

Analysis of Zig-Zag Gas Inlet Design Effectiveness to The Reduction of CO₂ and H₂S Gas at Purifier Equipment using Four Absorber Types

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Abstract. Design of inlet gas in purifier equipment was affected on the reduction of CO₂ and H₂S. This study has been conducted on the analysis of the effect of zig-zag gas inlet design on the level of CO₂ and H₂S gas reduction in purifier using 4 types of absorber. Ferrioxide, iron gram, limestone (CaO), and natural zeolite were used as absorber material. The objective of this research is to determine which the most effective type of absorber in reducing CO₂ and H₂S gas and create an economical and useful purifier equipment for society. The results was found that the natural zeolite absorber was an effective absorber in reducing CO₂ gas, CO₂ content before purification was 40.98 % and after purification was 25.80 %, decreasing of CO₂ was 15.18 %. Meanwhile, ferrioxide absorber, iron gram and CaO was not effective in reducing CO₂. Ferrioxide was found to be effective absorber in reducing H₂S, average decreasing was 16.95 ppm. Average decreasing of H₂S in natural zeolite and iron gram absorber were 2.13 ppm and 0.16 ppm, respectively. CaO was found to be ineffective absorber for H₂S due to increasing in H₂S levels after purification.

Keywords: Biogas, CO₂, H₂S, Purifier, Absorber.

INTRODUCTION

Human dependence on fossil fuels not only influence the decreasing of unrenewable energy but also the environment, such as air pollution. It cause people realize that dependence on fossil fuels should be reduced immediatly. Alternative fuel, which is cheap and easy to obtain, is required to solved this problem. Biogas is one of promising alternative fuel that can be used. Biogas is produced through the process of fermentation of organic waste such as garbage, food scraps, animal waste and industrial food waste. Biogas contain methane (CH₄), carbon dioxide (CO₂) gas, oxygen (O₂), hydrogen sulfide (H₂S), hydrogen (H₂) and carbon monoxide (CO). CH₄ and CO₂ are the component that determine the quality of biogas. Biogas have high heating value due to high level of CH₄. Meanwhile, high levels of CO₂ will result in low calorific value of biogas. Therefore, to increase the calorific value of biogas, CO₂ should be decreased. The content of CH₄ from biogas can be increased by separating CO₂ and H₂S which is corrosive from biogas

(Hamidi, Wardana, & Widhiyanuriyawan, 2011). In the combustion process, gases other than methane (CH₄) will decrease the biogas heat value and combustion efficiency. Maximazing the percentage of CH₄ to get a greater calorific value from biogas by reducing other gas, especially CO₂ due its content is the greatest after CH₄ (Sugiarto, Oerbandono, Widhiyanuriyawan, & Putra, 2013). The previous study has been done to solve the problem, several methods of absorbent variation were used to purify gas, they were natural zeolite, iron gram, CaO and peroxide. Absorbent is a substance that can absorb fluid, both liquid and gas so that it will form a thin layer on the surface of the substance. Zeolite, iron gram, CaO and peroxide were chosen due to easy to obtain and the price is also quite cheap. Activation process should be done before zeolite is used to accelerating zeolite adsorption process. The

activation process can be done in two ways, ie physically with heat treatment process and chemically by using acid or base solution. One type of chemical substances that can be used for the process of chemical activation is potassium hydroxide (KOH). KOH is one of the strongest stable and water-soluble base compounds that can be used as a zeolite activator (Hamidi et al., 2011).

