Effect of AC and DC sources of Dielectric Barrier Discharge System on Removal of Chemical Oxygen Demand using Palm Oil Mill Effluent (POME)

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1. Introduction

POME is classified as a very high polluting wastewater that has biochemical oxygen demand (BOD) and chemical oxygen demand (COD) values in the range of 2,500-5,000 mg/L and 17,995-18,995 mg/L, respectively [1]. Biological treatment with anaerobic digestion is a commonly used process in the palm oil mill industry due to its low cost compared to other processes, such as evaporation ponds, applying thermal and physicochemical treatments. In biological treatment, the BOD/COD ratio should be greater than 0.5. Zainal et al. [2] found that the removal efficiency of COD is 21.95% at a reaction temperature of 50 °C and a reaction time of 8 hours in an anaerobic batch study using POME. Furthermore, the POME was capable of producing about 28 m^3 of biogas per ton. [3]. The POME wastewater is a very prospective source for biogas production as an alternative renewable energy source. The aim of this study was to investigate the effect of AC and DC sources of a dielectric barrier discharge (DBD) system in accelerating the removal efficiency of COD and biogas production using POME compared to the previous researches mentioned above.

2. Material and Methods

The POME used in this study was the same as that used by Hazmi et al. [1]. The POME was taken after the fat-grease pit from a palm oil industry in West Sumatra, Indonesia. The experimental setup is shown in Fig. 1.

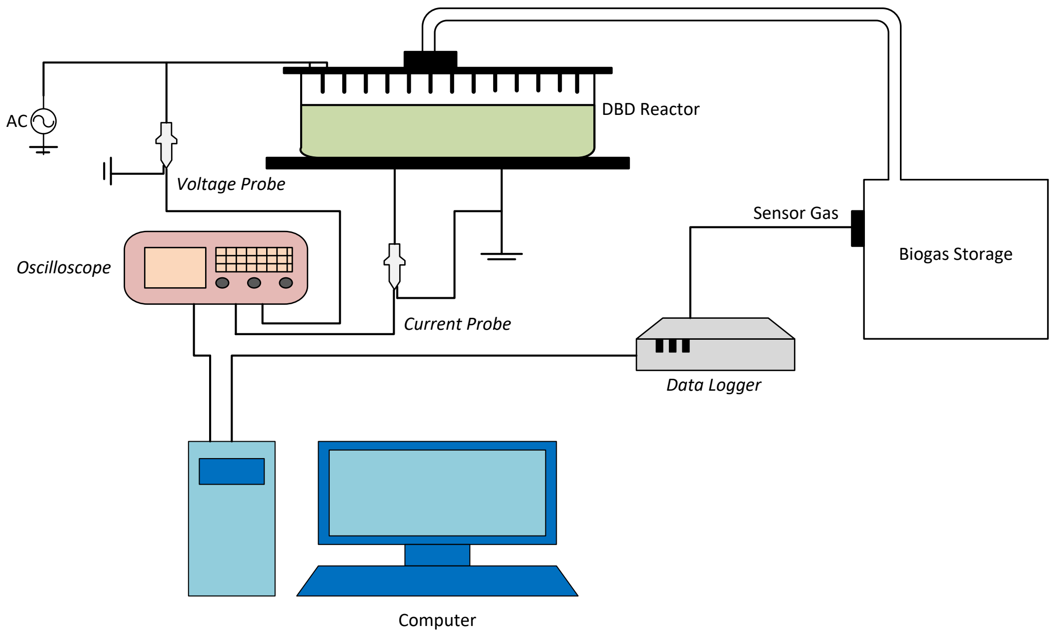

Fig. 1: Schematic Diagram of Experimental Set-up

The DBD reactor was made from glass and had a volume of 3500 mL. The working volume of the POME was 800 mL. The system included a needle-plane electrode, with needle electrodes connected to a high voltage alternating current (AC) source with a frequency system of 50 Hz and a direct current (DC) source, while the plane electrode was connected to ground. A needle-plane electrode system was used with a distance of 5 mm between the needle and the POME surface. The applied voltages of 20 and 25 kV for AC/DC source were recorded with a P6015A Tektronix high-voltage probe. The discharge currents were recorded using a TDS5104 Tektronix oscilloscope through a P6021A current probe. Furthermore, an acrylic container with a volume of about 1500 mL was used as gas storage. The hydrogen, carbon monoxide and other combustible gas concentrations such as methane were detected by commercial gas sensors (Figaro) attached to the gas storage. A personal computer recorded the changing electrical output signal of the gas concentration in the storage from all gas sensors for one hour through a data logger (ADC24 Pico). Pack test COD by Kyoritsu Chemical-Check Laboratory, Japan was used to analyze the COD concentration in the treated POME.

