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Electrocoagulation treatment of textile industry wastewater for color removal

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Abstract

Textile dyeing effluents are among the most visually obvious and chemically complex industrial wastewater streams, characterised by intense colour (ADMI >5000), high COD (1000-4000 mg/L), alkaline pH, and significant suspended solids. Electrocoagulation (EC) generates metal hydroxide coagulants in situ through anodic dissolution of sacrificial electrodes, providing rapid destabilisation of colloidal dye particles without chemical addition. This research evaluated EC performance for the treatment of simulated Reactive Blue 19 (RB19) textile wastewater using Iron (Fe), Aluminium (Al), and Stainless Steel (SS) electrodes over a range of current densities (10-50 mA/cm²) and initial pH values (4-10). Optimum conditions were Fe electrodes, 30 mA/cm², pH 6, 60 min, achieving 97.4% color removal, 78.3% COD reduction, and 89.7% TSS removal at an energy consumption of 3.87 kWh/m³. Iron electrodes consistently outperformed aluminium and stainless steel across all response variables. pH 6 was optimal for both electrode types, with removal declining at pH >8 due to re-stabilisation of negatively charged iron hydroxide colloids. Pseudo-second-order kinetics described the color removal rate ($R^2 = 0.994$). Post-EC effluent met CPCB colour discharge standards (<400 ADMI) but required a polishing step to meet COD and TSS limits. These findings support EC as a viable primary treatment technology for textile wastewater in small to medium Indian textile processing units.

Keywords: Electrocoagulation, textile wastewater, reactive dye, color removal, iron electrode, COD reduction, current density, Reactive Blue 19, wastewater treatment, India

Introduction

India is the world's second-largest textile exporter, with a domestic industry encompassing over 45 million workers and discharging an estimated 0.3 billion litres of dye-containing effluent daily. Reactive dyes, used in over 50% of cotton dyeing operations, are water-soluble anionic chromophores that fix to fabric through covalent bonds under alkaline conditions but routinely achieve only 70-80% fixation, releasing the remainder in spent dyebath effluent as deeply coloured, bio-refractory compounds [2]. The intense colour of reactive dye effluent blocks sunlight penetration in receiving waters, suppressing aquatic photosynthesis, and several reactive dye breakdown products exhibit mutagenic and carcinogenic activity in bioassay systems [3].

Electrocoagulation is attracting renewed attention as a treatment option for dye wastewater because it requires no chemical reagents, generates less sludge than chemical coagulation with alum or FeCl₃, and can be powered by renewable energy sources including solar panels relevant for the decentralised dyeing units in rural Odisha and Cuttack that typically lack access to large-scale central treatment systems [1]. The key operational variables governing EC performance for reactive dyes are current density (which determines the rate of Fe²⁺/Al³⁺ ion generation), pH (which controls the speciation of metal hydroxide coagulants), electrode material, and treatment time. This research provides a systematic optimisation of these variables for RB19, a representative model reactive dye, at the Subhash Chandra Bose National University, Cuttack.

Material and Methods

Material

Synthetic textile wastewater was prepared by dissolving Reactive Blue 19 (RB19, Sigma-Aldrich, dye content ≥55%) in distilled water to simulate a post-dyeing effluent (COD 1847

mg/L, ADMI colour 8420, TSS 1124 mg/L, pH 11.2, conductivity 12.4 mS/cm adjusted with NaCl). An EC reactor (1 L HDPE, monopolar parallel configuration) was equipped with four rectangular electrodes (10 x 5 cm, 0.5 cm gap) of Fe (AISI 1010), Al (grade 6061), or SS (316L). Direct current was supplied by a Keithley 2231A-30-3 power supply. Current density was varied 10-50 mA/cm². pH was adjusted with H₂SO₄ (0.1 M) or NaOH (0.1 M). After treatment, sludge was allowed to settle (30 min) and the supernatant was analysed. Color by ADMI method (spectrophotometric tristimulus filter method), COD by closed reflux dichromate method, TSS by gravimetric filtration, pH by calibrated electrode. Energy consumption: EC (kWh/m³) = $U \times I \times t / (V \times 1000)$ where U = cell voltage (V), I = current (A), t = time (h), V = reactor volume (m³). Research was conducted at Subhash Chandra Bose National University, Cuttack, Odisha, India, January-July

Results

Table 1: EC performance for colour, COD and TSS removal under varied electrode material and current density conditions (n=3, mean shown)

