Utilization of steel wool as removal media of hydrogen sulfide in biogas

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Abstract. In order to utilize biogas, hydrogen sulfide/H\textsubscript{2}S impurities reduction is needed to maximize methane/CH\textsubscript{4} content. Although H\textsubscript{2}S amount is relatively non-dominant, its presence can trigger corrosion, and is harmful to health and environment. Steel wool can be used as adsorption media to reduce H\textsubscript{2}S content. This study was conducted to identify the characteristics of steel wool and H\textsubscript{2}S concentration reduction efficiency. Biogas was flown to a PVC column (2 inches diameter) containing steel wool. The results showed that steel wool media contain active elements of Fe and Zn which are spread evenly on the media surface with a total amount of 97.5\% mass. The concentration of H\textsubscript{2}S at inflow ranged from 68 to 111 ppm with the outflow of 21.2-0 ppm, and the temperature in the system varied between 29-33 °C. Optimal H\textsubscript{2}S removal efficiency reaches 97\% in average, obtained at 100 cm column height and flow rate of 0.1 L/min. It can be concluded that the steel wool media has high content of active element and can reduce H\textsubscript{2}S content in biogas at ambient temperature condition.

1. Introduction
As a form of coping with energy and solid waste problems in Indonesia, Anaerobic Digestion (AD) has been developed and implemented widely. When the AD process takes place, the formation of energy in the form of biogas occurs through three stages, namely hydrolysis, acidogenesis, acetogenesis, and methanogenesis [1]. The biogas content is not only CH\textsubscript{4} but also contains CO\textsubscript{2}, H\textsubscript{2}O, and H\textsubscript{2}S. Although the composition of hydrogen sulfide in biogas is relatively non-dominant, its presence can trigger corrosion. Burning biogas containing hydrogen sulfide will also emit sulfuric acid during its combustion process, and most importantly hydrogen sulfide is highly toxic and can pose serious health risks [2]. Thus, it is necessary to process the purification of biogas produced so that the corrosion and health risks decreased, so it can be utilized better.

There are various purification processes that can be done to remove impurities, such as water scrubbing system, chemical absorption, pressure swing adsorption (PSA), membrane, biofilter, and cryogenic separation [3]. In particular, the process of removing H\textsubscript{2}S gas from biogas is very important before the installation of upgrading such as PSA. Various methods of removing H\textsubscript{2}S include adsorption, absorption, membrane separation, biological processes, and claus process [2] [4] [5] [6]. One of the various methods available which has long been used is in the form of chemical adsorption using iron oxide [6] [7] [8].
The chemical reactions occurring in the process of iron oxide reducing hydrogen sulfide content are expressed in Equations (1) and (2) below [6].

\[
\begin{align*}
\text{Fe}_2\text{O}_3 + 3 \text{H}_2\text{S} & \rightarrow \text{Fe}_2\text{S}_3 + 3 \text{H}_2\text{O} \quad (1) \\
\text{Fe}_2\text{S}_3 + \frac{3}{2} \text{O}_2 & \rightarrow \text{Fe}_2\text{O}_3 + 3 \text{S} \quad (2)
\end{align*}
\]

Therefore, this research uses iron oxide media in the column for the removal of H₂S from biogas. Iron oxide comes in various shapes/types and in this study used steel wool or iron sponge (iron fiber) that exist in everyday life as a form of iron oxide. This study identifies the characteristics of the steel wool that never been conducted before and its efficiency to reduce H₂S concentrations.

2. Methodology

The dependent variable of the research is the hydrogen sulfide concentration measured before and after biogas through the adsorption column which will be obtained the efficiency value of the removal. In this study, the biogas flows through the columns at ambient/room temperature. The first independent variable that the authors used in the study were the adsorption column height (50 cm, 75 cm, and 100 cm) with medium density to the adsorption column and the controlled flow rate was approximately 0.0943 g/cm³ and 0.5 L/minute, respectively. Furthermore, after the optimum column height is obtained, the experiment is continued to optimize flow rate (1.5 L/min, 1.0 L/min, 0.5 L/min and 0.1 L/min) to be tested at density and columns height that are controlled equally. The method used in the measurement of H₂S gas in this study is by using SNI Method 19-7117.7-2005. In addition, this study also conducted characterization tests on adsorption media before and after use (media sample from optimum condition). Characterization test using SEM-EDS test methods. The series of research equipment is illustrated in figure 1.

![Series of adsorption columns](image)

**Figure 1.** Series of adsorption columns.

3. Result and Discussion

The result of the experiment of column height variation can be seen in figure 2.

![Graph of H₂S Concentration](image)

**Figure 2.** The result of the experiment of column height variation.
Based on the data obtained that as the height increases, efficiency of media/columns in reducing the concentration of H$_2$S gas is relatively bigger. As shown in figure 2, the average removal efficiency of H$_2$S at 50 cm column height reaches 88±6%, then reaches 94±2% at a height of 75 cm and becomes 95±9% at height of 100 cm.

