EFFICIENCY OF ELECTROCOAGULATION METHOD TO REDUCE COD, BOD AND TSS IN TANNERY INDUSTRY WASTEWATER: APPLICATION OF THE BOX–BEHNKEN DESIGN

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ABSTRACT. This study intends to assess the removal efficiency of the chemical oxygen demand (COD), biochemical oxygen demand (BOD), and total suspended solids (TSS) from raw tannery wastewater using electrocoagulation by aluminum electrodes as well as to determine the effects of its main operating factors. Therefore, the response surface methodology was applied through an experimental Box–Behnken design by considering the current intensity (I), treatment time (T), and pH levels as the factors. In addition, the BOD, COD, and TSS removal percentages were considered to be the response variables. The results indicate that the treatment time, current intensity, and pH level were significant for COD and TSS, whereas only the treatment time was significant at a confidence level of p-value < 0.05 for BOD. For COD, the optimal operating conditions were I = 3 A, T = 24 min, and pH = 8.4; for BOD, the optimal operating conditions were I = 3 A, T = 24 min, and pH = 5.5; and for TSS, the optimal operating conditions were I = 2.7 A, T = 19 min, and pH = 7.4. Under these conditions, removal efficiencies of 56.8%, 69.2%, 99.9% were observed for COD, BOD, and TSS, respectively. The results suggest that electrocoagulation is an effective method for removing the parameters under study; therefore, it is a viable alternative for reducing the pollution issues caused by the tannery industry.
KEY WORDS: tannery, electrocoagulation, aluminum electrodes, Box–Behnken design

EFICIENȚA METODEI DE ELECTROCOAGULARE PENTRU REDUCEREA CCO, CBO ȘI TSS DIN APELE UZATE ALE INDUSTRIEI DE PIELĂRIE: APLICAREA EXPERIMENTULUI BOX-BEHNKEN

REZUMAT. Acest studiu are obiectivul de a evalua eficiența reducerii consumului chimic de oxigen (CCO), consumului biochimic de oxigen (CBO) și a totalului materiilor solide în suspensie (TSS) din apele reziduale ale tăbăcăriilor, folosind electrocoagularea cu electrozi de aluminiu, precum și de a determina efectele principalilor factori de operare ai acestei metode. Prin urmare, metodologia suprafeței de răspuns a fost aplicată printr-un design experimental Box-Behnken, luând în considerare factori precum intensitatea curentului (I), timpul de tratament (T) și nivelul pH-ului. În plus, procentele de eliminare a CBO, CCO și TSS au fost considerate variabile de răspuns. Rezultatele indică faptul că timpul de tratament, intensitatea curentului și nivelul pH-ului au fost semnificative pentru CCO și TSS; pe de altă parte, doar timpul de tratament a fost semnificativ la un nivel de încredere al valorii p <0,05 pentru CBO. Pentru CCO, condițiile optime de operare au fost I = 3 A, T = 24 min și pH = 8,4; pentru CBO, condițiile optime de funcționare au fost I = 3 A, T = 24 min și pH = 5,5; iar pentru TSS, condițiile optime de funcționare au fost I = 2,7 A, T = 19 min și pH = 7,4. În aceste condiții, s-au observat valori ale eficienței de reducere de 56,8%, 69,2%, 99,9% pentru CCO, CBO și, respectiv, TSS. Rezultatele sugerează că electrocoagularea este o metodă eficientă pentru reducerea parametrilor studiați; prin urmare, este o alternativă viabilă pentru reducerea problemelor de poluare cauzate de industria de pielărie.
CUVINTE CHEIE: tăbăcărie, electrocoagulare, electrozi din aluminiu, experiment Box-Behnken

EFFICACITÉ DE LA MÉTHODE D'ÉLECTROCOAGULATION POUR RÉDUIRE LA DCO, LA DBO ET LES TSS DANS LES EAUX USÉES DE L'INDUSTRIE DU CUIR : APPLICATION DE LA CONCEPTION BOX-BEHNKEN

RÉSUMÉ. Cette étude vise à évaluer l'efficacité d'élimination de la demande chimique en oxygène (DCO), de la demande biochimique en oxygène (DBO) et du total des matières solides en suspension (TSS) des eaux usées de la tannerie en utilisant l'électrocoagulation par des électrodes en aluminium ainsi qu'à déterminer les effets de ses principaux facteurs de fonctionnement. Par conséquent, la méthodologie de la surface de réponse a été appliquée par le plan expérimental de Box-Behnken en considérant l'intensité du courant (I), le temps de traitement (T) et les niveaux de pH comme facteurs. De plus, les pourcentages d'élimination de la DBO, de la DCO et du TSS étaient considérés comme les variables de réponse. Les résultats indiquent que le temps de traitement, l'intensité du courant et le niveau de pH étaient significatifs pour la DCO et le TSS, alors que seul le temps de traitement était significatif à un niveau de confiance de valeur p <0,05 pour la DBO. Pour la DCO, les conditions de fonctionnement optimales étaient I = 3 A, T = 24 min et pH = 8,4 ; pour la DBO, les conditions de fonctionnement optimales étaient I = 3 A, T = 24 min et pH = 5,5 ; et pour TSS, les conditions de fonctionnement optimales étaient I = 2,7 A, T = 19 min et pH = 7,4. Dans ces conditions, des rendements d'élimination de 56,8%, 69,2%, 99,9% ont été observés pour la DCO, la DBO et la TSS, respectivement. Les résultats suggèrent que l'électrocoagulation est une méthode efficace pour réduire les paramètres étudiés ; par conséquent, c'est une alternative viable pour réduire les problèmes de pollution causés par l'industrie du cuir.
MOTS-CLÉS : tannerie, électrocoagulation, électrodes en aluminium, conception Box-Behnken

