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Treatment of textile wastewater by electrocoagulation process assisted with biocoagulant obtained from the pitahaya peels

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ABSTRACT

This study proposes the treatment of textile wastewater by electrocoagulation process (EC) assisted with biocoagulant obtained from the pitahaya peels. The Box–Behnken design (BBD) was used to evaluate and optimize the parameters of EC (pH, current density and time), using Al and Fe electrodes, from the response surface methodology and desirability function for the response, turbidity removal. Then, optimized EC processes were assisted with different biocoagulant doses (30, 35, 40, 45 and 50 mg/L) for the treatment of textile wastewater, evaluating the turbidity, color and chemical oxygen demand. The results of BBD showed that for EC process using the Fe electrodes the variables pH, current density and time were significant, while for Al electrodes were significant the variables current density and time. Optimized EC processes assisted with biocoagulant improved significantly the treatment efficiencies of the wastewater, obtaining removal values of turbidity, color, and chemical oxygen demand of 98.05%, 95.11% and 86.21%, respectively, for Al electrodes; and 96.89%, 95.10% and 81.78% for Fe electrodes. Additionally, it was observed significant removals of inorganic elements presents in the textile wastewater as P, Mg and Si.

Keywords: Electrocoagulation; Biocoagulant; Chemical oxygen demand; Turbidity; Pitahaya peels

1. Introduction

Textile industries are responsible for the use of large amounts of dyes, inorganic and organic chemicals and additives in their processes, in addition to large volumes of water, which generates huge volumes of effluents [1]. These wastewaters, usually, contain a large variety of organic pollutants, which generate high chemical oxygen demand (COD). Additionally, they show environmental risks for the water bodies due to high levels of turbidity, color, and contents of surfactant, salts and others compounds that are used in the dyeing and finishing processes of their products [2]. Among the compounds present in the textile wastewaters, synthetic dyes deserve attention, once that they are difficult to degrade and toxic for aquatic organisms, its presence

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in the water bodies also promote the reduction of light passage, affecting the performing the photosynthesis [3,4].

Several processes have been researched to be used in treatment of wastewaters, such as electrocoagulation and coagulation processes. Electrocoagulation process (EC) is an electrochemistry technique which has been used in last years for treatment of wastewaters containing a wide variety of inorganic and organic pollutants. It has as main characteristics its versatile, easy installation and environmentally friendly [5,6]. This process consists in the generation of coagulation and flocculant species in situ from the reactions that occur in electrodes (anode and cathode) of an electrochemistry cell caused by the application of potential. The generated species in the processes promote the removal of pollutants from the coagulation and flocculation mechanisms [7]. The coagulation method, in turn, consists in the addition of coagulants from direct way in the wastewater, which has as advantages to be versatile and economically viable [8]. Various inorganic and organic compounds have been used as coagulants in coagulation processes. Among the inorganic compounds, aluminum sulfate is the most used, however it can cause environmental problems due to high concentrations of aluminum presents in the treated wastewaters [9]. On the other hand, organic coagulants have advantages as lower toxicity, cost and sludge formation, in addition to being biodegradable and presenting a low risk of environmental contamination [10]. The biopolymers are compounds obtained from certain kind of plants, which when used as organic coagulants show advantages as: cost-effective, unlikely to produce extreme pH values in the treated wastewater [11].

The pitahaya or dragon fruit is a fruit of a cactus specie of the genus *Selenicereus* belonging to the *Cacteaceae*, and that is cultivated in several countries around the world and throughout tropical and subtropical regions [12]. Pitahaya is a fruit of important commercial value for the medical, cosmetic and food industries due it shows compounds with nutritional, bioactive and prebiotic properties. Its composition consists of pulp 47%–74%, peel 38% and seeds 3%–15% [13]. The use of pitahaya in various industries has generated agro-industrial waste; the peels and seeds represent approximately 40% of the initial mass of the fruit [14]. The peels contain polysaccharides that can be extracted and then to be used in other processes, adding value to this waste [15]. Mucilage found in the pitahaya peel, it is a polysaccharides of branched structure, containing pectin wich has gelling properties [16]. This mucilage has been used as natural coagulant and floctuant for removal of different pollutants in several wastewaters [17–20].

The literatura also shows that the addition of mucilages extracted from plants in electrocoagulation processes improve the removal performance of pollutants in wastewater [21,22]. So, in recent years, there has been a search for compounds of natural origin, environmentally friendly, and low cost, which can be used as biocoagulants for removal of pollutants from aqueous systems.

