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Application of microbubble technique for CO_2 and CH_4 entrapment in biogas

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Abstract

Biogas has been found as the alternative renewable resource to replace fossil fuels, which contains 53-70% of CH_4, 30-50% of CO_2 and other gases. Water scrubber is the most popular technique for biogas cleaning due to economic and also high purification output. This research aimed to investigate biogas upgrading by using microbubble that generated from a developed swirl nozzle. The water flow rates were controlled of 10, 15, 20, 25, 30 and 35 litre/min. The bubble varied in the range of 50.44-116.04 µm for entire experiment. CO_2 removal from pilot scale by entrapping CO_2 reached 83.06%, and CH_4 was recovered to 96.26% at conditions of 35 litre/min of water, 0.1 litre/min of constant gas flow rate. Finally, flow characteristics form simulation result inside reactor including with nozzle part were discussed to understand flow phenomena.

Keywords**:** *biogas, CH_4, CO_2, microbubble, microbubble generator, microbubble technique, water scrubber*

1. Introduction

Due to increasing fuel prices, greenhouse gas emissions, and high energy demands from the ever-increasing developing world, the new and high technology for process developments of sustainable and renewable resource energy were needed (Fan, Liu, & Wang, 2016; Kainiemi, Eloneva, Toikka, Levänen, & Järvinen, 2015; Mao et al., 2014). Biogas has been exploited as one of the alternative sources of renewable energy that has potential to supplement the current energy requirements. Its advantage shown that the physical and chemical properties were similar to those of natural gas. The biogas potential was able to replace natural gas in all applications such as the production of heat, electricity, and can use as vehicle fuel or NGV (Natural Gas Vehicle). Biogas was also economical and environmentally advantageous because it helped minimize land, water, and air pollution by utilizing waste to produce energy.

Biogas was normally obtained by anaerobic digestion process of organic matter. The typical compositions contained of CH_4 (53–70 %), CO_2 (30–50 %) by volume (Xiao et al., 2014), and other compounds such as H_2S, and NH_3. Due to its flammability and renewability, biogas production and utilization have increasingly been seen as an emerging alternative energy technology. However, raw biogas still needed several purification processes to reach application standards, involving removal of CO_2 and other trace gas compounds.

There were four main techniques to remove impurities from biogas (Serejo, et al., 2015). First, Pressure Swing Adsorption (PSA) was a sensitive process that required H_2S removal before the adsorption which could harm the adsorbing material. It also incurred some high cost of operation. Second, cryogenic separation was not often to use as it required a number of process equipment such as heat exchangers, turbines, and compressors irrespective of the fact that it produced upgraded gas of high purity. It also had the highest cost of purification, which compared to the other techniques. Third, membrane separation was also used widely because it yielded high methane quality gas. Although it yielded high purity gas that was often achieved by increasing the number of modules, which leaded to lose methane. Finally, Chemical absorption was often preferred in industrial applications because it had high efficiencies, removed H_2S completely, operated at low pressures, and had higher reaction rates (Andriani, Wresta, Atmaja, & Saepudin, 2014).

2. Objectives

The objective of the present study was to investigate the new technique to purify biogas from small-scale biogas plants by entrapping CO_2

and CH_4 recovery including of developing nozzle that used to generate the swirling flow. The condition to create microbubble and size measurement were also experimented. Amount of CO_2 removal and CH_4 recovery were used to assess the ability to use microbubble technique for biogas upgrading. Moreover, flow simulation was also conducted to explain the flow phenomena.

3. Materials and methods

3.1 Experimental setup

The pilot scale was set as shown the flow of circuit and experimental apparatus in Figure 1. An acrylic column reactor of 1 m high and 20 cm of diameter for biogas upgrading system was connected horizontally with microbubble generator at the bottom. For water flow circuit, 1 hp centrifugal pump was used to circulate water as a media to upgrade the biogas. The water flow rates were varied of 10, 15, 20, 25, 30 and 35 litre/min. Water inlet temperature was controlled via PID control unit, which was set at 25 °C. The flow rate was adjusted by ball valve which installed at the discharge section and was monitored from rotameter. For raw biogas flow section, the room temperature gas was flowed vertically into reactor from the base of microbubble generator, which connected from low-pressure raw biogas container. When water pump was started to circulate the flow of water circuit, raw biogas was drawn into the microbubble generator by influencing of low-pressure that generated from swirling flow inside the generator. After water temperature was constant, the gas inlet was released to let into microbubble generator. For present study, constant gas flow rate was kept at 0.1 litre/min.

