

Biogas purification using water scrubber with variations of water flow rate and biogas pressure

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Abstract. Biogas is a form of alternative energy which can be obtained from the anaerobic degradation process of organic materials. The presence of CO₂ in biogas needs to be removed to increase its CH₄ concentration, which simultaneously increasing its calorific value and biogas qualities. This study used the water scrubber method to absorb CO₂ and separate it from the CH₄ contained in biogas. The variables used are the biogas pressures of 2, 3, and 4 bar and water flow rates of 0.1 and 0.15 L/s with a contact time of 60 seconds. The results of this study showed that the greatest effectiveness in both CO₂ removal of 99.5 percent and CH₄ increase of 38.18 percent were obtained at biogas pressure of 4 bar and water flow rate of 0.15 L/s. The most effective results of CO₂ biogas removal were obtained at greater biogas pressures and water flow rates.

1. Introduction

In general, the composition of biogas consists of 50-70 percent methane (CH₄), 25-45 percent carbon dioxide (CO₂) with the rest including H₂S gas and trace elements [1]. The main component which has a relatively high energy content is methane (CH₄) gas which can be used as fuel in combustion process. However, the percentage of methane and other gas is relatively low due to large amount of carbon dioxide (CO₂) gas present. This can becomes an issue caused by the characteristics of carbon dioxide that can reduce the heat value and interferes with the combustion process. One of the solutions to reduce the content of carbon dioxide (CO₂) is by the water-scrubbing method.

The water-scrubbing method is one way to improve the quality of biogas. The method is based on the physical effects of dissolving gas in liquids with water medium. In the process, carbon dioxide (CO₂) and hydrogen sulfide (H₂S) within the biogas will be absorbed by the water because these gases have greater solubility in water than methane gas (CH₄) [2].

The water-scrubbing method is carried out using a column in which the absorption process will occur. Biogas is inserted at high pressure from the bottom of the water scrubber column while a controlled flow of water is streamed from the top of the scrubber column, producing a contra-flow scrubbing process. There is an advantage in working at high pressure rather than at atmospheric pressure. The advantage is that solubility of CO₂ in water will increase due to higher pressure. This results in less of the amount of water used [2].

Other advantages from biogas CO₂ separation via the water-scrubbing process is the practicality, low investment costs, environmentally friendly processes and the effectiveness in removing carbon dioxide within the biogas. In addition, this method is also a continuous process and will simultaneously carry out a hydrogen sulfide (H₂S) washing process [3] [4]. The concentration of H₂S in biogas decreased



significantly with water level and increased with biogas flow rate through the water scrubbing. It was an effective technique for removing H_2S in a short operation time, but absorption capability of water declined rapidly with time [5].

Cooling of the water will increase the CO_2 sorption, whereas decreasing the operating pressure lowers the flow of water. However, the water flow is only dependent on temperature dependent solubility constant of CO_2 [6]. From the experiments that have been carried out test results obtained when the water temperature 20°C the content of H_2S was 0.7 ppm when the water temperature 17°C H_2S content was 0.6 ppm when the water temperature 15°C H_2S was 0.5 ppm. So, the lower of the water temperature in the water scrubber system, also increasing the reduction of levels of H_2S [7]. Some novel technologies such hydrate separation, biotechnologies (biofilter/biotrickling filter and insitu upgrading), cryogenic separation, and chemolithotroph-based bioreactors (which can convert CO_2 from the biogas into methane). This is particularly possible by the conversion of excess electricity grid power during the night into H_2 to serves as electron donor for the chemolithotroph-based bioreactors [8]. Regarding biogas purification using a water scrubber without considering contact time between the CO_2 gas and water, the research was able to reduce CO_2 content from 42.3 to 31.0 percent and increase the CH_4 content from 19.3 to 28 percent [9]. The water scrubbing technology which involves the use of a water scrubber with an additional modification which is the iron wool packed bed has been proven to achieve 82 percent purified biogas by reducing carbon dioxide and hydrogen sulfide. CO_2 was reduced from 31 percent to 14 percent while H_2S was reduced from 1 percent to 0.4 percent [10].

