Chemical Scrubbing for Removal of Carbon Dioxide and Hydrogen Sulfide in Biogas Purification Process

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Abstract. Biogas is a renewable energy source that can be used as an alternative to fossil fuels, given the increasing exploration and development of non-renewable energy sources. Biogas is processed through an anaerobic digester with the help of microorganisms in the reactor. However, the biogas production process produces acid gases such as CO_2 and H_2S which can reduce the quality of biogas and cause corrosion. Therefore, a purification process is carried out by the absorption method in a pressurized column called a scrubber. This purification process use potassium carbonate and monoethanolamine as an absorbent aims to reduce the acid gas content in biogas to produce biogas that is more environmentally friendly. The addition of absorbent monoethanolamine can increase the percentage of CO_2 gas removal and potassium carbonate can increase the percentage of H_2S gas removal.

Keywords: Biogas, acid gas, scrubber, potassium carbonate, monoethanolamine

1 Introduction

Biogas is a new, renewable energy that can be used as an alternative energy to replace fossil fuels, considering the increasing exploration and development of fossil energy sources which are non-renewable energy. Apart from that, the use of fossil energy also produces waste and causes environmental pollution. Thus, the use of biogas can reduce fossil energy consumption and reduce fossil energy.

Biogas is a type of fuel that is processed through an anaerobic digester with the help of microorganisms in the reactor. The anaerobic process occurs when biogas is stored in a digester, and the decomposition process occurs without oxygen. In this anaerobic process, a mixture of methane (CH_4), carbon dioxide (CO_2) and a small amount of hydrogen sulfide gas (H_2S) are produced. CO_2 and H_2S here are acid gas, where this gas is an impurity in biogas.

Acid gas or sour gas is formed due to natural processes as a by-product of the decomposition or decomposition of organic substances by bacteria or because it is deliberately created. Hydrogen Sulfide or commonly called rotten egg gas is a pollutant that can reduce the quality

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of biogas, because it can cause corrosion. At low levels, if humans are exposed to H_2S gas, it can cause headaches, the body feels lethargic, loss of appetite, and a dry feeling in the sense of smell. Under normal conditions, in the lungs oxygen is absorbed into the blood and transported throughout the body by hemoglobin. If someone breathes air mixed with H_2S, the composition of oxygen (O_2) will be replaced by H_2S, resulting in a lack of oxygen in body cells. In the case of blood flow carrying H_2S to the brain, it will paralyze the sense of smell nerve. To remove H_2S gas while improving the quality of the biogas, a purification process is carried out. Meanwhile, too much carbon dioxide gas released into the atmosphere will result in global warming and climate change. To remove acid gas, this can be done by purification.

Purification is a process of combining two absorption methods, namely physical and chemical, which is placed in a pressurized column or tower called a scrubber. In the scrubber, gas containing dissolved substances enters the distribution chamber through the filling gap in the opposite direction to the liquid. In this final project, biogas purification is carried out to reduce or reduce the acid gas content of the biogas content and the results of the purification are expected to form biogas that is more environmentally friendly.

There has actually been a lot of research on biogas purification using various methods, including absorption using a scrubber. The type of scrubber used and the purification media are varied to produce biogas that has low levels of impurity gas.

Biogas is produced when organic materials decompose into their constituent compounds in conditions without oxygen (anaerobic). The biogas produced mostly consists of a mixture of methane (CH_4), carbon dioxide (CO_2) and Hydrogen Sulfide (H_2S) and other gases. The H_2S content in biogas is only 0-3% of the product gas produced from biogas production [1-10]. Even though the amount is small, the H_2S content contained can reduce the quality of the biogas. In order for the quality of the biogas produced to be more productive, gas containing acid gas must be removed. To remove H_2S and CO_2 gas levels and improve the quality of biogas, purification is carried out.

