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Application of Electrocoagulation for the Removal of Color from Institutional Wastewater: Analysis with Response Surface Methodology

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Abstract

The removal percentage of color from institutional wastewater was studied using an electrocoagulation process with different electrode combination at the anode and cathode. This was done by considering operational parameters such as pH at (3, 6 and 9), current at (0.03A, 0.06A and 0.09A) and reaction time at (20, 40 and 60 minutes). When electrode combined in the form of Al-Al (anode-Cathode/Cathode-Anode) and Fe-Fe (anode-Cathode/Cathode-Anode) the percentage removal of color was up to 95.50% and 97.24% respectively. On the other hand around 98.03% and 91.95% of color was removed when Al-Fe (Anode-Cathode) and Fe-Al (Anode-Cathode) combined at pH 9 and 60 minutes of reaction time respectively. Central composite design from response surface methodology was used up to analysis the statistical and mathematical data based on experimental results such as the model was significant for all electrode combinations. Similarly a quadratic model was used for further study of operational effects on the removal (%) of color from institutional wastewater. The value of coefficient of the determination (R^2) also indicated the model was a good fit as well as optimization was done by Response Surface Methodology.

Keywords: Color, Electrocoagulation, Electrode, Institutional wastewater, RSM

1 Introduction

Water is a natural resource that is important for human beings and other creatures to survive on the earth (1–3). However, water scarcity was happening in the world, especially in developing countries due to over population (4–7), urbanization (5,8,9), industrialization (5,7–9), deforestation (5), Agriculture (7,9,10), global climate change that cause global warming (4,5) and also those problems and others cause the formation of wastewater.

Wastewater generated from different sources such as domestic (11–13), commercial (14), institution (15), agriculture (16), industrial (11,17) and etc. that contains different pollutants. Depending on the volume and quantity of wastewater and also the concentration of pollutants in wastewater, receiving environments can affect when directly emitted to an environment without any treatment which indirectly puts the life of animal and human in danger (18). Different researchers indicated there are different metho ds of water and wastewater treatment like; photo catalytic deg radation (19–21), adsorption (2,11,19,22,23), Ion exchange (11), chemical precipitation (11,23), reverse osmosis (11,22), ultrafiltration (11,24), electrocoagulation (22,23,25–28), sedimentation (27), Nano filtration (22,29), filtration (30, 31), electro-flotation (23,32) and etc. Electrocoagulation is a recent technology used for the treatment of water and wastewater by applying electric current to sacrificial electrodes based on the dissolving of cationic metallic species through an electrochemical process (33). It is the combination of electro which means applying an electrical charge to a water and coagulation which means the way of minimizing the colloidal particle surface charge that resulted suspended matter for the formation agglomeration with various electrodes like aluminum, iron, graphite and stainless steel (25). Electrocoagulation is preferable for water and wastewater treatment due to different reasons such as simple for installation (18,34,35), no chemical used up during the process (18,34–36), electron is the only reagent (18), shortest treatment time (18,32,34,35), highest removal efficiency (18,32,36–38), produce less sludge (18,35,36,38,39), reliable and cost (35,37,39,40). In most water and wastewater treatment Aluminum and Iron electrodes are used for electrocoagulation process and there are different chemical reactions taking place at the anode and the cathode which are shown in the equation shown below (41). At Anode reaction for Aluminum:

$$Al_{(s)} \rightarrow Al^{3+} + 3e^- \quad (1)$$

At Cathode reaction for Aluminum

$$3H_2O + 3e^- \rightarrow (\tfrac{3}{2})H_2 + 3OH^- \quad (2)$$

Overall reaction

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$$Al^{3+}_{(aq)} + 3H_2O \rightarrow Al(OH)_3 \downarrow_{(s)} + 3H^+ \quad (3)$$

The cationic monomeric species like Al^{3+} and $Al(OH)_2^+$ are produced due to the electrical dissolution of Aluminum at Anode at low pH such that the values are transferred to $Al(OH)_3$ at appropriate pH and finally polymerized to $AL_n(OH)_{3n}$ that shown in Eq.(4) (41).

$$nAL(OH)_3 \downarrow_{(s)} \rightarrow Al_n(OH)_{3n} \downarrow_{(s)} \quad (4)$$

On the other hand, there are two mechanisms for the production of $Fe(OH)_n$, either n is 2 or 3 based on the oxidation of Iron electrode that indicated below (41,42).

Mechanism 1

At Anode Reaction

$$4Fe_{(s)} \rightarrow 4Fe^{2+}_{(aq)} + 8e^- \quad (5)$$

$$4Fe^{2+}_{(aq)} + 10H_2O + O_{2(g)} \rightarrow 4Fe(OH)_{3(g)} + 8H^+_{(aq)} \quad (6)$$

At Cathode Reaction

$$8H^+_{(aq)} + 8e^- \rightarrow 4H_{2(g)} \quad (7)$$

Overall reaction

$$4Fe_{(s)} + 10H_2O_{(l)} + O_{2(g)} \rightarrow 4Fe(OH)_{3(g)} + 4H_{2(g)} \quad (8)$$

