Effect of Water Volume and Biogas Volumetric Flowrate in Biogas Purification Through Water Scrubbing Method

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***Abstract*—Energy supply is a crucial issue in the world in the last few years. The increase in energy demand caused by population growth and resource depletion of world oil reserves provides determination to produce and to use renewable energies. One of the them is biogas. However, until now the use of biogas has not yet been maximized because of its poor purity. According to the above problem, the research has been carried out using the method of water absorption. Under this method it is expected that the rural community is able to apply it. Therefore, their economy and productivity can be increased. This study includes variations of absorbing water volume (V) and input biogas volume flow rate (Q). Raw biogas which is flowed into the absorbent will be analyzed according to the determined absorbing water volume and input biogas volume rate. Improvement on biogas composition through the biogas purification method was obtained. The level of CO_2 and H_2S was reduced significantly specifically in the early minutes of purification process. On the other hand, the level of CH_4 was increased improving the quality of raw biogas. However, by the time of biogas purification the composition of purified biogas was nearly similar to the raw biogas. The main reason for this result was an increasing in pH of absorbent. It was shown that higher water volume and slower biogas volume rate obtained better results in reducing the CO_2 and H_2S and increasing CH_4 compared to those of lower water volume and higher biogas volume rate respectively. The purification method has a good promising in improving the quality of raw biogas and has advantages as it is cheap and easy to be operated.**

Keywords—Biogas, CH_4, CO_2, H_2S, water absorption

I. Introduction

In the last few years the continuously uninterrupted supply of energy has been a crucial problem in Indonesia. The increase of energy demand which is caused by population growth and acceleration in industries has pressured the government to explore much new and alternative energy to maintain the development. One of the alternative energy is biogas. Biogas is a promising energy among other alternative fuels as it is renewable with abundant feedstock and can be produced in rural area with relatively low operational cost [1, 2]. Therefore, biogas can be the solution for this renewable energy promotion scheme as well as an alternative for reduction of greenhouse gases emissions.

Biogas, a clean and renewable from of energy can be a good substitution of conventional sources of energy which are causing ecological-environmental problems and at the time depleting at a faster rate [3, 4]. Biogas is the combustible gas produced through an anaerobic digestion at low-temperature and without oxygen. Thus it application includes electricity, heating and cooking. On the other hand, there is lack of good management of the ever-increasing amounts of manure solid and liquid waste in many communities. Most of the rural communities discharged the manure without treatment directly onto wasteland or into rivers and streams. This behavior leads to unhygienic environment with attendant bad odors and flies [5]. With appropriate treatment, the manure can be converted into biogas. Biogas is defined as mixture of gases, consisting of methane (CH_4), carbon dioxide (CO_2), hydrogen sulfide (H_2S) and traces of other gases like nitrogen (N_2), oxygen (O_2), hydrogen (H_2) and ammonia (NH_3). The composition of biogas depends on the organic material as well as on the conversion technology used, varying between 50-75% CH_4, 25-45% CO_2, and 0-20 000 ppm of H_2S [6].

From the constituents of biogas, CH_4 and CO_2 are the main compounds in determining the quality of biogas. If the level of CH_4 is high, the biogas will has higher calorific value. On the other hand, if the level of CO_2 is high, the quality of biogas will be worse, marked by lower calorific value. Therefore, to improve the calorific value of biogas in order to be used effectively as fuel, the level of CO_2 should be reduced or eliminated [6]. On the other hand, H_2S, a kind of highly toxic and corrosive gas, inhibits the biogas process directly, as well as indirectly in the case of higher H_2S concentrations in digester. To avoid the negative effects of H_2S, a reduction of H_2S concentration in biogas is required before combustion [6, 7].

Removal of CO_2 and H_2S from biogas is the main factor to improve the biogas quality [8]. To pursue this aim, a purification method is required to treat raw biogas. Some biogas purification methods have been performed, and water scrubbing method can be a solution as it is a simple and cheap method among the methods [9].

Apart from cheap and simple, the water scrubbing method is easy to use specifically for cattlemen in rural areas. It is possible as the method use simple technology. Therefore, applying the biogas purification method is expected triggering the productivity and economy of rural community.