3. Results and Discussion

3.1. Profile of Biogas Production

According to Figs. 2(a) and (b), showing the biogas production profile of the DBD plasma system with AC source, the CH_4 yield increased enormously during the experimental runs. The H_2 yield only slightly increased when the voltage was 20 kV and 25 kV after 60 minutes of experimental run. When the voltage was 20 kV, the CH_4 and H_2 yields were 0.48 and 0.03 mL/mL POME, respectively. Similar results were also found when the voltage was 25 kV. The CH_4 and H_2 yields rose to 0.5 and 0.06 mL/mL POME, respectively. It was found that increasing the applied voltage has a significant effect on the degradation of organic substances from the POME.

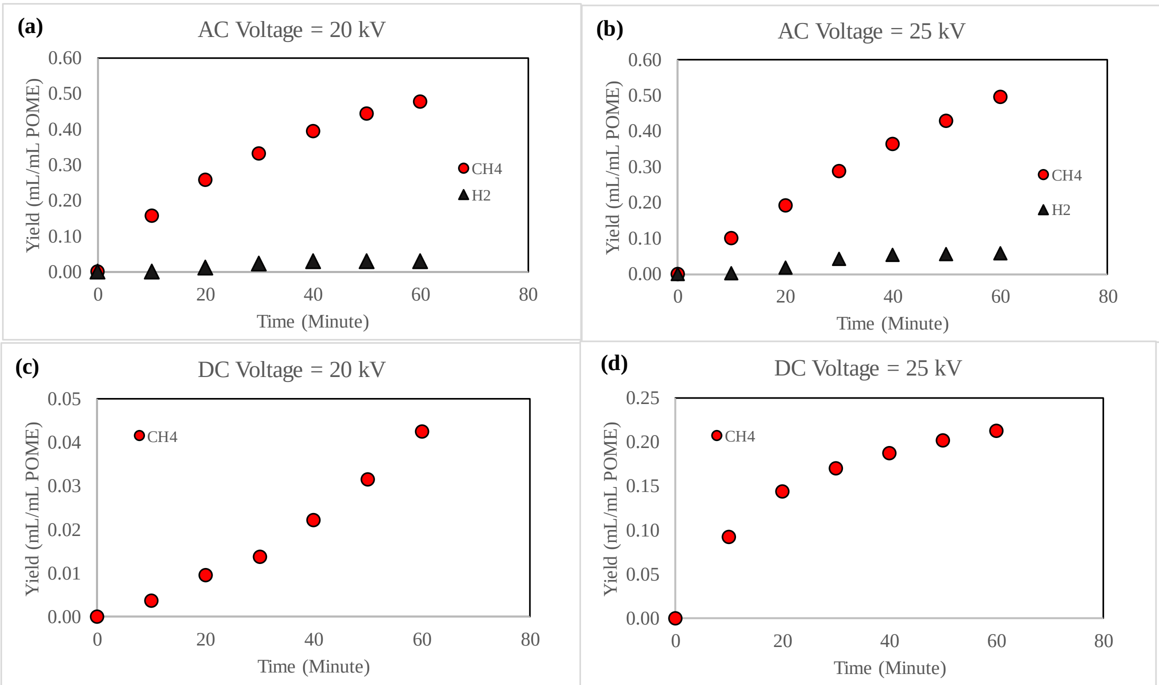

Fig. 2: Profile of biogas production by DBD plasma system

Due to the voltage enrichment, both the electron density and the concentration of radical species increased a great deal, which stimulates and activates the production of CH_4 and H_2. The type of voltage source also had a significant effect on the CH_4 and H_2 yield from the POME, as shown in Figs. 2(c) and (d) for the DC source. The CH_4 yield was 0.04 and 0.21 mL/mL POME, while H_2 was not detected for 20 kV and 25 kV, respectively. Radical species were generated by the C=O and C-H bounds when a high voltage was applied to the POME and reacted to form CH_4, H_2 and CO_2. The chain reaction led to a higher degradation of the POME when the applied voltage was increased. It is clear that, as Figs. 2 (a-b) show, the applied voltage significantly affects the CH_4 and H_2 production. These results are the same as those found by Mao et al. [4].

