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Adsorbent-based Biogas Quality Analysis through Purification Process

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Abstract— Biogas is a raw material utilized to produced biogas. Biogas is renewable energy source produced by the anaerobic activity of organic matter through the fermentation process. Quality of biogas is determined by its main composition, such as methane (CH_4). In addition, the composition of biogas also contains impurities such as unburnt carbon dioxide (CO_2) so that it reduces the heating value, hydrogen sulfide (H_2S) and water vapor (H_2O) which are corrosive as well as Nitrogen (N_2). Adsorption method on the impurity compositions can be used to improve biogas quality. This research used a column purifier containing four adsorbents in the form of calcium hydroxide $Ca(OH)_2$, iron gram ($Fe_2(O_3)$), zeolite and activated carbon with three volume variations 600 cm^3, 900 cm^3 and 1200 cm^3. The results of biogas testing using gas chromatography showed that the best quality obtained from the 1200 cm^3 volume of adsorbent. Methane content was increased up to 17.985% and the impurity gases were decreased, such as carbon dioxide in as much as 18.15%, hydrogen sulfide and water vapor in as much as 0.182%. The heat produced by unpurified biogas was 1518.312 kJ/m^3 and the highest heating value after purification was 2108.22 kJ/m^3. The biogas combustion resulted in a dominant blue flame color. The most optimum effectiveness of the technology resulted in an increase of the methane content up to 64.275%. Based on this research, the utilization of column purifier with the adsorption method was able to improve the quality of biogas so that it can be used directly to cook.

Keyword: Biogas, Purification, Adsorbent, Filter, Methane

INTRODUCTION

Petroleum fuel and natural gas are the basic needs of the community to support life. If the demand to use the fossil fuels increases, it can lead the reserves of energy source to decrease, it can also left a negative impact to the environment such as air pollution. To resolve this problem, we require an alternative fuel that is cheap and easy to obtain. One of them is the new renewable energy namely biogas.

The chosen raw material for biogas production was cow feces since feces was mostly produced in livestock business, especially in Bandar Lampung. One cow excreted for approximately 25 kg/day of feces (Nenobesi et al., 2017). If cow excrete waste is generated on a large scale, it will cause troubles, such as odors and environmental pollution. Therefore, The need for efforts to manage sewage in a sustainable manner for the environment and the livestock business sector as a solution for waste disposal. In addition biogas can be used for cooking and electricity purposes. The energy contained in biogas is high, so the electricity demand of 1KWH requires 0.62-1 m^3 of biogas (Ahmadi & Hastuti, 2014).

From all of the results of livestock waste fermentation process, not all of the gas can be burned. The heat of biogas combustion is influenced by the percentage of methane and carbon dioxide gas content. The content of biogas consists of methane (CH_4) 55-75%, carbon dioxide (CO_2) 25-45%, nitrogen (N_2) 0-0.3%, hydrogen (H_2) 1-5%, hydrogen sulfide (H_2S) 0- 3%, oxygen (O_2) 0.1-0.5%, and water vapor (H_2O) (Masrukhi & Ritonga, 2018). The quality of biogas can be determined from methane gas and carbon dioxide. If the methane content in biogas is high, the produced calorific value will be high. While if the value of carbon dioxide content is high, then the produced calorific value of biogas will be low. The low methane content can only be used as fuel in cooking activities, while to increase the advantage of biogas as the new environmentally friendly renewable energy, it is necessary to purify the methane content.

