Separating Methane and Carbon Dioxide from Household Biogas

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Abstract

The purpose of this study is to separate carbon dioxide from biogas at different pressures to obtain higher methane concentration for household use by mean of anaerobic fermentation of swine manure to produce biogas in four tanks of 200 liter fermentation tanks and to store in two tanks of 200 liter gas storage tanks. From the study, it was found that behavior of carbon dioxide capture affected in a direct variation. In other words, as gas pressure increased, percentage of carbon dioxide capture would increase also. In the portion of gas flow rate, it affected behavior of carbon dioxide capture in an inverse variation, that is, when gas flow rate decreased, the carbon dioxide capture percentage increased. From the results of the experiment, pressure swing adsorption (PSA) capture techniques were selected to capture carbon dioxide which was captured by molecular sieving carbon with 99.23% maximum CO_2 capability before passing through methane separation unit. As for methane separation to increase concentration from the experiment, methane gas was originally contained approximately 65-68 % biogas; after the gas separation process, concentration rose to 98.26 % or about 33.85 % increase from the original concentration. Therefore, if upgrade methane is compressed in a storage container, it can be used in a variety of functions, such as fuel for cars, households cooking and etc.

Keywords:

Biogas Separation, Biogas for Household, Methane, Carbon Dioxide

1. Introduction

Biogas is a clean energy that is generated from all kinds of wastes such as animal manure [1], wastewater from animal farms, wastewater from industrial factories and plants producing high organic wastes such as cassava starch factories, a palm oil mills, canned fruit factories, sugar processing factories, and alcohol distilleries, Included also are slaughterhouse wastes, municipal wastes and restaurants and other food establishment wastes. Biogas is produced through the fermentation of the wastes, which is an organic degradation process [2]. When environmental condition is suitable, enough biogas can be produced to generate heat and electrical power [3]. Currently, biogas is already widely produced from the treatment of wastewater from animal farms, high organic wastewater load from small and large industrial factories with, and municipal wastewater from general communities.

Use of biogas for cooking in households has become part of promoting households to produce biogas for their own use. Efforts are done to increase the methane concentration in biogas to obtain a fuel with a higher heating value for less cooking time [4].

Biogas is about 60-70% methane (CH_4), 30-40% carbon dioxide (CO_2), with rest consisting of hydrogen sulfide (H_2S) and Nitrogen Gas (N_2) [5]. Methane has thermal properties allowing it to be used as a renewable energy source. It is a gaseous fuel that can be used for cooking, to drive cars and other small vehicles [6], and if produced in large amounts, even as fuel for the industrial sector [7].

Degradation of organic matters produces biogas, but the amount generated is dependent on the types of organic matter being decomposed [8]. For example, it is hard to generate gas from fresh plants compared to animal manure, since the manure is already partially degraded by the digestive systems of the animals; thus, bacteria can degrade manure more quickly [9].

When studying biogas production from farms around the world, we found out that about 50% of methane emissions into the atmosphere causes 23 times higher greenhouse gas emission effects, compared to the effects of carbon dioxide coming from the combustion of hydrocarbons [10]. Therefore, the impact of using biogas, which contains high amounts of methane, as a renewable energy source, is to reduce GHG emissions into the atmosphere [11].

In addition, biogas can replace natural gas, natural gas can then be used more for industrial purposes rather than burned as a fuel. The composition and average properties of natural gas and biogas from various sources are shown in Table 1 [12].

Table 1 The composition and average properties of natural gas and biogas.

