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Research article

Development of electrocoagulation process for wastewater treatment: optimization by response surface methodology

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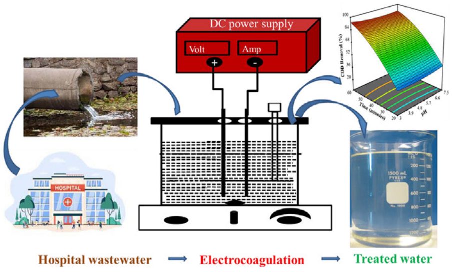
HIGHLIGHTS

- EC effective technology used to treat wastewater generated from hospital.
- Al was used as an electrode for hospital wastewater treatment using EC process.
- EC can eliminate pollutants from wastewater under various operating parameters.
- CCD used to optimize operational parameters for treatment of hospital wastewater.

GRAPHICAL ABSTRACT



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ABSTRACT

Electrocoagulation (EC) is a process used by supply of electric current with sacrificial electrodes for the removal of pollutant from wastewater. The study was experimentally investigated taking into account various factors such as pH (3–7.5), current (0.03–0.09 A), distance between the electrodes (1–2 cm), electrolytic concentration (1–3 g/L), and electrolysis time (20–60 min) which is impact on the % removal efficiency of color, chemical oxygen demand (COD), turbidity and determination of energy consumption used for aluminum (Al) electrode used. The surface response design process based on the central composite design (CCD) has been used to optimize different operational parameters for treatment of hospital wastewater using EC process. The % color, COD and turbidity removal, and energy consumption under different conditions were predicted with the aid of a quadratic model, as were the significance and their interaction with independent variables assessed by analysis of variance (ANOVA). The optimal conditions were obtained through mathematical and statistical methods to reach maximum % color, COD, and turbidity removal with minimum energy consumption. The results showed that the maximum removal of color (92.30%), COD (95.28%), and turbidity (83.33%) were achieved at pH–7.5, current–0.09A, electrolytic concentration–3g/L, distance between electrodes–2 cm and reaction time 60 min. This means that, the process of EC can remove pollutants from various types of wastewaters and industrial effluent under the various operating parameters.

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1. Introduction

Wastewater generated from various sources like agricultural [1, 2], industrial [3, 4, 5, 6], commercial [7, 8, 9], the institution [6, 10], and domestic [11, 12] with different contents of pollutants that affect the natural condition of the environment [6, 11]. Rendering to [6, 13] hospital is an institution that needs a huge quantity of water and abstemiously releases wastewater to an environment that contains toxic pollutants such as metal oxides, hazardous liquid waste from various units, radioactive waste, bacteria, viruses, blood, fluids, different concentration of chemical oxygen demand (COD) and biochemical oxygen demand (BOD) that affects environments in different aspects [14, 15]. A number of technologies are functional to minimize effects of hospital wastewater generated such as ion-exchange [16], adsorption [6, 17, 18, 19], coagulation-flocculation [6, 18], electro-dialysis [20], chemical oxidation [6, 21], reverse osmosis [19, 22, 23], filtration [24], ultrafiltration [23, 25, 26, 27] and activated sludge [21, 28, 29, 30, 31], etc., Based on the fundamentals of wastewater treatment techniques, their advantages and disadvantages are summarized in Table 1.

Electrocoagulation (EC) is an electrochemical process for the treatment of wastewater using an electric current without adding chemicals where tiny particles are removed in wastewater [32, 33, 34]. In addition to that, EC was progressive and highly adopted due to low initial cost installation and maintenance, a small amount of sludge production after treatment with a short period of settling time, and good removal efficiency of pollutant [35, 36]. The stainless steel (SS), aluminum (Al), and iron (Fe) are types of electrodes used in the EC process for the treatment of wastewater [37, 38].

In this investigation, Al was used as an electrode and the mechanism of EC process is given in the following Eqs. (1), (2), and (3). Metallic ions were produced from the EC process by electrochemically in the coagulants of hydroxide flocs formed which absorbs the precipitates of suspended particles and dissolved pollutants [39].

The electrochemical reaction involved in the reactor for anode and cathode when Al was used [40];

$$\text{Anodic reaction:} \quad Al \rightarrow Al^{3+} + 3e^{-} \tag{1}$$

$$\text{Cathodic reaction:} \quad 3H_2O + 3e^{-} \rightarrow 3/2H_2 + 3OH^{-} \tag{2}$$

$$\text{Overall reaction:} \quad Al^{3+} + 3OH^{-} \rightarrow Al(OH)_3 \tag{3}$$

In the above overall reaction, aluminum hydroxide $Al(OH)_3$ formed was used as a coagulant which forms flocs and absorbs dissolved and suspended pollutants of precipitates.

1.1. Response Surface Methodology

Design of Experiment (DoE) represents a collection of valuable mathematical techniques for statistical modeling and systematic analysis of the issue by using variables or factors for optimizing the desired responses or measurements of output [41, 42]. One of the frequent of DoE for model building is Response Surface Methodology (RSM), a key consecutive technology for original process, improving the design and formulation of new products and maximizing their performance [41, 43] and RSM is a common empirical statistic method used to set mathematical models, optimize multi-factor tests, and explore relationships between the response and explanatory variable [44]. The RSM main advantage over the conservative time-consuming approach to one variable at a time is the small number of experimental processes required, including simultaneous interaction of variables and modeling of the selected response parameters for a faster and more systematic examination of its parameters [41].

Table 1. Advantages and disadvantages of several wastewater treatment technologies.

Treatment Process	Advantages	Disadvantages
Anodic oxidation	Treatment of large volumes wastewater. Very large % removal of pollutant. No pH restrictions.	Attention to halogenated by-products. Electrode fouling. Expensive, high O_2 over potential anodes.
Photo	Slow but large % removal of pollutant.	High cost of UV lamps usage.
Photo-Electro-Fenton	Small bias potential required. Very large % removal of pollutant. No need of separation filtration after the treatment.	Attention to halogenated by-products High cost of UV lamps usage. Particular reactor configuration with photoactive anodes and quartz glass.
Electro-Fenton	The on-site production of H_2O_2. The continuous regeneration of Fe^{2+} on the cathode. The low iron sludge production.	Low H_2O_2 yield. Low current density. Low conductivity.
Electrocoagulation	It is a moderately fast treatment process. Can be treated large volumes and higher organic loadings. Particles electroflotation by H_2 bubbles. Very good removal efficiency of ionic and colloidal matter. Electrode cost is relatively low. Operation is probable to run in continual mode.	The sludge is produced during operation. The electrode is dissolved and replacement needed. Can separate only contaminants
Adsorption	High pharmaceutical contaminants removal is achieved. Lower energy consumption, simple operating conditions, fewer sludge production.	Making low operating cost and effective process is a challenge. Recycling and residue management are a serious concern
Ozonation	Excellent pharmaceutical removal Effectiveness. Oxidant assisting disinfection, sterilization properties. Organic contaminants can be removed Efficiently.	High depletion of energy, oxidative by-products production. Radical scavenger is disrupted. Little employment in pharmaceutical contaminants removal.
Ion exchange	Very useful and efficient method of water softening. No perforation of substances into the soft water. Most of the heavy metals can be reused. Wastewater that is produced by ion exchange machines is also used for water treatment.	The acidity level in the water can be increased for sodium ions entrance into the softened water which may make the water not very safe for use. The machines used to soften the water are known as Iron exchangers which must be cleaned for high saturation level. The process require high operational cost
Membrane filtration	Greater quantity can be treated. Finest removal efficiency of salts and organic matter. Moderately quick	Membrane cost is relatively high. Problems like membrane fouling occurred. Only can contribute to the separation of contaminants Operation work is possible in batch mode

Table 2. Characteristics of wastewater.

