Analysis of biogas production from palm oil mill effluent at different feed flow rates in biogas plant Sei Pagar Riau

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Abstract. Indonesia’s palm oil industry is considered one of the biggest in the world. Palm Oil Mill Effluent (POME) has the potential for further processing, which can be used as a substitute for boiler fuel (co-firing). Research on converting POME to biogas for boiler fuel (co-firing) in the oil palm plantation Sei Pagar Riau has been carried out. This study aimed to investigate and analyze the biogas production from Palm Oil Mill Effluent at different feed flow rates in Biogas Plant Sei Pagar Riau. Experiments were carried out using the Continuous Stirred-Tank Reactor (CSTR). The reactor capacity was 2000 m$^3$. The reactor was equipped with one unit of vertical agitator and three units of horizontal agitators. POME was distributed from the fat pit unit to the pretreatment unit using the fat pit transfer pump. From the pretreatment unit, then POME proceeds to the reactor using the reactor feed pump started from 2.4 m$^3$/h then gradually increase to 6.3 m$^3$/h as the highest feed flow rate. Biogas was produced in the anaerobic reactor at mesophilic temperature. This study showed that an increase in the POME feed flow rate into the reactor also increases the production of biogas generated in the reactor. The biogas production began to increase every day, with the highest average biogas production of 167 m$^3$/h. The methane concentration was also measured and showed that the highest methane concentration was on day 6, with a value of 70%. And then, the methane concentration trend decreased. However, it was relatively stable in the range of 62.1%-66.7% on day 18 to day 53. Based on this research, it was found that the optimal biogas production of the Biogas Plant in Sei Pagar Riau was generated when the POME feed flow rate was gradually increased and reached the maximum capacity according to its design.

1. Introduction

In 2019, the largest energy usage in Indonesia was dominated by transportation, industry, and households with 43%, 35%, and 14%, respectively. The remaining use is in the commercial and other sectors [1]. Meanwhile, the availability of fossil fuels continues to decline along with the increasing energy demand. Fossil fuels also produce emissions and have environmental problems if used continuously. Thus, mitigation of climate change is consistently integrated by the authorities into the national development agenda. In 2019, BAPPENAS conducted a study that resulted in proposed low-carbon policy recommendations. Supporting the transition to renewable energy, increasing efficiency, and using biofuels were the recommendations of the BAPPENAS study in the energy sector in the period of 2020 to 2045.

One of the plantation commodities that have an essential role in the Indonesian economy is palm oil. Indonesia’s palm oil industry is considered one of the biggest in the world. Palm oil is an important plantation crop-producing cooking oil, industrial oil, and biofuel (biodiesel). Palm oil has a positive influence on economic and social growth. Palm oil production in Indonesia has the potential...
to generate local benefits if its development follows sustainable management, including increased incomes for local communities, increased government revenues, poverty reduction, and improved natural resource management.

The prospect of the development of the palm oil industry is currently very rapid, where there is an increase in both the area and production of palm oil along with the increasing needs of the community. Palm oil is a plant that produces palm oil and palm kernel. The potential for Crude Palm Oil (CPO) production in Indonesia is immense when used as raw material for oil products for food and non-food purposes. Indonesia’s CPO production increased from 31 million tons in 2015 to 42.9 million tons in 2018 [2].

Given this vast amount of palm oil production, the quantity of waste produced is expected to be large. Along with the very high level of palm oil production, palm oil also has by-products such as empty fruit bunches shells, fibers, and palm oil mill effluents (POME) [3]. Shells and fibers can be used to generate heat in the boiler for CPO production. However, POME is channeled to holding ponds. Palm oil mill effluent (POME) is a liquid waste produced during the palm oil extraction process. POME is high-polluting wastewaters in the world. Each ton of CPO produces approximately 3.33 m$^3$ of POME [4]. Chemical oxygen demand (COD), biochemical oxygen demand (BOD), and high organic matter content are contained and can cause severe problems to the environment and water resources [5,6]. The palm oil mills operating in Indonesia are implemented with a ponding system. However, the ponding system requires extensive area and takes about 3-4 months to treat it. The problem with the ponding system is contributing to the emission of Greenhouse Gas (GHG) emissions such as CO$_2$ and CH$_4$ [7].

POME has enormous potential. It can generate electricity as a boiler fuel substitution and bio CNG. At the palm oil mill Sei Pagar Riau, electricity is readily available and meets capacity. However, they require fuel substitution for the boiler. Previously, they are using shells and fibers as boiler fuel. Thus, it is necessary to find a substitute for boiler fuel. The substitution can save most of the shells and earn additional income for the palm oil mill. Also, it can contribute to the emission of Greenhouse Gas reduction. Hence, this study aimed to investigate and analyze the biogas production from POME at different feed flow rates at Biogas Plant Sei Pagar Riau.