II. EXPERIMENTAL PROCEDURE

A. Raw biogas

The raw biogas used in the experiment come from anaerobic process in a digester located in the Renewable and New Energy Laboratory, engineering faculty Mataram University. The raw material for the biogas is from cow dung. The ratio of cow dung and water for biogas production in digester is 1 : 1. According to the previous experiment, it was found that this ratio could produce maximum biogas volume in relatively shorter period of anaerobic process. The produced biogas is then flowed to a receiving-station before directed to biogas scrubbing unit. Before colleting the experimental data of purified biogas, data of raw biogas components such as CO_2, H_2S and CH_4 was taken. The value for each component was 33.6%, 208.33 ppm and 59.36% respectively for CO_2, H_2S and CH_4.

B. Experimental variables and equipments

The experiment was performed by applying some variations such as biogas volume flow rate and water volume. The biogas volumetric rates were Q_1 = 1 lt/min, Q_2 = 2 lt/min, and Q_3 = 3 lt/min while the water volume was 10, 15 and 25 liters. The data were taken continuously for 30 minutes long for each operating condition. The research also has a purpose to know the relative humidity of the purified biogas as the contact with water may rise the relative humidity of biogas.

The component of biogas was measured using a biogas tester (GEO TECH) which measured compounds such as CH_4, CO_2, O_2 and H_2S with accuracy level of ± 0.5% vol. The relative humidity of purified biogas was measured using humidity sensor (SHT 11) which has ability to measure humidity under temperature range from -40 to 123 ^{o}C. The range of humidity measurement starts from 0 to 100%. To increase the biogas stream pressure which goes to scrubbing unit, biogas vacuum pump model BP-01 equipped with double-stage-pump was used. Biogas volume rate was measured accurately using biogas dedicated flow meter which has ability to measure flow rate until 4 m^3/hr.

C. Biogas scrubbing unit.

The biogas scrubbing unit used for the research has 250 mm long, 250 mm wide and 750 mm high. The unit was made from glass in order to observe visually the flow pattern governed by biogas in absorbent. The biogas input channel was located downstream at the top of the unit to allow the absorbent and biogas has longer contact. The schematic diagram of the unit is shown in Figure 1 below.

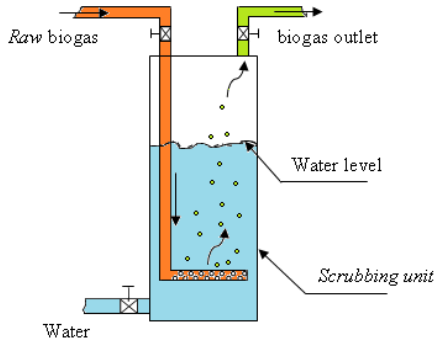

Figure 1. Schematic diagram of water scrubbing unit

The scrubbing unit was set up and connected to measurements apparatus and other components as can be seen in Figure 2 below.

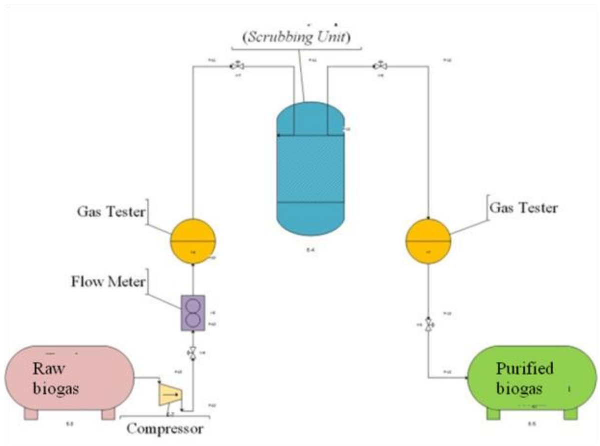

Figure 2. Schematic diagram of experimental setup

III. RESULTS AND DISCUSSION

A. Methane (CH_4)

Methane is the main component in biogas and can reach as much as 55% after anaerobic process in digester [10].

