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THE PERFORMANCE OF BIOGAS PRODUCTION FROM POME AT DIFFERENT TEMPERATURES

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ABSTRACT

Indonesia, as the largest palm oil producer in the world, also produces palm oil mill effluent (POME). While the latter is a liquid waste that is hazardous for the environment, with proper processing, it can be a potential energy source. The objective of this study was to study the performance of biogas production from POME at various temperatures. The POME and sludge mixture was fermented, according to the treatment, at 27-28°C, 45°C, and 55°C, with the results showing that methane could thereby be produced by as much as 0,19 m^3, 0,25 m^3, and 0,28 m^3 respectively. For each kilogram of chemical oxygen demand (COD) removal, with POME fermentation at room temperature, 45°C, and 55°C, biogas could be produced with methane content of 65.44%, 62.57%, and 59.15%, respectively.

Keywords: Biogas; Fermentation temperature; Methane gas; POME

1. INTRODUCTION

The process of oil extraction from palm oil requires significant quantities of water to steam-sterilize the palm fruit bunches and clarify the extracted oil. Oil palm mill plants also demand large amounts of water for their operation and discharge considerable quotas of liquid waste or palm oil mill effluent (POME). For each ton of crude palm oil (CPO) produced, an average of 0.9–1.5 m^3 of POME is generated (Saidu et al., 2013); or to put it another way, about 2.5–3.0 tons of POME per ton of produced CPO is obtained in the extraction process (Borja & Banks, 1994a).

POME is a colloidal suspension containing 95–96% water, 0.6–0.7% oil, and 4–5% total solids, including 2–4% suspended solids (Wu et al., 2007). The biological oxygen demand (BOD), chemical oxygen demand (COD), oil and grease, total solids, and suspended solids in POME range from 23,500–29,300 mg/L, 49,000–63,600 mg/L, 8,370–8,500 mg/L, 26,500–45,400 mg/L, and 17,100–35,900 mg/L respectively (Saidu et al., 2013). POME with an average COD and BOD of 70,000 and 30,000 mg/L, respectively, can cause serious environmental hazards if discharged untreated (Chan et al., 2012).

However, it contains methane, a flammable gas with high potential for use as a source of renewable energy. Khemkhao et al. (2012) stated that POME with organic loading rates (OLR)

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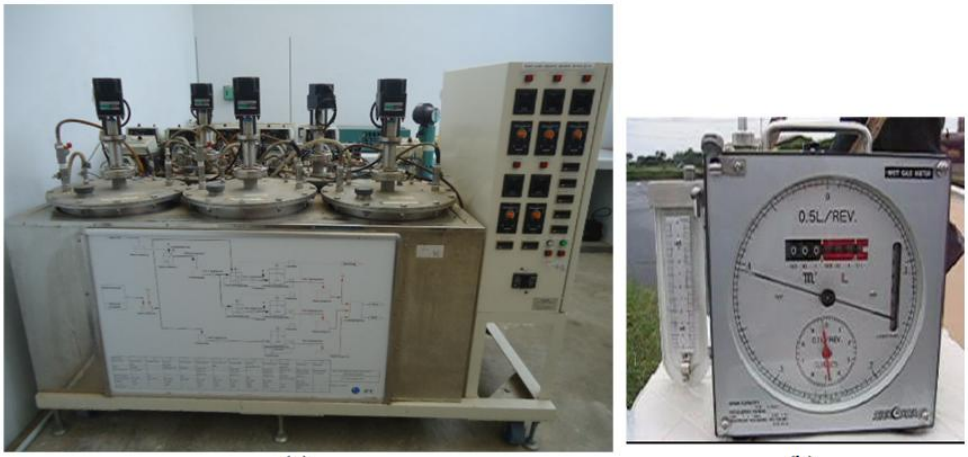
of between 2.2–9.5 g of COD per liter per day, with an overhaul anaerobic, can produce 13.2 liters of biogas each day. According to Tong (2011), a palm oil mill with a production capacity of 60 tons of fresh fruit bunches (FFB) per hour or 360,000 tons of FFB per year will yield as much as 216,000 m^3 of POME per year, with a total COD of 10,800 tons per year.

