Analysis of Biogas Power Plant Efficiency in Covered Lagoon Digester System

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Abstract

Palm oil mill liquid waste or often referred to as POME (Palm Oil Mill Effluent) was previously just left alone without any special treatment for the utilization of the energy contained in it. Along with the development of technology, liquid waste can be processed into useful energy sources. Wastewater treatment with a covered lagoon system is widely used in the palm oil industry. The result of wastewater treatment is biogas. Biogas is then used as a biogas generator engine fuel to be used as electricity. The amount of electricity to be obtained is directly proportional to the amount of biogas produced. While the amount of biogas produced depends on the amount of POME and the content of COD (Chemical Oxygen Demand) in the POME. To see how effective the Biogas Power Plant has been built, it is necessary to calculate the efficiency of each treatment. From the results of calculations, the efficiency of wastewater treatment reaches 94.80%. The efficiency of using biogas to energy reaches 99.29%. The work efficiency of a power plant is 19.65%. With the maximum processing prediction simulation, the maximum capacity of the power plant can only reach 1.48MW.

Keywords
POME, Palm Oil Mill, Chemical Oxygen Demand

1. Introduction

The palm oil industry is a very large foreign exchange earner for Indonesia. In the processing of FFB (Fresh Fruit Bunches), Palm Fruit at the factory will produce liquid waste. This liquid waste is usually called POME (Palm Oil Mill Effluent). This POME has the potential to be converted into energy. POME can produce biogas that can then be used as fuel and then using a biogas generator finally produces electricity [1-2].

Biogas is formed when microorganisms, ie bacteria, reduce the levels of organic matter content under conditions without oxygen (anaerobic). Biogas generally consists of 50% - 70% methane gas (CH_4), 25% - 45% is carbon dioxide (CO_2) and the rest is in very little content, such as water vapor (H_2O), Oxygen (O_2), Nitrogen (N_2), and others. Biogas is lighter than air. Biogas is an odorless and colorless gas. In biogas plants, the odor that smells is the smell of H_2S content. Biogas is usually measured in normal cubic meters (Nm^3).

There are various technologies for decomposing liquid waste. Some of these technologies are Continuously Stirred Tank Reactors (CSTR), made of concrete or cylindrical metal (like a tank) as the reactor [3]. Anaerobic filters use a "carrier" made of plastic where the active microorganisms attach and prevent the system from being pushed. Anaerobic filters can produce high biogas with 85% methane content. Fluidized and expanded beds, in fluidized and expanded beds, micro-organisms attract floating particles to form colonies. This system has a strong upward flow which causes particles to float so that microorganisms make contact with the substrate [4-5]. Covered Lagoon type in principle is a closed pond equipped with a stirring mechanism.

The data is taken from one of the biogas power plants that use Covered Lagoon System technology. The volume of waste that can be accommodated in closed ponds reaches 30,000m^3, with a depth of 11 meters. The bacteria that are developed are mesophilic. The number of biogas generators is two units with each unit having a 1.5MVA capacity.

Biogas Power Plant from palm oil liquid waste or often referred to as POME (Palm Oil Mill Effluent) has complex processing. Said to be complex because it involves bacteria as a reactant to produce biogas. POME originating from the Fat Pit area of the factory, then flowed into the Biogas Plant as shown in Figure 1. The final result of the biogas plant is the liquid waste that has reduced levels of COD (Chemical Oxygen Demand) which is then passed on to oil palm plantations. Whereas the biogas itself can be burned to reduce the impact of air pollution on the environment and / or be used as fuel for biogas generators that can produce electrical energy. Stages of processing in general can be seen in Figure 1. In the figure, the blue column shows the flow of liquid waste, while the yellow column is the flow of biogas. The brown color represents the initial product, POME from the Palm Oil Mill while the dark orange color column is the final sludge which is often referred to as sludge.