No	Parameters	Quantity	Unit
1	pH	7.8	_
2	Color (Absorbance)	λ	_
3	Turbidity	375	NTU
4	COD	448	mg/L
5	TSS	121	mg/L
6	TDS	512	mg/L
7	TS	633	mg/L
	λ = 2.95		

Table 3. Coded and actual values of the variables of the design of experiments for the electrocoagulation process.

Variables	Unit	Factors	Levels		
			-1	0	+1
pH	-	A	3	6	7.5
Current	A	B	0.03	0.06	0.09
Electrolytic concentration	g/L	C	1	2	3
Distance between electrodes	cm	D	1	1.5	2
Reaction time	min	E	20	40	60

According to [45] the Box–Behnken Design (BBD) and the Central Composite Design (CCD) are the two common design types of RSM that allow a reasonable amount of information for testing lack of fit statistically which needed for consecutive experiments. According to [46] BBD is used aimed at designing all quantitative numerical values varied over three levels and [47] elucidated CCD was used when the lower experiment was investigated. The CCD was used to examine the impacts of the factors on their responses and in optimization studies subsequently as well as this technique is appropriate for the installation of the quadratic surface and improves the viable parameters by a minimum number of experimentations [48].

Utmost of the previous research work focused by using synthetic solutions on the removal of pollutants by using the EC process and there was limited work using real wastewater. Also, most of the work focused on pollutant removal efficiency from wastewater. In the EC process, energy consumption is a significant parameter from the economic point of view. Therefore, the present study focused on the determination of energy consumption for the removal of % COD, color and turbidity from hospital wastewater using an EC process.

Intended for electrocoagulation process, several parameters were chosen to optimize statistically through RSM. In this study, operating parameters of the EC process like pH (A), current (B), electrolytic concentration (C), distance between electrodes (D), and reaction time (E) were optimized by CCD through RSM. The main objective of the optimization is to maximize the removal of % color, COD, turbidity and minimize consumption of energy with the minimum of reaction time from hospital wastewater. The DoE Software (11) was used to optimize the effect of the designated operating variables on the efficacy of wastewater treatment and the study combined effect of CCD analyses using the statistical analysis of the selected variables.

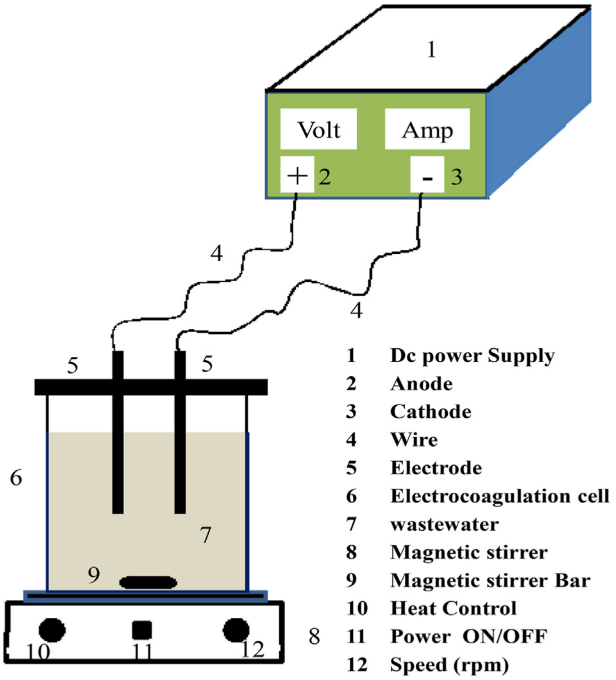

Figure 1. Experimental setup of electrocoagulation process.

2. Materials and methods

2.1. Characterization of wastewater

Wastewater was collected from the Jimma University (JU) specialized hospital, Jimma, Ethiopia and it was characterized for pH, color, COD, turbidity, TSS and TDS, and the results are given in the Table 2.

2.2. Reagents

Types of reagents were used in this study, particularly for determining the COD. Among these reagents such as $K_2Cr_2O_7$, H_2SO_4, and NaOH to adjust pH, $AgSO_4$ and $HgSO_4$ to produce CO_2 and H_2O, ferrous ammonium sulphate, Ferroin as an indicator, and distilled water.

2.3. Experimental procedures

An experimental setup of EC was shown in the Figure 1. The process was a batch that was performed with 1000 mL of wastewater in EC cell. The Al electrode is used up in the EC process with a dimension of 5.3 × 10 × 0.1 cm, respectively. The anode and cathode were positioned vertically and parallel to each other with an interelectrode distance of varied from 1 to 2 cm. The copper wires were connected to a direct current (DC) power source at one end and to the electrodes by electrical clips on the other end. Then, the anticipated current was applied to anode and cathode submerged in the solution. The current and cell voltage were measured periodically using a multimeter. The solution was continuously stirred using a magnetic stirrer at a constant speed. The pH of the wastewater was measured using pH meter and it was adjusted using a 0.1 N NaOH and H_2SO_4 solution. With required experimental conditions, the samples were collected from EC reactor and filtered using Whatmann 42 filter paper. The color, COD and turbidity were determined to examine the behavior of EC process for treatment of wastewater. The electrode plates were cleaned physically by washing with distilled water prior to every run, and owing to their sacrificial nature and also, they were replaced after every two runs. The % color, COD and turbidity removal efficiency, and energy consumption of the EC reactor were investigated under various conditions such as pH, current, electrolytic concentration, distance between electrodes and reaction time, respectively.

2.4. Design of experiment for optimization

A CCD was executed for five independent variables and DoE is used to minimize the number of runs and needed to combine various independent variables. The parameters chosen are pH (A), electric current (B), electrolytic concentration (C), distance between electrodes (D), and the reaction time (E). The coded and actual values of variables are showed in Table 3 and an experimental design matrix resulting from CCD was

Table 4. Removal percentage and energy consumption with actual versus predicted values.