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INTRODUCTION

The tannery industry is an important activity in the economic development of Peru and this is due to the diversity of articles that are generated from leather and the international demand of tanned skins until wet blue state (wet tanned skin). However, tanneries have been mainly characterized by the usage of low-technology and poor production practices that exacerbate the environmental problems associated with this industry by generating large volumes of highly polluted wastewater, mainly discharged in an untreated manner directly into rivers or sewage networks. According to the Peruvian national leather production data, between 45 and 50 m^3 of effluents were produced for each ton of tanned leather in 2017, indicating the generation of approximately 30,000 m^3 of effluents. The pollutant load of these effluents contains high amounts of chemical oxygen demand (COD), biochemical oxygen demand (BOD), and total suspended solids (TSS), sulfides, ammonium, chlorides, and heavy metals such as chromium. When high COD and BOD contents are reported in organic matter, water bodies lose a considerable amount of dissolved oxygen. This is harmful to aquatic organisms because it results in anaerobic activity that may release harmful gases. Therefore, the adoption of clean production and effluent treatment alternatives is of paramount importance. Estimates from the Center for Technological Innovation in Leather, Footwear, and Related Industries (CITEccal Lima) identified approximately 100 different tanneries in Lima. However, most of these tanneries have not yet implemented an effluent treatment system, which can ensure their compliance with the current environmental regulations, thus putting not only the environmental health but also the very existence of the industry at constant risk. Further, a possible solution to this issue may be the usage of electrocoagulation for treating raw tannery wastewater. In 2009, Ayhan Sengil *et al*. [1] applied electrocoagulation through steel and aluminum electrodes, achieving COD removal rates of 68%. In another study, Varank *et al*. [2] reported COD and TSS removal efficiencies of 82.2% and 85.5% when using aluminum electrodes and 67.4% and 86.2% when using steel electrodes, respectively, in 2014. Deghlesa *et al*. [3] also reported an optimal COD removal efficiency of 64.4% using aluminum electrodes. In 2017, Ufuk Durmaz *et al*. [4] determined the optimum operating values for COD and TSS removal through aluminum electrodes to be 18.9 mA/cm^2, 20 min of electrolysis time, and a pH level of 6.

Our study focuses on assessing the efficiency of the electrocoagulation process for removing the pollutants generated by the tannery industry expressed as BOD, COD, and TSS and on optimizing the process through the Box–Behnken (BBD) response surface methodology. Electrocoagulation offers many advantages over conventional treatments. In this process it is not necessary to add chemicals to the water, its reactors are more compact and simpler, and it has a high efficiency in the removal of various contaminants [5, 6]. In addition, as with any technology, it has some disadvantages, such as the periodic replacement of electrodes, the presence of high concentrations of aluminum and iron in the sewage sludge, and a high cost in places where there is no access to electrical energy [7]. Electrocoagulation is an electrochemical process in which metal plates, known as electrodes, are arranged in pairs, with one of the electrodes acting as the anode and the other acting as the cathode. Further, the cathode is oxidized, and the anode is reduced, generating hydroxide complexes acting as coagulants that allow the agglomeration of pollutants. Most of these agglomerates rise to the surface because of the fact that the hydrogen microbubbles perform a flotation process, whereas the rest are deposited in the bottom part of the water body [8]. Therefore, several types of electrodes, such as aluminum, iron, stainless steel, and platinum, have been tested [9]. In this study, we used aluminum electrodes as both the anode and the cathode, where reactions 1, 2 and 3 are generated [10].

At the anode:

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

At the cathode:

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

In the solution:

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

EXPERIMENTAL

Materials and Methods

Tannery Wastewater

Water was collected from the pilot treatment plant at the Center for Technological Innovation in Leather, Footwear, and Related Industries (CITEccal), which generates industrial effluents from its tanning processes, to recreate the actual treatment conditions. This type of water contains high amounts of organic matter, pollutants and exhibits high conductivity because of the low-technological tanning processes used by the industry. Table 1 displays the values obtained from the initial effluent characterization.

