Influence of power supply on the generation of ozone and degradation of phenol in a surface discharge reactor

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Abstract. A surface Dielectric Barrier Discharge (DBD) reactor was utilized to degrade phenol in water. Different power supplies applied to the DBD reactor affect the discharge modes, the formation of chemically active species and thus the removal efficiency of pollutants. It is thus important to select an optimized power supply for the DBD reactor. In this paper, the influence of the types of power supplies including alternate current (AC) and bipolar pulsed power supply on the ozone generation in a surface discharge reactor was measured. It was found that compared with bipolar pulsed power supply, higher energy efficiency of $O_3$ generation was obtained when DBD reactor was supplied with 50Hz AC power supply. The highest $O_3$ generation was approximate 4 mg kJ⁻¹; moreover, COD removal efficiency of phenol wastewater reached 52.3% after 3 h treatment under an AC peak voltage of 2.6 kV.

1. Introduction
In recent years, degradation of biologically recalcitrant and toxic organic compounds in water has become the focus of environmental remediation efforts. As a new advanced oxidation process, non-thermal discharge plasma technology exhibits a great prospect in wastewater treatment. There are two kinds of processes (physical and chemical processes) during non-thermal discharge plasma treatment, which are thought to occur simultaneously in synergism for direct or indirect degradation of toxic organic compounds. The physical processes include strong electric field, ultraviolet light and shock waves etc. The chemical processes mainly include the formation of various active radicals, such as $•OH$, $•H$, $•O$, $•O_2$ and $•HO_2$, and active molecules, such as $H_2O_2$ and $O_3$ [1].

In the present study, a surface discharge type DBD reactor with a waste water volume of 40 L was designed by Dalian university of technology to purify the phenol wastewater. As we know, the types of power supply for the surface discharge type DBD reactor has an important effect on pollutants degradation efficiency and energy yield. The discharge characteristics of self-designed power supplies (50 Hz AC, 200 Hz AC and bipolar pulse power supplies) and their influences on the $O_3$ generation were studied. The power supply which is advantageous for $O_3$ generation was selected to degrade phenol in water.

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2. Experimental

2.1. Surface discharge type DBD reactor

The schematic diagram of the surface discharge type DBD reactor was shown in figure 1. The reactor was a cylindrical stainless steel tube with an inner diameter of 280 mm and a height of 1000 mm. The high-voltage electrode was made of stainless steel spiral, which was tightly attached on the inside wall of a cylindrical quartz tube [2]. The diameter of the spiral was 1.5 mm and the thread pitch was about 15 mm. The inner diameter of the quartz tube was 40 mm and the length was 900 mm. The whole discharge length of quartz glass tube was 700 mm. The high-voltage electrode system was up-scaled by adding four parallel connections of quartz tubes. There was an aerator at the bottom of each quartz glass tube. The outside wall of the cylindrical stainless steel tube reactor was grounded.

In each experiment, 40 L phenol wastewater was treated. Air was injected into the four quartz glass tubes before discharge treatment, and then the high voltage electrode system was immersed into the wastewater.

![Schematic diagram of the reactor](image)

**Figure 1.** Schematic diagram of the reactor

2.2. Methods and analyses

The discharge voltage and current were measured with a Tektronix TDS2012 digital oscilloscope equipped with a Tektronix (P6015A) high voltage probe and a Tektronix (A6021) current probe.

Ozone concentration was measured by the method of potassium iodide. The equation is showed following:

\[
c(O_3) = \frac{A \times B \times 2400}{V_0}
\]  

(1)

Where \(c(O_3)\) is the concentration of \(O_3\), \(A\) is the usage volume of \(Na_2S_2O_3\), \(B\) is the concentration of \(Na_2S_2O_3\) and \(V_0\) is the volume of a gas extracted from reactor.

The COD removal efficiency (\(\eta\)) is defined as the equation (2).

\[
\eta = \frac{m_{COD_0} - m_{COD_t}}{m_{COD_0}} \times 100\%
\]  

(2)

Where \(m_{COD_0}\) is the removed amount of COD (g), the \(m_{COD_0}\) and \(m_{COD_t}\) are the amount of COD at time 0 and \(t\), respectively.
3. Results and Discussion

3.1. Effect of power supply type on discharge characteristics of reactor

Three power supplies (power frequency AC, high frequency AC, bipolar pulse power supply) were designed to investigate the effect of power supply types on their discharge characteristics. Figure 2-4 present the discharge characteristics of surface discharge reactor supplied by AC power supply (50Hz), AC power supply (200Hz) and bipolar pulse power supply, respectively.

