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Analysis of cross-sectional area of digester on biogas production rate

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ABSTRACT

Biogas has become one of the promising alternative fuels. This is triggered by relative ease of production while on the other hand the raw material is cheap and easy to be obtained. In order to get higher biogas production rate, a work has been done with digester cross-sectional area modification. Under the modification an improvement in biogas yield was obtained. The research also has opened up new outlook to set up a better digester design for maximum biogas production. The experimental results showed that a higher biogas volume yield was obtained in larger cross-sectional area compared to that of smaller one. Increasing the cross-sectional area twice will benefit at least three times in terms of biogas volume produced under similar raw material input volume. A wide-open cross-section surface is a major factor for good breeding of microbial to produce methane. Under the condition, microbes experience less pressure due to the evenly distributed volume of the substrate which resulted in a comfortable environment for bacteria.

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1. INTRODUCTION

Recently, biogas production technology has not experienced encouraging developments. Some of the obstacles faced such as lack of technical expertise, the reactor does not function due to leaks or construction errors, improper design, still requires manual handling (feeding or removing sludge from the reactor) and expensive construction costs (Yong et al, 2015). Therefore, it needs a deeper technical and economic study and new approaches in its development.

Various attempts have been made to produce biogas in large quantities for several reasons, such as: fossil energy sources have decreased, environmental quality has decreased due to the massive use of hydrocarbon fuels, the development of technology that utilizes biogas, and a very abundant source of raw materials. Although there are still various obstacles as mentioned earlier, the interest in producing large biogas is supported by the various advantages above. Therefore, efforts to increase the volume of biogas are continuously being pursued. Various efforts to increase biogas production have been proposed and developed. Among the methods to accelerate the rate of biogas production is to use biomass containing thermophilic acetogenic and methanogenic bacteria. Bacteria

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are inoculated before and during the biogas production process. Under this treatment the substance being increased is not the rate of biogas production but the methane content in the biogas. The bacteria used in the work are pure cultures of *caldicellulosiruptor saccharolyticus* and bacteria from animal manure, wastewater sludge and sewage treatment units (Kovacs et al., 2008).

Another effort to increase the methane gas content in biogas is to use an improved two-stage digester design. The substance of this study is not to increase the rate of biogas production but to increase the methane content through a digester design approach to separate hydrolysis and acidogenesis from methanogenesis. It was found that by separating the process stages in anaerobic digestion, the methane concentration was greater than if there was no separation in the process (Hayes et al., 1988).

Another method is an attempt to increase the methane gas content in the biogas by absorbing CO_2 gas from the biogas using the sludge from the digestion of the digester. After stripping the absorbed CO_2 gas, the sludge can be reused for anaerobic digestion in the digester. Through this method, the biogas produced has a methane content above 90% (Sunarso and Budiyono, 2011).

From several studies conducted above, they focused on increasing the methane concentration. Research does not touch or discuss the physical shape of the digester. Based on previous studies, it encourages a study to find answers to the gaps in knowledge about the impact of differences in digester surface area on biogas yield. Although several articles discuss the dimensions of the digester on the resulting biogas production, they do not specifically discuss the impact of the ratio of the cross-sectional area to the height of the digester (Bello and Alamu, 2016; Guimaraes et al., 2018; Manyuchi et al., 2015). The substance of this research is an effort to increase the rate of biogas production by engineering the digester design model.

2. MATERIAL AND METHOD

The substrate used in this study was cow dung. Before being fed into the digester, the substrate is cleaned of various impurities that might interfere during the anaerobic digestion (AD) process takes place. 10% EM-4 of total substrate volume was also given along with the substrate in order to accelerate the fermentation process to obtain a large volume of biogas. Giving EM-4 is in line with previous studies which suggested giving this compound in a certain amount so that the performance of microbes in degrading the substrate increases (Tira et al., 2018)

The level of acidity of the substrate greatly affects the ability of microbes to produce biogas (Elyased et al, 2016). Therefore, before and after the test is carried out, the acidity level is measured. The acidity level of the substrate when put into the digester was neutral. These are the best conditions for achieving optimal results. When the fermentation process takes place in the digester, the acidity of the substrate will increase.