To our best knowledge, there is a gap related to the removal of pollutants when it is added mucilage from pitahaya after EC process for treatment real textile wastewaters. In this sense, this work aims to evaluate the efficiency of the EC process assisted with the biocoagulant of pitahaya peels for treatment of textile wastewater. The biocoagulant was extracted of direct way from the fruit and chemometric tools were used to evaluate and optimize the parameters pH, current density and reaction time of the EC process, using Fe and Al electrodes. The optimized EC processes were assisted by addition of biocoagulant doses of the pitahaya peels for treatment of the real textile wastewater.

2. Materials and methods

2.1. Preparation of biocoagulant from pitahaya peels

The biocoagulant was prepared from the direct extraction method. Initially, pitahaya fruits were acquired from the local marked and take to the laboratory. Then, the peels were removed from the fruits, washed with tap water in abundance and distilled water. The peels were submitted to maceration process using mortar piston and then centrifuged at a speed of 3,700 rpm for 15 min. The mucilage (gel) was separated from the resulting material and property stored in a refrigerator at 4°C for further studies.

2.2. Characterization of biocoagulant

The surface groups of biocoagulant were investigated from the Fourier-transform infrared (FTIR) spectrum recorded at 4 cm^{-1} of resolution with 16 scan between range of 4,000–400 cm^{-1}, using a Perkin Elmer spectrometer in the resolution.

2.3. Wastewater

The wastewater was obtained from a textile industry located Arequipa city, Peru, which carries out the process of making, dyeing and finishing clothes with cotton fiber. The sample was taken from a tank that stores wastewater from the washing, bleaching, mercerizing, dyeing and finishing stages of cotton fiber fabrics. The determination of chemical oxygen demand (COD), pH, color, conductivity and turbidity of wastewater were performed according to APHA [23] and results are shown in Table 1.

2.4. Electrocoagulation process (EP)

The treatment of textile wastewater by EC was carried out in a 0.8 L polypropylene monopolar batch reactor. The electrodes (Al and Fe), with dimensions of 10 cm × 5 cm × 0.3 cm (109 cm^2 of active area), were placed 3 cm apart and connected in monopolar parallel connection mode. Before each experiment, the electrodes were washed with a mixed

Table 1
Characteristics of wastewater of textile industry

Parameter	Value
COD	418.4 mg/L
Turbidity	55.89 NTU
Conductivity	367 μS/cm
pH	8.65
Color	388.7 Pt-Co

solution prepared from the 100 mL of HCl (36.5%) and 200 mL of hexamethylenetetramine (2.8%) to remove the oxide layers on them [24]. Each experiment was performed with 0.7 L of the wastewater sample under constant agitation at 400 rpm. Current density adjustment was performed using a direct current power supply (MESTEK DP3030) operated in galvanic mode. All experiments were performed at room temperature and in triplicate. Fig. 1 shows the experimental system used for EC process.

2.5. Experimental design of EC

The EC parameters for treatment of textile wastewater were evaluated using the Box–Behnken design and optimized from the desirability function. This design allows to evaluate the possible interaction between factors and provides the response surfaces. The operating parameters (variables) evaluated were pH (x_1), current density (x_2) and reaction time (x_1), and response was turbidity removal percentage value. The values of real and coded variables and its levels are shown in Table 2. These values were selected from the previous studies and those reported in the literature.

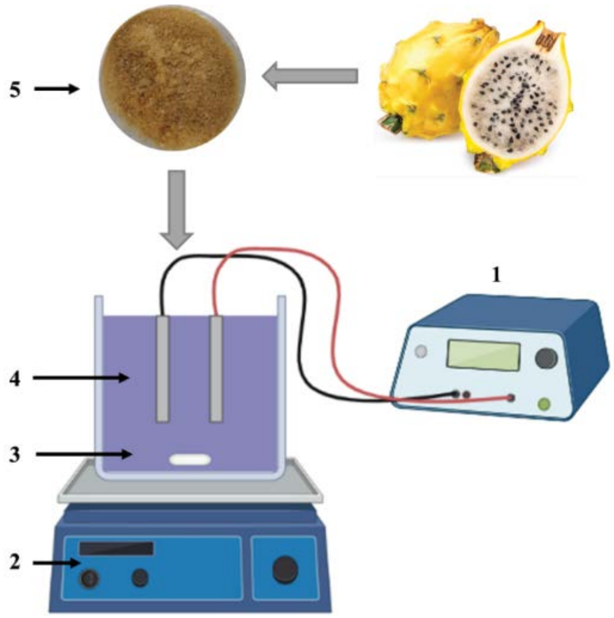

Fig. 1. Experimental system. (1) DC power supply; (2) stir plate; (3) stir magnet; (4) electrodes; (5) pitahaya biocoagulant.

