

Optimization of oil removal from oily wastewater by electrocoagulation using response surface method

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Abstract

Electrocoagulation process with sacrificial aluminium anode was used to separate oil from oily wastewater emulsion. A preliminary experimental study was performed to evaluate the most accurate operating parameters, which are then used for the determination of oil removal efficiency. An experimental design using response surface method (RSM) was then applied and oil separation was estimated by measuring turbidity and chemical oxygen demand (COD). An optimal region characterised with low values of turbidity and COD was found. As part of the optimized process, the main effects of the operational parameters were also investigated. The experimental results indicated that electrocoagulation was very efficient and able to achieve 99% turbidity and 90% chemical oxygen demand (COD) in less than 22 min and current density of 25 mA cm⁻². Analysis of variance (ANOVA) showed a high variance coefficient (R^2) value of 0.998, thus ensuring a satisfactory adjustment of the second-order regression model with the experimental data.

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1. Introduction

The mechanical and metallurgical industries generate great quantities of oily wastewater which in the majority of cases are rejected into nature because of non-adaptation of the processes of treatment. Generally, the presence of oil in water can appear in three manners: immiscible mixture, unstable emulsion and secondary oil-in-water emulsion. In the first both cases, the separation of oil is easy and requires the use of mechanical or physicochemical processes. Due to the presence of surfactants, and co-surfactants, the secondary emulsions are very stable and the emulsified oil droplets are of the order of few micrometers in diameter. This stability arises from the formation of interfacial films encapsulating the oil droplets. Thus, the electrostatic repulsion forces make separation by conventional methods difficult [1].

Appropriate treatment of these wastewaters is necessary in order to reduce the impact of their discharge. Several meth-

ods have been used for the treatment of these wastes, such as chemical destabilization by using inorganic salts [2], flocculation [3], dissolved air flotation [4], and membrane processes [5,6]. A review of literature indicated a certain number of studies which show the success of the oil separation from oily rejections by using electroflotation [7,8]. The principal disadvantage of this method is the limitation of separation efficiency by the oil concentration in the emulsion. To reduce this limitation, other techniques based on the combination of the electroflotation with flocculation were used successfully [9].

Recently, there is a need to identify new technologies that achieve technically and economically efficient separation of oil from oil-in-water emulsion. For this purpose, electrocoagulation process is playing a more prominent role in the treatment of oily wastewaters [10–12], because it provides some advantages: no chemical additives are added to destabilize the emulsion, simple equipment, easy operation, low capital and operating cost and decreased amount of sludge.

Electrocoagulation is a process consisting of creating a floc of metallic hydroxides within the effluent to be treated by electrodisolution of a soluble anode. The coagulant in this technique is mentioned in situ by dissolution of a sacrificial anode and it

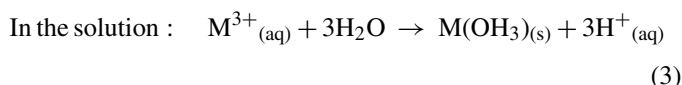
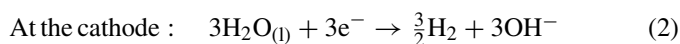
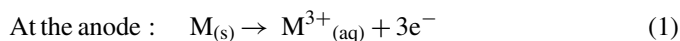
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Nomenclature

C_0	oil concentration (% in wt.)
COD	chemical oxygen demand ($\text{mg O}_2 \text{ l}^{-1}$)
E	electrical energy consumption (kWh m^{-3})
EC	electrocoagulation
i	current density (A m^{-2})
R^2	variance coefficient
Re	removal efficiency (%)
RSM	response surface method
T	temperature ($^\circ\text{C}$)
t_e	electrocoagulation time (s)
x_i	real value
x_{cp}	real value of the centred point
Δx_i	value of variable change step
X_i	coded level
Y_i	predicted response
Y_0 and Y	initial and final turbidity or COD
β_0	offset term
β_i	linear effect coefficients
β_{ii}	squared effect coefficients
β_{ij}	first-order interaction effect coefficients

involves three main processes [13,14]: electrolytic reaction at electrode surface, formation of coagulants by electrolytic oxidation in aqueous phase and adsorption of colloidal particles on coagulant, and removal by sedimentation or flotation. Therefore, the appropriate selection of the electrode materials is very important. The most common used materials for electrocoagulation are aluminium or iron. They are cheap, readily available. However, aluminium was found to be a more appropriate electrode material according to the iron electrode performance [15].