To date, Indonesian palm oil factories have not made serious efforts to capture and deploy methane gas, due to the prohibitive investment cost and low practicality. Previous studies have shown that biogas production from POME at room temperature is sub-optimal, as the amount of methane produced is negligible (< 0.35 L per g of COD) and takes an unreasonably long time. The objective of the present research was therefore to study the performance of biogas production from POME at different temperatures. The expected benefit to be obtained from this study was a mapping of the implementation of technological use of POME to become electrical energy.

2. METHODS

The experiment was conducted using three anaerobic bioreactors, according to the "Bench Scale Advance Methane Fermentation Model AR-50L-3," with a capacity of 50 L each and featuring a stirrer and automatic temperature control, as shown in Figure 1a. During the fermentation, gas produced was measured continuously using a gas flow meter "Wet Gas Meter; Model W-NK 0.58," as shown in Figure 1b. POME and sludge were obtained from PTPN VII Bekri, Central Lampung.



(a) (b)

Figure 1 (a) Anaerobic bioreactors "Bench Scale Advance Methane Fermentation"; (b) Gas flow meter

The temperatures deployed were 27–28^{o}C (room temperature), 45±3^{o}C and 55±3^{o}C. A stirring speed of 100 rpm was used at 45^{o}C and 55^{o}C, while the bioreactors with manual stirring were used for the treatment conducted at room temperature. The procedure was carried out three times per day, each time stirring for five minutes. This was in accordance with the actual conditions present in the field. The substrate was formed from a mixture comprising 80% POME and 20% sludge; such a combination determined an adjustment or lag phase in the fermentation process.

We began the study by characterizing the sample, which included mixed POME and sludge to the proportions mentioned above. Then, the mixture was fermented at different temperatures according to the treatment. The experiment was terminated if the COD value of the effluent was less than 10,000 mg/L. The stages of the research can be observed in Figure 2.

The parameters noted during fermentation were biogas production, temperature, pH, COD and composition of biogas (CH_4, CO_2, and N_2). Biogas production was measured using a gas flow meter (WK-NK-0.5B, Shinagawa Corporation, Japan). The composition of the gas was analyzed using gas chromatography (Shimadzu GC 2014) with a thermal conductivity detector (TCD) and a shin-carbon column of four meters' length; pH was measured using a gas pH meter (DKK-TOA Corporation, Japan), while COD value measurement was conducted using HACH Spectrophotometry DR4000 (HACH Company, Japan) at 620 nm wave length. Biogas production and temperature were measured every day, while the pH, COD, and gas composition were measured every seven days.

