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Dielectric Barrier Discharge Plasma Analysis and Application for Processing Palm oil mill effluent (POME)

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1. Introduction

Plasma generator by using Dielectric Barrier Discharge Reactor has been done for many areas of research and applications. DBD is one of low-temperature plasma that can be applied in several areas, among others, the environment, ozone generator, and much more [1,2,3]. DBD's application on the environment has been carried out among others for removal of NOx [4], for the production of biodiesel from fatty acids from food industry waste [5], for upgrading heavy oil in a conventional thermal cracking system under atmospheric pressure [6]. Palm oil mill effluent (POME) is the wastewater of palm oil production process that is not only extremely damaging environment (especially soil and water bodies) but also disrupts the aesthetics of the environment. Chemically, POME is a colloidal suspension containing 95-96 % water, 0.6- 0.7 % oil and 4-5 % total solids including 2-4 % solids suspended. Levels of Biological Oxygen Demand (BOD) LCS is located between 25 000 and 65714 mg/L. Meanwhile, levels of Chemical Oxygen Demand (COD) of POME is between 44300 and 102696 mg/L. Treatment of POME should be done by a combination of several methods. The treatment via up-flow anaerobic sludge blanket–hollow centred packed bed (UASB–HCPB) reactor [7], for thermophilic (POME) [8]. There is some research for POME treatment by

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using non-thermal plasma. Treatment of POME by a combined sand filtration-DBD system for a preliminary study has been done [9].

This paper discusses the analysis of DBD Plasma screw rod - spiral configuration and separates by a dielectric of pyrex tube. This paper also discusses on macroscopic electrical such as voltage-current characteristics and microscopic concerning the mobility of the charge carriers. Furthermore, this paper explains the application on DBD Plasma for a treatment of wastewater used for processing oil palm that is often called palm oil mill effluent (POME).

2. The object of the study

The object this study was developing dielectric barrier discharge plasma that will be used for the treatment of palm oil mill effluent (POME). This research includes characterization of DBD plasma with spiral- screw electrodes; POME treatment and analysing.

3. Methods

3.1. Experimental set up

Figure 1 shows the experimental setup of this research. Dielectric barrier discharge plasma was constructed by an active electrode that was made of stainless steel screw with a diameter of 8 mm, Pyrex pipe with a diameter of 20 mm and an outer diameter of 22.5 mm as barrier and the outer electrode was made of copper wire with a diameter of 1.83 mm and its wrapped around the pipe as much as 54 windings. This DBDP was generated by AC high voltage. Electrical parameters of DBDP determined through a voltage divider (HV Probe DC Voltage DC Max 40 kV; 28 kV AC EC code number 1010, En G1010). The electrical signal from the probe detected by an Oscilloscope GOS-653, 50 MHz. The electric current, that was generated in the reactor was measured by using a multimeter (Sunwa TRXn 360) and ammeters (Kyoritsu, AC/DC Digital Clamp Meter). Argon gas as the industrial gas (Ar, 99.95%) was inserted into the reactor by regulating the gas flow rate in the range of 1-10 L/min. Voltage and electronic signals are generated can be observed using an oscilloscope. Gas flow rate was measured using a flow meter (Koploc Kojima Model RK 1600 R). Pome together with an argon gas introduced into the DBD reactor. Plasma generated in the reactor. Capacitive current measured as an average current of charge carriers. For measurement of total suspended solids (TTS), standard test methods for filterable matter (Total Dissolved Solids) and nonfilterable matter (Total Suspended Solids) in water has been exploited. For COD, we used Standard Test Methods for Chemical Oxygen Demand (Dichromate Oxygen Demand) of water.

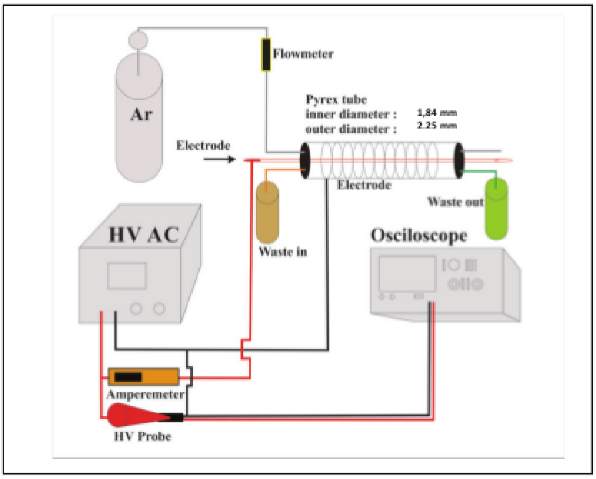

Fig. 1. Experimental set up .

