

The production of biogas from palm oil mill effluent as substrate with variation of agitation speed with fed-batch system

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Abstract. The purpose of this research is to determine the effect of variation of agitation speed on biogas production from palm oil mill effluent and cow dung as substrate by using modified digester fed-batch. The addition of agitation in the fermentation tank digester in this research to accelerate the contact between the microorganisms with the substrate so that the process runs more effectively. Thus biogas production with variations of agitation velocity have 90 and 102 rpm. The research is conducted by fed-batch that is the addition of substrate in fermentation tank as much as 1 liter for 2 days which aim to get optimum biogas production result. The results of this research indicate that the speed of agitation affects for biogas production. The optimum biogas production occurred at 102 rpm agitation speed after 30 days fermentation time was 26.5116% mol CH₄.

1 Introduction

Palm oil mill effluent (POME) is one of the most frequent agro-industrial liquid wastes causing pollution. Liquid wastes from these palm oil mills are generally high-temperature 70-80°C, brownish, containing dissolved solids and suspended colloids and high oil residues with biological oxygen demand (BOD) and chemical oxygen demand (COD). The colloidal suspension of POME in PT Mitra Ogan was containing 92-96% water; 0.5-0.7% oil and fat, and 3-7% total solids [1]. Palm oil production requires large amounts of water. One tonne of palm oil produces was derived by 3 tons of POME [2], which is liquid waste derived from water input in separation, clarification and sterilization processes. If POME is immediately discharged into the water, some will settle, break down slowly, consume dissolved oxygen, cause turbidity, emit a sharp odour and can damage the aquatic ecosystems due to the long decomposition process. Before this liquid waste can be discharged into the environment it must first be processed to conform to the waste quality standard set by the environmental agency.

POME is a nutrient rich in organic compounds and carbon, decomposition of organic compounds by anaerobic bacteria can produce biogas [3]. If these gases are not managed and allowed to escape into the open air it can be one of the causes of global warming because the released methane and carbon dioxide gas is including a greenhouse gas that is touted as a source of current global warming. Methane gas (CH₄) emissions are 21 times more dangerous than carbon dioxide (CO₂) and methane is one of the largest greenhouse gas [4].

In this research, there is an idea to optimally process POME by creating a tool that represents the modelling system in industrial waste ponds, so it is expected to provide more benefits in treating waste. This research applies the principle of processing done by sedimentation and fermentation process [5], in the hope that the result of waste treatment is discarded without exploiting its content by using modified digester as modification of truncated pyramid and beam [4 and 6].

2 Materials and methods

2.1 Materials and process

Raw material and process fermentation with the method from Aznury et.al. [6]. This research was conducted to produce biogas from POME and activator microorganisms as a substrate to the addition of variation of agitation in digester tool. The parameters observed in producing biogas are CH₄, CO₂, H₂S and O₂.

2.2 Experimental set-up

The feeding tank will be flowed by the pump to a truncated pyramid digester (tank A) and after the full tank, A is allowed to stand for 24 hours for the sedimentation process. Then, open the valve that is in the middle of tank A and tank B and drain into the tank B for the fermentation process for CH₄ gas formation.

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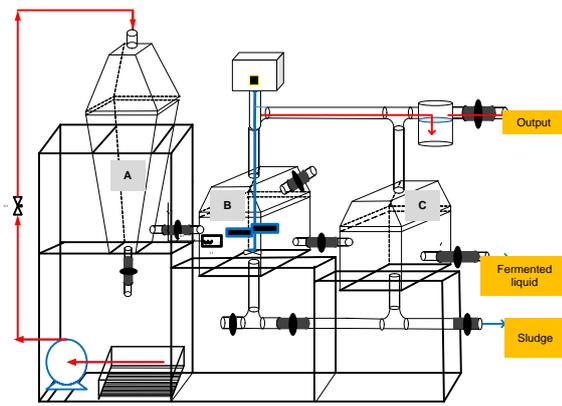


Figure 1. Design Modification Digester

The feed flow rate of 6 L/min and the sedimentation time for 24 hours, the mud and water will be separated after the residence time of 24 hours, the mud and water are separated to analyze the quality of POME processing as the initial waste data before the process fermentation. This is done so as not to block the mud in the next tank (tank B).