Run	A	B	C	D	E	Color removal, (%)		Turbidity removal, (%)		COD removal, (%)		Energy consumption (kWhr/m^3)	
	-	A	g/L	cm	min	Actual Value	Predicted Value	Actual Value	Predicted Value	Actual Value	Predicted Value	Actual Value	Predicted Value
1	7.5	0.03	2	1.5	60	85.71	81.90	70.00	67.16	91.70	89.39	8.00	7.86
2	6	0.03	2	1.5	60	79.31	78.01	66.67	61.47	90.44	85.89	7.00	7.21
3	7.5	0.06	3	2	20	33.33	31.38	33.33	33.54	35.27	31.78	16.00	16.85
4	6	0.06	2	1.5	60	85.20	79.62	63.63	66.24	94.10	90.22	18.00	16.90
5	3	0.03	1	1	20	25	20.20	18.20	16.31	27.50	24.54	9.00	8.91
6	3	0.06	2	1.5	60	83.30	76.61	66.70	65.42	93.90	93.53	14.00	13.91
7	3	0.03	2	1.5	40	46.40	45.52	40.00	43.25	65.20	64.77	6.00	6.45
8	6	0.09	3	2	20	48.28	43.78	30.00	31.89	35.85	36.05	33.00	34.03
9	3	0.09	3	2	40	86.40	65.33	75.00	66.06	94.80	78.21	27.00	29.04
10	7.5	0.06	3	2	40	54.17	56.73	66.67	67.06	67.19	68.61	16.00	16.86
11	6	0.09	3	2	40	62.10	66.76	70.00	66.89	73.58	74.90	33.00	33.65
12	7.5	0.03	2	1.5	40	53.57	55.28	50.00	57.11	69.00	72.19	8.00	6.78
13	7.5	0.06	2	1.5	40	56.14	59.24	60.00	59.46	76.00	72.95	18.00	18.11
14	7.5	0.09	3	2	40	69.23	69.28	75.00	70.55	77.00	76.02	39.00	36.53
15	6	0.09	3	2	60	89.66	93.82	80.00	82.31	95.28	97.70	33.00	34.09
16	3	0.03	2	1.5	60	75	73.83	60.00	56.58	89.10	84.45	6.00	7.05
17	7.5	0.03	2	1.5	20	30.36	32.74	30.00	27.49	35.50	38.95	7.00	6.52
18	7.5	0.06	2	1.5	20	35.08	39.63	30.00	29.45	35.25	38.51	18.00	18.07
19	6	0.03	2	1.5	20	27.59	27.72	22.22	19.60	33.12	33.80	7.00	6.18
20	6	0.06	2	1.5	20	31.50	35.19	27.27	23.59	33.55	35.73	16.00	16.33
21	6	0.06	3	2	20	30.77	27.71	27.27	26.76	32.14	27.46	16.00	15.54
22	6	0.03	2	1.5	40	47.78	50.82	44.44	50.33	66.18	67.87	7.00	6.29
23	6	0.06	3	2	60	84.62	83.61	71.73	76.40	85.00	86.71	16.00	16.06
24	6	0.03	1	1	40	49.15	45.54	50.00	50.92	54.70	57.89	10.00	9.43
25	3	0.06	3	2	40	49.20	51.03	60.00	56.48	60.85	63.67	14.00	13.60
26	7.5	0.06	3	2	60	85.42	86.15	83.33	81.00	89.96	89.38	16.00	17.68
27	3	0.03	1	1	40	42.50	38.70	45.50	45.72	61.80	57.88	9.00	8.72
28	7.5	0.03	1	1	40	51.85	50.77	57.14	56.78	58.15	60.67	10.00	10.36
29	7.5	0.06	2	1.5	60	87.71	82.93	70.00	69.90	95.25	91.35	18.00	18.96
30	3	0.09	3	2	20	31.81	41.21	25.00	28.87	32.76	37.71	33.00	29.74
31	6	0.03	1	1	20	27.12	28.18	25.00	23.70	30.42	26.20	9.00	9.30
32	3	0.06	2	1.5	20	27.10	29.92	16.70	18.39	30.30	35.72	14.00	13.98
33	3	0.06	2	1.5	40	50	51.23	50.00	51.69	70.30	72.65	14.00	13.54
34	7.5	0.03	1	1	60	70.37	71.65	64.29	63.32	74.77	75.49	11.00	11.47
35	3	0.03	2	1.5	20	21.4	21.29	10.00	10.33	26.10	29.04	5.00	6.66
36	7.5	0.09	3	2	60	92.30	95.77	83.33	84.88	95.10	98.00	39.00	37.13
37	3	0.06	3	2	20	25.40	23.99	20.00	19.67	28.93	24.37	14.00	14.07
38	3	0.09	3	2	40	54.50	65.33	62.50	66.06	72.40	78.21	27.00	29.04
39	6	0.06	3	2	40	53.85	53.62	63.64	61.37	62.46	65.11	16.00	15.39
40	7.5	0.03	1	1	20	35.19	33.97	28.57	30.65	32.92	29.81	10.00	10.07
41	6	0.06	2	1.5	40	53.70	55.37	54.54	54.70	73.00	71.00	16.00	16.20
42	3	0.03	1	1	60	50	61.27	54.50	55.56	70.70	75.18	10.00	9.35
43	6	0.03	1	1	60	66.10	66.99	58.33	58.57	70.23	73.53	10.00	10.38
44	3	0.06	3	2	60	79.60	82.15	70.00	73.70	82.21	86.93	16.00	13.95
45	7.5	0.09	3	2	20	53.85	46.86	33.33	36.64	38.03	38.00	36.00	36.75

Table 5. Sequential model sum of squares and summary statistics for % COD removal.

Sequential Model Sum of Squares

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Mean vs Total	1.752E+05	1	1.752E+05			
Linear vs Mean	22757.41	4	5689.35	96.97	<0.0001	Aliased
2FI vs Linear	939.33	7	134.19	3.15	0.0117	Aliased
Residual	1407.44	33	42.65			
Total	2.003E+05	45	4451.60			

Model Summary Statistics

Source	**Std. Dev.**	**R^2**	**Adjusted R^2**	**Predicted R^2**	**PRESS**	
Linear	7.66	0.9065	0.8972	0.8802	3006.76	Aliased
2FI	6.53	0.9439	0.9252	0.8903	2753.21	Aliased

Table 6. ANOVA of quadratic model for % color removal.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	19356.51	13	1488.96	39.18	<0.0001	Highly Significant
A-pH	286.83	1	286.83	7.55	0.0099	Significant
B-Current	104.15	1	104.15	2.74	0.1079	
C-Electrolytic Concentration	148.32	1	148.32	3.90	0.0572	
D-Distance Between Electrodes	0.0000	0				
E-Electrolysis Time	8088.05	1	8088.05	212.83	<0.0001	Highly Significant
AB	4.97	1	4.97	0.1307	0.7201	
AC	8.92	1	8.92	0.2347	0.6315	
AD	0.0000	0				
AE	13.53	1	13.53	0.3560	0.5550	
BC	164.52	1	164.52	4.33	0.0458	Significant
BD	0.0000	0				
BE	50.78	1	50.78	1.34	0.2565	
CD	218.63	1	218.63	5.75	0.0227	Significant
CE	210.41	1	210.41	5.54	0.0251	Significant
DE	0.0000	0				
A^2	13.95	1	13.95	0.3671	0.5490	
B^2	0.0000	0				
C^2	0.0000	0				
D^2	0.0000	0				
E^2	41.52	1	41.52	1.09	0.3040	
Residual	1178.06	31	38.00			
Lack of Fit	669.25	30	22.31	0.0438	1.0000	
Pure Error	508.81	1	508.81			
Cor Total	20534.57	44				

revealed in Tables 3 and 4 and it consists of 45 coded conditions for Al–Al electrode combination.

In Table 3, actual values are the original values that are given to different factors, and the coded values are also given for the levels of factors by default or they may be adjusted. In this case, the actual and coded factors are all variables and A, B, C, D, and E, respectively.

2.5. Removal analysis

Data processing and analysis were done through the laboratory based on the sample obtained from the selected place and optimized using RSM.

