Plasma Discharge with Different Electrode Diameters for Reducing Methylene Blue Concentration

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Abstract. Recently, plasma technology has gained attention since it overcomes the shortcomings of water treatment. This research studies the effect of electrode diameter of plasma discharge reactors on the concentration reduction of methylene blue as an organic solution. The plasma discharge reactor was built from a pair of stainless needle electrodes connected with high-AC voltage. The electrodes were placed approximately 2 mm above the solution and stirred at 5.5 rpm. The diameters of the electrodes were 2, 3.2 and 4 mm. The times for plasma treatment were set at 2, 4, 6, 8 and 10 min. Absorbance, temperature and pH of the solution were measured to know the effects of electrode diameter of the plasma reactor. Absorbance and pH significantly decreased after plasma treatment. The best of the absorbance reduction were obtained when the sample was treated under plasma discharge using the smallest diameter electrodes for 8-10 min.

1. Introduction
Water is one of the most important natural resources for living creatures, and is used in hydroelectric power plants to produce electricity and for various other purposes. Increasing the number of living things causes the need for water to increase. However, the increasing number of living creatures, especially humans, increases water pollution, which makes it difficult to obtain clean water. Therefore, a solution is needed to overcome water pollution by water treatment. Current water treatment methods use physics, chemistry and biology. However, such methods, for example adsorption method, are inefficient and may cause secondary pollutants [1].

Plasma technology began to be used as a water treatment process because it does not cause secondary pollutants or require a large area or span of time [2]. Plasma technology oxidizes or decomposes organic

pollutants in water using active species, such as negative and positive ions, radical, etc., by decomposing the organic compounds in water [1].

The oxidation process of organic compounds can occur in plasma in water [3]. Electrical discharge is formed on the water (and or in the air) and then diffuses into a thin layer of contaminated water. Ions and electrons generated in the plasma process have very high energy, which causes the water to decompose and generate active species such as OH, oxygen, hydrogen and H_2O_2 [4]. Active species are strong oxidants that can oxidize various organic compounds, such as carbon, hydrogen, nitrogen and sulphur, that are contained in liquid waste. In this study, this is done using a solution of methylene blue ($C_{16}H_{18}ClN_3S$).

The great benefits of plasma technology in water treatment make it an interesting topic of research. This study examines the effects of stainless steel electrode diameter used in plasma discharge generation on the reduction of methylene blue concentration.

2. Experimental

The plasma discharge reactor was built with a pair of stainless steel needle electrodes connected with high-AC voltage at 46.5 kV. The diameters of the electrodes were 2, 3.2 and 4 mm. The distance between the two electrodes mounted parallel to the plasma reactor was set at 2 cm. Materials used in this study were 0.006 grams of methylene blue powder dissolved in 1,000 mL of distilled water.

Initial measurements of absorbance, pH and temperature in methylene blue were performed before plasma treatment generation. A sample without the plasma treatment was also prepared as a reference. A 30 ml sample was stirred in a glass beaker with a magnetic stirrer at 5.5 rpm. Plasma treatments lasted 2, 4, 6, 8 and 10 mins for each sample. Absorbance, pH and temperature measurements were performed using UV-Vis, a pH meter and a thermometer, respectively, for each solvent that had been treated by plasma. The same procedure was applied to all electrodes. A detailed schematic of the experimental setup is presented in Figure 1.
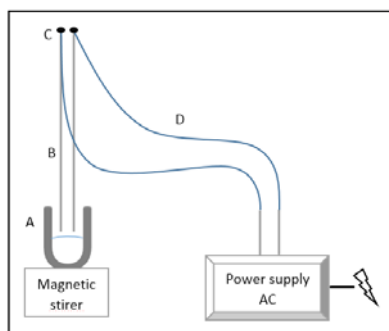

Figure 1. Experimental setup scheme. Beaker glass (A); Stainless steel electrodes (B); Clamp (C); necting cable (D)

3. Results and Discussion

Figure 2 shows the decreasing methylene blue absorbance with time on various electrode diameters. With plasma treatment, the methylene blue absorbance decreased with the increase of contact time. Contact times in the plasma process were 2, 4, 6, 8 and 10 mins. As a reference, we used a control sample, the methylene blue samples without plasma discharge.

Figure 2 (a) shows the experiment using a 2-mm-diameter electrode. The percentages of absorbance reduction at contact times 2, 4, 6, 8 and 10 mins were 30.4%, 82.5%, 94.8%, 99.5% and 100%, respectively. Experimental results using a 3.2-mm-diameter electrode are shown in Figure 2 (b). The percentages of absorbance reduction at the same contact time variations as for the 2-mm-diameter electrode were 20%,

76.9%, 93.8%, 97.5% and 99.7%, respectively. Figure 2 (c) shows the experiment using a 4-mm-diameter electrode. The percentages of absorbance reduction at the same contact time variations as in previous trials were 14.1%, 58.8%, 91.8%, 93.6% and 97.6%, respectively.