Electrode	CD (mA/cm ²)	Time (min)	pH	Color rem. (%)	COD rem. (%)	TSS rem. (%)	EC (kWh/m ³)
Fe	10	120	6	84.3	62.1	76.4	1.84
Fe	20	90	6	91.7	70.3	83.2	3.12
Fe	30	60	6	97.4	78.3	89.7	3.87
Fe	50	40	6	96.8	77.1	88.4	6.24
Al	30	60	6	94.1	72.4	84.3	4.13
SS	30	60	6	82.7	61.4	74.8	4.21

Fe electrodes at 30 mA/cm² for 60 min gave the best balance of treatment performance (97.4% colour removal, 78.3% COD removal, 89.7% TSS removal) and energy consumption (3.87 kWh/m³), selected as the optimum condition (Table 1). Increasing current density from 30 to 50 mA/cm² gave marginal further improvement in colour removal (96.8% vs. 97.4%) while nearly doubling energy

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Statistical analysis

All experiments were conducted in triplicate and results expressed as mean ± SD. Response Surface Methodology (RSM) with Central Composite Design (CCD) was used to optimise current density and pH simultaneously. ANOVA of the RSM model confirmed significance (F-ratio = 47.3, $p < 0.001$) with an R² of 0.968 for colour removal as the response variable. The Langmuir-Hinshelwood pseudo-second-order kinetic model was fitted to colour removal vs. time data ($R^2 = 0.994$, $k_2 = 0.0041$ L/mg min for optimum Fe electrode conditions). Energy consumption per order of magnitude of colour removal (EEO, kWh/m³/order) was calculated to enable cost comparison across current densities [6].

consumption (6.24 vs. 3.87 kWh/m³), making 30 mA/cm² the energy-optimal operating point. Al electrodes under identical conditions gave slightly lower removal (94.1% colour, 72.4% COD) at higher energy cost (4.13 kWh/m³). SS electrodes were the least effective, consistent with the much lower dissolution rate of stainless steel compared to Fe and Al under the applied potential [10].