Mechanism 2

At Anode Reaction

$$Fe_{(s)} \rightarrow Fe^{2+}_{(aq)} + 2e^- \quad (9)$$

$$Fe^{2+}_{(aq)} + 2OH^- \rightarrow Fe(OH)_{2(s)} \quad (10)$$

At Cathode Reaction

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^- \quad (11)$$

Overall Reaction

$$Fe_{(s)} + 2H_2O_{(l)} \rightarrow Fe(OH)_{2(s)} + H_{2(g)} \quad (12)$$

Recent studies are indicating electrocoagulation technology was used in different wastewater treatment area such as Health institution (15,43), slaughter house (24,44,45), automobile service stations (25) and etc. After experimental investigation, optimizations of analytical processes are done by applying multivariate statistical techniques called Response Surface methodology (RSM) (15). The main objective of Response surface methodology was to determine the optimum conditions of different variables to predict the targeted responses (46). It works based on the input or independent variables and the output or responses after the design of experiments; RSM was applied according to the central composite design to determine optimum conditions of variables (46).

In this study the removal percentage of wastewater Color was evaluated that generated from the Jimma University Institute of technology by using electrocoagulation under the operational parameters such as pH, current and reaction time. This was done for Al-Al, Fe-Fe, Al-Fe and Fe-Al and also the statistical and mathematical analysis was evaluated with Response Surface Methodology.

2 Materials and methods

2.1 Materials

The sample was collected from Wastewater generated from the Jimma University Institute of technology and experimental investigation was conducted at the Jimma University Institute of technology, Environmental engineering Laboratory. So during Color removal percentage evaluation, different materials were used such as DC power supply, Electrocoagulation cell, electrodes (Aluminum and Iron), magnetic stirrer, magnetic bar stirrer, electrical clips, copper wires and spectrophotometer.

2.2 Experimental setup of electrocoagulation

An electrocoagulation experiment conducted was a batch mode where a removal percentage was evaluated at different time intervals. As shown in Fig. 1, an experimental setup of electrocoagulation was performed where two parallel electrodes either Aluminum or Iron was immersed into a batch beaker of 1.5L holding capacity. The electrodes are connected in the form of Al-Al (Anode-Cathode/Cathode-Anode), Fe-Fe (Anode-Cathode/Cathode-Anode), Al-Fe (Anode-Cathode) and Fe-Al (Anode-Cathode) that connected to a DC power supply by using copper wires before immersed into a batch beaker. Since pH was one operational parameter considered in this study, sodium hydroxide or sulfuric acid was used to adjust the pH of the wastewater sample. The surface area of both electrodes was the same and after each experimental run, electrodes are cleaned by hydrochloric acid and followed by distilled water. Magnetic stirrer bar was placed inside an electrocoagulation cell in order to obtain a uniform concentration of a sample. A power supply was turned on for DC power and magnetic stirrer after all operational parameters are adjusted.

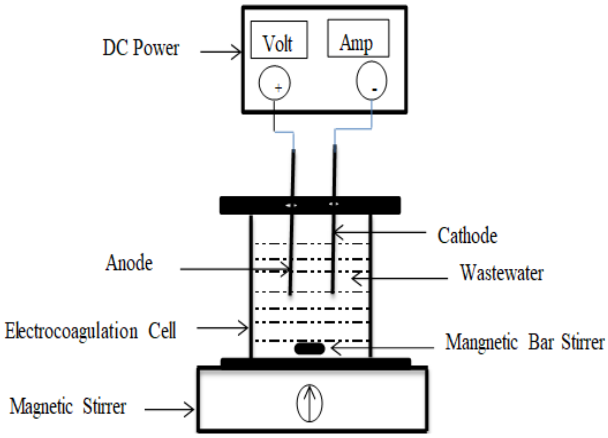


Figure 1: Schematic setup of electrocoagulation

2.3 Experimental Design with RSM

Experimental parameter for color removal was studied for by using the electrocoagulation process for the treatment of institutional wastewater (i.e. on the wastewater generated from the Jimma University Institute of Technology). The mathematical and statistical analysis was done by Central Composite design (CCD) for three operating parameters. Design of Expert software (Version 11) was used for optimization and effect of those variables on the removal percentage of color. All variables are coded from -1 to +1 such that pH (X_1), Current (X_2) and Reaction time (X_3) that ranges from 3 - 9, 0.03 - 0.09A and 20 - 60 minutes respectively. The levels and variables of an experimental design were shown in Table 1. Based on the Central Composite Design for three variables, eighteen experiments were performed, including replications from center points.

Table 1: Experimental Design for variables with CCD

Variables	Units	Factors	Levels		
			-1	0	+1
pH		X_1	3	6	9
Current	Ampere (A)	X_2	0.03	0.06	0.09
Reaction Time	minutes	X_3	20	40	60

2.4 Analysis

Based on experimental results spectrophotometer was used to determine the absorbance of institutional wastewater treatment that empirically calculated using Eq. (13) shown below (23,26,34) and also based on the response surface methodology was used up for analyzing and evaluating statistical and mathematical based on experimental data as an input.

$$\text{Percentage removal of Color} = \frac{\text{Abs}_\text{i} - \text{Abs}_\text{f}}{\text{Abs}_\text{i}} * 100 \qquad (13)$$

where, Abs_i and Abs_f are initial and final absorbance of a solution respectively.

