ELECTROCOAGULATION-BASED TREATMENT OF TEXTILE WASTEWATER: OPTIMIZATION OF PROCESS PARAMETERS FOR POLLUTANT REMOVAL

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ABSTRACT

The textile industries in Bangladesh play a significant role in both the economy and employment. However, a large amount of wastewater is produced from these industries, which contains dyes, heavy metals, etc. Traditional treatment processes often fail to treat these wastewaters, resulting in pollution of the water bodies and affecting the ecosystem. The purpose of this study was to investigate the efficiency of the electrocoagulation process in removing colour, pH, electrical conductivity, and turbidity from the textile effluent. The parameters chosen to determine the efficiency of the process were electrocoagulation time, voltage, inter-electrode distance, and settling time. The primary objective was to identify the optimum electrocoagulation parameters for maximum pollutant removal, including pH, electrical conductivity, colour, turbidity, and heavy metals. A sample from the Knitwears company was used in this research, which underwent electrocoagulation under varying conditions. Steel electrodes were used in the process. The values of treated parameters pH, colour, turbidity, and EC were compared with the standards set by the ECR'23 for textile wastewater. The most satisfactory results were obtained for electrocoagulation of 2 hours at 30V voltage and 8cm inter-electrode distance, followed by 3 hours of settling time. Maximum pollutant removal efficiency was achieved for electrical conductivity (80.9%), colour (99.9%), and turbidity (95.8%) at these parameters. However, no significant changes in pH were observed in the overall process. Heavy metal analysis was also conducted in both raw and treated samples. Though the existing concentration of Lead (Pb), Chromium (Cr), and Zinc (Zn) in the raw sample was also below the standard value according to ECR'23, the research was done to determine the efficiency of the process in removing them. The removal efficiency for heavy metals shows 14.3% for Pb, 66.7% for Cr, and 46.2% for Zn. The electrocoagulation process demonstrated the highest effectiveness in removing colour, followed by turbidity and EC. This research presents electrocoagulation as an efficient process for textile wastewater treatment, especially in removing colour. Future studies are recommended to explore alternative electrode materials and additional wastewater samples to validate the scalability and cost-effectiveness of the process.

Keywords: *Wastewater treatment, Electrolysis, Pollutant removal, Heavy metals, ECR'23*

1. INTRODUCTION

The textile and clothing industries provide a single source of growth in Bangladesh's rapidly growing economy. About 85% of Bangladesh's entire export revenue comes from textiles and clothing (Hasan et al.,2016). However, this growth has been accompanied by serious environmental challenges, particularly the generation of large volumes of highly polluted wastewater.Wastewater is a major environmental impediment for the growth of the textile industry, besides other minor issues, e.g., solid waste and resource waste management. The textile industry consumes a significant amount of water and produces highly coloured wastewater (Pearce et al.,2003). Besides persistent colouring pollutants (dyes), this wastewater contains different heavy metals like lead (Pb), cadmium (Cd), arsenic (As), chromium (Cr), zinc (Zn), and nickel (Ni), etc., which cause serious environmental and public health hazards (Gupta et al.,2025). Due to their persistence, the textile dyes are not totally degraded by the conventional wastewater treatment processes. The discharge of inadequately treated textile effluents can severely impact aquatic ecosystems by causing reduction of light penetration, affecting aquatic organisms, and introducing toxic, mutagenic, and carcinogenic substances into water bodies (Ranga & Sinha 2023; Sandi et al. 2020; and Negash et al. 2023). It may also be lethal to certain marine life due to component metals and chlorine present in the synthetic dyes(Pearce et al.,2003). According to studies, txtile effluent has high BOD, which indicates a high pollution load of the wastewater. Due to this high level of BOD, the available oxygen will be reduced in the receiving water body (Yusuf et al.,2004). So, textile wastewater must be treated before its discharge as per the national discharge quality standards.