Table 1: Physicochemical Effluent Analysis

Parameter	Value
COD (mg/L)	4162.3
BOD (mg/L)	1825
TSS (mg/L)	1600
Conductivity (µS/cm)	10560
pH	8.5
Turbidity (NTU)	1330
Chromium (mg/L)	114.56

Electrocoagulation Reactor

For these purposes, a Bacth type reactor with the following dimensions was used: length: 30 cm; width: 20 cm; and height: 25 cm. The total volume of the reactor was 15 liters, with the capacity to treat 12 liters of wastewater and a free volume of 3 liters for the accumulation of sludge. In total, we used 8 aluminum electrodes (4 as the anode and 4 as the cathode, each 10 cm wide and 10 cm long with a total area of 100 cm^2). In addition, we used a series configuration, and the plates were spaced at 2 cm to reduce the demand of electric current owing to high water conductivity. Figure 1 displays a diagram of the reactor.

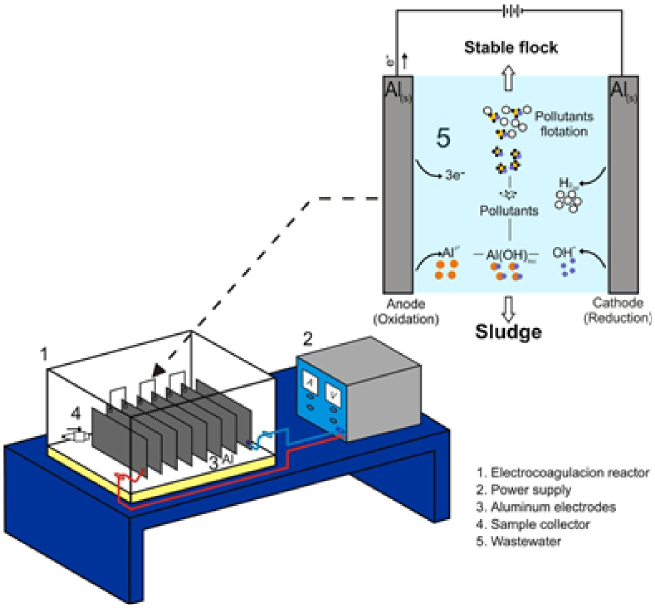

Figure 1. Electrocoagulation Reactor

Experimental Procedure

The experimental procedure proposes tests for three pH values of water (8.5, 7, and 5.5). In these three stages, different electric current intensities were applied (1, 3, and 5 A), and samples were obtained at different times (8, 16, and 24 min). To measure the pH and conductivity, an Oakcton CON450 field meter was used. In addition, COD (SMEWW-APHA-

AWWA-WEF Part 5220 D; 23rd), BOD (SMEWW-APHA-AWWA-WEF Part 5210 B; 23rd), and TSS (SMEWW-APHA-AWWA-WEF Part 2540-D; 23rd) were used to quantify the response variable. Finally, we used Equation 4 to determine the COD, BOD, and TSS removal percentages.

$$Y = \%R = \left(\frac{C_i - C_f}{C_i}\right) \times 100 \quad (4)$$

Here,

Y : Removal percentage of COD,BOD,and TSS
C_i: Concentration of COD,BOD,and initial TSS
C_f: Concentration COD,BOD,and final TSS

Box–Behnken Experimental Design

For this study, the response surface methodology with a Box–Behnken experimental design was used using three factors, each factor with three levels, and 13 experiments by considering two experiments to denote the central values. The factors considered in the design were the electric current intensity (x_1), treatment time (x_2), and pH level (x_3) (see Table 2). To develop a response surface regression model, a complete quadratic model was applied (see Equation 5), where the experimental observations of the response variable were the COD , BOD, and TSS removal percentages. For the statistical analysis, the Statgraphics Centurión XVI software was used, which reported an analysis of variance (ANOVA) at a 95% confidence level. The polynomial model was evaluated by the value of the correlation coefficient R^2 and R^2 adj.

$$y_i = b_0 + \sum_{i=1}^{n} b_i x_i + \sum_{i=1}^{n} b_{ii} x_i^2 + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} b_{ij} x_i x_j \quad (5)$$

Table 2: Experimental Design Factors and Levels

Factors	Levels		
x_1 : Current Intensity (A)	1	2	3
x_2 : Time (min)	8	16	24
x_3: pH Level	5.5	7	8.5

