

Electrocoagulation of Rhodamine B Dye Using Zinc Electrodes

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Abstract

The textile wastewater containing Rhodamine B is difficult to degrade naturally and poses serious environmental threats. This study evaluated the effectiveness of electrocoagulation using zinc electrodes for Rhodamine B removal. Variables analyzed were concentration (10, 30, and 50 mg/L), time (15, 30, 45, 60, and 75 min), pH (5, 6, 7, 8, and 9), voltage (2.5, 5, 7.5, and 10 V), and electrode distance (1, 2, 3, and 4 cm). Removal efficiency was measured using UV-Vis spectrophotometry at λ 545 nm, while FTIR characterization confirmed molecular changes. The optimum condition was obtained at 75 min, pH 6, 5 V, and 1 cm electrode distance, resulting in 98.68 % removal efficiency. FTIR spectra supported the successful removal of Rhodamine B. This demonstrates that electrocoagulation with zinc electrodes is an effective and eco-friendly method for textile wastewater treatment.

Keywords

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1. Introduction

The textile industry is one of the strategic sectors that plays an important role in the national economy. However, its production processes generate wastewater containing hazardous chemicals, including synthetic dyes such as Rhodamine B. This dye has a complex aromatic structure that is highly stable, making it resistant to natural degradation. Rhodamine B is difficult to decompose in the environment primarily due to its rigid aromatic xanthene ring system, which provides high structural stability and resistance toward biological and chemical oxidation. Moreover, Rhodamine B is toxic and carcinogenic, and its presence in aquatic environments may cause severe ecological disruptions and threaten human health. Therefore, the development of effective and environmentally friendly wastewater treatment methods is urgently required to reduce Rhodamine B concentrations before its discharge into the environment^[1].

Several methods for treating dye-containing wastewater have been developed, including adsorption, chemical oxidation, membrane filtration, and coagulation-flocculation. Nevertheless, most of these approaches still face limitations, such as high operational costs, the need for chemical reagents, and the potential generation of secondary pollutants. An alternative technique that has shown promising potential is electrocoagulation, which combines electrochemical and

coagulation processes to generate coagulants in situ from sacrificial metal electrodes. Compared to conventional methods, electrocoagulation offers several advantages, such as eliminating the need for external coagulants, simplicity in operation, short reaction time, and high pollutant removal efficiency^[2,3].

In this study, zinc (Zn) electrodes were employed as the source of coagulants, expected to generate Zn(OH)_2 through electrolysis to bind Rhodamine B molecules. Zinc was chosen due to its suitable electrochemical properties and its effectiveness in forming flocs that can adsorb and precipitate dye molecules. Furthermore, variations in electrode spacing were investigated to evaluate their influence on the efficiency of the electrocoagulation process.

2. Materials and Methods

2.1. Materials

Rhodamine B (Merck) was used as the model dye solution. Sodium chloride (NaCl, Merck) was applied as the supporting electrolyte. Sodium hydroxide (NaOH, Merck) and sulfuric acid (H_2SO_4 , $\geq 98\%$, Smart Lab) were used for pH adjustment. Acetone ($\text{C}_3\text{H}_6\text{O}$, Merck) was applied for electrode cleaning. Distilled water was used throughout all experiments. Zinc plates (5×2 cm, thickness 0.3 mm) served as electrodes.

2.2. Instruments

The main equipment included a glass reactor (100 mL) connected to a DC power supply (Gratten APS3003S-3D), a magnetic stirrer, analytical balance (Ohaus Pioneer PX), pH universal indicator, and filter paper. UV-Vis spectrophotometer (Shimadzu) was employed to measure dye concentration at 545 nm, while Fourier Transform Infrared Spectroscopy (FTIR, JEOL JSM 6950) was used to confirm structural changes after treatment.

2.3. Electrocoagulation Procedure

Penul Electrocoagulation experiments were performed in a batch reactor containing 100 mL of Rhodamine B solution at various initial concentrations (10, 30, and 50 mg/L). Sodium chloride (2 g/L) was added as the electrolyte. The effect of initial pH was studied by adjusting the solution to pH 5, 6, 7, 8, and 9 using NaOH or H₂SO₄ prior to electrocoagulation. Zinc electrodes were immersed at defined interelectrode distances (1, 2, 3, and 4 cm) and connected to a DC power supply at different applied voltages (2.5, 5, 7.5, and 10 V). The solution was stirred at 400 rpm during treatment, and reaction time was varied between 15, 30, 45, 60, and 75 min, at constant room temperature. After treatment, the solution was filtered to remove flocs, and the residual dye concentration was measured using UV-Vis spectrophotometry^[4].