Conventional technologies for textile wastewater treatment comprise flocculation, chemical coagulation, sedimentation, aerated lagoons, aerobic activated sludge, trickling filters, and reverse osmosis. But these treatments are not effective in the removal of all dyes and chemicals used in the industry. In addition to having a high dye concentration, these effluents also contain the chemicals utilized during the various stages of processing. Electrocoagulation stand out among the traditional treatment methods, due to its versatility, cost-effectiveness, and environmental compatibility. (Naje et al., 2017; Moradi et al., 2020). The EC process involves the in-situ generation of coagulants through the electrochemical oxidation of sacrificial anodes, typically made of aluminum or iron. These electro-generated metal ions hydrolyze to form various hydroxyl complexes and flocs, which destabilize pollutants, promote coagulation and flocculation, and subsequently remove contaminants through precipitation, adsorption, and flotation (Naje et al., 2017; Moradi et al., 2020). It is more efficient and environmental friendly and capable of removing chemicals and dyes. When textile wastewater is treated through electrocoagulation, the organic and toxic pollutants present in the wastewater, e.g., dye usually destroyed by the oxidation process. In a direct anodic oxidation process, the pollutants are first absorbed on the anode surface and then destroyed by the anodic electron transfer reaction (Louhichi et al.,2008). All the oxidants are generated in situ and are utilized immediately. Electrocoagulation seems to be a promising treatment method due to its environmental compatibility, high removal efficiency, energy efficiency, no requirement for chemicals, less sludge generation, and cost effectiveness (Can et al.,2003). Electrocoagulation shows a more satisfactory performance than conventional methods in removing complex organic contaminants. Although several studies have reported the effectiveness of electrocoagulation for textile wastewater treatment, systematic evaluations under the specific operational and wastewater characteristics of Bangladeshi textile effluents remain limited.

Therefore, This research is conducted to assess the efficiency of electrocoagulation to treat the textile effluent in Bangladesh. It will provide a clearer picture of the performance of electrocoagulation in reducing the contaminants in textile wastewater.

2. METHODOLOGY

2.1 Sample Collection

The wastewater sample was obtained from a knitwear company, a textile industry located in Dhaka, Bangladesh on November 24, 2022. This facility operates an effluent treatment plant (ETP) that processes wastewater from its printing section. Approximately 30 liters of untreated wastewater were collected from the equalization tank at the ETP inlet, as this tank holds a well-mixed (homogenized) sample of the plant's wastewater.

2.2 Experimental System

The experiment used a water-holding tank containing sample wastewater. A wooden plate was placed on top of the tank to support the electrodes, which were attached to it with bolts and submerged to a suitable depth in the water. Two electrodes were positioned at varying inter-electrode distances for different tests. They were connected to a DC power supply via wires and crocodile clips, and the applied voltage was adjusted using the supply's control knob.

2.3 Electrocoagulation

The sample underwent multiple electrocoagulation trials with varying durations, voltages, and electrode spacings. In each trial, 3 liters of the sample were subjected to electrocoagulation for either 1 or 2 hours. After each run, the treated wastewater was allowed to settle for 1, 2, and 3 hours, respectively, before being analyzed for pH, electrical conductivity (EC), colour, and turbidity.

2.3.1 Optimization of Electrocoagulation Parameters

To optimize the electrocoagulation process, three key operational parameters- electrocoagulation time, applied voltage, and inter-electrode distance were systematically varied and analyzed.

2.3.1.1 Optimum Electrocoagulation Time

Electrocoagulation was conducted for 1 hour and 2 hours at 30V with an 8 cm inter-electrode distance. After each run, samples were allowed to settle for 1, 2, and 3 hours. Tests for electrical conductivity, pH, colour, and turbidity were performed, and the results were analyzed graphically to determine the optimum electrocoagulation time.

2.3.1.2 Optimum Voltage

Using the previously determined optimum electrocoagulation time, electrocoagulation was carried out at 15V and 30V. Samples were collected and analyzed under the same settling and testing conditions to determine the optimum voltage.

2.3.1.3 Optimum Inter-Electrode Distance

Electrocoagulation was performed at 4 cm, 8 cm, and 12 cm inter-electrode distances while keeping the voltage and time constant. Samples were again analyzed for conductivity, pH, colour, and turbidity, and the optimum inter-electrode distance was identified from the graphical results.

2.3.2 Heavy Metal Analysis of Raw and Treated Water

The concentrations of four heavy metals- lead (Pb), cadmium (Cd), chromium (Cr), and zinc (Zn) were tested in both raw water and treated samples obtained under optimum electrocoagulation conditions. Sample preparation was carried out using a water bath, and analysis was performed using Shimadzu AA-6800 FLASS for cadmium and zinc, and Shimadzu AA-6800 GFAAS for chromium and lead. The tests followed standard methods: USEPA 200.9 Rev 2.2 and SM 3111 B for lead and chromium, USEPA 213.2 and SM 3111 B for cadmium, and USEPA 200.9 and SM 3111 B for zinc.

