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# Preliminary Study on Treatment of Palm Oil Mill Effluent by Sand Filtration-Dielectric Barrier Discharge System

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**Abstract.** In the palm oil industry, open ponding, aerobic and anaerobic digestion, physicochemical treatment and membrane filtration are generally applied as conventional treatments of palm oil mill effluent (POME). In this study, a sand filtration-dielectric barrier discharge (DBD) system was investigated as an alternative process for treating POME. This system can reduce land usage, processing time and costs compared to conventional systems. The removal efficiency of chemical oxygen demand (COD), biological oxygen demand ($BOD_5$), and oil-grease in relation to the applied voltage were studied. Furthermore, the pH and temperature profiles were investigated. The obtained results indicate that the removal efficiency of COD, $BOD_5$, and oil-grease increased with an increase of the applied voltage. The electrical energy consumption needed is about 10.56 kWh/L of POME.

**Keywords:** *dielectric barrier discharge; plasma; sandfiltration; POME; energy consumption.*

## 1 Introduction

Indonesia is the largest palm oil producer in the world. Indonesia's palm oil industry continues to grow rapidly and is significantly agriculture-based. The total production of crude palm oil (CPO) is shown in Figure 1 [1]. One ton of CPO produces around 2.5 $m^3$ of wastewater, or palm oil mill effluent (POME). The POME wastewater causes serious water pollution when it is directly discharged into a river or lake, because it contains high levels of chemical oxygen demand (COD), biochemical oxygen demand (BOD), and oil-grease. Generally, the palm oil industry uses conventional methods for the treatment of POME, such as open ponding and a combination of anaerobic and aerobic systems [2]. In Indonesia, more than 95% of the palm oil plants use open ponding for POME treatment because this process has low capital and operating costs. However, the disadvantage of this system is that it requires a large area of land and a long hydraulic retention time (40-65 days). A number of researchers have investigated the use of membrane bioreactors (MBR) [2-4]. They found

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that the membrane flux decreased with time due to fouling of the membrane surface. A dielectric barrier discharge (DBD) system is generated by electrical discharges in a liquid in order to produce oxidizing species radicals (H• and •OH) and molecules ($H_2O_2$, $O_3$, etc.) [5]. These chemical reactants are effective in degrading organic pollutants. The removal efficiency of the organic contaminants increases with an increase of the applied voltage and the treatment time [6-8]. The aim of the present work was to study the performance of the DBD system as an alternative for treating POME. This system can reduce land usage, processing time and costs when compared to a conventional system to achieve the water quality standards.

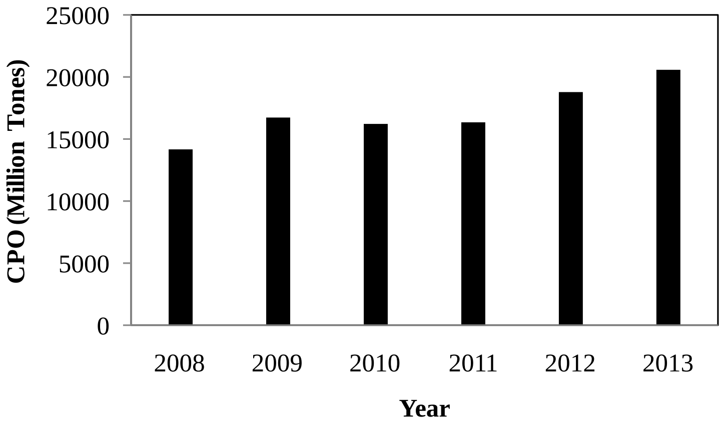


**Figure 1** The total production of crude palm oil (CPO) in Indonesia [1].

## 2 Materials and Methods

### 2.1 Source of Palm Oil Mill Effluent

The palm oil mill effluent (POME) used for this study was collected from the palm oil mill in Pasaman, West Sumatra, Indonesia. The POME was taken after the fat-grease pit in the wastewater treatment system. The samples were transported to the laboratory and stored in the dark at 5°C prior to use. The characteristics of the POME samples are summarized in Table 1.