Compounds	Biogas	Landfill Gas	Natural gas (Danish)*	Natural gas (Dutch)
Methane (vol-%)	60 –70	35 – 65	89	81
Other hydro carbons (vol-%)	0	0	9.4	3,5
Hydrogen (vol-%)	0	0-3	0	–
Carbon dioxide (vol-%)	30 – 40	15 – 50	0.67	1
Nitrogen (vol-%)	~0.2	5 – 40	0.28	14
Oxygen (vol-%)	0	0-5	0	0
Hydrogen sulphide (ppm)	0 – 4000	0 –100	2.9	–
Ammonia (ppm)	~100	~ 5	0	–
Lower heating value (kWh/nm3)	6.5	4.4	11.0	8.8

*Average during 2007

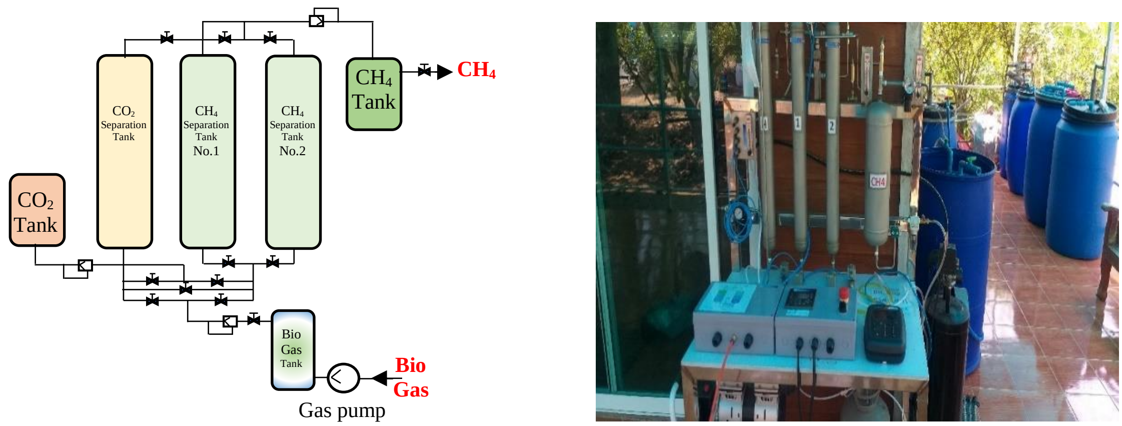
The table shows the two gases that are useful contained in biogas and natural gas The first is of CH_4 (about 60-70 %) which is generally used in the heating form .The second is CO_2 (30-40 %) which can be used for a wide range of applications, such as in the food industry [13].

2. Study Methodology

2.1. Description of tests done with the anaerobic digester

The proportion of manure mixed with vegetable waste or food waste was set as follows: 2 parts of animal manure was fermented with 3 parts of food wastes (that is, a ratio of 10 kg to 15 kg), and then 20-30 liters of water was added to adjust C/N (carbon/nitrogen) ratio [14].

The raw materials and water were mixed and the fermentation period was set to about 15-30 days. Fermentation of swine manure to produce=d biogas was performed using 2 sets of aerated biogas digester: two of 200- liter gas fermentation tanks and one of a 150-liter gas storage tank. Thirty kg swine manure and 30 liters water were gradually put into each fermentation tank. Gas was produced within 7-15 days. There was much air than methane inside the gas storage tank later, so a vent valve was opened to release the air [15]. After 15 days, biogas from swine manure was produced at112 liters per batch, see Fig.1 (b) showing biogas fermentation from pig manure.



(a) (b)

Fig.1 (a) Diagram of biogas separation and (b) Separation equipment set of Methane, Carbon Dioxide and other gases.

Fig.1 (a), it shows how methane and carbon dioxide in biogas are separated as conducted in this study. The gas pump sucked the produced biogas into the biogas tank at a required pressure (pressure ranges at 1, 2 and 3 bar) [16] and then, the biogas was sent further to the carbon dioxide gas separation tank. At this stage, the carbon dioxide gas was absorbed by the black cylindrical carbon molecular sieve with particle size of 2.800 – 1.180 mm. and density of 705 kg/m^3 [17]. The quantity of sieving carbon used in CO_2 separation tank was 0.86 kg. Some CO_2 was sent to the carbon dioxide tank [18]. The methane gas then rose to the top to be stored in the methane tank; however, partial amounts of carbon dioxide were still mixed with methane [19]. Therefore, to increase methane concentration as required, the gas separation procedure was repeated by circulating the methane gas from methane separation tank No. 1 to the carbon dioxide separation tank again and then the “upgraded” methane gas was stored in the methane tank [20]. The methane separation tank No. 2 was reserved for storing biogas with pressure higher than 3 bar. (The highest pressure of biogas for this study was 3 bar.) For this fermentation experiment on biogas from swine manure, the biogas was analyzed using the portable gas analyzer: Biogas 5000. The detailed composition and the average properties of biogas are shown in Table 2**.**