2. Biogas Power Plant

In the Biogas power plant, the process of processing wastewater and the utilization of Biogas produced can be seen in Figure 1. In general, the processing process is divided into three areas namely, the Factory Area, PLTBg Area, and Plantation area [6-7].

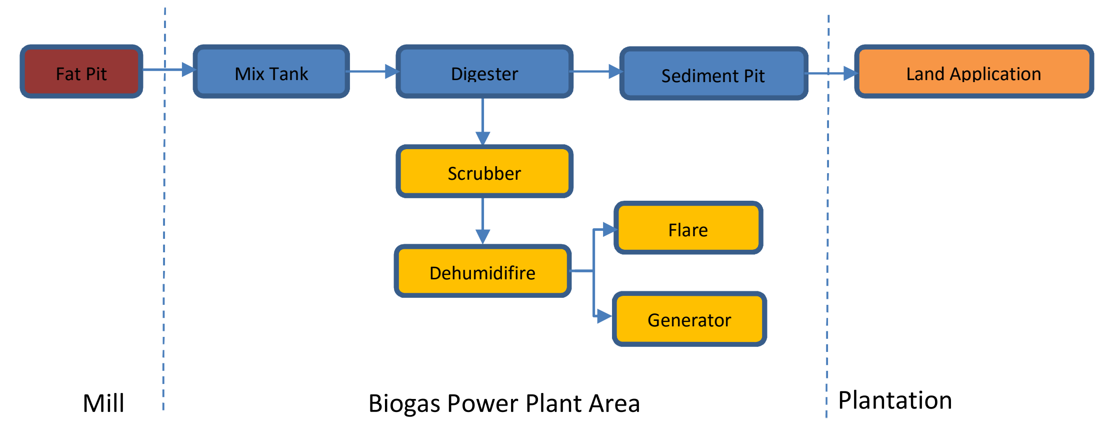


Figure 1. Flowcahrt of Liquid Waste Process Cair

2.1. Cooling Tower

Cooling Tower functions to change the temperature of the overheating POME into the expected POME temperature. The temperature must be regulated because the bacteria that will process/produce biogas requires an environment that is following its conditions. In this Cooling Tower, POME is passed through the Cooling Tower grating and then there is a heat transfer because there is an angina fan that will suck out the heat that is on POME. Cooling Tower can be seen in Figure 2. Generally, cooling towers are expected to reduce temperatures around 40-50°C [8]. This temperature is needed if mesophilic bacteria are developed.

Figure 2. Cooling Tower

2.2. Mix Tank

Mix tanks function to help homogenize new POME with sludge, POME after production. This is needed to help ensure the pH in the reactor pool can be controlled. Mixing new liquid waste and old liquid waste (Output from the reactor) can also help ensure the condition of the waste is good for input into the reactor. In some specialists, the oil content in POME is too high due to the disruption of processing on the palm oil mill side. It is not so good to be passed into the reactor. In the Mix Tank sample plant, there are two areas, the first area is where the mixing of POME from the cooling tower, while the other is the sludge taken from the waste treatment output. The mix tank picture can be seen in Figure 3.

