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Removal of Contaminants from Biogas: A Study on H_2S, CO_2, and Water Vapor Reduction

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ABSTRACT

This study investigates the effectiveness of a biogas treatment process utilizing anhydrous sodium sulfate, iron fillings, and ash as treatment materials to enhance the quality of raw biogas. The treated biogas exhibits a significant increase in methane content (94.75%) compared to the raw biogas (67.10%), rendering it a more valuable fuel. Notably, the treatment process reduces carbon dioxide content (4.90% vs. 32.15%), hydrogen sulfide content (0.20% vs. 0.50%), and eliminates water vapor, thereby minimizing environmental impact, pipeline corrosion, and equipment damage. The upgraded biogas demonstrates improved safety and handling characteristics, making it suitable for various applications, including power generation, industrial processes, and transportation fuel. A comparative analysis with existing literature highlights the efficacy of the treatment process in producing high-quality biogas, aligning with industry standards and requirements. The use of anhydrous sodium sulfate, iron fillings, and ash as treatment materials proves to be a effective and efficient method for biogas upgrading

Keywords:
Biogas,
purification,
H_2S,
CO_2,
Water vapor

INTRODUCTION

The anaerobic digestion of organic biomass from agricultural, agro-industrial, and urban sources generates raw biogas, a mixture of methane (CH_4), carbon dioxide (CO_2), and hydrogen sulfide (H_2S). However, CH_4 and CO_2 are potent greenhouse gases, with methane having a global warming potential 25 times higher than CO_2, according to the Intergovernmental Panel on Climate Change (Vega et al., 2022). One strategy to mitigate greenhouse gas emissions is to produce biogas from controlled biodigesters, which can be purified and used as a fuel (Mahmoodi-Eshkaftaki and Houshyar, 2020). Methane's chemical properties make it suitable for combustion. Nevertheless, the presence of CO_2 and H_2S in biogas poses challenges, including reduced heating value and corrosion damage from H_2S. Therefore, removing these impurities is crucial to enhance biogas combustion quality, energy efficiency, and material durability. Purified biogas (CH4 >95%) can compete with conventional fuels like gasoline, diesel, and natural gas, enabling diversification and commercialization. However, the biogas industry faces a significant challenge: the poor quality of raw biogas from bio-digesters, which hinders its marketability (Srichat et al., 2017).

Biogas upgrading technologies have primarily targeted the removal of carbon dioxide (CO_2) and hydrogen sulfide (H_2S), employing various methods categorized into physical, chemical, biological, or hybrid processes. Research has demonstrated the effectiveness of several techniques in removing CO_2, including membrane separation, chemical absorption, aqueous solutions, biological purification, pressure swing adsorption (PSA), and cryogenic separation. Additionally, chemical adsorption, iron-based absorption (Chuanchai and Ramaraj, 2018; Duran et al., 2022), and microbiological separation (Piechota, 2021; Srichat et al., 2020) have been explored for H2S removal. To ensure practical implementation, purification processes must be efficient, cost-effective, and user-friendly, providing end-users with accessible and manageable solutions. Ultimately, the goal is to integrate methane production into a sustainable, waste-to-energy process that minimizes carbon footprint and maximizes the utilization of organic waste.

This study aims at investigating and optimizing the removal of hydrogen sulfide (H_2S), carbon dioxide (CO_2), and water vapor from biogas, enhancing its quality and suitability for energy applications.

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MATERIALS AND METHODS

Chemicals/Reagents

Analytical grade ≥ 99%(Sigma-Aldrich), Analytical grade ≥ 99% and anhydrous sodium sulfate (Merck) and wood ash (locally source)

Sample and Sampling

Raw biogas was generated at the Sokoto Energy Research Centre, located within the Usmanu Danfodiyo University in Sokoto, Nigeria. Prior to analysis, the biogas was vented to the atmosphere for a brief period, allowing for initial release and stabilization before further testing and evaluation.

Upgrading of Biogas Process

Biogas typically contains significant impurities, including carbon dioxide (CO_2), hydrogen sulfide (H_2S), and water vapor. These impurities can react with water vapor to form corrosive acids, damaging metal components and hindering combustion (Divyang et al., 2015). To enhance the quality of biogas, it is essential to remove these impurities using a scrubbing unit. The biogas purification process comprises three distinct units, each designed to remove H_2S, CO_2, and water vapor, respectively. These units work in tandem to upgrade the biogas, making it suitable for various applications.