2.4. Analytical Method

Removal efficiency of Rhodamine B was calculated based on the decrease in absorbance at 545 nm using UV-Vis spectrophotometry. The efficiency (%) was determined using the following equation:

$$\% \text{ Re} = \frac{\text{Initial absorbance} - \text{Final absorbance}}{\text{Initial absorbance}} \times 100\% \quad (1)$$

Structural changes in the dye and flocs formed were further analyzed by FTIR to confirm the interaction between Rhodamine B and Zn(OH)₂^[4].

3. Results and Discussion

3.1. Effect of Dye Concentration and Contact Time

The efficiency of Rhodamine B removal decreased with increasing initial concentration (10, 30, and 50 mg/L), yet improved with longer contact time (15, 30, 45, 60, and 75 min). At higher concentrations, the amount of Zn²⁺ ions generated from the zinc anode was insufficient to neutralize all dye molecules, resulting in lower removal efficiency. Conversely, at lower concentrations, available Zn(OH)₂ flocs could effectively bind dye

molecules, leading to higher efficiency. After 75 minutes, removal efficiency approached 98 – 100% across all concentrations, indicating that sufficient reaction time allows nearly complete dye removal. This trend aligns with previous studies reporting that electrocoagulation performance improves with extended electrolysis time, due to increased coagulant generation and enhanced adsorption-flocculation processes^{[5][6]}.

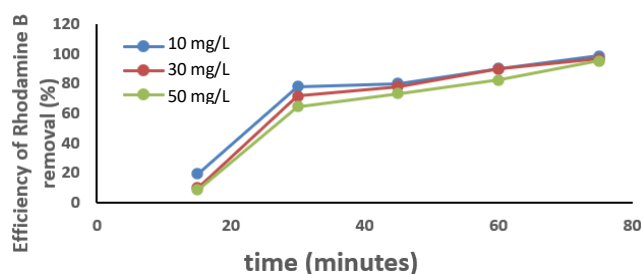


Figure 1. Effect of dye concentration on removal efficiency at different contact times (pH = 6; electrode distance = 1 cm; applied voltage = 5 V; stirring speed = 400 rpm)

3.2. Effect of pH

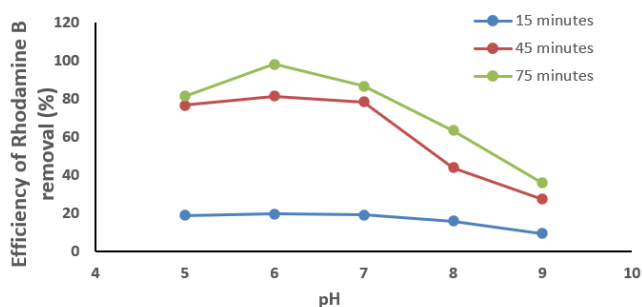


Figure 2. Effect of pH on dye removal efficiency at different contact times (concentration = 10 mg/L; electrode distance = 1 cm; applied voltage = 5 V; stirring speed = 400 rpm)

The initial solution pH significantly influenced electrocoagulation performance. The optimum removal efficiency (97.8%) was achieved at pH 6, while efficiency decreased under more acidic (pH 5) and alkaline (pH 7–9) conditions. At acidic condition (pH 5), Zn(OH)₂ flocs dissolve more readily, reducing coagulation effectiveness. In contrast, at alkaline condition (pH 8, 9), Zn(OH)₂ may convert to soluble complexes such as [Zn(OH)₄]²⁻, limiting floc formation. Thus, a near-neutral condition promotes stable Zn(OH)₂ precipitation and maximizes dye removal. These findings are consistent with earlier reports highlighting the pH-dependent solubility of metal hydroxides in electrocoagulation systems^[7].