The removal percentage of COD [45, 49, 50, 51], color, and turbidity [52] were determined according to the formula given in Eqs. (4), (5), and (6) for each parameter.

$$\text{COD removal}, (\%) = \left(\frac{\text{COD}_o - \text{COD}_t}{\text{COD}_o}\right) \times 100 \tag{4}$$

Where, COD_o and COD_t are the chemical oxygen demand at time = 0 (initial) and at t (reaction time, t) respectively.

$$\text{Color removal}, (\%) = \left(\frac{A_o - A_t}{A_o}\right) \times 100 \tag{5}$$

Where, A_0 and A_t are Absorbance registered at time t = 0 (initial) and at t (reaction time), respectively.

$$\text{Turbidity removal}, (\%) = \left(\frac{C_o - C_t}{C_o}\right) \times 100 \tag{6}$$

Where, C_0 and C_t are turbidity registered (in NTU) at time t = 0 (initial) and at t (reaction time), respectively.

2.6. Determination of energy consumption

In the electrochemical process determining the energy consumption (kWh/m^3) is required in which contains the different parameters [51].

$$E = \frac{VIt}{V_R} \tag{7}$$

Where, *V, I*, and *t*, stand for average cell voltage of the electrochemical system (V), electrical current intensity (I), and reaction time (t), respectively, and V_R is a volume of wastewater used.

Table 7. ANOVA of quadratic model for % COD removal.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	24380.69	13	1875.44	80.36	<0.0001	Highly Significant
A-pH	0.4070	1	0.4070	0.0174	0.8958	
B-Current	83.23	1	83.23	3.57	0.0684	
C-Electrolytic Concentration	75.42	1	75.42	3.23	0.0820	
D-Distance Between Electrodes	0.0000	0				
E-Electrolysis Time	12228.82	1	12228.82	523.98	<0.0001	Highly Significant
AB	82.69	1	82.69	3.54	0.0692	
AC	35.69	1	35.69	1.53	0.2255	
AD	0.0000	0				
AE	28.96	1	28.96	1.24	0.2738	
BC	98.78	1	98.78	4.23	0.0481	Significant
BD	0.0000	0				
BE	8.53	1	8.53	0.3657	0.5498	
CD	454.79	1	454.79	19.49	0.0001	Highly Significant
CE	36.20	1	36.20	1.55	0.2223	
DE	0.0000	0				
A^2	33.01	1	33.01	1.41	0.2433	
B^2	0.0000	0				
C^2	0.0000	0				
D^2	0.0000	0				
E^2	643.26	1	643.26	27.56	<0.0001	Highly Significant
Residual	723.49	31	23.34			
Lack of Fit	472.61	30	15.75	0.0628	0.9996	
Pure Error	250.88	1	250.88			
Cor Total	25104.18	44				

Table 8. ANOVA of quadratic model for % turbidity removal.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	18093.95	13	1391.84	103.89	<0.0001	Highly Significant
A-pH	269.71	1	269.71	20.13	<0.0001	Highly Significant
B-Current	129.89	1	129.89	9.70	0.0040	Significant
C-Electrolytic Concentration	35.00	1	35.00	2.61	0.1162	
D-Distance Between Electrodes	0.0000	0				
E-Electrolysis Time	7645.12	1	7645.12	570.67	<0.0001	Highly Significant
AB	60.61	1	60.61	4.52	0.0415	Significant
AC	13.17	1	13.17	0.9828	0.3292	
AD	0.0000	0				
AE	50.90	1	50.90	3.80	0.0604	
BC	2.91	1	2.91	0.2176	0.6442	
BD	0.0000	0				
BE	0.9015	1	0.9015	0.0673	0.7970	
CD	33.52	1	33.52	2.50	0.1239	
CE	78.27	1	78.27	5.84	0.0217	Significant
DE	0.0000	0				
A^2	45.17	1	45.17	3.37	0.0759	
B^2	0.0000	0				
C^2	0.0000	0				
D^2	0.0000	0				
E^2	957.03	1	957.03	71.44	<0.0001	Highly Significant
Residual	415.30	31	13.40			
Lack of Fit	337.17	30	11.24	0.1439	0.9869	
Pure Error	78.13	1	78.13			
Cor Total	18509.25	44				

Table 9. ANOVA of quadratic model for energy consumption.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	3959.97	13	304.61	181.50	<0.0001	Highly Significant
A-pH	93.20	1	93.20	55.53	<0.0001	Highly Significant
B-Current	378.42	1	378.42	225.47	<0.0001	Highly Significant
C-Electrolytic Concentration	20.74	1	20.74	12.36	0.0014	Significant
D-Distance Between Electrodes	0.0000	0				
E-Electrolysis Time	0.6681	1	0.6681	0.3981	0.5327	
AB	29.24	1	29.24	17.42	0.0002	Significant
AC	2.85	1	2.85	1.70	0.2021	
AD	0.0000	0				
AE	1.07	1	1.07	0.6361	0.4312	
BC	155.16	1	155.16	92.45	<0.0001	Highly Significant
BD	0.0000	0				
BE	0.3146	1	0.3146	0.1875	0.6680	
CD	32.41	1	32.41	19.31	0.0001	Highly Significant
CE	0.0042	1	0.0042	0.0025	0.9603	
DE	0.0000	0				
A^2	1.39	1	1.39	0.8300	0.3693	
B^2	0.0000	0				
C^2	0.0000	0				
D^2	0.0000	0				
E^2	1.66	1	1.66	0.9896	0.3275	
Residual	52.03	31	1.68			
Lack of Fit	52.03	30	1.73			
Pure Error	0.0000	1	0.0000			
Cor Total	4012.00	44				

3. Results and discussion

3.1. Removal efficiency of color, COD, turbidity and energy consumption

The removal efficiency of % color, COD, and turbidity, with an energy consumption were shown in Table 4, which is based on the Al–Al electrode combination with its respective predicted values from RSM. In Table 4, column 1, 2, 3, 4, 5, and shows that, the number of runs or experiments, indicates pH value, electric current (A), electrolytic concentration (g/L), distance between electrodes (cm), and electrolysis time (minute), respectively and it was performed in the laboratory. The NaCl was used as an electrolytic concentration to facilitate the removal of color, turbidity, and COD from wastewater. The rest columns represent the actual results of percentage of color, turbidity, COD, and energy consumption (kWhr/m^3) from the laboratory and the predicted value determined by RSM.

In addition to that, the Table 4, factors such as pH, electric current, electrolyte concentration, distance between electrodes, and reaction time were considered with different ranges which applied for Al–Al electrode combination. Similarly, the removal efficiency for color, turbidity, COD, and energy consumption was determined by considering all factors. The EC method is sound recognized to be tremendously dependent on the pH of the wastewater at the beginning. The production of metallic hydroxides is influenced by pH of the aqueous solution, and the initial pH of the wastewater has an influence on EC performance [53].

As showed in Table 4 increasing the pH of the initial wastewater, the removals efficiency was increased. The EC process is significantly influenced by the current intensity. Because of anodic dissolution in accordance with Faraday's law, the removal efficiency was increased as the current intensity was increased, as well as at higher current values [54]. The effect of applied current on examined reactions is especially important since the rate at which electro-coagulants and gas bubbles are released has a significant impact on the rate at which flocs develop [55]. Because, it regulates the quantity of Al and Fe ions discharged from electrodes, as well as the release of gas bubbles, and the creation of flocs it should be considered in any EC method for wastewater treatment [55]. As the electric current was increased from 0.03 to 0.09A, the removal of % COD, color and turbidity were increased which were shown in Table 4.