3 Results and discussion

3.1 Decolorization of Wastewater

3.1.1 Decolorization using Al-Al Combination

During experimental investigation Aluminum electrode is combined in the form of Al-Al (Anode-Cathode/Cathode-Anode) to evaluate the removal percentage of color on institutional wastewater which shown in Table 2. When the pH is 3 and current is 0.03A and also when the pH is 6 and current is 0.06A, color removed up to 61.54% and 69.5% at the reaction time of 60 minutes respectively. The maximum removal efficiency of color was observed when the pH is 9 and current is 0.09A at the reaction time of 60 minutes that is 95.50%. On the other hand, keeping the pH to 3 and increasing the electric current to 0.006A, Decolorization of an effluent was relatively increased.

Similarly, the removal percentage of color from an effluent was 42.25, 57.10 and 74.34% when the pH is 6 and current is 0.09A at the reaction time of 20, 40 and 60 minutes respectively. When the pH is 9 and electric current is 0.03A, Decolorization of an effluent was up to 65% at the reaction time of 60 minutes. So using Al-Al (Anode-Cathode/Cathode-Anode) is somewhat a good combination to remove a color from wastewater.

3.1.2 Decolonization using Fe-Fe Combination

When an electrode is combined in the form of Fe-Fe (Anode-Cathode/Cathode-Anode) different percentage of color removal was registered at different pH, current and reaction time that shown in Table 2. When the pH is 3 and current is 0.03A as well as when the pH is 6 and current is 0.06A, the removal percentage of an effluent was up to 78.87 and 81.88% in 60 minutes respectively. Similarly, when the pH is 3 and current 0.06A and also when the pH is 9 and current is 0.09A, Decolorization was increased with the reaction time such that 81.80 and 87.52% respectively. Using this electrode combination around 97.24% of color was removed from wastewater when the pH is 9 and 0.09A. On the other hand around 38.47, 59.90 and 75.86% of color was removed from an effluent when the pH of a wastewater is adjusted to 9 and electric current is 0.03A at 20, 40 and 60 minutes respectively. Hence, depending on the results this combination is an effective for Decolorization especially at high pH, current and reaction time.

3.1.3 Decolorization using Al-Fe Combination

This is another combination that considered evaluating the removal percentage of color from institutional wastewater. At different pH values and current the removal percentage of color from an effluent was varied at different reaction time. Based on this when the pH is 3 and the current is 0.03A and 0.06A, Decolorization of an effluent were 48.48, 61.21, 73.94% and 52.08, 67 and 78.54% at the reaction time of 20, 40 and 60 minutes respectively which shown in Table 2. When the pH was increased to 6 and the current was 0.06A and 0.09A, the removal percentage of color was up to 89.33 % and 92.40% at the reaction time of 60 minutes respectively. But the maximum removal efficiency was registered when the pH is 9 and an electric current was 0.09A at the reaction time of 60 minutes. At this level around 98.03% of color was removed from an effluent. Similarly, around 50.70%, 64.67% and 79.23% of color was removed just keeping the pH to 9 and reducing the current to 0.09A at the reaction time of 20, 40 and 60 minutes respectively. Hence this indicates that Al-Fe (Anode-Cathode) combination is an effective way to remove color from an effluent.

3.1.4 Decolorization using Fe-Al Combination

When Fe-Al (anode-Cathode) was combined the removal efficiency of color was evaluated with the operating parameters, such as pH, current and reaction time that shown in Table 2. Keeping the pH to 3 and when an electric current was 0.03A and 0.06A, Decolorization was up to 42.86% and 55% at the reaction time of one hour respectively. This indicates the removal percentage was increased by increasing the current. On the other hand, when the pH is 6 and varying the current to 0.06A and 0.09A, 48.29%, 65%, 83.57% and 54.32%, 70.45% and 88.64% color was removed respectively at the reaction time of 20, 40 and 60 minutes. Around 91.95% was removed when the pH was 9 and an electric current was 0.09A and also keeping the pH to 9 and by reducing an electric current to 0.03A, Decolorization of an effluent was 25.88%, 31.50% and 52.12% at the reaction time of 20, 40 and 60 minutes respectively.

Generally, when pH was 3 and current was 0.03A, Al-Fe (Anode-Cathode) was at best on the removal of color especially on the 20 and 40 minutes of reaction time. However, at 60 minutes of reaction time Fe-Fe (Anode-Cathode/Cathode-Anode) was a good combination that removed up to 78.87%. Similarly, when the pH was 6 and 9 and also current was 0.06A and 0.09A, Al-Fe (Anode-Cathode) was the best combination to others on the removal percentage. When the pH was 3 and 6 as well as also the current was 0.06A and 0.09A, Fe-Fe and Al-Fe combinations are relatively the best relative to another. Again, when pH 9 and an electric current was 0.03A, Al-Fe was an effective compared to others.

