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Biogas Purification by Adsorption Method Using Activated Carbon and Zeolite Adsorbents

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ABSTRACT. Biogas is an alternative energy that is formed from the fermentation of organic matter in gaseous form. Biogas consists of several gas mixtures with the main components methane (CH_4) and carbon dioxide (CO_2) with a small amount of steam. Biogas is an alternative technology that produces environmentally friendly, cheap and renewable fuel because it comes from biomass, organic liquid waste, food scraps, organic waste, leaves and animal manure resulting from the fermentation process. This study aims to purify biogas by adsorption method using activated carbon and zeolite adsorbents to obtain optimal methane gas by varying the biogas flow rate and the amount of adsorbent composition. The adsorbent ratio of activated carbon and zeolite (%-weight) are 0:100, 30:70, 50:50, 70:30, and 100:0 with the flow rate are 0.2, 0.4 , and 0.6 liter/minute. The composition of the biogas after purification was analyzed using a gas analyzer "Nova Plus". The flow rate was 0.2 liters/minute, and the optimal adsorbent ratio was 0%:100% (activated carbon: zeolite) yielding 81.40% methane content.

1. INTRODUCTION

Energy is needed to carry out various activities like industrial, transportation, and household activities. Energy consumption which increases every year is inversely proportional to the decrease in energy availability. One of which is by utilizing renewable and environmentally friendly alternative energy sources [1]. It can disturb energy security in the future so it needs a diversified source of energy.

Biogas is one of the alternative energy that can produce environmentally friendly, cheap and renewable fuel because it comes from organic waste. These organic wastes include biomass waste, human waste, animal waste, and biodegradable waste [2].

The process of forming biogas takes place in a closed state in the biodigester. In the digester, the organic waste will be digested and fermented by bacteria. Biogas fermentation can produce methane (55 – 70%-volum), carbon dioxide (30 – 45%-volum), hydrogen disulfide (<1%-volum), and some moisture content [3]. In order to optimally utilize biogas, biogas produced from a biodigester must be upgraded beforehand because biogas still contains high levels of CO_2 which results in low heat efficiency and can cause corrosion of biogas installation equipment. Improving the quality of biogas is referred to as the purification process. Several biogas purification technologies have been developed using various methods, one of which is the adsorption method. Adsorption is an event in which a substance attracts other substances around it to interact and bind with that substance.

Several studies, including research by Gantina et al (2020), have explored the use of activated natural zeolite for biogas purification, which can increase methane concentrations from 52.51% to 70.65%-volume and decrease CO_2 concentrations from 36.48% to 0.1%- volume at an optimal flow rate of 1.1 L/minute [5]. While Irvan et al (2018) found that zeolite pellets with 140 mesh were the most effective for biogas purification, reducing CO_2 levels from 40% to 3% with a CO2 absorption rate of 92.5%, activated carbon has also been widely employed for this purpose, with Vivo-Vilches et al (2017) reporting its selective adsorption of CO_2 [7]. Iriani et al (2016) study found that activated carbon with a 32 mesh size was most effective in purifying biogas and increasing CH_4 content [8]. Consequently, this study aims to optimize methane gas production by adsorbing biogas using activated carbon and zeolite adsorbents while varying the biogas flow rate and adsorbent composition.

Activated carbon

Activated carbon often also referred to as activated charcoal is a type of carbon that has a very large surface area. This can be achieved by activating the carbon or charcoal. Generally, activated carbon has a surface area ranging from 300 - 3500 m2/g. This surface area has a relationship with the pore structure on activated carbon so activated carbon has properties as an adsorbent. Activated carbon has several functions including in the adsorption process where activated carbon can adsorb solids and gases. In addition, activated carbon can also be used in industrial waste treatment to remove colour, odour, organic substances and contaminants such as heavy metals.

Natural zeolite

Is a hydrated aluminosilicate compound consisting of SiO_4 and AlO_4 tetrahydrate bonds connected by oxygen atoms to form a framework. In the zeolite framework, each Al atom is negative and will be neutralized by bonds with easily exchangeable cations that will affect the adsorption process and thermal properties of zeolites.