Th sodium chloride was chosen as a supporting electrolytic because of its inexpensive cost and availability. The electrolytic concentration of wastewater in an electrochemical process has a significant impact on the removal efficiency of pollutant for the wastewater treatment process [56]. When it comes to treating strong wastewater, using a highly conducting solution with a supporting electrolyte has several advantages such as avoiding migration effects, increasing solution conductivity, lowering electrode resistance, lowering energy consumption, and increasing process efficiency [57]. The electrolytic concentration it has a considerable impact on the kinetic electro-dissolution of the sacrificial anodes, as well as the protective layer of the double coagulant and the flocs' shape [57]. Table 4 shows that, there is an increment of removal efficiency of color, COD and turbidity from wastewater whereas the electrolytic concentration was increased. The formation of adequate quantities of various ions from electrodes which are required for the generation of adsorbents such as $Al(OH)_3$ in the case of Al electrodes. The discharging of gases bubbles from both electrodes, which are essentially provided with more assistance to carry the destabilized pollutants toward the surface of the solution it is dependent on electrolysis time [55].

The quantity of Fe and Al released from electrodes is directly influenced by electrolysis time, in which turn the effects amount of Fe and Al released from the anode and determined the COD, color, and turbidity removal efficiency [58]. The movement of the ions will be faster as the distance between the two electrodes reduces due to the shorter travel

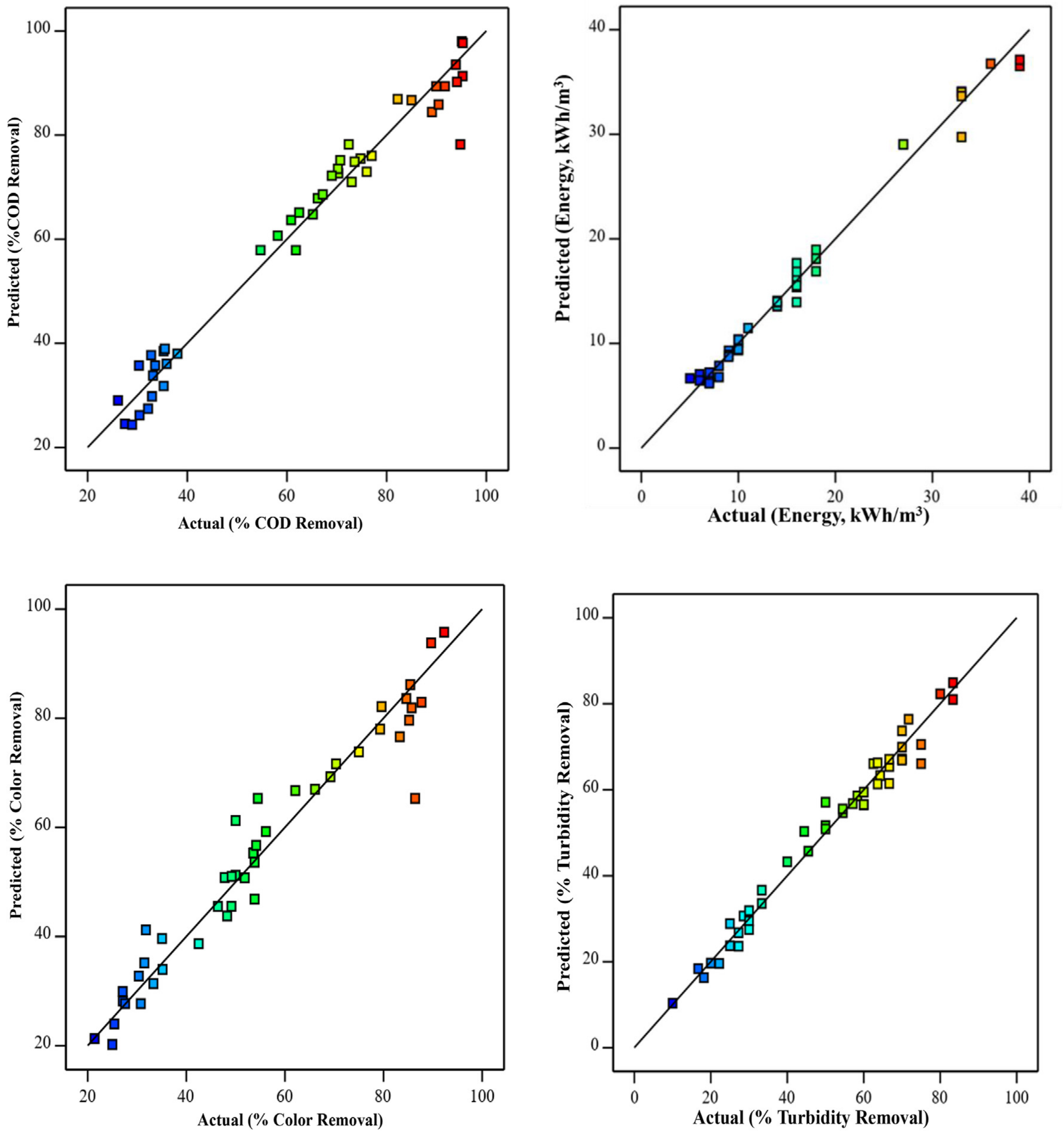

Figure 2. Actual versus Predicted values for % color and % turbidity and, % COD removal and energy consumption.

path, and the ions will have a better chance of colliding and producing $^{\bullet}$OH [59]. Table 4 expands, it has high removal efficiency of COD, color, and turbidity in both electrode combinations while electrolysis time increased from 20 to 60 min. Also, when the distance between two electrodes was decreased, the formation of hypochlorite rises due to lower electrolyte ohmic potential and cell voltage, resulting in higher removal efficiency [59] which is showed in Table 4, when the distance between electrodes ranges from 1 to 2 cm. The maximum removal

Table 10. Sequential model sum of squares and summary statistics for % color removal.

Sequential Model Sum of Squares

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Mean vs Total	1.365E+05	1	1.365E+05			
Linear vs Mean	18789.20	4	4697.30	107.65	<0.0001	Aliased
2FI vs Linear	513.00	7	73.29	1.96	0.0908	Aliased
Residual	1232.37	33	37.34			
Total	1.571E+05	45	3490.18			
Model Summary Statistics						
Source	**Std. Dev.**	**R^2**	**Adjusted R^2**	**Predicted R^2**	**PRESS**	
Linear	6.61	0.9150	0.9065	0.8887	2286.38	Aliased
2FI	6.11	0.9400	0.9200	0.8758	2550.86	Aliased

Table 11. Sequential model sum of squares and summary statistics for % turbidity removal.

Sequential Model Sum of Squares						
Source	Sum of Squares	df	Mean Square	F-value	p-value	
Mean vs Total	1.139E+05	1	1.139E+05			
Linear vs Mean	16497.96	4	4124.49	82.03	<0.0001	Aliased
2FI vs Linear	582.82	7	83.26	1.92	0.0972	Aliased
Residual	1428.47	33	43.29			
Total	1.324E+05	45	2942.14			
Model Summary Statistics						
Source	**Std. Dev.**	**R^2**	**Adjusted R^2**	**Predicted R^2**	**PRESS**	
Linear	7.09	0.8913	0.8805	0.8622	2550.80	Aliased
2FI	6.58	0.9228	0.8971	0.8602	2587.09	Aliased

Table 12. Sequential model sum of squares and summary statistics for energy consumption.

