

Preliminary Study on biogas production from POME by DBD plasma

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Abstract

A new technology to produce biogas using a dielectric barrier discharge (DBD) plasma system from palm oil mill effluent (POME) was investigated. The batch experiments were examined at applied voltages of 15, 20 and 25 kV. The results showed that the highest yields of hydrogen and methane were achieved at an applied voltage of 25 kV after 1 hour were 2.42 and 1.32 mL/mL of POME, respectively. The biogas was composed of 65% hydrogen and 35% methane. In order to make the results of this study applicable to biogas plants, the effects of flowrate and consumed energy are important parameters that should be further investigated in a future study.

Keywords: POME, plasma, dielectric barrier discharge, biogas production

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1. Introduction

Indonesia's palm oil industry is developing rapidly due to Indonesia being the largest palm oil producer in the world [1]. Each ton of crude palm oil (CPO) creates approximately 2.5 m³ of POME, which is considered wastewater. POME wastewater can cause serious water pollution because it contains high levels of organic contents such as high chemical oxygen demand (COD), biochemical oxygen demand (BOD), and oil-grease. However, there is an opportunity to convert the wastewater from POME into biogases, such as hydrogen and methane gas, as potential sources of renewable energy. Generally, conventional methods are used in the palm oil industry for the treatment of POME to produce biogas, such as open ponding, anaerobic and aerobic systems, or combinations of both. The advantage of these methods is that biological treatment is easy, but disadvantages are that they require a long hydraulic retention time (HRT) and a large area of land [2-5]. Furthermore, Budiman and Wu [6] and Norfadilah et al, [7] reported that the treatment of POME to produce biogas required between 1 and 10 days, respectively. Recently, Hazmi et al, [8] have successfully demonstrated how POME can be treated using a combined sand filtration-DBD plasma system. This system is not only able to reduce the HRT for treatment of COD, BOD₅ and oil-grease to achieve standard water quality but also produce biogases.

This paper reports an investigation of biogas production from POME using a DBD plasma system. The DBD plasma system is generated by electrical discharges in a liquid in order to produce ions and active species that are oxidizing radicals (H• and •OH) and molecules (H₂O₂, O₃, etc.) to improve the chemical reaction speed. These chemical reactants are effective in degrading organic compounds in POME [9-12]. The purpose of this work was to investigate the performance of the DBD plasma system as an alternative method for producing biogas from POME. Comparison of our investigation result with other methods of previous studies is reported.

2. Materials and Methods

The POME used in this study was similar to that used by Hazmi et al [8]. The POME was taken after the fat-grease pit from the wastewater treatment system in Padang, Indonesia. A summary of the POME characteristics is shown in Table 1.

A schematic diagram of the experimental setup is depicted in Figure 1. Upper needle electrodes and a lower plane electrode were connected to a high voltage with a frequency system of 50 Hz and ground, respectively. A needle-plane electrode system was used with a distance of 5 mm between the needle and the POME surface. The needle electrode was made of 1 mm diameter stainless steel and the plane electrode was made of 1 mm thick stainless steel. The applied voltages and discharge currents were recorded using an oscilloscope (TDS5104 Tektronix) through a high-voltage probe (P6015A Tektronix) and a current probe (P6022 Tektronix). The applied voltages were set at 15, 20 and 25 kV. A bigger acrylic container with a storage volume of about 3500 mL was used as the DBD reactor. The volume of the POME in the DBD reactor was 1000 mL. Furthermore, a smaller acrylic container with a storage volume of about 1500 mL was used as gas storage. The hydrogen and methane gas concentrations were detected by commercial MQ8 and MQ4 gas sensors (Hanwei), respectively. In addition, an air pressure sensor (BMP180 Bosch) was used to detect the air pressure change in the acrylic container. All sensors were connected to a data logger (ADC24 Pico) to record the conductivity change related to the electrical output signal of gas concentrations in the storage container every second for one hour, controlled by a personal computer (PC). Figure 3 shows the voltage variations to generate the discharge current in the DBD reactor.