However, ANOVA test results show the significance of 0.202 whose value is greater than 0.05 indicating that the column height variations applied in the study of H$_2$S removal efficiency have no significant impact on H2S adsorption. Nevertheless, the height of 100 cm is applied in the next experiment of flow rate variation because 100% removal efficiency was observed. In addition, this is also based on the value of H$_2$S gas concentrations at outlets that have been below 10 ppm so as to be designated as stove fuel, even at this 100 cm height can reach natural gas standards under 4 ppm [5].

![Figure 3](image3.png)

**Figure 3.** Relation of H$_2$S Concentration (inlet and outlet) to Time at Flow Rate 0.1 L / min; 0.5 L / min; 1 L / min; and 1.5 L / min.

The second set of experiment demonstrates that as the flow rate increases, the efficiency of media/columns in reducing the concentration of H$_2$S gas are relatively inversely proportional to the decrease in H$_2$S decreases with increasing flow rate. The average removal efficiency of H$_2$S at a flow rate of 0.1 L/min reached 97±5%, then reached 95±9% at a flow rate of 0.5 L/min, 94±2% at a flow rate of 1 L/min and became of 93±3% at a flow rate of 1.5 L/min.

ANOVA test of 0.662 (greater than 0.05) demonstrated that the variation of the flow rate applied to the study on H$_2$S removal efficiency has no significant difference. This is different compared to [9], that showed that the smallest flow rate variation resulted in the smallest impurity content (in research in the form of CO$_2$) in biogas due to biogas having longer contact time with the adsorption media. Although compared with [10], optimum removal of H$_2$S at 3.5 L/min flow rate (variations used 2.5, 3.5 and 5 L/min). Then when compared with [11], there is also a correspondence that the lower the flow rate the greater the H$_2$S is absorbed although only seen the effect of very small results.

![Figure 4](image4.png)

**Figure 4.** SEM Test Result of Media Before Used with Magnification (a) 100x; (b) 500x; and (c) 1000x.
Figure 4 shows the active area in the adsorption process located on the surface of the medium with a size of about 0.3 mm along the fiber of the adsorption medium. The surface of the media also looks relatively rough, uneven, and has a hollow pore as seen at 1000x magnification, with the illumination of a bright pattern indicating a higher elevation position than the dark one.

EDS media test results showed a large amount of iron (Fe) and Zinc (Zn) elements, respectively reaching 75.49% mass and 22.04% mass. These Fe and Zn elements are the principal active metal elements which can react with H₂S in biogas so that the amount is reduced. The distribution of these elements is even on the surface of the media as shown in figure 5. This illustrates that almost the entire surface of the media is comprised of active element.

![Figure 5](image)

**Figure 5.** Active elements distribution on surface media: (a) Steel Wool; (b) Sulfatreat 410-HP®.

The relatively uniform distribution makes the steel wool media a potentially no lesser medium in the H₂S gas adsorption process when compared to existing commercial media such as Sulfatreat 410-HP® with the distribution of Fe elements as illustrated. With a thorough dissemination on the surface of the media, it illustrates that almost the entire surface of the media is enveloped by an active element.

From the test result, the amount of iron oxide reach 56%, theoretically (stoichiometry), of steel wool media can absorb H₂S with the amount equal to 64% of Fe₂O₃ available. However, there is 0.02% Pb as activator. Activators are elemental ingredients such as Platine, Gold, Silver, Copper, Cadmium, Nickel, Tanker, Mercury, Zinc and Cobalt with amounts of 0.125%-5% on commercial media such as Sulfatreat 410-HP® [4]. So, steel wool media contain fewer activators than the commercial media.

After the process of adsorption, the media used for the process is also tested analysis of SEM-EDS characteristics. Figure 6 is the result of SEM-EDS analysis of the media after the adsorption process. Based on the result of figure 6 there is a defect on the surface of the steel wool media after being used as an adsorption medium. The bright gradient of the image shows the elevation position of the higher surface than the dark portion, indicating the adsorbed material when compared to the medium before it is used with relatively homogeneous or uniform morphological adsorption.

Based on the test sample it is clear that there is a decrease of iron oxide compound which shows that there has been a reaction between H₂S and the compound so that its content in biogas decreases. This suggests that the Fe₂O₃ content decreases from 56.01% to 23.03%, obtained after flowing about 6 L of biogas through the column. This indicates that about 33% of Fe₂O₃ reacts with H₂S gas at the certain point of sample. The remaining Fe₂O₃ content in the media illustrates that the media still have the capacity to reduce H₂S gas further.
4. Conclusions
The active content in this steel wool (Fe and Zn) reaches a total of 97.5% mass with a uniform Fe distribution across the surface and a uniform Zn spread but there are some surfaces that do not contain Zn. The maximum removal efficiency of H$_2$S gas in Biogas reaches 100% (95% average) obtained at a height of 100 cm. Then 100% H$_2$S removal efficiency was also obtained at flow rate of 0.1 L/min with 100 cm column height (mean removal efficiency of H$_2$S was 97%).

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