3. RESULTS AND DISCUSSION

3.1 Characteristics of Raw Effluent

The initial properties of the textile wastewater and the standards according to ECR'23 are shown in Table 3-1. No standards were found for electrical conductivity and turbidity. The amount of cadmium present in the sample was below its minimum detection limit of 0.1 mg/l, so the treated sample was not tested further for cadmium. Lead, chromium, zinc, and pH were below the standards of ECR'23. Only pH and colour value exceeded the standard values.

Table 3-1: Properties of Raw Textile Wastewater

Parameter	Initial value	Standards According to ECR'23			
		Maximum Allowable Limit in Textile Industry (Washing, dyeing, Printing)	Inland Surface Water	Public Sewerage System Connected to treatment at second stage	Coastal Area
pH	7.81	6-9	6-9	6-9	6-9
Lead (Pb) (mg/l)	0.021	0.1	0.1	1	2
Cadmium (Cd) (mg/l)	< MDL	0.02	2	1	2
Chromium (Cr) (mg/l)	0.003	0.5	0.5	1	1
Zinc (Zn) (mg/l)	0.26	-	5	15	15
Colour (Pt-Co)	14100	150	-	-	-
EC (µS/cm)	769	-	-	-	-
Turbidity (NTU)	863	-	-	-	-

3.2 Determination of Voltage

Several tests were conducted at different settling times to determine the optimum voltage for electrolysis. The test results are given in Table 3-2.

Table 3-2: Effect of Electrocoagulation and Settling Time on Water Quality

Parameters	15 Volt			30 Volt		
	1 hour settling	2 hours settling	3 hours settling	1 hour settling	2 hours settling	3 hours settling
pH	7.65	7.93	7.9	8.4	8.46	8.38
Electrical Conductivity(µS/cm)	790	783	781	517	211	147
Colour (Pt-Co unit)	281	238	224	25	17	13
Turbidity (NTU)	585	625	427	91.8	35	36.5

The table summarizes the results obtained at different voltages. The initial electrical conductivity of the raw sample was 769 µS/cm. When the test was conducted at 15 volts, the electrical conductivity increased (780-790 µS/cm). In contrast, a significant drop in electrical conductivity was seen at 30 volts, after a 3-hour settling period, with the value decreasing to 147 µS/cm. For colour removal, there was a reduction at both voltages, with a much greater reduction achieved at 30 volts and 3 hours of settling. The best pollutant removal occurred at 30 volts with 3 hours of settling time, resulting in the highest efficiency for both conductivity and colour removal.