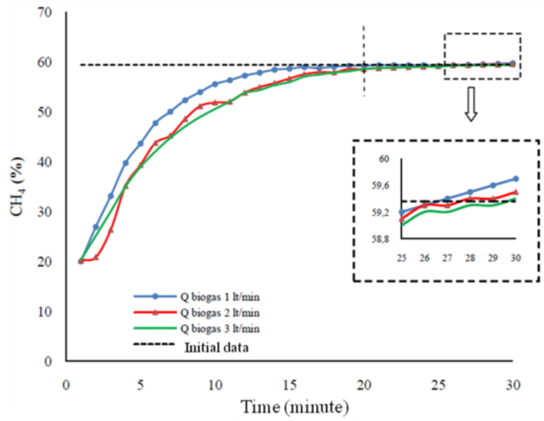

Figure 3. Methane concentration at 15 liter of water volume

This percentage is considered relatively low for heating and as a fuel purposes. The experiment results show that the level of methane before purification is 59.36%. However, after the purification process, the level of CH_4 was increased. Results show that the concentration of CH_4 was improved to 60.4% where reached in the operating condition of 25 liter of water volume and 1 lt/min for biogas volumetric flow rate respectively. Additionally, the lowest improvement for CH_4, it was of 59.36%, was gained in operating condition of 15 liter of water volume and 3 lt/min for biogas volumetric flow rate respectively (Figure 3).

It was shown that the higher water volume, the higher content of methane in biogas (Figure 4). It is resulted by the longer contact time occurred between water and biogas molecule in higher water volume operating condition. The contact between molecules leads to the absorption of the impurities substances in biogas into water molecule. Under higher water volume, the rate of reaching the higher methane concentration is faster compared to that of lower water volume (Figure 5).

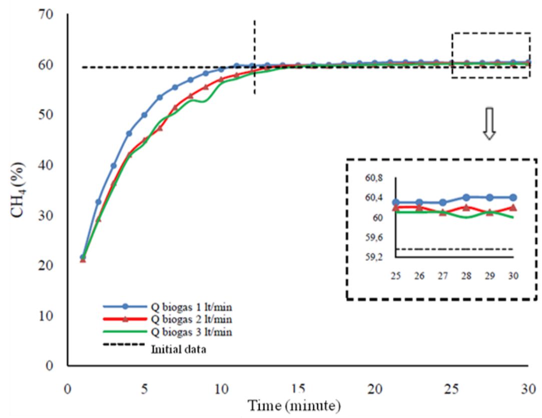

Figure 4. Methane concentration at 25 liter of water volume

However, the level of methane is maintained at constant rate even without more improvement. This is resulted by the maximum portion of acid substances absorbed into biogas molecule. This is indicated by the increase of acidity level of absorbent water. The change of water acidity brings the ability of absorbent water down to minimum. Therefore, it is required to maintain the absorbent acidity, pH 7 is the best for biogas scrubbing, in order to keep the absorbent water performance.

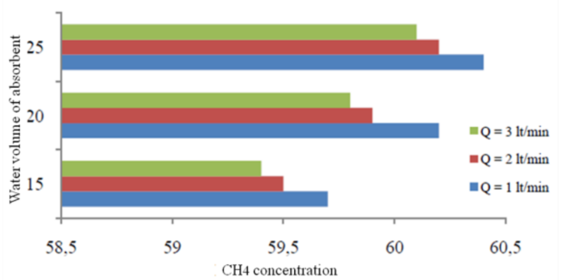

Figure 5. Methane concentration at different water volume with varied biogas volumetric flow rate

The increase rate of methane concentration in the experiment is not too high. This is due to methane is dissolved into water molecule and hence reducing the methane content in purified biogas. However, the dissolved rate of methane is higher compared to those of carbon dioxide and hydrogen sulfide. Methane solubility rate in water at 10 °C is 42 mg/liter of water. The solubility of methane in water decreases along with the increase of water temperature [11].

The results show that in the early minutes of data collection, from 10th to 18th minute, the methane concentration is relatively low. The air concentration in the top of scrubbing unit is still exist at the beginning of measurement. Therefore, from early minutes to 10th minute, most of the gas measured comes from air.