3.2 Design of expert Software for the evaluation of experimental results

The removal percentage of color was determined based on the operating parameters such as pH (X_1), Current (X_2) and Reaction time (X_3). Design of expert was used and the quadratic regression equation obtained from Al-Al, Fe-Fe, Al-Fe and Fe-Al that is given in Eq. (14-17) respectively.

$$\text{Color Removal (\%)} = +50.20 + 8.93X_1 + 9.38X_2 + 17.94X_3 + 7.74X_1X_2 - 0.2403X_1X_3 - 1.61X_2X_3 + 3.103.10X_1^2 - 3.82X_2^2 + 3.20X_3^2 \quad (14)$$

$$\text{Color Removal (\%)} = +61.94 + 3.18X_1 + 3.99X_2 + 12.64X_3 + 2.43X_1X_2 - 0.7187X_1X_3 + 2.20X_2X_3 + 0.3906X_1^2 - 0.1594X_2^2 - 1.28X_3^2 \quad (15)$$

$$\text{Color Removal (\%)} = +78.53 + 5.77X_1 + 5.83X_2 + 13.50X_3 + 3.94X_1X_2 + 0.6150X_1X_3 - 0.2150X_2X_3 - 5.69X_1^2 - 2.77X_2^2 - 1.80X_3^2 \quad (16)$$

$$\text{Color Removal (\%)} = = +62.99 + 12.92X_1 + 11.64X_2 + 13.57X_3 + 10.54X_1X_2 - 0.2040X_1X_3 + 1.29X_2X_3 - 13.74X_1^2 - 6.12X_2^2 + 3.95X_3^2 \quad (17)$$

This coded equation or that explained in terms of coded are needed to do the predictions about the response for given levels of each factor and comparing the factor coefficients for identifying the relative impact of the factors. Central composite Design from Design of Expert (11), analyzed the sequential model sum of squares and model summary statistics for different models such as linear, interactive, quadratic and cubic to get a good regression model. The expected results were indicated in Table 3, 4, 5 and 6 for the color removal using Al-Al, Fe-Fe, Al-Fe and Fe-Al electrode combination respectively. In Table 3, 5 and 6 the values of the coefficient of determination (R^2), Adjusted R^2 and Predicted R^2 were the highest in Quadratic model, but in Table 4, the two interaction model (2FI) exhibited the highest R^2, adjusted R^2 and predicted R^2 compared to other models. On the other hand the cubic model is aliased, which indicates for further investigation the model is not appropriate and not enough experiments have been run to estimate independently in all terms of the model. According to the sequential model of squares indicated the P-values lower than 0.0022 for Al-Al (Quadratic, two factorial interaction and linear models), 0.0105 for Fe-Fe (Linear and two factorial interaction models), 0.0008 for Al-Fe (Quadratic and Linear models), and 0.0016 for Fe-Al (Quadratic and Linear models) could be for further investigation that shown in Table 3, 4, 5 and 6 respectively. Hence this indicates Quadratic models was chosen for further study and describe the effects operational parameters on the Application of Electrocoagulation for the removal of Color from Institutional wastewater.

3.2.1 Adequacy of the model on Color Removal

ANOVA (Analysis of Variance) was used to test the adequacy and the significance of the model. As shown in Table 7, 8, 9 and 10 a very low P-value (< 0.0001) was produced by the F-test of the regression models which indicating high significance of all models. On the other hand coefficient of determination (R^2) and Adjusted R^2 were greater than 89% and 87% respectively as shown in Table 3, 4, 5 and 6. This was a high significance of Color removal from institutional wastewater with the application of electrocoagulation. It was clearly observed that the percentage removal of color with the linear coefficients of pH (X_1), Current (X_2) and Reaction time (X_3), interaction of pH (X_1) with Current(X_2) and interaction of current (X_2) with reaction time (X_3) were the significant operational factors at P-value less than 0.05 for Al-Al and Fe-Fe, electrode combination that were shown in Table 7 and 8 respectively.

Table 2: Experimental design matrix by CCD and responses based on actual and predicted values on Color removal (%) for different electrode combinations

Run	X_1 pH	X_2 Current (A)	X_3 Reaction time (minutes)	Color Removal (%), Al-Al		Color Removal (%), Fe-Fe		Color Removal (%), Al-Fe		Color Removal (%), Fe-Al	
				Actual	Predicted	Actual	Predicted	Actual	Predicted	Actual	Predicted
1	3	0.03	20	23.10	22.32	33.10	34.99	48.48	47.52	23.81	20.57
2	3	0.03	40	38.48	38.91	57.75	57.43	61.21	62.41	28.57	29.12
3	3	0.03	60	61.54	61.89	78.87	77.30	73.94	73.71	42.86	45.55
4	6	0.06	20	37.50	35.46	39.38	38.02	61.33	63.24	48.29	53.37
5	6	0.06	40	50.00	50.20	62.00	61.94	81.33	78.53	65.00	62.99
6	6	0.06	60	69.50	71.34	81.88	83.30	89.33	90.23	83.57	80.51
7	9	0.09	20	62.50	62.65	43.50	46.36	70.15	69.92	71.10	67.52
8	9	0.09	40	75.00	75.54	72.00	71.77	85.07	85.62	79.52	78.23
9	9	0.09	60	95.50	94.82	97.24	94.62	98.03	97.71	91.95	96.82
10	3	0.06	20	27.30	29.39	35.10	34.51	52.08	52.39	27.90	26.51
11	3	0.06	40	45.20	44.37	58.00	59.15	67.00	67.07	34.00	36.34
12	3	0.06	60	67.00	65.74	81.80	81.24	78.54	78.16	55.00	54.06
13	6	0.09	20	42.25	42.64	41.90	39.65	66.78	66.51	54.32	57.60
14	6	0.09	40	57.10	55.77	65.34	65.77	82.00	81.59	70.45	68.51
15	6	0.09	60	74.34	75.29	87.52	89.34	92.40	93.08	88.64	87.31
16	9	0.03	20	25.00	25.20	38.47	37.93	50.70	49.94	25.88	25.74
17	9	0.03	40	40.30	41.30	59.90	58.93	64.67	66.07	31.50	33.87
18	9	0.03	60	65.00	63.80	75.86	77.37	79.23	78.59	52.12	49.90