The experimental process will be carried out for 30 days and the measurement of the volume of biogas produced will be carried out every 5 days. Biogas volume measurement is carried out using the water displacement method as shown in figure 1. This method is quite simple but has proven effective measuring the volume of biogas. To monitor the temperature that occurs during the AD process, thermocouples are installed in several parts of the digester. The temperature is maintained constant throughout the process to eliminate the involvement of temperature in the volume of biogas produced. This is because temperature also plays an important role in biogas production (Sole-Bundo et al., 2017).

It is necessary to be able to determine a clear picture of the influence of the surface area of the digester to the activity of microbes to degrade the substrate. There are 4 digester or reactor used in this study with different cross-sectional area. The four digesters can be seen in figure 2. The reactor is made of zinc plate and is made in such a way that it is free from leaks. All reactors have the same volume of 50 liters. Despite having the same volume but each reactor has different cross-sectional area with the ratio of the cross-sectional area and volume of each reactor is as follows: reactor 1 (0,050 : 1), reactor 2 (0,025 : 1), reactor 3 (0,017 : 1), and reactor 4 (0,013 : 1). Because of the difference in the ratio of cross-sectional area and volume, the height of each reactor is also different as seen in figure.

One-way ANOVA analysis is applied to observe and draw accurate conclusions about the effect of the observed change in digester shape.

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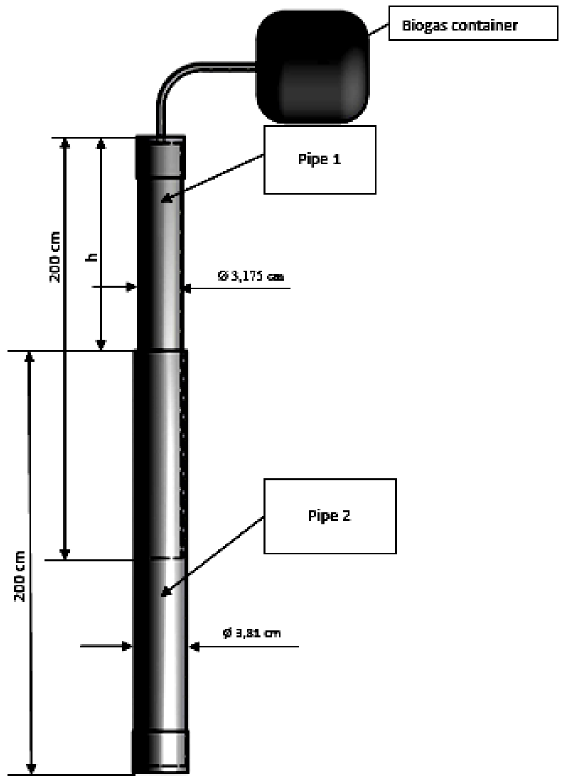

Figure 1. apparatus for measuring biogas volume

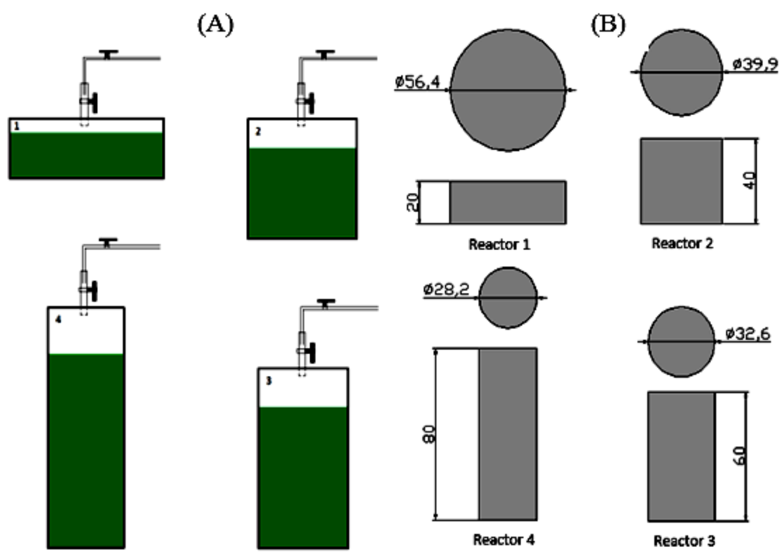

Figure. 2 the cross-sectional shape of the reactor A). side view, B). the cut image with the size