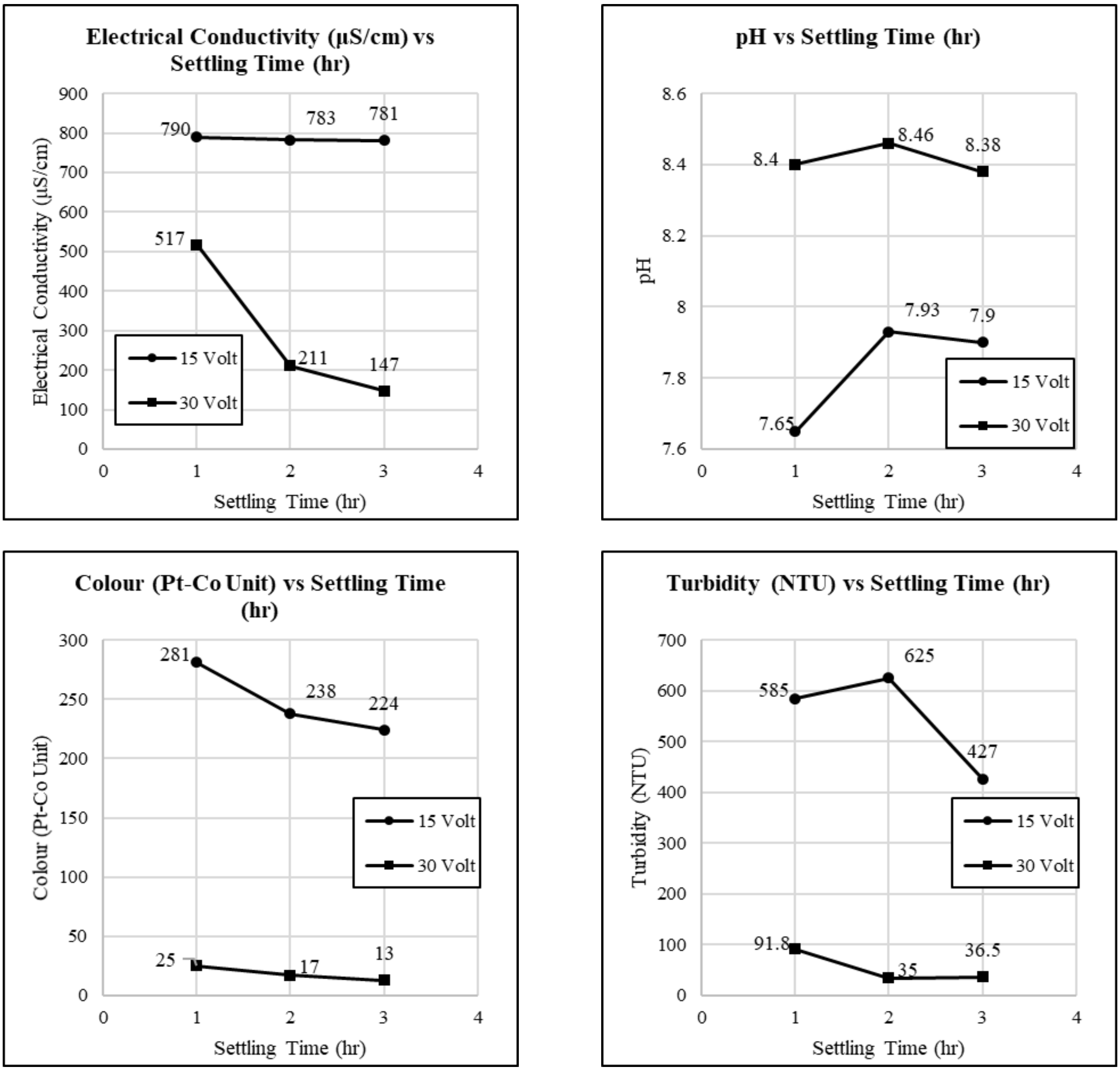


Figure 1: Variation of Parameters with Voltage & Settling Time

The graphs show how different voltages (15V and 30V) affect the removal of key water quality parameters, electrical conductivity, colour, and turbidity over three different settling times: 1 hour, 2 hours, and 3 hours. As the settling time increased, there was a clear reduction in these parameters, with the highest removal seen at 30V. Electrical conductivity dropped from 790 µS/cm to 147 µS/cm after 3 hours of settling at 30V, which is much less than the value obtained at 15V. Similarly, the colour removal rate was much higher at 30V, with a sharp decrease from 238 Pt-Co units to just 13 Pt-Co units. Turbidity followed the same trend, reducing from 434 NTU to 33 NTU at 30V, compared to a smaller decrease at 15V. P^H levels stayed relatively stable with only minor changes at both voltages. Overall, the results suggest that using 30V for 3 hours of settling time provides the best results for reducing these parameters.