RESULTS AND DISCUSSION

Effect of Current Intensity

Current intensity is one of the most critical parameters, which can significantly impact the effectiveness of the electrocoagulation process [8-11, 12]. As has been previously reported, as the intensity increases, the amount of anodic aluminum dissolution also increases, which leads to improved coagulation and pollutant removal [7]. For this study, we applied current intensities of 1, 2, and 3 A in a serial circuit to reduce energy consumption due to the high conductivity values presented by this type of wastewater. As the current intensity increases in Figures 2a, b; 4a, b; and 6a, b, it can be seen that the rate of removal of COD, BOD and TSS increases significantly. This is caused when a high current intensity is supplied to the reactor, generating a large number of monomeric and polymeric species according to Faraday's law, which reduces the amount of wastewater pollutants [8]. In Table 3 it can be seen that the highest removal values were obtained at 2 and 3 amps. With these current intensities a removal of COD, BOD and TSS of 54%, 66% and 97%, respectively, was achieved. These results are not consistent with the results reported by Feng Jing-Wei *et al*. [13] in 2007, which indicate COD removal rates of more than 68% when using Al electrodes under current intensities of 0 to 1 A. The BOD removal results from our study also deviated from the results reported by Kongjao *et al*. [14], and Benhadji *et al*. [15], who reported efficiency values of 96% and 90%, respectively. However, these differences may be attributed to the different characteristics of the tested effluents. In 2014, Thirugnanasambandham *et al*. [8] reported values similar to the values reported herein, where an efficiency of 56.98% was achieved when applying a current density of 20 mA cm^{-2} for 20 min. In addition, Espinoza *et al*. [16] obtained efficiencies of 50% and 65% for COD and TSS, respectively, when using a current density of 68 mA cm^{-2}. However, Ufuk Durmaz *et al*. [4] reported maximum removal efficiencies of 49% for COD and 42% for TSS when applying a current density of 22.7 mA/cm^{-2}, a pH level of 6, and a treatment time of 60 min. Tables 5 and 6 show the regression or slope coefficients of the model used. In the model for TSS, the regression coefficient of the current intensity is positive, which indicates that the percentage of TSS removal (response variable) increases by an average of approximately 29,1667. In contrast, for BOD and COD the percentage of removal increases by approximately 19.3333 and 2.91667, respectively.

Effect of pH

The metal hydroxide precipitations are controlled by pH variations, which remove the pollutants while acting as coagulants [8]. To assess their impact on the treatment efficacy, the pH was changed from 5.5 to 8.5. The results from these variations are presented in Table 3 and Figures 2, 4, and 6. These results are very similar to the results obtained by Espinoza *et al*. [16], where optimal COD and TSS removal rates were reported for pH values of 6.5–8.0 and 6.5–8.5, respectively. Based on these results, a reduction of the pH to 5.5 improves the removal of organic matter (COD and BOD), whereas this does not result in a noticeable removal of TSS. In 2015, Deghlesa *et al*. [3] reported optimal COD removal values at a pH of 7. By considering that pH only had a minimal impact on the efficiencies, the modification of this parameter is not justified in practical applications, generating reagent consumption expenditure savings. In addition, Ufuk Durmaz *et al*. [4] reported optimal efficiencies at a pH of 6 with a treatment time of 60 min.

Effect of Treatment Time

As known, the removal efficiency of pollutants increases as the electrolysis time increases due to the generation of metal ions and flocs [17-19]. The results for this parameter are shown in Table 3 and Figure 2, 4 and 6 which offer proof that the COD, BOD, and TSS removal rates increase as the treatment time progresses. These results are very similar to the ones reported by Tak *et al*. [20], which indicate an increase in efficiency after 10 to 20 min of treatment. In addition, Thirugnanasambandham *et al*. [8] reports that efficiencies may reach up to 72% after a treatment time of 20 to 60 min. Thus, determining the optimum treatment times becomes critical, especially when considering that very long treatment times generate high energy consumption and electrode wear [21], which would increase the treatment costs.

Results of the Box–Behnken Design

Table 3 presents the results obtained from the Box–Behnken factorial design for all 13 experiments with 2 central experiments using the pH, current intensity, and treatment time as independent variables.

Table 3: Box–Behnken Design for COD, BOD, and TSS removal

Exp. No	Factors			Removal		
	Current (A)	Treatment Time (min)	pH	COD (%)	BOD (%)	TSS (%)
	x_1	x_2	x_3	y_1	y_2	y_3
1	1	16	5.5	36	57	74
2	2	8	5.5	43	60	79
3	2	24	5.5	54	66	85
4	3	16	5.5	51	63	89
5	1	8	7	24	43	76
6	1	24	7	30	45	89
7	3	8	7	36	48	94
8	3	24	7	46	54	97
9	1	16	8.5	22	57	81
10	2	8	8.5	23	59	86
11	2	24	8.5	36	63	95
12	3	16	8.5	35	63	96
13	2	16	7	37	46	96
14	2	16	7	38	47	97
15	2	16	7	36	46	96

An empirical relation was observed between the COD, BOD, and TSS removal efficiency percentages, and the influence of the variables on the process can be obtained by correlating the experimental results with the response functions using the Statgraphics Centurion XVI software program.

In addition, ANOVA yielded a 95% confidence level (see Table 4) by comparing the variation sources against the Fisher's distribution (F-test) to validate the viability of the regression model. Table 5 shows the regression coefficients for the second order response model. The response surface models are shown in Table 6. The coefficients of determination R^2 for COD (y_1), BOD (y_2), and TSS (y_3) are 98.5551%, 99.5823%, and 99.573%, respectively, which indicate a good model fit. Further, the results suggest that the treatment time, current intensity, and pH are significant for both COD and TSS, whereas only the treatment time was significant at a confidence level of p-value < 0.05 for BOD.