Sequential Model Sum of Squares						
Source	Sum of Squares	df	Mean Square	F-value	p-value	
Mean vs Total	12005.00	1	12005.00			
Linear vs Mean	3703.46	4	925.86	120.03	<0.0001	Aliased
2FI vs Linear	253.53	7	36.22	21.73	<0.0001	Aliased
Residual	55.01	33	1.67			
Total	16017.00	45	355.93			
Model Summary Statistics						
Source	**Std. Dev.**	**R^2**	**Adjusted R^2**	**Predicted R^2**	**PRESS**	
Linear	7.66	0.9065	0.8972	0.8802	3006.76	Aliased
2FI	6.53	0.9439	0.9252	0.8903	2753.21	Aliased

efficiency was color-92.30%, turbidity-95.28%, and COD-83.33% and power consumed 39 kWhr/m^3. The results indicates that, the removal efficiency of color, turbidity, and COD was achieved maximum with consumed low energy consumption. The performance of the EC system is influenced by the electrode material it is particularly by the anode which is determines the type of cations released into the solution [60]. Since coagulants with a greater charge valence are chosen because the metallic ions produced from the anode play a significant role in the coagulation of pollution particles [61].

3.2. Optimization with RSM

The RSM is a particular set of mathematical and statistical methods and it is has experimental design, model fitting, and validation as well as for the optimization [62]. The RSM aims to optimize the response of interest which is influenced by numerous variables [63]. The RSM is a useful statistical method for the optimization of chemical reactions and/or industrial processes and it is widely used for experimental design, in this technique the response surface is optimized that is affected by process parameters [64].

Table 5 shows that, the sequential model sum of squares and summary statistics for % COD. From Table 5, the model was significant for COD removal since the value of $p < 0.005$ which means that, the model was significant at a probability level of 95%. The model result indicates that, the coefficient of determination (R^2) and adjusted coefficients of determination (R^2) are 0.9911 and 0.9834 for COD removal, respectively. According to ANOVA (Tables 6, 7, 8, and 9) results the interaction of pH, current, electrolytic concentration, the distance between electrodes, and electrolysis time affects the color, COD, turbidity, and the energy consumption.

3.2.1. Validity of the model

The significance of the models was investigated at a 95% confidence level. The *F*-value and p-value are key metrics that illustrate the significance and appropriateness of the models, while the coefficient of determination (R^2) expresses the quality of the fit [65]. In Table 4, an experimental (actual) value and predicted values are shown for COD and energy consumption. The model-predicted values matched the experimental data in which all points are closed to the diagonal line, as showed in Figure 2. The quadratic models were shown to be significant ($P < 0.05$) in the ANOVA study and can be used to predict the % of COD, color and turbidity removal, as well as energy consumption. Figure 2 the % removal of color, COD, turbidity, and energy consumption indicates that the actual and predicted values are plotted which is linear regression, as well as the model is the best fit by using RSM.

3.2.2. Experiment performance analysis utilizing DoE

The % removal efficiency of color, COD, turbidity, and the energy consumption is expressed as a function of operating variables such as pH (A), current (B), electrolytic concentration (C), the distance between electrodes (D), and reaction time (E). The DoE provided the quadratic model regression which shown in Eqs. (8), (9), (10), and (11) for color, COD, turbidity removal and energy consumption, respectively.

$$\begin{aligned}\text{Color removal, (\%)} = {} & +53.88 + 4.01\text{A} + 4.83\text{B} + 6.45\text{C} + 0.0000\text{D} \\ & + 22.50\text{E} - 0.8727\text{AB} - 1.16\text{AC} + 0.0000\text{AD} - 0.8475\text{AE} + 8.59\text{BC} \\ & + 0.0000\text{BD} - 2.93\text{BE} - 7.81\text{CD} + 5.74\text{CE} + 0.0000\text{DE} + 1.35\text{A}^{\wedge}2 \\ & + 0.0000\text{B}^{\wedge}2 + 0.0000\text{C}^{\wedge}\ 2 + 0.0000\text{D}^{\wedge}2 + 2.04\text{E}^{\wedge}2\end{aligned} \tag{8}$$

$$\text{COD removal}, (\%) = +70.72 + 0.1509\text{A} + 4.32\text{B} + 4.60\text{C} + 0.0000\text{D} + 27.66\text{E} - 3.56\text{AB} + 2.32\text{AC} + 0.0000\text{AD} - 1.24\text{AE} + 6.66\text{BC} + 0.0000\text{BD} + 1.20\text{BE} - 11.26\text{CD} + 2.38\text{CE} + 0.0000\text{DE} + 2.08\text{A}^\wedge 2 + 0.0000\text{B}^\wedge 2 + 0.0000\text{C}^\wedge 2 - 0.0000\text{D}^\wedge 2 - 8.02\text{E}^\wedge\ 2 \tag{9}$$

$$\text{Turbidity removal}, (\%) = +53.14 + 3.88\text{A} + 5.40\text{B} + 3.13\text{C} + 0.0000\text{D} + 21.87\text{E} - 3.05\text{AB} + 1.41\text{AC} + 0.0000\text{AD} - 1.64\text{AE} + 1.14\text{BC} + 0.0000\text{BD} + 0.3903\text{BE} + 3.06\text{CD} + 3.50\text{CE} + 0.0000\text{DE} + 2.44\text{A}^\wedge 2 + 0.0000\text{B}^\wedge 2 + 0.0000\text{C}^\wedge 2 + 0.0000\text{D}^\wedge 2 - 9.79\text{E}^\wedge 2 \tag{10}$$

$$\text{Energy consumption}, (kWhr / m^\wedge\ 3) = +15.40 + 2.28\text{A} + 9.21\text{B} + 2.41\text{C} + 0.0000\text{D} + 0.2045\text{E} + 1.12\text{AB} - 0.6543\text{AC} + 0.0000\text{AD} + 0.2381\text{AE} + 8.35\text{BC} + 0.0000\text{BD} - 0.2306\text{BE} - 3.01\text{CD} - 0.0257\text{CE} + 0.0000\text{DE} + 0.4279\text{A}^\wedge 2 + 0.0000\text{B}^\wedge 2 + 0.0000\text{C}^\wedge 2 + 0.0000\text{D}^\wedge 2 + 0.4078\text{E}^\wedge 2 \tag{11}$$

The sequential model sum of squares and model summary statistics are tests used to evaluate the experimental results by CCD from RSM. These tests are used to generate different models like mean, linear and two factorial interactions for the removal of % color, COD, turbidity, and energy consumption as shown in Tables 5, 10, 11, and 12 respectively. The sequential model sum of squares and model summary statistics indicates linear and two factorial interactions were aliased such that this indicates that enough number of experiments was not worked and the model was not used for further implementation.