2. Materials and method

2.1. Biogas Plant Sei Pagar

The biogas plant is located at palm oil mill Sei Pagar, Riau Province. The biogas plant is designed with an anaerobic reactor with Continuous Stirred Tank Reactor (CSTR). The dimension of the CSTR is ID 14 meters with 13.5 meters in height and the reactor’s volume of 2,000 m$^3$. Mild steel is used as the material of CSTR.

![Process scheme of biogas plant Sei Pagar](image)

**Figure 1.** Process scheme of biogas plant Sei Pagar.
The biogas plant consists of three subsystems: pretreatment, anaerobic treatment, and post-treatment. The pretreatment subsystem consists of a vibrating screen, equalization tank, and cooling tower. The biogas production subsystem consists of a buffer tank, CSTR, foam arrestor, and lamella clarifier. The post-treatment subsystem consists of a gas holder, blower, and burner. Figure 1 shows scheme of biogas plant Sei Pagar.

2.2. Properties of POME
POME is waste from the palm oil mill process, generated from oil extraction, washing, and cleaning up [8]. Disposing of POME directly into the surrounding environment will cause serious pollution issues to the environment [9]. An effective way to remove dissolved and biodegradable constituents in wastewater is by biological treatment using microorganisms such as bacteria [10]. The characteristic of POME at palm oil mill Sei Pagar shows in table 1.

| Parameter                     | Value          | Unit   |
|-------------------------------|----------------|--------|
| COD Inlet                     | 60,000 – 80,000 | mg/L   |
| pH                            | 6.9 – 7.1      |        |
| Ratio VFA/Alkalinity          | < 0.5          |        |
| TSS                           | 4,000 – 9,000  | Mg/L   |
| Temperature inlet             | 70 – 85        | °C     |

2.3. POME Treatment Process
A biogas plant was used to produce biogas from POME. The capacity of the palm oil mill Sei Pagar was 30 FFB/hour. The POME treatment scheme consists of two processing stages: pretreatment and anaerobic treatment followed by an existing pond for disposal of POME, which has been processed into a biogas handling system consisting of a gas holder, biogas blower, biogas burner, and flare unit. Pretreatment consists of a vibrating screen, equalization tank, and cooling tower.

The raw POME from the mill fat pit was directly taken into the vibrating screen to remove the debris, floating materials, fibers, shells from the POME. A 50 rpm static mixer was provided in an equalization tank to mix and equalize the flow and characteristics variations in the raw effluent. Effluent transfer pumps were provided for equalization tanks to transfer effluent to the cooling tower. The temperature of the raw POME that pumps from the palm oil mill were about 70-85 °C. Pretreatment aims to prepare POME to meet operating conditions before being reacted in the biogas reactor. The POME temperature which is reacted in the reactor is 37-39 °C. Therefore, before entering the biogas, the POME reactor must be cooled first.

Anaerobic treatment consists of a buffer tank, anaerobic reactor (CSTR), foam arrestor, and clarifier. Bio reaction is a microbiological process of decomposition of organic material without involving oxygen (anaerobic). The anaerobic reaction process consists of four stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis[11]. In the anaerobic reactor, temperature and pH are important in determining the performance of the microbial [12]. Thus, these parameters have to maintain carefully.

The cooled effluent was collected from the cooling tower. The homogenized effluent from the butter tank is then pumped downstream of CSTR for complete anaerobic treatment of the effluent. A continuous stirred tank reactor (CSTR) is a mesophilic reactor that operates in a temperature range of 37-39 °C. It has been reported that mesophilic reactors are greater in-process stability [13].

In CSTR, raw POME and recycled sludge were entered from the top of the reactor. The mixture of POME and recycled sludge then flowed downward through the central shaft. CSTR was equipped with one unit of 10 HP vertical agitator and three units of 7.5 HP horizontal agitators. Active bacteria in
suspension can be maintained by continuous and constant stirring. Biogas was produced from organic matter in wastewater by bacteria. The solids from the reactor outlet were separated in the lamella clarifier. It was then returned to the system by a recirculation pump. Recirculation of settled solids was important because it can maintain active bacteria in the reactor. A foam arrestor unit was utilized to arrest and remove the dissolved gas to achieve better settling in the lamella clarifier. The foam arrestor is then entered into a lamella clarifier where the active biomass will be separated and part of it recirculated back to the reactor. Excess sludge from the reactor was removed from the lamella clarifier, where sludge was settled and sent to the collection sump. Sludge recirculation flow was adjusted based on the inlet POME to the reactor and based on the reactor’s sludge content. Lamella clarifier overflow was then taken to open pomp or collection sump from there it was pumped to existing ponds for further treatment.