Table 2 Composition and average properties of biogas from the study.

Gas	Biogas
CH_4 (%)	65-68
H_2 (%)	0-3
CO_2 (%)	15-50
N_2 (%)	5-40
O_2 (%)	0-5
H_2S (ppm)	0-310
Heating value, MJ/Nm^3	15.5

In general, desulfurization is the first step to purify biogas by removing H_2O and CO_2, especially when considering biogas purification technique for removing impurities, and the removal of large amounts of water and CO_2 [21, 22]; However, this depends on the specific technology used for methane separation [23]. Before using biogas, it should be purified to less than 2-4 % carbon dioxide in content, particularly as fuel for home cooking and vehicles.

The process of purifying biogas from carbon dioxide separation is the most expensive that will be considered in this article. This selected technique: pressure swing adsorption method is the process in which biogas is compressed between 1 - 3 bar pressure (in this study) and is fed to CO_2 separation tank and is exposed to the absorbent [24]. H_2S is primarily trapped by a metal fiber before entering the CO_2 tank. CO_2 is selected and retained by the absorbent, which is in the form of porous solids and usually with a large surface area. The absorbent in this process is a pelletized form molecular sieving carbon. Its unique diameter characteristic consists of a porous compressed carbon particle surface to absorb gas mixture. This allows for production of pure CH_4 with very slight pressure drop. After a period, the absorbent in the separation tank becomes saturated with CO_2 and is returned to reabsorption [25]. It can produce high purity gas, and this is mostly used for commercial purposes. Therefore, this process is an alternative way to separate CO_2, which is then kept in storage tanks for further industrial use.

Table 3 Specification of molecular sieving carbon [17].

Item	Unit	Description
Appearance	-	Cylindrical
Color	-	Black
Particle diameter	[mm]	1.8
Loss on drying *	[%]	1.0 max
Particle size * (2.800 – 1.180 mm) (7 - 14 mesh)	[%]	99.0 min.
Hardness *	[%]	98.0 min.
PSA performance of 99 % Nitrogen at 30°C, 0.588MPa		
Cycle time	[sec]	60
Adsorption pressure	[barG]	7-15

3. Results and Discussion

Biogas generation was done with the fermentation of swine manure for 15 days. 1 kg of pig manure was added every day during the first five days of the fermentation process. From day 6 to day 10, this was increased to 2 kg of manure per day. Finally, from day 11 to day 15, this was further increased to 3 kg of manure per day. Data was recorded every day for the 15 days to monitor the biogas production from the fermentation of swine manure.

The generated biogas then went through a separation process to separate methane, carbon dioxide and other gases (see Fig 2).

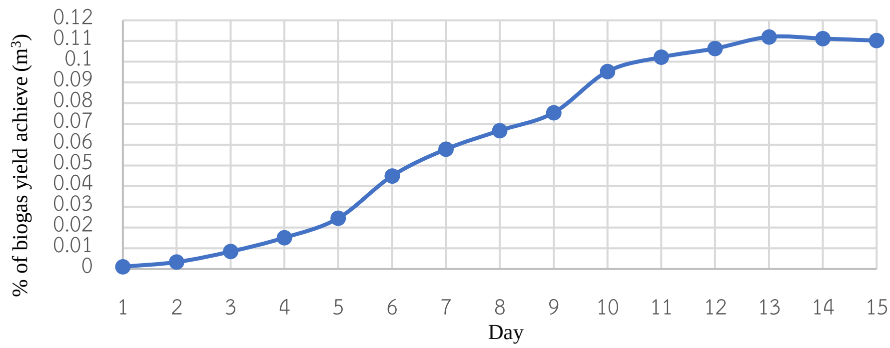


Fig. 2 Comparison of biogas emission from pig manure.