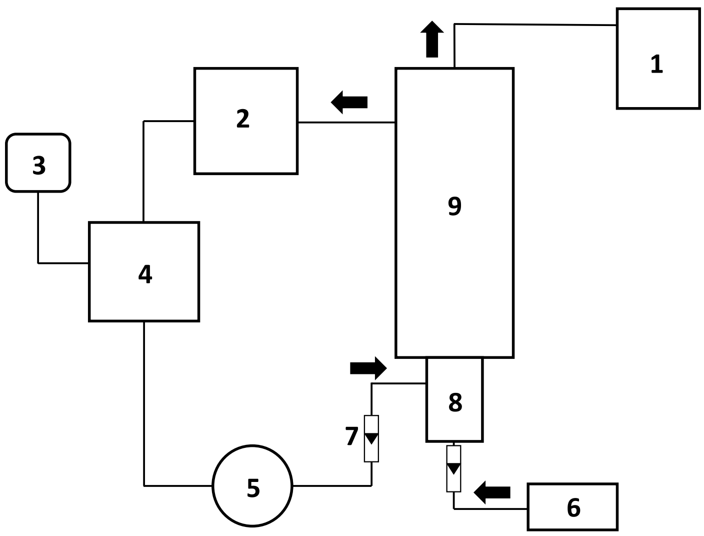
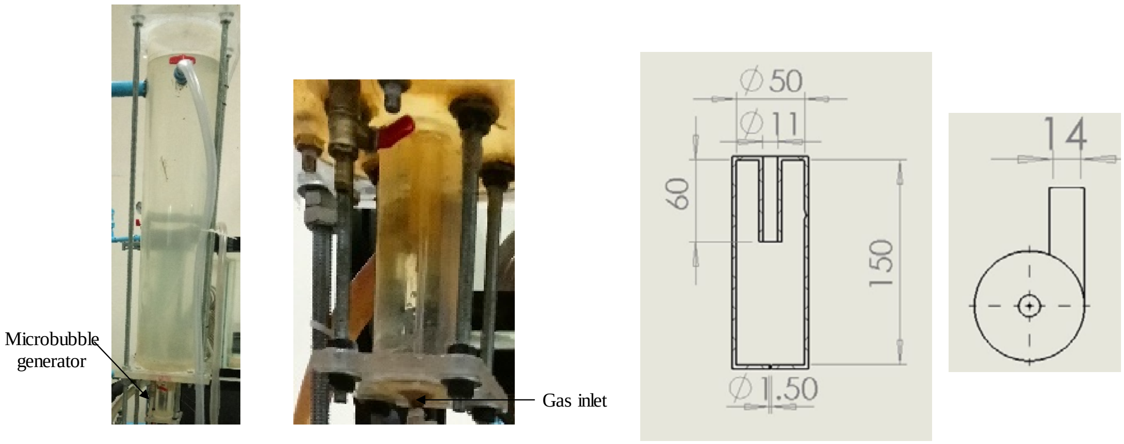


Figure 1 Flow circuit (blue: water, orange: gas) and experimental apparatus of biogas upgrading pilot scale: (1) biogas analyzer, (2) cooling unit, (3) temperature control unit, 4) heater chamber, (5) pump, (6) raw biogas container, (7) gas flow meter, (8) microbubble generator and (9) reactor

Duration of gas scrubbing was 15 min before taking the sample to analyze the gas product. Then upgraded gas product was sucked by potable gas analyzer (Geotech, Leamingon, UK) from the upper section of reactor to analyze the gas quality (Fernández-Delgado, et al., 2018).

3.2 Microbubble generator

Figure 2 shows the actual image of reactor and microbubble generator. Water inlet (nozzle) with diameter of 14 mm was attached horizontally at tangent generator wall. Swirling flow of injected water due to the attachment position of nozzle induced raw gas at the bottom from gas container to mix with water for scrubbing purpose.