3.2 Determination of Mobility

The mobility of charge carriers in each plasma reactor can be determined by an I-V characteristics. The relationship between current and voltage has been investigated, both theoretically and experimentally [12,13]. Robinson theoretical formulation expressed in equation 1

$$I_s = \frac{2\mu_0 \varepsilon_0}{d}\left(V - V_i\right)^2 \quad (1)$$

Where I_s is a saturation current in mA, μ_0 is avarage charge carrier mobility in cm^2/volt.scond, ε_0 is a permittivity, V is operating voltage, and Vi corona threshold voltage in volts. According to our results in DBD plasma, where we find that I-V characteristics are follow Robinson's formulation [12,13]. It has to harmonise of Robinson's formula with our experimental condition where there are three types of dielectric materials between two electrodes. Robinson's formula must be modified, and the relationship between Is (V) follow:

$$I_s = \frac{2\mu_{RT} \varepsilon_t S}{d^3}\left(V - V_i\right)^2 \quad (2)$$

Where S is a surface area of passive electrode in cm^2 and d is the distance between the electrodes in cm. Into the space between the electrodes inserted dielectric materials eg air/gas, liquid and solid, with each of the dielectric permittivity is ε_1 for material 1, ε_2 for material 2, and ε3 for material 3. Futhermore, ε_t is an effective permittivity for 3 dielectric materials. By using the formula (2) average mobility μ_{RT} of charge carriers can be determined.

4. Results and Discussion

4.1. Voltage-current characteristics

Voltage-current characteristics of DBD reactor without a sample for several flow rates of argon gas shown in figure 4. From the graph, it can be seen that the threshold voltage for all flow rates (1.5 L/min – 4.0 L/min) of gas has the same value. The same graph also shows that the flow rate affects the discharge currents that occur in the DBD plasma. The larger the flow rate greater the discharge current for the same voltage. It can be seen that discharge current for flow rate 4 L/min is two-time compare with discharge current for flow rate 1.5 L/min. In this experiment, reactors work area for treatment in the voltage of 3 kV. Without sample, discharge current varies from 4.7 mA (for the flow rate of 1.5 L/min) to 31.4 mA (for the flow rate of 4.0 L/min). As seen in figure 2 that the more debit Argon is used, the easier the occurrence of discharge and the larger the discharge current. This condition is especially for Argon as an inert gas. It is easier to ionise become plasma. Argon plasma is often used for the application, including for treating wastewater [1].

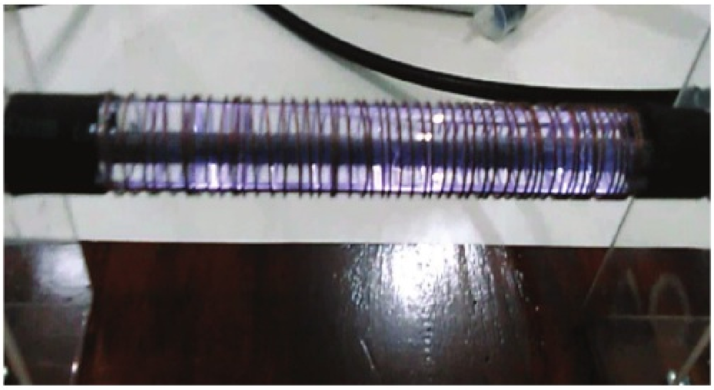

Fig. 2. Dielectric barrier discharge plasma with Argon gas of 4 L/min without POME sample.

Figure 4 shows voltage-current characteristic of DBD reactor with sample for several flowrates of argon gas. In figure 3 we show the characteristic of square root electric current vs voltage with sample, for the flow rate of 3 L/min. Sample is palm oil mill effluent (POME). Pome together with argon gas introduced into the DBD reactor. Plasma generated in the reactor. Capacitive current measured as an avarage current of charge carriers. Charge carrier particles are a mixture positive ions, negative ions and electrons that origineted of argon and POME. The avarage current with POME inside reactor are always larger than without samples inside the reactor for the same voltage and flow rate.

