Sustainable Development Proceedings, Volume 1, 2023 doi: 10.5281/zenodo.8398428

The removal of hydrogen sulfide from biogas by water absorption combined with iron oxide (Fe_2O_3)

Jiraporn Paoaiang [1]*, Juntima Chungsiriporn[2] , Prukraya Pongyeela[3], and Nirana Chairerk[4]

[1]Energy Technology Program, Faculty of Engineering, Prince of Songkla University, Hatyai, Songkhla 90110, Thailand
[2,3,4]Department of Chemical Engineering, Faculty of Engineering, Prince of Songkla University, Hat Yai, Songkhla, 90110, Thailand.
*Correspondence: jiraporn.6447@gmail.com

Abstract

The removal of hydrogen sulfide (H_2S) from biogas is necessary due to the H_2S having corrosive properties to ensure safe biogas utilization. Iron oxide (Fe_2O_3) sorbents are extensively studied for H_2S removal due to their easy operation and low operating cost. This study aimed to measure the efficiency of H_2S removal from biogas by the technique of water absorption combined with Fe_2O_3 chemical adsorption. The biogas flow rate of 1 l/min with an H_2S concentration of 3,000–3,200 ppm was monitored for the experimental time of 60 min. The experiments were tested by varying 100–300 ml water absorbent, 10–40 g Fe_2O_3, and combining 100–300 ml water with 25 g Fe_2O_3. It was found that the volume of water and Fe_2O_3 had significant effects on H_2S removal from biogas. The combination of 300 ml of water and 25 g of Fe_2O_3 has shown promising results, with the highest H_2S removal efficiency of 84.8%. This system offered exceptional techniques of absorption combined with chemical adsorption capacity and, therefore, capable of upgrading biogas to biomethane.

Keywords: Biogas, Hydrogen sulfide (H_2S), Iron oxide (Fe_2O_3), Absorption, Adsorption

Peer-review under responsibility of the organizing committee 1st International Conference on ASEAN Sustainable Development (ICASD 2023).

Sustainable Development Proceedings, Volume 1, 2023 doi: 10.5281/zenodo.8398428

1. Introduction

Biogas produced by anaerobic digestion is a clean and environmentally friendly alternative to fossil fuels. It contains about 55–65% methane (CH_4) and other constituents, including 30–40% carbon dioxide (CO_2), fractions of water vapor, and trace amounts of hydrogen sulfide (H_2S) [1]. Biogas production helps in waste management by utilizing organic waste, reducing greenhouse gas emissions, and promoting sustainable energy practices. H_2S in biogas, typically ranging from 1,000 to 30,000 ppm, occurred during the microbial breakdown of organic matter, making it a relevant consideration for biogas utilization [2, 3, 4]. H_2S is highly undesirable in energy transformation because it can be reverted into highly corrosive and environmentally hazardous sulfur dioxide (SO_2) and sulfuric acid (H_2SO_4). Hydrogen sulfide removal is essential for any eventual utilization of biogas [5, 6, 7]. Fe_2O_3 was used for biogas purification in packed column reactors and had H_2S removal efficiency. It is typically used with other H_2S removal techniques to achieve optimal results and ensure the overall quality of the biogas [8]. Water absorption has been generally used to remove H_2S [9]. To improve the H_2S removal efficiency, water absorption combined with Fe_2O_3 is another choice as a straightforward, practical, low-cost method that solves problems for the end users of biogas technology. This research studied the H2S removal from biogas by water absorption combined with Fe2O3 chemical adsorption in a packed column system. The quantities of water absorbent and Fe_2O_3 added in the column were determined for H_2S removal efficiency.

2. Materials and methods

2.1 Biogas

The study was carried out at an agricultural farm in Hatyai, Songkla, Thailand, using biogas from a fermentation dome with a capacity of 750 l/day. Biogas from pig manure and food waste were fermented in the dome digester at 35°C for 20 days of hydraulic retention time (HRT). Biogas 1 m^3/day, containing hydrogen sulfide (H_2S) around 3,200 ppm, was analyzed using the Determination of H_2S Content of Fuel Gas Streams in Petroleum Refineries method [10].