(1) (2) (3)

Figure 2 Actual image of: (1) water column and (2) microbubble generator and (3) details of microbubble generator

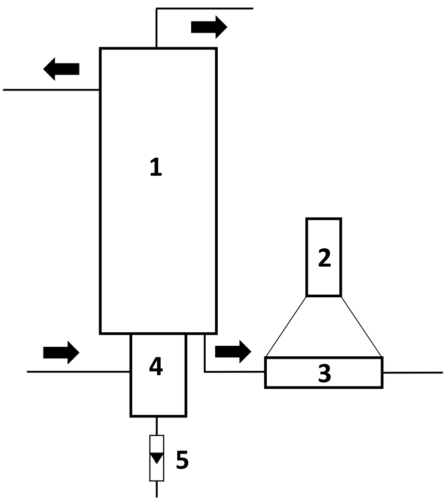


Figure 3 Experiment setup for bubble size measurement (1) Water column, (2) microscope camera, (3) glass chamber, (4) microbubble generator and (5) flow meter

3.3 Microbubble size measurement

Microbubble in the sampling water inside the glass chamber was measured by using high resolution camera as shown the details of the process in Figure 3. The grass chamber dimensions were 12 width, 16 long and 0.2 cm thickness. Image processing method via MATLAB coding was employed to average the bubble diameter from the sampling picture that taken from high microscope camera which 1000x magnification and 5.0 megapixels resolution. For each of water flow rate, the sampling water was drained every 15 min from reactor to measure bubble size. An average diameter of bubbles was received from 10 sampling pictures.

3.4 Biogas upgrading evaluation

The CO_2 removal efficiency and CH_4 enrichment of different compounds were calculated from equation (1) and (2), respectively:

$$CO_2 \text{ removal } (\%) = \frac{(C_r - C_p)}{C_r} x100\% \quad (1)$$

$$CH_4 \text{ enrichment } (\%) = \frac{(C_{p(CH_4)} - C_{r(CH_4)})}{C_{r(CH_4)}} x100\% \quad (2)$$

where $C_{r(CH_4)}$ is the content of compound in raw gas, $C_{p(CH_4)}$ is the content of compound in product gas.

3.5 Computational method

The governing equations for mass, momentum, energy, turbulent kinetic energy (k) and the specific dissipation (ω) are discretized in a three-dimensional computational domain to yield a set of algebraic equations, which are solved by imposing the boundary conditions with the second order upwind scheme using Ansys-Fluent 15.0. SIMPLE algorithm has been employed for pressure velocity coupling to solve pressure correction equation. In the present study, the SST k-ω turbulence model has been used (Ashok, Arnab, & Patro).

4. Results and discussion

This topic presents the experimental results of biogas upgrading from the pilot scale which employs the developed microbubble generator to induce the gas inlet automatically by affecting of swirling flow.

4.1 Flow characteristics

Figure 4 shows velocity streamline for water flow 35 litre/min at center-plane of reactor and bubble generator from simulation result. The swirling flow form the generator induces the gas inlet from inlet at the bottom. Consequently, high velocity is injected into reactor. Large counter rotating flow is established due to shear force effect. This phenomenon presents to all cases of water flow rate. After high velocity stream merges into large volume of water inside reactor, the laminar flow is presented at the middle section. For upper section, stream lines are compressed at the outlet while top section region shows the quiescent fluid.

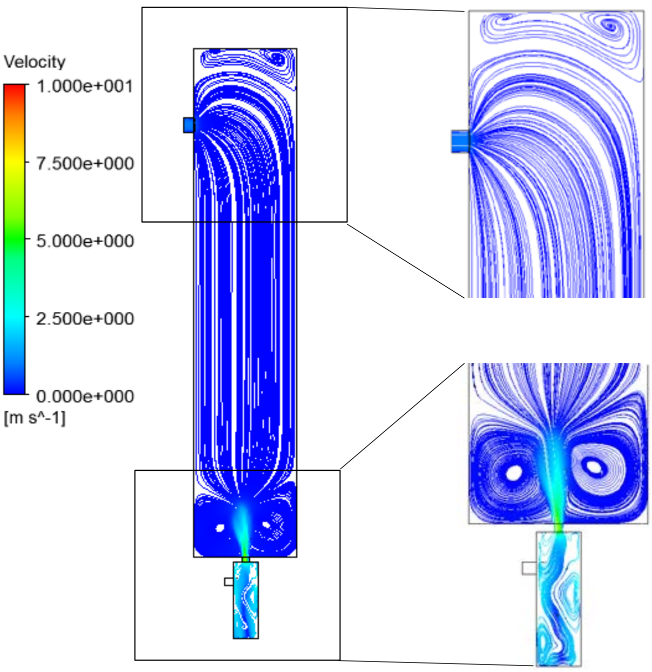


Figure 4 Velocity streamline at the center plane

4.2 Generated microbubble

Figure 5 shows the sampling bubble that take from the glass chamber by using microscope camera. The results show that the size is decreased when water flow rate is increased. Every bubble that present in this picture is accounted to calculate bubble diameter. It is notice that regardless the result of bubble density. Nevertheless, high density bubble can be seen for high water flow rate condition, i.e., 30 litre/min and 35 litre/min.