3.3. Effect of Applied Voltage

Applied voltage directly affects current density, which governs the rate of Zn^{2+} release and floc formation. At 5V, removal efficiency reached 99%, while both lower (2.5 V) and higher voltages (7.5 – 10 V) yielded reduced performance. Excessive voltage led to rapid gas bubble formation, producing fine flocs prone to redispersion and reducing settling efficiency. This observation agrees with prior studies that reported an optimum voltage range is crucial to balance efficiency and energy consumption in electrocoagulation processes^[8].

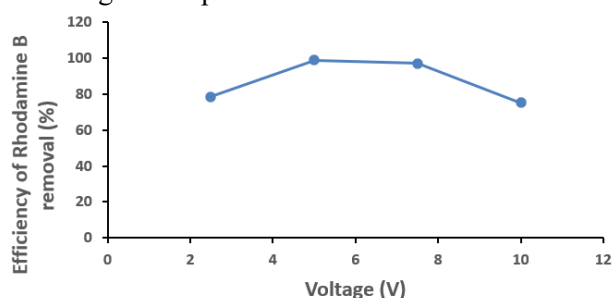


Figure 3. Effect of applied voltage on dye removal efficiency (concentration = 10 mg/L; pH = 6; electrode distance = 1 cm; time = 75 min; stirring speed = 400 rpm)

3.4. Effect of Electrode Spacing

Electrode spacing influenced both electrical resistance and coagulant distribution. Maximum removal efficiency (98%) was obtained at 1 cm spacing, while performance declined drastically at 2 – 4 cm. Wider spacing increased solution resistance, lowered current density, and consequently reduces the release of Zn^{2+} ions. Moreover, longer distances hinder ion transport between electrodes, further decreasing floc formation. Conversely, spacing values below 1 cm are generally not recommended in practical applications because excessively narrow gaps can promote intense gas bubble accumulation, hinder floc settling, and increase the risk of short-circuiting between electrodes. These results corroborate reports that short electrode spacing improves electrocoagulation efficiency while minimizing energy demand^[5].

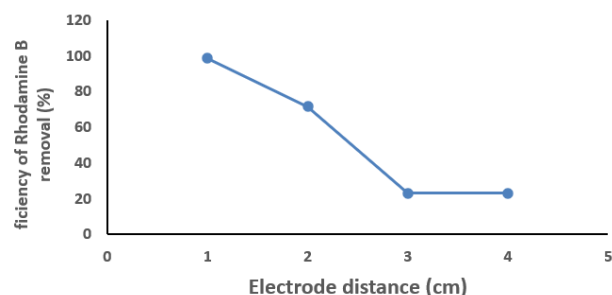


Figure 4. Effect of electrode distance on dye removal efficiency (pH = 6; applied voltage = 5 V; time = 75 min; stirring speed = 400 rpm)

3.5. FTIR Analysis

FTIR spectra confirmed the successful removal of Rhodamine B through electrocoagulation. In the treated samples, several characteristic absorption bands of Rhodamine B decreased markedly or disappeared. The prominent C–H stretching peak around 2978 cm^{-1} was reduced, and the aromatic C=C stretching bands in the region of $1580 - 1620\text{ cm}^{-1}$ showed significant attenuation, indicating disruption of the conjugated xanthene ring system. Additionally, the C–N stretching vibrations around $1200 - 1300\text{ cm}^{-1}$ also diminished, suggesting adsorption and structural alteration of multiple functional groups. In contrast, the FTIR spectrum of the sludge produced after treatment exhibited a broad –OH band at $\sim 3172\text{ cm}^{-1}$, corresponding to $\text{Zn}(\text{OH})_2$. These spectral changes collectively demonstrate that Rhodamine B molecules were effectively adsorbed onto and interacted with $\text{Zn}(\text{OH})_2$ flocs through multiple functional groups. This structural evidence also supports the proposed mechanism in which Zn^{2+} ions generated from the anode react with OH^- ions at the cathode to form $\text{Zn}(\text{OH})_2$, which subsequently binds Rhodamine B and facilitates its removal^[9].