Table 2
Real and coded levels for independent variables investigated in the EC process, using Fe and Al electrodes

Variable	Coded values		
	–1	0	+1
	Real values		
pH (x_1)	4	7	10
Current density (mA/cm^2), (x_2)	20	30	40
Time (min), (x_3)	30	40	50

It was proposed second-order polynomial regression models [Eq. (1)], evaluating the responses on the investigate variables, for EC experiments with the Fe and Al electrodes.

$$Y = \beta_0 + \sum_{i=1}^{k}\beta_i x_i + \sum_{i=1}^{k}\beta_{ii} x_i^2 + \sum_{1\le i\le j}^{k}\beta_{ij} x_i x_j + \varepsilon \quad (1)$$

where Y is the experimental response that consists in the turbidity percentage removal, x_i and x_j are the independent variables; β_0 is the constant term; β_i, is linear regression coefficient, β_{ii} is quadratic regression coefficient and β_{ij} is the interaction regression coefficients; k is the number of variables studied and optimized in the experiment, and ε is the residues of model.

The analysis of variance (ANOVA) was used to evaluate the significance of variables and their terms on the experimental response, as well as, the significance of the regression model at the confidence interval of 95%. The variables and its terms were evaluated from the p-values. The p-values $\le$ 0.05 were considered significant and those p-values > 0.05 were non-significant [25]. The software Design-Expert® 7.1.3 was used for design, statistical analysis and to obtain the response surfaces.

2.6. Electrocoagulation processes assisted with biocoagulant

The EC assisted with biocoagulant (BPh) for treatment of textile industrial wastewater was performed adding amounts of BPh with dosages of 0, 30, 35, 40, 45 and 50 mg/L. The system was shaken constantly using the magnetic shaker under the optimized EC conditions. The evaluated parameters of treated wastewater were removal percentages of turbidity, color and chemical oxygen demand, which were calculate from Eq. (2):

$$\text{Removal value}(\%) = \frac{(\text{Initial value} - \text{Final value})}{\text{Initial value}} \times 100 \quad (2)$$

The results were evaluated from the statistical analysis of Tukey test at level of 95% of confidence, using the software Statistica.

2.7. Determination of inorganic elements

The determinations of inorganic element concentrations in the textile industrial wastewater and after treatments of EC and EC assisted with biocoagulant carried out from the inductively coupled plasma mass spectrometry (ICP-MS), using an ICP-MS equipment, Agilent model 7900, according to ISO 17294-2 water quality analysis methodology.

3. Results and discussion

3.1. Biocoagulant characteristics

Fig. 2 shows the FTIR spectrum of biocoagulant, from which it is possible to observe three main bands that are associated with presence of carbohydrates, proteins and moieties [26]. The peaks in the region at 1,000 and 2,000 cm^{-1} are associated to the main functional groups found in

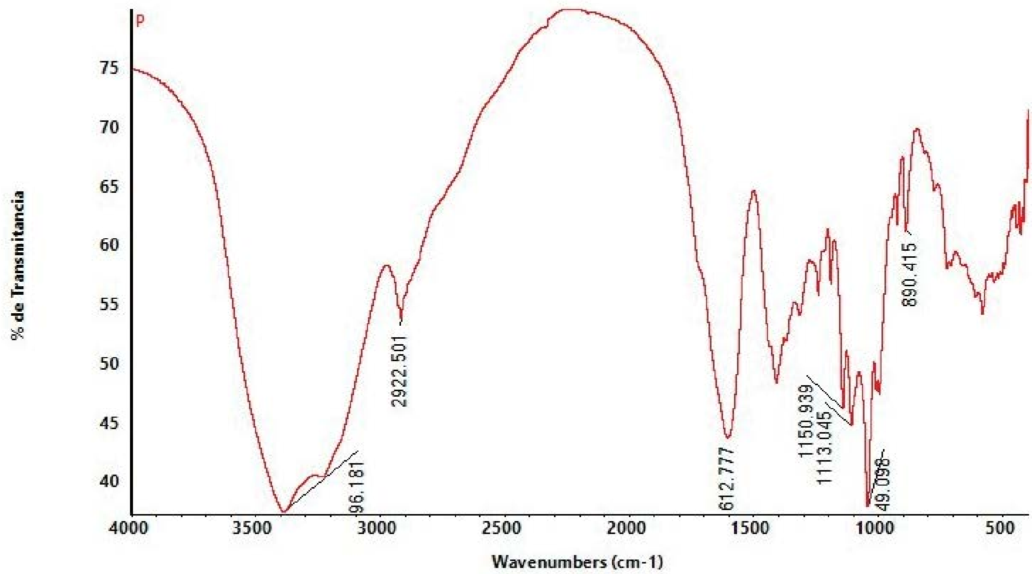

Fig. 2. FTIR spectrum of biocoagulant of the pitahaya peel.

