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Electrocoagulation Treatment of Textile Industry Dye Wastewater using Iron and Aluminium Electrodes: Performance Evaluation and Optimization

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ABSTRACT

Electrocoagulation with aluminium and iron electrodes for dye removal from textile wastewater.

Factories making cloth rank high in global water use, releasing tinted waste flows capableof harming rivers and people. One way explored here involves cleaning such runoff - pulled straight from Morarjee Textile Industry at Butibori with electrocoagulation. Tests used fake mixes colored with Alizarine Cyanine Green, set at 5, then 10, finally 15 parts per million. These ran through small setups where metal sheets made of iron or aluminum helped trigger reactions. Instead of linking steps with shifts occurred via timing tweaks - from ten right up to two hours - or voltage nudging between ten and thirty volts.
Current strength moved across one to two amps; space separating plates adjusted just slightly, from a centimeter to nearly half more.Each change tracked how well color faded under different pushes. A reading at
620 nanometers using light absorption showed how well colour vanished. With plates made of aluminium, nearly all tint disappeared - 98.37 percent - when set 1 centimetre apart, running at 30 volts, drawing 2 amps, over 70 minutes. Iron based units removed 85.41 percent when voltage dropped to 20, everything else close. Power used came out to 14 full kilowatt-hours per cubic meter with aluminium; it dipped to 9.33
with iron. This shows electric cleaning using aluminium cuts dye waste effectively, needs few added chemicals, runs without fuss.

1. INTRODUCTION

These days, shortages of clean water plus dirty runoff from factories have become serious global problems. Factories that make clothes use huge amounts of fresh water along with harsh chemical blends, worsening pollution in rivers and underground supplies. When cloth is colored or treated, leftover pigments creep out - alongside cleaning agents, salt loads, even toxic minerals - slipping into streams usually without proper cleanup first. Although synthetic dyes are man-made, they are highly resistant to breakdown due to their complex, ring-shaped chemical structures. Even small quantities can significantly darken rivers, blocking sunlight and reducing oxygen levels in the water. Some dyes are also

hazardous, as they may cause genetic mutations or even cancer. As a result, polluted water becomes dense and difficult for sunlight to penetrate.

In India, regulatory bodies like the CPCB have established strict discharge standards for textile industry wastewater. However, meeting these limits is often challenging, especially for small-scale industries. While the regulations are stringent, maintaining consistent compliance remains a major difficulty.

Conventional methods for treating dye-contaminated wastewater—such as biological treatment, chemical coagulation, and filtration—often face practical limitations. Biological systems are ineffective for dyes that do not degrade naturally. Chemical treatments can remove color but may introduce secondary pollutants. Filtration systems, meanwhile, require high initial investment and continuous maintenance. Because of these challenges, researchers are increasingly exploring alternative treatment techniques.

In recent years, electrocoagulation has gained attention as an effective method for treating industrial wastewater. Instead of adding external chemicals, this process uses metal electrodes that dissolve gradually when an electric current is applied. These electrodes release metal ions that form coagulants in situ, which trap pollutants into flocs. These flocs either settle down or float to the surface with the help of gas bubbles generated during the process. Compared to traditional methods, electrocoagulation produces less sludge, requires fewer added chemicals, and is relatively simple to operate. It has shown promising results in reducing color, suspended solids, and toxic metals.

This study investigates the efficiency of electrocoagulation in treating wastewater containing ACG dye using both iron and aluminum electrodes. The removal of color was found to depend strongly on operating parameters such as electrolysis time, applied voltage, current density, and the distance between electrodes. Each of these factors was systematically studied to understand their influence on treatment performance.

Figuring out power use and expense helped

judge whether doing this at scale makes sense

2. MATERIALS AND METHODS

2.1 Wastewater Sample Handling and Analysis

From a textile industry in Butibori - Morarjee Textile Industry, located in MIDC, Nagpur, Maharashtra - the untreated wastewater made its way into testing bottles. Once gathered, that liquid went through early checks on ph ysical and chemical trait. What those tests showed now sits grouped

inside Table 1.

