Parameters	Quantity of water used (L)	Time taken (Min)	Biogas consumed (m^3)
Values	18	54	2.437

The water boiling test is a technique used to determine the quantity of fuel (biogas) and the time required to boil a certain amount of water. In this research, 18-L water was boiled to 100 ^{0}C within 54 min by 2.437 m^3 biogas. This implies that 0.14 m^3 must raise 1 L of water to 100 ^{0}C within 3 min.

4.0 CONCLUSION

This research work entails the empirical investigation of cow dung yield and subsequent biogas generation for domestic applications. The total daily yield of cow-dung was obtained at an optimal feed concentration of four different feedstocks with a mixing chamber total capacity of 2.674 m^3~2,674 L at a dilution factor of 1:5. At the end of the experiment, a total of 75.098 m^3 of biogas was obtained after a retention period of 4 weeks, with an average yield of 1 kg of cowdung per 0.028 m^3 of biogas. Since the average daily dung production was 31.9±7.73 kg, it infers that a 70-day supply of dung was required to produce 2666.6 kg for a single experiment that generates ~75.098 m^3 of biogas. Similarly, 2.437 m^3 of biogas was used to raise 18-L water to 100 ^{0}C in 54 min.

ACKNOWLEDGMENT

We wish to acknowledge the management of the Tertiary Education Trust Fund (TertFUND) for funding this research under its National Research Fund (NRF) category. Similarly, we acknowledge the contribution of the Sokoto Energy Research Center (SERC) for providing the necessary support needed for the success of this research.

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