2.2 Adsorbent Preparation

Iron oxide (Fe_2O_3) SCM440 type from industrial lathe waste, with a size of 0.3–0.5 cm and a length of 5–10 cm, was utilized as an adsorbent in the H_2S adsorption system. Firstly, the Fe_2O_3 was treated by immersing it in deionized water at a ratio of 2:1 (water to adsorbent) at ambient temperature for 8 hours. Then, the treated Fe_2O_3 was left to sundry under ambient temperature for 7 days to react iron with oxygen and water to form iron (III) oxide (Fe_2O_3), known as hematite.

2.3 H_2S removal system

In this experiment, H_2S removal from biogas was achieved by using the packed column. Fig. 1. shows a schematic diagram of the H_2S removal system, which mainly consisted of an acrylic column with a diameter of 5.6 cm and a height of 30 cm. The bottom of the column was filled with 100–300 ml of water and 10–50 g of treated Fe_2O_3 adsorbent. Inside the column was a small pipeline for feeding biogas from top to bottom, and a pipe tip had immerged to bubble in the water reservoir. The biogas continuously flowed up, passed through the Fe_2O_3, and exited at the top of the column. Rotameters were equipped to measure the volumetric flow rate of inlet and outlet biogases.

Peer-review under responsibility of the organizing committee 1st International Conference on ASEAN Sustainable Development (ICASD 2023).

Sustainable Development Proceedings, Volume 1, 2023 doi: 10.5281/zenodo.8398428

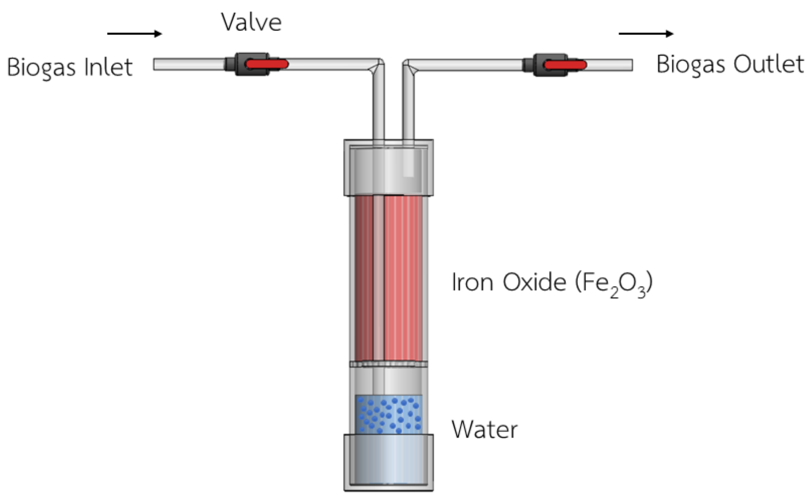

Fig.1 H_2S adsorption system

Experiments were conducted to find the efficiency of H_2S removal from biogas using a packed column as calculated by Eq. (1). The biogas was constantly controlled at one l/min and measured for inlet and outlet H_2S concentration every 20 min during the experimental time for 60 min. An inlet H_2S concentration in the produced biogas was maintained at 3,000–3,200 ppm. The Determination of H2S Content of Fuel Gas Streams in Petroleum Refineries method analyzed the H2S concentrations. The H_2S concentration was measured by an air sampling pump and a series of impingers containing a solution of cadmium sulfate ($CdSO_4$) by iodometric method [11].

$$H_2S \text{ removal efficiency} = \frac{H_2S_{inlet} - H_2S_{outlet}}{H_2S_{inlet}} \times 100 \quad (1)$$

where H_2S_{inlet} and H_2S_{outlet} is inlet and outlet H_2S concentration, respectively.

3. Results and Discussion

3.1 Results of H_2S removal from biogas

The experiments of H_2S removal from biogas were performed by using water absorption, Fe_2O_3 chemical adsorption, and combining water absorption with Fe_2O_3 adsorption in a packed column system. The biogas flow rate was kept at a constant 1 l/min for all the experiments. The result of these experiments can be shown in Fig. 2. Using 300 ml water absorbent got very low H_2S removal efficiency by decreasing from 48.4 to 21.3% with time. Also, for the use of 25 g of Fe_2O_3, the efficiency decreased from 87.6 to 52.7%. The highest H_2S removal efficiency of 92.9% was achieved using Fe_2O_3 at 25 g combined with water at 300 ml and decreased to 76.9% after 60 min.