The use of zeolite requires an activation process to improve the special properties of zeolite as an adsorbent and remove impurities. The activation process can also change the type of cation, Si/Al ratio and zeolite characteristics to suit the material to be absorbed. The zeolite structure can also perform adsorption and absorption of H_2O, CO_2, SO_2, H_2S compounds. Zeolites can control the gases that are the main cause of the greenhouse effect, namely CO_2 and N_2O, except CH_4 which is not absorbed.

2. MATERIALS AND METHODS

This research was conducted for approximately 1 month, from 16 March - 20 April 2023 at the Waste Treatment Technology Laboratory, Department of Chemical Engineering, and Oil and Coal Laboratory Sriwijaya State Polytechnic.

2.1 Materials and Tools

The study employed a set of biodigester tools, purification tools and a gas analyzer equipped with an adsorption column featuring a 4.5 cm diameter and 27 cm height. Activated carbon adsorbents, zeolite, biogas reservoirs (urine bags) and biogas samples constituted the materials used for the said study.

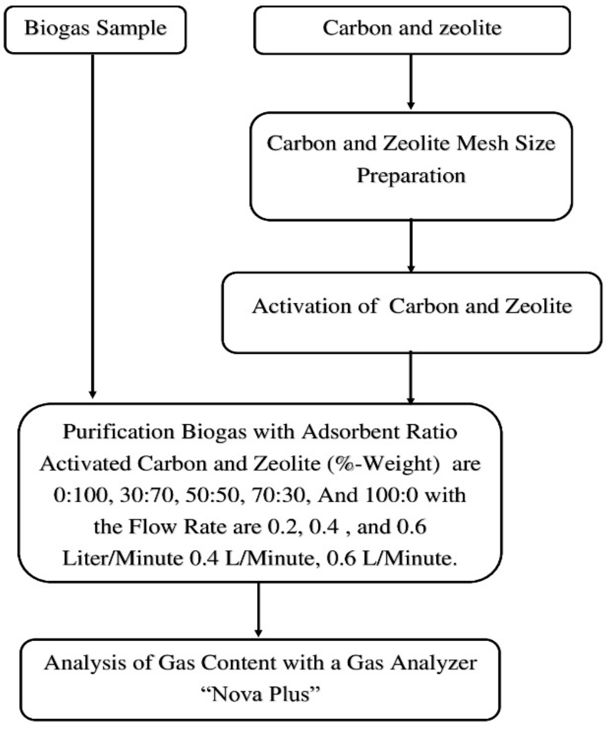

Figure 1. Biogas Purification Process Flowchart

2.2 Adsorbent preparation

Activated carbon and zeolite grind until the size of them about 30-60 mesh and further activation of both adsorben using heating at the temperature of 100-200 °C for 1-2 hours.

2.3 Biogas purification process

The biogas sample is to be purified, then the adsorption column with activated carbon and zeolite adsorbents. The adsorbent ratio of activated carbon and zeolite (%-weight) are 0:100, 30:70, 50:50, 70:30, and 100:0 with the flow rate are 0.2, 0.4, and 0.6 liter/minute. the capacity of the biogas purification tank is 500 ml. Set the biogas flow rate, which was 0.2 liter/minute, and the best variation in the amount of adsorbent was 0%:100% adsorbent (activated carbon: zeolite). The purified biogas is analyzed using a gas analyzer "Nova Plus".

Figure 2. biodigester equipment

3. RESULTS AND DISCUSSION

3.1 Biogas Analysis Results Before Purification

After fermentation for 40 days, the biogas yield without purification was obtained. Biogas yield data before purification can be seen in Table. 1.

Table 1. Biogas Analysis Results Before Purification

CH_4 (%-volume)	CO_2 (%-volume)	H_2S (%-volume)
52,50	37	0,0246

3.2 Biogas Analysis Results After Purification

After a purification process with predetermined variables, the biogas sample is sent to the Sriwijaya State Polytechnic Oil and Coal Laboratory to be analyzed using a gas analyzer so that the gas content in the biogas can be determined. The results of biogas purification data can be seen in Table 2.

