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Optimization of Hydrogen Sulfide Reduction in Biogas Using a Dual-Column Water Scrubbing System

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ABSTRACT: *This study investigates the purification of biogas using water in a dual-column system, focusing on the reduction of hydrogen sulfide (H_2S) levels. Raw biogas, produced from cow dung via anaerobic digestion, initially contained 255 ppm of H_2S. The purification process reduced this concentration to 5 ppm. The experiment varied water temperatures (18°C, 28°C, and 38°C) and circulation methods (continuous, 5-minute pause, and 10-minute pause). Results indicated that the lowest water temperature of 18°C provided the most efficient H_2S removal, while continuous water circulation outperformed intermittent methods. Additionally, the pH of the water, initially at 7.6, decreased due to the absorption of acidic gases, with the most significant pH drop at 38°C (to 6.2) and the least at 18°C (to 6.4). The pH in the regeneration unit was consistently higher than in the scrubbing unit. These findings emphasize the importance of optimizing water temperature and circulation methods to enhance biogas purification, ensuring cleaner biogas output and more efficient operation.*

NOMENCLATURE

Symbol	Description	Unit
H_2S	Hydrogen sulfide	*ppm*
CO_2	Carbon dioxide	%
CH_4	Methane	%
PID	Proportional Integral Derivative	-

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I. INTRODUCTION

Renewable energy plays a crucial role in global efforts to reduce dependence on fossil fuels and minimize negative environmental impacts. Biogas, produced through the anaerobic fermentation of organic materials such as animal manure, is a promising source of renewable energy [1]. However, raw biogas contains various compounds, including hydrogen sulfide (H_2S), which is corrosive and harmful to both health and the environment. High levels of H_2S in biogas can cause severe equipment damage and increase maintenance costs, as well as pose health risks and contribute to air pollution [2]. Therefore, reducing H_2S content in biogas is an essential step in the purification process to produce safe and efficient biogas for use.

Various biogas purification methods have been developed to remove contaminants such as hydrogen sulfide (H_2S), carbon dioxide (CO_2), and water vapor to improve the quality and efficiency of biogas as an energy source. Physical methods like absorption using water or chemical solutions are commonly used, where H_2S is absorbed into the liquid, which can then be regenerated or disposed of [3]. Other chemical methods involve the use of adsorbents such as zeolites or activated carbon that capture H_2S through adsorption [4]. Biological methods utilize specialized microorganisms capable of oxidizing H_2S into elemental sulfur or sulfur dioxide [5]. Additionally, membrane methods are employed to separate gases based on differences in molecular size and permeability, allowing for the separation of H_2S and CO_2 from methane [6]. Each method has its own advantages and disadvantages, depending on factors such as cost, efficiency, and resource availability, making it crucial to select the appropriate method tailored to the specific needs and conditions of the biogas production process.

Numerous studies have been conducted to reduce hydrogen sulfide content in biogas, considering its detrimental effects on equipment and the environment. Physical methods like absorption using water or chemical solutions have been extensively researched, showing high effectiveness in reducing H_2S when used in scrubbing columns or packed towers [7]. Research on natural and synthetic adsorbents such as zeolites, activated carbon, and iron-based materials has also demonstrated significant capability in capturing H_2S through adsorption processes [8]. Other studies have explored biological methods using H_2S-oxidizing bacteria in biofilters or biological reactors, offering environmentally friendly solutions with low operational costs [9]. Furthermore, the use of membranes for gas separation has been a recent research focus, with polymer-based membranes showing great potential in selectively separating H_2S from methane [10]. Although each method has its strengths and limitations, ongoing research aims to optimize combinations of these techniques to achieve higher purification efficiency and lower costs.

Purifying biogas using water has several key advantages, including process simplicity and relatively low operational costs. Water as an absorption medium is readily available and does not require additional chemicals, making it more environmentally friendly. This process can also be implemented with simple and easy-to-operate equipment, such as scrubbing columns. Additionally, this method is effective in reducing H_2S and water vapor content in biogas, improving its quality and reducing the risk of equipment damage. These advantages make water purification an attractive option for small to medium-scale operations, particularly in rural areas or locations with limited access to advanced technology.