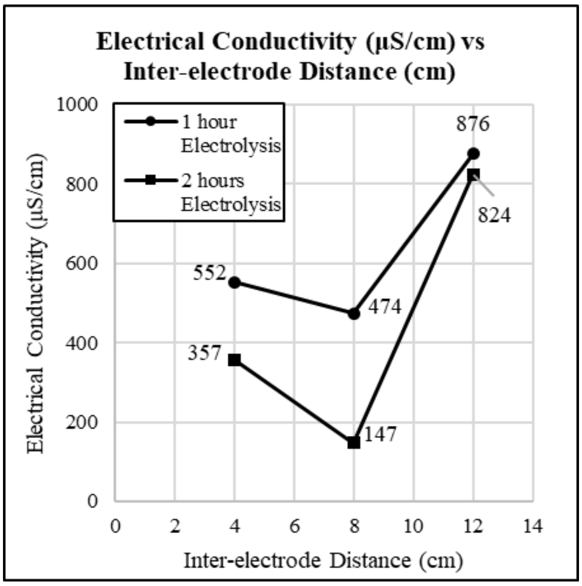
3.3 Optimum Inter-Electrode Distance

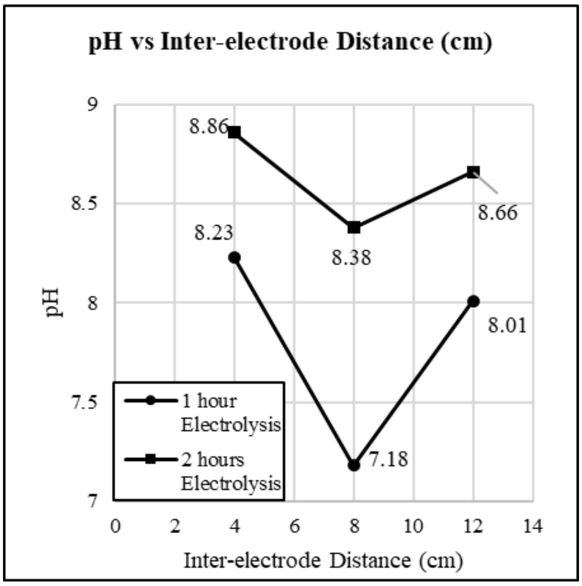
Electrocoagulation was carried out at 30V and three inter-electrode distances (4cm, 8cm,12cm) to determine the optimum inter-electrode spacing. Samples were collected after 1hour and 2 hours of electrolysis. The following test parameters were then tested for the collected samples.

Table 3-3: Parameters for varying Inter-electrode distance

Parameters	Electrocoagulation Time (hr)	4 cm	8 cm	12 cm
Electrical Conductivity (µS/cm)	1	552	474	876
	2	357	147	824
P^H	1	8.23	7.18	8.01
	2	8.86	8.38	8.66
Colour (Pt-Co unit)	1	44	140	105
	2	19	13	45
Turbidity (NTU)	1	81.4	434	566
	2	14.6	36.5	199

Table 3-4 presents the results of varying inter-electrode distances (4 cm, 8 cm, and 12 cm) on the removal of various water quality parameters over different electrocoagulation times (1 and 2 hours). These results are showed in graph below.