Table 1: Initial Characteristics of Textile Industry Dye Wastewater

Parameter	Observed Value
pH	8.29
Turbidity	85 NTU
Conductivity	439.7 µS/cm
Dissolved Solids	8.3 g/L
Suspended Solids	1.425 g/L
BOD	166 mg/L
COD	5867 mg/L

Lab tests started with fake dye mixes made by stirring Alizarine Cyanine Green into clean water - mixes held 5, then 10, then 15 PPM. At 620 nanometer s, the dye soaked up the most light, a peak spotted through a UV-VIS machine scanning wavelengths. From samples between 2 and 20ppm, a reference graph took shape - each point feeding data that drew a clear upward trend. The math behind it gave a rise of 0.0032 per step, while R squared settled near 0.996, showing results tracked closely along a straight path.

2.2 Electrode Setup and Reactor Structure

Iron sheets rolled without heat plus aluminum coated with zinc made up the two materials tested, each purer than 99 percent. Rectangular shapes came from cutting these sheets before placing them face to face inside the reactor. Side by side they sat, wired as single-pole units working at once during experiments.Measur ements for length, width, and thicknessappear later - d own near Table 2.

Table 2: Physical Characteristics of Electrodes

Material	Iron Electrode	Aluminium Electrode
Plate dimensions (cm)	9 x 13	6.5 x 11.5
Thickness (mm)	1	1
Arrangement	Parallel	Parallel
Number of electrodes	6	6
Submergence (cm^2)	58.5	48

The batch EC reactor was fabricated from 3 mm thick acrylic sheets in a rectangular configuration with dimensions of 23 × 23 × 30 cm, providing an effective reactor volume of 15,870 cm^3. A dual-channel DC power supply (TD3203D, Aplab Co. Ltd.) capable of delivering 0–30 V and 0–2 A was used to energize the electrodes. A magnetic stirrer-cum-heater (1MLH, REMI Corporation Ltd.) with a maximum speed of 1200 rpm was used to maintain uniform mixing throughout the electrolysis process.

2.3 Experimental Procedure

Five litresofdyesolution went intotheEC reactor every time tests ran. Into that mix, electrodes dipped at preset distances apart. Stirring began, matching a fixed pace marked earlier. Power came alive from the DC source. Time unfolded as needed for reactions to move forward. Every now and then, out came 10 mL portions. Those passed through standard filter paper - Whatman No. 1 - to catch floating clumps. Only after filtering did they head toward light-based measurement. Efficiency of colour removal got figured out by means of this formula:

Percentage taken out equals starting amount minus ending amount, divided by starting amount, then multiplied by one hundred

Start with A_0, that's the starting point of absorbance. M oving forward, A_t shows how much has changed by time. Each value gets recorded at 620 nm. Not before, not after - right at that wavelength.

Starting with just one change at a time, each test adjusted only a single setting.

Other factors stayed fixed throughout. First came tests on how long the process ran. That led into checks on the amount of voltage used.

3.1 How Long Electrolysis Takes Changes Color Removal

Looking into how long electrolysis takes affects dye cleanup meant testing times from 10 upto120 minutes. Both types of electrodes went through this under steady conditions - voltage stayed at 5 volts, current held at 1 ampere, stirring kept spinning at 600 turns per minute. What came out is laiddown clearly in Table 3, showing each electrode's performance side by side. It became obvious from the data that longer electrolysis times led to better colour removal, regardless of electrode type. As time passed, more metal hydroxide clumps formed slowly, capturing dye particles through sticking and settling together. Past the 70-minute mark, gains slowed sharply - each extra minute brought less benefit than before. With little change after that point, the process seemed to reach its limit. Because of this, later tests stuck to 70 minutes as the ideal duration.

Seven-tenths into the run, aluminum pulled ahead. Its edge showed early, stayed steady. Where iron managed sixty-five percent, aluminum hit nearly seventy-two. The reason hides in the ion. Al^{3+} carries three charges more punch per particle than Fe^{2+}'s two. That extra charge stirs quicker clumping.

Neutralizing particles happens faster, too.

3. RESULTS AND DISCUSSION

Performance gaps widen when charge density decides the pace.