MATERIALS AND METHODS

Experimental Methods

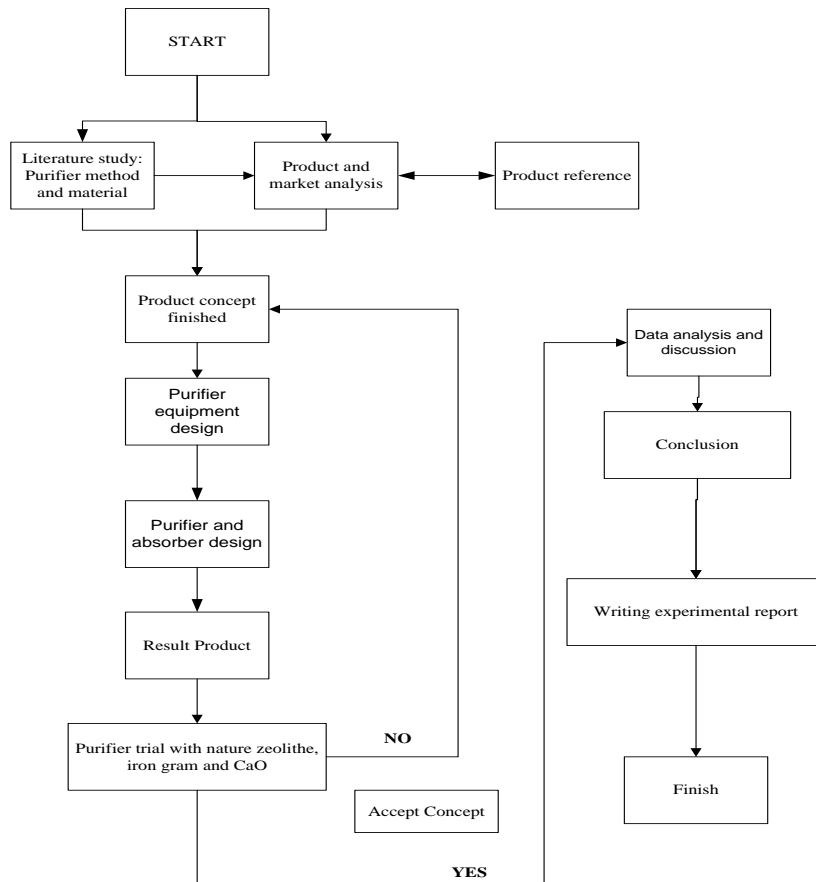


FIGURE 1. Experiment Flow Diagram

Literature study and Product Analysis in Marketplace

Learn and seek information as much as possible from books, journals, internet and consult with people who have understood about the purification system in biogas to get information and reference. In addition to literature studies, product analysis that already exist in the market is also very important as a comparison to conduct research that will be done.

Product Concept

Based on literature study and product analysis that has been done, reference products for experiment was obtained. Based on this reference, the concept of both the dimensions and the effectiveness of the product will be produced later.

Calculation of Zig –Zag Flow Purifier Equipment

Data is given below :

$$3 \text{ inch} = 38 \text{ cm}$$

$$4 \text{ inch} = ?$$

$$5 \text{ inch} = 17 \text{ cm}$$

$$4-3 / 5-4 = x-38 / 17-x \rightarrow x = 27.5 \text{ cm}$$

Determining of gas pipe size :

$$27.5 \text{ cm} - 4 \text{ cm} = 23.5 \text{ cm}$$

Overall volume of absorber column :

$$\pi \times 5.05 \times 5.05 \times 27.5 = 2202.1 \text{ cm}^3$$

Volume of inside gas pipe:

$$\pi \times 0.5 \times 0.5 \times 23.5 = 18.45 \text{ cm}^3 \rightarrow \pi \times 0.5 \times 0.5 \times (4 + 4 + 4 + 2 + 2) = 15.7 \text{ cm}^3$$

Volume loss:

$$18.45 + 15.7 = 34.15 \text{ cm}^3$$

Differences of loss volume to pipe cross sectional area:

$$34.15 / \pi \times 5.05 \times 5.05 = 0.426 \approx 0.4$$

Total of increasing gas pipe :

$$0.4 : 3 = 0.13 \text{ cm}$$

Overall absorber tube length :

$$23.9 \text{ cm} + 4 \text{ cm} = 27.9 \text{ cm}$$

1 kg of absorber material can be filled at length of 27.9 cm absorber tube.

Equipment Design

The next step after product concept was the design of purifier equipment. This step was to determine the material for making the effective and economical equipment and prepared all component to produce the equipment.

Absorber and Purifier Equipment Design

After all the needs and materials were prepared then the next step was to make the equipment and design. The purpose of this step was to determine the appropriate layout for gas inlet and absorber material, so the purifier equipment run in accordance with its function.