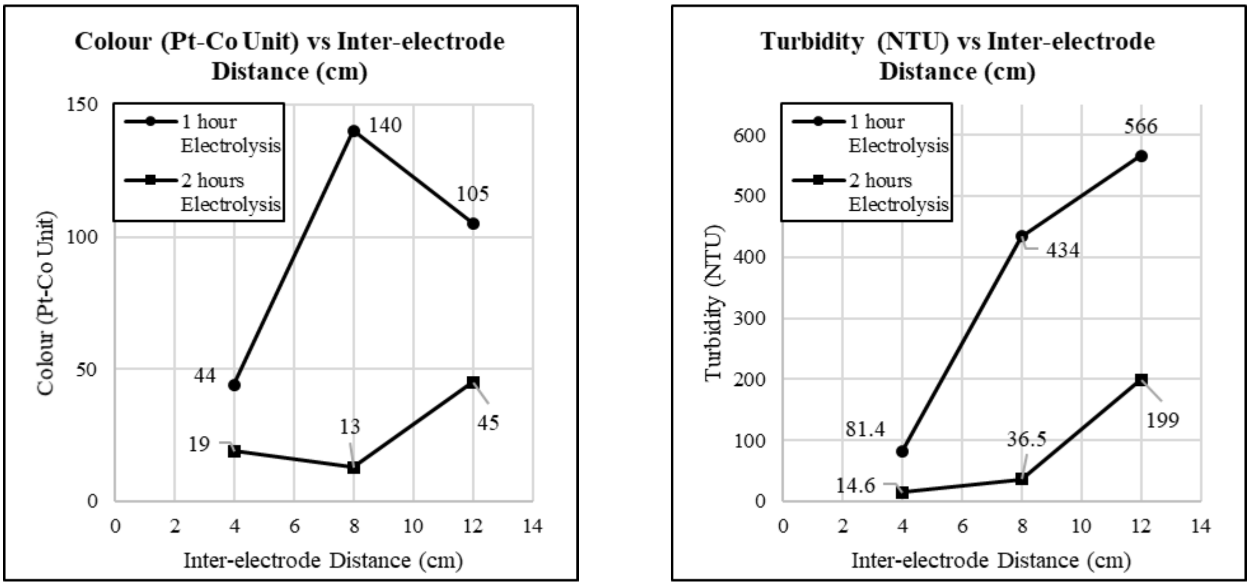


Figure 2: Variation of Parameters with Inter-electrode Distance

The graphs show how water quality parameters changed with different inter-electrode distances and electrocoagulation times. The electrical conductivity decreased with shorter inter-electrode distances. It measured 552 µS/cm at 4 cm, 474 µS/cm at 8 cm, and 876 µS/cm at 12 cm after one hour of electrolysis. After two hours, electrical conductivity further decreased at 4 cm (357 µS/cm) and 8 cm (147 µS/cm) but increased at 12 cm (824 µS/cm). The pH stayed relatively stable across the different distances. It was 8.23 at 4 cm, 7.18 at 8 cm, and 8.01 at 12 cm after one hour of electrolysis, with slightly higher pH values after two hours. The pH of the textile wastewater did not show significant changes during the electrocoagulation process, remaining within a narrow neutral to slightly alkaline range. This stability is due to the simultaneous generation of acidic and alkaline substances during iron electrode dissolution and cathodic hydrogen evolution, which help to buffer the solution. The minimal pH fluctuations are a notable advantage in operations, as they remove the need for extra chemical pH adjustment and help meet discharge standards. Also, stable pH conditions improve the practical use of electrocoagulation as a treatment method that can easily fit into existing effluent treatment plants.

Colour removal was the most efficient at 4 cm, with a decrease from 44 Pt-Co units at 1 hour to 19 Pt-Co units at 2 hours. At 8 cm, colour reduction was moderate (from 19 to 13 Pt-Co units), and at 12 cm, there was a less significant decrease (from 105 to 45 Pt-Co units). Turbidity also decreased with shorter inter-electrode distances, with a reduction from 81.4 NTU at 4 cm to 14.6 NTU after 2 hours, compared to 434 NTU at 8 cm and 566 NTU at 12 cm after 1 hour of electrolysis. After 2 hours of electrolysis, turbidity further decreased to 36.5 NTU at 8 cm and 199 NTU at 12 cm. These results suggest that shorter inter-electrode distances lead to more efficient pollutant removal, especially in terms of electrical conductivity, colour, and turbidity.

3.4 Optimum Time for Electrocoagulation

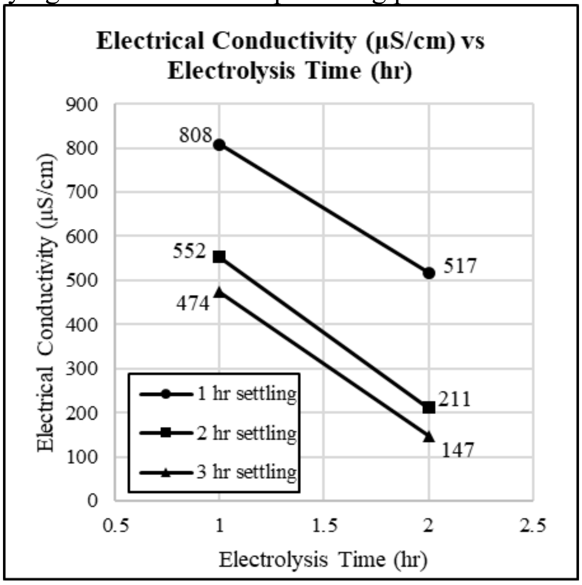
Trial was given at 30 V and 8cm inter-electrode distance to determine the electrocoagulation time. Settling was provided for 1 hour, 2 hour and 3 hours after the process. The values of the parameters (electrical conductivity, pH, turbidity and colour) obtained due to variation of electrocoagulation time and settling time are given in Table 3-4.