**Table 1** Characteristics of POME after oil-grease pit [9].

| 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 |

## 2.2 Experimental Procedure

Three series of batch experiments were performed to investigate the removal efficiency of COD, $BOD_5$, and oil-grease, as shown in Table 2. In the first series, sand filtration (Run 1) was examined. In the second series, the performance of the dielectric barrier discharge (DBD) system was investigated. A high voltage with a frequency system of 50 Hz was applied to a needle electrode for 2 hours (Run 2-4) and 4 hours (Run 5-7). Based on both experimental results, a third series was conducted to study a system that combines sand filtration and DBD treatment of POME for 2 and 4 hours (Run 8-9). A schematic diagram of the experimental set-up is displayed in Figure 2.

**Table 2** Batch experimental conditions for treatment of POME.

| Process | 2 hours | | | 4 hours | | |
|---|---|---|---|---|---|---|
| | 13 kV | 16 kV | 19 kV | 13 kV | 16 kV | 19 kV |
| Sand Filtration | Run 1 | | | | | |
| DBD | Run 2 | Run 3 | Run 4 | Run 5 | Run 6 | Run 7 |
| Sand Filtration + DBD | | | Run 8 | | | Run 9 |

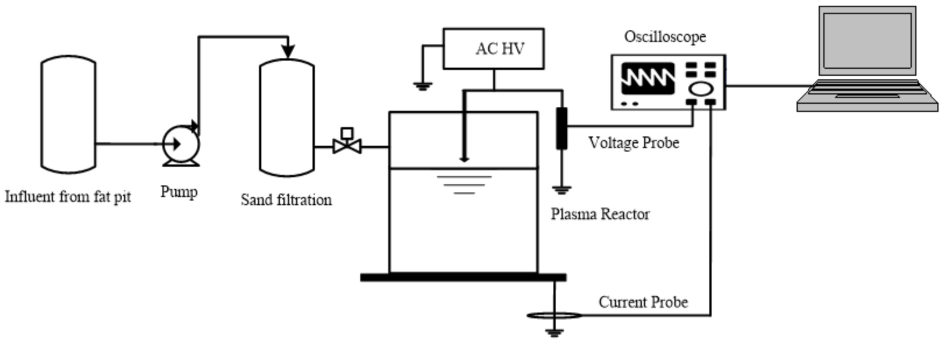


**Figure 2** Schematic diagram of experimental system.

In the DBD system a high-voltage generator was used to generate plasma in the POME. The degree of ionization, or plasma mode, was controlled by varying the AC voltage input. 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 10.4 mm diameter stainless steel. The needle electrode was connected to the high voltage supply and the plane electrode was connected to the ground. The applied voltages and discharge currents were monitored using an oscilloscope (TDS5104 Tektronix) through a high-voltage probe (Tektronix P6015A) and current probe (Tektronix P6021A). The applied voltages were set at 13, 16 and 19 kV. A glass bottle with a storage volume of 250 mL was used as the plasma reactor. The volume of the POME in the reactor was 75 mL. Figure 3 shows voltage variations to generate discharge current into the plasma reactor.

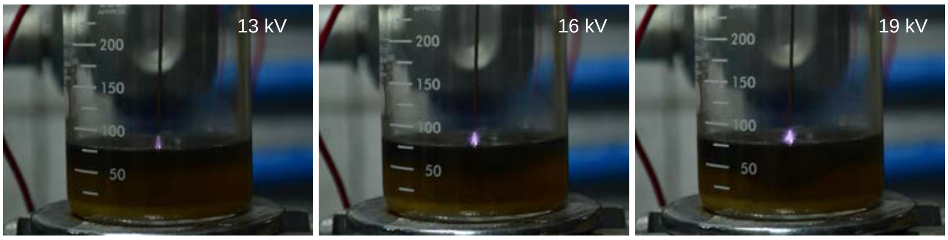


**Figure 3** POME surface plasma with applied voltage variations.

The COD, $BOD_5$, and oil-grease were analyzed following the American Public Health Association standard methods for the examination of water and wastewater [10]. Additionally, pH and temperature were analyzed, using a Milwaukee MI 180 laboratory bench meter.