Trial of Absorber and Purifier Equipment

In the experimental stage of this device, the purifier was filled with 4 types of absorber ie ferrioxide, iron gram, CaO and natural zeolite in different purifier and reactor with 6 m³ digester capacity. Trial was done for 8 days with data collecting as much as 4 samples every 2 days. Meanwhile, the pure sample was collected on day-0 before the purifier equipment installed. All samples were tested at LPPM-ITS Energy Laboratory.

The Step of Biogas Sample Analysis:

1. Pure biogas sampling was done before the purifier installed by using the air ball at 4 reactors which have been determined for testing at Energy Laboratory - LPPM ITS and in Environmental Laboratory - LPPM ITS.
2. After 4 purifier equipment installed on every home, then 2 sample was collected in every house using air ball, where sample was taken as much as 4 times in about 8 days.
3. Collecting 2 samples in each house was done 2 days after the purifier installed for the first sample, on the 4th day for the second sample, on the 5th day for the third sample and on the 8th day for the fourth sample.
4. CO₂ gas levels was analyzed in the energy laboratory using Gas Chromatography (GC). The gas inside the air ball was taken by using the injector then injected into the GC column.

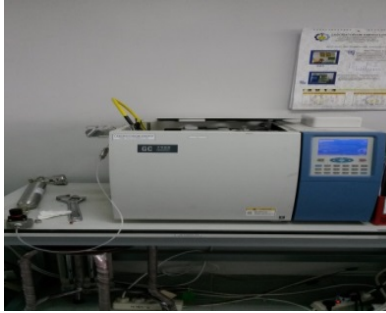


FIGURE 2. Gas Chromatography

5. H₂S gas levels was analyzed in the environment laboratory using PID Detector. It has gas output located on the air ball directly in connect with the inject hose on the equipment.



FIGURE 3. PID Detector

Design of Zig-Zag Flow Equipment



FIGURE 4. Zig-Zag Flow Equipment Design

This equipment is a combination of previous tool design, where in the gas cylinder there is a ½ inch pipe designed in the form of zig-zag shaped. The function of zig-zag pipe inside the tube is to drain the gas from the input to be distributed to the absorber in the tube. Production costs of Purifier equipment is described in Table 1:

TABLE 1. Production cost of Purifier Equipment

No	Materials	Production cost (IDR)
1	Outside Sock Drat 4"	15.000
2	Pipe connector 2"- ½ "	10.000
3	Paralon Header 4"-2"	15.000
4	Paralon 4"	7.500
5	Elbow Clear (8 Pieces)	10.000
6	Pipe cover ½ "	1.000
7	Clear Pipe	8.000/2 m
8	Paralon Pipe 2"	25.000
9	Cop Nipple ½ " (2 Pieces)	10.000
10	Inside Sock Drat ½ " (2 Pieces)	10.000
TOTAL PRODUCTION COST		± 112.000

Testing Procedure

Testing procedure of purifier through two stages, the first stage was the assembly stage of the purifier equipment and the second stage was the testing phase of biogas sample on the purifier.

RESULTS AND DISCUSSION

Data Analysis

Head Losses

Determining the value of gas discharge on the stove (m³/s)

$$K = \sqrt{\rho \left(1 - \frac{A_2}{A_1}\right)} \quad (1)$$

$$K = \sqrt{0.8 \text{ Kg/m}^3 \left(1 - \frac{2 \text{ mm}}{5 \text{ mm}}\right)}$$

$$K = 1.118$$

$$V = A \times K \sqrt{2x\Delta P} \quad (2)$$

Where : V : Gas Volume Discharge (m³/s)

A : Cross Sectional Area (m²)

ΔP : Pressure Differences (Pa)

K : Constants

$$V = A \times K \sqrt{2x\Delta P}$$

$$V = 3.14 \times 10^{-6} \times 1.118 \sqrt{2,6335.21 \text{ Pa} - 5756.03 \text{ Pa}}$$

$$V = 0.0001194 \text{ m}^3/\text{s} \text{ (Stove Gas Discharge)}$$

It was assumed that the gas debit inside the gas pipe was the same as the gas discharge was fed.