The novelty of this research lies in the approach of purifying biogas using water in two parallel columns with varied water circulation. This study introduces innovation by testing variations in water temperature (18°C, 28°C, and 38°C) and circulation patterns (continuous, every 5 minutes, and every 10 minutes), which have not been extensively explored in previous studies. The goal of this research is to observe and determine the optimal conditions that can maximize the reduction of hydrogen sulfide content in biogas, resulting in cleaner and safer biogas for use. Thus, this research not only enhances scientific understanding of the biogas purification process but also offers practical solutions that can be adapted to various scales of biogas production.

II. EXPERIMENTAL SETUP

The raw biogas used in this experiment is produced from an anaerobic digestion process in a digester located at the Renewable and New Energy Laboratory, Faculty of Engineering, University of Mataram. The raw material for the biogas is cow dung, with a ratio of 1:1 between cow dung and water for biogas production in the digester. The produced biogas is then directed to a receiving station before being sent to the biogas scrubbing unit. Before collecting experimental data on the purified biogas, the components of the raw biogas, such as CO_2, H_2S, and CH_4, were measured.

The experiment was conducted by varying water temperature and circulation duration. The water temperatures applied in the research were 18°C, 28°C, and 38°C, representing low, ambient, and high temperatures, respectively. To minimize errors in temperature readings, a PID controller (Proportional Integral Derivative) connected to thermocouples was used. Additionally, the scrubbing unit was insulated to minimize heat dissipation. The water flow rate was set at 1 liter per minute, based on previous research indicating that a slower water flow rate can achieve better performance. Data were continuously collected for 40 minutes under each operating condition.

The scrubbing unit consists of two columns: an absorption column and a regeneration column. This setup allows for water recirculation. In the first column, or absorption column, CO_2 and H_2S are absorbed by water molecules. The water is then circulated to the second column, or regeneration column, where there is a small vent to release the absorbed CO_2 and H_2S into the ambient air. Figure 1 shows a schematic diagram of the biogas scrubbing unit. The components of the biogas were measured using a biogas tester (GEO TECH) that measures compounds such as CH_4, CO_2, O_2, and H_2S with an accuracy level of ±0.5% vol. The humidity of the purified biogas was measured using a humidity sensor, capable of measuring humidity within a temperature range from 40 to 123°C. To increase the biogas stream pressure entering the scrubbing unit, a biogas vacuum pump model BP-01 equipped with a double-stage pump was used. The biogas volumetric rate was accurately measured using a dedicated biogas flow meter, capable of measuring flow rates up to 4 m^3/hr.

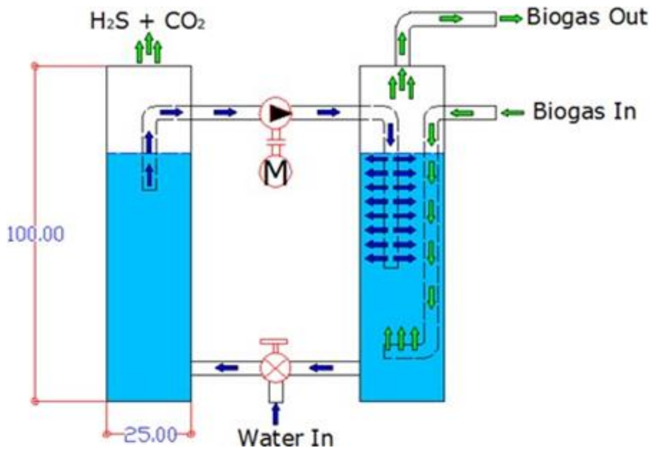

Fig. 1 Experimental setup scheme

III. RESULTS AND DISCUSSION

The initial concentration of hydrogen sulfide in the raw biogas was measured at approximately 255 ppm. After undergoing the purification process, the H_2S levels significantly decreased to just 5 ppm, indicating a substantial improvement in biogas quality. When examining the impact of water temperature on the purification efficiency, the lowest water temperature of 18°C yielded the best results, outperforming the higher temperatures of 28°C and 38°C. Over the duration of the purification process, which was monitored continuously for 40 minutes with data recorded every minute, there was a gradual increase in H_2S concentration. For water at 18°C, the H_2S levels rose to 50 ppm, while for water at 38°C, the levels increased to 65 ppm.

In terms of purification method variations, the continuous circulation method demonstrated the most effective reduction in H_2S levels compared to the circulation-pause methods (5-minute and 10-minute intervals). The difference in H_2S concentration was particularly pronounced at the highest water temperature of 38°C. This trend suggests that maintaining a constant flow of water in the scrubbing unit enhances the absorption capacity and efficiency, likely due to the continuous exposure of fresh water to the biogas, preventing saturation and maintaining a higher absorption rate.