Peer-review under responsibility of the organizing committee 1st International Conference on ASEAN Sustainable Development (ICASD 2023).

 doi: 10.5281/zenodo.8398428

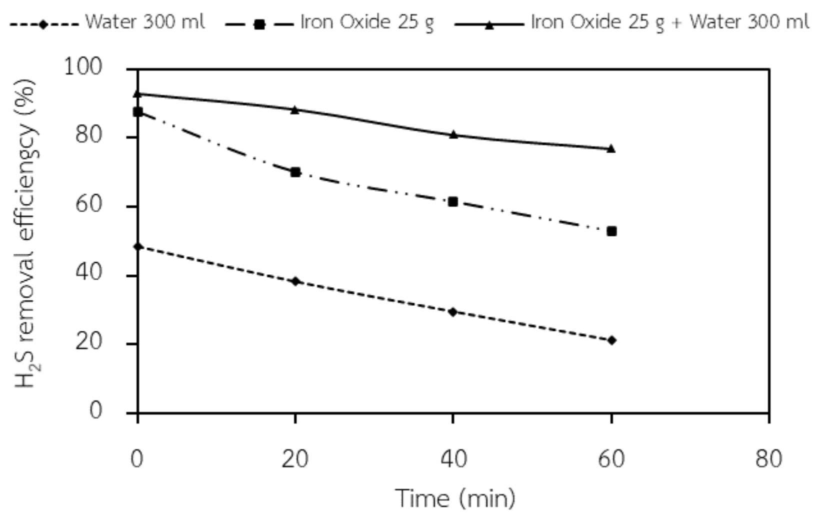

Fig.2 Effect of comparison of the H_2S removal efficiency by water absorbent, Fe_2O_3, and combining water with Fe_2O_3

3.2 Water absorption for H_2S removal from biogas

To show the result of H_2S removal from biogas by absorption, water quantity of 100, 150, 200, 250, and 300 mL was added to the column, and bubbling 1 l/min biogas into the water. It was found that H_2S removal efficiency slightly increases with increasing water volume, as presented in Fig. 3. The highest removal efficiency of 34.4% was obtained with 300 ml of water. These results were consistent with the study reported by Horikawa et al., [9] in which the removal of H_2S in distilled water was about 20% for a biogas flow rate of 1 l/min.

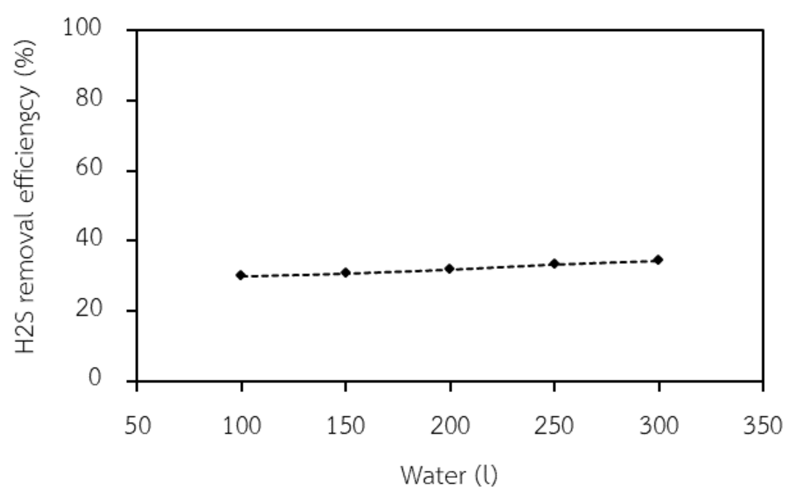

Fig.3 Effect of water quantity on H_2S removal from biogas

Sustainable Development Proceedings, Volume 1, 2023 doi: 10.5281/zenodo.8398428

3.3 Iron oxide (Fe_2O_3) adsorption for H_2S removal from biogas

The results of H_2S removal by Fe_2O_3 adsorbent were investigated in the adsorption column, as shown in Fig. 4. The experimental tests were all carried out using a biogas flow rate of 1 l/min for 60 min. H_2S removal efficiency from 49.4% to 76.9% by Fe_2O_3, increasing the quantity of Fe_2O_3 adsorbent. These suggested that using Fe_2O_3 had higher H_2S removal efficiency than using the water-absorbent technique and confirmed a decrease in H2S outlet concentration by Fe2O3 increasing, as reported by David Marín et al. [12].