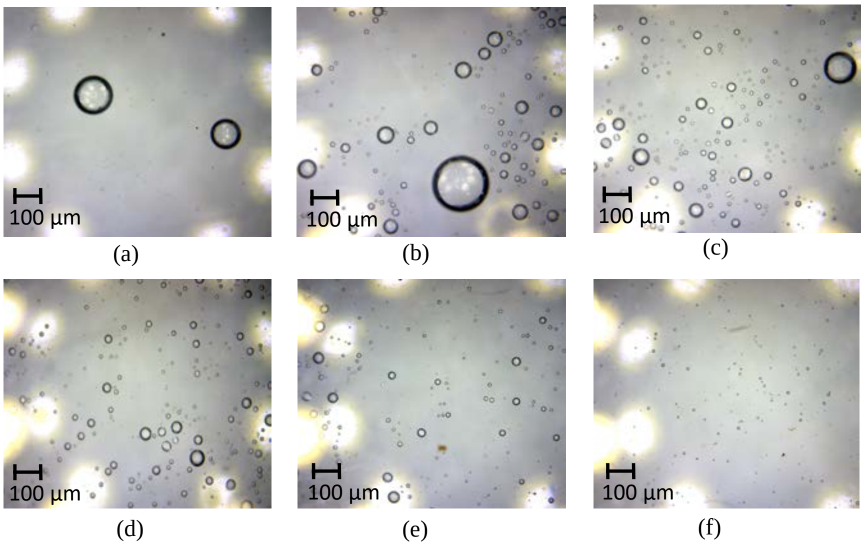


Figure 5 Sampling bubble from microscope camera in cases of water flow rate (a) 10 litre/min, (b) 15 litre/min, (c) 20 litre/min, (d) 25 litre/min, (e) 30 litre/min, (f) 35 litre/min.

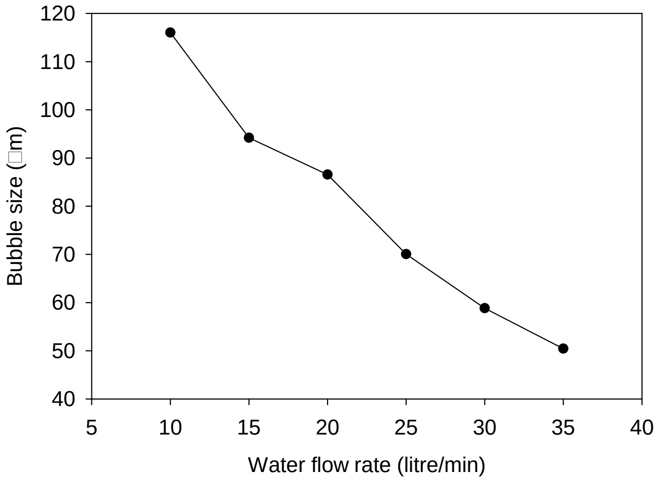


Figure 6 Bubble size of each water flow rate

Figure 6 shows the average dimeter of the bubbles according to the water flow rate. The range of the bubble size lies between 50.44-116.04 µm for entire experiment. According to the raw picture, smaller bubble are achieved from increasing the water flow rate. Almost half of size decreasing is obtained by adding the flow from 10 litre/min to 35 litre/min. At the higher water flow rate the different of bubble size was decreased.

4.3 Biogas upgrading

Figure 7 shows the effect of water flow rate to the CH_4 enrichment. The maximum of CH_4 enrichment is obtained at water flow rate of 35 litre/min. This result shows that the smallest bubble dominates to enrichment factor. At 30 minutes from the staring of the upgrading process, the enrichments for all water flow rate show reach to the maximum. It is concluded that the bubble size does not affect to maximum enrichments time.

