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Enhancing Biogas Quality and Energy Content through Calcium Hydroxide Treatment: A Study on the Effectiveness of 20% $Ca(OH)_2$ Solution in Improving Methane Content and Reducing Impurities

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ABSTRACT

This study investigates the effectiveness of treating biogas with 20% calcium hydroxide solution to improve its quality and energy content. The treatment process significantly increased methane content from 64.0% to 98.1% and reduced impurities like CO_2, H_2S, CO, and water vapor. Treated biogas demonstrated a 35% faster heating time compared to raw biogas and outperformed kerosene, showcasing its potential as a more efficient and cleaner-burning fuel source. The results highlight the benefits of biogas treatment, making it a viable alternative energy source for cooking, heating, and other applications. This research contributes to the development of sustainable energy solutions, emphasizing the importance of biogas treatment for improved energy efficiency and reduced environmental impact.

Keywords: Biogas, scrubber, calcium hydroxide, kerosene, Efficiency

1.1 INTRODUCTION

Energy is fundamental to human activities, and Nigeria is richly endowed with diverse energy resources, including abundant solar, wind, biomass, crude oil, natural gas, and coal reserves. Despite this natural wealth, the country has struggled to effectively harness these resources for sustainable development and economic growth (Eke *et a*., 2020). Electricity is crucial for achieving national development goals, powering industries, and enhancing the quality of life, yet a significant 60% of Nigerians lack access to this essential energy source (Sustainable Energy for All Progress Report, 2023). The reliance on hydrocarbon resources has not driven economic growth, provided a stable energy mix, or ensured energy security, leading to a range of economic and environmental challenges (Ogwu *et al*., 2022). The increasing cost of petroleum products has made kerosene unaffordable for many Nigerians, leading to a dependence on fuelwood, which contributes to environmental degradation, deforestation, and severe health hazards (Ibrahim *et al*., 2020). Nigeria's deforestation rate is among the highest globally, with severe environmental and health consequences, including loss of biodiversity, soil erosion, and increased greenhouse gas emissions (FAO, 2020). The development of biogas technology offers a sustainable alternative energy source, addressing waste management and environmental concerns, while providing energy access and reducing reliance on fossil fuels (Adesanya *et al*., 2022). Anaerobic digestion can convert organic waste into biogas and compost, providing a waste-to-wealth solution, reducing waste disposal challenges, and creating new economic opportunities (Ojo *et al*., 2021). Sugarcane Bagasse and poultry waste, abundant in Nigeria, can be harnessed as feed materials for biogas production, reducing waste, generating wealth, and supporting sustainable agriculture (Adeoye *et al*., 2022; Olugbenga *et al*., 2023). This research aims to explore biogas technology as a sustainable energy solution for Nigeria, addressing environmental and economic challenges, and contributing to the country's sustainable development goals.

2.1 MATERIALS AND METHODS

2.2 Chemicals/Reagents

Analytical grade ≥ 95% Calcium Hydroxide (British drug house)

2.3 Sample and Sampling

The raw biogas was produced from co-digestion of 25% sugarcane bagasse and 75% Chicken droppings (SB25%:CD75%) and its chemical composition is reported in Table 1 below.

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2.4 Upgrading of Biogas with Calcium Hydroxide

The raw biogas was purified by passing it through a 20% calcium hydroxide solution to remove carbon dioxide and other impurities. This was achieved by setting up a purification system consisting of a 500mL plastic container filled with 150mL of 20% calcium hydroxide solution. Two hose were attached to the container's cover, one connected to the digester and the other serving as the outlet for the purified biogas. The container was sealed, and the raw biogas was allowed to flow into the calcium hydroxide solution through the inlet hose. The purified biogas was then collected through the outlet hose. The methane content of the purified biogas was subsequently analyzed. The equations below depicted the reactions that took place during the scrubbing process.

$$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O \quad 1$$

$$Ca(OH)_2 + H_2S \longrightarrow CaS + 2H_2O \quad 2$$

3.1 RESULTS AND DISCUSSION

3.2 Composition of the Biogas before and after treatment (Scrubbing)

Table 1 presents the composition of biogas before and after undergoing scrubbing process

Table 1: Biogas composition, raw biogas and treated biogas

Biogas composition	Raw biogas	Treated biogas
CH_4	64.0	98.1
CO_2	33.8	1.8
H_2S	1.2	0.1
CO	0.8	0
Water Vapor	0.2	0