On the average, one kg pig manure produced 0.0105 m^3 of biogas, two kg produced 0.0680 m^3 of biogas, and three kg produced 0.1084 m^3 of biogas.

An analysis of the biogas showed that is composed of 66.6 % methane, 29.0 % oxygen, and 0.6 % the hydrogen sulfide. The biogas contained 371 PPM. See Fig. 3 for graphical presentation of results.

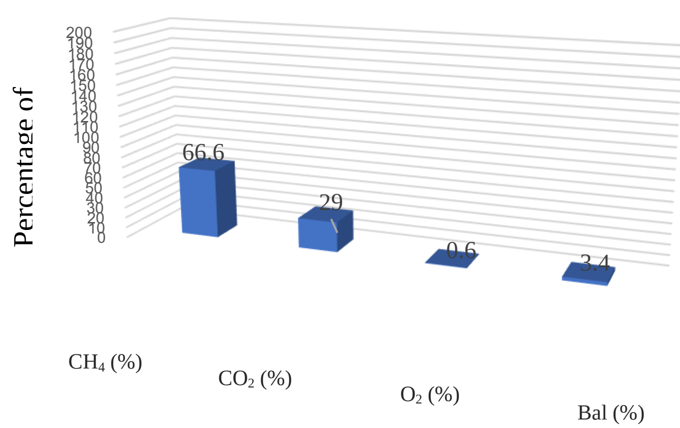


Fig. 3 Gas volumes from biogas fermentation of pig manure before gas separation.

Previous studies of biogas production, showed that biogas with a methane content of 66.6 % and carbon dioxide of 29.0% has on the average a lower fuel heating value at 15.5 MJ/Nm^3. The separation of methane from biogas using a pressure adsorption process to produce pure methane gas will result to a fuel with a higher heating value.

A pressure pump was used to increase the pressure in the biogas as needed (pressure ranges between 1, 2 and 3 bar) and the biogas was then be sent to the carbon dioxide separator tank. In this section, the carbon dioxide was absorbed by a black cylindrical carbon molecular sieve with particle size of 2.800 – 1.180 mm. under a 1.5 second setting of the delay timer.

The system was operated automatically using a programmable logic control system. Methane gas rose or float up inside the methane tank, however, the was methane still mixed with some carbon dioxide. Thus, the process of circulating the methane gas through the methane separator tank for the CO_2 separator process, was repeated. This was a process in which the biogas was compressed to a pressure of between 1 - 3 bars and was then fed to the separation tank to make contact with the adsorbent to retain selectively the CO_2 gas.

Gas mixture adsorption can produce high purity CH_4 gas but with a slight pressure drop. The absorbent used in the separation tank become saturated with CO_2 after a period and is re-absorbed. This process is also a way to extract CO_2 and to store the gas for industrial use.