Table 1. Characteristics of POME after oil-grease pit [13]

Parameter	Unit	Value
pH		3.9
BOD ₅	mg/L	251.4
COD	mg/L	440.8
Oil-grease	mg/L	132.4
Oxidation Reduction Potential (ORP)	mV	162.3
Electrostatic Conductivity (EC)	μS/cm	64.8
Total Dissolved Solid (TDS)	mg/L	32.400

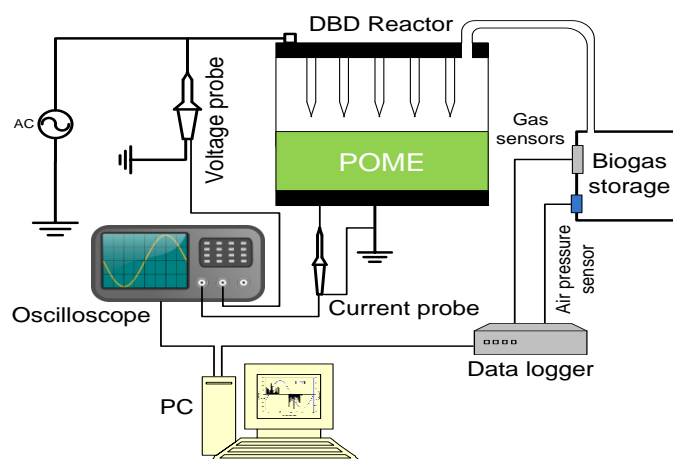


Figure 1. Schematic diagram of experimental setup

3. Results and Discussion

The experiment investigated the discharge current in the DBD reactor and the product yield in the biogas storage with variations of applied voltage and time. The discharge current of the applied voltage in the DBD reactor was recorded by oscilloscope through voltage and current probes, while the product yield in the biogas storage detected by the gas sensors was recorded by a data logger.

3.1. Discharge Current Characteristics

Figure 2a shows that a discharge current pulse train of about 8 A occurred at an applied AC voltage of 25 kV. It can be seen that the discharge current took place around the peaks of

the applied voltage for both the positive and the negative half cycles, distributed around the phase of 0-360°. The discharge current pulse increased with the increase of the voltage applied to the reactor, causing the POME decomposition rate to increase with an increase of the treatment time. The discharge current on the POME surface produced UV and many active species with high oxidation potential ions and molecules such as ozone (O_3), hydrogen peroxide (H_2O_2), hydroxyl radical ($\bullet OH$), and perhydroxyl radical ($\bullet H^+$), which effectively decompose organic compounds [14]. The final products of the decomposition process were water, inorganic salts [15], and biogases such as hydrogen (H_2), methane (CH_4) and carbon monoxide (CO). In Figure 2b, the plasma discharges origin from the needle tip on the POME surface is displayed.

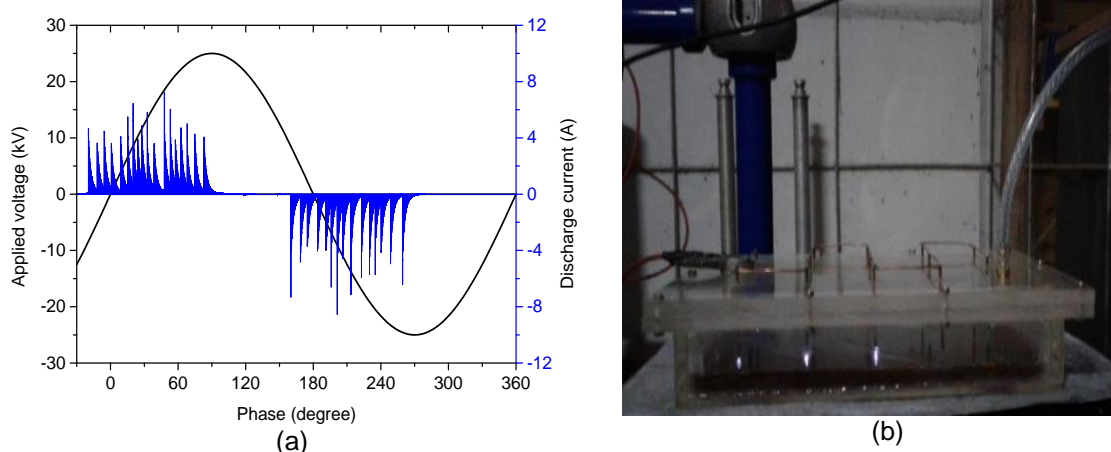


Figure 2. Waveform for the applied voltage of 25 kV (a) The discharge current was recorded on one cycle of the sinusoidal waveform; (b) Plasma discharges occurred between the needle tip and the POME surface

3.2. Profile of Temperature and Air Pressure

Figure 3 displays the profile of the temperature and the air pressure in the container. Figure 3 shows that slight changes in temperature and air pressure occurred in the gas container. The temperature increased with an increase in time, while the air pressure decreased with an increase in time. The decreasing air pressure indicated that there was increasing gas volume in the container due to the oxidation process in the POME producing several gases. We predict that the changes in temperature and air pressure are due to the production of biogases such as hydrogen and methane gas in the plasma reactor during the experiment.