Determining the velocity value (v):

$$v = \frac{V}{A} \quad (3)$$

Where : v : Gas Velocity (m/s)
 V : Gas Volume Discharge (m³/s)
 A : Cross Sectional Area (m²)

$$v = \frac{0.0001194 \text{ m}^3/\text{s}}{3.14 \times (0.5 \times 0.01)^2} \rightarrow v = 1.52 \text{ m/s}$$

Determining the loss major value at Insulted Purifier Equipment Design

$$H_{I \text{ major}} = f \frac{L}{D} \times \frac{V^2}{2g} \quad (4)$$

Where : $H_{I \text{ major}}$: Head Loss
 f : Friction Factor
 L : Gas Pipe Length (m)
 V : Gas Velocity in Pipe (m/s)
 D : Pipe Inside Diameter (m)
 g : Gravitation (m/s²)

Determining the value of friction factor (f):

$$f = \frac{2xhxDxg}{LxV^2} \quad (5)$$

$$f = \frac{2 \times 0.315 \text{ m} \times 0.1 \text{ m} \times 10 \text{ m/s}}{0.315 \text{ m} \times 1.52^2 \text{ m/s}} \rightarrow f = 0.863$$

Major head loss value at Purifier:

$$H_{I \text{ major}} = f \frac{L}{D} \times \frac{V^2}{2g} \quad (6)$$

$$H_{I \text{ major}} = 0.863 \times \frac{0.315 \text{ m}}{0.1 \text{ m}} \times \frac{1.52^2 \text{ m/s}}{2 \times 10 \text{ m/s}^2} \rightarrow H_{I \text{ major}} = 0.313$$

Minor head loss at Purifier:

$$H_{I \text{ minor}} = K \frac{v^2}{2g} \quad (7)$$

$$H_{I \text{ minor}} = 0.04 \times \frac{1.52^2 \text{ m/s}}{2 \times 10 \text{ m/s}} \rightarrow H_{I \text{ minor}} = 0.0046$$

Determining the major head loss value at insulated zig zag equipment design, according to equation (4).

$$H_{I \text{ major}} = f \frac{L}{D} \times \frac{V^2}{2g} \quad (8)$$

Determining friction factor value (f) using equation (3):

$$f = \frac{2xhxDxg}{LxV^2} \quad (9)$$

$$f = \frac{2 \times 0.315 \text{ m} \times 0.1 \text{ m} \times 10 \text{ m/s}}{0.53 \text{ m} \times 1.52^2 \text{ m/s}} \rightarrow f = 0.516$$

Major loss value at purifier equipment:

$$H_{I \text{ major}} = f \frac{L}{D} \times \frac{V^2}{2g} \quad (10)$$

$$H_{I \text{ major}} = 0.516 \times \frac{0.53 \text{ m}}{0.1 \text{ m}} \times \frac{1.52^2 \text{ m/s}}{2 \times 10 \text{ m/s}^2} \rightarrow H_{I \text{ major}} = 0.328$$

Minor head loss value at purifier equipment:

$$H_{l \text{ minor}} = K_L \frac{v^2}{2g} \quad (11)$$

$$H_{l \text{ minor}} = (1.5 \times 4) \frac{1.52^2 \text{ m/s}}{2 \times 10 \text{ m/s}} \rightarrow H_{l \text{ minor}} = 0.72$$

Determining major head loss at nestle wire gas equipment design according to equation (4).

$$H_{l \text{ major}} = f \frac{L}{D} \cdot \frac{V^2}{2g} \quad (12)$$

Determining friction factor value (f) using equation (3):

$$f = \frac{2xhxDxg}{LxV^2} \quad (13)$$

$$f = \frac{2 \times 0.315 \text{ m} \times 0.01 \text{ m} \times 10 \text{ m/s}}{0.57 \text{ m} \times 1.52^2 \text{ m/s}} \rightarrow f = 0.058$$