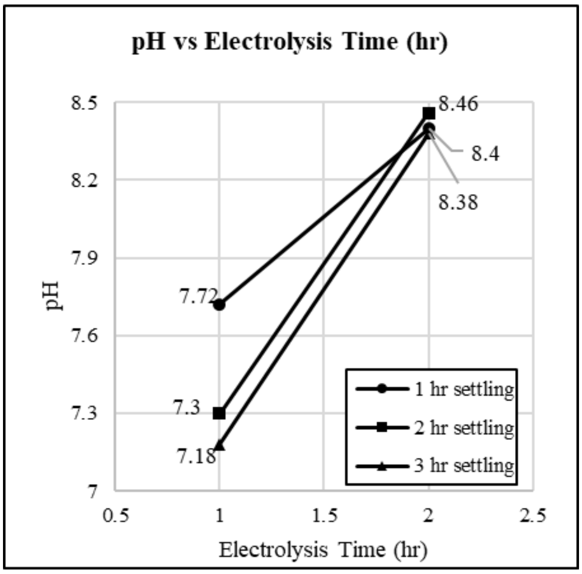
Table 3-4: Effect of Electrocoagulation and Settling Time on Water Quality

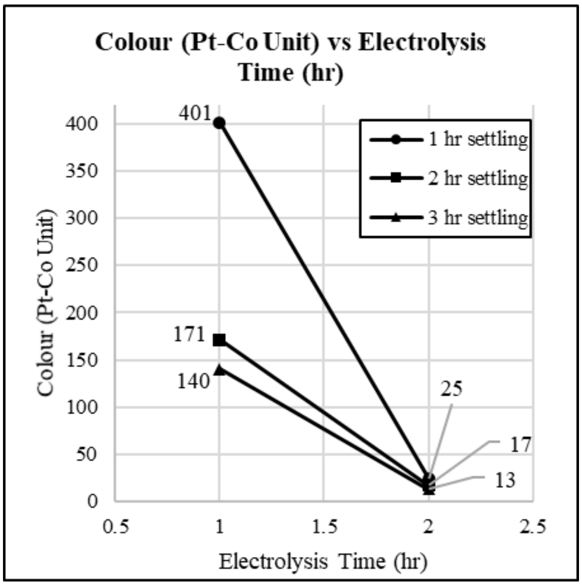
Parameters	Electrocoagulation Time (hr)	1 hour settling	2 hours settling	3 hours settling
Electrical Conductivity	1	808	552	474
	2	517	211	147

(µS/cm)				
P^H	1	7.72	7.3	7.18
	2	8.4	8.46	8.38
Colour (Pt-Co unit)	1	401	171	140
	2	25	17	13
Turbidity (NTU)	1	474	270	434
	2	91.8	35	33

The study focused on optimizing electrocoagulation-based treatment for textile wastewater by examining the effects of electrocoagulation time and settling time on key water quality parameters. Results revealed a significant reduction in electrical conductivity, from 808 µS/cm after 1 hour of electrocoagulation to 474 µS/cm after 3 hours of settling. pH remained relatively stable, varying between 7.72 and 7.18. A notable decrease in colour intensity was observed, from 401 Pt-Co units to 140 Pt-Co units, while turbidity decreased from 474 NTU to 33 NTU. These findings demonstrate the potential of electrocoagulation-based treatment in effectively reducing pollutants such as colour and turbidity in textile wastewater, with process parameters like electrocoagulation and settling times playing a critical role in optimizing pollutant removal.







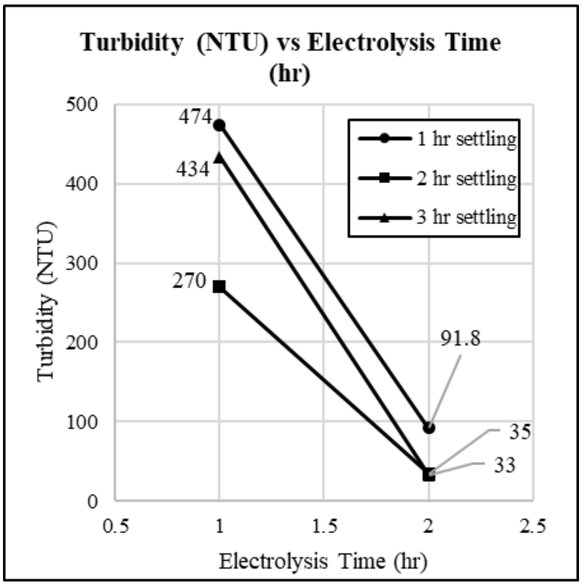


Figure 3: Variation of Parameters with Electrocoagulation Time

The graphs illustrate the effect of electrocoagulation time and settling time on various water quality parameters. As electrocoagulation time increases, electrical conductivity decreases. The most significant drop happens after 3 hours of settling, reaching 147 µS/cm, which indicates better pollutant removal. P^H shows a slight increase over time, and it stabilizes around 8.4 after 2 hours of electrocoagulation and 3 hours of settling. Turbidity and colour (Pt-Co units) decrease substantially with longer electrocoagulation and settling times, with the most noticeable improvements after 3 hours of settling. The combination of 2 hours of electrocoagulation and 3 hours of settling is optimal, as it balances effective pollutant removal without excessive processing, leading to significant improvements in water clarity and quality.