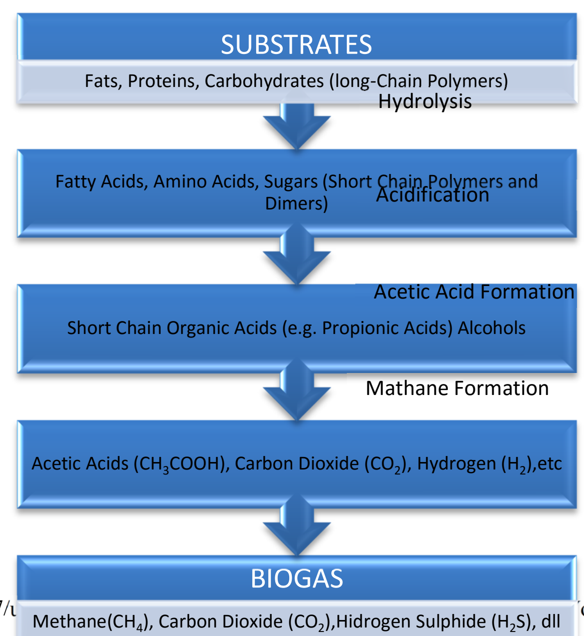
Figure 3. Mix Tank

2.3. Reactor Pond

Reactor Pond is a place for breaking down liquid waste into biogas. Biogas is accumulated in the pond cover can be seen in Figure 4. The pond cover using elastic polymer material, this allows biogas to be collected in this reactor.

Figure 4. Reactor Pool

In the reactor pond, the decomposition process occurs by bacteria as in Figure 5. The decomposition process is anaerobic. Starting with the Hydrolysis Phase, Water will react with long-chain organic polymers and then split into shorter ones. The next stage is acidogenesis, anaerobic oxidation utilizing sugars and other substances formed during the hydrolysis process, the next stage is the acetogenesis stage, at the acetogenesis stage, the acetogenic bacteria that produce hydrogen convert fatty acids and ethanol/alcohol into acetate, carbon dioxide, and hydrogen. The last stage is the methanogenesis. During the methanogenesis stage, methane is formed through two main routes. On the primary route, the fermentation of the main products that originate from the acid formation stage ie acetic acid is converted into methane and carbon dioxide. The bacteria that convert acetic acid are acetoclastic bacteria.



2.4. Sediment Pond

Sediment pond functions as temporary shelters before being applied to oil palm plantations. Besides, Sludge decomposition results from POME can be mixed feedback in the Mix Tank. In Figure 6 the sediment pond is an open black pool.

Figure 6. Sediment Pool

2.5. Scrubber

Scrubber serves to bind the content of H_2S in Biogas. As we know H_2S is not very good when reacting with metals. Metal can quickly corrode. That is why reducing H_2S content must be minimized. The impact is very detrimental if the high H_2S content is that it can damage the Biogas engine combustion chamber. This is very detrimental because the investment value of biogas generators is very high. In the scrubber, there is oxygen input from the environment. Figure 7. is an example of a Scrubber on a biogas sample plant.

Figure 7. Scrubber

2.6. Dehumidifier

Dehumidifier functions to ensure the temperature and pressure of biogas to be burned and/or used as biogas generator fuel to be ideal. The dehumidifier includes a Chiller and Heat Exchanger to ensure the ideal biogas temperature for dumping as fuel. Meanwhile, to regulate the flow rate and pressure a blower is used. The dehumidifier area can be seen in figure 8.

Figure 8. Dehumidifier

2.7. Flare

Flares are a place to burn excess biogas. Biogas that is not used as fuel must be burned in flares to reduce the impact of environmental pollution. Apart from this aspect, another very important aspect is safety reasons. Methane gas is very dangerous if only released to the environment. Methane gas is very poisonous and can burn quickly. Image flares can be seen in Figure 9.

Figure 9. Flare

2.8. Biogas Generator

Biogas generator is a machine to produce electrical energy that uses biogas fuel. The equipment system on the biogas engine is similar to other generators, which distinguishes only the fuel. The combustion configuration is adjusted to the fuel configuration. The biogas generator can be seen in Figure.

Figure 10. Biogas Generator

3. Method

The stages of the research process carried out can be seen as in the flowchart, which is in Figure 11. The methodology used is the method of field observation and field study. A literature study is carried out by studying literature that has been previously researched by previous researchers whose topic of discussion relates to the topic investigated by the author. Data is taken at one of the biogas power plants that use closed pond technology. The volume of waste that can be accommodated in a covered lagoon reaches 30,000m^3, with a depth of 11 meters. The bacteria that are developed are mesophilic bacteria. The number of biogas generators is two units with each unit having a 1.5 MVA capacity.