B. Carbon dioxide

Carbon dioxide is an impurities gas which has relatively high percentage in biogas. Carbon dioxide is an unburned gas and therefore resulted in the calorific value of biogas reduce significantly. The more CO_2 in biogas, the less calorific value of biogas is. In order to improve the biogas calorific value, reducing the content of CO_2 through biogas purification is a must. Carbon dioxide is a water-soluble gas. At room temperature, the solubility of carbon dioxide is about 90 cm^3 of CO_2 per 100 ml water (Shakashiri, 2014). The application of water scrubbing method is expected to improve the quality of biogas by reducing carbon dioxide content.

The research showed that the most effective condition to reduce CO_2 was gained at 25 liter of water volume and 1 lt/min of biogas volumetric flow rate. While 15 liter of water volume and 3 lt/min of biogas volumetric flow rate showed the least effective to improve biogas quality as shown in Figure 6 and Figure 7.

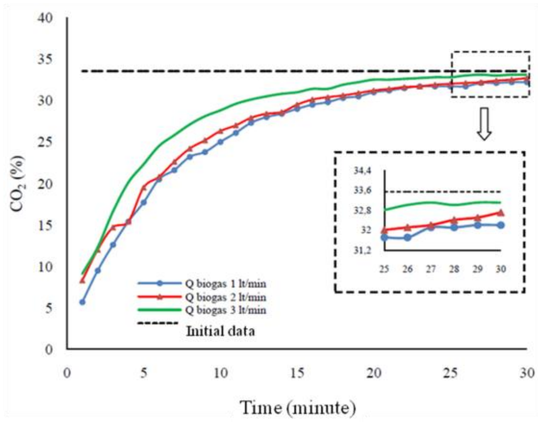

Figure 6. Carbon dioxide concentration at 15 liter of water volume

Slower biogas volumetric flow rate leads carbon dioxide dissolve in water faster than that of higher biogas volumetric flow rate. It is shown in Figure 8. This condition provides longer contact time between water and biogas which results more carbon dioxide molecule in biogas absorbed into water. This could be happen as biogas stream is upward to the top where the biogas outlet inside the scrubbing unit is positioned at the bottom of the unit and thus develops high mixing rate between biogas and water.

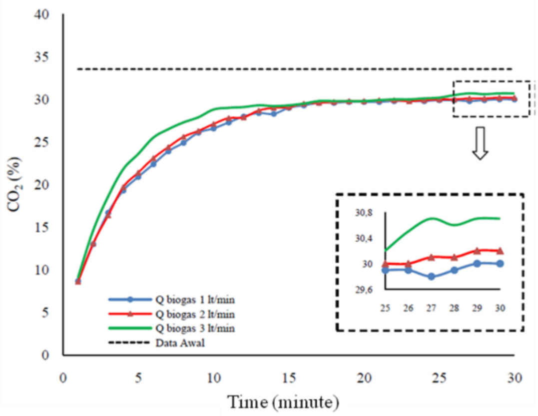

Figure 7. Carbon dioxide concentration at 25 liter of water volume

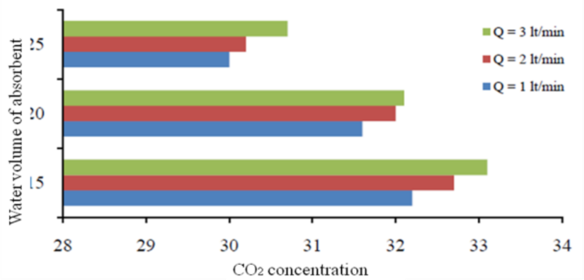

Figure 8. Carbon dioxide concentration at different water volume with varied biogas volumetric flow rate

Higher mixing rate occurred mainly due to slower biogas flow rate triggered faster reaction of molecules bonding among water, CO_2 and H_2S molecules. This increased the partial pressure of the molecules to water molecules creating relatively strong bond among the molecules. Supported by higher water volume, the previous acid water created by CO_2 and H_2S content in water was minimized. This condition made the concentration of CH_4 in biogas increased.

C. Hydrogen sulfide (H_2S)

Although the concentration of hydrogen sulfide is very small in biogas but it has adverse effect both to environment and health [12]. Combustion of H_2S leads to sulfur dioxide emissions which have harmful environmental effects. Removing H_2S as soon as possible is recommended to protect downstream equipment, increase safety, and enable possible utilization of more efficient technologies such as combustion engines and fuel cells [13].

