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Upgrading of Biogas Produced from Cattle Dung for Household Energy Usage

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Abstract
Raw biogas produced through anaerobic digestion contains substantial amounts of carbon dioxide, hydrogen sulphide and water vapour which are impurities that reduce its effectiveness as a domestic fuel. Hence, this work aimed at upgrading biogas produced from cattle dung for household energy usage. Cattle dung of 340 kg was collected from an abattoir in Ogbomoso, Nigeria (8.13º N, 4.25º E) and dissolved into a slurry at a ratio of 1:2 (cattle dung:water) and used to fill a 1000 litres tank to 70% of its volume. It was allowed to decompose in the absence of air. The gas produced was upgraded by passing it through a desulphrizer to remove sulphur, a scrubber to remove water, CO_2, and H_2S. The filtered gas then passes through a flow meter to the storage bag. The biogas produced was analysed with a gas chromatograph equipment and the rate of combustion in a biogas cooker was evaluated. The biogas produced per day ranged 0.001 - 0.322 m^3. The total volume of biogas produced was 3778 m^3. The composition of the raw biogas was 67.53% methane, 0.25% carbon monoxide, 2.12% oxygen and 1.52% hydrogen sulphide, while the upgraded biogas had methane 95.47%, carbon monoxide 0.21%, oxygen 0.25% and hydrogen sulphide 0.20%. Biogas performance in a gas cooker showed that water had a boiling rate of 49 g/min and rice had a cooking rate of 6.2 g/min. The biogas generated is suitable for cooking food and other household applications. It is recommended for household energy usage.

Keywords: Cattle dung, Biogas, Upgrading, Fuel, Energy

Introduction
Nigeria relies heavily on fossil fuels, which account for a substantial portion of its energy needs. Ashekuzzamana *et.al.,* (2010) had suggested that biogas has the innate potential to meet rural energy demand and contribute to new wealth generation. Nigeria's vast agricultural sector generates substantial amounts of organic waste, making it an ideal candidate for biogas production. According to Alabi *et al.* (2021), Nigeria produces large quantities of agricultural residues, such as cassava peels, rice husks, and palm kernel shells, which can be used for biogas production. The potential for biogas production in Nigeria is further supported by Ilesanmi *et al.* (2021), who estimated that the agricultural sector alone could generate enough biogas to meet a substantial portion of the country's electricity demand.

Various initiatives have been undertaken by both the Nigerian government and the private sector to explore the feasibility of biogas electricity generation. Ogunjuyigbe *et al.* (2020) documented government efforts to promote biogas through policies such as the National Renewable Energy and Energy Efficiency Policy (NREEEP), which recognizes the role of biogas in the country's energy mix. Additionally, the Nigerian government has partnered with international organizations such as the International Fund for Agricultural Development (IFAD) to implement small-Scale biogas projects, particularly in rural communities (Okoye *et al.*, 2021).

The challenges facing the implementation of biogas systems in Nigeria are multifaceted. One of the major challenges identified by Alabi *et al.* (2021) is the financial barriers to large-scale biogas development. The initial capital required for setting up biogas plants and procuring the necessary equipment can be prohibitive, particularly in a country like Nigeria, which faces a financial crisis. Furthermore, the absence of substantial government subsidies or incentives for private investors makes it difficult to attract investment in the biogas sector (Ilesanmi *et al.*, 2021).

Moreover, waste management practices in Nigeria are often inadequate, particularly in rural areas. Many communities lack the infrastructure for the proper collection and transportation of organic waste, which limits the availability of feedstock for biogas plants (Ilesanmi *et al.,* 2021). Sustainability theory is central to the understanding of biogas as a renewable energy source. According to this theory, energy systems should be developed in a way that meets the needs of the present without compromising the ability of future generations to meet their own energy needs (Ogunjuyigbe *et al.*, 2020). Biogas, as a renewable source of electricity, aligns with the principles of sustainability by reducing reliance on non-renewable fossil fuels, decreasing carbon emissions, and offering a waste-to-energy solution that promotes circular economy principles.

In Nigeria, the adoption of biogas technology has been slow due to high initial costs, lack of technical know-how, and limited awareness of the technology's benefits. According to Alabi *et al.*, *(*2021), the successful diffusion of biogas technology will require targeted policy interventions, financial incentives, and capacity-building initiatives to overcome these barriers. Energy access and development theory focuses on the role of energy in socio-economic development, particularly in rural areas. According to this theory, access to reliable and affordable energy is a critical enabler of development, especially in areas like education, healthcare, and agriculture (Ilesanmi *et al.*, 2021). Biogas offers an opportunity for decentralized energy solutions, providing rural communities with a stable electricity supply that can spur economic growth, improve living standards, and promote sustainable development in remote areas.