Table 3: sequential model sum of squares and statistical model summary for Color Removal (%) Using Al-Al

Sequential Model Sum of Squares

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Mean vs Total	50839.04	1	50839.04			
Linear vs Mean	6163.67	3	2054.56	56.39	< 0.0001	
2FI vs Linear	389.91	3	129.97	11.89	0.0009	
Quadratic vs 2FI	99.02	3	33.01	12.46	0.0022	Suggested
Cubic vs Quadratic	19.57	5	3.91	7.24	0.0670	Aliased
Residual	1.62	3	0.5405			
Total	57512.82	18	3195.16			

Model Summary Statistics

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	6.04	0.9236	0.9072	0.8649	901.30	
2FI	3.31	0.9820	0.9722	0.9442	372.14	
Quadratic	1.63	0.9968	0.9933	0.9826	115.91	Suggested
Cubic	0.7352	0.9998	0.9986	0.9717	189.11	Aliased

Table 4: sequential model sum of squares and statistical model summary for Color Removal (%) Using Fe-Fe

Sequential Model Sum of Squares

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Mean vs Total	68401.91	1	68401.91			
Linear vs Mean	6551.44	3	2183.81	247.76	< 0.0001	
2FI vs Linear	77.20	3	25.73	6.13	0.0105	Suggested
Quadratic vs 2FI	6.99	3	2.33	0.4754	0.7081	
Cubic vs Quadratic	38.44	5	7.69	29.60	0.0093	Aliased
Residual	0.7791	3	0.2597			
Total	75076.75	18	4170.93			

Model Summary Statistics

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	2.97	0.9815	0.9776	0.9638	241.53	
2FI	2.05	0.9931	0.9893	0.9669	221.20	Suggested
Quadratic	2.21	0.9941	0.9875	0.9564	290.69	
Cubic	0.5096	0.9999	0.9993	0.9895	69.80	Aliased

Table 5: sequential model sum of squares and statistical model summary for Color Removal (%) Using Al-Fe

Sequential Model Sum of Squares

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Mean vs Total	94217.06	1	94217.06			
Linear vs Mean	3436.19	3	1145.40	102.98	< 0.0001	
2FI vs Linear	14.52	3	4.84	0.3769	0.7715	
Quadratic vs 2FI	122.18	3	40.73	17.13	0.0008	Suggested
Cubic vs Quadratic	4.40	5	0.8795	0.1804	0.9522	Aliased
Residual	14.63	3	4.88			
Total	97808.97	18	5433.83			

Model Summary Statistics

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	3.34	0.9566	0.9474	0.9396	216.95	
2FI	3.58	0.9607	0.9392	0.9267	263.45	
Quadratic	1.54	0.9947	0.9887	0.9762	85.46	Suggested
Cubic	2.21	0.9959	0.9769	0.8608	499.86	Aliased

Table 6: sequential model sum of squares and statistical model summary for Color Removal (%) Using Fe-Al

Sequential Model Sum of Squares						
Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Mean vs Total	52756.18	1	52756.18			
Linear vs Mean	7998.53	3	2666.18	39.35	< 0.0001	
2FI vs Linear	140.06	3	46.69	0.6352	0.6077	
Quadratic vs 2FI	677.92	3	225.97	13.84	0.0016	Suggested
Cubic vs Quadratic	113.53	5	22.71	3.99	0.1420	Aliased
Residual	17.07	3	5.69			
Total	61703.30	18	3427.96			
Model Summary Statistics						
Source	**Std. Dev.**	**R^2**	**Adjusted R^2**	**Predicted R^2**	**PRESS**	
Linear	8.23	0.8940	0.8713	0.8406	1426.42	
2FI	8.57	0.9096	0.8603	0.8276	1542.35	
Quadratic	4.04	0.9854	0.9690	0.9109	797.51	Suggested
Cubic	2.39	0.9981	0.9892	0.8662	1197.18	Aliased

Table 7: ANOVA for the adequacy of the model using Al-Al

Source	Sum of Squares	df	Mean Square	F-value	p-value	Remarks
Model	6652.59	9	739.18	279.11	< 0.0001	Highly significant
X_1-pH	478.83	1	478.83	180.80	< 0.0001	Highly significant
X_2-Current	527.91	1	527.91	199.33	< 0.0001	Highly significant
X_3- Reaction Time	3860.33	1	3860.33	1457.63	< 0.0001	Highly significant
X_1X_2	269.35	1	269.35	101.71	< 0.0001	Highly significant
X_1X_3	0.4332	1	0.4332	0.1636	0.6965	
X_2X_3	19.41	1	19.41	7.33	0.0268	significant
X_1^2	24.71	1	24.71	9.33	0.0157	significant
X_2^2	37.46	1	37.46	14.14	0.0055	significant
X_3^2	40.90	1	40.90	15.44	0.0044	significant
Residual	21.19	8	2.65			
Cor Total	6673.78	17				