Major head loss at purifier equipment:

$$H_{l \text{ major}} = f \frac{L}{D} \times \frac{V^2}{2g} \quad (14)$$

$$H_{l \text{ major}} = 0.058 \times \frac{0.57 \text{ m}}{0.01 \text{ m}} \times \frac{1.52^2 \text{ m/s}}{2 \times 10 \text{ m/s}^2} \rightarrow H_{l \text{ major}} = 0.40$$

Minor head loss value at purifier equipment:

$$H_{l \text{ minor}} = K \frac{v^2}{2g} \quad (15)$$

$$H_{l \text{ minor}} = 1.5 \times \frac{1.52^2 \text{ m/s}}{2 \times 10 \text{ m/s}} \rightarrow H_{l \text{ minor}} = 0.18$$

Determining major head loss at zig zag flow gas equipment design according to equation (4).

$$H_{l \text{ major}} = f \frac{L}{D} \times \frac{V^2}{2g} \quad (16)$$

Determining friction factor value (f) using equation (3):

$$f = \frac{2xhxDxg}{LxV^2} \quad (17)$$

$$f = \frac{2 \times 0.279 \text{ m} \times 0.01 \text{ m} \times 10 \text{ m/s}}{0.439 \text{ m} \times 1.52^2 \text{ m/s}} \rightarrow f = 0.055$$

Major head loss at purifier equipment:

$$H_{l \text{ major}} = f \frac{L}{D} \times \frac{V^2}{2g} \quad (18)$$

$$H_{l \text{ major}} = 0.055 \times \frac{0.439 \text{ m}}{0.01 \text{ m}} \times \frac{1.52^2 \text{ m/s}}{2 \times 10 \text{ m/s}^2} \rightarrow H_{l \text{ major}} = 0.289$$

Minor head loss at purifier equipment:

$$H_{l \text{ minor}} = K_L \frac{v^2}{2g} \quad (19)$$

$$H_{l \text{ minor}} = (1.5 \times 6) \frac{1.52^2 \text{ m/s}}{2 \times 10 \text{ m/s}} \rightarrow H_{l \text{ minor}} = 1.035$$

The absorbent permeability value of the purifier was determined by using this equation:

$$K = \frac{Q \cdot \mu \cdot L}{A(P_1 - P_2)} \quad (20)$$

Where: K = Permeability; μ = Viscosity (Poise)

L = Tube length (cm); A = Cross sectional area (cm)
P₁ = Initial pressure (atm); P₂ = End pressure (atm)
Q = Gas debit (m³/s)

$$K = \frac{Q \cdot \mu \cdot L}{A(P_1 - P_2)}; K = \frac{0.0001194 \frac{\text{m}^3}{\text{s}} \times 0.01027 \text{ centipoise} \times 23.5 \text{ cm}}{75.36 \text{ cm}^2 \cdot (6335.21 \text{ Pa} - 5756.03 \text{ Pa})} \rightarrow K = 66.89 \times 10^{-3} \text{ mD}$$

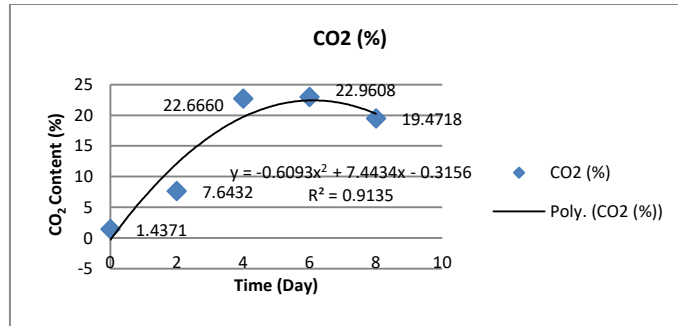


FIGURE 5. CO₂ Removal at Reactor I

Figure 5 shows that ferrioxide did not reduce CO₂; it was proved with increasing in CO₂ gas content. The highest CO₂ content was obtained on the 6th day amounted to 1497 %.