The electrochemical reactions with aluminium as anode may be summarized as follows:



$\text{M}^{3+}_{(aq)}$ and OH^- ions generated by the electrode reactions (1) and (2) react, respectively, to form various monomeric species, depending on pH range, which transform finally into $\text{M}(\text{OH})_3$ according to complex precipitation kinetics. Freshly formed amorphous $\text{M}(\text{OH})_3$ (sweep flocs) with large surface areas which are beneficial for a rapid adsorption of soluble organic compounds and trapping of colloidal particles. Consequently, these flocs can be removed by sedimentation or by flotation using H_2 bubbles produced at the cathode [16].

Optimizing the electrocoagulation process implies determination of the experimental conditions for separation of oil from oil-in-water emulsion. In the preliminary study, the problem can be defined as destabilizing the emulsion by destroying the inter-

facial film and overcoming the repulsion effects of the electrical double layer to allow the finally sized oil droplets to form larger droplets through coalescence. In the second stage, the optimal operating conditions will be applied and the research will concern the optimal operational parameters aimed to separate oil using the electrochemical method. While the objective is to evaluate one or more factors that have an unquestionable effect on the process separation. In conventional multifactor experiments, optimization is usually carried out by varying a single factor while keeping all other factors fixed at a specific set of conditions. It is not only time-consuming, but also usually incapable of reaching the true optimum due to ignoring the interactions among variables. Thus, it is desirable to develop an acceptable process in shortest possible time using minimum number of men, hours and raw materials. In addition, the technique of the experimental design is an efficient method of indicating the relative significance of a number of variables and their interactions [17]. For this purpose, response surface method (RSM) was proposed to determine the influences of individual factors and their interactive influences. RSM is a statistical technique for designing experiments, building models, evaluating the effects of several factors, and searching optimum conditions for desirable responses [18]. The main advantage of this method of other statistical experimental design methods is the reduced number of experiments trials needed to evaluate multiple parameters and their interactions [19]. Recently, this method has been used to determine optimum parameters in different processes [20,21].

In this study, electrocoagulation using aluminium sacrificial anode was used for the treatment of oily emulsion. In order to evaluate the decrease of turbidity and increase of oil removal from the emulsion three important electrochemical factors were investigated: current density, initial pH, electrocoagulation time. A response surface method was used to obtain the best parameters for the optimum process design with the least number of experiments.

2. Experimental

2.1. Materials

Test fluids consisted of oil-in-water emulsion prepared from a concentrated cutting fluid containing 80% mineral oil, 10% surfactant 6% co-surfactant and 4% of additive. Commercial cutting oil, Tasfalout 22 B was manufactured by Naftal (Algeria). The emulsions were prepared by adding the concentrated oil to distilled water at room temperature with magnetic stirring at 350 rpm for 10 min. The concentration of the treated emulsion is 5% (in wt.) corresponding to the industrial applications. The conductivity of sample was adjusted to the desired level by adding an appropriate amount of sodium sulphate (Na_2SO_4 0.07 M). Then, the supporting electrolyte dissolved in deionised water was added slowly while the mixture was being stirred to finally obtain oil-in-water emulsion. The properties of the emulsion are shown in Table 1. Aluminium flat electrode of rectangular shape was used as sacrificial anode and two stainless steel plates were used as cathodes.

Table 1
Properties of the emulsion

Parameters	C_0 (% in wt.)	Density (kg m^{-3})	pH	Turbidity (NTU)	COD ($\text{mg O}_2 \text{ l}^{-1}$)	Conductivity ($\mu\text{s cm}^{-1}$)
Value	5	993	8.65	29700	62300	1121

2.2. Experimental devices

The electrocoagulation experiments were conducted in a monopolar batch reactor (Fig. 1) with three electrodes connected in parallel to a digital DC power supply (0–30 V, 2.5 A). The electrodes were disposed vertically in the cell at a distance of 1 cm from each other. The volume of the treated emulsion was 400 cm^3 and the total effective electrode area was 40 cm^2 . The pH was adjusted to a desirable value using NaOH or H_2SO_4 . The runs were performed at room temperature (20–22 °C).

