Study on the Removal Efficiency of Pollutants by Electrochemical Oxidation

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Abstract. In this study, magnetic field and electrochemistry were combined to treat Rhodamine B (RB) wastewater. This paper discussed the influence of electrolysis time, voltage, electrolyte type, electrolyte concentration and electrode material on the decolorization rate of RB. Under the optimum condition (100.0 mg/L concentration, electrode distance 3.0 cm, magnetic field intensity 20.0 mT, voltage 7.0 V, titanium as anode material, 0.1 mol/L KCl electrolyte), the decolorization rate reached 99.32% after 40 min.

1. Introduction

Rhodamine B (RB), as one of the common color effluents which is largely used in the textile industry. It is carcinogenic and cannot be easily degraded with brilliant colors, good color fastness and stable structure[1]. Electrochemical oxidation techniques were treated organics for the anode surface and the production of active oxidant hydroxyl radicals, chlorine and other oxidants. The electrochemical oxidation has compact reaction system, with mild reaction conditions, strong controllability, high safety, no secondary pollution, low demand for auxiliary chemicals, large processing capacity and strong versatility[2]. Magnetic strengthening technique is an emerging bio-enhancement technology in recent years, due to its non-toxicity, environmental protection, and no external energy. Magnetic field can strengthen mass transfer of the conductive liquid and enhance electrochemical reaction, owing to the existence of ions movement and transfer, as well as the transmission of electrons. The trajectory of ionization ions were changed by the action of Lorentz force, so the diffusion ability and the electrochemical reaction were improved[3]. Therefore, the combined magnetic field and electrochemistry were treated RB wastewater. In this experiment, the effects of electrode material, voltage, electrolyte type on decolorization rate of RB wastewater were investigated, which provided a theoretical basis for the application of electrochemical methods in dye wastewater treatment.

2. Experiment

2.1. Experimental materials

The electrolysis was performed in a reactor having 1.50 L of working volume containing 100.0 mg/L(RB) with an electrolyte support. The effective area of the working electrodes was 10.0 mm×8.0 mm. The electrode gap was 3.0 cm, and the electrode gap was adjustable. The reactor was equipped with a microporous aeration device, and the aeration rate was 1.20 L/min. Magnetic field were placed outside the reactor in parallel, the magnetic field intensity was 20.0 mT with 11.0 cm length and 6.0 cm width.
2.2. Analysis methods
The concentration of RB wastewater was analyzed via a 723 spectrophotometer at the maximum wavelength of 550.0 nm.

2.3. Experimental designs
The decolorization rate of RB wastewater was studied by the mono-factor analysis, and the previous result is the condition of the next experiment. The effects of electrolysis time, electrolyte type, electrolyte concentration, voltage and electrode material were investigated. During the electrolysis, samples were removed every 10.0 min. After centrifugation, the absorbance of the solution was determined, then put it into the standard curve \( y = 0.2199x + 0.0811 \), the concentration of RB dye wastewater was obtained after electrolysis. The decolorization rate was calculated: \( DR = \frac{(C_0 - C_e)}{C_0} \times 100\% \), DR means decolorization rate, \( C_0 \) is the initial concentration of RB wastewater, and \( C_e \) is the concentration of RB wastewater after electrolysis.

3. Results and analysis
3.1. Effect of electrolysis time
As shown in Fig. 1, the effect of electrolysis time was studied. When the electrolysis time was less than 30.0 min, the decolorization rate of RB wastewater increased rapidly and it was 89.86% at 30.0 min. Then, the decolorization rate increased slowly after 40.0 min, and even showed a downward after 70.0 min. This result attributed to the high concentration of RB oxidized on the electrode surface in the beginning. The decolorization rate decreased with increasing of reactants and products on the electrode surface, which hindered the mass transfer and reduced the current efficiency. In addition, the concentration of RB wastewater decreased by electrolysis, 40.0 min electrolysis time were selected for further experiments and the electrolysis decolorization rate was 90.08%.

![Fig. 1 Effects of electrolysis time on decolorization rate](image)

3.2. Effect of voltage
The effect of voltage is shown in Fig. 2. The decolorization rate increased at beginning, and little change after that. It indicated that initial concentration of RB was high at beginning, and the decolorization rate increased rapidly. As the concentration of RB decreased, the degradation rate became slowly.