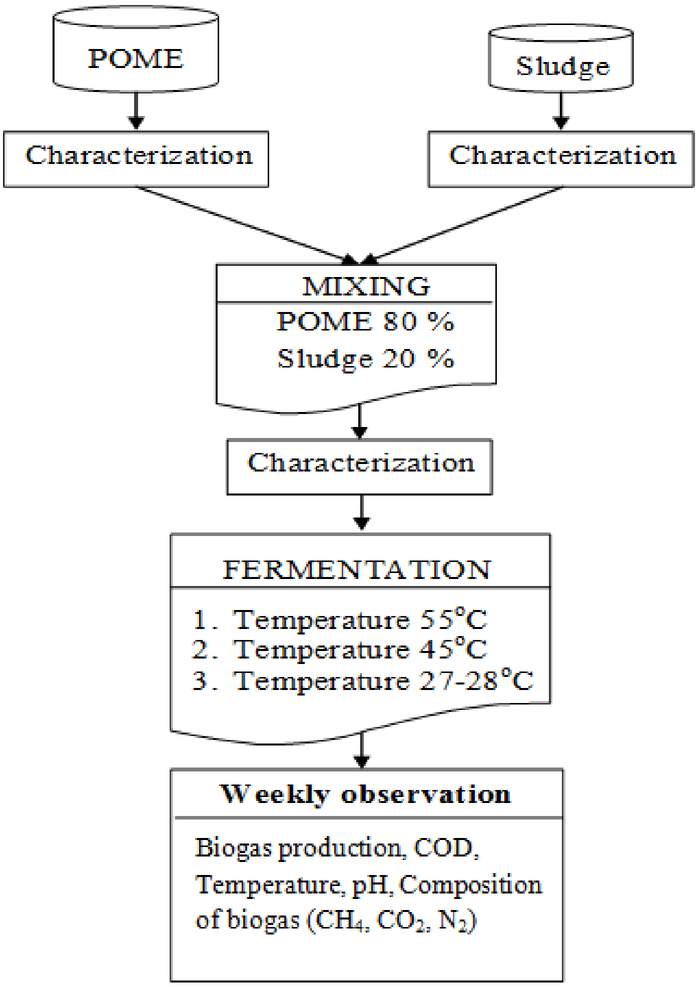


Figure 2 Stages of the research

3. RESULTS AND DISCUSSION

3.1. Production Pattern of Biogas

Figure 3 shows the daily biogas production at temperatures of 55°C, 45°C, and 27–28°C during the study period. The lag phase of biogas production at room temperature (27–28°C) reached 151 days, while at 45°C this was 25 days, and at 55°C there were active microorganisms that were directly producing the biogas, which were reconfiguring the group anaerobes, were thermophilic microorganisms such as Methanosarcina, Methanococcus, Methanobacterium, and Methanobacillus (Weiss et al., 2011).

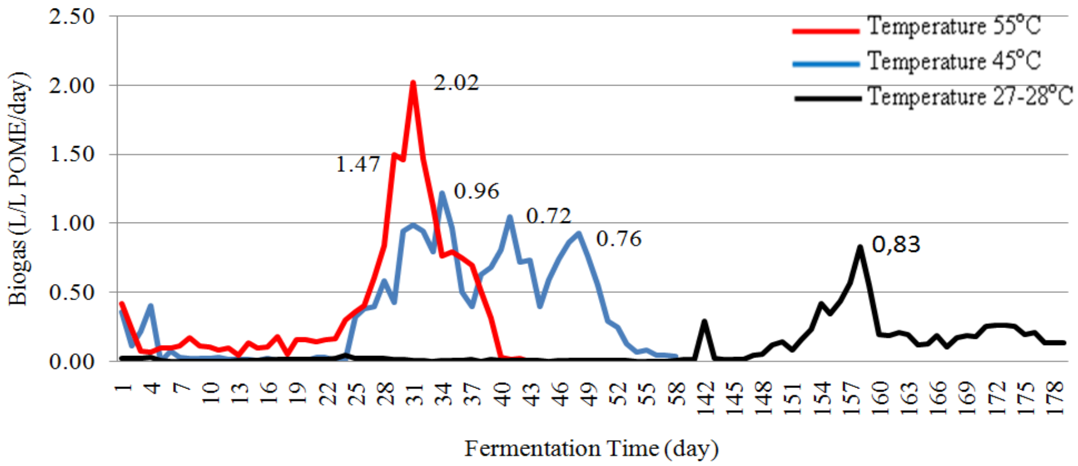


Figure 3 The pattern of biogas production from POME at different fermentation temperatures

3.2. The Acidity Level (pH) of POME

The pH value of POME during fermentation at different temperatures is shown in Figure 4. The initial measurement demonstrated that the fresh POME being emitted from the factory had a pH value of 5.63–5.64; meanwhile, the sludge taken from the end of the anaerobic pond had a pH value of 8.15–8.18. After mixing with 80% POME and 20% sludge, the pH value was 6.27–6.29. According to Saidu et al. (2013), POME is a creamy brown colloid with a pH of 4–5, which is affected by the quality of the raw materials (FFB).

Under controlled conditions, the temperature rise will accelerate the growth of active microorganisms, especially thermophilic varieties such as Methanosarcina, Methanococcus, Methanobacterium, and Methanobacillus (Weiss et al., 2011). Meanwhile, the microorganisms that grow at mesophilic temperatures are Streptococcus (approximately 50%), Lactobacillus (approximately 30%), and the Clostridium group (approximately 20%).