pectin [27]. On the other hand, it is also observed that the most representative band is located between the region of 3,000–3,600 cm^{-1}, which is attributed to the vibrational stretching of the O–H functional group. The peak observed at the peak 2,900 cm^{-1} is attributed to the stretching of CH_2–CH_2 or CH_3 of the methyl ester of galacturonic acid [28,29]. The peak in the region 1,630–1,660 cm^{-1} is attributed to carbonyls esterified with methyl (C=O) and carboxylate anions (COO–) of vibrational stretching, which also refers to the possible presence of uronic acid from polysaccharides [30]. According to the Cárdenas et al. [31], the peak located at 1,749 cm^{-1} indicates the degree of esterification of the mucilage, the spectrum shows a peak located in the region 1,605 cm^{-1} which it can indicate a low degree of esterification of the biocoagulant (mucilage). The peaks located between 1,150–1,046 cm^{-1} are recognized by the presence of carboxyl and phenolic groups with C–OH stretching. The absorption peaks between the 800–1,200 cm^{-1} are observed, which it can be attributed to the fingerprint of the pectin's (P) present in the extracted mucilage [28].

3.2. Statistical analysis and model fittings

The Box–Behnken design (BBD) proposed was an incomplete factorial design of 3 levels (12 experiments) and 3 central points, which totalized 15 experiments. These experiments for EC, using the Al and Fe electrodes, and the response turbidity percentage removal are shown in the Table 3. According to the results, among the ranges of studied variable values, turbidity removal values ranged from 61.91% to 85.92% and 59.98% to 77.11%, using the Al and Fe electrodes, respectively. The results suggest a turbidity removal more efficient for EC using Al electrode than Fe electrode.

Table 4 shows variance analysis (ANOVA) of variables and its terms for EC process using the Fe electrodes. The results suggest that significant terms (those that show *p*-values £ 0.05) are: linear terms of variables pH (x_1), current density (x_2), time (x_3) and quadric term of time (x_3^2). The quadric model obtained was considered significant (*p*-value < 0.05) and it is shown by Eq. (3), considering only the significant terms.

$$Y = 76.59 + 2.81x_1 + 3.77x_2 + 3.86x_3 - 5.94x_3^2 \quad (3)$$

According to results, the obtained model [Eq. (3)] shows coefficients with positive signals for linear terms of variables pH (x_1), current density (x_2) and time (x_1), suggesting synergic effects with the response (turbidity removal) inside the herein investigated range. The highest responses can be obtained for the high values of these variables. On the other hand, the model shows negative signal for quadric term x_3^2, indicating an antagonistic effect for time variable, beside of range herein investigated. The greatest value of coefficient for quadratic term of time variable (x_3^2) in comparison to the coefficient of linear term (x_3), suggests an antagonist effect more pronounced to high values of this variable than synergic effect.

The variance analysis (ANOVA) of variables, its terms and model for EC using the Al electrodes is shown in the Table 5. The fitting of a quadric model for response (turbidity removal) in the experiments using Al electrode was not significant, as well as for other mathematical functions which could be applied on it. In this sense, it was suggested a model linear, which was considered significant (*p*-value < 0.05). Additionally, the terms considered significant were linear terms x_2 and x_3, from which it was obtained the linear model shown by Eq. (4).

$$Y = 72.63 + 4.65x_2 + 3.86x_3 \quad (4)$$

According to the results [Table 5 and Eq. (4)] is possible to infer the non-significance of the pH variable, inside range herein investigated, for EC using the Al electrode.