Table 4: ANOVA Table

	Variation Source	Sum of Squares	DF	MS	F-Test	P-Value
COD	x_1 : Current Intensity (A)	392.0	1	392.0	108.9	0.0001
	x_2 : Time (min)	200.0	1	200.0	55.56	0.0007
	x_3: pH Level	578.0	1	578.0	160.56	0.0001
	x_1^2	33.2308	1	33.2308	9.23	0.0288
	x_1x_2	4.0	1	4.0	1.11	0.3401
	x_1x_3	1.0	1	1.0	0.28	0.6207
	x_2^2	0.0	1	0.0	0.00	1.0000
	x_2x_3	1.0	1	1.0	0.28	0.6207
	x_3^2	14.7692	1	14.7692	4.10	0.0987
	Total error	18.0	5	3.6		
	Total (corr.)	1245.73	14			
	$R^2 = 98.5551\%$, Adj $R^2 = 95.9542\%$					
BOD	x_1 : Current Intensity (A)	84.5	1	84.5	115.23	0.0001
	x_2 : Time (min)	40.5	1	40.5	55.23	0.0007
	x_3 : pH Level	2.0	1	2.0	2.73	0.1296
	x_1^2	0.641026	1	0.641026	0.87	0.3927
	x_1x_2	4.0	1	4.0	5.45	0.0668
	x_1x_3	0.0	1	0.0	0.00	1.0000
	x_2^2	9.25641	1	9.25641	12.62	0.0163
	x_2x_3	1.0	1	1.0	1.36	0.2956
	x_3^2	732.333	1	732.333	998.64	0.0000
	Total error	3.66667	5	0.733333		
	Total (corr.)	877.733	14			
	$R^2 = 99.5823\%$, Adj $= 98.8303\%$					

TSS	x_1 : Current Intensity (A)	392.0	1	392.0	500.43	0.0000
	x_2: Time (min)	120,125	1	120,125	153.35	0.0001
	x_3: pH Level	120,125	1	120,125	153.35	0.0001
	x_1^2	68.0064	1	68.0064	86.82	0.0002
	x_1x_2	25.0	1	25.0	31.91	0.0004
	x_1x_3	0.0	1	0.0	0.00	1.0000
	x_2^2	34.1603	1	34.1603	43.61	0.0012
	x_2x_3	2.25	1	2.25	2.87	0.1509
	x_3^2	183.083	1	183.083	233.72	0.0000
	Total error	3.91667	5	0.783333		
	Total (corr.)	917.333	14			
	R^2= 99.573%,	Adj = 98.8045%				

Table 5: Regression coefficients for the 2nd order response surface models

Term	COD removal (%)		BOD removal (%)		SST removal (%)		Confidence intervals - 95.0 %		
	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Mean	Lower limit	Upper limit
Constant	88.2222	0.0192	348.37	0.0000	-129.185	0.0001	88.66	84.1559	93.0441
x_1	19.3333	0.0273	2.91667	0.4193	29.1667	0.0001	2.0	1.58138	2.41862
x_2	0.0833333	0.9194	-0.46575	0.1448	2.19271	0.0014	16.0	12.651	19.349
x_3	-18.1111	0.0370	-87.2963	0.0000	45.3981	0.0000	7.0	6.37207	7.62793
x_1^2	-3.0	0.0288	-0.416667	0.5623	-4.29167	0.0002	4.533	2.83461	6.23206
x_1x_2	0.125	0.3401	0.125	0.0493	-0.3125	0.0016	32.0	22.2362	41.7638
x_1x_3	-0.333333	0.6207	0	1.0000	0	1.0000	14.0	10.7811	17.2189
x_2^2	0	1.0000	0.0247396	0.0074	-0.047526	0.0010	290.113	181.415	398.852
x_2x_3	0.0416667	0.6207	-0.0416667	0.2532	0.0625	0.1219	112.0	86.2489	137.751
x_3^2	0.888889	0.0987	6.2596	0.0000	-3.12963	0.0000	50.2	41.3855	59.0145

x_1 (current intensity, A), x_2 (time, min), x_3 (pH).

Table 6: Response surface model for COD, BOD and TSS removal (%)

Response	Quadratic polynomial model		P-value
COD removal (%)	$y_1 = 88.2222 + 19.3333x_1 + 0.0833333x_2 - 18.1111x_3 - 3.0x_1^2 + 0.125x_1x_2 - 0.33333x_1x_3 + 0.0416667x_2x_3 + 0.888889x_3^2$	98.5551	0.0005
BOD removal (%)	$y_2 = 348.37 + 2.91667x_1 - 0.46575x_2 - 87.2963x^3 - 0.416667x_1^2 + 0.125x_1x_2 + 0.0247396x_2^2 - 0.0416667x_2x_3 + 6.25926x_3^2$	99.5823	0.0000
TSS removal (%)	$y_3 = -129.185 + 29.1667x_1 + 2.19271x_2 + 45.3981x_3 - 4.29167x_1^2 - 0.3125x_1x_2 - 0.047526x_2^2 + 0.0625x_2x_3 - 3.12963x_3^2$	99.573	0.0000

The effects of the process variables are presented in Figures 2, 3, 4, 5, 6 and 7, which represent the three-dimensional (3D) and contour (2D) response surface plots. These plots use the mathematical models developed in Equations 6, 7, and 8, where the COD, BOD, and TSS removal percentage variations may be observed according to the variation of their current intensity (x_1), treatment time (x_2), and pH (x_3). In addition, this allowed us to determine the optimum condition for each factor to maximize the COD, BOD, and TSS removal.