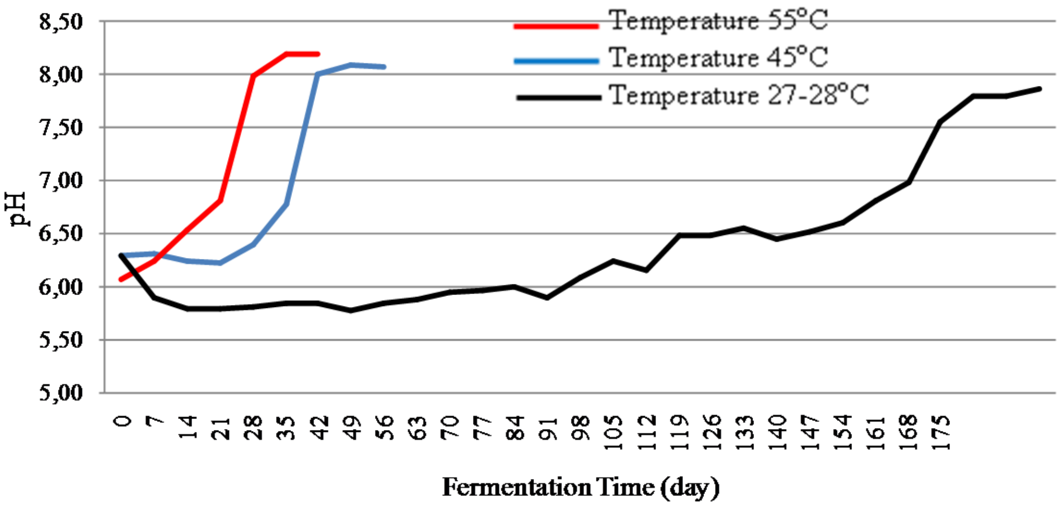


Figure 4 The changes in the pH value of POME during fermentation at different temperatures

3.3. COD and COD Removal

The reduction of COD values, when conducted at 55^{o}C, was faster than when conducted at 45^{o}C and 27–28^{o}C (Figure 5). This phenomenon was caused by the microorganisms derived from sludge POME, which were categorized as thermophilic; similar results were reported by other researchers (O-Thong et al., 2008). In this research, the microorganism source was 20% sludge (10 liters). Such sludge tends to contain many bacteria, such as Clostridium, Escherichia coli, and Enterobacter (Chen et al., 2005; Chong et al., 2009). Some studies have shown that these thermophilic microorganisms are widely found in soil, sludge, and compost (Hu & Chen, 2007; Wang & Wan, 2008).

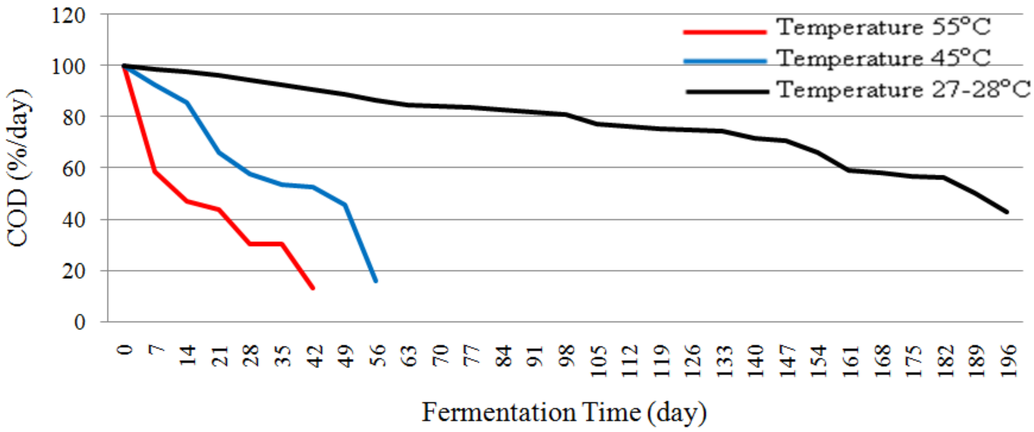


Figure 5 The decreasing pattern of COD value at different fermentation temperatures

The decrease in COD values indicated the decomposition of organic material into simpler substances. The organic materials contained within the POME were complex compounds, such as carbohydrates, proteins, and fats (Poh & Chong, 2009), while the simple compounds resulting from the fermentation process were formic acid, acetate, propionate, butyrate, lactate, succinate, ethanol, carbon dioxide, and hydrogen gas (Poh & Chong, 2009). The results show that the COD removal at 55°C was greater than at 45°C and room temperature (27–28°C) (Figure 6).