The water scrubber packed with sponge carriers instead of conventional packing materials, which has the advantage of increased hydraulic retention time for the scrubbing water. The results of biogas purification experiments indicate that the proposed scrubber can perform high purification even under atmospheric conditions. An artificial biogas of 60 percent methane is purified to more than 90 percent methane with no hydrogen sulfide detected; this quality level is acceptable for use as city gas [11].

In this research, the process of absorption of biogas CO_2 with a water scrubber will be carried out by varying the biogas pressure and the water flow rate with a specific contact time. The pressure measurement is the pressure of the gas that enters the water scrubber column. This research expected to obtain a more effective CO_2 absorption and greater percentage of CH_4 gas in the final product.

2. Methodology

The research was carried out using a water scrubber. The water scrubber column is a single phase type, equipped with a 13-mm Rashing ring. Rashing rings are known for the most commonly used in the gas separation process and easier to make as well. The maximum working pressure of the scrubber column is 10 atm [12, 13]. The specifications and dimensions of the water scrubber are as follows:

- Water scrubber material: Iron
- Column height: 97.5 cm
- Column diameter: 5.5cm
- Column packing: rasching ring 13 mm x 13 mm.

The steps of the water scrubber process carried out are as follows: first test the maximum column pressure followed by leak examination by flowing the biogas at a pressure of 8 bar; second is the initial sampling before it gets passed through the water scrubber as a control; and then third by testing the water flow rate variations of 0.1 and 0.15 L/s combined with biogas pressure variations of 4 bar, 3 bar, and 2 bar with contact time of 60 seconds and finally sampling after it gets passed through the water scrubber. Biogas composition testing was carried out using a gas chromatography.

At the time of testing, open the water valve until flow rate is constant, then open the gas valve at a desired pressure and allow the water and biogas to come into direct contact for about 60 seconds. Note that the openings of the water supply valve and the bottom valve of the water scrubber must be opened regularly so that the pressure in the column can be kept balanced to ensure there is neither over pressure nor pressure loss. The installation scheme of the water scrubber testing process is shown in Figure 1.

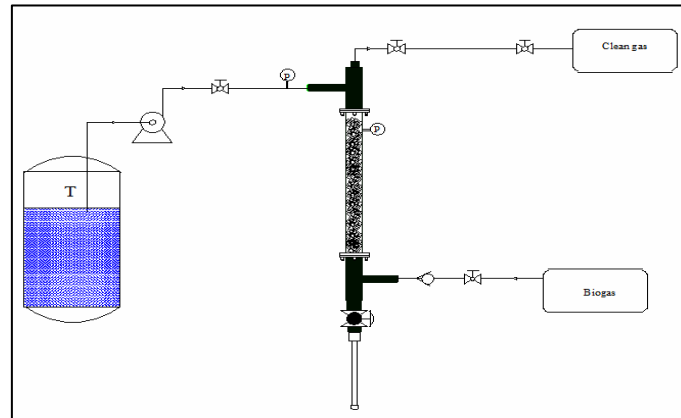


Figure 1. Water scrubber installation.

3. Results and discussion

3.1. Biogas testing

Before testing the absorption or the removal of CO_2 biogas with a water scrubber, biogas is first tested for its composition. The initial biogas composition (before passing through the water scrubber) is shown in Table 1.

Table 1. Initial biogas composition.

No	Parameters	Composition (percent)
1	CO_2	20.1
2	N_2	20.8
3	O_2	7.1
4	CH_4	51.1

Tests are carried out with variations of absolute biogas pressure of 4 bars, 3 bars and 2 bars, and variations in the water flow rate of 0.15 L/s and 0.1 L/s with a contact time 60 seconds. The biogas composition of the test results after passing through the water scrubber is shown in Table 2.

Table 2. Biogas composition after passing through the water scrubber.

Biogas Pressure (bar)	Water Flow Rate (L/s)	Biogas Composition (percent)			
		CO_2	N_2	O_2	CH_4
2	0.10	15.7	21.9	6.7	54.7
	0.15	15.0	21.1	7.8	55.2
3	0.10	8.0	19.8	9.2	63.3
	0.15	6.7	19.5	7.4	66.1
4	0.10	1.7	21.9	8.2	68.1
	0.15	0.1	22.0	7.3	70.6

3.2. Effectiveness of CO_2 absorption and of CH_4 increase in biogas

Based on the data in Table 3 it can be calculated the effectiveness of CO_2 absorption and the effectiveness of increasing CH_4 using a water scrubber. It is done by comparing the difference in

composition of CO₂ or CH₄ composition before and after passing the water scrubber divided by the composition of CO₂ or CH₄ before passing the water scrubber. The results of the calculation are shown in Table 3.