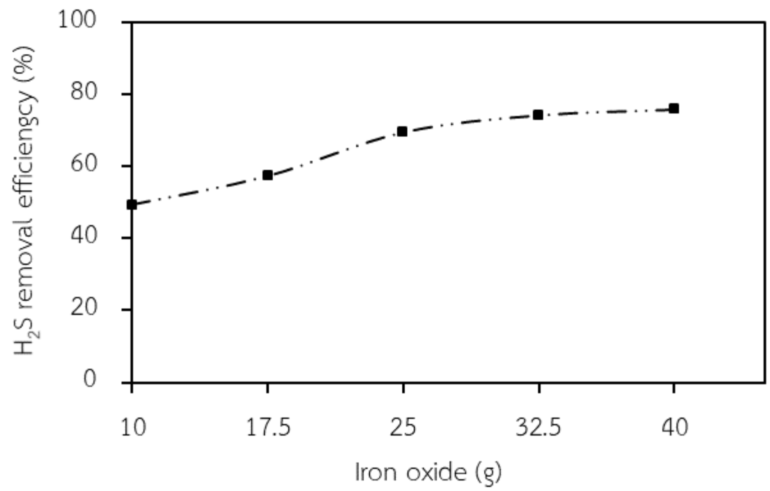

Fig.4 Effect of iron oxide quantity on H_2S removal from biogas

3.4 Water and iron oxide combined for H_2S removal

The H_2S removal by combining water absorption and Fe_2O_3 adsorption was conducted at 25 g Fe_2O_3 with varying water of 100, 150, 200, 250, and 300 ml. The biogas flow rate was kept at a constant 1 l/min for all the experiments. The highest H_2S removal efficiency of 84.8% was obtained at Fe_2O_3 25 g and water of 300 ml. Then, the combining technique was more effectively performed for H_2S removal than adsorption or absorption alone. According to Sisani et al. [13], this system was capable of upgrading biogas to biomethane.

 doi: 10.5281/zenodo.8398428

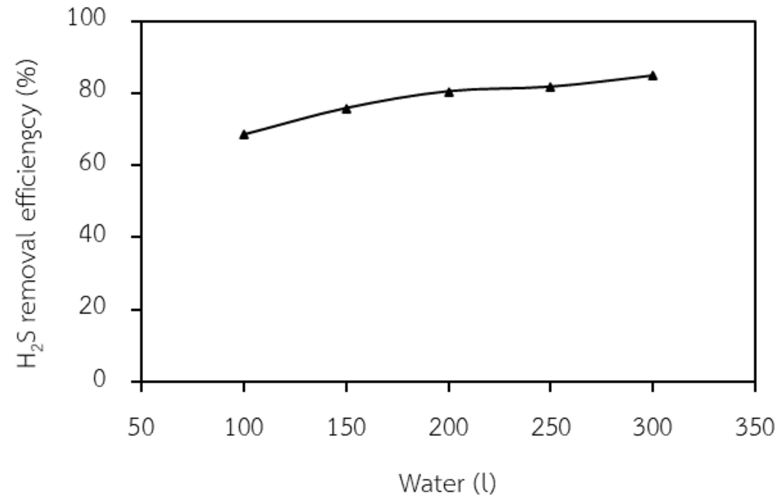

Fig.5 Effect of water and iron oxide quantity on H_2S removal from biogas

4. Conclusions

This work demonstrated the removal of H_2S for biogas upgrading by combining the techniques of water absorption and Fe_2O_3 adsorption. The highest H_2S removal efficiency of 85% was achieved by applying 25 g Fe_2O_3 and 300 ml water in a packed column with a biogas flow rate of 1 l/min. The discovery revealed that increasing the water content and Fe_2O_3 in the absorption system enhanced H_2S absorption. The method proposed here for upgrading biogas has promised a technique to maximize energy efficiency and reduce environmental impact and cost.