3. RESULTS AND DISCUSSION

Before the substrate is introduced into the reactor, the level of acidity is measured and the results of its pH value of 6.7. This value corresponds to limit the allowable level of acidity substrate ranged between 6.6-7.0. If the pH value of the substrate is outside of the allowable limit, microbial reproduction will be hampered due to unfavorable environmental conditions (Rajput et al., 2019). Changes in pH in the AD process will result in uncontrolled biogas production. At low pH, a number of organic acids will be formed causing less biogas production. at low pH the activity of acidic compounds will be more active which causes the methanogenic process to be inhibited. On the contrary, if the pH is too large or alkaline conditions will hinder metahnogenic activity. This condition will also cause biogas production to decrease (Yang et al., 2015).

The result of the recording in-reactor temperature showed values ranging from 26-30^{o}C (figure 3). This working temperature is categorized as mesophilic condition where the temperature is around the ambient temperature (Kasinski, 2020). The difference in temperature around 4^{o}C is due to different temperature conditions during the day and night. However, this difference is still within tolerance limits so that the temperature difference in the reactor is considered not to affect the final result. The location of the temperature measurement in the digester is carried out at 2 places and expressed in T1 and T2. The methanogenic activity process slightly affects the temperature rise in the digester. The digester temperature increases in line with the biogas production as shown in figure 4. The significant growth of bacteria started on the fifth day and peaks on the fifteenth day, in addition to increasing biogas production, it is also followed by an increase in substrate temperature. This indicates that the biochemical reaction that occurs is an exothermic reaction that releases heat which affects the substrate temperature.

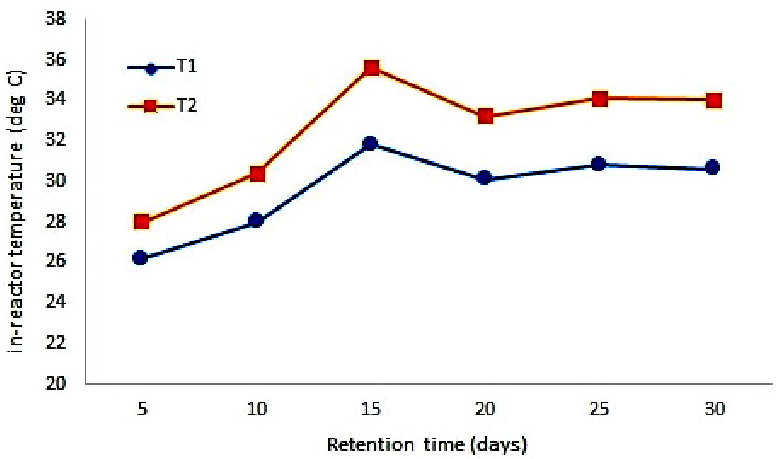

Figure 3. In-reactor temperature profile

Biogas volume measurement results obtained from all reactors indicates that reactor number 1 recorded the best results. Meanwhile, the lowest yield was achieved by reactor number 4 as can be seen in figure 4.