After the fermentation process in the tank B, it is then channelled to the tank C for final processing before the feed in the form of POME is discharged into the environment. At the top of the tank B and C is provided with a cover which is accompanied by a swan neck containing NaOH which will absorb the CO₂ content in the gas flowing to the CH₄ gas shelter formed and the sides are equipped with filter paper to filter the water formed for then accommodated. As for the bottom product of mud will be issue after some time.

This research begins with preparing a feed of POME. The bait stored in the storage tank is loaded into the feeder until it is full. POME that has been separated from the sediment sludge due to the sedimentation process will be channelled to tank B and tank C with the addition of one-litre substrate per day given on tank B with 70:30 ratio where 70% POME and starter in the form of mixture 30%. The tank B bait for 30th days consisted of 9th days of feed on tank B flowed to tank C every two days 1 time as much as 2 litres, but on the 9th day the feed was added to 3 litres into tank C and the total volume was 19 litres. For research fed-batch fermentation will be regular substrate addition that is every two days 1 time as much as 1 litre in tank B without any output. During the fermentation process, the result is obtained gas in the tedler bag. After 30 days the fermentation process is complete the samples in each treated tank will be taken for analysis of the content of TDS, TSS, COD, BOD, and pH.

2.3 Analytical

Raw POME and fermented POME was analyzed by the American Public Health Association [7]. Biogas was analyzed by using using a gas chromatograph (GC-8A, Shimadzu, Kyoto).

3 Results and discussion

3.1 Analysis of raw materials

Processing raw materials in the form of POME using the modification of digester through the stages of sedimentation and fermentation process. Before getting treatment, the first waste will be examined the initial content of the waste to determine the waste container. The following is an initial analysis of the POME which can be seen in **Table 1**.

Table 1. Preliminary Analysis of POME

No	Parameters	Analysis results	The maximum limit allowed
1	TDS	281 mg/L	-
2	TSS	243 mg/L	250 mg/L
3	pH	4.55	6-9
4	BOD	117 mg/L	100 mg/L
5	COD	345 mg/L	350 mg/L

Table 1 shows that the initial content of the palm oil industry's wastewater obtained for pH and BOD values exceeds the quality standard established under Governor Regulation No. 8 of 2012 on the Standard of Waste for the Palm Oil Industry [8]. The COD and TSS values contained in the initial POME did not exceed the standards permitted by the Governor Regulation of South Sumatera No. 8 of 2012 on the quality standard of liquid waste for the palm oil industry is a maximum of 350 mg/L for COD and 250 mg/L for TSS. Whereas for BOD and pH values in POME waste exceeded the permitted standard, the BOD value contained in POME 117 mg/L waste with a maximum limit of 100 mg/L. The pH is still within the acid of 4.55 and for the limit is 6-9. This is because the content of COD, BOD, TSS, TDS, and pH for each of the oil palm wastewater is different according to the source of the POME waste. Sometimes the results vary between good and bad waste. It is not possible to not do waste treatment because there is still some content that exceeds the threshold value.

The wastewater treatment of POME in Indonesia is generally processed with an open pond system, hereinafter called conventional system, consisting of three phases: precipitation, anaerobic pool, and aerobics pool. Handling waste by such methods requires large areas of land and high costs, without any other benefits. Generally, liquid waste management of palm oil mills is applied biologically, which is channelled into reservoir ponds before finally entering the public water body, the waste disposed of is still above a predetermined threshold. Wastewater generated as a whole is a potent liquid mixture as a source of the pollutant. In addition, O₂ gases, greenhouse gas emissions, and other gases have the potential to cause negative impacts on the environment, especially the large contribution to the risk of global warming and climate change. This underlying research to utilize methane gas as biogas in conventional anaerobic ponds was replaced by a closed pool system. Digester serves to replace an anaerobic pool in a

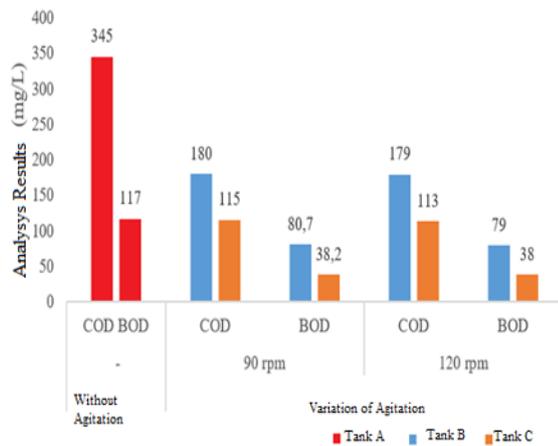


Figure 2. Effect of Agitation Speed on Chemical Content Analysis Oxygen Demand (COD) and Biological Oxygen Demand (BOD)

conventional system assisted by the use of bacteria for decomposition of waste organic compounds in producing biogas.