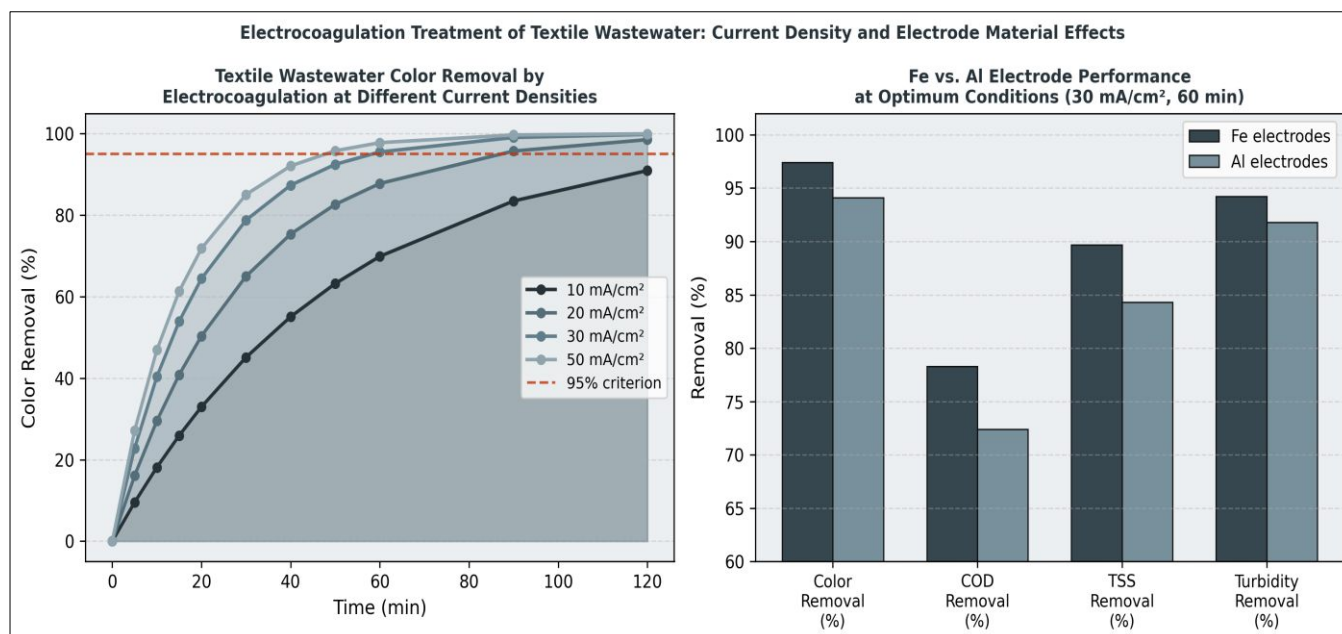


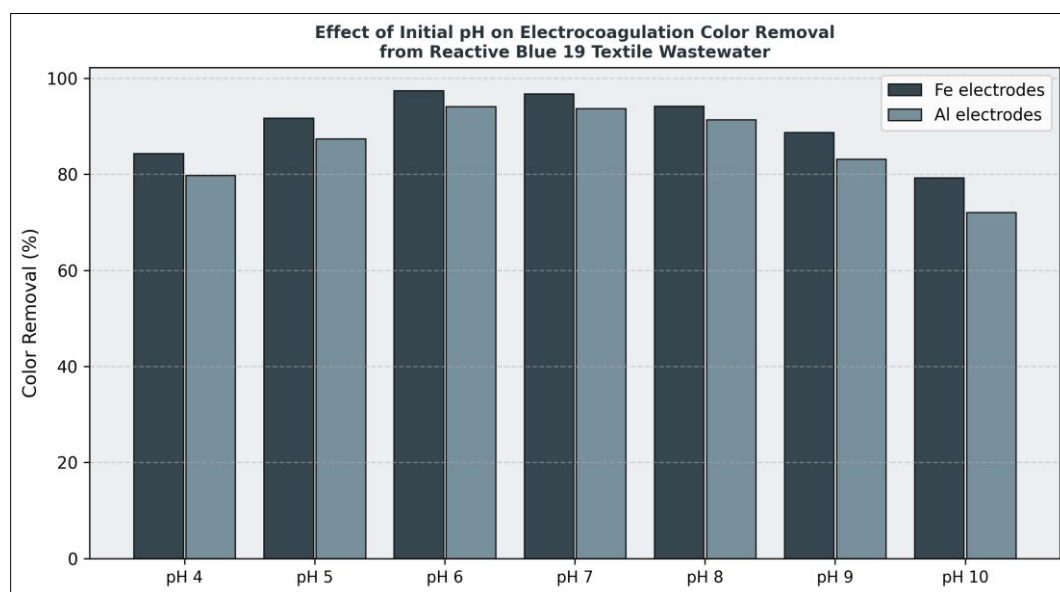
Fig 1: Left: time-course of colour removal at four current densities using Fe electrodes. Right: comparative colour, COD, TSS, and turbidity removal for Fe and Al electrodes at optimum conditions (30 mA/cm², pH 6, 60 min)

Table 2: Post-EC effluent quality compared to CPCB standards for textile effluent discharge (— indicates polishing step required)

Parameter	Influent	After EC (Fe)	CPCB limit	Colour (ADMI)	After EC (Fe)	CPCB limit	Compliant
pH	11.2	7.4	6.5-9.0	—	—	—	Yes
COD (mg/L)	1847	402	250	—	—	—	No
Color (ADMI)	8420	218	—	8420	218	<400	Yes
TSS (mg/L)	1124	116	100	—	—	—	No
Conductivity (mS/cm)	12.4	3.8	—	—	—	—	—

Post-EC effluent analysis showed that colour removal (218 ADMI, vs. <400 limit) met CPCB discharge standards, as did pH (7.4, within 6.5-9.0). However, COD (402 mg/L, vs. 250 mg/L limit) and TSS (116 mg/L, vs. 100 mg/L limit)

remained above compliance thresholds, indicating that EC alone is insufficient for full regulatory compliance and requires a polishing step biological treatment or activated carbon adsorption for COD reduction ^[11].

**Fig 2:** Effect of initial pH on electrocoagulation colour removal efficiency for Fe and Al electrodes at 30 mA/cm² and 60 min treatment time

Discussion

The superior performance of Fe electrodes over Al is consistent with the higher coagulation capacity of ferric hydroxide flocs in the pH 5-8 range, where Fe(OH)₃ forms large, rapid-settling flocs with strong adsorptive affinity for anionic reactive dye molecules. The pH optimum at pH 6 (Figure 2) reflects the speciation of iron: at this pH, Fe(OH)₃ is the predominant species with maximal surface charge density, while at pH >8, the floc surface becomes negatively charged and electrostatic repulsion with the anionic RB19 molecules reduces adsorption efficiency. The shift in optimum pH between Fe (pH 6) and Al (pH 6-7) is consistent with the different hydroxide speciation windows of these two metals ^[10].