Table 3
Box–Behnken experimental design (BBD) for EC processes, using Al and Fe electrodes, and TB removal values (%)

Experiment	X_1^a (x_1)[b]	X_2^a (x_2)	X_3^a (x_3)	TB removal values (%)	
				Al	Fe
1	4 (–1)	20 (–1)	40 (0)	75.22 ± 2.19	70.91 ± 1.02
2	10 (+1)	20 (–1)	40 (0)	65.78 ± 1.58	77.11 ± 0.88
3	4 (–1)	40 (+1)	40 (0)	85.92 ± 0.92	76.23 ± 1.03
4	10 (+1)	40 (+1)	40 (0)	73.76 ± 1.23	79.67 ± 1.26
5	4 (–1)	30 (0)	30 (–1)	61.91 ± 2.16	59.98 ± 1.48
6	10 (+1)	30 (0)	30 (–1)	68.09 ± 0.61	69.96 ± 2.03
7	4 (–1)	30 (0)	50 (+1)	83.75 ± 0.47	73.10 ± 1.22
8	10 (+1)	30 (0)	50 (+1)	75.89 ± 1.24	75.98 ± 1.41
9	7 (0)	20 (–1)	30 (–1)	67.64 ± 1.44	60.76 ± 1.02
10	7 (0)	40 (+1)	30 (–1)	74.81 ± 1.08	75.25 ± 1.50
11	7 (0)	20 (–1)	50 (+1)	71.22 ± 0.59	69.99 ± 0.89
12	7 (0)	40 (+1)	50 (+1)	80.95 ± 1.54	77.76 ± 1.35
13	7 (0)	30 (0)	40 (0)	78.34 ± 1.24	76.45 ± 1.31
14	7 (0)	30 (0)	40 (0)	75.40 ± 1.06	77.26 ± 1.19
15	7 (0)	30 (0)	40 (0)	78.98 ± 1.08	76.06 ± 1.69

[a]Real value: X_1 = pH; X_2 = current density (mA/cm^2); X_3 = time (min).
[b]Coded values.

Table 4
Analysis of variance (ANOVA) of the model, variables (factors) and terms on the response (TB removal) for EC process using Fe electrodes

Source	Sum of square	DF	Mean square	F-value	p-value
Model	454.96	9	50.55	7.28	0.0208
x_1	63.28	1	63.28	9.11	0.0295
x_2	113.55	1	113.55	16.34	0.0099
x_3	119.20	1	119.0	17.16	0.0090
x_1x_2	1.90	1	1.90	0.27	0.6230
x_1x_3	12.60	1	12.60	1.81	0.2359
x_2x_3	11.29	1	11.29	1.62	0.2584
x_1^2	2.97	1	2.97	0.43	0.5418
x_2^2	0.31	1	0.31	0.044	0.8423
x_3^2	130.17	1	130.17	18.74	0.0075

DF = degree of freedom

Table 5
Analysis of variance (ANOVA) of the variables (factors) on the response (TB removal) for EC process using Al electrodes

Source	Sum of square	DF	Mean square	F-value	p-value
Model	297.69	3	99.23	4.83	0.0221
x_1	5.88	1	5.88	0.29	0.6032
x_2	172.61	1	172.61	8.40	0.0145
x_3	119.20	1	119.20	5.80	0.0347

DF = degree of freedom.

In addition, it is considered that variables current density and time show synergistic effects on the response (turbidity removal), once that its linear coefficients showed positive signals. The similar values of these coefficients indicate similar influence them on the response.

3.3. Response surface

Fig. 2 shows the three-dimensional response surface plots for turbidity removal as function of two variables, keeping the third at its central level for EC experiments carried out with Fe (Fig. 3a–c) and Al (Fig. 3d and e) electrodes. According to Fig. 3a, the EC using Fe electrodes shows the high responses when pH and current density variables are in the high levels. The tendencies for these variables also are observed in Fig. 3b and c, however, the plots show curvatures with convex characteristics due the significant term x_3^2 of Eq. (2), which represents the quadratic term of variable time. In this sense, it possible to infer that a tendency of decrease for response for longer times and that inside the studied range there is a value which can represent a maximum response.

The fit of linear model for EC using the Al electrode is represented by response surface plots with features planar (Fig. 3d–f). These results indicate that highest values of response can be obtained for values beside of range herein investigated and that there is not interaction between variables. Additionally, the biggest slopes of plots with the variables current density and time show the greatest influence of these variables on the response. The lowest slope of plots with variable pH indicate the non-significance of this variable inside of investigated range.