Table 3. The results of the calculation.

Biogas pressure (bar)	CH ₄ Increase (percent)		CO ₂ Absorption (percent)	
	Q1 ^a	Q2 ^b	Q1 ^a	Q2 ^b
2	7.1	8.1	22.1	25.5
3	23.8	29.3	60.0	66.5
4	33.3	38.2	91.6	99.5

^a Water flow rate 0.1 L/s.

^b Water flow rate 0.15 L/s.

3.3. The effectiveness of CO₂ absorption

The effectiveness of CO₂ absorption shows how effective is the absorption of CO₂ by water within the water scrubber. Based on the test results data in Table 3, the graph in Figure 2. shows the relationship between the effectiveness of CO₂ absorption after passing through the water scrubber on the variations of biogas pressure and water flow rate.

From Figure 2. it can be seen that the effectiveness of CO₂ absorption of biogas increases along with higher biogas pressure and water flow rate. This is because when the pressure used is high enough, the contact between gas and water in the column will be more effective. The pressure within the column water scrubber and the reaction time affect the CO₂ absorption process as well. At the time of the testing, the pressure in the column should be maintained as to not become over-pressured nor drop back to atmospheric pressure (under-pressured). These conditions may lead to flooding and causing the contact between the gases and water within the column to become not optimal. The contact between the biogas and the water causes the CO₂ in the gas, which has a higher solubility compared to CH₄, to be absorbed into the water. With the water flow rate raised, the water will fill the water scrubber column which in turn makes the contact area even greater.

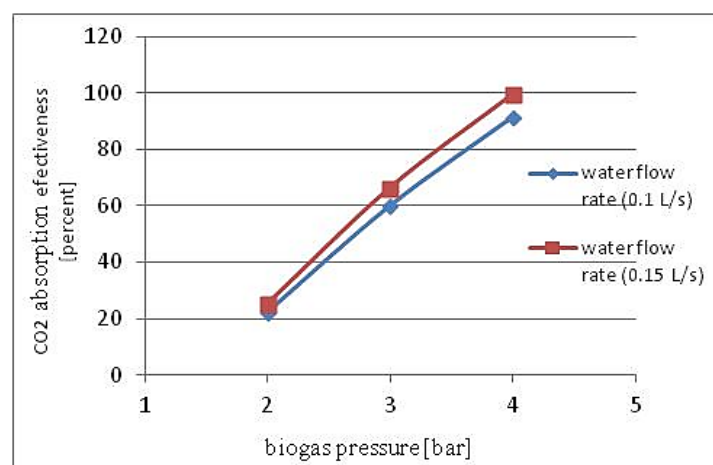


Figure 2. Increased absorption of CO₂ at higher water flow rate.

From the test results it was obtained within a pressure of 2 bar a 22.1 percent effectiveness of CO₂ absorption for a water flow rate of 0.1 L/s and a 25.47 percent effectiveness for a water flow rate of

0.15 L/s. Meanwhile, within a pressure of 3 bar it resulted in the effectiveness of CO₂ absorption at 60 percent and 66.46 percent at water flow rates of 0.1 L/s and 0.15 L/s respectively.

The highest percentage of 99.5 percent in CO₂ absorption where it has reached the optimal condition is obtained at 4 bar pressure and water flow rate of 0.15 L/s along with a decrease in CO₂ composition from 20.1 percent to 0.1 percent (Table 2.), while the absorption of CO₂ at a pressure of 4 bar with a water flow rate of 0.1 L/s is 91.6 percent.

3.4. Effectiveness of CH₄ increase

The effectiveness of the increase in CH₄ shows how effective the CH₄ increase from before purification and after purification pressure variations of 2 bar, 3 bar and 4 bar with water flow rate variations of 0.1 L/s and 0.15 L/s respectively. Based on the result data in Table 3, it can be obtained a graph of the relationship between the increase in the methane gas content after passing the water scrubber with various biogas pressures and water flow rates as shown in Figure 3.