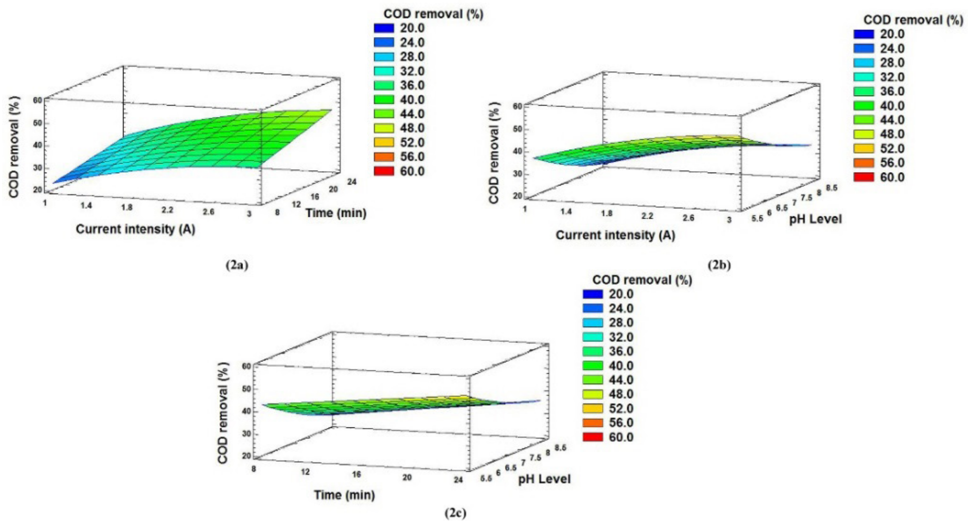

Figure 2. Three-dimensional (3D) response surface charts for COD removal percentages: 2a) current intensity and treatment time; 2b) current intensity and pH; and 2c) treatment time and pH

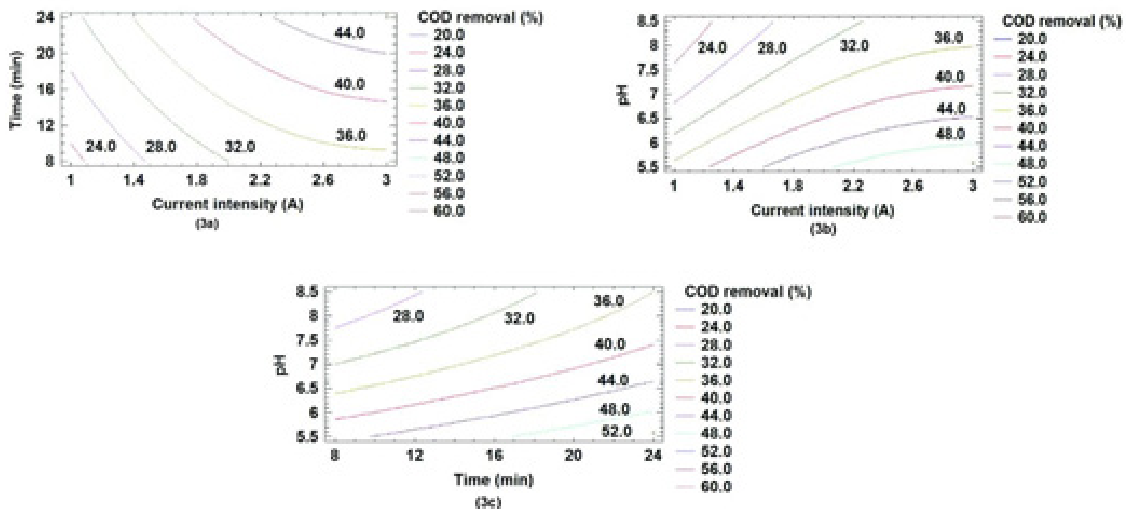

Figure 3. Two-dimensional (2D) response surface charts for COD removal percentages: 3a) current intensity and treatment time; 3b) current intensity and pH; and 3c) treatment time and pH