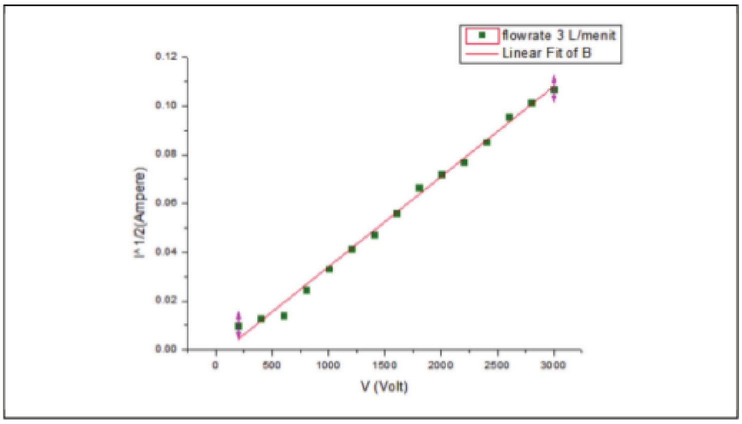

Fig. 3. Characteristik of square root electric current vs voltage with sample, for the flow rate of 3 L/min.

From the graph, it can be seen that the threshold voltage for all flow rates (1.5 L/min – 4.0 L/min) of gas has the same value. The same graph also shows that the flow rate affects the discharge currents that occur in the DBD plasma. The larger the flow rate greater the discharge current for the same voltage. It can be seen that discharge current for flow rate 4 L/min is two-timed compare with discharge current for flow rate 1.5 L/min. In this experiment, reactors work area for treatment in the voltage of 3 kV. Without sample, discharge current varies from 4.7 mA (for the flowrate of 1.5 L/min) to 31.4 mA (for the flowrate of 4.0 L/min). As seen in figure 2 that the higher flow rate of Argon is used, the easier the occurrence of discharge and the larger the discharge current. This condition is especially for Argon as an inert gas. It is easier to ionise become plasma. Argon plasma is often used for the application, including for treating wastewater[1,2].