The highest peak of each graph indicates the initial absorbance of the methylene blue before plasma treatment. Experiments with plasma treatment at the given time variations show the decrease of absorbance in each graph. The decrease of absorbance occurred because the methylene blue decomposed as a result of the active species produced during the plasma process. Longer contact times meant that more methylene blue decomposed. The highest percentage of absorbance decrease was obtained by using the 2-mm-diameter electrode.
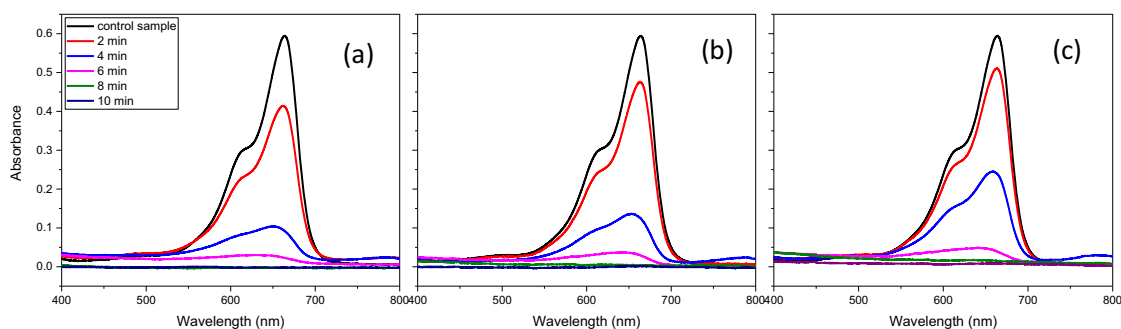

Figure 2. Decrease of absorbance at the given time variations of plasma treatment for electrode diameter of (a) 2 mm (b) 3.2 mm (c) 4 mm.

The effects of electrode diameter variation on the absorbance at given times is shown in Figure 3. The results show that the smaller the diameter of the electrode, the lower the absorbance. This happens because the electrodes with short diameters produce high-intensity plasma so that more active species form. As more active species form, more organic compounds decompose [5]. The graphic in Figure 3 is drawn from data with a contact time of 2 mins to show the most significant absorbance reduction.
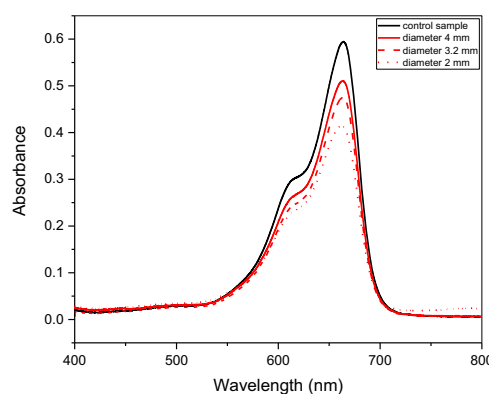

Figure 3. The effects of electrode diameter variation on the absorbance of methylene blue at a contact time of 2 mins.

The effects of electrode diameter and contact times on pH and temperature are shown in Figures 4 (a) and (b), respectively. Figure 4 (a) shows that smaller electrode diameters result in lower pH. This phenomenon happens because the oxidation process in the plasma reactor breaks the complex bonds in the methylene blue solution into mild acids. Longer contact times mean that more mild acids form so that the solution becomes more acidic. The formation of mild acids during the process decreases the solution's pH with the addition of contact time [6].

The lowest pH in this study was obtained with the 2-mm-diameter electrode. Figure 4 (b) shows the effects of electrode diameter on temperature. The results show that smaller electrode diameters are correlated with higher resulting temperatures. This occurs because the electric discharges generated from short diameter electrodes have a high velocity that causes strong collisions between water molecules, increasing heat. Along with increased contact time, the collisions lead to the increasing of solution temperature.
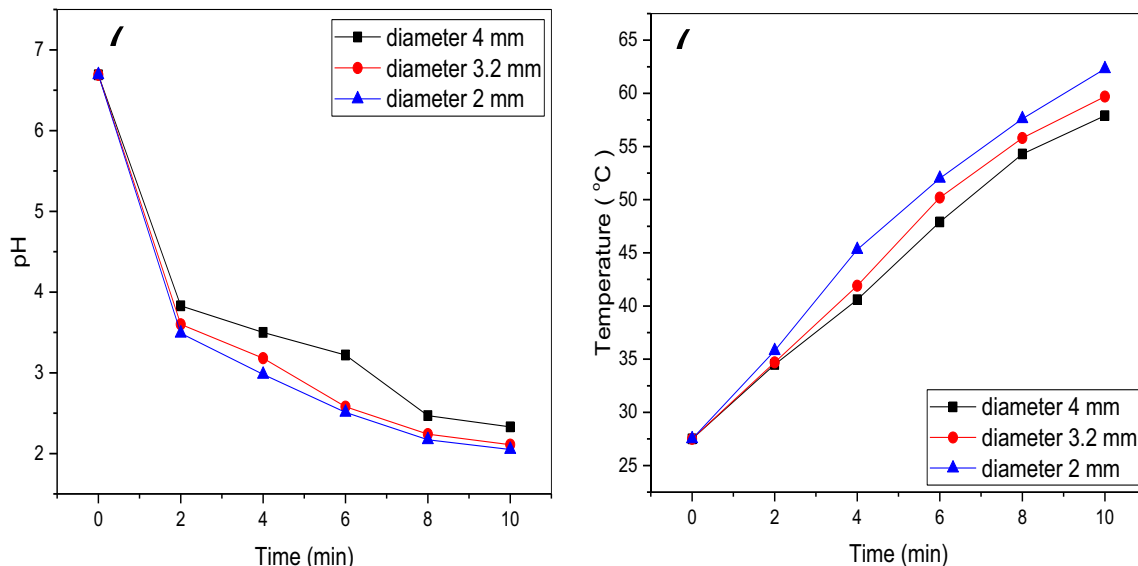

Figure 4. The relationship between (a) pH and (b) the temperature with contact times and electrode diameter variations

4. Conclusion

The plasma discharging performed in this study successfully decreased the absorbance of methylene blue. The results show that the methylene blue absorbance after plasma treatment significantly decreased compared with the concentration before the plasma process. Smaller electrode diameters are correlated with a greater reduction of methylene blue absorbance. Moreover, smaller electrode diameters are also linked with higher temperatures and lower pH. The lowest methylene blue absorbance and best results obtained in this study were achieved under plasma treatment for 10 mins using 2-mm-diameter electrodes.

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