These findings are consistent with previous studies that highlight the effectiveness of lower water temperatures and continuous flow in gas absorption processes. For instance, previous research has indicated that lower temperatures enhance the solubility of H_2S in water, thereby improving its removal from biogas [11]. Additionally, research has highlighted that continuous circulation systems are typically more effective in sustaining low contaminant levels over longer durations compared to intermittent circulation methods [12].

The solubility of gases in liquids is governed by Henry's Law, which states that at a constant temperature, the amount of gas dissolved in a liquid is directly proportional to the partial pressure of the gas above the liquid. Lower temperatures increase the solubility of H_2S in water, as solubility typically decreases with rising temperature [13]. This explains why the 18°C water temperature showed better performance in reducing H_2S levels compared to higher temperatures. The lower temperature enhances the water's capacity to absorb H_2S, leading to more efficient removal of this contaminant from the biogas.

Overall, the data indicates that optimizing both the temperature and the circulation method of the water used in biogas purification can significantly enhance the removal of H_2S, ensuring a cleaner and more efficient biogas output. The superior performance of the continuous circulation method, especially at lower temperatures, provides a valuable insight for improving biogas purification systems.

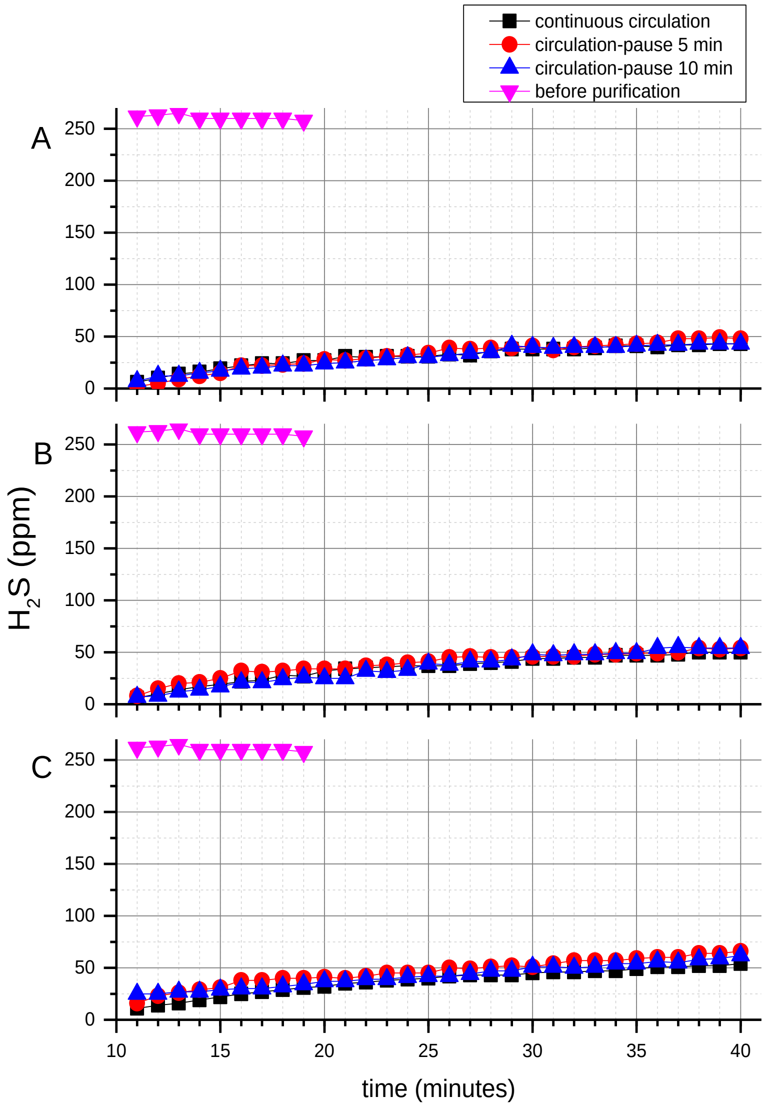

Fig. 2 The relationship between hydrogen sulfide and time based on regeneration time at: A. Temperature of 18°C B. Temperature of 28°C C. Temperature of 38°C

The experiment utilized two water columns: the first column, referred to as the scrubbing unit, where biogas from the digester initially contacts the water, and the second column, known as the regeneration unit, where water from the scrubbing unit is directed using a pump. Both columns initially had the same water volume, with an initial pH of 7.6 before contacting the biogas. After the purification process, the pH of the water in both columns decreased, with the most significant pH drop observed at the highest water temperature of 38°C, and the least at 18°C. At 38°C, the pH dropped to 6.2, whereas at 18°C, it dropped to 6.4. Additionally, for all temperature variations, the pH in the regeneration unit was consistently higher than in the scrubbing unit.

