Utilizing Palm Oil Mill Waste for Co-Production of Biogas and Microalgae Biomass

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Abstract. In 2013 Indonesia produced about 28 million ton/year of CPO. This large CPO production has an impact on liquid waste called as Palm Oil Mill Effluent (POME) and Empty Fruit Bunches (EFB). About 80 million ton of POME and 32 million tons of EFB are produced per year. Open anaerobic pond (conventional treatment) is widely used to reduce COD and BOD content from POME emits uncontrolled CO2 and CH4, which are the main greenhouse gasses and harmful for the environment. POME has high content of COD (50000-100000 mg/L) and BOD (25,000 mg/L) and this is a potential for biogas production. Due to the C/N ratio of POME (6.5) is far below optimal C/N ratio for biogas production using anaerobic digester (between 20 and 30), combining high C/N ratio (60) EFB with POME is predicted to improve the biogas production. The effluent of anaerobic digester containing rich nutrients such as Nitrogen, Phosphor and Kalium are potential for plant or microalgae growth. This experiment used two types of reactor, which are batchly operated in the room condition: (i) a 13L-UASB (Up-flow Anaerobic Sludge Blanket) reactor made of PVC and (ii) 1.5L tube reactors made of PET (Poly Ethylene Terephthalate) plastic. Adding EFB into POME was proven to increase biogas production. The results indicate that the higher EFB composition the faster the biogas formation is. Based on this result, the conversion factor (volume base) of the mixture of POME and EFB into biogas is range from 13 to 47 %. The highest conversion is 47 % from ratio 7.5 of POME to 1 EFB. Based on this result it can be concluded that ratio 7.5 of POME to 1 EFB generated high volume of biogas and methane content. This research also shows significant increase in biomass production of spirulina when biogas was fed into POME medium. Total produced biomass on POME medium with biogas is double than that on POME medium without biogas. This increase could be due utilization of CO2 content in the biogas as a carbon source by Spirulina sp.

Keywords: biogas, microalgae, Spirulina sp., POME, UASB reactor

1. Introduction
As a largest crude palm oil (CPO) producer in the world, in 2013 Indonesia produce about 28 million ton/year of CPO. About 21 million tonnes are intended for export purposes while the rest is to cover
national demand. However, this large production of CPO has an impact on liquid waste called as Palm Oil Mill Effluent (POME). About 1 ton of Fresh Fruit Bunches (FFB) can produce 0.2 ton of CPO while 0.5-0.6 ton are POME[1]. As a result, 80 million ton of POME is produced from production of 28 million ton of CPO.

For environmental side, POME contains high concentration of COD (50,000 mg/L) and BOD (25,000 mg/L)[2]. However, some nutrients are still available such as nitrogen, Phosphor and Kalium. These nutrients are potential for plant or microalgae growth. Currently, open anaerobic pond is widely used to reduce COD and BOD content from POME. On average, pond technology is only able to reduce COD and BOD up to 1400 mg/L and 700 mg/L, respectively [3]. Open anaerobic pond is considered as a conventional POME treatment method because it needs long retention time and large treatment areas [4]. Conventional treatment of POME emits uncontrolled CO\textsubscript{2} and CH\textsubscript{4}. Both gasses are the main greenhouse gasses and harmful for the environment. It is considered do not follow the principles of sustainability [5]. In a conventional POME treatment, each pond can release about 1043.1 kg methane per day [6]. Furthermore, unwell-treated EFB and POME at dumping site will enrich heavy metals in soil due to their heavy metals content [7]. Therefore, another treatment method that environmentally friendly is needed and one of the treatment methods is anaerobic digestion.

POME has high content of COD (50000-100000 mg/L) and this is a potential for biogas production. The C/N ratio of POME is low, about 6.5. This value is far below optimal C/N ratio for biogas production using anaerobic digester, which is between 20 and 30 [8]. Therefore, another high C/N ratio organic material is needed to increase the C/N ratio. Combining (Empty Fruit Bunches) EFB that has high C/N ratio with POME is predicted to improve the biogas production. The effluent of anaerobic digester still contains rich nutrient that can be utilized for microalgae growth. However, as our knowledge there is no full-scale application of this technology in Indonesia yet. Therefore, to bring this technology into a full-scale application, a pilot reactor is needed to be built. This research will evaluate influence of mixing between EFB and POME at several ratios on co-production of biogas and microalgae biomass.