## 3 Result and Discussion

### 3.1 Discharge Characteristics

Figure 4 shows that the evolution time of the discharge current pulse train took place in a half cycle at an applied voltage of 19 kV for the second series (a) and the third series (b), as previously described. It can be seen that the discharge current occurred around the peaks of the applied voltage for both the positive and negative half cycles, distributed around a phase angle of 0-90° for the positive half cycles and around a phase angle of 180-270° for the negative half cycles.

The discharge current waveform shows that the current pulse amplitude for the second series was lower than that of the third series, while the number of current pulses for the second series was higher than that of the third series. This indicates that the suspended solid of POME may contribute to the change in the discharge current pulse train.

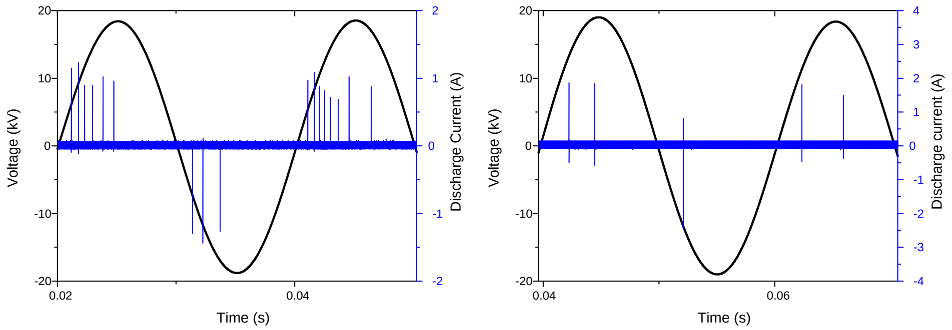


**Figure 4** The waveform of voltage and discharge current for 19 kV: (a) Series 2 and (b) Series 3.

## 3.2 Profile of Discharge Current

The profile of the discharge current throughout the process is shown in Figure 5. The discharge current pulse increased with the increase of the voltage applied to the reactor. Figure 5 shows that the average discharge current also increased over time. POME decomposition increased with the increase of the treatment time.

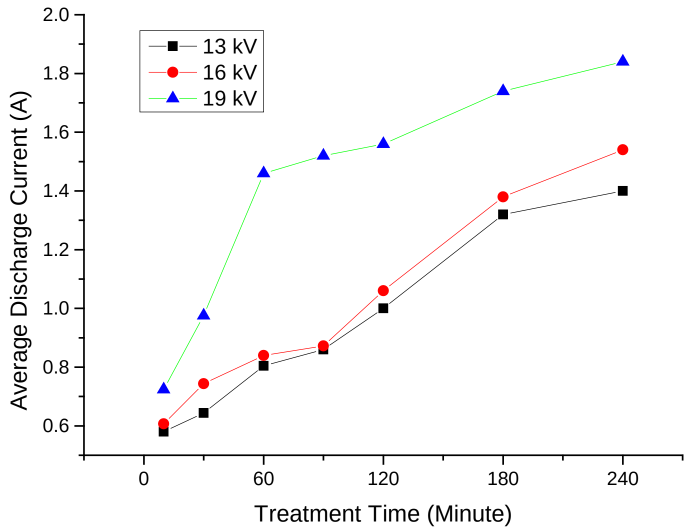


**Figure 5** Profiles of discharge current.

On the other hand, when the decomposition of organic compounds is plotted against the applied voltage, as shown in Figure 6, the points for the three applied voltages are all on the same curve. The lower discharge current could degrade organic compounds with a low energy, but a longer processing time was needed. For the higher discharge current, the degradation rate was higher than for the lower discharge currents. However, it required more consumed energy. The removal efficiency of COD and $BOD_5$ (Series 2) also increased with the increase of the voltage applied to the reactor, as can be seen in Figure 6.