3.5 Optimum Parameters

The most satisfactory results were obtained for electrocoagulation for 2 hours at 30V voltage and 8cm inter-electrode distance. The result summary is given in Table 3-5.

Table 3-5: Optimum Parameters

Parameters	Value
Electrocoagulation Time	2 hours
Voltage	30 V
Inter-Electrode Distance	8 cm

From the previous sections, pH, EC, colour, and turbidity were removed the most while the sample underwent electrocoagulation at optimum conditions. The obtained values are shown in table 3-6.

Table 3-6: Test Parameters at Raw Effluent and Treated Sample

Test parameters	**Raw Effluent Concentration**	**Concentration of treated sample**	**Percent removal**
EC (µS/cm)	769	147	80.88%
pH	7.81	8.38	-
Color (Pt-Co unit)	14100	13	99.9%
Turbidity (NTU)	863	36.5	95.77%

Table 3-6 shows, the concentration of EC (µS/cm), pH, Color (Pt-Co unit), Turbidity (NTU) in the raw wastewater and after treatment and the removal efficiency of the process. Among these four parameters, the highest removal efficiency was observed for color (99.9% in Pt-Co unit). It also removed turbidity and EC almost 95.77% (NTU) and 80.88% (µS/cm) respectively. So, electrocoagulation is also effective in removing turbidity and EC. Though the pH increases, but it remains within the allowable limit (pH 6-9).

3.6 Heavy Metal Analysis

The heavy metal test was done for both the raw wastewater and a treated sample. The sample was treated by electrolyzed using 2 hours of electrocoagulation at 30V and 8cm inter-electrode distances. As the concentration of Cd in raw water was below the MDL, it wasn’t tested for the treated sample. The test results are shown in Table 3-7. Although the measured values were already below the regulatory limit, the process was conducted to evaluate the removal capability of the electrocoagulation process and its potential effectiveness under varying wastewater compositions.

Table 3-7: Heavy Metal Analysis

Parameters	Raw Effluent concentration (mg/L)	Concentration after treatment (mg/L)	Standards for wastewater from industrial units (ECR'97) (mg/L)	Percent Removal
Lead (Pb)	0.021	0.018	0.1	14.28%
Chromium (Cr)	0.003	0.001	0.5	66.67%
Zinc (Zn)	0.26	0.14	5	46.15%

4. CONCLUSIONS

The optimum experimental conditions were determined to be 2 hours of electrocoagulation time at 30V and 8 cm inter-electrode spacing. Under these conditions, the test parameters in the treated sample were reduced to electrical conductivity (EC) of 147 µS/cm, pH of 8.38, color value of 13 Pt-Co units, and turbidity of 36.5 NTU. The percent removal achieved through electrocoagulation under these optimum conditions were 80.88% for electrical conductivity (µS/cm), 99.9% for color (Pt-Co Unit), and 95.77% for turbidity (NTU). Electrocoagulation demonstrated the highest efficiency in removing color, making it the most effective method for color removal. Additionally, electrocoagulation was effective in removing significant amounts of EC and turbidity from textile effluent. The concentrations of heavy metals in the treated sample under optimum conditions were found to be Pb = 0.018 mg/L, Cr = 0.001 mg/L, and Zn = 0.14 mg/L, with percent removals of 14.28% for lead, 66.67% for chromium, and 46.15% for zinc. Overall, electrocoagulation proved to be an effective method for removing significant amounts of Zn, Cr, and Pb from textile effluent.

5. DECLARATION OF USE OF AI

The authors declare that Artificial Intelligence (AI) tools were used during the preparation of this manuscript for language editing, clarity improvement, and formatting assistance. The AI tools were not used to generate original research ideas, data, results, analyses, or conclusions. All scientific content, interpretations, and final decisions remain the sole responsibility of the authors.

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