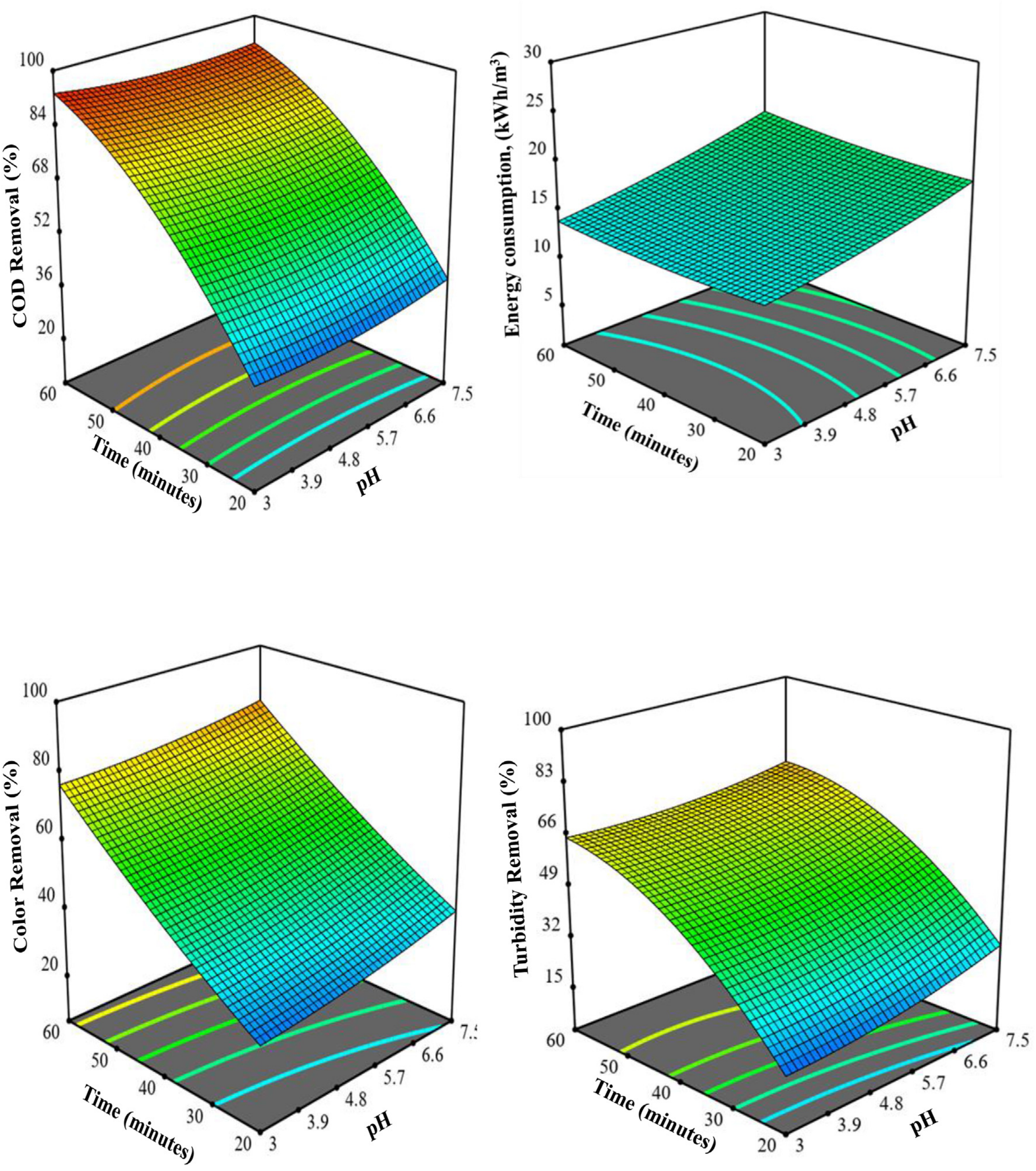

Figure 3. Percentage removal of COD, color, turbidity, and energy consumption using a combination of reaction time and pH.

3.2.3. Combination of operating parameters

The % removal of color, COD, and turbidity with energy consumption were determined by considering different factors which affect parameters, and the effects of variables are plotted in Figure 3 to Figure 5 using RSM concerning each variable, the effect of operating settings in predicting the maximum % removal of COD, color, turbidity, and energy consumption. The removal efficiency of color, COD, and turbidity was increased with the increasing of electrolysis time and pH as well as the energy consumption also highly increased due to the increasing of electrolysis time as shown in Figure 3. In Figure 4, the increment of electrolytic concentration from 1 to 3 g/L and the current from 0.03 to 0.09 A, increased % color, COD, % turbidity, and energy consumption with a gradual increase of current. Similarly, Figure 5 indicated that good removal efficiency of color, COD, turbidity were obtained with minimum of energy consumption under the operating parameters of the distance between electrodes and current.

3.2.4. Optimization with RSM

One of the main rewards of RSM concerning CCD is to obtain the optimum conditions for the removal of pollutants as well as energy consumption based on laboratory experiments. Based on the CCD, the results were optimized using the regression equation. To optimize the process, DoE software searches the design space while keeping several restrictions in mind. To obtain the genuine maxima or minima, several random starting points are chosen. Every process variable and response variable must have a target set in advance. Maximize, minimize, target, within range, and none are the answer options offered [54]. Factors can be set to a precise value as well.

In the optimization of pH (A), current (B), electrolytic concentration (C), distance between an electrode (D) and electrolysis time (E) were selected as within the range and the responses such as % color, COD, and turbidity removal efficiency were maximized and energy consumption was minimized. Based on these operating parameters the optimum value