Modified digester refers to previous research that has been done [4 and 6]. However, the previous design was inefficient, since the previous design had the same tank shape, but in the fermentation tank, there was no stirring so it would take a little time to contact between the substrate and the microorganism. Sedimentation tank that is used as a pyramid-shaped design that can make the sedimentation process quickly. While the fermentation tank on the modified beam-shaped digester with the addition of agitation is able to perform the fermentation process well and quickly because the contact between the substrate with the microorganism becomes more effective. In addition, agitation can also avoid the formation of sediments in the digester which can inhibit the production of biogas. Modifications to the digester are carried out to develop a fed-batch waste treatment process. From the statement, it is necessary treatment in the form of waste treatment in modified digester so that the organic content in the waste can be degraded into sludge or can be used as another product in the form of biogas.

3.2 POME analysis after treatment

The result of COD value obtained from fermentation process of palm oil waste or POME for 30 days at tank B was 180 mg/L for agitating speed of 90 rpm and for agitation speed 102 rpm obtained COD value of 179 mg/L, where COD value is far lower when compared with Aznury, et al [4] with fermentation time of 10 days with COD value obtained 362 mg/L. From the COD value data, it can be seen that the COD value is determined based on the type of POME itself which means that the COD value of each oil palm liquid waste varies based on the source of the POME waste and the fermentation time greatly influences the reduced COD content. While for BOD value after fermentation 30 days was 80.7 mg/L for agitation speed 90 rpm and BOD value 79 mg/L for speed agitation 102 rpm which value

still lower when compared with the result of research by Aznury, et.al [4] have value BOD 125.3 mg/L.

In this research, the results of COD, BOD, TSS and TDS content analysis in POME after anaerobic fermentation process for 30 days have met the standard quality standard for which has been established based on the governor regulation of South Sumatra No. 8 of 2012 on the quality standard of liquid waste for the palm oil industry [8]. So that liquid waste can be directly discharged into the river or to the recipient body of water.

3.2.1 Effect of agitation variation on COD and BOD

The purpose of the addition of agitation in tank B for modification of this digester is to accelerate the contact between the substrate with the microorganisms become larger so that the microorganisms easily and much decompose organic materials and decrease the value of COD. The use of agitation during the study is only 15 minutes per day because of the excessive use of agitation will disrupt microbial activity. In this research, agitation has an effect on the result of COD and BOD content analysis. Effect of agitation on the content of COD and BOD from the results of the study can be seen in Fig. 2.

Fig. 2 shows that agitation speed is very influential for COD and BOD values. The content of BOD value in tank A without agitation still exceeds the permitted threshold while COD has met the permissible condition. Since this is the initial content of the waste, so there is a need for processing to reduce the value of COD and BOD in POME waste. In Fig. 2 it can be observed that after the waste treatment in the tank B and tank C in the presence of agitation speed of 90 rpm then there is a decrease in the value of COD and BOD. The COD value of 345 mg/L before treatment (without agitation) to 180 mg/L for tank B then fell back to 115 mg/L in tank C after treatment. While the BOD value before the treatment was 117 mg/L indicating the BOD value exceeded the permitted threshold of 100 mg/L. Furthermore, the BOD value also decreased up to 80.7 mg/L in tank B and fell back in the C tank to 38.2 mg/L. For the agitation speed of 102 rpm is the same at 90 rpm, the COD and BOD value is almost the same. This is because the composition used is the same as the 70% POME and 30% substrate ratio.

The occurrence of COD and BOD decrement during the given agitation variation means that the substrate has been dispersed or mixed (homogeneously) with microbes, thus affecting microbial work in removing or reducing organic compounds. The greater the reduction of COD, the organic matter degraded into organic acids is also greater. These organic acids are then converted into biogas, so if the COD reduction is greater and the rate of biogas formation is also greater [9].