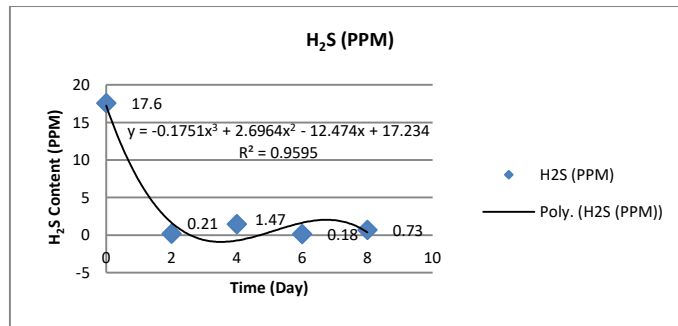
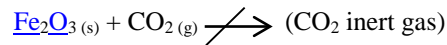


FIGURE 6. H₂S Removal at Reactor I

It can be seen from Figure 6 that the ferrioxide absorbent was very effective in reducing H₂S gas, the highest absorption was obtained at 6th day, amounted to 98.9 % removal.

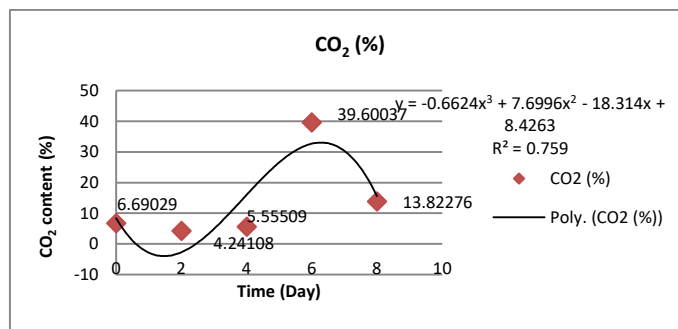
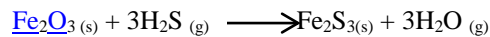


FIGURE 7. CO₂ Removal at Reactor II

Figure 7 represent that the absorbent of iron gram was effective in reducing CO₂ gas until the 4th day, meanwhile on the 6th day the absorbent of iron gram had saturated, it was showed by increasing of CO₂ gas up to 491.9 %.

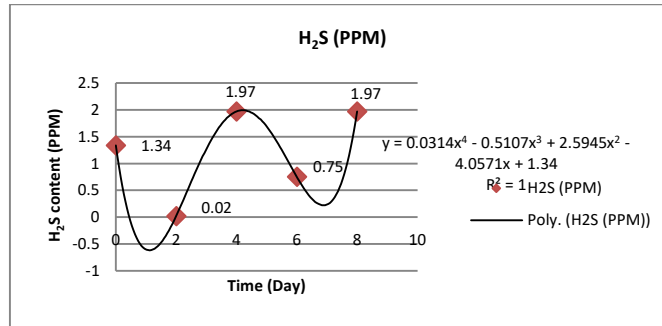
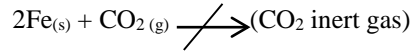


FIGURE 8. H₂S Removal at Reactor II

Figure 8 shows that iron gram was only effective in reducing H₂S gas until day 2, the gas decreasing was amounted to 98 %. Absorbent was already saturated on the 4th day.

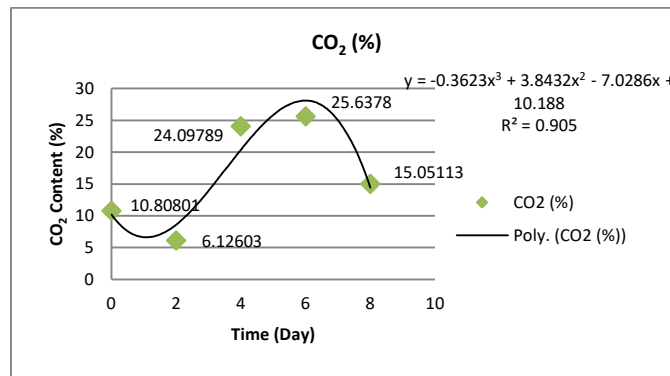
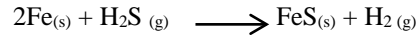


FIGURE 9. CO₂ Removal at Reactor III

Figure 9 present that CaO absorbent was effective in reducing CO₂ gas only for 2 days, the removal was amounted to 43.27 %. Meanwhile, CaO had saturated at 4th day, it was proved by increasing of CO₂ up to 12.3 %.