In research by Mufidatul Islamiyah in 2014 which used a plate/tray scrubber purification column with variations using CaO, NaOH absorbents in the tray trap adjacent to the nozzle, the purpose of this variation was to make a more practical and simpler filter. In the control variables, the mass of the NaOH and CaO absorbents was varied by 2 ounces. The parameters observed are the ability of the absorbent (CaO, NaOH) and the water scrubber to absorb CO_2 and H_2S for biogas purification, how long it takes CaO, NaOH, and the water scrubber to reduce CO_2 and H_2S gas, as well as the results of the absorption of CO_2 and H_2S gas which will be will be analyzed. The research results show that the ability of NaOH to reduce CO_2 gas reaches 24.3%, while with CaO it reaches 0.1% and absorption using a water scrubber reaches 21.2%. For the ability to reduce H_2S gas, using the NaOH absorbent can reduce H_2S gas by 77.5% of the H_2S content before purification, for the CaO absorbent it can reduce H_2S gas by 21.2%, while with a water scrubber it is 18.28%. Based on research conducted carried out by Mufidatul Islmaiyah, the most effective absorbent in reducing CO_2 and H_2S gas is by adding NaOH to the tray near the nozzle compared to adding CaO and a water scrubber.[11]

In research by Nurkholis Hamidin, ING., et al. in 2013 who conducted research on biogas purification with adsorbents using natural zeolite, they chose zeolite because it was easy to obtain and the price was affordable. The zeolite activator used is the KOH compound. KOH is a strong basic compound that is stable and easily soluble in water. In this research, natural zeolite that had been activated with KOH was used as an absorption or purification system. Researchers used variations in the addition of KOH of 0-15% in increments of five percent. Mixture of zeolite and KOH kemudian dilakukan proses *heat treatment* dengan temperatur sebesar 300 ℃ selama 2 jam. Dari penelitian yang dilakukan oleh Nurkholis, dkk. didapatkan hasil bahwa waktu pengujian dan kadar senyawa KOH pada zeolit bepengaruh terhadap nilai kalor biogas, semakin tinggi kadar dari senyawa KOH yang digunakan untuk aktivator zeolite maka semakin tinggi nilai kalor biogas dan kemampuan adsorpsi zeolit menurun jika digunakan secara terus menerus akibat terbentuknya lapisan film pada permukaan zeolit.[12]

In research by Adrianto Ahmad, et al. in 2021 who conducted research on the purification process using monoethanolamine (MEA) with the aim of determining the effect of using monoethanolamine (MEA) on biogas purification. The research variables used were variations in MEA concentration ranging from 5-30% as an absorbent and using a bubble column absorber in semi-batches. Where the biogas flows through a column containing 0.678 L of MEA absorbent with varying MEA concentrations. From the results of research conducted by Adrianto Ahmad, et al. MEA concentration of 30% can reduce H_2S gas with an efficiency of 100%. However, the higher the MEA concentration variation used, the longer the absorption time required for the absorbent to reach the saturation point.[13]

The aim of this research is to design and make a biogas purification tool from acid gas, and to determine the effect of potassium carbonate and monoethanolamine absorbents on the percentage of acid gas removal in biogas.

2. Method

2.1 Determination of scrubber design

The type of scrubber that will be used is the Tray Scrubber type with additional filling in each tray, filling in the scrubber column using a pall ring.

2.2 Theoretical Calculations

1. Calculation of tray requirements

By using equation (1), the number of trays needed is calculated as follows: From the calculation results, it is obtained that the number of trays needed is 4.

$$L' \left(\frac{x_0}{1-x_0}\right) + V' \left(\frac{y_{n+1}}{1-y_{n+1}}\right) = L' \left(\frac{x_N}{1-x_N}\right) + V' \left(\frac{y_1}{1-y_1}\right) \tag{1}$$

$$29,82123 \left(\frac{0}{1-0}\right) + 97,594 \left(\frac{0,4}{1-0,4}\right) = 29,82123 \left(\frac{x_N}{1-x_N}\right) + 97,594 \left(\frac{0,01}{1-0,01}\right)$$

Table 1 Operating Line line calculation

Operating Line	
x_n	y_{n+1}
0,607954	0,4
0,361679	0,2
0,192619	0,1
0,0912821	0,05
0	0,01

2.3 Biogas Purification Equipment

Fig 1. *Scrubber.*

The biogas purification tool uses a scrubber with specifications:

- Outer diameter: 15 cm
- Inner diameter: 14.7 cm
- Height: 70 cm
- Material: acrylic

2.4 Design of Measuring Instruments

The measuring instrument is a gas sensor which is used to detect gas levels before purification and after purification. Later the data from the sensor is used to calculate the percentage of removal in the purification system.