2.3. Analyses

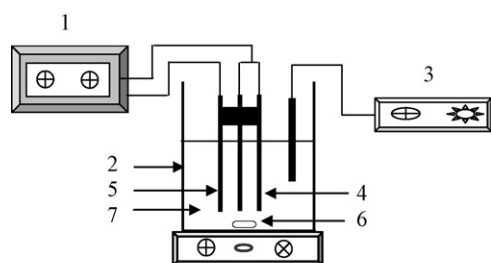
The emulsion turbidity was measured by using a WTW turbidimeter (Germany) with a highest sensitivity of 0.01 NTU and the chemical oxygen demand was determined by conventional potassium dichromate oxidation process. Microscopic observations on the emulsion and on the flocs were realized using an optical microscope (Biostar B4, Germany). The microscope was coupled to a CCD camera connected to a computer. The turbidity and COD were chosen as responses of this system. The removal efficiency ($Re\%$) was calculated using the following equation:

$$Re(\%) = \frac{Y_0 - Y}{Y_0} \times 100 \quad (4)$$

where Y_0 and Y represent, respectively, the initial and final turbidity or COD.

2.4. Experimental design

Response surface method was applied to evaluate and determine the optimum operating conditions. The main effects of



1. DC power supply
2. EC cell
3. pH-meter + Thermometer
4. Cathode
5. Anode
6. Bar stirrer
7. Oily wastewater

Fig. 1. Schematic diagram of the electrocoagulation cell.

three independent factors: current density (x_1), pH of the solution (x_2) and electrocoagulation time (x_3) were investigated using a D-optimal design. The D-optimal method is relatively a new technique, related to response surface methodology, used for carrying out the design of experiments, the analysis of variance, and the empirical modeling. The D-optimal criterion was developed to select design points in a way that minimizes the variance associated with the estimates of specified model coefficients [22]. In a sense this method is more useful than central composite design method that it demands smaller number of experiments to be conducted and also it can tackle categorical factors included in the design of experiments [23]. Plans with high D-value are constructed from the data by a computer algorithm. Table 2 presents the levels of predictor variables tested following D-optimal design of experiments. The variables were coded according to Eq. (5):

$$X_i = \frac{x_i - x_{cp}}{\Delta x_i} \quad (5)$$

where X_i is the coded level, x_i is the real value, x_{cp} is the real value of the centred point, and Δx_i is the value of variable change step.

Experimental data were fitted to a second-order polynomial model and regression coefficients were obtained. The generalized second-order polynomial model used in the response (Y_i) surface analysis was as follows:

$$Y_i = \beta_0 + \sum_1^3 \beta_i X_i + \sum_1^3 \beta_{ii} X_{ii}^2 + \sum_1^3 \beta_{ij} X_{ij} \quad (6)$$

where β_0 , β_i , β_{ii} and β_{ij} are the regression coefficients for intercept, linear, quadratic and interaction terms, respectively, and X_i and X_j are the independent variables.

The quality of this model and its power of prediction, are related to the variance coefficient, R^2 . The responses fixed as objectives in this process are turbidity removal (Y_1) and COD removal (Y_2). The model of surface response corresponding to the D-optimal experimental design takes into account all the principal retained factors and their interactions.

Table 2
Factors and level of experimental design

Factors	Original factors (x)	Coded factors (X)		
		−1	0	+1
Current density (mA cm^{-2})	x_1	5	20	35
pH	x_2	5	8	11
Electrocoagulation time (min)	x_3	6	18	30

3. Results and discussion

3.1. Preliminary experiments

One of the most important characteristic of the oil-in-water emulsion is a high turbidity and COD. The turbidity of an emulsion is related to the concentration of droplets. Rajinder [24] reported that this parameter can be used to determine the oil concentration in the emulsion. Furthermore, turbidity also depends on the size of oil droplets and, as the droplets tend to coalesce, the turbidity may decrease due to a lower number of droplets or an increase in their size. Then the important parameters which affect the efficiency of oil removal by EC process are current density, time of electrolysis and pH.