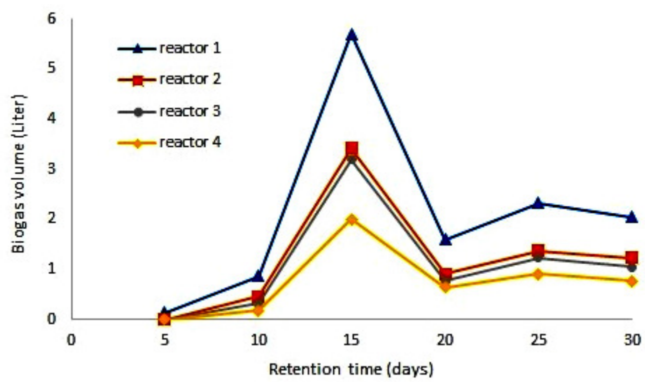

Figure 4. Biogas volume produced from the reactor

Based on the results obtained, it can be stated that the difference in the ratio of the cross-sectional area and volume of the reactor during the AD process greatly affects the production of biogas. From figure 4 it can be seen that reactor number 1 until the fifth day has produced biogas, while biogas has not been produced in other reactors. Biogas production that has not occurred in reactors number 2,3 and 4 indicates that the hydrolysis stage is very slow. Moreover, biogas production began on the tenth day and reached peak production on the fifteenth day. Biogas production then decreases after it has passed the peak production. The decrease in biogas production is most likely caused by the formation of crust on the surface of the substrate. The formation of crust on the surface of the substrate is caused by the water content both from cow dung itself and from water as a substrate mixture. This causes the methanogenic process to be hampered as a result the rate of biogas production slowing down. In reactors 2 and 3, it can be seen that there is a small difference in the volume of biogas production. However, based on the results of the ANOVA analysis, it was found that the calculated F value was greater than the critical F. Likewise, the alpha value or the specified confidence level of 95% gives very little results. This suggests that the difference in the shape of the digester arrangement affects the biogas yield.

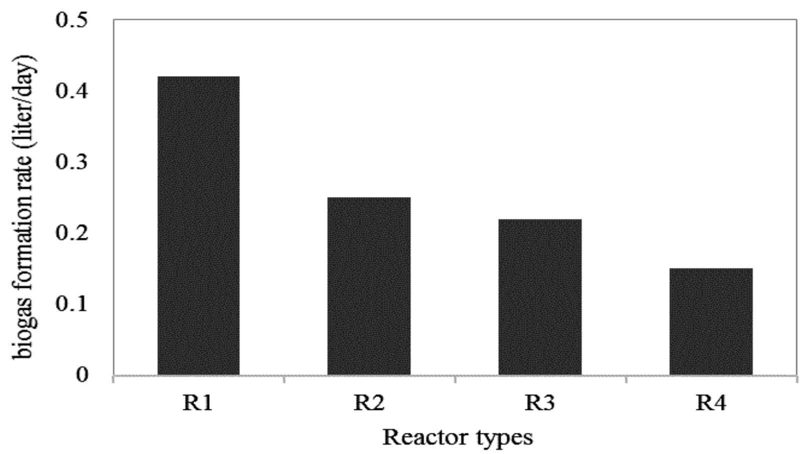

Figure 5. Biogas formation rate for each cross-sectional area ratio

Figure 5 shows the daily biogas formation rate from each different reactor cross-sectional ratio. Reactor number 1 shows the highest yield in terms of biogas production compared to other reactors. This high production rate is due to the fact that the gas molecules formed in reactor number 1 tend to flow more quickly to the surface due to the lack of pressure resistance from the substrate. Microbes on the substrate are likely to experience a very good development, especially which contained in the surface. The opposite is experienced by microbes that are at the bottom where microbial growth is inhibited because the chances of CO_2 in direct contact with H_2 are depleted to form CH_4 (Isidorova et al., 2019). Due to their light relative mass, CO_2 and H_2 compounds will be lifted to the upper surface and react to form CH_4 on the substrate surface. Because reactor number 1 has a larger surface area compared to other reactors, it leads to the rate of biogas formation is better.

4. CONCLUSION

The cross-sectional area of the reactor greatly affects the biogas formation process. The larger the cross-sectional area of the reactor, the faster the rate of biogas formation. On the other hand, the smaller the cross-sectional area of the reactor causes the gas in the digester unit to be obstructed so that the biogas formation process in the gas holder is not optimal. The substrate surface in the reactor in contact with the empty space is believed accelerating the biogas formation process through a chemical reaction between CH_4 and CO_2.

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