The sensors used are:

1. Methane gas sensor (CH_4) or MQ-4.
2. Carbon dioxide (CO_2) gas sensor or MG-811.
3. Hydrogen sulfide (H_2S) gas sensor or MQ-136.

From the sensors used, sensor validation was carried out using the datashe linearity method. Datasheet linearity refers to the ability of a sensor to produce a linear response to changes in the input or variable being measured.

Sensor validation uses the sensor datasheet and then applies coding on the Arduino.
For example, the MQ-4 sensor datasheet is as follows:

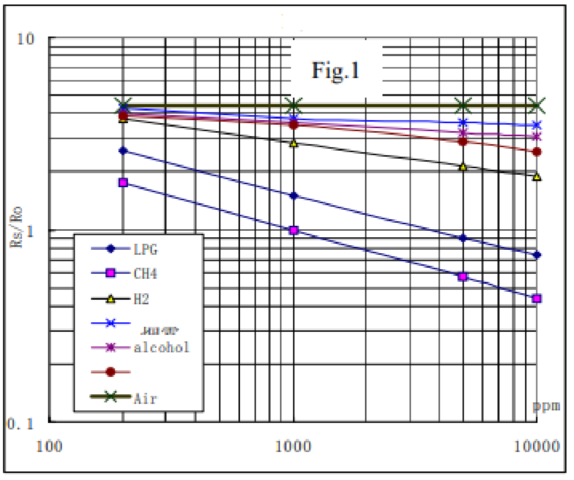


Fig. 2. *Datasheet Sensor* MQ-4.

2.5 Test Mechanism

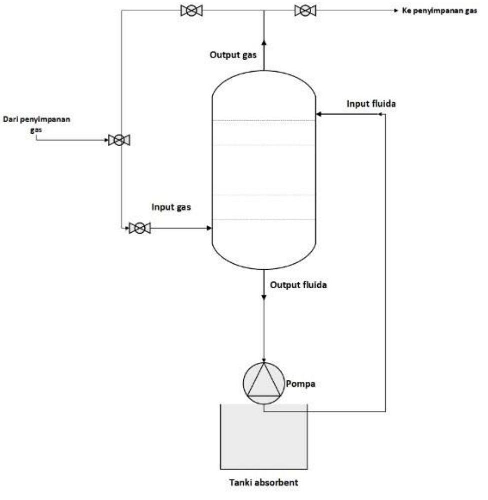


Fig. 3 P&ID Biogas purification equipment.

The biogas purification tool that uses a tray scrubber to reduce acid gas works when the acid gas enters through the bottom of the scrubber via the gas inlet direction and at the same time fluid enters from the absorbent tank towards the top of the scrubber with the help of a pump.

The purification process occurs in the scrubber counter currently, in the scrubber there are four tray stages and the gaps between the trays are filled with pall rings. Structurally, the use of trays and pall rings is useful for narrowing the contact space between gas and fluid so that the percentage of contaminant gas is reduced. Biogas that has gone through the purification process will flow upwards to the gas storage tank, and contaminant gas carried by the absorbent fluid will be carried downwards towards the absorbent tank.