The solution pH is an important parameter in the EC processes, once that it is responsible by speciation and

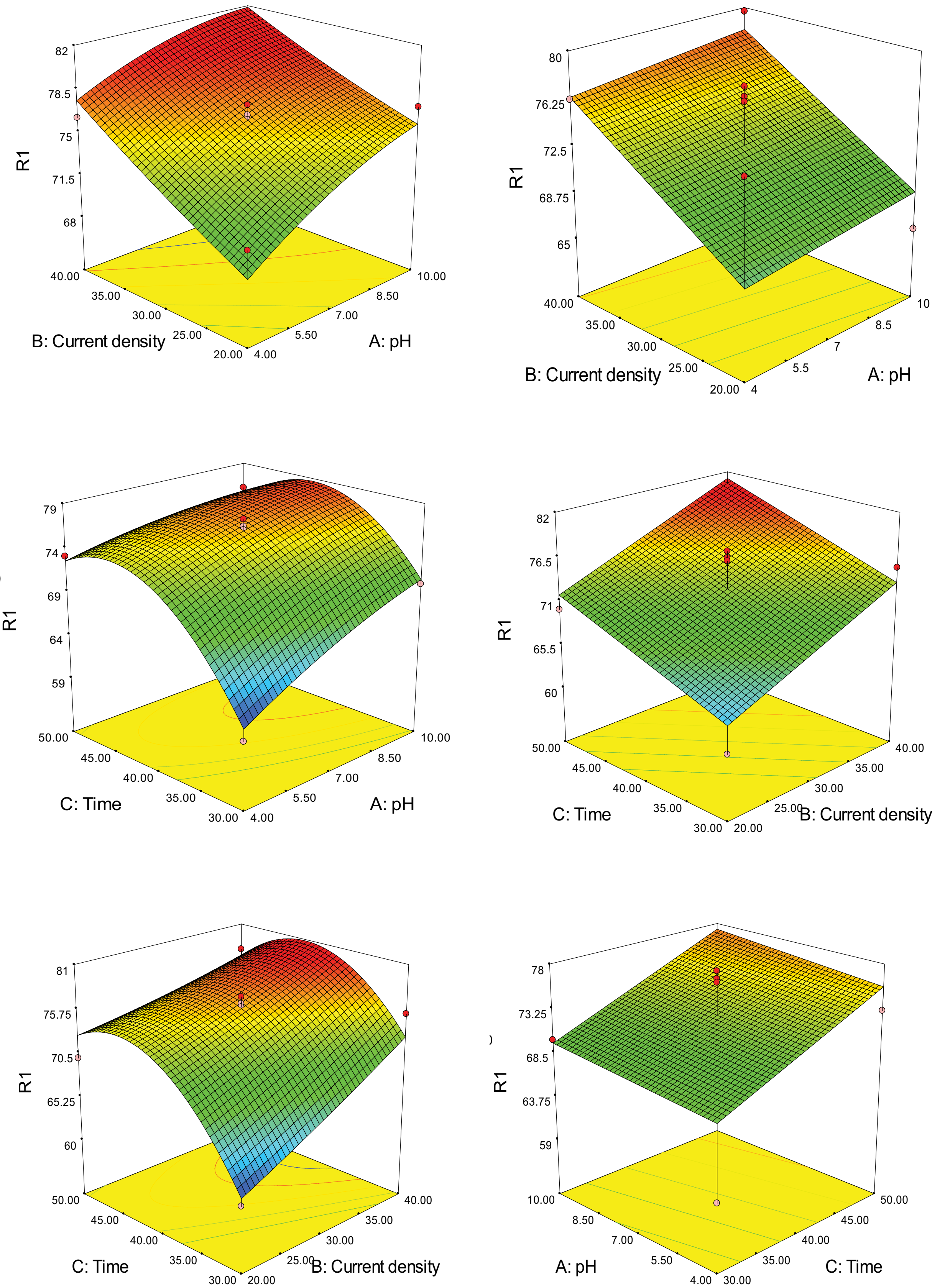

Fig. 3. Three-dimensional response surfaces for the values of turbidity removal value (5) for EC processes using Fe electrodes (a–c) and Al electrodes (d–f).

solubility of electrode metallic ions in aqueous solutions. The electrochemical reactions which occur in this process, using the Fe and Al electrodes, are as following [32,33]:

In the Fe anode:

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

In acid medium:

$$4Fe^{2+}_{(aq)} + O_{2(g)} + 10H_2O_{(l)} \rightarrow 4Fe(OH)_{3(s)} + 8H^{+}_{(aq)} \quad (6)$$

In alkaline medium:

$$Fe^{2+}_{(aq)} + 3OH^{-}_{(aq)} \rightarrow Fe(OH)_{2(s)} \quad (7)$$

In the Al anode:

$$Al_{(s)} \rightarrow Al^{3+}_{(aq)} + 3e^{-} \quad (8)$$

In acid medium:

$$Al^{3+}_{(aq)} + 3H_2O_{(l)} \rightarrow Al(OH)_{3(s)} + 3H^{+}_{(aq)} \quad (9)$$