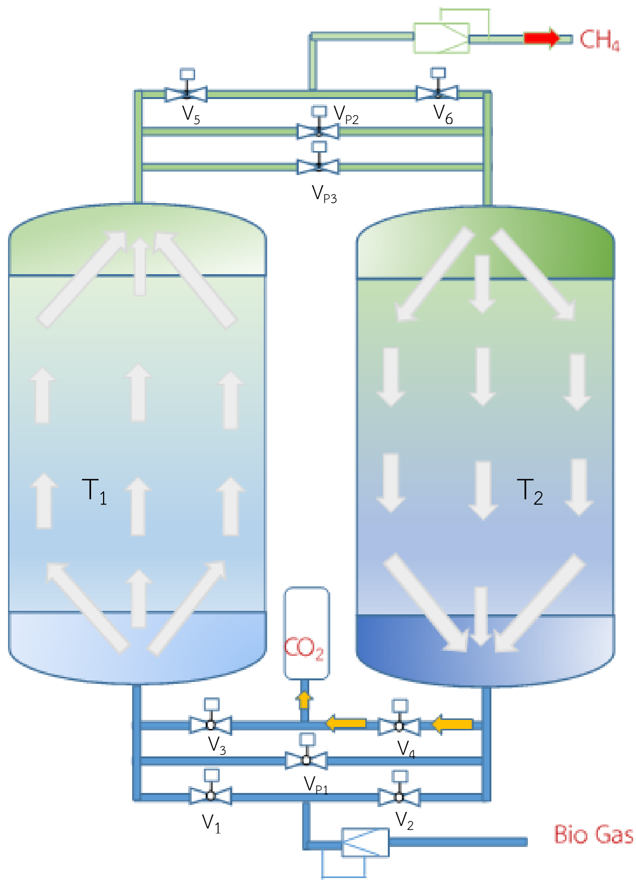


Fig. 4 The process of separating methane and carbon dioxide from biogas.

Fig. 4 shows the gas separation system design and the separation process. The biogas is fed into the system as at the required pressure through a check valve. Valve No. 1 allows the biogas to enter Tank No. 1 (T_1) through a gas separator set. This tank can separate CO_2 and CH_4 and allows pure CH_4 gas to pass through Valve no. 5 into the container. The remaining gas is fed to the Tank No. 2 (T_2) to further separate the CO_2 and CH_4 gas. Then, the remaining gas is fed into T_1 to reduce losses of CH_4 gas. The system work automatically in the separation of CO_2 and CH_4 gases using a programmable logic control (PLC).

At this stage, the biogas is sucked by the gas compressor with a pressure of 1 to 3 bars from the holding tank to test the suitability of the methane volume with applied pressure. The test results are shown in Fig. 5-6.

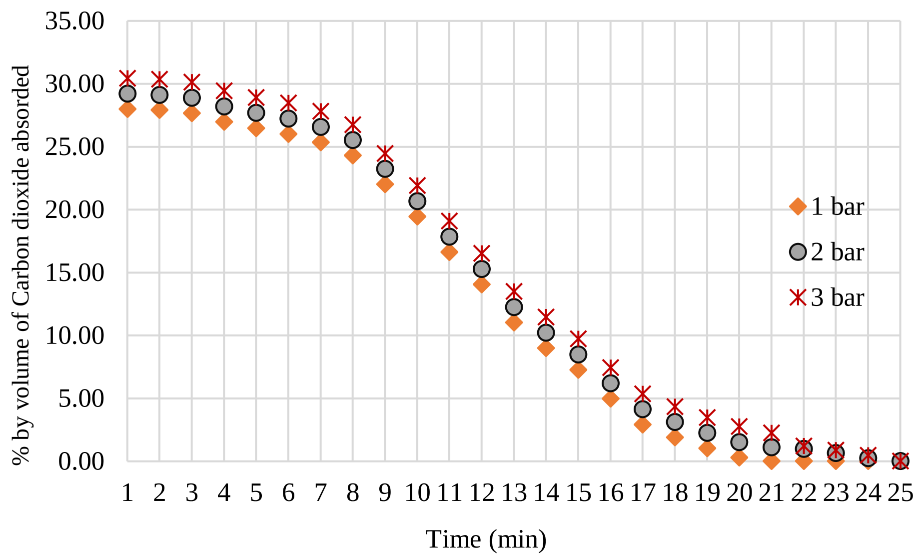


Fig.5 Percent by volume of CO_2 separator at a constant flow rate of 5 liters per minute.