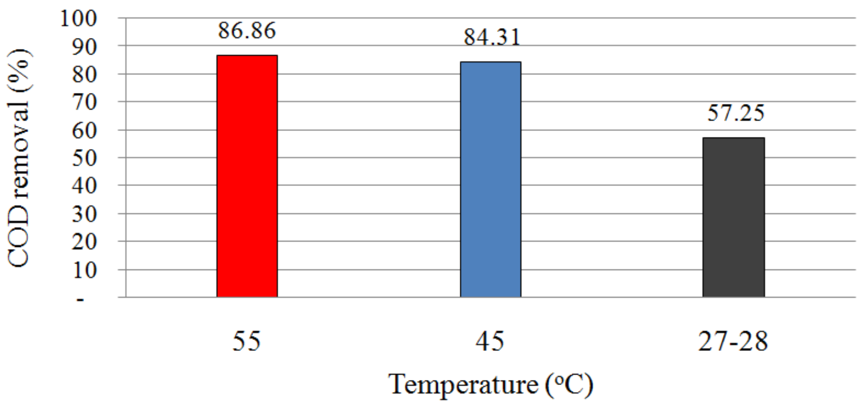


Figure 6 COD removal from POME at different fermentation temperatures

3.4. Methane Productivity

The results show that the methane productivity from POME varied between different temperatures, as shown in Figure 7. Fermentation at 55°C produced more biogas (0.28 L for each g of COD removal), while a temperature of 45ºC and room temperature yielded 0.25 L and 0.24 L, respectively. A stoichiometric estimation of each g of COD would produce 0.35 L methane gas. This shows that the biogas produced was less than the stoichiometric estimation.

This was caused by the imperfect methanogenesis process, resulting in significant formation of CO_2.

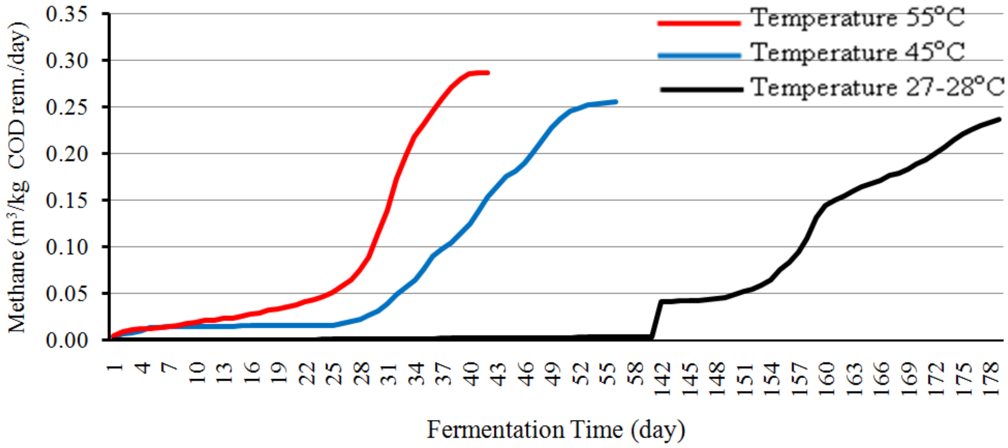


Figure 7 The patterns of biogas production from POME at different fermentation temperatures

A fermentation temperature of 55°C produced biogas with a methane content that was higher than that yielded at 45°C and room temperature (Figure 8). Choi et al. (2013) reported that the use of a high-rate anaerobic reactor in the POME process could produce biogas with a yield of 0.171 to 0.269 L per g of COD, while methane concentration may reach 59.5–78.2%. In addition, the 55°C fermentation temperature produced biogas with fewer impurities (CO_2 and N_2) than what was yielded at 45°C and room temperature. It is very important when producing biogas as fuel, especially for electrical energy, to remove carbon dioxide; such a measure could increase the biogas' quality and raise the heating energy point (Kapdi et al., 2005). Some results of COD removal and the methane gas content of POME can be seen in Table 1.