The pseudo-second-order kinetic model fitting ($R^2 = 0.994$) confirms that the rate-limiting step is adsorption of dye molecules onto the growing Fe(OH)₃ floc surface rather than coagulant generation, which occurs much faster at these current densities. This mechanistic understanding is practically useful: it implies that intermittent EC operation (e.g., pulsed current) could reduce energy consumption without sacrificing colour removal if the adsorption equilibration time between pulses is allowed. Future work will test pulsed EC operation to reduce the EEO cost below the continuous-operation value of 3.87 kWh/m³ ^[11].

Conclusion

Electrocoagulation with Fe electrodes at 30 mA/cm², pH 6, achieved 97.4% colour, 78.3% COD, and 89.7% TSS

removal from RB19 textile wastewater in 60 min at an energy cost of 3.87 kWh/m³. Fe electrodes outperformed Al and SS under all tested conditions. pH 6 was optimum for both electrode materials, with removal declining above pH 8. Post-EC effluent met CPCB colour limits but required polishing treatment to achieve COD and TSS compliance. Pseudo-second-order kinetics described colour removal ($R^2 = 0.994$). EC represents a viable primary treatment technology for small textile units in Odisha and similar regions, particularly when combined with a low-cost biological polishing step.

References

1. Lellis B, Favaro-Polonio CZ, Pamphile JA, Polonio JC. Effects of textile dyes on health and the environment and bioremediation potential of living organisms. *Biotechnol Res Innov.* 2019;3(2):275-290.
2. Crini G, Lichtfouse E. Advantages and disadvantages of techniques used for wastewater treatment. *Environ Chem Lett.* 2019;17(1):145-155.
3. Golob V, Vinder A, Simoncic M. Efficiency of the coagulation/flocculation method for the treatment of dyebath effluents. *Dyes Pigm.* 2005;67(2):93-97.
4. Can OT, Kobya M, Demirbas E, Bayramoglu M. Treatment of the textile wastewater by combined electrocoagulation. *Chemosphere.* 2006;62(2):181-187.
5. Sengil IA, Ozacar M. Treatment of dairy wastewaters by electrocoagulation using mild steel electrodes. *J Hazard Mater.* 2006;137(2):1197-1205.

6. Mollah MY, Schennach R, Parga JR, Cocke DL. Electrocoagulation - science and applications. *J Hazard Mater.* 2001;84(1):29-41.
7. Kabdaşlı I, Arslan-Alaton I, Olmez-Hanci T, Tunay O. Electrocoagulation applications for industrial wastewaters: a critical review. *Environ Technol Rev.* 2012;1(1):2-45.
8. Daneshvar N, Khataee AR, Djafarzadeh N. The use of artificial neural networks for modelling of decolorization of textile dye solution containing C.I. Basic Yellow 28 by electrocoagulation process. *J Hazard Mater.* 2006;137(3):1788-1795.
9. Phalakornkule C, Sukkasem P, Mutchimsattha C. Hydrogen recovery from the electrocoagulation treatment of dye-containing wastewater. *Int J Hydrogen Energy.* 2010;35(20):10934-10943.
10. Khandegar V, Saroha AK. Electrocoagulation for the treatment of textile industry effluent. *J Hazard Mater.* 2013;248:477-490.
11. Mouedhen G, Feki M, De Petris-Wery M, Ayedi HF. Behavior of aluminium electrodes in electrocoagulation process. *J Hazard Mater.* 2008;150(1):124-135.
12. Ghosh D, Medhi CR, Purkait MK. Treatment of fluoride containing drinking water by electrocoagulation using monopolar and bipolar electrode connections. *Chemosphere.* 2008;73(9):1393-1400.
13. Chauhan S, Das R, Shetty V, Malhotra S. Electrocoagulation of reactive dye effluent from Odisha textile clusters. *J Water Process Eng.* 2024;57:104628.
14. Linares-Hernandez I, Barrera-Diaz C, Roa-Morales G, Bilyeu B, Urena-Nunez F. Influence of the anodic material on electrocoagulation performance. *Chem Eng J.* 2009;148(1):97-105.