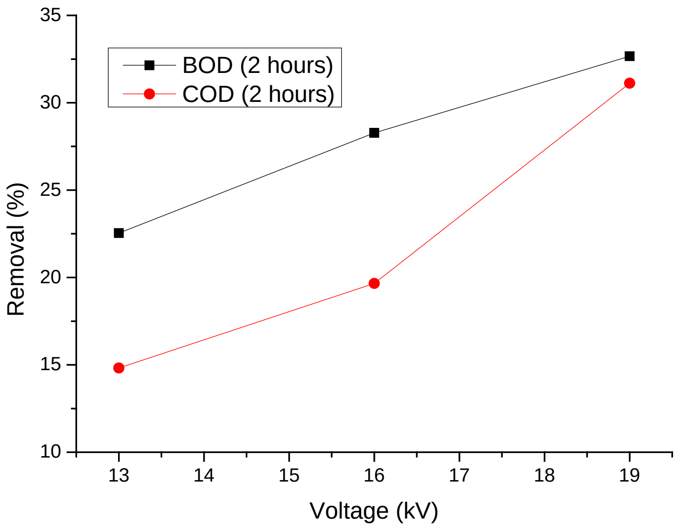


**Figure 6** Effect of applied voltage on removal of $BOD_5$ and COD.

## 3.3 Profile of pH and Temperature

In Yulastri, *et al.* [9] pH was stable at around 3.9-4.9 and temperature increased over time from 28.4 to 32.8°C. The change in pH is due to active species such as hydroxyl radicals ($OH^-$) production during the treatment, which results in the POME becoming slightly alkalic. The oxidation of compounds was caused by hydroxyl free radicals that actively attacked the organic compounds.

Further study is needed to investigate the addition of chemical substances such as NaOH to obtain pH in the POME at around 6-9 before or after treatment with the DBD system, because a higher POME pH is capable of producing potential oxidizing radicals to degrade organic materials. The end products of the degradation process are water, carbon dioxide, and inorganic salts [11].

### 3.4 The Characteristics of POME

A comparison of POME treatment with sand filtration (Series 1), DBD (Series 2) and a combination of sand filtration and DBD (Series 3) is displayed in Table 3. It can be seen that the removal efficiency of COD, $BOD_5$, and oil-grease was at 37, 36, and 27% respectively after treatment with sand filtration. For the treatment with DBD (Series 2), the removal efficiency of COD, $BOD_5$, and oil-grease was 33, 32, and 23% respectively, after applying a voltage of 19 kV for 2 hours. Sato [12] reported that the discharge current on the water surface produces many active species that effectively decompose the organic compounds. In this study, the discharge current on the POME surface that was generated by the DBD system produced active species and UV light. High oxidation potential ions and molecules strike the POME surface, which effectively reacted with organic compounds. In Figure 3, the filamentary discharges from the needle tip on the POME surface can be seen. Ozone and active species produced by the discharge current may also dissolve into the POME through the POME surface and then decompose into some kind of radicals or $H_2O_2$. High oxidation potentialions and molecules may dissociate organic compounds and then generate some active species. Some chemical reactions may take place on the POME surface in a DBD plasma reactor that degrade organic compounds in the POME.

**Table 3** Characteristics of POME after treatment with sand filtration and DBD plasma system.

| **Parameter** | **POME after Oil Pit** | **Series 1 Sand filtration** | **Series 2 DBD (19 kV)** | | **Series 3 Sand filtration + DBD (19 kV)** | | **Quality Standard*** |
|---|---|---|---|---|---|---|---|
| | | | 2 h | 4 h | 2 h | 4 h | |
| pH | 3.90 | 4.70 | 4.40 | 4.90 | 4.70 | 4.70 | 6-9 |
| $BOD_5$ (mg/L) | 251.36 | 157.49 | 169.26 | 113.69 | 103.68 | 98.55 | 100 |
| COD (mg/L) | 440.84 | 281.77 | 303.65 | 207.84 | 182.24 | 163.70 | 350 |
| Oil-grease (mg/L) | 132.39 | 97.08 | 101.43 | 79.1 | 73.51 | 50.27 | 25 |

* Ministry of Environment, Indonesia (Ministry of Environment of Republic of Indonesia Regulation No. 5/2014).