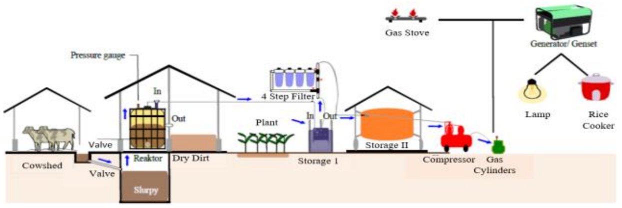

Figure 1. Schema of Biogas Research using Column Purifier Equipment

Biogas purification is an important consideration to utilized biogas as the engine fuel. The content of impurity gases affects the quality and heat value such as carbon dioxide, water vapor and hydrogen sulfide. The presence of carbon dioxide in biogas is undesirable because carbon dioxide causes low heat generation. Water vapor can cause corrosion of equipment or machines used in biogas utilization. Meanwhile, hydrogen sulfide gas is burned and released into the air and being oxidized into SO_2 and SO_3 which are corrosive and H_2O will produce acids able to damage the machine tools components (corrosive). Corrosion can be a problem in the carburetor and combustion system (Fahriansyah et al., 2019; Masrukhi & Ritonga, 2018).
Gases which are not needed for combustion process need to be removed because they will hinder the combustion process. Biogas purification is needed to separate methane gas from the gas impurities so that the heat of combustion becomes higher
Zeolite can be activated using a heat treatment at temperatures between 500, 600, and 700 ºC (Ahmadi & Hastuti, 2014).

Based on these studies, the authors conducted further research on “Adsorbent-based Biogas Quality Analysis through Purification Process”. The biogas purification technique uses the adsorption method to separate methane gas from a mixture of impurity gases through molecular filtration into an adsorbent that has a different solvent selectivity from the gas to be separated. The results of this test are expected to be able to produce good quality biogas and can be used directly into cooking or lighting equipment without corroding

METHOD

The research scheme of cow feces waste untilization into biogas can be seen in Figure 1. The technology design was carried out at the Manufacturing Laboratory, Institut Teknologi Sumatera and Sanjaya Farm Sukabumi, Bandar Lampung. The content of biogas was then being tested to determine its composition by using gas chromatography test method at the Agricultural Product Engineering Laboratory, University of Lampung.
The raw material used to produce biogas was livestock waste mixed with water in the ratio of 1:2. The type of water tank used as a biogas reactor was Intermediate Bulk Containers with the capacity of 1000 L. The start-up period of biogas fermentation will last 1-3 weeks(Pandey et al., 2011).
The gas produced from the biogas reactor was flowed into the storage drum so that the gas pressure was increased. Furthermore, the obtained biogas was purified using a horizontal purifier with four columns containing adsorbents as shown in Figure 2. The type of adsorbent used were activated carbon as a binder of water vapor (H_2O), zeolite as a binder of carbon dioxide (CO_2), $Ca(OH)_2$ as a binder of carbon dioxide (CO_2) and grams of ferric oxide lathe residue ($Fe_2(O_3)$) as a binder and indicator of hydrogen sulfide content (H_2S). The results from the purification are channeled to the reservoir used for cooking with a stove and lighting.

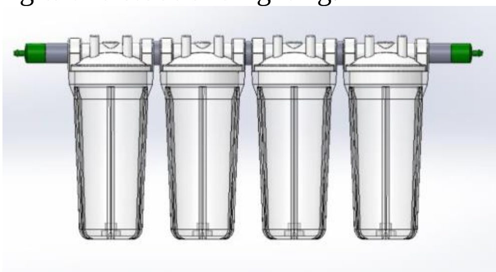

Figure 2. Design of Purifier

A. Biogas Content Composition Test

Biogas samples were taken before and after biogas purification. Biogas samples that have not been purified are taken directly from the biogas digester through the digester gas outlet. Biogas samples were purified by taking three samples at various adsorbent volumes of 600 cm^3, 900 cm^3 and 1200 cm^3 through the gas purifier outlet channel. Each of the samples were taken after 10 minutes of gas entering the purifier. The biogas samples were stored in one liter gas sampling bag. Airtightness must be considered during the sampling to obtain an accurate biogas volume. The purification stage was carried out to separate biogas content from the gas impurities so that the percentage of methane content will become higher.

B. Heating Value (HV)

CO_2 Absorption Effectiveness of heating (calorific) value is the total energy released when a fuel is completely burned in a steady stream and the products return to the reactants state. There are two types of heating (calorific) value:

- Higher Heating Value (HHV), is the upper heating (calorific) value used when the resulted H_2O from combustion process was in a liquid form.