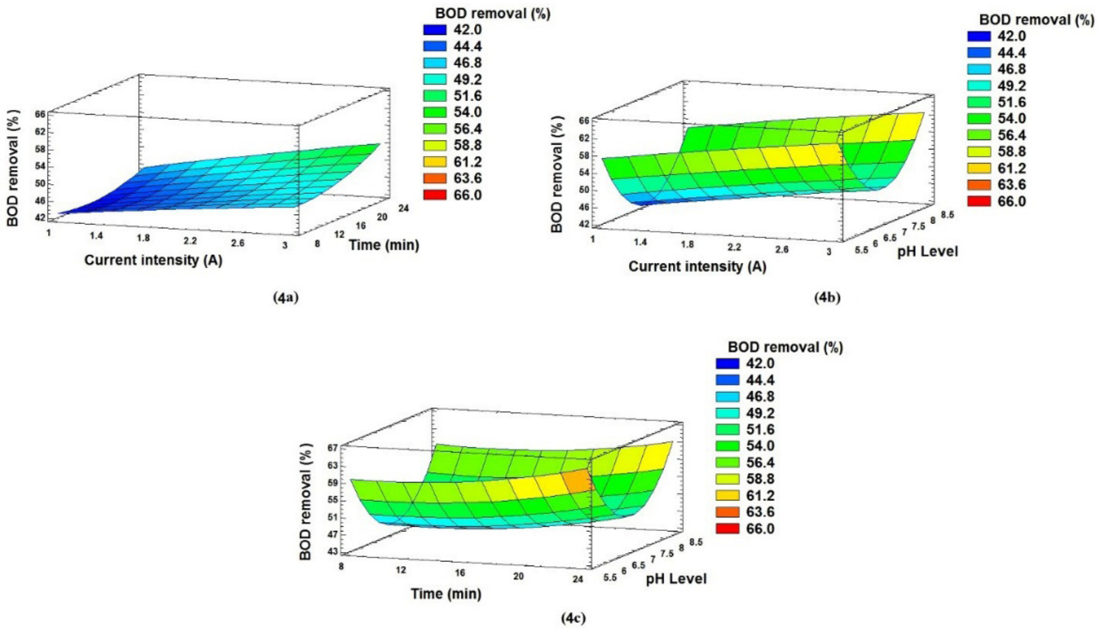

Figure 4. Three-dimensional (3D) response surface charts for BOD removal percentages: 4a) current intensity and treatment time; 4b) current intensity and pH; and 4c) treatment time and pH

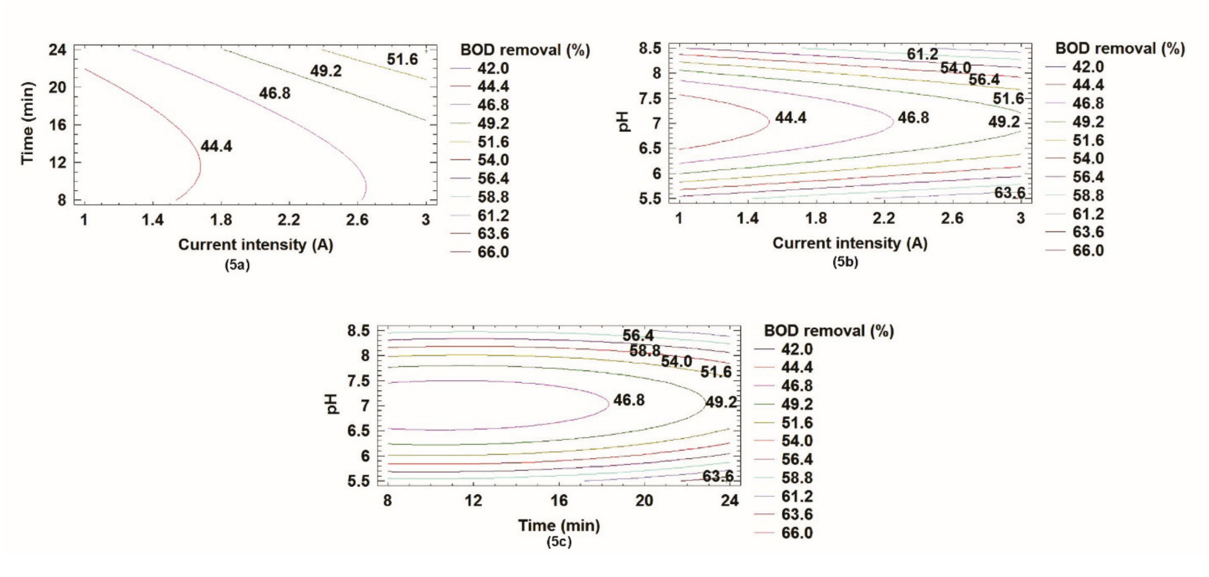

Figure 5. Two-dimensional (2D) response surface charts for BOD removal percentages: 5a) current intensity and treatment time; 5b) current intensity and pH; and 5c) treatment time and pH