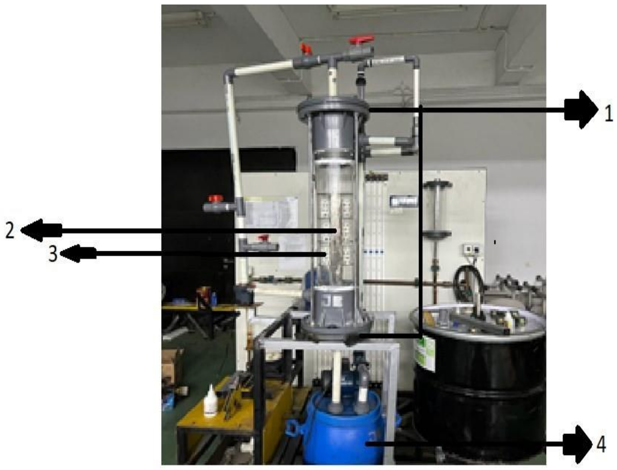


Fig. 4. Design and build biogas purification equipment.

Tabel 2. Name of components in biogas purification equipment.

No	Component Name
1	*Scrubber*
2	*Tray*
3	*Pall-ring*
4	Absorbent Tank

2.6 Variation Absorbent

Absorbent is the fluid used in the biogas purification process. The fluid used is a solution of amine (monoethanolamine) or abbreviated as MEA and potassium carbonate or K_2CO_3.

If the MEA solution is mixed with water and then subjected to CO_2 gas, a reaction occurs between the CO_2 gas and the MEA solution which produces bicarbonate ions (HCO_3^-) and hydrogen ions (H+) as follows:

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \text{ (carbonic acid) } H_2CO_3 + MEA \rightleftharpoons HCO^{3-} + MEAH^+$$

In this reaction, CO_2 reacts with water to form carbonic acid, and carbonic acid then reacts with MEA to form bicarbonate ions and hydrogen ions. This reaction is also exothermic.

Meanwhile, in potassium carbonate which is reacted with CO_2, the CO_2 contained in the biogas reacts with a solution of potassium carbonate (K_2CO_3) and water (H2O) to form a solution of potassium bicarbonate ($KHCO_3$).

$$K_2CO_3\ (aq) + CO_2\ (g) + H_2O\ (l) \rightarrow 2KHCO_3\ (aq)$$

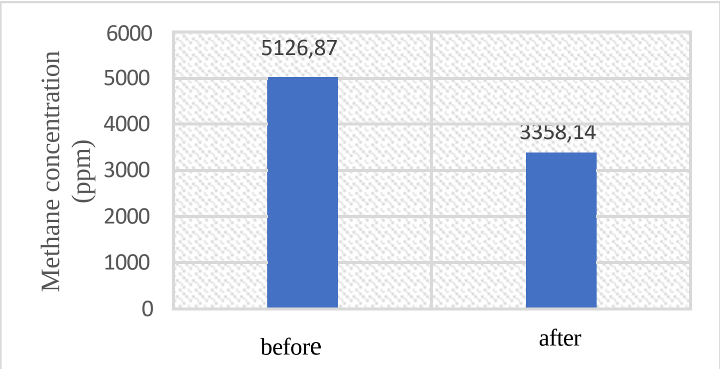
In this research, variations in the mole ratio of the absorbent were used to reduce acid gas in biogas. The fluids used are potassium carbonate (K_2CO_3) and monoethanolamine (MEA). The variations used are one to one, one to two, and two to one.

The one to one ratio referred to is five moles of potassium carbonate mixed with five moles of monoethanolamine; The two to one ratio referred to is ten moles of potassium carbonate mixed with 5 moles of monoethanolamine; then for a ratio of one to two, namely five moles of potassium carbonate mixed with ten moles of monoethanolamine. Determining the number of moles can use the molar mass formula.

These three variations will be used as variations in the absorbent. Then look at the addition of potassium carbonate or monoethanolamine, what the results will be if used to purify biogas.

3. Result

Biogas purification equipment testing uses variations in the mole ratio of the absorbent fluid. The absorbent mole ratio used is the mole ratio of potassium carbonate (K_2CO_3 and monoethanolamine. In variation one, a 1:1 mole ratio is used, where 5 moles of K_2CO_3 will be added with 5 moles of K_2CO_3.