3.3. The Effects of Applied Voltage on Yield Production of H_2 and CH_4

A previous study [8] found that the removal efficiency of COD, BOD_5 and oil-grease was 61, 63 and 62% with the applied voltage at 19 kV in the DBD plasma system. The concentration of COD was 304 to 163 mg/L and indicated that a decrease of COD was followed by formation of hydrogen and methane. Similar results have been reported by other researchers, such as hydrogen production using fermentation under mesophilic condition at 37 °C [7, 16] and under thermophilic condition at 55 °C [17-19]. It was concluded that the degradation rate of POME increased with an increased voltage.

To increase biogas production, the applied voltage was selected at 15, 20 and 25 kV in a batch experiment based on previous studies [8,12]. Figure 4 illustrates the applied voltage effect on the yield of hydrogen (a) and methane (b). Figure 4a shows that the yield of hydrogen increased from 0.12, 0.69 and 0.83 mL H_2 /mL POME after 30 minutes with the applied voltage at 15, 20 and 25 kV, respectively, and continuously increased until 60 minutes. Figure 4b shows that the yield of methane increased from 0.01, 0.06 and 0.21 mL CH_4 /mL POME after 30 minutes with the applied voltage at 15, 20 and 25 kV, respectively. The highest yield of biogas in this experiment was achieved when the applied voltage was 25 kV. The effect of applied voltage on biogas yield is displayed in Figure 5. The biogas comprised mostly of hydrogen and methane.

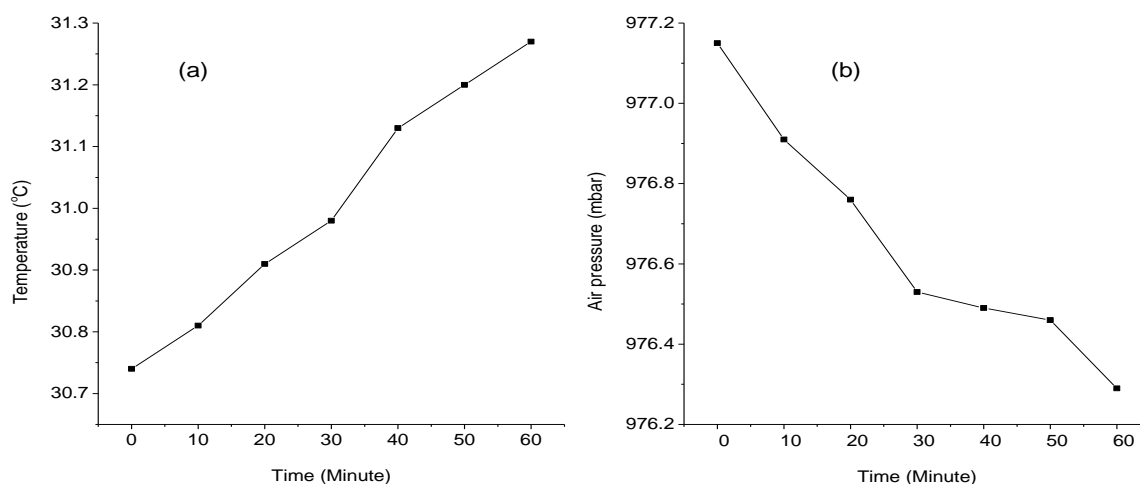


Figure 3. Profile of temperature and air pressure in the container at 25 kV of applied voltage. (a) Change of temperature in one hour; (b) Change of air pressure in one hour.