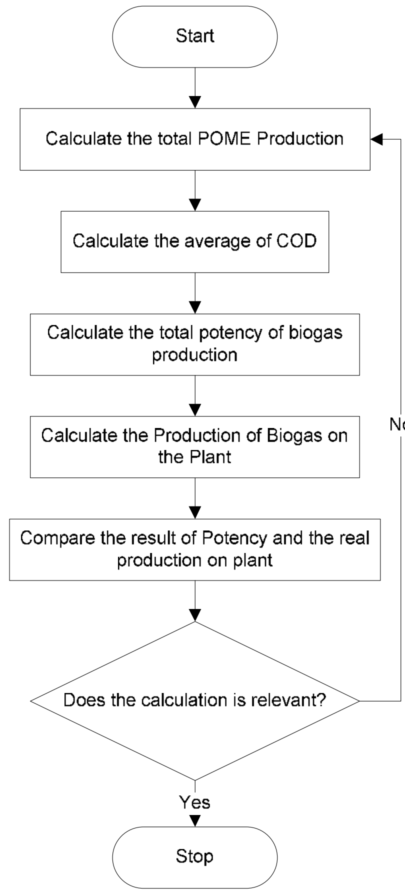


Figure 11. Flowchart

4. Result

Calculation of work efficiency of Palm Oil Mill Liquid Waste Processing into Biogas in a closed pond in this characteristic we call CGR (Covered Gas Reactor), carried out with certain stages following the stages that have been determined in the research methodology.

4.1. Total POME Produced

Palm Oil Mill with a processing capacity of 60 tons/hour is generally targeted to operate 20 hours in 1 day. The remaining 4 hours in 1 day are expected to be used for maintenance of production machinery. Actual in the field when processing crude palm oil is very volatile. The fluctuating condition of crude oil processing is caused by the availability of raw materials which at present is FFB palm oil.

TABEL I
Data of Product and POME

Month	PRODUCT (TON)	POME (m^3)
June	17783.413	10712
July	24951.687	12241
August	20521.35	9821
September	19803.78	11682
October	18051.29	10653
November	16847.77	10112
December	13523.258	11525
January	13241.472	13060
February	11233.77	9912
March	19833.229	14523

April	23728.298	11246
May	29222.873	13128
Total	228742.19	138615

At the factory sample process norms show 0.7-1 m^3 POME for each ton of fresh fruit bunches processed [3]. This means that if in one year the 60 Ton plant operates 360 days and 20 hours per day, the total FFB Production can reach 432,000 tons and the POME produced can reach 345,600 – 432,000 tons. In the actual data of the first year of operation of biogas processing that occurred in a sample of one plant, from June 2017 to May 2018, the processed FFB and POME data can be seen in Table 1. From the above data, real FFB production can be said to be very minimal. This factor depends on the availability of FFB produced in plantations. FFB production from plantations is highly dependent on the environment and age of oil palm trees [6]. The POME produced when compared to FFB production is 60.6% [3]. The amount of POME produced depends on the technology used in the oil separation system at the clarification station. At this PKS plant, the Oil Separation System uses the CSTR (Continuous Settling Tank Recovery) system.

4.2. COD Average

COD content in POME is taken from the initial input of POME entering the wastewater treatment area. As you know, the amount of COD will be proportional to the amount of potential gas to be produced. In the case of wastewater treatment, it is COD output that is measured to see a decrease in the level of waste. In table 2. is the average COD input data and the average COD output at the sewage treatment plant, besides that it can be seen the percentage of the work of the wastewater treatment plant from the presentation of decreasing COD content in the liquid waste.