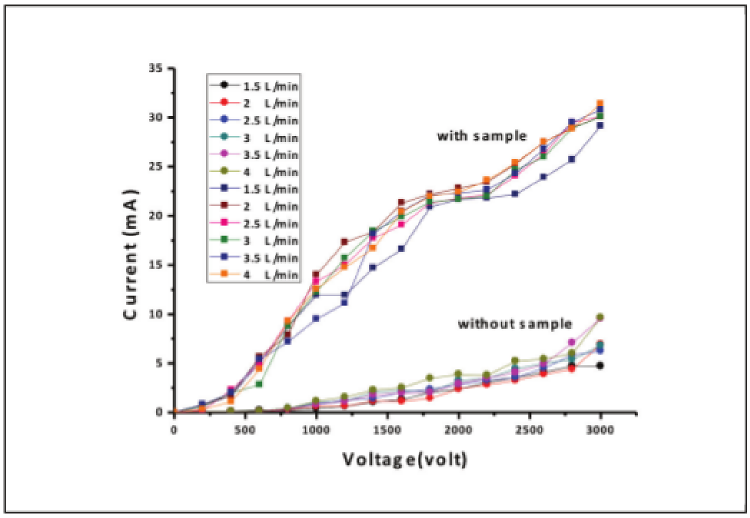

Fig. 4. Current as fuction of voltage with and without sample

4.2. Charge carrier mobilities

Charge carrier particles such as, such as positive and negative ions, electrons, in an electric field, would move with the average speed. The magnitude of the drift velocity is proportional to the magnitude of the electric field and the value of mobility. Mobility is defined as the freedom of the particles to move, either in random motion. The mobility of the charge carriers can be determined using equation (2). By using the value of the gradient of linear graph the relationship $\sqrt{I}$ as a function of V average mobility can be found. Figure 5 shows a graph of charge carrier mobility as a function of gas flow rate. It can be seen graph in the figure 5; we found that the value of the average mobility of the charge carriers increases with increasing value of argon gas flow rate, both for the mobility of charge carriers without sample and mobility of charge carrier with a sample. In the reactor without a sample, we found the charge carrier mobility values increased from 25.88 to 39.90 cm^2/V.s. with argon gas flow rate from 1.5 to 4 L/min. While, the mobility's value of the charge carriers with samples inside of reactor obtained always higher than mobility's value without the sample. The mobility's value with inside reactor increased from 138.45 to 178.61 cm^2 / V.s. with flow rate from 1.5 to 4 L/min. he comparison of the value of the mobility of the charge carriers with charge carrier mobility samples with no sample. The comparison of costs between 4.21 up to 5.53. It can be concluded that the mobility of the sample equal to 4-5 times greater than the mobility without a sample.

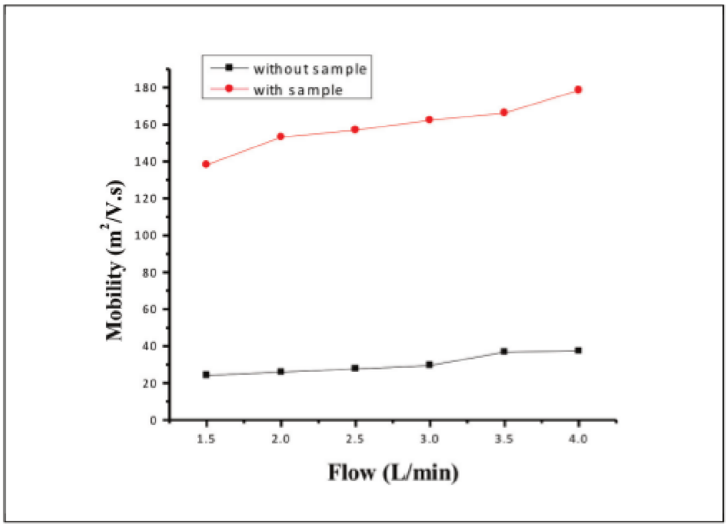

Fig. 5. Avarage mobility as a function of gas flowrate, without sample and with sample

Figure 5 shows the charge carrier particles mobilities as the function of gas flow rate in present of samples and without a sample. The charge carrier particles, in this case, are positive ions, negative ions, electrons, in electric field would move with the average speed. The magnitude of the drift velocity is proportional to the magnitude of the electric field and the value of mobility. Mobility is defined as the freedom of the particles to move, either in random motion. The mobility of the charge carriers can be determined using equation (2). By using the value of the gradient of the linear graph the relationship$\sqrt{I}$ as a function of V average mobility can be found.

4.3. Chemical Oxygen Demand

Chemical Oxygen Demand (COD) or chemical oxygen requirement is the amount of oxygen required to oxidise organic substances contained in 1 litre of water samples. Oxidizing K2Cr2O4 used as a source of oxygen. The COD value indicates the need of oxygen required to decompose organic matter in water is chemical, especially for organic compounds that cannot be decomposed because of biological processes, and so we need the help of the oxidation reagent.

Figure 6 shows that the Chemical Oxygen Demand (COD) overall decrease with the length of time the plasma treatment. Reactive species in plasma can treat POME and duration of treatment gives effect to changes in Chemical Oxygen Demand (COD). In the control samples (0 min) has a number of Chemical Oxygen Demand (COD) of 645.99 mg/L, the sample POME after treatment of 30 minutes has a number of Chemical Oxygen Demand (COD) of 118.55 mg/L, and the after treatment time of 60 minutes has a number COD of 115.62. In this research, the sample with a treatment time of 60 minutes has a number COD is lower than the samples of the other, so it has a tendency to decrease COD and the results obtained for a treatment time of 60 minutes is approaching the value of COD were allowed to enter aquatic environments of 100 mg/L. So the results of this can be concluded that that the spiral–screw dielectric barrier discharge plasma can potentially treat liquid waste palm oil.