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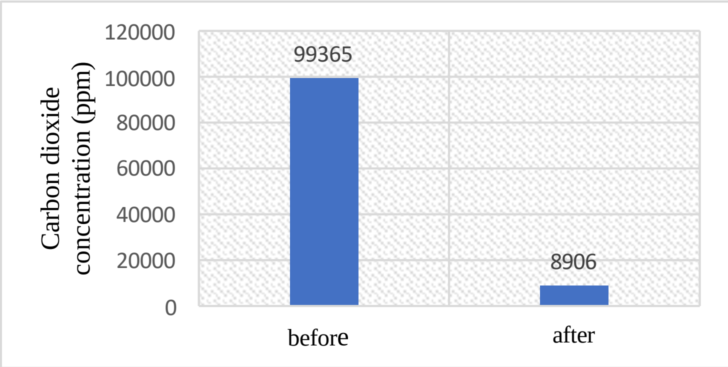

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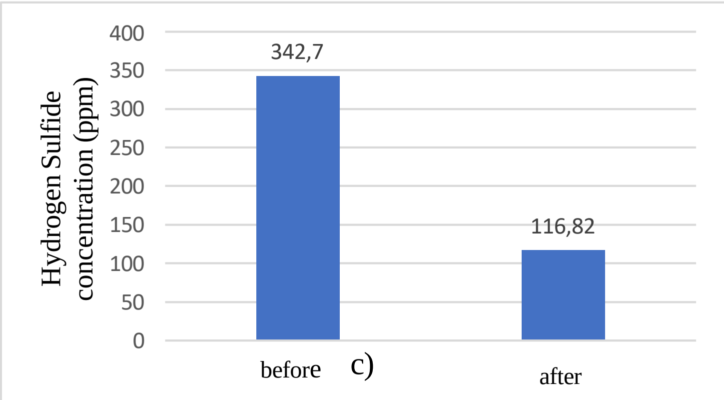


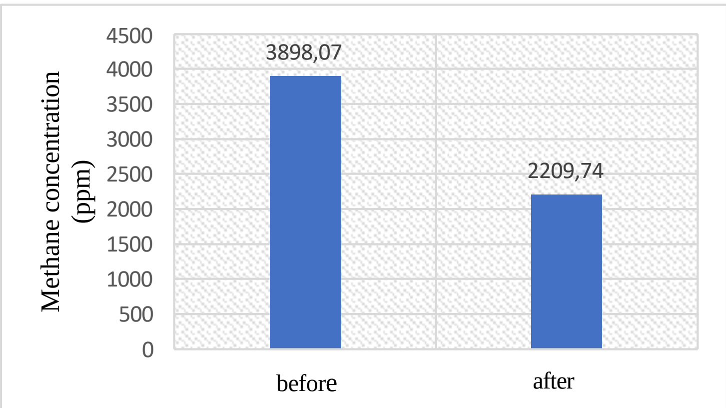
c)

Fig. 5 a) methane concentration, b) carbon dioxide concentration, c) hydrogen sulfide concentration, variations of 5 moles of K_2CO_3 will be added with 5 moles of K_2CO_3

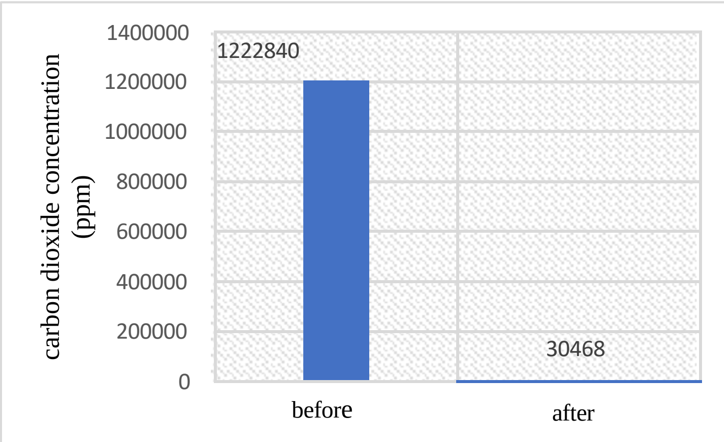
From testing variation one, the results obtained are as in Figure 5. From the picture above, the gas content value is taken, namely the sum of the sensor readings used between the sensors placed on the gas inlet side or before purification and the gas outlet side or after purification.