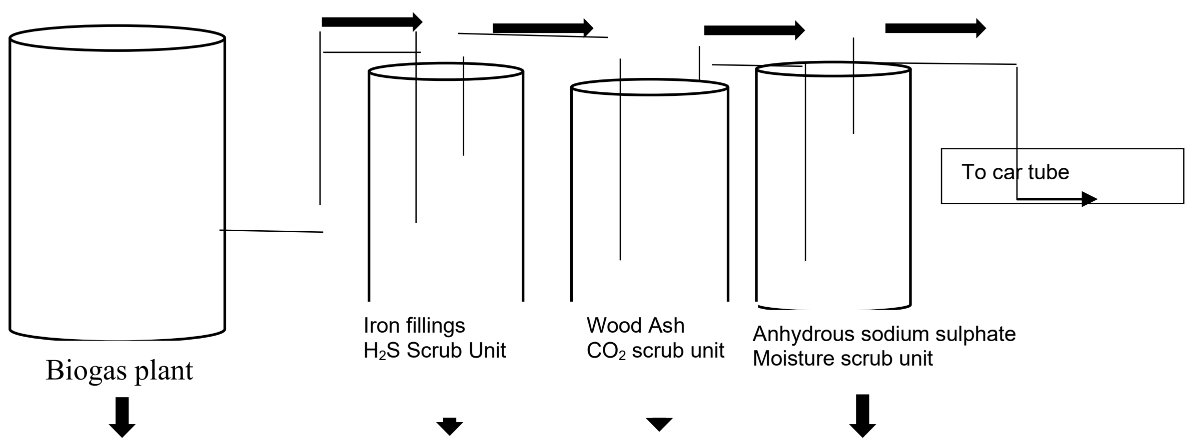

Figure 1: Schematic Diagram of Biogas Purification Unit

Hydrogen Sulphide Scrubbing Unit

The initial step in biogas purification involves the removal of hydrogen sulfide (H_2S) contaminants. This is achieved by passing the biogas through a container filled with iron filings, which acts as a scrubbing medium. In this setup, approximately 863g of iron filings was used in an enclosed container with designated inlet and outlet channels. The biogas from the digester enters the container through the inlet, where it reacts with the iron filings, resulting in the removal of H_2S. The treated gas, now free from H_2S, is then transported to the subsequent scrubbing chamber via the outlet pipe. This process is based on the principle that when biogas comes into contact with iron filings, iron oxide is converted into elemental sulfur, as described by previous researchers (Ray et al., 2016). The corresponding chemical reactions are as follows:

$$2Fe_2O_3 + 6H_2S \longrightarrow 2Fe_2S_3 + 6H_2O \quad (1)$$

$$2Fe_2S_3 + 3O_2 \longrightarrow 2Fe_2O_3 + 6S \quad (2)$$

Carbon Dioxide using Scrubbing Unit

Approximately 100g of ash was mixed with distilled water in a volumetric flask until a solution of $5000cm^3$ was obtained. It was then poured into a 5L container. The biogas was then channeled to pass into the solution through a ¾ inch pipe and goes through the outlet to the next container (Johan and Åke, 2017).

Water Vapor Scrubbing Unit

The moisture content of the gas was trapped using approximately 1245g of anhydrous sodium sulfate (Na_2SO_4) crystals contained in a 5L rubber container. The color of the crystals usually changes as it absorbs water vapor and can be seen visibly. The gas channel from the CO_2 scrubbing unit enters the silica gel container and the outlet leaves the gas without water vapor.

Figure 2: H_2S, CO_2 and Water vapor scrubbers

Analyses of the Biogas

The biogas produced was analyzed with Crowcon (Tetra 3) Personal Multi-gas Monitor (model 19576H made in England). The gas detector is equipped with sensors for the determination of the percentage concentration of CH_4, H_2S, and CO. While the percentage of CO_2 was determined using Chinese gas analyzer model XUNDER XD-B-HP

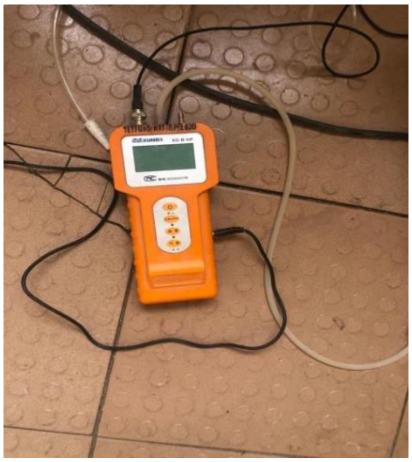

Figure 3: Gas Analyzer Used

Flammability Test

The flammability test of raw biogas and treated biogas was carried out with locally fabricated burner as presented in Figure 4.