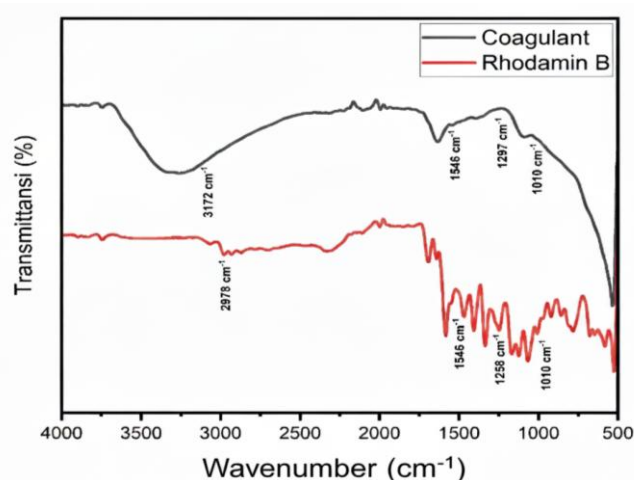


Figure 5. FTIR Spectra of Rhodamine B dye and the coagulant

4. Conclusions

This study demonstrated that electrocoagulation using zinc electrodes is highly effective in removing Rhodamine B dye from aqueous solutions. Under the optimum operating conditions (initial concentration 10 mg/L, pH 6, applied voltage 5 V, electrode spacing 1 cm, contact time 75 min, and stirring speed 400 rpm), a maximum removal efficiency of 98.68% was achieved. The results highlight the critical role of operational parameters in electrocoagulation performance. Removal efficiency decreased with increasing dye concentration

but improved with longer reaction time. The optimum pH was found to be near neutral (pH 6), while both excessively acidic and alkaline conditions reduced floc formation. Similarly, optimum applied voltage (5 V) and short electrode spacing (1 cm) ensured sufficient coagulant generation and efficient dye removal. FTIR analysis confirmed the interaction between Rhodamine B molecules and $\text{Zn}(\text{OH})_2$ flocs, validating the proposed removal mechanism through adsorption and coagulation.

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Investigation: B.M.S.

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Visualization: B.M.S.

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Conflict of interest

The authors declare no conflict of interest.

References

- [1] Agustina, L., Sitorus, S. & Sari, I. Y. L., Utilization Of Active Charcoal From The Powderwaste Of Bangkirai Timber (*Shorea Laevifolia* Eudert) As Adsorbent Of Rhodamin B Colors. *J. At.*, 6(2): 119–123 (2022).
- [2] Lestari, N. D. & Agung, T., Penurunan TSS dan Warna Limbah Batik. *Envirotek J. Ilm. Tek. Lingkungan.*, 6(1): 37–44 (2014).
- [3] Apriyani, N., Industri Batik: Kandungan Limbah Cair dan Metode Pengolahannya. *Media Ilm. Tek. Lingkungan.*, 3(1): 21–29 (2018).
- [4] Emriadi, E., Refinel, R. & Khalishah, S., Diazo Red B Dye Removal by Electrocoagulation Method using Aluminum Electrode. *Aceh Int. J. Sci. Technol.*, 13(2): 149–158 (2024).
- [5] Moneer, A. A., El-Mallah, N. M., Ramadan, M. S. & Shaker, A. M., The effect of a novel electrode on the removal of Reactive Yellow 17 dye by Electrocoagulation technique. *Egypt. J. Aquat. Res.*, 48(3): 191–197 (2022).
- [6] Hassani, G., Alinejad, A., Sadat, A., Esmaeili, A., Ziaei, M., Bazrafshan, A. A. & Sadat, T., Optimization of landfill leachate treatment process by electrocoagulation, electroflotation and sedimentation sequential method. *Int. J. Electrochem. Sci.*, 11(8): 6705–6718 (2016).
- [7] Zhou, J., Chen, D., Jiang, Y., Yang, K., Wang, H. & Zhou, J., Removal of color caused by dissolved organic matter from groundwater by electroflotation-filtration continuous flow reactor and optimization by response surface methodology. *Desalin. Water Treat.*, 57(2): 754–764 (2016).
- [8] Hmida, E. S. B. H., Abderrazak, H. & Ounissi, T., Electrocoagulation. *Adv. Sci. Technol. Innov.*, Part F2460: 227–237 (2024).
- [9] Giechaskiel, B. & Clairotte, M., Fourier transform infrared (FTIR) spectroscopy for measurements of vehicle exhaust emissions: A review. *Appl. Sci.*, 11(16): (2021).