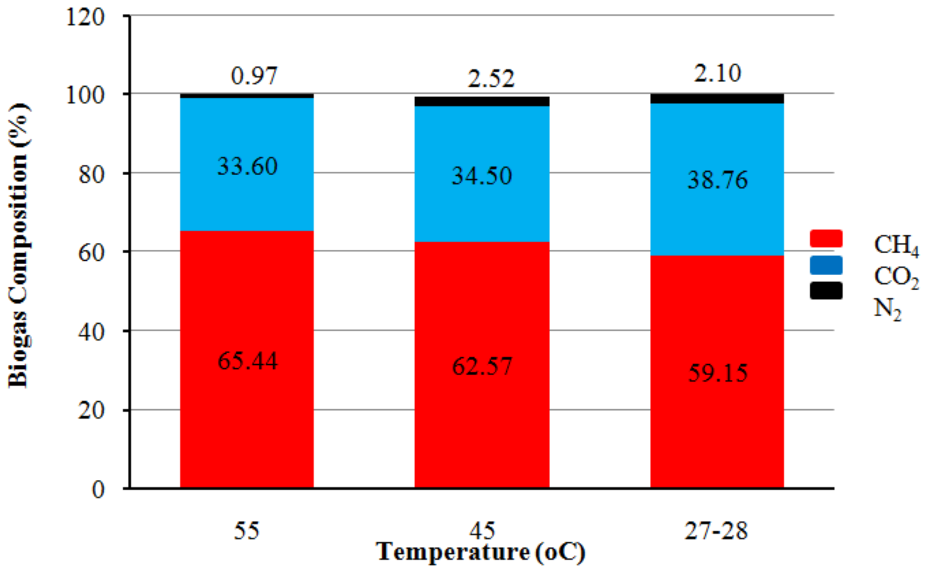


Figure 8 The biogas composition generated from POME fermentation at different temperatures

Table 1 Research studies on the reduction of COD and methane capture from POME

Methods	COD removal efficiency (%)	Highest methane composition (%)	Reference
Anaerobic filtration	94.00	63.00	Borja and Banks (1994a)
Anaerobic filtration	94.00	63.00	Borja and Banks (1994b)
UASB reactor (based on methanogenic reactor)	96.7–98.4	54.2–62.0	Borja and Banks (1994b)
UASB	98.40	54.20	Borja and Banks (1994a)
Fluidized bed reactor	78.0–94.0	N/A	Borja and Banks (1995a)
Fluidized bed	78.00	N/A	Borja and Banks (1995b)
UASFF in various wastewater treatments	89.5–97.5	62.0–84.0	Najafpour et al. (2006)
Anaerobic pond	97.80	54.40	Yacob et al. (2006)
Anaerobic digester	80.70	36.00	Yacob et al. (2005)
CSTR	80.00	62.50	Tong and Jaafar (2006)
CSTR at 55^{o}C	86.86	67.58	Results of research
CSTR at 45^{o}C	84.31	67.58	Results of research
Bioreactors in which manual stirring was performed three times per day, for five minutes at a time, at 27-28^{o}C	57.25	60.70	Results of research

N/A: data unavailable

4. CONCLUSION

POME fermentations at 55^{o}C, 45^{o}C, and room temperature (27–28^{o}C) can produce methane of as much as 0.28 m^{3}, 0.25 m^{3}, and 0.19 m^{3}, respectively for each kg of COD removed. POME fermentation at 55^{o}C, 45^{o}C, and room temperature can produce biogas with methane contents of 65.44%, 62.57%, and 59.15%, respectively.

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