2. Experimental Methods

2.1 Cultivation Medium (biogas production)

There were two types of reactor used in this experiment. The first one was a 13L-UASB reactor made of PVC. The second type was 1.5L small reactors made of PET (Poly Ethylene Terephthalate) plastic. The UASB reactor was chosen because it can achieve high chemical oxygen demand (COD) removal efficiencies without any support material due to the availability of granular or flocculent sludge [9]. The POME and EFB used in this experiment were collected from Palm Oil Mill at PTPN VII, Lampung. The POME was collected from the first open pond lagoon. Since the mill was shut down for a month due to less production of fresh fruit bunches (FFB), this POME has less COD than fresh POME. The EFB was also already in the open air for more than a month. Some POME characteristics are listed in the Table 1 below.

| Parameters | Measured | Literature |
|------------|----------|------------|
| pH         | 7.5      | 3.91-4.9   |
| COD        | 1050 mg/L| 83356 mg/L|
| N total    | 136.7 mg/L| 1494 mg/L |

All reactors were batch operated in the room condition at C-BIORE lab. The small reactors were named as reactor A, B, C and D. The experiment was run for about 3 weeks. The compositions of POME and EFB in the reactors were listed in the Table 1. Generated biogas was sampled in 5 ml glass tubes. These samples were sent to analytical laboratories at Chemical Engineering Department, Gajahmada
University, Yogyakarta, Indonesia to measure methane and CO₂ content. The UASB reactor was run two times and each run was about 3 weeks. The first run was with pure POME and the second run was with a mixture of POME and EFB. The ratio between POME and EFB was determined based on the result of the small reactors that produce the highest volume of biogas. The temperature and pressure inside UASB were recorded everyday using analogue thermometer and pressure meter fixed in the reactor.

Table 2. Generated biogas was sampled in 5 ml glass tubes. These samples were sent to analytical laboratories at Chemical Engineering Department, Gajahmada University, Yogyakarta, Indonesia to measure methane and CO₂ content. The UASB reactor was run two times and each run was about 3 weeks. The first run was with pure POME and the second run was with a mixture of POME and EFB. The ratio between POME and EFB was determined based on the result of the small reactors that produce the highest volume of biogas. The temperature and pressure inside UASB were recorded everyday using analogue thermometer and pressure meter fixed in the reactor.

| Reactors | Mass ratio (%) | POME: EFB |
|----------|----------------|-----------|
| A        | 100            | 0         | Pure POME  |
| B        | 95.24          | 4.76      | 20: 1      |
| C        | 93.75          | 6.25      | 15: 1      |
| D        | 88.23          | 11.77     | 7.5: 1     |

2.2 Microalgae cultivation (Spirulina sp culture)

The microalgae in this research was Spirulina sp. It was collected from BPPT Jepara and cultivated in Bioprocess laboratory UNDIP. Spirulina sp was chosen because it is able to live in various condition. It can live by utilizing sugar as source of carbon and hydrolysed protein as source of carbon and nitrogen [10]. Both carbon and nitrogen are available in POME. Before it was used, Spirulina sp was pre-cultivated at pH 9 – 10 in a 1.5 L plastic tank and agitated using an aquarium pump. A fluorescent lamp with 4000-6000 lux intensity was used as light source. Spirulina sp growth was kept by adding 1 gr/L NaHCO₃, 50 ppm urea, 10 ppm TSP, and 50 mcg/l B12 vitamin [3]. When the biogas was produced by the UASB reactor, the microalgae (Spirulina sp) is cultivated on POME. The biogas flowrate was maintained as small as possible. The number of added Spirulina sp was 10% V of POME medium. There were two times of Spirulina sp cultivation that was fed with biogas on a glass tank with surface area of 0.5 x 0.5 m². Each cultivation was done for 10 days. The first cultivation was using 10 L POME and the second one was using 20 L POME. As a comparison, there were also Spirulina sp cultivation on POME in 1 L beaker glass without biogas. The Spirulina sp growth was using natural light (12 hours). Algae growth was measured for its optical density (OD) using spectrophotometer SP-300 at wave length 680nm. Relations among biomass, cell numbers and optical density (OD) were investigated in former research [10]. Biomass content of Spirulina sp was calculated using following equation:

Biomass (gr/L) =0.396 OD - 0.041

Cell number of Spirulina sp was determined with following formula

Cell number = 4074 OD – 96

2.3 Sampling and measurement

Total carbon of POME was calculated from its COD using a factor 12/32. COD value was measured at C-BIORE laboratory using HANNA reactor HI 839800-02 with high range reagent (HI 93754C-25HR).
To measure total nitrogen, POME sample was sent to Environmental Engineering Research Laboratory, Diponegoro University. Total N was tested using Indonesian standard for water and wastewater quality method. pH was measured using HANNA digital pH meter HI 98107.