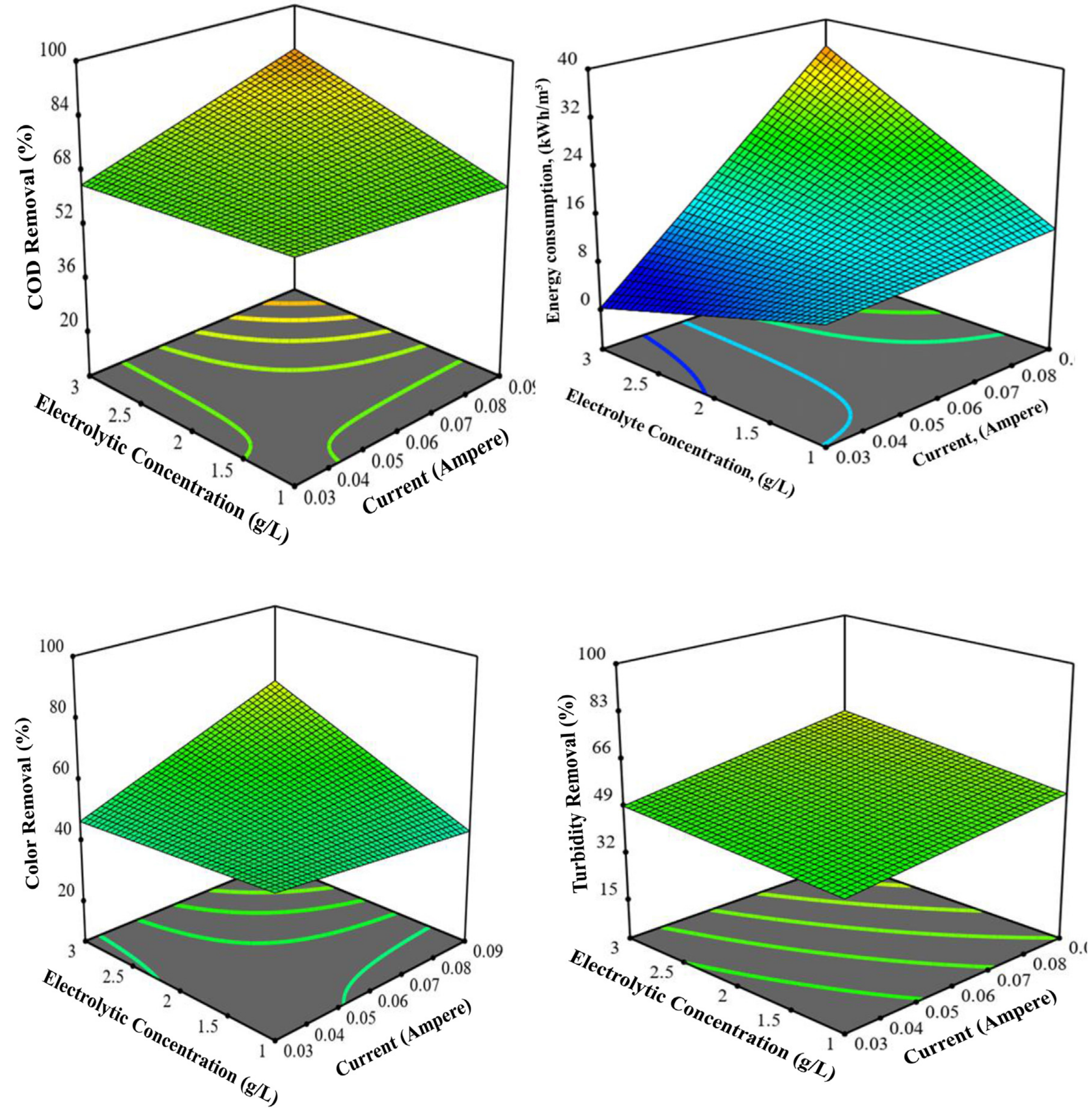

Figure 4. Percentage removal of COD, color, turbidity, and energy consumption using a combination of electrolytic concentration and current.

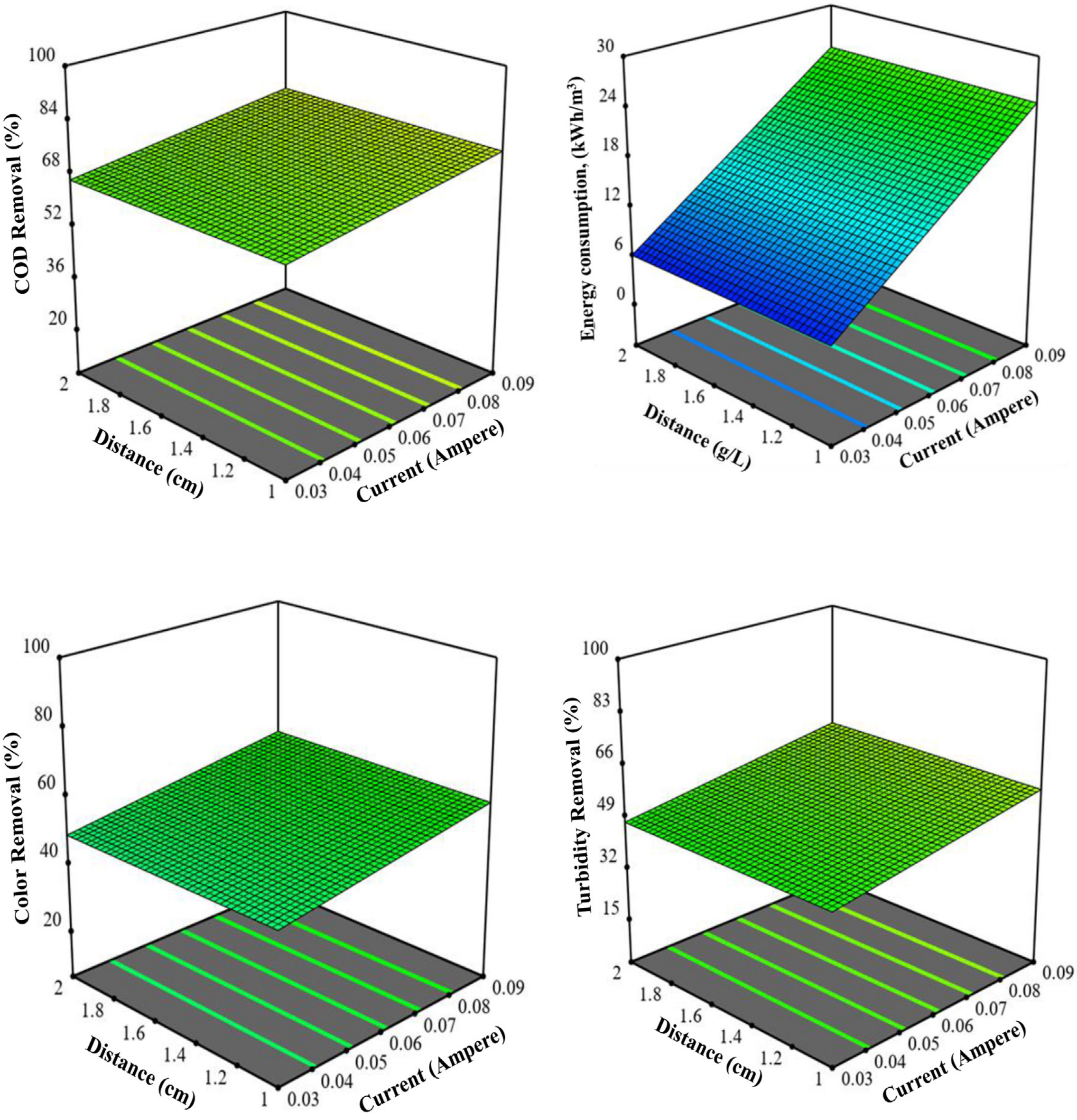

Figure 5. Percentage removal of COD, color, turbidity, and energy consumption using a combination of distance between electrodes and current.

was obtained at pH–7.497, current–0.037A, electrolytic concentration–2.999 g/L, distance between electrodes–1.263cm, and electrolysis time–60 min such that the optimum value of color, COD, turbidity, and energy consumption were 90.12%, 94.92%, 73.4% and 6.9 kWhr/m^3, respectively.

4. Conclusion

The hospital is supplies huge amounts of water for all activities with this results wastewater is produced. Water is then consumed and discharged into the environment as waste without any treatment that has an impact on the condition of the natural environment. An EC is an effective technology that is used to treat wastewater generated from the hospital only by using a sacrificial Al electrode. The results showed that, it is efficient to remove the COD, color, and turbidity from hospital wastewater under different factors like pH (3–7.5), current (0.03–0.09 A), electrolytic concentration (1–3 g/L), distance between electrodes (1–2 cm), and electrolysis time (20–60 min) using Al electrode. On the other hand, the study was indicated with less energy consumption higher pollutant removal percentages were achieved. The optimum value was done via RSM by maximizing the removal efficiency of color, COD, and turbidity and by minimizing the energy consumption. In addition to this RSM display the predicted value based on the actual value obtained from laboratory analysis as well as evaluates the statistical modeling of an experiment. Finally, the result of this study suggested that the EC process would be an effective and efficient method for treatment of wastewater and industrial effluent.

Declarations

Author contribution statement

Million Ebba: Performed the experiments; Wrote the paper.

Perumal Asaithambi: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Esayas Alemayehu: Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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