Fig. 5 shows the result of a study of the behavior of the adsorption of carbon dioxide using a pelletized form of molecular sieving carbon. The gas flow rate was 5 liter per minute. The pressure varied from 1, 2 and 3 bar. The study showed that the adsorption of carbon dioxide behavior directly proportional to the pressure as well as the adsorbent saturation time. If the pressure is increased, the maximum carbon dioxide adsorption increased accordingly.

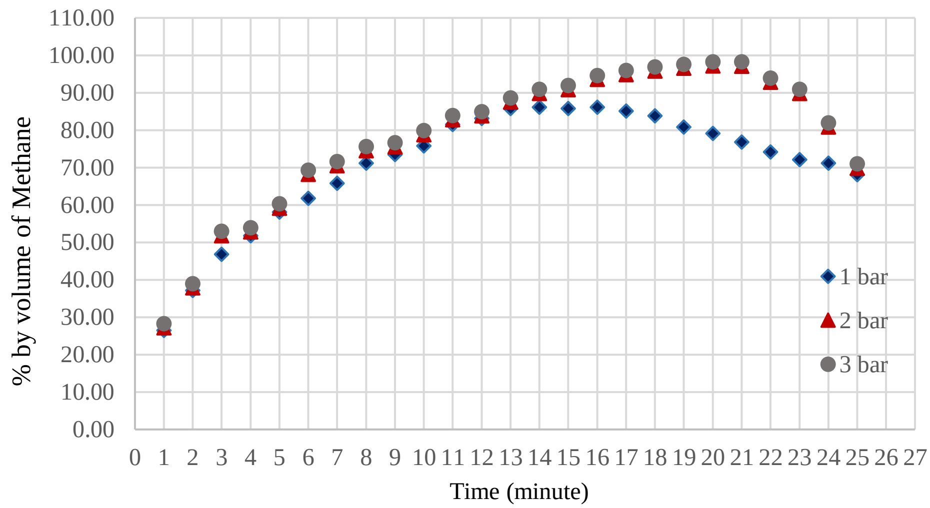


Fig.6 Percent-volume relationship of methane gas separated at a constant gas flow rate of 5 liters per minute.

Fig. 6 shows the result of the study on behavior of the separation of methane gas using a carbon molecular sieve with the following specifications. The gas flow rate was at 1 liter per minute. The pressure values were at 1, 2 and 3 bar. It was found that the methane gas separation behavior was directly proportional to the pressure as well as the saturation time of the adsorbent. If the pressure increased, the maximum carbon dioxide adsorption increased accordingly. At a pressure of 1 bar, the maximum separation potential for methane was at 86.13 %, which was lower than the maximum separation potential of 97.18% at 2 bar and at 98.26% at 3 bar.

This study, however, was not able to do test at a pressures higher than 3 bar because the volume of biogas produced was insufficient [26].

4. Conclusion

The experimental results showed that pressure and gas flow rate affect carbon dioxide capture behavior. Gas pressure directly affects carbon dioxide capture behavior. That is, when gas pressure is increased, the percentage of carbon dioxide captured also increases. On the other hand, the gas flow rate affects the behavior of carbon dioxide capture in an inverse way, that is, when gas flow rate decreases, carbon dioxide capture percentage increases.

If the PSA capture technique is used in the capture of carbon dioxide, the carbon molecular sieve will be able to capture a maximum 99.23 % of carbon dioxide volume before the gas passes through the gas capture kit. Thus, capturing the carbon dioxide and packing it into cylinders for sale, will also be a way to reduce carbon dioxide emissions into the atmosphere [27].

The experimental results also showed that through the CH_4 separation process, the concentration of methane in the biogas can increased from 65-68% to up 98.26%, an 33.85% increase in the original concentration of methane in the biogas. Therefore, if methane is separated and stored in separate storage containers, it can be used for various applications such as for cooking in households and food establishments and as motor fuel for cars and other small vehicles. These applications of methane will also contribute to climate change mitigation by helping reduce emission of greenhouse gases [28, 29].

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