3.2. Composition of biogas

The degradation of organic compounds to CH_4 and H_2 reached 84.74-92.31% and 6.72-15.26%, respectively, for the AC source with applied voltage at 20 and 25 kV. Using DC source with applied voltage at 20 and 25 kV, only CH_4 was detected, as shown in Table 1. A comparison with previous studies is shown in Table 2. Lattif et al. [5] studied biogas production from date palm fruit waste and found that the biogas contained 63% methane under well-controlled temperature at 37 °C. Reaction time is a significant parameter for degradation of organic substances to biogas and COD removal. The reaction time in the this study was 238 times faster compared to the results using batch fermentation in a continuous process and 24 times faster than ultrasonification pretreatment followed by photofermentatition. Therefore, a future study could present the correlation between reaction time and conversion of organic compounds to biogas. Our results showed that CH_4 production increases with a higher applied AC voltage.

Table 1: Production of biogas by DBD Plasma

Source	**Voltage (kV)**	**Composition of biogas (mL/mL POME)**				**pH**
		CH_4*	**%**	**H_2***	**%**	
AC	20	0.48±0.05	92.31±2.72	0.04±0.01	6.72±2.72	5
	25	0.50±0.03	84.74±4.26	0.09±0.08	15.26±2.26	5
DC	20	0.04±0.02	100	0	0	4
	25	0.21±0.09	100	0	0	4

* The data was calculated for 5 replicates

Table 2: Previous Studies of biogas production form POME

Process	**Substrate**	**Processing time (hour)**	**Yield (mL/mL POME)**		**Biogas composition (%)**			**Reference**
			H_2	**CH_4**	**H_2**	**CH_4**	**CO_2**	
Batch Fermentation	POME	240	5.99	-	36	-	64	Norfadilah et al., [6]
Ultrasonification pretreatment following Photofermentative	POME	24[a]	8.72	-	-	-	-	Budiman and Wu [7]

[a] Hydraulic retention time

3.3. Removal of COD

The removal efficiency of COD is displayed in Fig. 3. The COD removal efficiency for the AC source with applied voltage at 20 and 25 kV for 1 hour was 50.54% and 53.37%, respectively. For the DC source with applied voltage at 20 and 25 kV it was 33.02% and 45.57%, respectively. These interactions indicate that the source of electricity and the applied voltage significantly affect the COD removal efficiency. Zainal et al. [2] studied the COD removal from POME using a thermophilic anaerobic process and found a COD removal efficiency of 21.95% at 30°C for 8 h reaction time. Khemkhao et al. [8] have reported that the COD removal efficiency increases when the organic loading rate (OLR) is increased. The COD removal efficiency of 49.50% by using dark fermentation was the same as reported in [9].

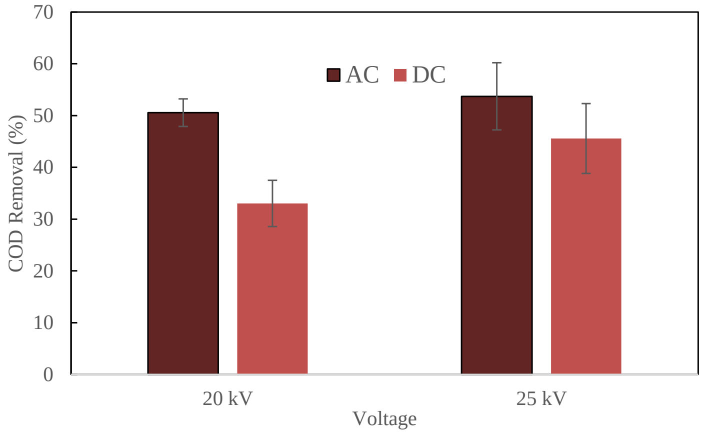

Fig. 3: Removal efficiency of COD with 5 replicates data

4. Conclusions

The effects of AC and DC voltage applied at 20 kV and 25 kV on biogas production and COD removal efficiency using POME were studied using a DBD plasma system. The biogas production and COD removal efficiency when using an AC source was higher than when using a DC source. The biogas consisted of CH_4 and a small amount of H_2. The highest COD removal efficiency was 53.37%, for applied voltage at 25 kV and reaction time at 1 hour. This result is 2 times higher and 8 times faster than a biological process.

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