Key factors influencing biogas production include feedstock type, temperature, pH, and retention time in the digester. The temperature ranges for biogas production are between 30 and 40 °C for mesophilic conditions and 50 to 60 °C for thermophilic conditions. The temperature range of 40 to 50 °C is called the dead zone or transition zone for anaerobic digestion. The pH should ideally be maintained between 6.8 and 7.4 (Liu *et al.*, 2020). Retention time is crucial as it dictates the extent of microbial digestion and biogas yield (Wu *et al*., 2021). Biogas production occurs through anaerobic digestion, a biological process where microorganisms decompose organic matter in the absence of oxygen. This process consists of four key stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Duan *et al*., 2020). Biogas is produced by anaerobic digestion of biomass residues such as cattle dung, poultry droppings, pig manure, vegetable waste, municipal solid waste and industrial waste water (Adebayo *et al.*, 2015a, Adebayo *et al.*, 2015b). Upgraded biogas intended for household energy applications should contain at least 90% methane (IEA, 2020). This research is an attempt to provide affordable and clean energy which is the seventh goal of Sustainable Development Goals. The aim of this research is to upgrade biogas produced from cattle dung for household energy usage.

Materials and Methods
Collection of materials
Wet cattle dung of 340 kg was collected from an abattoir in Ogbomoso, Nigeria (8.13º N, 4.25º E) and dissolved into a slurry at a ratio of 1:2 (cattle dung:water).

Assembly of biogas production plant
A biogas plant was assembled for the production of biogas from cattle dung. (Plates 1 & 2). The biogas plant comprised a 1000 litres digester tank having a mechanical stirrer for the digestion of the substrate; the hose for the channelling of the gas; the desulphurizer to remove the sulphuric acid; the scrubber for the removal of carbon dioxide, hydrogen sulphide and water; the flow meter for recording the amount of gas produced and the storage bag for the storage of the gas for usage.

Plate.1: Assembled biogas plant

Plate.2: The picture of an assembled biogas plant

Experiment procedure

Cattle dung was dissolved into a substrate and filled the biogas tank to seventy percent of its volume, at a ratio of 1:2, that is one part of dung to two part of water, which accumulated to 700 litres of water. It was allowed to decompose in the absence of air. The mixture in the tank was stirred every 2hr. The gas produced was upgraded by passing it through a desulphrizer to remove sulphur, and through a scrubber to remove water, CO_2, and H_2S. The filtered gas then passes through a flow meter to the storage bag. The rate at which biogas flowed from the tank to the storage bag was taken note of every hour of the day that is at the time range of 7am – 9pm daily using the gas flow meter. The cumulative biogas volume was measured using the gas flow meter. This was done in accordance with Adebayo *et al*. (2024). The raw gas produced and the upgraded gas were analysed using a Varian 3800/4000 gas chromatograph mass spectrometer equipped with an Agilent equipped with a capillary column DB5ms (30.0m x 0.25mm, 0.25μm film thickness).

Evaluation of biogas as an energy source for cooking

A flammability test was carried out using a small hose about 6.35 mm hose. One end of the hose was connected to the gas bag outlet duct and the other connected to a burner. A cooking test was conducted using these parameters;

1. Amount of water for cooking the rice was measured with a weighing balance.
2. Time taken for the cooker to ignite was measured with a stop watch
3. Cooking rate was determined as the amount of time to cook a unit mass of food substance.
4. Biogas consumption rate was determined as the amount of biogas used in cooking for 1 minute.

Results and Discussions

Cumulative biogas production

Table 1 summarizes the cumulative biogas volume obtained during the experiment. There was a steady increase in cumulative biogas volume, reflecting the effectiveness of the anaerobic digestion process using cattle dung. As shown in Table 1**,** the cumulative biogas volume reached 3778 liters by Day 28, indicating a steady growth in production. The table clearly shows a marked increase in production during the latter half of the fermentation period, suggesting that optimal conditions for microbial activity were achieved. Moreover, the data in Table 1 also highlights the initial lag phase in biogas production, where lower volumes were recorded during the first few days. This aligns with previous research indicating that microbial communities typically require time to establish before significant gas production occurs (Tonanzi, *et al.*, 2021) The cumulative data provides insights into the overall efficiency of biogas production, helping to evaluate the potential for scaling up biogas systems for household energy needs. Furthermore, the cumulative volumes demonstrated the feasibility of using biogas as a reliable energy source for cooking and heating, particularly in rural areas reliant on cow dung as a resource. This table clarifies that cumulative readings commenced on Day 5 and ended on Day 28.