3. Result and Discussion

3.1 Biogas production

As one of the purposes of this research is to find the best composition between POME and EFB, four batch reactors with different composition of POME and EFB were run and investigated. Table 3 shows the composition of methane and CO\textsubscript{2} from generated biogas. It can be seen that the pure POME, both in small reactor and UASB reactor, does not produce biogas.

| Samples | POME:EFB | C/N ratio | % of total volume | % between CH\textsubscript{4} and CO\textsubscript{2} only |
|---------|----------|-----------|-------------------|-----------------------------------------------|
| A       | Pure POME| 6.5       | 0                 | 0                                              |
| B       | 20:1     | 9         | 8.4               | 7.7                                           |
| C       | 15:1     | 10        | 8.2               | 11.6                                          |
| D       | 7.5:1    | 13        | 24.3              | 19.4                                          |

Adding EFB into POME was proven to increase biogas production due to increase in C/N ratio. The results indicate that the higher EFB composition the faster the biogas formation is. Error! Reference source not found. shows that all containing EFB reactors started to produce biogas on the 6\textsuperscript{th} day. Then, the gas production stopped based on the order of reactor B, C, and D (less EFB to high EFB fraction). Total volume of generated biogas was only observed based on the size of plastic gas collector. In the end of experiment, out of 4 small reactors reactor D generated the highest volume of biogas (±700 ml) followed by reactor C (±400 mL) and D (±200 mL). Based on this result, the conversion factor (volume base) of the mixture of POME and EFB into biogas is range from 13 to 47 %. The highest conversion is 47 % from ratio 7.5 of POME to 1 EFB. The generated biogas volume from UASB reactor was not measure but it used as a carbon source for microalgae. Based on this result it can be concluded that ratio 7.5 of POME to 1 EFB generated high volume of biogas and methane content.

3.2 Microalgae production

On the former research it has been proven that POME without additional nutrient can be used as medium for microalgae growth [10]. Its performance (OD =0.197) was comparable to those of fresh water (OD = 0.22) and saline water (OD = 0.242) with nutrient. On this research maximum optical density (OD) = 0.231 was achieved when biogas was fed into POME.

This research shows significant increase in biomass production of spirulina when biogas was fed into POME medium (Figure). Total produced biomass on POME medium with biogas is double than that on POME medium without biogas.
Table 4). This increase could be due to utilization of CO\textsubscript{2} content in the biogas as a carbon source by *Spirulina sp* that brings its ratio almost near C/N ideal (56:9) for algae growth [3] [11].

![Figure 1. Spirulina sp biomass production](image1)

*Spirulina sp* growth rate (\(\mu\)) in this experiment was calculated based on changes of its optical density at 680nm wavelength at exponential phase.

\[
\mu = \frac{\ln OD_2 - \ln OD_1}{t_2 - t_1}
\]

\(OD_2\) and \(OD_1\) are optical density of *Spirulina sp* at end and beginning of exponential phase. \(t_2\) and \(t_1\) are time growth od *Spirulina sp* at end and first of exponential phase [3] [12].

![Figure 2. Optical density of Spirulina sp](image2)

The exponential phase of *Spirulina sp* in POME medium with biogas was occurring between day 2 and day 7 while it was happening from day 8 to day 10 in POME medium without biogas. The growth rate constant for Spirulina sp in the POME medium with biogas is 0.0989 day\textsuperscript{-1}. This growth rate constant is more than twice of that in the POME medium without biogas that only 0.0598 day\textsuperscript{-1}. It should
be noticed that this growth rate is only observed for a short period (10 days). These growth rate may be different if the time of experiment is extended more than 10 days.

| Experiment | Total biomass harvested (gr/L) on medium |  |
|------------|-----------------------------------------|--|
|            | POME without biogas | POME with biogas |
| 1 (10 L POME) | 0.0206 | 0.0463 |
| 2 (20 L POME) | 0.0218 | 0.0487 |

Measurement with spectrometer is only based on optical density (OD). *Spirulina sp* growth in the medium can be monitored by green colour. In this research, due to low concentration of biomass production the change in colour of POME was hardly observed. Therefore, *Spirulina sp* growth was monitored using microscope with 10 times enlargement. Figure shows that *Spirulina sp* cell in the POME medium with biogas is denser and longer than those in POME medium without biogas.

![Spirulina sp cells](image)

**Figure 3. Spirulina sp cells**

4. Conclusions

Researches were done by investigating several ratios of POME to EFB to generate biogas and cultivating *Spirulina sp* in POME medium with and without biogas. Result shows that ratio 7.5 POME to 1 EFB (mass base) generates the highest methane content (56%). Result also shows that the higher the EFB fraction in the reactor feed (mixture of EFB and POME), the higher generated biogas volume and methane content. It means the EFB can be used to enhance biogas productivity in combination with POME. The generated biogas from palm oil mill waste can be used to increase more than 100% of biomass production of *Spirulina sp* in POME medium. *Spirulina sp* community cultivated in the POME medium with biogas is denser and has longer size than that in the same medium without biogas.

There are some recommendations for the future research. First, due to low density of EFB, a large reactor is needed to investigate high EFB ratio over POME as biogas source. As a result, a wide range of EFB to POME ratios can be investigated to find the maximum volume of generated biogas and methane content. Second, close system of microalgae reactor is needed to investigate how much CO₂ is absorbed by the microalgae.

5. References

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