Hydrogen sulfide dissolves in water under 437 ml/100 ml of water at 0 ^oC and 186 ml/100 ml of water at 40 ^oC [14].

Before purification process, the concentration of H_2S in biogas is 208.33 ppm, and reduced to 151 ppm after the treatment. Similar to carbon dioxide result, the highest reduction of H_2S is gained in slower biogas volumetric flow rate (1 lt/min) and higher water volume (25 liter) as shown in Figure 9. Other results at 15 and 20 lt/min are shown in Figure 10. However, after about 20 minutes the productivity of absorbent decreased as the measured H_2S in biogas almost similar to initial raw biogas. It indicated that the absorbent has been filled with H_2S, CO_2 and other impurity gases from biogas. Therefore, this method is feasible to be applied for biogas purification specifically in the early measuring time. For longer continuous-measurement, a modification and improvement are required not only to scrubbing unit but also to operating conditions to obtain better results.

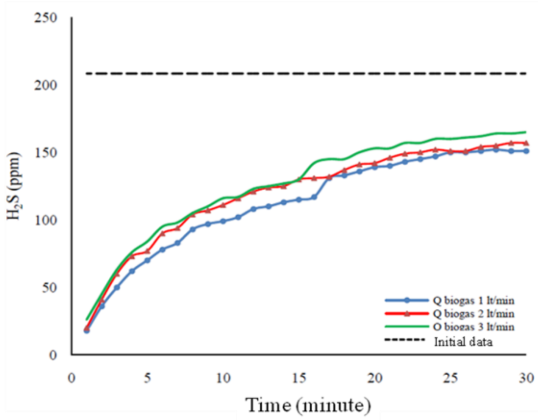

Figure 9. Hydrogen sulfide concentration at 25 liter of water volume

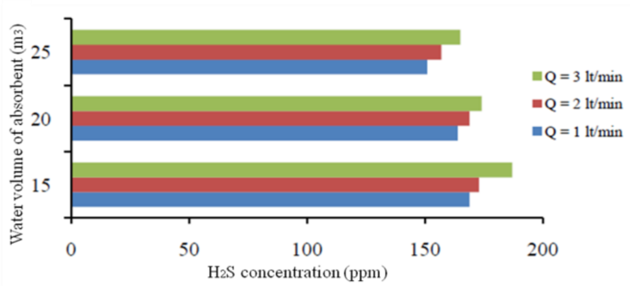

Figure 10. Hydrogen sulfide concentration at different water volume with varied biogas volumetric flow rate

Despite the water scrubbing method has an advantage in removing CO_2 and H_2S from raw biogas, it has a weakness as the moisture content in biogas increases (result not shown). A physical reaction between water and biogas resulted in more water molecules are attached to the biogas molecules. For this reason an improved water management technique is desirable to obtained better biogas quality.

On the other hand, like the moisture content, pH samples from the purified biogas were increased, ranging from 8 to 6 (result not shown). The most significant pH drops were noticed at slower biogas volumetric flow rate (1 l/min) and lower water volume (15 liter). One possible explanation for this phenomenon is longer contact between biogas and water. A drop in pH is an indication of an increase the water acidity due to CO_2 and H_2S dissolve in absorbent. The largest decrease of pH were noticed when the CO_2 and H_2S in purified biogas were high. The major reason for this is the absorbent has reached the ultimate point to absorb the compounds.

IV. SUMMARY

Biogas purification through water scrubbing method is promising. This method is feasible as it can improve the biogas quality by reducing the biogas impurities compounds such as CO_2 and H_2S. Moreover, this method has low operational cost, durable and easy to be operated. This allows rural communities to apply this method for gaining their own energy resources. The research has found that the most effective condition to achieve the best results is running the experiment at slower biogas volumetric flow rate and higher water volume. At this operating condition the CO_2 can be improved up to 10.5%, and H_2S up to 27.5%. A further research is required to make this method more promising and efficient as the reduction of CO_2 and H_2S is occurred at the early minutes of measurement. Maintaining the pH of absorbent and eliminating moisture content of purified biogas are also a challenge in order to obtain high quality of biogas.

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