Table 2. Biogas Analysis Results Data After Purification

Activated Carbon : Zeolite (%-weight)	Biogas Flow Rate (L/min)	CH_4 (%-volume)	CO_2 (%-volume)	H_2S (%-volume)
0 : 100		81,40	0,01	30
30 : 70		78,20	0,04	35
50 : 50	0,2	71,86	0,26	45
70 : 30		75,06	0,10	41
100 : 0		70,86	0,38	47
0 : 100		74,26	0,04	35
30 : 70		70,22	0,04	37
50 : 50	0,4	66,18	2,28	45
70 : 30		69,28	2,34	43
100 : 0		62,96	1,60	50
0 : 100		70,02	0,04	38
30 : 70		68,88	0,04	41
50 : 50	0,6	64,84	2,32	50
70 : 30		66,88	2,34	47
100 : 0		62,60	1,62	52

3.3 Effect of Biogas Flow Rate on Methane Content Produced

Methane (CH_4) is a chemical compound that can be used as fuel, and its combustion produces a blue flame and has a high calorific value. The main focus on refining is to produce high methane. The percentage increase in methane content was obtained from comparing the methane level before purification with the methane level after biogas purification. The graph of the influence of adsorbent variations on the percentage increase in methane (CH_4) at a flow rate of 0.2 liters/minute can be seen in Figure 2.

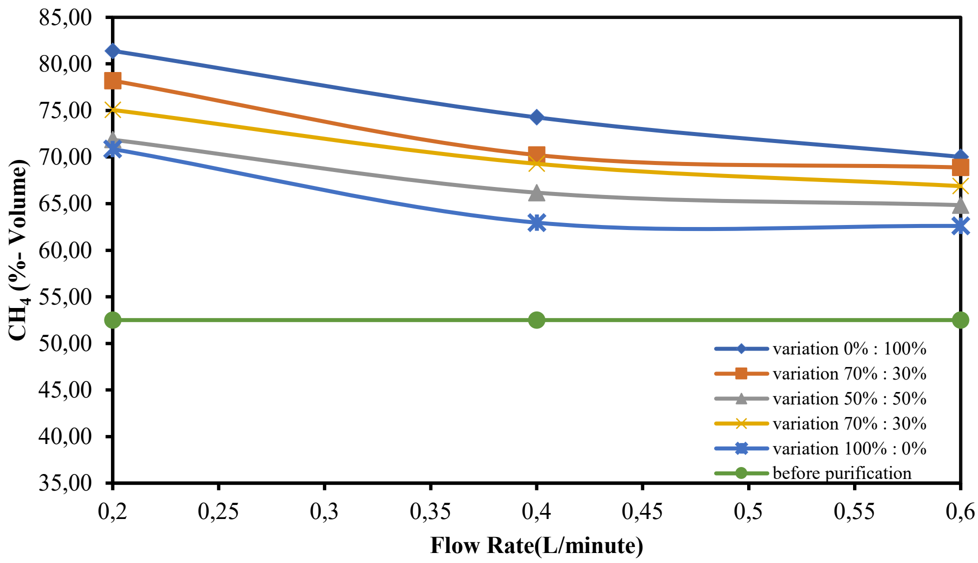

Figure 2. Effect of Flow Rate on Methane Content in Different Amounts of Adsorbents.