- Lower Heating Value (LHV), is the lower heating (calorific) value used when the resulted H_2O from combustion process was in a gas form .
-

A pressure of 1 atm and an ambient temperature of 37^0C, the LHV value of CH_4 is 50,020 kJ/kg, and the density of CH_4 is 0.656 kg/m3. Then the heat of biogas can be calculated using equation 2.1 (Moran et al., 2014).

$$= \quad HV = LHV \times \rho\, metana \times CH_4 \quad (1)$$

C. CO_2 Absorption Effectiveness

The success relationship between adsorbed CO_2 into the adsorbent is calculated using effectiveness. CO_2 is assumed by 100% elimination so that the equation becomes:

$$Efectiveness = \frac{CO_{2\,Input} - CO_{2\,Output}}{CO_{2\,Input}} \times 100\% \quad (2)$$

DISCUSSION

A. Biogas Composition without purification process

The test of the biogas composition was taken on the seventh day with the pH condition of 6.98 and the temperature condition of 30°C. The results of the unpurified biogas analysis showed that it contained materials such as nitrogen, hydrogen sulfide, water vapor, methane and oxidized carbon. The percentage of each biogas content can be seen in Figure 3.

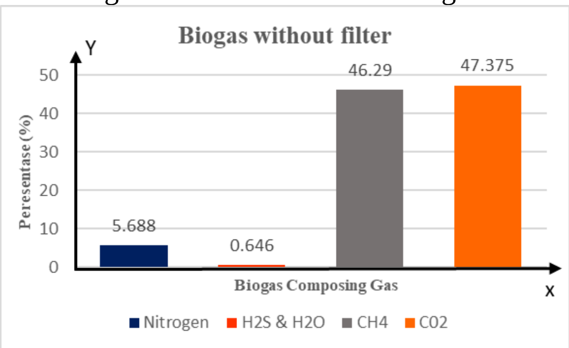

Figure 3. Biogas Composition Without Purification Process

Methane gas content of 46.29% indicated that the quality of biogas was not good. This result was supported by a reference (Iriani & Heryadi, 2014) which stated that biogas with good quality has the methane content of around 50-75%. Several gas compositions contained in biogas are impurities, including carbon dioxide which was around 47.375%, nitrogen was 5.688%, hidrogen sulfide and water vapor was 0.646%. Composition of the gas impurities was higher than the methane content in the biogas, which was 53.709% in total. This result can be caused by several factors during anaerobic processes, such as the degree of acidity (pH) and temperature.
A decrease in the temperature of the reactor from 1–20°C will cause the production of biogas to be significantly reduced. It occurs due to the metagonic bacteria properties being highly sensitive to temperature changes (Iqbal et al., 2014).

Good biogas content can be sampled on days 10 to 21 because the CH4 content is above 45%. This biogas can turn on a modified generator. (Elly et al., 2020) The same study was conducted by A. Pertiwiningrum (2016), the CH4 content of 55-75% is influenced by the semi-continuous system used which adds and reduces impurities every day so that the anaerobic fermentation process is not optimal.

B. Biogas Composition with purification process

The results of biogas composition analysis with the adsorbent volume of 600 cm^3 indicated that the increased methane content was 0.826% and decreased carbon dioxide gas content was 6.241%, hydrogen sulfide and water vapor was 0.5145%. This decrease was resulted from the interaction between biogas and the adsorbent surface in the form of activated carbon, zeolite, gram iron and calcium hydroxide. Compressed biogas can pass a columnar purifier containing the adsorbents then the impurity gas was bounded at the pores of the adsorbent. Meanwhile, the nitrogen content was increased for around 5.926%. It is possibly caused by air contamination, such as the remaining air within the sampling bag, mix of the air during the adsorption process and gas chromatography analysis.