Based on the results in Series 1 and 2, the POME was treated with a combination of sand filtration and DBD. The removal efficiency of COD, $BOD_5$ and oil-grease was calculated at 59, 59 and 44% respectively, after applying a voltage of 19 kV for 2 hours. After treatment for 4 hours, the removal efficiency of COD, $BOD_5$ and oil-grease was calculated at 61, 63, and 62% respectively. The results in Table 3 show that the POME treated in the third series complies with wastewater quality standards for palm oil effluent after a voltage of 19 kV was supplied to the reactor for 2 and 4 hours. The results of this study indicate that treatment of POME with DBD for 2 hours could achieve the quality standards of POME for COD in all runs. The required processing time was much shorter than for an anaerobic-aerobic system, which takes 40-65 days [1], or treatment with a membrane bioreactor (MBR), which takes 1-2.2 days [1-3]. The oil-grease and $BOD_5$ values do not meet the quality standards of POME. Further research needs to be conducted by modifying the number of electrodes and application of a higher voltage.

Removal efficiency of COD, $BOD_5$ and oil-grase increased with increasing the applied voltages and treatment time because the discharge current produced much more active species, UV light, and high oxidation potential ions and molecules struck the POME that effectively reacted with organic materials [12]. Table 3 indicates that the removal efficiency of COD and $BOD_5$ by the sand filtration-DBD system to treat the POME is about 59%.

### 3.5 Consumed Energy

The consumed energy for the DBD system can be calculated using Eq. (1).

$$E_d = \frac{U_s i_d t}{V}\left(\frac{kWh}{L}\right) \tag{1}$$

where $E_d$ is discharge energy consumption (kWh/L), $U_s$ is secondary voltage or applied voltage (V), $i_d$ is average discharge current (A), $t$ is treatment time (h), and $V$ is volume of POME (L) in the reactor plasma. The average discharge currents for 75 mL of POME for 2 and 4 hours are displayed in Figure 5. For applied voltage at 19 kV, the consumed discharge energy was about 18.24 kWh/L for treatment during 4 hours, respectively. The energy cost needed for treating of POME can be estimated using Eq. (2),

$$E_p = \frac{U_p i_p t}{V}\left(\frac{kWh}{L}\right) \tag{2}$$

where $E_p$ is electrical energy consumption (kWh/L), $U_p$ is primary voltage (V), $i_p$ is primary current (A). For a primary voltage of 220 V and a primary current of 0.9 A, the electrical energy consumption and cost (based on electric power industrial pricing in Indonesia) were about 10.56 kWh/L and Rp 10,845/L, respectively.

Further research is needed to study the effects of flow rate, hydraulic retention time (HRT), electrical parameters such as secondary voltage and current on the degradation rate of organic compounds in POME to achieve not only the water quality standars but also the economical consumed energy costs. The oxidation reaction between organic compounds and the active species could produce carbon monoxide (CO), carbon dioxide ($CO_2$) and hydrogen ($H_2$). Identification of produced gases is necessary before application. The next studies will calculate mass and energy balance to improve produced gases on a large scale, which could be used as energy resource to generate electric power.

## 4 Conclusion

Treatment of POME by a combined sand filtration-DBD system has been demonstrated. The results indicate that the removal efficiency of COD, $BOD_5$ and oil-grease increased with applied voltage. The electrical energy consumption needed is about 10.56 kWh/L of POME. To reduce HRT, a higher applied voltage should be applied. However, further research must be conducted to treat POME using a combination of plasma and other treatment processes to achieve POME quality standards and economical energy consumption costs.

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