This pH decrease is primarily due to the absorption of acidic gases like hydrogen sulfide (H_2S) and carbon dioxide (CO_2) from the biogas into the water. When H_2S dissolves in water, it forms weak acids such as hydrosulfuric acid ($H_2S \rightleftharpoons H^+ + HS^-$), and CO_2 forms carbonic acid ($CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO^{3-}$), both of which lower the pH of the water. The greater decrease in pH at higher temperatures (38°C) can be attributed to the increased solubility and reaction rates of these gases at higher temperatures, leading to a higher concentration of acidic species in the water.

The higher pH in the regeneration unit compared to the scrubbing unit can be explained by the degassing of acidic components. In the regeneration unit, absorbed H_2S and CO_2 are released back into the air, thereby increasing the pH of the water as the concentration of acidic species decreases [14]. This aligns with earlier research findings that support these observations which indicate that water used in biogas scrubbing tends to become more acidic due to the absorption of H_2S and CO_2, and that temperature and continuous circulation significantly impact the efficiency of gas absorption and subsequent pH levels [15].

Overall, these results underscore the importance of temperature management and continuous water circulation in optimizing the biogas purification process, not only for H_2S removal but also for maintaining the pH balance in the system, which is crucial for the longevity and effectiveness of the scrubbing solution.

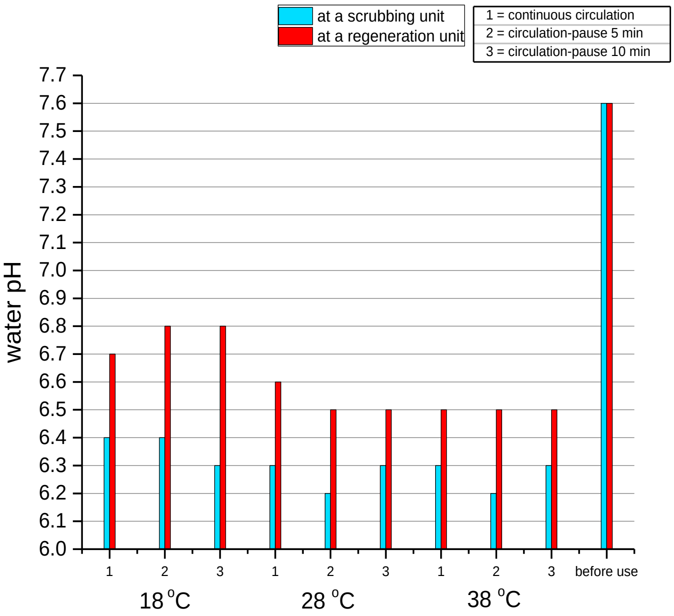

Fig. 3 The pH values of the absorbing water before and after use based on the determined variations.

IV. CONCLUSION

This study demonstrated that the purification of biogas using water in a dual-column system effectively reduces hydrogen sulfide (H_2S) concentrations. The initial H_2S concentration of 255 ppm in raw biogas was significantly reduced to 5 ppm after purification. The most efficient reduction in H_2S was observed at a water temperature of 18°C, while the highest H_2S concentration post-purification was recorded at 38°C. Continuous water circulation was found to be more effective than intermittent circulation methods, particularly at higher temperatures. Furthermore, the study revealed that the water pH decreased due to the absorption of acidic gases such as H_2S and CO_2, with the greatest pH reduction observed at 38°C (from 7.6 to 6.2) and the smallest at 18°C (to 6.4). The pH of the water in the regeneration unit was consistently higher than in the scrubbing unit, likely due to the release of absorbed gases back into the atmosphere. These findings highlight the critical role of temperature and continuous water flow in optimizing the biogas purification process. Lower temperatures enhance the solubility of H_2S in water, thereby improving absorption efficiency. Continuous circulation prevents water saturation with absorbed gases, maintaining higher purification efficiency. This study provides valuable insights for improving biogas purification systems, ensuring cleaner biogas output and more efficient operation.

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