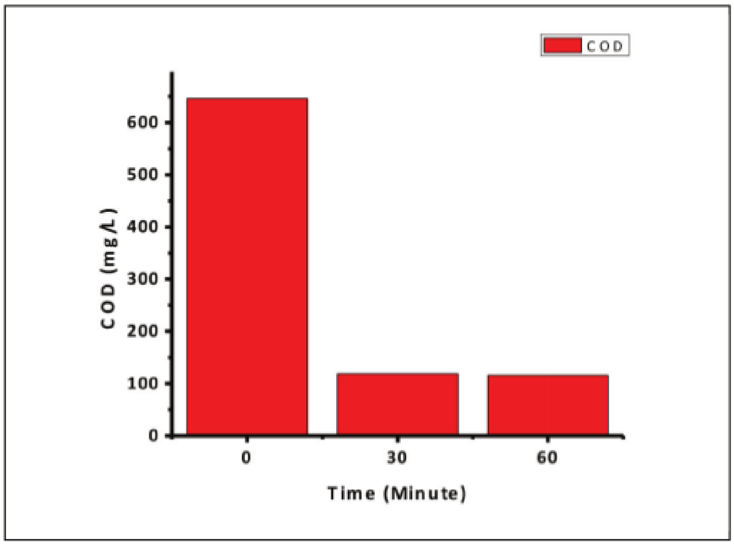

Fig. 6. The COD content levels in waste palm oil due to plasma irradations

4.4. Total Suspended Solid

Figure 7 shows that the value of Total Suspended Solid (TSS) overall decrease with the length of time for plasma treatment. It can be said that plasma treatment time gives the effect of changing in Total Suspended Solid (TSS). In the control samples (0 min) has a number of Total Suspended Solid (TSS) of 1192 mg/L, the sample liquid POME has a number of Total Suspended Solid (TSS) of 1132 mg /L, and sample liquid waste palm with treatment time of 60 minutes has a number of Total Suspended Solid (TSS) of 1018 mg /L. Results of after treatment 30 minutes. TSS for a treatment time of 60 minutes has a tendency to decline in value of TSS so that the result can be concluded that the dielectric barrier discharge plasma has a potential to reduce the liquid waste of POME. However, the sample with a treatment time of 60 minutes has some Total Suspended Solid (TSS) which is lower than the other samples; these results did not approach the TSS values are allowed to enter the aquatic environment of 100 mg/L[14,15]. We need more development technological aspect of this method

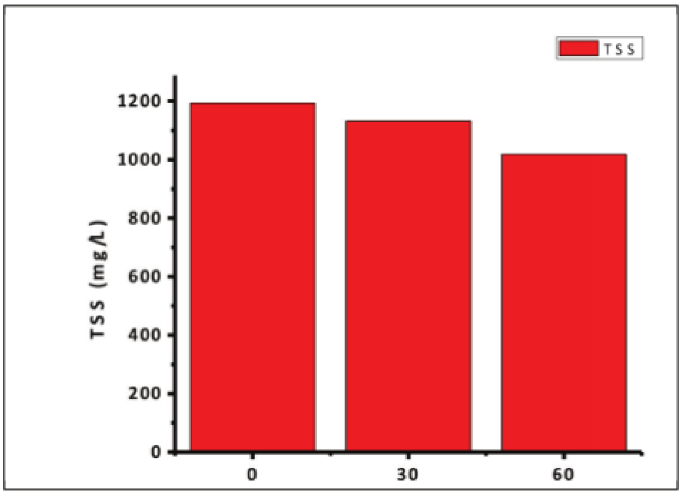

Fig. 7. The TSS content levels in waste palm oil due to plasma irradation

5. Conclusion

Characteristics of current (I) - voltage (V) has to be used to determine the average charge carrier mobility of argon gas and argon gas mixture with the sample. Increased discharge Argon lead to increased current is generated in the voltage and the value of the average charge carrier mobility. Processing of liquid waste oil palm can be done by using a dielectric barrier discharge plasma with configuration spiral - screw penalty and obtained the best results with a voltage of 4 kV and discharge argon 4 L/min is 60 minutes, with COD into 115.62 mg/L and TSS 1018 mg/L. Dielectric barrier discharge plasma can be used to reduce COD and TSS to enter a value that is allowed by the environment ministry of Indonesia so that the spiral–secrew dielectric barrier discharge plasma can potentially treat liquid waste palm oil.

Acknowledgements

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