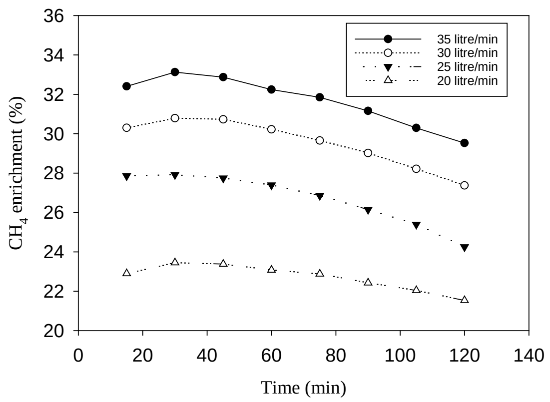


Figure 7 Amount of CH_4 recovery according to the testing time

To consider the factors of simplicity and economic, these four methods were rather complex process. Water scrubbing was the most popular used technology for biogas cleaning and upgrading due to simple and economic (Thrän et al., 2014). The maximum CH_4 enrichment shows in figure 6 is 33.13% at 30 minutes after purification which CH_4 content before purification was higher than 70%. The CH_4 enrichment can be improved from low CH_4 concentration before purification. The comparison of different pilot and commercial biogas upgrading parameters are shown in the Table 1.

Table 1. Comparison of different pilot and commercial biogas upgrading technologies

Considered parameter	PSA	Water scrubbing	Physical scrubbing	Chemical absorption	Membrane separation
Consumption for raw biogas (kWh/Nm^3)	0.23-0.30	0.25-0.30	0.2-0.3	0.05-0.15	0.18-0.20
Consumption for clean biogas (kWh/Nm^3)	0.29-1.00	0.30-0.90	0.4	0.05-0.25	0.14-0.26
Heat consumption (kWh/Nm^3)	None	None	< 0.2	0.50-0.75	None
Heat demand (°C)	-	-	55-80	100-180	-
Cost	Medium	Medium	Medium	High	High
CH_4 losses (%)	< 4	< 2	2-4	< 0.10	< 0.60
CH_4 recovery (%)	96-98	96-98	96-98	96-99	96-98
Pre-purification	Yes	Recommended	Recommended	Yes	Recommended
H_2S co-removal	Possible	Yes	Possible	Contaminant	Possible
N_2 and O_2 co-removal	Possible	No	No	No	Partial
Operation pressure (bar)	3-10	4-10	4-8	Atmospheric	5-8
Pressure at outlet (bar)	4-5	7-10	1.3-7.5	4-5	4-6

Figure 8 presents amount of CO_2 removal relating to the water flow rate. The result indicates that the water flow rate does not significant affect to CO_2 removal while the trends of the results show similar pattern that reach the maximum values at the 30 minutes of running process and continuously decline after that. The mean values from the present study is deviated of ± 10 % from the result of previous study (Xiao et al., 2014).

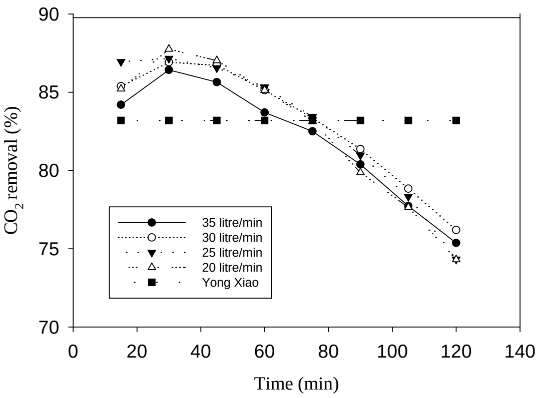


Figure 8 CO_2 removal for gas flow rate of 0.1 litre/min

5. Conclusions

The experiment of biogas upgrading was conducted from the pilot scale in the laboratory. Based on the experiment results, the following main conclusions can be stated:

1. Water flow rate direct affects to bubble size, which is obtained smaller bubble from the higher water flow rate.

2. Bubble size affect to amount of CH_4 recovery due to increase contacting area of biogas to water. Moreover, smaller bubble has lower floating speed which benefit to the enrichment. For CO_2 removal, the water flow rates show less affect to the removal value.

3. The swirling flow form the developed microbubble generator induces the gas inlet automatically from inlet at the bottom. This benefit could be impacted to apply for applications extend.

6. Acknowledgements

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