In Figure 3. it can be seen that the amount of CH₄ after passing through the water scrubber during testing has increased along with the increasing biogas pressure and water flow rate. This is because as the biogas pressure used is becoming greater, it affects the column pressure within the water scrubber. When the column pressure increased, the gases that will come in contact with the water will also increase. When the rate of water flow increases, the contact point between gases and the water will be wider such that the reaction between CO₂ and water absorption will become more effective resulting in increased CH₄ levels. As discussed in the previous point, CO₂ absorption and CH₄ purification are closely related. Within the process it shows that the greater the pressure and flow rate of the water, the easier over-pressuring will occur. This causes the pressure within the column to become unbalanced with the flow rate of water which in turn will push water into the gas reservoir and vice versa. When the water flow is not balanced with the gas pressure, the water will push the gas past through the biogas tube hose. The packing (filling material) in the absorption column will cause resistance to the flow of fluid that passes through the column.

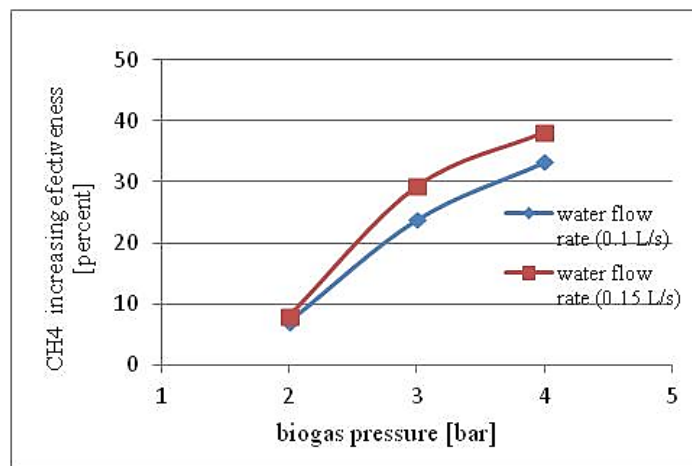


Figure 3. Increased CH₄ at higher water flow rate.

As a result, gas or liquid passing through will experience a pressure drop. Over pressure, however, is caused by the space between the fillers that were originally passed through by the gas, becomes more bypassed by water which in turn will increase hold-up. As a result, an increase in the water flow rate will further cause fluid collection within the upper column (flooding). Therefore, the biogas pressure and water flow rate must be carefully regulated. Unregulated pressure and flow rate may cause the hose and PVC pipe connection at the bottom of the water scrubber to leak. From the test results, the percentage of CH₄ increase is 7.2 percent at a pressure of 2 bar with a water flow rate of 0.1 L/s and 8.1

percent at a water flow rate of 0.15 L/s. While for a pressure of 3 bar the percentage value of CH₄ increase is 23.8 percent at a water flow rate of 0.1 L/s and 29.3 percent at 0.15 L/s. The highest percentage of CH₄ increase is 38.2 percent at 4 bar pressure and water flow of 0.15 L/s while for a water flow rate 0.1 L/s the percentage is 33.3 percent.

In the water scrubber test, the higher the biogas pressure and the water flow rate used, the easier shocks and leaks will occur. This can be seen at a pressure of 4 bar percentage of nitrogen (N₂) rising in amount to 22.0 percent from the initial 20.9 percent. Increased nitrogen levels can have an effect on the CH₄ purification process, where the desired CH₄ content does not increase in percentage, but instead decreases due to the presence of nitrogen indicated by the mixture of outside air due to leakage.

From the results it is also can be seen that the initial O₂ and N₂ gases (Table 1) and after passing the water scrubber (Table 2) tend to be constant and not decrease. This indicates that O₂ and N₂ gases are not absorbed by the water scrubber. This is because the solubility of O₂ and N₂ gas in water are very small.

4. Conclusions

The greatest effectiveness in both CO₂ removal of 99.5 percent and CH₄ increase of 38.2 percent were obtained at biogas pressure of 4 bar, water flow rate of 0.15 L/s and contact time 60 seconds. The most effective results of CO₂ biogas removal were obtained at greater biogas pressures and water flow rates.

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