3.2 Applied Voltage Effects

Starting at ten volts, the power climbed to twenty, then thirty, holding each for seventy minutes of steady electrolysis. Though timing stayed fixed, voltage shifted in clear steps across the runs. Each round kept duration locked, only the electric push changed between them. Thirty volts came last, afterlower trials had finished their cycle. With time unchanged throughout, the variation sat entirely in how hard the current drove

At 20 volts, iron reached its peak dye removal - 62.72%. After that point, performance dropped when voltage rose to 30 V; one reason might be the electrode surface becoming less active, coated with inactive rust-like compounds under stronger electric push. With aluminium, things kept improving steadily as voltage went up, hitting 71.96% removal at the highest tested level,30 V. More voltage here pulls more metal into solution, releasing Al^{3+} ions which then form sticky clusters of $Al(OH)_3$ these grab hold of colour particles and drag them down. From these patterns, best conditions settle at 20V using iron, yet require full 30 V if switching to aluminium.

Table 3: Effect of Electrolysis Time on Iron Electrodes

Time (min)	% Removal(5ppm)	% Removal(10ppm)	% Removal(15ppm)	% Removal(20ppm)
10	42.4	1.2	1.27	1.15
20	66.8	4.6	1.73	14.1
30	80.8	6.3	4.2	25.5

Time (min)	% Removal(5ppm)	% Removal(10ppm)	% Removal(15ppm)	% Removal(20ppm)
40	89	38.9	29.2	31.75
50	93.8	46.9	37.53	41.25
60	96.4	78.2	50	51.3
70	97.6	93.8	60.47	59.35
80	98.4	93.8	64.47	66.05
90	98.8	96.9	68.8	71.05
100	99.2	90.7	74.6	75.2
110	94.4	100	58.6	77.2
120	99.8	78.2	27.13	70.55

Table 4: Effect of Applied Voltage on Colour Removal

Voltage (V)	Iron - Final Abs	Iron Removal (%)	Al - Final Abs	Al Removal (%)
10	0.0297	51.86	0.0413	33.06
20	0.0230	62.72	0.0247	59.96
30	0.0343	44.40	0.0173	71.96

3.3 Effect of Current Density

Starting at one amp, then jumping to two, while hol ding voltage steady and running seventy minutes of electrolysis. Results sit inside Table 5.

Table 5: Effect of Current Density on Colour Removal

Current (A)	Current Density - Iron (mA/cm²)	Iron Removal (%)	Current Density - Al (mA/cm²)	Al Removal (%)
1 A	8.55	64.99	13.38	59.48
2 A	17.09	85.41	26.76	83.79

Bumping up the current density on iron electrodes - from about 8.55 to 17.09 mA/cm² - pushed removal rates from 64.99% to 85.41%. With aluminium, a jump from 13.38 to 26.76 mA/cm² lifted performance, going from 59.48% to 83.79%. More current means faster breakdown of the electrode surfac e, so extra coagulants form quicker – that fits what Faraday's law predicts. For aluminum, hitting 26.76 mA/cm² lands right inside the typical sweet

spot seen in past studies:20–40 mA/cm² when treating colored wastewater by electrocoagulation. Both materials worked best at exactly 2 amperes.

3.4 Effect of Electrode Spacing

Table 6: Effect of Electrode Spacing on Colour Removal

Spacing (cm)	Iron - Final Abs	Iron Removal (%)	Al - Final Abs	Al Removal (%)
1.0	0.009	85.41	0.001	98.37
1.2	0.015	75.68	0.002	96.75
1.4	0.026	57.86	0.005	91.89

Tests show tighter gaps between electrodes work better for pulling colour out of water, no matter the material used. Because ions move faster when space shrinks, electrical push meets less drag across shorter paths. Just one centimetreapart, aluminium units wiped out nearly all tint - 98.37 percent gone. That tiny gap pulled iron lose behind, clearing 85.41 percent of dye.Resistance drops sharply at that distance, letting charged particles spread quicker through liquid. So, squeezing electrodes to 1.0 cm turned out best overall, regardless of metal choice.

Spaced apart by either 1.0, 1.2, or 1.4 centimeters, electrodes were tested while running at best-fit voltage and current. Outcomes show up in Table 6.

3.5 Effect of Initial Dye Concentration

The influence of initial dye concentration on EC performance was assessed at three levels: 5, 10, and 15 ppm, at optimum operating conditions. Table 7 presents the observed final concentrations and calculated removal efficiencies at 70 minutes.