3.2.2 Analysis of agitation effect on biogas production

Biogas is clean and renewable energy that can be an alternative to conventional energy sources that can cause

problems for the environment and increase the rate of energy depletion in a long time. The process of biogas formation requires a special installation called a digester, its function is that anaerobic reshuffle can take place well. The process of organically changing anaerobic materials consists of four stages of the process of hydrolysis, acidogenesis, acetogenesis and methanogenesis.

Therefore, this research treats POME to reduce the harmful chemical compounds content of POME by utilizing the resulted products from the processing of sludge and biogas (methane gas) by using pyramid-beam shaped digester with the addition of agitation. The agitation treatment was performed to obtain a homogeneous substrate and starter composition in the reactor. Agitation is also done to prevent the occurrence of floating objects on the liquid surface and to obtain a uniform temperature at the reactor. Stirring in this study was done once a day and was done during the day for 15 minutes. The analysis obtained for the effect of agitation with a speed of 90 rpm on the production of biogas on the modification of digester fed-batch can be seen in **Fig. 3**.

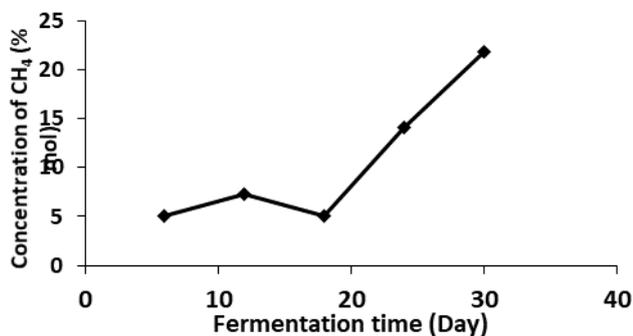


Figure 3. CH₄ Concentration in Fermentation with 90 Rpm

In **Fig. 3** above can be observed the effect of Agitation Speed 90 rpm on CH₄ produced. CH₄ data retrieval at fermentation time for 6th days, 12 days, 18 days, 24 days and 30 days. Initially, there was an increase of % CH₄ production on the 6th day by 5.0234% mole and the 12th day was 7.312% mole. Decrease in CH₄ production on the 18th day due to leakage in the sampling bag (gas container) so that obtained a little. Increased CH₄ production was significant to 14.1043 % more on day 24 so that the peak reached on the 30th day was 21.8097 % mole. The occurrence of increased production of biogas indicates that the activity of the bacteria goes well.

As for the effect of agitation velocity on biogas production result, **Fig. 4** below is the effect of agitation speed 102 rpm on CH₄ concentration produced.

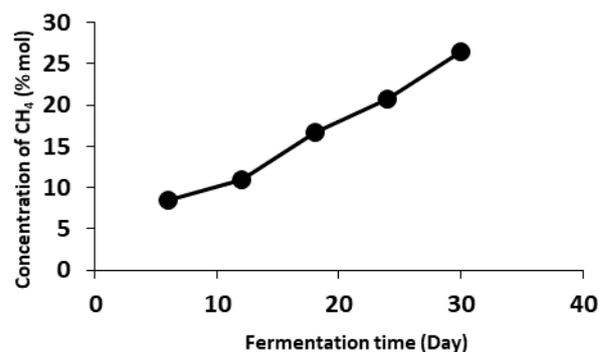


Figure 4 CH₄ Concentration in Fermentation with 102 rpm

Fig. 4 can be observed the effect of agitation speed 102 rpm on CH₄ produced. The agitation speed of 102 rpm produces more biogas than agitation speed of 90 rpm. At the beginning of the product on 6th fermentation produced CH₄ as much as 8.4845% mole while for the speed of 90 rpm produced only equal to 5.0234% mole. Further of fermentation time are 12nd, 18th, 24th and 30th days continue to increase of CH₄. At day 30th is the peak of biogas product that is 26.5116% mole CH₄, this result is higher than agitation speed of 90 rpm which equal to 21.8097 % mole CH₄. According to Mujdalipah, et al [10], fermentation time gives a significant difference to gas production, where fermentation time has a direct effect on biogas production. So the gas volume increases with increasing fermentation time.