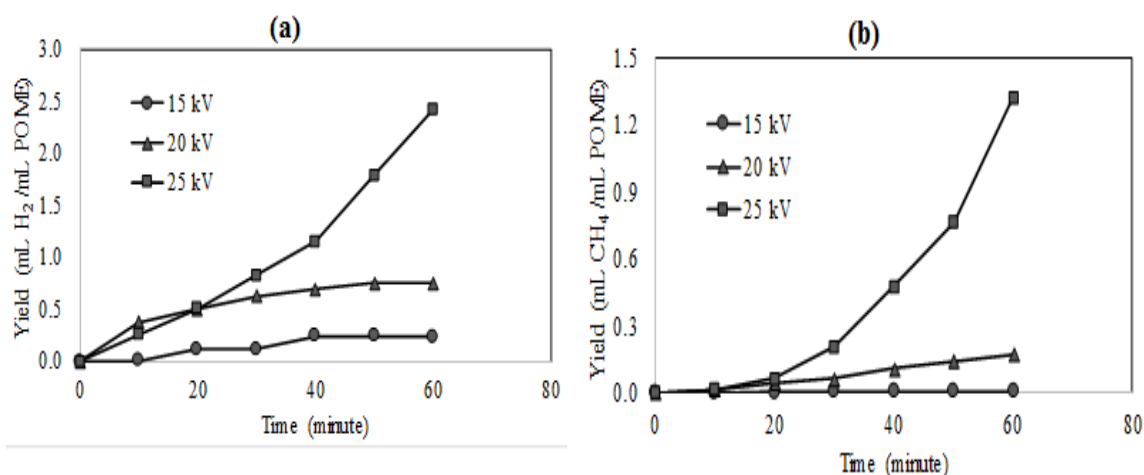


Figure 4. Profiles of biogas production. The applied voltage was set at 15, 20 and 25 kV. (a) Yield production of H₂; (b) Yield production of CH₄.

Table 2 shows a comparison of the biogas yield from different processes and substrates. The processing time in the present study was 6-238 times faster compared with the results using batch fermentation in a continuous process in previous studies. In the previous studies, the production of hydrogen based on processing time was lower than in the present study. Biogas production using a fermentation process depends on substrate concentration, volume of inoculum, pH and temperature [16]. The fermentation process also needs more time to degrade the substrate using microorganisms and produce biogas following hydrolysis, acidogenesis and methanogenesis [20]. For this process, Lattif et al [21] investigated biogas production from date palm fruit waste. Their results confirmed a biogas composition with 63% methane; the system should be well controlled under mesophilic condition (37 °C). In our study, the biogas composition consisted of 65% hydrogen and 35% methane and a small amount of carbon monoxide. In a future study, an attempt could be made to remove the carbon monoxide using absorption.

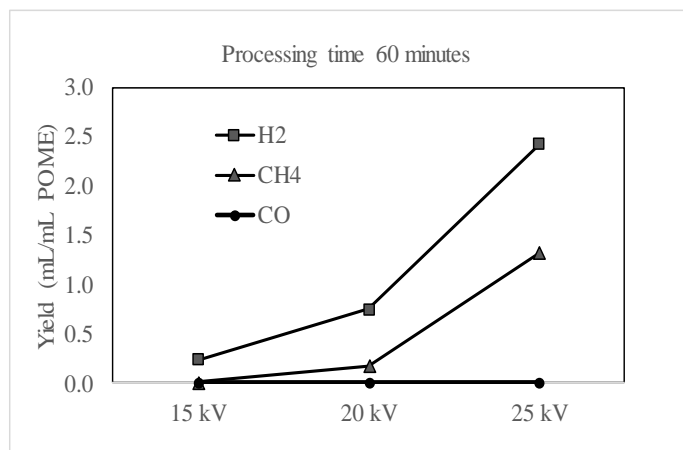


Figure 5. The effects of applied voltage on yield production of H₂, CH₄ and CO

Table 2. Comparison of biogas production with references

Process	Substrate	Processing time (day)	Yield (mL/mL POME)		Gas Composition (%)			Reference
			H ₂	CH ₄	H ₂	CH ₄	CO ₂	
DBD at 25 kV	POME	0.042	2.42	1.32	65	35	-	This study
Batch fermentation	POME	10	5.99	-	36	-	64	Norfadilah et al., [7]
Continuous fermentation	Rice straw	1.96 ^a	7.1	-	-	-	-	Sattar et al., [19]
Ultrasonification pretreatment following Photofermentation	POME	1 ^b	8.72	-	-	-	-	Budiman and Wu [6]
Continuous fermentation	Glucose	0.25 ^b	2.1 ^c	-	-	13	87	Fang and Liu., [18]
Continuous fermentation	Glucose	0.5 ^b	2.39 ^c	-	64	-	36	Ueno et al., [17]

^a Hydraulic retention time
^b In mol/mol glucose
^c in mL/volatile solid

4. Conclusion

The effect of applied voltage on biogas production from POME was studied using a DBD plasma system. Increasing the applied voltage caused an increase in the yield of hydrogen and methane. The highest hydrogen and methane yields were 65% and 35%, respectively. Biogas production using the DBD plasma system was 6-238 times faster than conventional processes such as fermentation. In future studies, the effect of flowrate and consumed energy should be further investigated.

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