The biogas produced from the reactor was then stored in a gas holder and then distributed to the burner using a blower and pipe system. The biogas plant was also equipped with a flare to burn the remaining biogas.

Biogas plant Sei Pagar was also equipped with instrumentation such as pH meter, liquid flow meter, pressure gauge, and level sensor to measure the parameter of POME and biogas in this system. COD was measured with a COD meter and portable gas analyzer to analyze gas contents such as CH₄, CO₂, O₂, H₂, and H₂S. In this study, data were recorded hourly for 53 days. The flow of POME was increased slowly to increase biogas production.

3. Result and discussion

3.1. Temperature Analysis

Temperature conditions in the reactor were measured daily. The temperature data inside the reactor can be seen in figure 2. This research was conducted using a mesophilic reactor. In this study, the temperature range in the reactor on day 1 to day 28 is relatively about 33.5-34.9 °C. Furthermore, the temperature increased to 35.6 °C on day 29. From day 29 to day 53, the temperature continued to increase, and then it was relatively stable in the temperature range of around 35.1-37.1 °C. At this temperature, the growth of mesophilic bacteria worked optimally. The increase in temperature occurred due to anaerobic activity by bacteria in the reactor.

![Figure 2. Daily temperature data in the reactor.](image-url)
3.2. pH Analysis
In addition to temperature, another factor that affects the growth of microbes forming biogas in the reactor was pH. To obtain optimum biogas production, the pH value in the reactor was around 6.8-7.2, with a tolerable range of about 4-9.5 [14]. Figure 3 is the average pH data in the reactor measured at five points on the reactor's shell. From day 1 to day 7, the pH value in the reactor was around 6.89-6.92. On day 8, the pH value increased to 7.02. The highest pH value was 7.07 on day 17. From day 9 to day 53, the pH value was relatively stable in the range of 6.96-7.07.

The pH value is related to the growth activity of bacteria. If the pH value is below 6.5, the activity of methanogenic bacteria will decrease. If the pH value is below 5.0, the fermentation will stop. However, if the pH is above 8.5, it will affect the bacterial population, resulting in the growth rate of biogas in the reactor. Maintaining a pH value of around 6.8-7.2 can maintain the growth of bacteria and increase biogas production. By maintaining the pH in this range, it shows methanogenic activity [15].

![Figure 3: Daily pH data in the reactor.](image)

3.3. Biogas Production Analysis
Biogas production is related to the methanogenic activity. Temperature, pH, hydraulic retention time, etc., are some factors that are affecting methane production. Figure 4 shows the effect of POME feeding flow rate on biogas production. This study recorded data on feeding flow rate and biogas production every hour for a full 24 hours for 53 days of data collection. The flow rate and biogas production data are shown in figure 4 are the average data per day (24 hours). Flow rate data was recorded from the liquid flow meter at the inlet of the reactor pipe, while biogas production was measured using a gas flow meter at the reactor outlet to the gasholder. On day 1, the POME flow rate started from 2.4 m³/h. The flow rate increased periodically to see the effect of biogas production. The lowest feeding rate was about 1.7 m³/h, and the highest was about 6.3 m³/h.

The average biogas production on day 1 to day 8 was still relatively low, around 23–37 m³/h. The trend of biogas production began to increase every day, with the highest average biogas production of 167 m³/h on day 50. From figure 4, the increase in biogas production in the reactor increases along with the rise in the POME feeding rate into the reactor.
3.4. Biomethane Analysis

The biogas content was measured using a portable gas analyzer which showed the content of CH₄, CO₂, O₂, H₂, and H₂S. Figure 5 shows the methane content of biogas production for 53 days. Methane content varies. The highest methane content was on day 6, with a value of 70.7%. Then the trend shows decreasing methane content. From day 18 to day 53, the methane content in biogas was relatively stable in the range of 62.1 – 66.7%. Using POME as a raw material proves that bacteria do not need a long time to produce biogas with high methane content.
4. Conclusion
This research was conducted to see the effect of increasing biogas production on increasing feed flow rate. The POME feed flow rate was introduced into the reactor starting from 2.43 m$^3$/h, then gradually increasing until it reached 6.3 m$^3$/h. This process was carried out for 53 days. Biogas production also increased. Biogas production started from 22 m$^3$/h to 167 m$^3$/h on day 50. In addition, the temperature was maintained at the mesophilic bacteria temperature of around 35.1-37.1 °C. Another factor is the importance of maintaining the pH of POME in the reactor, around 6.89–7.07, for bacteria to thrive. In this study, the methane content in biogas was also measured. The methane content in biogas was relatively stable in the range of 62.1 – 66.7% from day 18 to day 53. This study proves that the increase in biogas production is associated with an increase in the feed flow rate of POME into the reactor.

5. Reference
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