Biogas production in this study achieved optimal results on the 30th day of producing 26.5116% mole CH₄ gas obtained from the fermentation process with a concentration of 30:70% substrate by fed-batch. This indicates that the substrate is maximally converted completely into biogas. As the number of bacterial populations increases, bacterial activity produces CH₄ also increases to produce CH₄ with a larger composition. The speed of agitation is highly influential for biogas products because the faster the agitation the contacts between substrate and microorganisms are more efficient and the process also works better and faster. But the speed of agitation is also very bad for biogas products because if excessive agitation speed will cause bacterial activity to be disturbed.

3.2.3 Comparison of biogas production results from POME processing with fed-batch system

Biogas production is obtained from the fermentation process of POME in the reactor, where the fermentation system used is the fed-batch process. According to Widjaja [11], the fed-batch system is a system that adds new media regularly to the closed culture that exists in the reactor so that the volume of culture is increasingly increasing. According to Rusmana [12], the fed-batch method of introducing some sources of nutrients into bioreactors with a certain volume to obtain a product that is close to maximum, but the concentration of nutrients source is made constant. Comparison of biogas production results from previous researchers can be seen in **Table 2**.

Table 2. Comparison of Biogas Production Results on a fed-batch basis with Previous Research

Digester	% Vol Starter	Agit (rpm)	Ferm. time (Day)	% mole CH ₄	Ref.
Beam	10%	-	4	1.3811	[13]
Truncated Pyramid	10%	-	4	1.7972	[14]
Beam	20%	-	4	2.0607	[13]
Truncated Pyramid	20%	-	4	1.4938	[14]
Beam	30%	-	4	7.3564	[13]
Truncated Pyramid	30%	-	4	6.439	[14]
Beam	30%	-	40	30.0951	[5]
Modification of Truncated Pyramid and Beam	30%	-	10	10.882	[4]
Modification of Pyramid and beam with the addition of Agitation	30%	102	30	26.5116	2018

From **Table 2** shows the beam-shaped digester produces more biogas than the pyramid-shaped diets. The pyramid-shaped digester is more efficient in the process of sedimentation than the beam digester seen from the production of CH₄ by Aznury, et al [4] which is 10.8817% in fermentation time for 10 days.

The biogas production results from the Fahlevi [14], Saputri [13], and Aznury, et al [4] studies are still below the biogas production by modified digester with the addition of agitation obtained by 26.5116 %mole CH₄ in fermentation time for 30 days. The longer the fermentation time the more biogas produced. Biogas production is influenced by fermentation time because the fermentation time is directly related to the amount of time required to pass through the stages of CH₄ formation are hydrolysis, acetogenesis, and methanogenesis. Because each reshuffle takes time enough, so the influence of fermentation time factor on the substrate under anaerobic conditions gives different results on biogas production, the longer the fermentation process increases the biogas production.

4 Conclusion

Pursuant to result of research on modification of pyramid-shaped digester for sedimentation stage and beam-shaped with the addition of agitation at fermentation stage in wastewater treatment of POME, it can be concluded: With agitation speeds of 90 rpm and 102, obtained:

The COD value of POME after a 30-day fermentation process was 155 mg/L for 90 rpm and 113 mg/L for 102 rpm. These results have met the standard quality of waste that is below 350 mg/L. The BOD value of POME after a 30-day fermentation process was 38.2 mg/L for 90 rpm and 38 mg/L for 102 rpm. These results have met the standard quality of waste that is below 100 mg/L that has been determined based on the Governor Regulation of South Sumatera No. 8 of 2012 [8].

Percentage of biogas production on days 6th, 12nd, 18th, 24th and 30th days for agitation speed of 90 rpm that are 5.0234, 7.3120, 5.0076, 14.1043, and 21.8097 % mole CH₄, approximately. The agitation at 102 rpm are 8.4845, 10.9531, 16.7398, 20.7552, and 26.7552% mole CH₄, approximately on biogas production at day 6th, 12nd, 18th, 24th and 30th days. Thus biogas production with variations of agitation velocity has an effect on biogas production. While for the optimum biogas production obtained from the digester modifier produced on day 30 with the agitation speed of 102 rpm is 26.5116 % mole CH₄. The pH value of POME after a 30-day fermentation process is 6.21 for 90 rpm and 6.21 for 102 rpm. These results have met the standard quality of waste that is below 6.0 – 9.0 [8].

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