Acknowledgment

The authors are grateful for the support of the Department of Chemical Engineering, Faculty of Engineering, Prince of Songkla University. The authors also thank the Interdisciplinary Graduate School of Energy System (IGS-Energy) for the financial support.

References

[1] Appels, Lise., Baeyens, J., Degre`ve, J., & Dewil, R. (2008). Principles and potential of the anaerobic digestion of waste-activated sludge. Progress in Energy and Combustion Science, 34, 755–781. https://doi.org/10.1016/j.pecs.2008.06.002

[2] Scholz, M., Frank, B., & Stockmeier, F., Fal, S., & Wessling, M. (2013). Techno-economic analysis of hybrid processes for biogas upgrading, Industrial & Engineering Chemistry Research, 52, 16929–16938. https://dx.doi.org/10.1021/ie402660s

[3] Hong, N., Hao, J., & Chong, D. (2013). Comparison of water scrubbing and propylene carbonate absorption for biogas upgrading process, Energy Fuels, 27, 3239–3245. https://doi.org/10.1021/ef400233w

[4] Nishimura, S., & Yoda, M. (1997). Removal of hydrogen sulfide from an anaerobic biogas using a bio-scrubber, Water Science and Technology, 36, 349–356. https://doi.org/10.2166/wst.1997.0610

[5] Frare, L.M., Vieira, M.G.A., & Silva, M.G.C. (2010). Hydrogen sulfide removal from biogas using Fe/EDTA solution: Gas/liquid contacting and sulfur formation, Environmental Progress & Sustainable Energy, 29(1), 34–41. https://doi.org/10.1002/ep.10374

[6] Kapdi, S.S., Vijay, V.K., Rajesh, S.K., &, Prasad, R. (2005), Biogas scrubbing, compression and storage: perspective and prospectus in Indian context, Renewable Energy, 30(8), 1195–1202. https://doi.org/10.1016/j.renene.2004.09.012

[7] Barzagli, F., Lai, S., Mani, & F.Novel. (2014). Novel non-aqueous amine solvents for biogas upgrading, Energy and Fuels, 28, 5252–5258. https://doi.org/10.1021/ef501170d

[8] Kulkarni, M.B., & Ghanegaonkar, P.M. (2019). Hydrogen sulfide removal from biogas using chemical absorption technique in packed column reactors. Global Journal of Environmental Science and Management, 5(1), 155-166. https://doi.org/10.22034/gjesm.2019.02.02

[9] Horikawa, M., Rossi, F., Gimenes, M., Costa, M., & Silva, M. (2004). Chemical absorption of H2S for biogas purification. Brazilian Journal of Chemical Engineering, 21(3), 415–422. https://doi.org/10.1590/S0104-66322004000300006

[10] Environmental Protection Agency (EPA) Method 11. (2017). Determination of Hydrogen Sulfide Content of Fuel Gas Streams in Petroleum Refineries, Code of Federal Regulations (CFR) 40, Part 60-Standards of Performance for new Stationary Sources, Appendix A- Test Methods, 788-815.

[11] Rakmak, N., Wiyaratn, W., & Chungsiriporn, J. (2010). Removal of H2S from biogas by iron (Fe3+) doped MgO on ceramic honeycomb catalyst using double packed columns system. Engineering Journal, 14, 15–24. https://doi.org/10.4186/ej.2010.14.1.15

[12] Marin, D., Vega, M., Lebrero, R., & Munoza, R. (2020). Optimization of a chemical scrubbing process based on a Fe-EDTA-carbonate based solvent for the simultaneous removal of CO2 and H2S from biogas. Journal of Water Process Engineering, 37, 101476. https://doi.org/10.1016/j.jwpe.2020.101476

[13] Sisani, E., Cinti, G., Discepoli, G., Penchini, D., Desideri, U., & Marmottini F. (2014). Adsorptive removal of H_2S in biogas conditions for high temperature fuel cell systems. International journal of hydrogen energy, 39(36), 21753-21766. http://doi.org/10.1016/j.ijhydene.2014.07.173