TABEL II
COD Average

Month	COD INPUT (PPM)	COD Output (ppm)	μ_{COD} (%)
January	73111	2697	96.31
February	74443	2307	96.90
March	77479	5013	93.53
April	75558	4517	94.02
May	68115	4981	92.69
June	71678	3861	94.61
July	71647	3933	94.51
August	74809	4147	94.46
September	76383	2801	96.33
October	75412	4063	94.61
November	91053	4081	95.52
December	88511	4804	94.57
Average	76516	3933	94.86

From the above data it can be said that the performance of the wastewater treatment plant reaches 94.80%.

TABEL III
Total of COD

Month	COD (PPM)	COD (kg/month)
June	73111	783165.03
July	74443	911256.76
August	77479	760921.26
September	75558	882668.56
October	68115	725629.10
November	71678	724807.94
December	71647	825731.68
January	74809	977005.54
February	76383	757108.30
March	75412	1095208.48
April	91053	1023982.04
May	88511	1161972.41
Total	76516	10629457.07

To calculate the total COD that enters every month at a wastewater treatment plant can be calculated by equation [3]:

$$COD = COD\ input \times POME \times \frac{kg}{1000000\ mg} \times \frac{1000L}{m^3} \quad (1)$$

Where COD is the total COD entering the wastewater treatment plant per month (kg/month), POME is the total amount of POME flowed into the waste treatment plant (m3). Table 3 shows the total COD flowed into the wastewater treatment plant.

4.3. Estimated Biogas Produced

To calculate the estimated biogas produced can use the equation:

$$CH_4Prod = COD \times \mu_{COD} \times \alpha \quad (2)$$

Where CH_4Prod is the total estimated biogas produced (Nm^3 CH_4 / month), μCOD is the efficiency of decomposition of COD in this wastewater treatment or it can be said that the ratio between COD input and COD output (%), α is the ratio of CH_4 to COD of 0.35. Estimates of total biogas produced each month and real biogas used in the field can be seen in Table IV. Because there is an additional O_2 of about 14% in Real Biogas used, the total CH_4 real must be subtracted by 14% of the total price.

TABEL IV
Estimated Biogas Produced

Month	CH_4Prod (Nm^3CH_4/ Month)	Biogas Real (Nm^3CH_4/ Month)	CH_4 real Without O_2 (Nm^3CH_4/ Month)
June	263996.17	285935	245904.10
July	309055.87	281322	241936.92
August	249091.01	237755	204469.30
September	290465.34	298953	257099.58
October	235398.28	341520	293707.20
November	240017.93	272651	234479.86
December	273141.35	363572	312671.92
January	322996.00	364237	313243.82
February	255270.67	287080	246888.80
March	362670.54	453716	390195.76
April	342330.49	403749	347224.14
May	384616.92	484102	416327.72
Total	3529050.56	4074592	3504149.12

From the calculation result, the estimated biogas produced compared to the real biogas used is:

$$\mu_{pemanfaatan\ biogas} = \frac{CH_4real}{CH_4prod} \times 100\% \quad (3)$$

$$= \frac{3504149.12}{3529050.56} \times 100\%$$

$$= 99.29\ \%$$

Where the use of biogas is the efficient use of biogas in the biogas plant (%), CH_4 real is the estimated total biogas produced in 1 year without O_2 content input into the scrubber (Nm^3 / year), CH_4Prood is the total biogas used in 1 year (Nm^3 / year). From the calculation of the efficiency of the utilization of biogas produced is 99.29%. It means that only about 0.71% of biogas is released into the air or around 24,901 Nm^3 CH_4.

4.4. Power Plant Efficiency

In this sample power plant, there are two biogas engines. Each engine has a capacity of 1.5 MVA or around 1.2 MW. To calculate the total operating capacity of the developer, it can be calculated by:

$$P_{generation} = \frac{P_{total}}{30 \times 24} \quad (4)$$

Where $P_{generation}$ is the operating capacity of the electricity generating plant (MW), P_{total} is the total power in 1 month produced in 1 month (MWh), the number 30 × 24 is the dividing number of the total time of 30 days and 24 hours.