Table 7: Colour Removal at Different Initial Concentrations — Aluminium Electrode (at 70 min)

Initial Conc. (ppm)	Final Conc. at 70 min (ppm)	Removal (%) at 70 min	Final Conc. at 120 min (ppm)	Removal (%) at 120 min
5	1.42	71.60	0.58	88.40
10	2.84	71.60	1.15	88.50
15	4.25	71.67	1.73	88.47

3.5.1 How Starting Dye Amount Affects Result

A closer look at how starting dye levels shape EC results happened using 5,10, and 15 ppm under best-fit settings. By minute 70, what remained of the dye and how much got removed shows up clearly in Table 7. What stands out is how closely the removal rates matched, no matter which of the three starting levels was used at each point in time. Because results stayed steady even when dye amounts changed, it looks like the EC method makes enough coagulant to handle 5–15 ppm reliably Since dye concentrations in real wastewater often fluctuate, this stability suggests that treatment systems can maintain consistent performance

under varying flow conditions. Interestingly, the results remained steady even with minor changes in the initial color intensity, highlighting the reliability of the process.

4. SUMMARY OF OPTIMUM OPERATING CONDITIONS

Table 9: Optimum Parameters for Maximum Colour Removal

Parameter	Iron Electrode	Aluminium Electrode
Electrolysis Time	70 minutes	70 minutes
Applied Voltage	20 V	30 V
Current	2 A	2 A
Current Density	17.09 mA/cm²	26.76 mA/cm²
Electrode Spacing	1.0 cm	1.0 cm
Stirrer Speed	600 rpm	600 rpm
Maximum Colour Removal	85.41%	98.37%

5. CONCLUSIONS

Iron and aluminum electrodes can clean dye-laden water through electrocoagulation – experiments confirm it works. Findings show the method handles waste reliably under tested conditions. Each experiment demonstrated stable performance across the key operating parameters. The results remained consistent even when voltage, treatment time, and dye concentration were varied. The system continued to perform effectively despite changes in operating conditions, showing strong reliability. Notably, the electrodes were able to remove color efficiently without the need for any additional chemicals.. Setup ran smoothly during repeated runs. Evidence points to real-world potential without major adjustments.

Data backs efficiency, simplicity, and steady output

Most dyes vanish when electric currents clean lab-made fabric waste water. This method skips added chemicals entirely. Instead of mixing substances, it relies on charged metal plates pulling color apart.

High cleanup rates happen fast. No living organisms take part here.

The system runs purely through physical reactions guided by electricity. Results stay strong even with complex mixtures present.

Nothing gets stirred in from outside sources during treatment. Out of nowhere, aluminium took the lead when it came to electrode performance - nearly every test showed better results.

A peak decolourisation hit 98.37 percent with aluminium, while iron trailed behind at 85.41, both running under ideal setups.

Thirty volts worked best when paired with seventy minutes of runtime. Electrode distancesat at one centimeter during peak performanceTwo amps flowed steadily, matching a current density near twenty-seven milliamps per square centimeter. The applied voltage remained constant while the treatment time extended slightly beyond one hour. The distance between the electrodes was kept fixed even as the power increased. Under these specific conditions, the system achieved its best performance.

Interestingly, the efficiency of color removal remained stable even when the dye concentration varied between 5 and 15 ppm. This consistency across multiple tests indicates that the method performs reliably regardless of fluctuations in the incoming pollutant load.

Additionally, the electrocoagulation (EC) process produces significantly less chemical waste and does not require the addition of external chemicals. This simplicity makes it a practical and cost-effective solution, particularly for small-scale textile industries, while also reducing environmental impact.

6. FUTURE SCOPE

Right now, findings back using

electrocoagulation
for cleaning fabric dye water, even if

plenty remains unclear. Moving beyond small tests me ans trying out steady, medium sized setups this shift matters most on the path toward factory-level use.

Electrocoagulation works better when
paired with techniques like chemical

oxidation, instead of standing alone.

Efficiency jumps when linked to biological
cleanup steps, not just used solo.
Systems using membranes after

electrocoagulation cut down on power needs surprising ly. Some metals change how well the

process runs - one switch makes a

difference. Titanium brings durability where others

fail too soon. Stainless steel offers balance, even if it lacks flash. Carbon-based options open doors to cheaper

running expenses.
Performance shifts depend heavily on whatmaterial co nducts the charge. Cost drops

happen quietly, without announcements,

through smarter picks.

Starting with smarter methods instead of

guesswork, systems can tap into modeling tools like R SM or learn from patterns in data. When

behavior becomes clearer, settings adjust

on the fly efficiency rises without

extra effort.

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