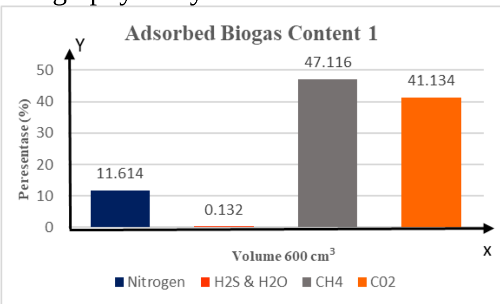

Figure 4. Biogas Composition at adsorben by the volume of 600 cm3

The content of methane gas was increased into 53.128% as shown in Figure 5. Meanwhile, the percentage of gas impurities were also decreased. The decrease occurred in the carbon dioxide gas percentage by 8.2%, hydrogen sulfide and water vapor by 0.402%. Hydrogen sulfide adsorbent was iron gram contaminated with the powder-form calcium hydroxide. When the biogas flew at a pressure of 1 bar, it sprayed the surface of the iron powder coated with calcium hydroxide, thus inhibiting the absorption of hydrogen sulfide.

The higher the pressure used, the more CO_2 gas absorbed (Gunawan, 2017).Reduction in hydrogen sulfide and water vapor content was slightly smaller than the first sample. Meanwhile, nitrogen content was higher than biogas without purification but there was a decrease from sample one in as much as 3.7%.

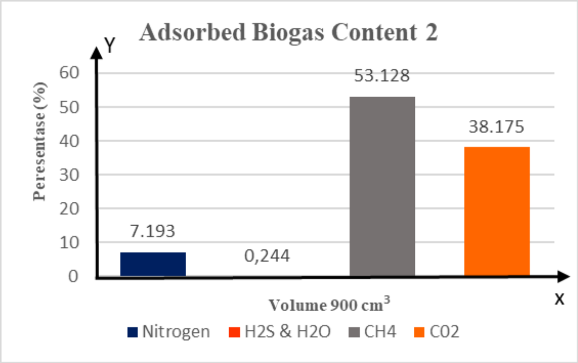

Figure 5. Biogas Composition at adsorben by the volume of 900 cm3

The third sample in this purification process used a volume of 1200 cm^2 which is the maximum capacity of the adsorbent-accomodated device which can be seen in Figure 6. Gas chromatography analysis on the adsorbent at the volume of 1200 cm^3 resulted in the highest methane gas content of 64.275% compared to the adsorbent volume of 600 cm^3 and 900 cm^3 with the value 17.985%. The increase in methane content was directly proportional to the adsorbent volume. The increase adsorbent volume will increase the percentage of methane gas content. This is in accordance with the adsorption factor, namely the surface area (Gao et al., 2016).
Meanwhile, carbon dioxide gas impurity was decreased into 18.15%, hydrogen sulfide gas and water vapor decreased into 0.182% and nitrogen still increased upto 0.317%. The analysis result of this sample showed the high percentage of methane and low gas impurities, which is correlated with the higher quality of obtained biogas.

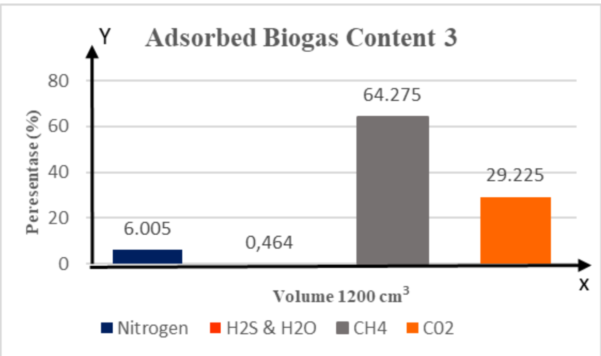

Figure 6. Biogas Composition at the adsorbent volume of 1200 cm3

The decrease in the impurity gas content by giving the absorbent volume variation is the same as the results of the research by (Apriyanti, 2012) that the zeolite adsorbents used were 100 gr, 200 gr and 300 gr. The results showed that the mass of 300 g was the most optimal for CO_2 adsorption. The adsorption process is influenced by CO_2 concentration and flow rate. The higher the concentration and flow rate, the greater the adsorption capacity and absorption

C.Analysis of heating (calorific) value

The heating (calorific) value of biogas can determine the amount of methane content contained within the biogas. The higher the methane content, the higher the calorific value produced. However, when the value of the content is low, the heat (calor) produced is getting smaller (Suprianti, 2016). Observation of the heating (calorific) value both of biogas without and with the purification process can be seen in Table 1.