Figure 4: Biogas Burner

RESULTS AND DISCUSSIONS

Composition of the Biogas before and after treatment (Scrubbing)

Table 1: Biogas composition, raw biogas, treated biogas and treated biogas

Biogas composition	Raw biogas	Treated biogas
CH_4	67.10	94.75
CO_2	32.15	4.90
H_2S	0.50	0.20
Water vapor	0.15	0.00

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

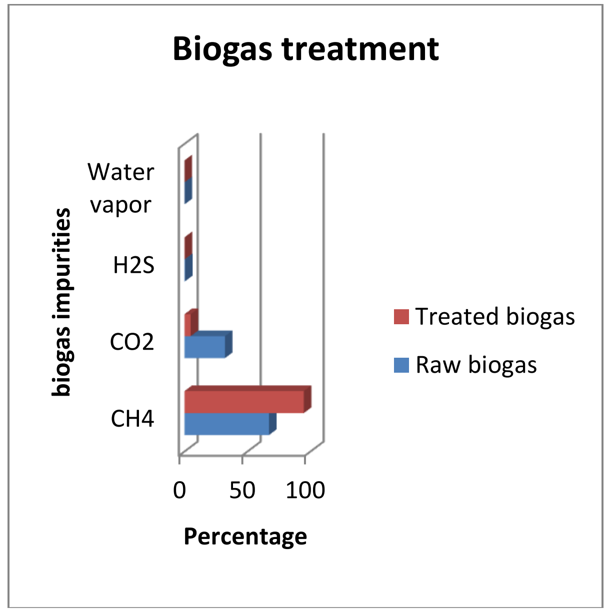

Figure 5: Biogas Treatment

Prior to treatment, the biogas composition consisted of 67.10% methane, 32.15% carbon dioxide, 0.50% hydrogen sulfide, and 0.15% water vapor. Following purification, analysis revealed a significantly improved composition of 94.75% methane, 4.90% carbon dioxide, and 0.20% hydrogen sulfide. This upgraded composition indicates that the biogas is highly combustible and meets the minimum requirement for bio-methane as a fuel for automobile applications, which stipulates a methane content of at least 90% (Bureau of Indian Standard, 2013). After purification, the biogas was stored in a tractor tube before being compressed for further use, paving the way for its potential application as a sustainable fuel source.

The treated biogas has a significantly higher methane content (94.75%) compared to the raw biogas (67.10%) and this is comparable to the literature elsewhere 85-95% (Santibanez et al., 2017); 90-92% (Yuan et al., 2018)**.** This increase in methane content makes the treated biogas a more valuable fuel. The treated biogas has a substantially lower carbon dioxide content (4.90%) compared to the raw biogas (32.15%) and this result found to be better than 5-15% and 8-12% documented elsewhere Santibanez et al., 2017 and Yuan et al., 2018 respectively. This reduction in CO_2 content is beneficial for several reasons for instance CO_2 is a greenhouse gas, so reducing its content helps minimize the environmental impact also the CO_2 can corrode pipelines and equipment, so reducing its content can help extend the lifespan of infrastructure. The treated biogas has a lower hydrogen sulfide content (0.20%) compared to the raw biogas (0.50%).

More so, this result found to be better than research carried out by Santibanez et al., 2017; Yuan et al., 2018. H_2S is a toxic and corrosive gas, so reducing its content improves the safety and handling of the biogas. The treated biogas has zero water vapor content, whereas the raw biogas contains 0.15% water vapor. Removing water vapor is essential because it cause pipeline corrosion, equipment damage and reduced biogas quality.

The treatment process has significantly improved the quality of the biogas, making it a more valuable and safer fuel. The increased methane content and reduced impurities (CO_2, H_2S, and water vapor) make the treated biogas suitable for various applications, such as power generation, industrial processes and transportation fuel

Biogas flammability test

The raw biogas and treated biogas (before and after scrubbing) was tested utilizing the locally fabricated burner reported in Figure 4. The color of the raw biogas was found to be light blue while after scrubbing it was found to be a deep blue color indicating the presence of high methane content. This result corroborates with the research elsewhere (Joshi *et al*., 2017).

Compression and Storage

The purified biogas was compressed and stored in a cylinder for further use. To accurately determine the amount of biogas stored, the cylinder's weight was measured before and after compression. The initial weight of the cylinder was recorded at 13.5 kg. Following compression, the weight increased to 13.6 kg, indicating that approximately 0.1 kg of purified biogas was stored in the cylinder. However, due to the relatively small weight of the biogas, which may not provide a precise indication of the stored amount, the pressure of the gas was also measured. The pressure gauge reading showed a pressure of 3 bar, providing a more accurate indication of the quantity of biogas stored in the cylinder. By combining the weight and pressure measurements, a more comprehensive understanding of the stored biogas amount was achieved

CONCLUSION

The treatment process has yielded a remarkable enhancement in biogas quality, aligning with findings from previous studies. The substantial increase in methane content and reduction of impurities, such as carbon dioxide, hydrogen sulfide, and water vapor, has transformed the biogas into a superior fuel. This upgraded biogas boasts a higher energy density, making it an attractive option for various applications, including power generation, industrial processes, and transportation fuel. The improved biogas quality also mitigates environmental concerns, as it minimizes greenhouse gas emissions and reduces the risk of pipeline corrosion and equipment damage. Furthermore, the treated biogas meets the minimum requirements for bio-methane as a fuel for automobile applications, opening up new avenues for its utilization. Overall, the successful treatment process has unlocked the full potential of biogas as a valuable, safer, and more versatile fuel, paving the way for its increased adoption in diverse sectors.

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