SB=Sugarcane Bagasse, CD=Chicken Droppings

The results show a significant improvement in the quality of biogas after treatment (Kumar *et al*., 2022). The methane content increased from 64.0% in raw biogas to 98.1% in treated biogas, indicating a significant enhancement in the energy content of the biogas. The carbon dioxide content decreased from 33.8% in raw biogas to 1.8% in treated biogas, which is a substantial reduction. The hydrogen sulfide content decreased from 1.2% in raw biogas to 0.1% in treated biogas, which is a significant removal of this harmful impurity. The carbon monoxide content decreased from 0.8% in raw biogas to 0% in treated biogas, indicating complete removal. The water vapor content decreased from 0.2% in raw biogas to 0% in treated biogas, indicating complete removal.

Overall, the treatment process has significantly improved the quality of biogas, making it more suitable for use as a fuel or energy source. The removal of impurities and increase in methane content make the treated biogas more efficient and cleaner-burning (Kumar *et al*., 2022).

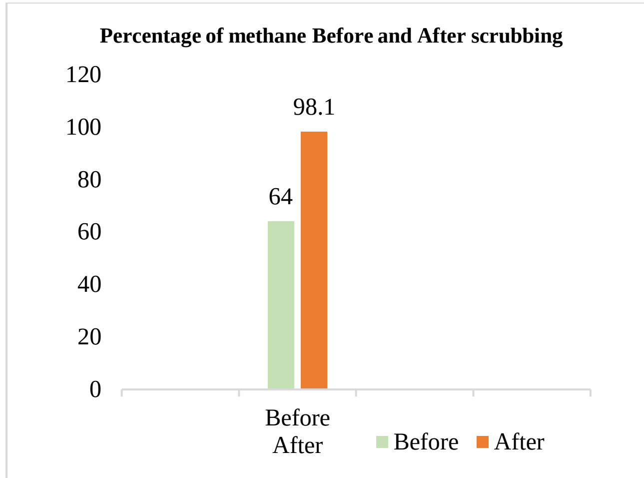

Figure 1: Percentage of Methane Before and after scrubbing

Comparison of Heating Efficiency

3.3 Heating rate performance

The digester (D3) which produced the highest methane was connected to a biogas stove to raise the temperature of water (500ml) to 77.6^{0}C, the initial temperature of the water was 27.6°C and the final temperature was 77.6°C, the time taken was recorded using stopwatch. The thermometer was placed in the water allowing only a tip of it in contact with the water. And comparison was made with a kerosene stove.

Table 2: Comparison of Heating rate Between raw Biogas, Treated Biogas and Kerosene

Sample	Raw biogas	Treated biogas	Kerosene
Heating time	2 min 12 sec.	1 min 27 sec.	2 min 48 sec

The biogas stove designed in the Usmanu Danfodiyo University Energy Research Centre was utilized to carry out this test. The results show the heating time required for each fuel source to heat 500mL of water to a certain temperature (77.6 degrees celcius). Raw biogas required 2 minutes 12 seconds while treated biogas needs 1 minute 27 seconds (approximately 35% faster than raw biogas) and Kerosene 2 minutes 48 seconds (approximately 23% slower than raw biogas). The treated biogas heats the water significantly faster than the raw biogas, which is expected due to its higher methane content (98.1% vs 64%). The higher methane content means more energy is

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released during combustion, resulting in faster heating times. In contrast, kerosene takes longer to heat the water than both the raw and treated biogas. This suggests that biogas, especially treated biogas, is a more efficient fuel source for heating water compared to kerosene. Overall, the results demonstrate the benefits of treating biogas to increase its methane content and energy density, making it a more efficient and effective fuel source.

4.1 CONCLUSION

In conclusion, this study demonstrates the effectiveness of treating biogas to enhance its quality and energy content. The treatment process significantly increased the methane content from 64.0% to 98.1%, while substantially reducing impurities like carbon dioxide, hydrogen sulfide, carbon monoxide, and water vapor. The treated biogas showed a 35% faster heating time compared to raw biogas and outperformed kerosene, indicating its potential as a more efficient and cleaner-burning fuel source. The results highlight the benefits of biogas treatment, making it a viable alternative energy source for various applications, including cooking and heating. The biogas stove design used in this study showcases a practical application of treated biogas, further supporting its potential for real-world implementation. Overall, this research contributes to the development of sustainable energy solutions and emphasizes the importance of biogas treatment for improved energy efficiency and reduced environmental impact.

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