When voltage was 5.0 V, the least decolorization rate were appeared and only 63.71% at 50.0 min. However, as for the change from 7.0 V to 10.0 V, a much smaller increase. The decolorization rate increased faster at voltage of 7.0 V and reached to 98.25 % at 30.0 min. Voltage is the direct driving force of electrochemical reaction. If the voltage is too low, the reaction is slow, and certain active substance cannot be stimulated, resulting a decrease in processing capacity[4]; Otherwise if the voltage is too large, the bypass current will be increased, and cause unnecessary power consumption. Therefore,
the voltage of 7.0 V was selected for the next experiment, and the electrolytic decolorization rate was 98.48%.

3.3. Effect of electrolyte

Fig. 3 displays the decolorization rate using two supporting electrolytes (Na$_2$SO$_4$ and KCl). It can be observed from Fig. 3 that the decolorization rate is much better when KCl as supporting electrolyte. The decolorization rate of KCl as electrolyte increased from 74.85% to 98.62%, while Na$_2$SO$_4$ as electrolyte increased slowly from 20.78% to 52.93% during 10.0 to 50.0 min. It was found that different electrolyte produced different electrochemical reactions[5]. The electrolyte changed the speed of ions movement in the solution, improved conductivity and decolorization rate[6]. Chloride ions produced strong oxidizing substances during the reaction process, which can promote degradation of organics. The chemical reactions of Na$_2$SO$_4$ and KCl are as follows:

3.3.1. KCl as electrolyte:

\[ 2Cl^- \rightarrow Cl_2 + 2e^- \]  
\[ Cl_2 + H_2O \rightarrow HClO + H^+ + Cl^- \]  
\[ HClO \rightarrow ClO^- + H^+ \]

3.3.2. Na$_2$SO$_4$ as electrolyte:

\[ SO_4^{2-} + \cdot OH + H^+ \rightarrow SO_4^{2-} + H_2O \]

The concentration of SO$_4^{2-}$ and \cdot OH reduced by electrolysis. The reaction formula was shown in (4). Therefore, KCl was chosen for the next experiment.
3.4. Effect of electrolyte concentration

As shown in Fig. 4, decolorization rate reached peak value of 99.10% when electrolyte concentration was 0.1 mol/L, and then decreased. The increase of electrolyte concentration means that the concentration of conductive medium increased, so the conductivity was improved, the cell voltage was reduced, and the power efficiency was improved[7]. However, when the concentration exceeded a certain value, the interaction force between positive and negative ions increased, resulting in the decrease of conductivity, which was more than that caused by the increase of conductive particles, so the decolorization rate showed downward trend. Therefore, the increase of electrolyte concentration not only has no obvious promotion effect on decolorization rate, but also caused waste of resources. Therefore, 0.1 mol/L electrolyte was selected for the next experiment, and the decolorization rate was 99.10%.

3.5. The effect of anode material

Titanium mesh, iron mesh and stainless steel as anode were investigated. When the iron was used as electrode, there appeared rust precipitated. After centrifugation, we examined the supernatant. As shown in Fig. 5, the decolorization rate increased with the increase of electrolysis time. The decolorization rate of iron electrode was lower. Itanium electrode showed the best decolorization rate for 70%, which was better than stainless steels——only 61.39% at 25 min. Anode material plays an important role in the electro-degradation of organics[8]. Which should not only have good conductivity, but also cannot participate in the electrochemical reaction, unless the by-products are easy to handle. The selection of electrode should be based on the principles of stability and efficiency, with good
catalytic effect. In addition, the potential of titanium electrode is higher than that of other anode materials, so the oxidation is more prone to occur, and its decolorization effect is better[9].

![Graph showing removal rate at different electrodes](image)

**Fig. 5 Removal rate at different electrodes**

4. Conclusion
The results showed that electrolysis time, electrolyte type, electrolyte concentration, voltage and electrode material have an effect on the decolorization rate of RB. When electrolysis time was 40.0 min, KCl as electrolyte with 0.10 mol/L, 7.0 V of voltage and titanium mesh as the anode, the decolorization rate achieved good results for 99.32%.

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