Table 1. Heating (Calorific) Value of Biogas

Sample	CH_4 Content (%)	Heatinf Value of Biogas (kj/m^3)
Without purification	46.29	1518.312
Purification at adsorbent volume 600 cm3	47.116	1545.404
Purification at adsorbent volume 900 cm3	53.128	1742.598
Purification at adsorbent volume 1200 cm3	64.275	2108.220

Table 1 showed the heating (calorific) value produced without purification process which was lower than that of with purification process. The increase in heating value occurs when adsorbent volume was increased so that the methane content resulted the high heat. Biogas with a methane concentration of more than 45% is a combustible fuel and is quite good because of its high calorific value. However, if the CO2 content exceeds 45%, the biogas will have a low calorific value and the H2S value exceeding 0.5% can cause corrosiveness to the equipment (Sayuti, 2020).Then, Ihsan's study revealed that the fire produced from the combustion of biogas was blue because it contained approximately 45% of methane elements. (Ihsan et al., 2013) Meanwhile, a reddish yellow flame indicated that the CO_2 levels contained in biogas are quite high (Uwar et al., 2012).

D.The Equipment Effectivity to Adsorb CO_2

The installation of a biogas purification device by using a purifier type of equipment which was made by horizontally arranged 4 exhaust filters. Each filter column was filled with a different adsorbent to determine the volume of efficient adsorbent and the effectiveness value of the device in the biogas purification. Adsorption effectiveness stated the ability of the device to adsorb carbon dioxide gas (Gao et al., 2016). The results of the effectiveness calculation can be seen in Table 2.

Table 2. The adsorption effectiveness of the device

Pressure (Bar)	Adsorbent Volume (Cm3)	CO_2 COntent		Effectiveness (%)
		Without Purification	Purification	
1	600	47.375	41.134	11.138
	900	47.475	38.715	17.53
	1200	47.375	29.222	36.865

The effectiveness of the device was increased when the adsorbent volume increases as shown in Table 2. The lowest effectiveness was found in the adsorbent volume of 600 cm^3 which was 11.138% and the greatest effectiveness was found in the adsorbent volume of 1200 cm^3 which was 386.865%. The results showed that the volume variation of the adsorbent could reduce the CO_2 content in biogas.

CONCLUSION

Biogas content which had been purified using activated carbon adsorbent, zeolite, calcium dioxide, gram iron was successful. The adsorbent volume were varied from 600 cm^3, 900 cm^3, 1200 cm^3 resulted in an increase in biogas quality. The largest amount of 1200 cm^3 adsorbent could improve the quality of biogas with the main constituent elements methane gas (CH_4) was increased up to 17.985%. The heating (calorific) value produced from the biogas purification process was 2108.22 kJ/m^3 which had the higher value than unpurified biogas which was 1518.312 kJ/m^3. The higher the methane content, the higher the calorific value produced. Meanwhile, the gas impurities carbon dioxide (CO_2) was decreased into 18.15%, H_2S and H_2O were also decreased. Therefore, the largest adsorbent volume, the higher the percentage of methane the gas content. Meanwhile, the device effectiveness of the carbon dioxide adsorption will increase when the volume of the adsorbent increases. This good quality biogas can be used directly on cooking and lighting equipment without causing corrosion.

This study is necessary to activate the adsorbent in order to increase the ability of the adsorbent to adsorb and characterize the adsorbent after being used as a methane gas purifying agent.

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