Based on Figure 2, the CH_4 percentage graph at flow rates of 0.2, 0.4, and 0.6 liters per minute exhibited a decline or was comparable to the methane concentration in biogas before the purification process. The biogas flow rate of 0.2 liters per minute demonstrated the highest CH_4 percentage, whereas the lowest CH_4 percentage was observed at a biogas flow rate of 0.6 liters per minute. At a flow rate of 0.2 liters/minute, a significant increase was observed. The methane level prior to purification was 52.50%-volume, which rose to 81.40%-volume after passing through the adsorption column, indicating the effectiveness of increasing CH_4 at a flow rate of 0.2 liters per minute, the methane content reaches 55.05% by volume. When the flow rate is decreased to 0.6 liters per minute during the purification process, methane levels increase from 52.50% to 70.02% by volume. However, the effectiveness of this increase is only 33.37%-volume. These results indicate that a higher CH_4 percentage can be achieved with a lower flow rate. The results indicate that the adsorption process encountered elevated absorption levels as the flow rate diminished, concurring with Sidabutar et al (2023) report regarding the retention of CO_2 and other particles by the adsorbent. Technical term abbreviations will be clarified when first introduced. The manuscript also adheres to standard grammar, citation, and footnote format, as well as a clear structure with logical progression. The results indicate that the adsorption process encountered elevated absorption levels as the flow rate diminished, concurring with Sidabutar et al. (2023) report regarding the retention of CO_2 and other particles by the adsorbent. The results indicate that the adsorption process encountered elevated absorption levels as the flow rate diminished, concurring with Sidabutar et al (2023) report regarding the retention of CO_2 and other particles by the adsorbent. Decreased flow rates of biogas led to a rise in gas retention time within the column. Biases are prohibited, while precision and clarity in word choice are emphasized. Moreover, informal language, ornamental expressions, filler words, and first-person perspectives are avoided, and sentence structure follows traditional conventions. In the study conducted by Isya and Elida (2023), it was discovered that reducing the biogas flow rate leads to increased absorption of CO_2, resulting in elevated levels of CH_4 [10].

3.3 The Effect of Variation in the Amount of Adsorbent on the Produced Methane Content

The goal of purifying biogas with this adsorption pathway is to capture the CO_2 content in the biogas. CO_2 gas in biogas is absorbed by adsorbents of a mixture of activated carbon and zeolite with various compositions in the adsorption column. The more CO_2 content absorbed, the higher the CH_4 content in the biogas. The biogas flow (input) of the adsorption column was tested for each variation of the adsorbent. CH_4 adsorption using a mixture of activated carbon and zeolite adsorbents is a way to get the best possible end result, namely obtaining biogas with the best or maximum CH_4 content and reduced CO_2 content. The graph of the influence of the number of adsorbent variations on the resulting methane content can be seen in Figure 3.

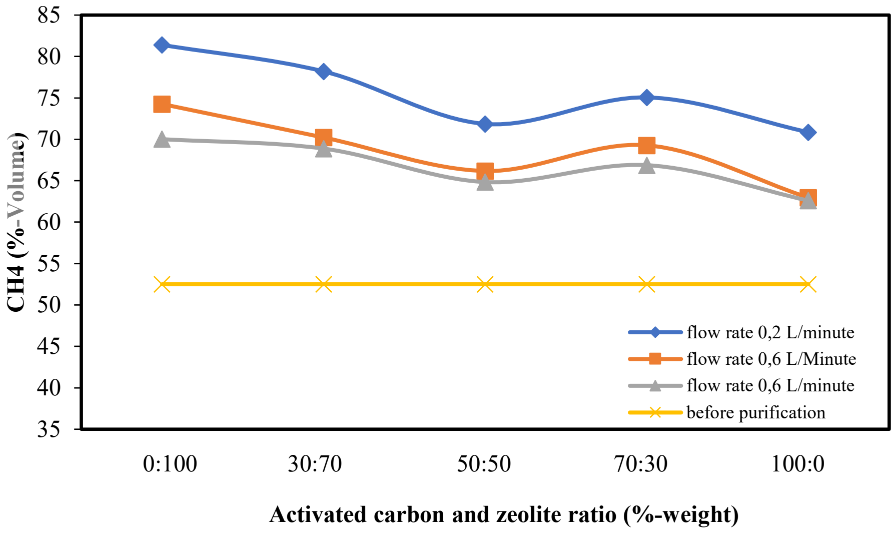

Figure 3. The Effect of Variation in the Amount of Adsorbent on the Methane Levels Produced.