Table 1: Cumulative Biogas Volume Production Over 28 Days

Time (Days)	Cumulative Volume (Liters)
5	1325
6	1597
7	1919
8	2152
9	2324
11	2586
12	2711
13	2862
14	2932
16	3068
20	3181
21	3283
22	3397
23	3474
24	3479
25	3634
26	3716
27	3777
28	3778

The data show that biogas production was notably high during the initial period of 13 days. This surge in production indicates that the microbial community was very active and effectively converting the organic substrate into biogas under optimal conditions. It was still observed that starting from the 14th day upward the production began to fluctuate, with daily outputs varying significantly. These fluctuations may suggest that the microbial community was experiencing stress possibly due to changes in environmental conditions or depletion of easily digestible materials. Following the fluctuations, there was a noticeable decline in biogas production from 23rd day onward. The daily outputs steadily diminished, indicating that the anaerobic digestion process was becoming less effective. This decline could be attributed to substrate depletion, where the available organic matter for digestion was insufficient to sustain high levels of microbial activity, leading to reduced gas production.

Upgrading of biogas

Analysis of raw and upgraded biogas are shown in Tables 2 and 3. Methane is the main energy carrier, which was determined as 67.53 wt% for raw biogas and 95.47 wt% for upgraded biogas. This concentration is significant as it exceeds the 60% threshold typically required for efficient combustion (Kadam *et al.*, 2024; Kabeyi and Olanrewaju, 2022).

Table 2: Analysis of Raw biogas

Peak	**RT**	**Name of Gas**	**Molecular Formula**	**Molecular Mass**	**Peak Area**	**% Composition**
1	5.87	Hydrogen	H_2	2	0.21	0.25
2	7.64	Carbon monoxide	CO	28	0.21	0.25
3	9.85	Water vapour	H2O	18	0.75	0.89
4	13.11	Ethane	C_2H_6	44	0.45	0.53
5	18.45	Hydrogen Sulphide	H_2S	34	1.28	1.52
6	24.01	Methane	CH_4	16	57.04	67.53
7	26.62	Nitrogen	N_2	28	1.45	1.72
8	29.17	Carbon dioxide	CO_2	44	21.16	25.05
9	33.01	Oxygen	O_2	32	1.79	2.12
10	39.54	Ammonia	NH_3	20	0.13	0.15

Table 3: Analysis of Upgraded biogas

Peak	**RT**	**Name of Gas**	**Molecular Formula**	**Molecular Mass**	**Peak Area**	**% Composition**
1	2.15	Carbon monoxide	CO	28	0.18	0.21
2	4.39	Oxygen	O_2	32	0.21	0.25
3	9.80	Methane	CH_4	16	80.64	95.47
4	12.16	Ethane	C_2H_6	30	0.42	0.50
5	15.82	Carbon dioxide	CO_2	44	2.09	2.47
6	18.67	Nitrogen	N_2	28	0.43	0.51
7	20.01	Hydrogen sulphide	H_2S	34	0.17	0.20
8	22.18	Water vapour	H2O	18	0.05	0.06
9	24.63	Hydrogen	H_2	2	0.17	0.20
10	26.91	Ammonia	NH_3	20	0.11	0.13

Performance evaluation of Biogas for Cooking

The stove using biogas demonstrated blue flame. The absence of yellow or sooty tips indicates complete combustion and high methane purity (Manesh *et al*., 2020; Odejobi *et al*., 2022). In the performance evaluation shown in Table 4, water had a boiling rate of 49 g/min and rice had a cooking rate of 6.2 g/min which proves that the upgraded biogas had sufficient thermal energy that could be used for cooking (Manesh *et al*., 2020; Ajieh *et al*., 2020). This results established the effectiveness of upgraded biogas in rural domestic cooking conditions (Odejobi *et al*., 2022; Kabeyi and Olanrewaju, 2022). The cooking time and biogas consumption rates were comparable to those reported in similar studies (Awulu *et al.*, 2020). The results indicate that biogas from cow dung can effectively meet household cooking needs, promoting sustainability in rural areas.

Table 4: Summary of Mean Values for Upgraded Biogas as a Fuel for Boiling Water and Cooking Rice.

Parameters	Water	Rice
Mean quantity of materials (g)	60	150
Time taken for all Jets to ignite (s)	1.0	1.0
Boiling/Cooking rate (g/min)	49.0	6.2
Biogas consumption rate (L/min)	1.5	2.4

Conclusion

The cumulative biogas volume from an assembled biogas plant increased steadily over the 28 days study period, reflecting consistent microbial activity and effective anaerobic digestion processes. The biogas produced per day ranged 0.001 - 0.322 m^3. The total volume of biogas produced was 4200 m^3. The composition of the raw biogas was 67.53% methane, 0.25% carbon monoxide, 2.12% oxygen and 1.52% hydrogen sulphide, while the upgraded biogas was methane 95.47%, carbon monoxide 0.21%, oxygen 0.25% and hydrogen sulphide 0.20%. Biogas performance in a gas cooker showed that water had a boiling rate of 49 g/min and rice had a cooking rate of 6.2 g/min. The biogas stove exhibited efficient performance of biogas in cooking applications, effectively converting produced biogas into usable heat for household needs. This study has established the composition of upgraded biogas from cattle dung and demonstrated its application for household energy usage.

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