To calculate the efficiency of a generator can use the equation [9-12]:

$$\mu_{generator} = \frac{P_{generation} \times t}{CH_4 Prod \times 35.7} \quad (5)$$

Where $\mu_{generator}$ is the work efficiency of electricity generation (%). t is the total time converted into seconds (s). 35.7 is the number of methane energy content (MJ / m^3). The efficiency of the generator can be seen in Table V.

TABEL V
Generator Efficiency

Month	Power Generation (MWh)	Average Capacity of Power Plant (MW)	Generator Efficiency (%)
June	559.54	0.78	19.73
July	516.58	0.72	18.52
August	494.73	0.69	20.98
September	616.76	0.86	20.80
October	623.66	0.87	18.42
November	520.80	0.72	19.26
December	695.49	0.97	19.29
January	672.19	0.93	18.61
February	512.90	0.71	18.02
March	897.65	1.25	19.95
April	806.76	1.12	20.15
May	1022.09	1.42	21.29
Total	7939.13	11.03	19.65 (Average)

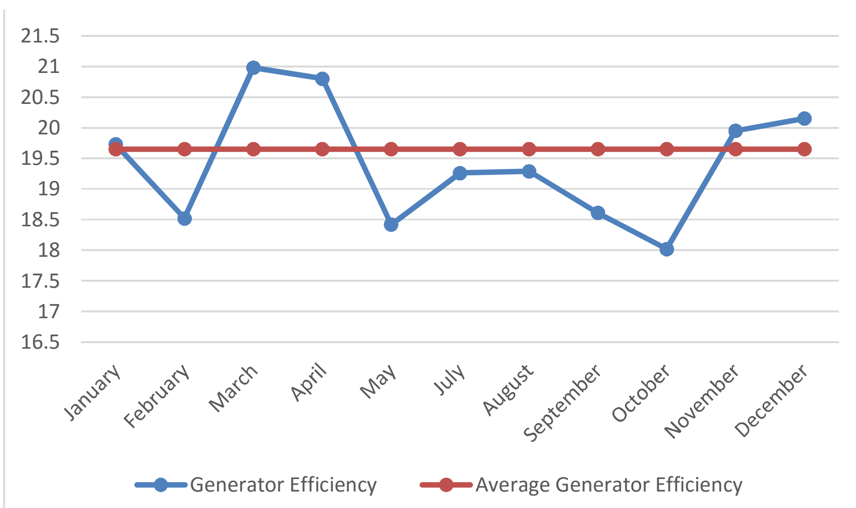


Figure 12. The curve of Generator Efficiency

4.5. Calculation Maximum Potential for Electric Power Generation

Based on the results of the efficiency analysis above, the estimated maximum electrical energy that can be generated at this Biogas Power Plant can be done. To get it, we can simulate using the maximum potential data. A factory with a processing capacity of 60 tons of FFB / hour can process FFB reaching 432,000 tons. If the POME to TBS ratio data is 60.6%, the POME that can be produced is 261792 m3. By knowing the maximum amount of POME that can be obtained, the maximum potential of biogas that can be produced can be predicted. By using the average COD data that can be produced at this sample plant which amounted to 766,516 ppm and wastewater treatment ratio of 94.80%. The predicted total gas that can be obtained in 1 year is 664,637,759.9 8 Nm^3 / year. Using equation (5), moving the power plant, and entering the seconds in 1 year, the maximum capacity of the plant can reach 1.48 MW.

5. Conclusion

From the calculation of the efficiency of the Biogas Power Plant in a closed pond treatment system, the efficiency of wastewater treatment reaches 94.80%. The efficiency of the utilization of biogas into energy reaches 99.29%. The work efficiency of a power plant is 19.65%. With a maximum processing simulation, the maximum capacity of this power plant can only reach 1.48MW. With the results above, the efficiency of the Biogas Power Plant in this sample plant needs to be evaluated on the efficiency side of the biogas engine generator which only operates 19.65%.

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