From the results of the analysis in Figure 3, the largest increase in CH_4 was obtained in the purification process using a variation of activated carbon adsorbent: zeolite with content of 0%:100%, namely 81.40%, the second position using a variation of adsorbent 30%: 70%, which is equal to 78.20%. , in the third position using an adsorbent variation of 70%: 30% which is equal to 75.06%, the fourth position uses a variation of adsorbent 50% : 50% which is equal to 71.86%, and finally using a variation of adsorbent 100% : 0% which is equal to 70, 86%. CH_4 levels with no purification and without purification increased, so it can be concluded that adsorbents with variations of activated carbon and zeolite 0%: 100% are able to absorb CO_2 content in biogas which can be used as an adsorption medium for biogas purification because it causes CH_4 levels to increase. This is in accordance with Fahriansyah's at all (2019) research, with an increase in methane (CH_4) content caused by a decrease in carbon dioxide gas (CO_2) and H_2S contained in biogas [11].

According to the analysis of Figure 3, the most significant increase in CH_4 purification was observed in the process that employed a variation of activated carbon adsorbent: zeolite with a composition of 0:100 % weight, which amounted to 81.40% volume. The second position was occupied by the variation of adsorbent with a composition of 30:70%-weight, with a value of 78.20%-volume. The third position was occupied by the variation of adsorbent with a composition of 70:30%-weight, which yielded a value of 75.06%-volume. The fourth position was held by the variation of adsorbent with a composition of 50:50%-weight, with a value of 71.86%-volume. The lowest value was observed in the variation of adsorbent with a composition of 100:0%-weight, which amounted to 70.86%-volume. The methane content experiences an increase both with and without purification, leading to the conclusion that the adsorbent comprising a mixture of active carbon and 0: 100%-weight zeolite is capable of absorbing CO_2 in biogas. This adsorbent can therefore serve as a medium for purifying biogas, as it enhances the methane content. This is in line with Fahriansyah et al (2019) study, showing an increase in methane (CH_4) content due to the decrease of carbon dioxide (CO_2) and H_2S gases present in biogas [11].

The use of adsorbent variations of 0: 100%-weight can increase the purity of methane better and can absorb it to the maximum compared to the use of activated carbon adsorbents. Figure 3 displays that utilizing adsorbents composed of activated carbon and zeolite in a 70:30%-weight ratio results in a methane content of 75.06%-volume, denoting the increase in methane content. Thus, activated carbon adsorbents contribute to biogas purification, albeit not to the extent of zeolite adsorbents. Zeolite can enhance the purity of biogas by absorbing water vapour, CO_2, and H_2S, which are the main impurities while leaving the main gas to be purified CH_4, unabsorbed [12]. This attribute of zeolite makes it a valuable tool in biogas production. Zeolite is a highly effective alternative adsorbent that can operate within a broad temperature range. Its versatility renders it a suitable candidate for adsorption purposes. Moreover, zeolites have multiple applications, such as molecular filtration, ion exchange, filtering and catalytic applications [13]. Zeolites have various applications including hydrogen purification, small to medium-scale industrial drying of airflow, separation of nitrogen from methane, separation of linear hydrocarbons from isomeric mixtures, and separation of P-xylene.

4. CONCLUSION

Based on research on Biogas Purification from Co-Digestion of Tofu Liquid Waste with Cow Manure using Activated Carbon and Zeolite Adsorbents that have been carried out, it can be concluded that:

1. At a biogas flow rate of 0.2 liter/minute, the optimal increase in methane levels was achieved, reaching 81.40%-volume. The adsorption process is more efficient with a lower flow rate, as a longer interaction time between biogas and adsorbent increases the level of purity.
2. In the range of adsorbents tested, utilizing a combination of 0% zeolite and 100% activated carbon demonstrated the highest effectiveness in increasing methane content, achieving a maximum of 81.40%-volume. Zeolite was found to be more selective in absorbing CO_2 from biogas than activated carbon.

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