Table 8: ANOVA for the adequacy of the model using Fe-Fe

Source	Sum of Squares	df	Mean Square	F-value	p-value	Remarks
Model	6635.63	9	737.29	150.41	< 0.0001	Highly significant
X_1-pH	60.57	1	60.57	12.36	0.0079	Significant
X_2-Current	95.65	1	95.65	19.51	0.0022	Significant
X_3- Reaction Time	6152.65	1	6152.65	1255.15	< 0.0001	Highly Significant
X_1X_2	26.47	1	26.47	5.40	0.0486	Significant
X_1X_3	3.87	1	3.87	0.7902	0.4000	
X_2X_3	36.45	1	36.45	7.44	0.0260	Significant
X_1^2	0.3922	1	0.3922	0.0800	0.7845	
X_2^2	0.0654	1	0.0654	0.0133	0.9109	
X_3^2	6.55	1	6.55	1.34	0.2809	
Residual	39.22	8	4.90			
Cor Total	6674.84	17				

Table 9: ANOVA for the adequacy of the model using Al-Fe

Source	Sum of Squares	df	Mean Square	F-value	p-value	Remarks
Model	3572.88	9	396.99	166.93	< 0.0001	Highly significant
X_1-pH	199.72	1	199.72	83.98	< 0.0001	Highly significant
X_2-Current	204.21	1	204.21	85.87	< 0.0001	Highly significant
X_3- Reaction Time	2185.65	1	2185.65	919.07	< 0.0001	Highly significant
X_1X_2	69.90	1	69.90	29.39	0.0006	Significant
X_1X_3	2.84	1	2.84	1.19	0.3066	
X_2X_3	0.3467	1	0.3467	0.1458	0.7125	
X_1^2	83.17	1	83.17	34.97	0.0004	Significant
X_2^2	19.74	1	19.74	8.30	0.0205	Significant
X_3^2	12.92	1	12.92	5.43	0.0481	Significant
Residual	19.02	8	2.38			
Cor Total	3591.91	17				

Table 10: ANOVA for the adequacy of the model using Fe-Al

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	8816.51	9	979.61	60.01	< 0.0001	Highly significant
X_1-pH	1001.04	1	1001.04	61.32	< 0.0001	Highly significant
X_2-Current	812.70	1	812.70	49.78	0.0001	Highly significant
X_3- Reaction Time	2209.74	1	2209.74	135.36	< 0.0001	Highly significant
X_1X_2	499.91	1	499.91	30.62	0.0006	Significant
X_1X_3	0.3121	1	0.3121	0.0191	0.8934	
X_2X_3	12.40	1	12.40	0.7598	0.4088	
X_1^2	485.22	1	485.22	29.72	0.0006	Significant
X_2^2	96.36	1	96.36	5.90	0.0412	Significant
X_3^2	62.30	1	62.30	3.82	0.0865	
Residual	130.60	8	16.33			
Cor Total	8947.11	17				

Also, the linear coefficients of pH (X_1), Current (X_2) and Reaction time (X_3) and interaction of pH (X_1) with Current(X_2) were the significant operational factors at P-value less than 0.05 for Al-Fe and Fe-Al electrode combination that were shown in Table 9 and 10 respectively. Experiments (Actual) and Predicted values are shown in Table 2 for all electrode combinations and in addition to this, the relationship between Actual and predicted values are indicated in Fig. 2 (a), (b), (c) and (d). In this case all the data or points are closed or arranged towards the diagonal line which shows as the predicted data are matched to an actual (experimental values). Hence, for all electrode combinations the regression of Coefficient of Determination (R^2) for quadratic equation was a good fit for removal of color.