In alkaline medium:

$$Al^{3+}_{(aq)} + 3OH^{-}_{(aq)} \rightarrow Al(OH)_{3(s)} \quad (10)$$

According to reactions [Eqs. (5)–(10)], after electrochemical reactions, from which produce metallic ions in solution, occur the formation of metallic hydroxides that are responsible by coagulation. Thus, it is possible to observe that for Fe electrodes in acid medium is produced $Fe(OH)_{3(s)}$ and in alkaline medium $Fe(OH)_{2(s)}$, while for Al electrodes, in both medium is produced $Al(OH)_{3(s)}$. The formation of two hydroxides from the Fe electrodes and one hydroxide for Al electrodes in solution with different medium, can justify the more influence of medium pH in the EC using Fe electrode.

The influence of current density in both EC processes (using Fe and Al electrodes) occur once that it is responsible by the dosage rate of formed coagulant, bubble production rate and the floc distribution [34]. This can be explicated from the Faraday law, which describes that current density is correlated to the amount of metallic ion that is generated in the EC process [35]. These results herein agree with those obtained by Bener et al. [36], who reported that great efficiencies in EC were observed for high current densities.

The reaction time tends to improve the efficiency of EC due to greater generation of coagulant species in the system from longer times [37] However, the tendency to decrease the turbidity removal for EC using the Fe electrodes in longer time it can be due the largest amount of these hydroxides, which can remain in suspension.

3.2.3. Optimization of EC

The EC processes using the Fe and Al electrodes for treatment of textile industry wastewater were optimized from the desirability function (*d*) provided by software Design-Expert® 7.1.3. The *d* function transforms the estimated response of each variable to desirability value, in which should be $0 \leq d \leq 1$, therefore, the better responses are those which show the highest *d* values [38]. In order to obtain the highest responses of turbidity removal percentages (maximize the response), the evaluation criteria of variables were kept inside the investigated ranges. The *d* values equal to 1.0 were obtained for both EC processes and suggested conditions for pH, current density and time were: 4.93, 40 mA and 49 min for Al electrode, and 9.60, 39 mA and 44 min for Fe electrode, showing estimated responses (turbidity removal) of 80.05% and 80,77%, respectively. The experiments were carried out these conditions and the experimental responses were of 86.50% for Al electrodes and 80.53% for Fe electrodes, which showed variation of 6.45% and 0.03%.

3.3. Optimized EC assisted with biocoagulant

The optimized EC process using the Al and Fe electrodes were assisted with prepared biocoagulant (BPh). The parameters turbidity (TB), color and COD were investigated varying the biocoagulant dosage.

According to the results (Table 6), it is possible to observe that addition of bio-coagulant in the EC processes improve efficiency of wastewater treatment, increasing the removal

Table 6
Removal percentages of turbidity (TB), color (CL) and chemical oxygen demand (COD) for EC processes of textile industrial wastewater, using Al and Fe electrodes, assisted by different dosages of biocoagulant (BPh)

BPh dosage (mg/L)	Al electrode			Fe electrode		
	Removal (%)					
	TB	CL	COD	TB	CL	COD
0	86.50[a,A]	83.97[a,A]	71.99[a,A]	80.53[a,B]	78.72[a,B]	63.65[a,B]
30	87.94[ab,A]	86.65[ab,A]	75.03[b,A]	82.09[a,B]	79.88[a,B]	67.15[a,B]
35	90.28[bc,A]	89.42[bc,A]	77.05[bc,A]	84.95[b,B]	83.69[b,B]	71.22[b,B]
40	93.42[cd,A]	91.45[cd,A]	81.80[d,A]	91.61[c,A]	88.94[cd,A]	77.75[c,B]
45	98.05[e,A]	95.11[e,A]	86.21[e,A]	96.89[d,A]	95.10[e,A]	81.78[d,B]
50	96.40[de,A]	94.30[de,A]	84.16[e,A]	95.62[d,A]	92.23[de,A]	76.82[c,B]

Small letters differ between biocoagulant treatments and capital letters differ between electrode treatments at the 5.0% level by Tukey test.