Variation one produces a carbon dioxide gas removal percentage of 91.037% and a hydrogen sulfide removal percentage of 65.9119%. However, this purification reduces methane gas by 34.4992. In biogas purification to remove the acid gas content in biogas, methane gas will be reduced slightly, but the reduction of methane gas must be taken into account. The percentage of acid gas removal is also large in variation 1, K_2CO_3 can reduce H2S gas by 65.9119% and monoethanolamine can reduce carbon dioxide gas by 91.037%.

The second variation uses a ratio of 1:2, the variation in question is using an absorbent as an absorbent where 5 mol K_2CO_3 is added with 10 mol MEA which will be used as a media to absorb acid gas in biogas.



a)



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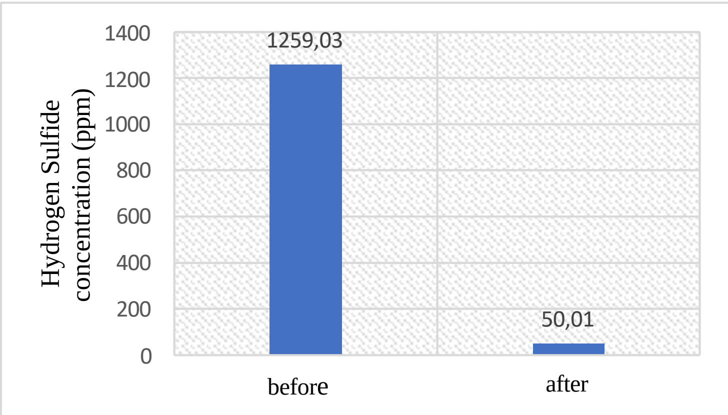

c)

Figure 6 a) methane concentration, b) carbon dioxide concentration, c) hydrogen sulfide concentration, variations of 5 mol K_2CO_3 is added with 10 mol MEA

In variation two, a ratio of 1:2 is used, where MEA is 10 mol and MEA is 5 mol. Using the second variation can reduce acid gas in biogas as follows, the percentage of carbon dioxide gas removal is 97.51% and the percentage of hydrogen sulfide gas removal is 96.02 %. From the percentage of gas removal, variation two is compared to variation one. When moles of MEA are added the reduction of carbon dioxide gas increases. Considering that MEA can dissolve carbon dioxide gas with high affinity. The percentage removal of hydrogen sulfide gas also increases in the second variation. The addition of MEA moles also affects the percentage of hydrogen sulfide gas removal.

In the second variation, adding moles of monoethanolamine also reduces methane gas by 43.312 percent. The reduced methane gas increases. This needs to be taken into consideration when using increased monoethanolamine because the principle of the biogas purification tool is to improve the quality of biogas by reducing the content of biogas acid gas, so it should be What is reduced is carbon dioxide gas and hydrogen sulfide gas in biogas, methane gas can be reduced but only slightly.

The purification test uses the third variation using a mole ratio of 2:1, 10 mol K_2CO_3 is mixed with 5 mol K_2CO_3 and put into an absorbent tank as a medium to absorb acid gas in biogas.

4. Conclusion

1. Biogas purification equipment is an important method for reducing the acid gas in it. The three variations that have been studied show a significant percentage in reducing acid gas in biogas. The use of absorbents such as monoethanolamine (MEA) and potassium carbonate (K_2CO_3) has been proven to have an important role in the biogas purification process. MEA is used to reduce carbon dioxide (CO_2), while K_2CO_3 is used to remove hydrogen sulfide (H2S) from biogas.

2. Purification of biogas using MEA and K_2CO_3 as absorbents can improve the quality of biogas by removing unwanted components such as carbon dioxide and hydrogen sulfide. In practice, selecting the right variation and optimal ratio between these two adsorbents is important to achieve the desired results in biogas purification.

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