The waveforms in figure 2-4 were obtained at the highest normal input, namely, when the applied voltage increased further, spark breakdown or other abnormal discharge would occur. From figure 2 and 3, the amplitude of current and voltage input by 50 Hz AC power supply was higher than 200 Hz AC power supply.

![Figure 2. Voltage and current waveforms of 50Hz AC power supply.](image)

![Figure 3. Voltage and current waveforms of 200Hz AC power supply.](image)

![Figure 4. Voltage and current waveforms of bipolar pulse power supply.](image)

The input power ($P$) of AC power supply was calculated by voltage-charge (V-Q) Lissajous method, and the input power ($P$) of pulse power supply was calculated by integration of the voltage ($u$) and
current \((i)\) according to equation (3). The input energy was calculated by discharge power \((P)\) multiplied by time.

\[
P = \int \text{v} \text{d}t
\]

(3)

According to the calculation results of discharge power, higher input power was obtained by 50 Hz AC power supply, which may attribute to the fact that the breakdown voltage of 50Hz AC power supply was much higher than 200Hz AC power supply and bipolar pulse power supply in our experimental systems.

3.2. Effect of types of power supply on generation of ozone

Gas phase surface discharge plasma can generate a large number of reactive species (such as high energy electrons, ions, radicals and \(O_3\)) and ultraviolet light etc, which are directly related to the type of power supply for plasma reactor [3]. Figure 5 presented the effect of types of power supply on ozone generation efficiency. The experimental results show that compared with 200 Hz AC and bipolar pulse power supply, the \(O_3\) generation efficiency was higher when DBD reactor was supplied with 50Hz AC power supply. For example, when the air flow rate was 1\(\text{m}^3\text{ h}^{-1}\), approximately 4 mg \(\text{kJ}^{-1}\) of \(O_3\) concentration was obtained when 50Hz AC power supply was utilized, while only 1.5 and 1.6 mg \(\text{kJ}^{-1}\) \(O_3\) was obtained when 200 Hz AC and bipolar pulse power supply were utilized, respectively. Therefore, 50Hz AC power supply was selected to supply reactor for phenol degradation in water.

![Figure 5. O3 concentration can be obtained by different type of power supply.](image)

3.3. Effect of discharge voltage on COD removal of phenol wastewater

Discharge voltage is an important parameter to evaluate the practical application of this technology in pollution control. The effect of discharge voltage on COD removal of phenol wastewater was evaluated and the result was shown in figure 6. The air flow rate was 1\(\text{m}^3\text{ h}^{-1}\). It was found that COD removal efficiency increased with the discharge voltage. At discharge voltage of 26 kV, COD removal rate reached 52.8% within 3 h, while approximately 47.4% and 39.2% of COD could be removed at 22 kV and 18 kV within the same time, respectively. It is generally believed that more energetic electrons are produced at higher discharge voltage, leading to the accelerated formation of active species such as ozone [4].

Therefore, higher COD removal efficiency was achieved in higher discharge voltage, and the optimized discharge voltage was 26 kV in the present study. The experiments were all conducted under the condition of discharge voltage of 26 kV in the following studies.
3.4. Effect of air flow rate on COD removal of phenol wastewater

Figure 7 presented the effect of air flow rate on COD removal of phenol wastewater. As shown in figure 7, COD removal efficiency decreased with the increase of air flow rate [5]. When the air flow rate increased from 1 to 2 m³ h⁻¹, COD removal efficiency decreased from 52.8% to 40.3% after 3 h of discharge treatment. It may be due to the fact that the residence time of ozone in aqueous was shortened and the utilization efficiency of ozone decreased with the increase of air flow rate.

Due to the pressure restriction of water, the air flow rate must be not less than 1 m³ h⁻¹ (if the air flow rate decreased further, water maybe penetrate the aerator into the discharge tube) in the present system. The optimized air flow rate was 1 m³ h⁻¹.

4. Conclusions

In this paper, a surface discharge type DBD reactor was utilized to degrade phenol in water, and the effect of different power supplies on the ozone generation was studied. The energy efficiency of ozone generation in surface DBD reactor with 50 Hz AC power supply was higher than 200 Hz AC power supply and bipolar pulse generator, respectively. Thus, 50 Hz AC power supply was selected to degrade phenol in water. The results show that COD removal efficiency of phenol wastewater increased with the discharge voltage and decreased with the air flow rate. COD removal efficiency of
phenol wastewater reached nearly 53% at the air flow rate of 1 m\(^3\) h\(^{-1}\) and a peak voltage of 26 kV.

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