Table 7
Concentrations of inorganic elements in the textile industrial wastewater before and after the treatment with electrocoagulation process assisted and not with biocoagulant from the pitahaya peels (BPh)

Elements (mg/L)	Textile industrial wastewater	Electrocoagulation			
		Al electrode	Fe electrode	Al electrode/BPh	Fe electrode/BPh
Al	0.0582	1.92	0.0614	0.1496	0.0296
B	1.37	1.04	1.37	1.2	1.37
Ca	4.24	8.79	4.24	5.98	4.89
P	9.94	n.d.	0.206	n.d.	n.d.
Fe	0.206	0.0256	0.0908	0.0286	0.0435
Mg	30.7	2.62	1.88	1.66	3.02
Mn	0.0155	0.4855	0.0162	0.288	0.0266
K	29.8	37.5	38	50.2	45.4
Si	36.9	n.d.	n.d.	n.d.	n.d.
Na	811	970	1069	1096	1076
Zn	0.0415	0.0052	0.0063	0.0065	0.0053

n.d. – not detected.

values of turbidity, color and COD. The Tukey test indicated significative differences between treatment without biocoagulant (dosage zero) with those which were added dosages of biocoagulant. Values greater than 90% were obtained for parameters turbidity and color, and values greater than 80% for COD in both EC processes, using Al and Fe electrodes. The treatments with 45 mg/L of biocoagulant showed the highest removal values, suggesting to be ideal dosage for systems herein evaluate. Additionally, the Tukey test indicated significative difference from the different electrodes used (capital letter in the Table 6). These differences were observed in the dosages 0, 30 and 35 mg/L for parameters turbidity and color, and for other dosages considering the parameter COD.

The pH biocoagulant has a positive effect on the removal of turbidity, color and COD for treatments of textile wastewaters with EC process assisted with biocoagulant, using electrodes of Fe and Al. The results herein obtained agree with those reported by [22], who indicated that the addition of a biocoagulant from *Opuntia ficus* improves the removal of turbidity from synthetic wastewater by electrocoagulation. Similarly, Djerroud et al. [39] reported that the addition of *Opuntia ficus indica* mucilage improves the efficiency of the electrocoagulation process in removing turbidity in synthetic wastewater. The natural coagulant extracted from pitahaya presents environmental and operational advantages as well as other coagulants such as okra mucilage that can remove turbidity and COD in textile wastewater [18]. Shak and Wu [40] showed that the combining chemical and natural coagulants improves COD removal from highly contained effluents such as water from oil plants.

3.4. Inorganic elements in the textile industrial wastewater before and after EC treatments

The determination of inorganic element concentrations in the textile wastewater before and after the treatment optimized EC assisted or not with biocoagulant (BPh dosage of 45 mg/L), using the Al and Fe electrodes, were carried out and the values are shown in Table 7.

The results show that among the determinations of several elements, the textile wastewater has higher concentrations of Ca, P, Mg, K, Si and Na (concentration higher than 4.00 mg/L). The presence of these elements in large concentrations it can be related to the industrial process performed. After EC treatments assisted or not with BPh it was observed a significative decreasing in the concentrations of P, Mg and Si. This can has occurred due the possible interactions of these elements with the coagulant species, which in turn were separated from the solution to sludge produced. The increase of Al concentration with the treatments, it was significant only for EC process using the Al electrodes. This increase is due to electrode oxidation, releasing ions for solution. Additionally, the increase in the concentrations of some other elements (Ca, K, Na) can be due the formation of sludge in the solution, which pre-concentrated in the liquid part those elements which show high solubility.

4. Conclusion

The chemometric tools were successfully used to evaluate and optimize the electrocoagulation processes (EC) for treatment of textile industrial wastewater. The results showed that parameters pH, current density and time are significant for turbidity removal of EC using the Fe electrode and, current density and time for EC using Al electrode. Additionally, the parameters can be evaluated and optimized from the response surface methodology and disability function, respectively. The optimized EC and assisted with the biocoagulant obtained from the pitahaya peels improved the treatment of textile industrial wastewater obtaining turbidity, color and COD removal values of 98.05%, 95.11% and 86.21%, respectively, for the Al electrode; and 96.89%, 95.10% and 81.78% for the Fe electrode. The EC processes assisted with biocoagulant promoted the decrease of inorganic element contents as P, Mg and Si from the wastewater.

The results herein obtained support the application of innovative green technologies and the recovery of agricultural residues for the treatment of real industrial effluents from the textile industry. The biocoagulant obtained from the peels (residue) of pitahaya provides evidence of being an ecological, profitable and accessible compound; and at the same time suitable for the removal of organic and inorganic pollutants such as heavy metals, dyes, additives, among others present in textile wastewater.

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