3.2.2 Effects of combined operating parameters on Color Removal

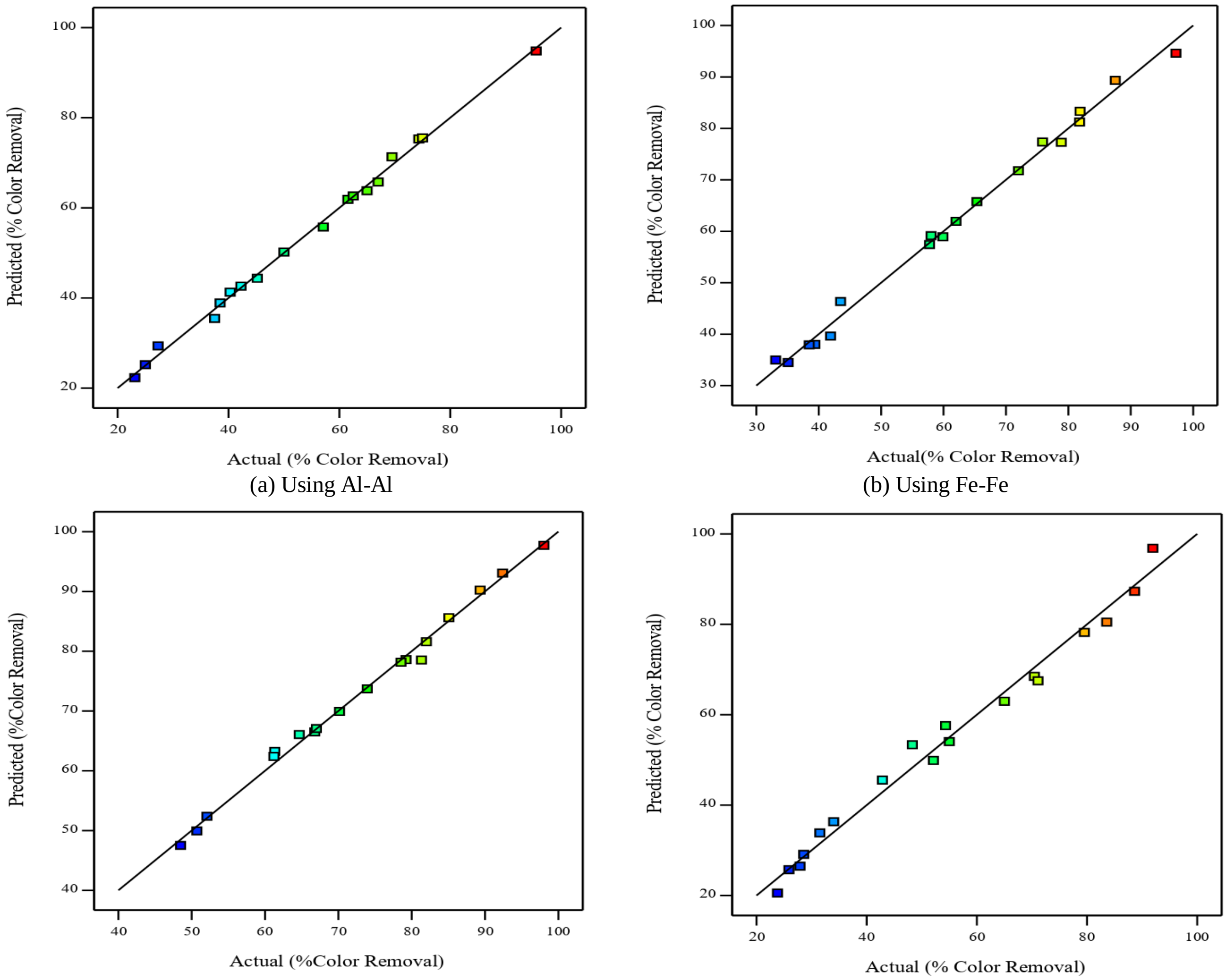
Different operating parameters are considered by central Composite Design from response surface Methodology such as pH with current, pH with reaction time and current with reaction time and their effects on the removal percentage of Color.

3.2.2.1 Current with pH

During experimental study pH and electric current applied were operational factors that influence the removal percentage color using electrocoagulation process. As shown in Fig. 3 (a), (b), (c) and (d) the three dimensional response was observed on the removal of color. In all figures the removal percentage of color was increased as the pH increases from 3-9 and electric current increases from 0.03A-0.09A. In all electrode combination the highest removal percentage of color was observed when the solution was in basic condition. This was due to high concentration of hydroxide ions (OH^-) formed because of water reduced at the cathode that related to the increasing of pH (47).

3.2.3 Optimization

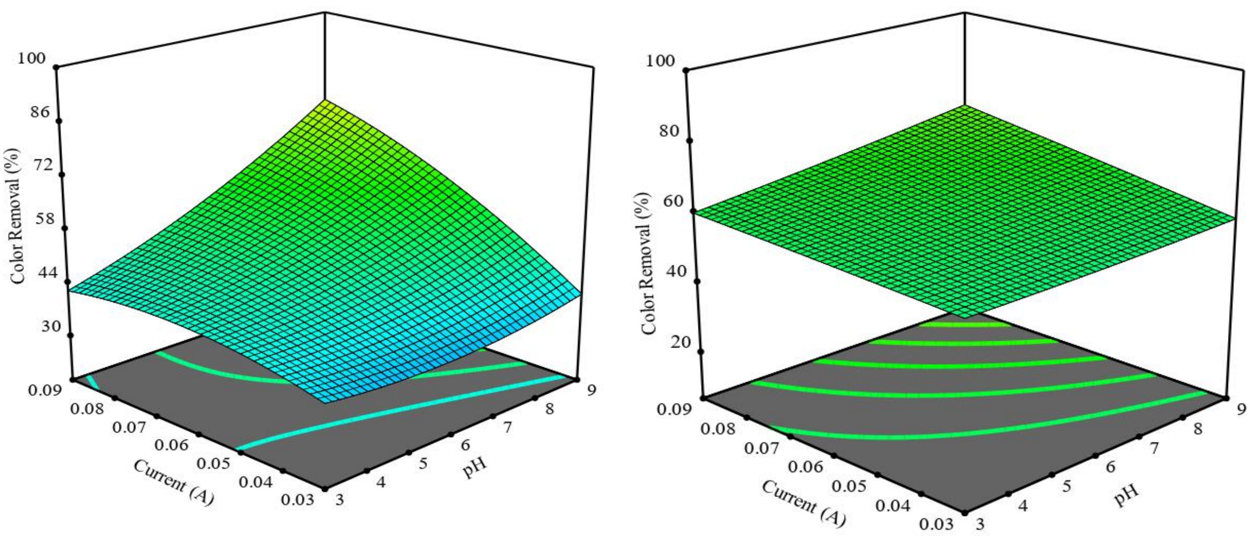
The other crucial study part of this investigation is to get an optimum conditions on the removal percentage of color from institutional wastewater through the application of electrocoagulation by considering different operational factors and that was implemented Central Composite Design from Response Surface Methodology. During the optimization process operational factors such as pH (X_1), Current (X_2) and Reaction time (X_3) were selected in a range and removal percentage of color was maximized. The optimum values were obtained for color removal (%) using Al-Al, Fe-Fe, Al-Fe and Fe-Al that was shown in Table 11.