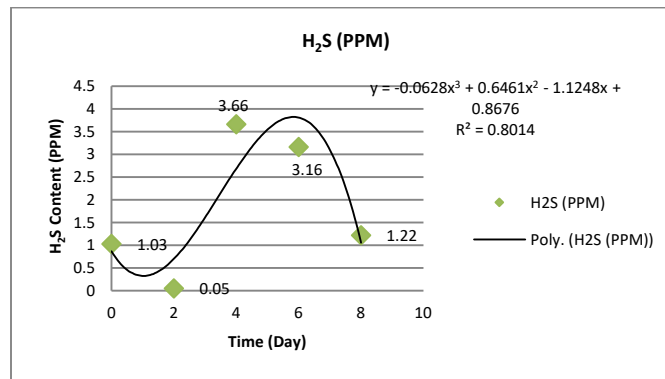
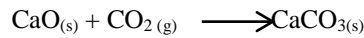


FIGURE 10. H₂S Removal at Reactor III

From Figure 10, it can be seen that the absorbent CaO effectively absorbed CO₂ gas until the 2nd day, decreasing of CO₂ was amounted to 95.14 %.

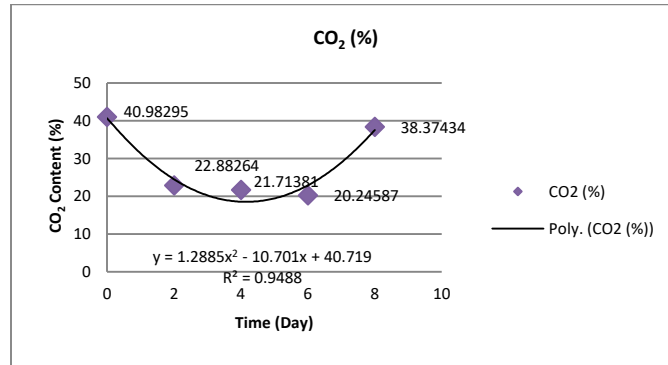
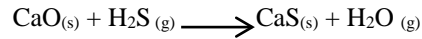


FIGURE 11. CO₂ Removal at Reactor IV

Figure 11 represent that natural zeolite absorbent was effective in reducing CO₂ gas, it was indicated by the largest decreasing of CO₂ content on day 6, amounted to 50.61 %. Decreasing of CO₂ was reduced on 8th day, amounted to 6.368 %.

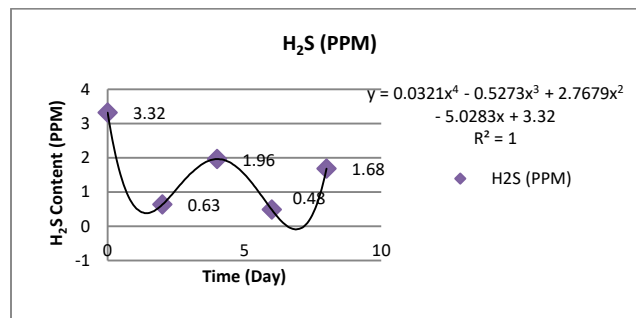
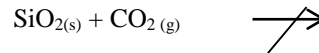


FIGURE 12. H₂S removal at Reactor IV

Figure 12 shows that natural zeolite absorbent was effective in reducing H₂S gas, it was proved by decreasing of H₂S content about to 85.54 % on the 6th day. The absorption was still effective until the 8th day, even though the decreasing level of H₂S was getting smaller to 49.39 %.



CONCLUSION

Based on data calculation that was obtained during the experiment and analysis, the conclusions of this experiment are mention below:

1. Absorber was effective in reducing CO₂ gas is the nature Zeolite absorber because it is able to remove CO₂ gas up to 50.61 %.
2. Ferroxide, iron gram, and natural zeolite were effective absorber in reducing H₂S. The removal of H₂S were amounted to 98.9 %, 98.5 % and 85.54 %, respectively.
3. H₂S in biogas was not corrosive for biogas stoves due to very few particles of H₂S elements produced.

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