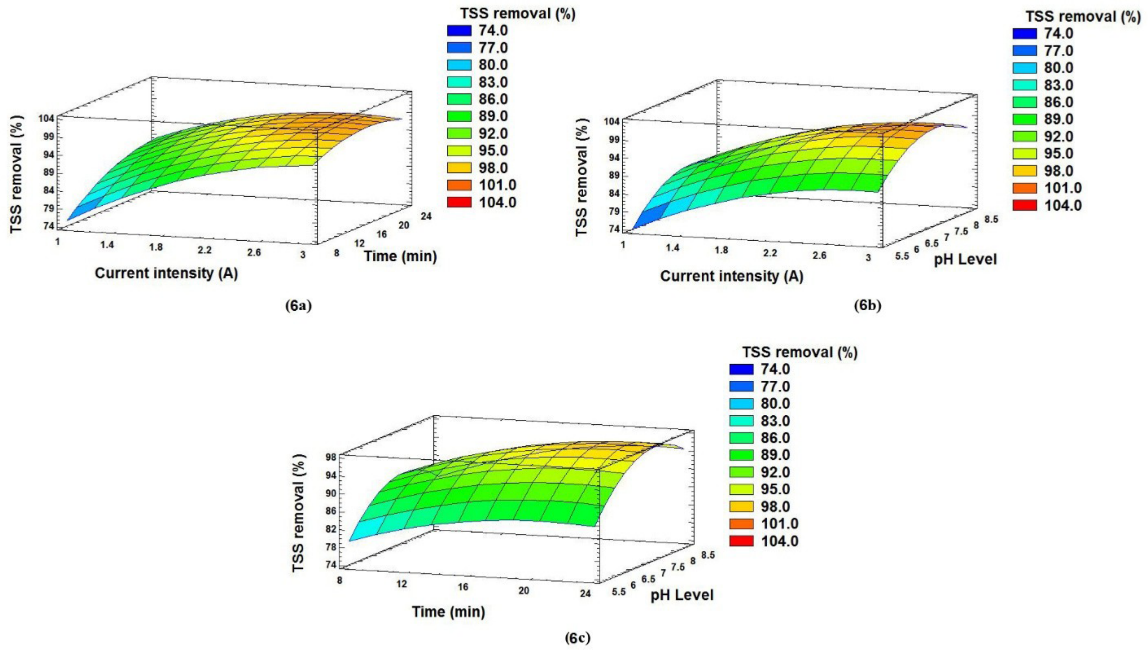

Figure 6. Three-dimensional (3D) response surface charts for TSS removal percentages: 6a) current intensity and treatment time; 6b) current intensity and pH; and 6c) treatment time and pH

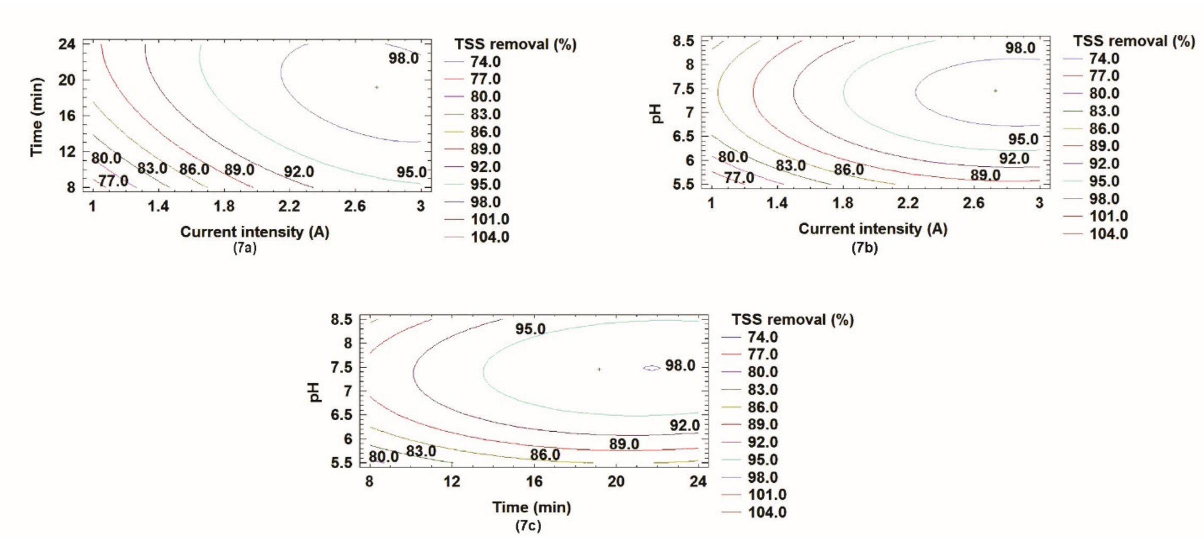

Figure 7. Two-dimensional (2D) response surface charts for TSS removal percentages: 7a) current intensity and treatment time; 7b) current intensity and pH; and 7c) treatment time and pH

CONCLUSIONS

This study proves that electrocoagulation by aluminum electrodes is effective for reducing COD, BOD, and TSS from tannery wastewater. As per the experimental design, all the factors (current intensity, treatment time, and pH) significantly affected COD and TSS, whereas only the treatment time significantly affected BOD. The correlation coefficient R^2 for COD, BOD, and TSS was 98.5551%, 99.5823%, and 99.573%, respectively, indicating a good model fit. For COD, the optimal operating conditions were established as I = 3A, T = 24 min, and pH = 8.4; for BOD, the optimal operating conditions were I = 3A, T = 24 min, and pH = 5.5; and for TSS, the optimal operating conditions were I = 2.7A, T = 19 min and pH = 7.4. Thus, optimum removal efficiencies of 56.8%, 69.2%, and 99.9% were achieved for COD, BOD, and TSS, respectively. Finally, it must also be emphasized that under actual treatment conditions, using reagents for changing pH would not be justified because the obtained efficiencies are very similar.

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