(a) Using Al-Al (b) Using Fe-Fe

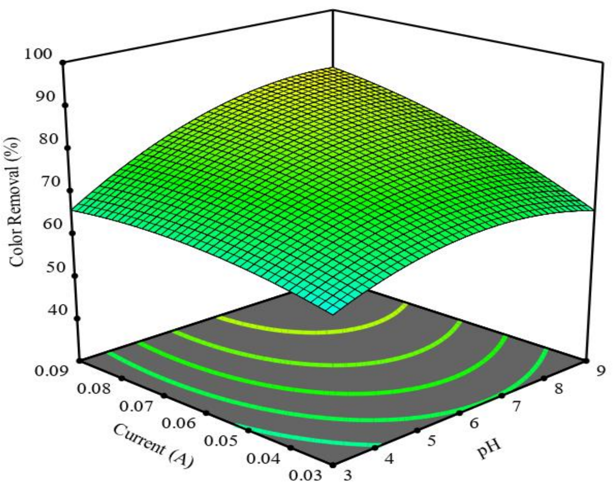
(c) Using Al-Fe (d) Using Fe-Al

Figure 2: Relationship between Actual and Predicted values for % of color removal using (a) Al-Al, (b) Fe-Fe, (c) Al-Fe and (d) Fe-Al

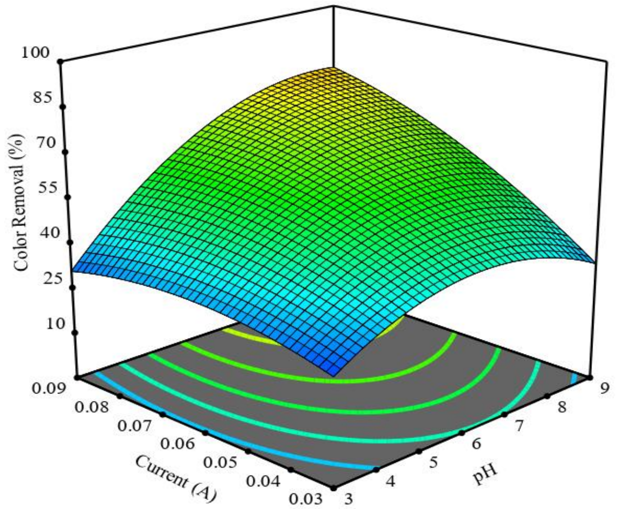


(a) Using Al-Al (b) Using Fe-Fe

Figure 3a: 3D surface plot on the interaction of current and pH for the removal of Color (a) Using Al-Al, (b) Using Fe-Fe, (c) Using Al-Fe and (d) Using Fe-Al



(c) Using Al-Fe



(d) Using Fe-Al

Figure 3b: 3D surface plot on the interaction of current and pH for the removal of Color (a) Using Al-Al, (b) Using Fe-Fe, (c) Using Al-Fe and (d) Using Fe-Al

Table 11: Optimum conditions for Color Removal (%) using CCD design

Number	pH	Current	Reaction Time	Color Removal	Desirability	Form of Electrode Combination	Remark
1	9.000	0.090	60.000	94.819	0.991	Al-Al	Selected
2	9.000	0.090	60.000	94.616	0.959	Fe-Fe	selected
3	8.726	0.090	60.000	97.762	0.995	Al-Fe	Selected
4	7.980	0.083	57.916	92.203	1.000	Fe-Al	Selected

4 Conclusion

Electrocoagulation is a good technology used for the treatment of institutional wastewater like wastewater discharged from the higher educational center. Evaluation of decolorization from university wastewater studied by application of electrocoagulation by considering factors such as pH, current and reaction time for an electrode combination of Aluminum and iron at the anode and cathode. Experimental results indicated color removal was somewhat an effective for all combinations of Aluminum and Iron within one hour reaction time. Statistical and mathematical data were analyzed by Central Composite Design. The significance of the model, operational factors and the interaction of each operational factor was made by CCD from RSM. In addition to this Central Composite Design was implemented that checked the validity and adequacy of the model as well as optimization was done for all electrode combinations.

Ethical issue

Authors are aware of, and comply with, best practice in publication ethics specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests and compliance with policies on research ethics. Authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language.

Competing interests

There is no conflict of interest.

Authors' contribution

I am a sole author of this paper and I have a contribution for data collection, data analyses and manuscript writing.

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