It has been established that the initial pH is an important parameter in determining the performance of EC process [25]. In order to examine the effect of pH on the removal efficiency of turbidity and COD, it was varied between 5 and 11. As seen in Fig. 2, the pH of the treated emulsion increases during the process up to basic pH. Vik et al. [26] attributed the pH increase to hydrogen evolution at cathodes (reaction (2)). However, Chen [27] explained this increase in pH by the release of CO_2 from wastewater owing to H_2 bubbles. In addition, the chemical dissolution of aluminium (reaction (1)) will consume H^+ and gives rise to the pH increase. Fig. 2 shows also the removal efficiency of turbidity and COD as a function of the initial pH. It is clear that the maximum removals of turbidity and COD was observed at acidic medium (pH 5) and it remains unchanged between pH 6 and 7. On the other hand, removal efficiency dropped dramatically at pH 8. Therefore, it can be explained that at $\text{pH} > 9$, the flocs of aluminium hydroxide are less reactive and the flocculation is less effective, because the formation of flocs of small size, which causes the formation of a deposit on the anode and leads to an increase of the ohmic resistance of oily wastewater. Inside this range of pH (5–7), the obtained removals of turbidity and COD are 99% and 90%, respectively. This result is in accord with previous study [10,28].

In the batch electrocoagulation process, current density is a critical parameter, as it is the only operational parameter that

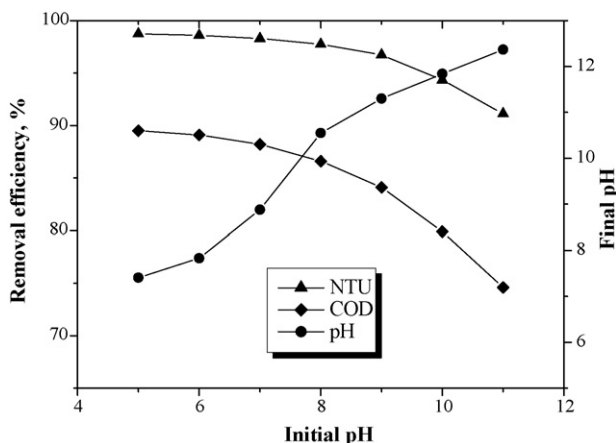


Fig. 2. Effect of initial pH on the turbidity and COD removals, $i = 20 \text{ mA cm}^{-2}$, $t_e = 30 \text{ min}$, $T = 20\text{--}22^\circ\text{C}$, $C_0 = 5\%$ in wt.

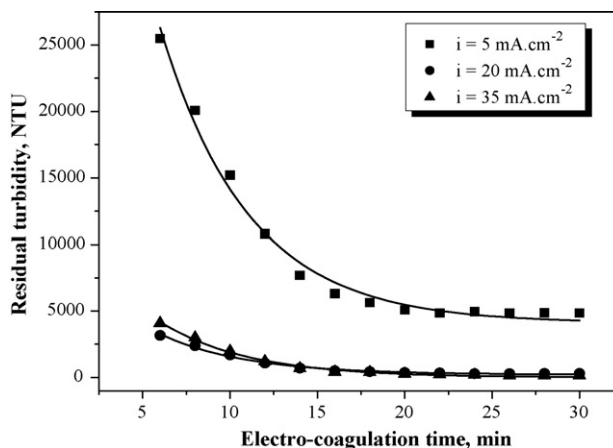


Fig. 3. Effect of current density on the residual turbidity, $\text{pH } 6\text{--}7$, $T = 20\text{--}22^\circ\text{C}$, $C_0 = 5\%$ in wt.

can be directly controlled; it was suggested that current density determines both coagulant dosage and bubble generation rates [29]. To investigate the effect of current density on the turbidity and COD removals, a series of experiments were carried out. Figs. 3 and 4 show the effects of current density on the residual turbidity and COD upon electrolysis time, when it was varied from 5 to 35 mA cm^{-2} . It appears that turbidity and COD exhibit regular variation, with a more continuous decrease with time to reach to a constant value. This behaviour may be due to the destabilization of emulsion. The applied current density at 20 and 35 mA cm^{-2} produced the quickest removal of turbidity and COD just after 20 min. The higher current density allowed faster treatment of the oil–water emulsion. This is ascribed to the fact that a high current density will generate significant amount of oxidized aluminium, resulting in a greater amount of precipitate for the removal of colloidal particulates. In addition, it was reported that bubbles density increases and their size decreases with increasing current density [8], resulting in a greater upwards flux and a best removal of pollutant and sludge flotation. The obtained results showed that an increase in the current density increased the removal efficiency, which is also stated in literature [11,13,30]. Thus, an increase in current density implies

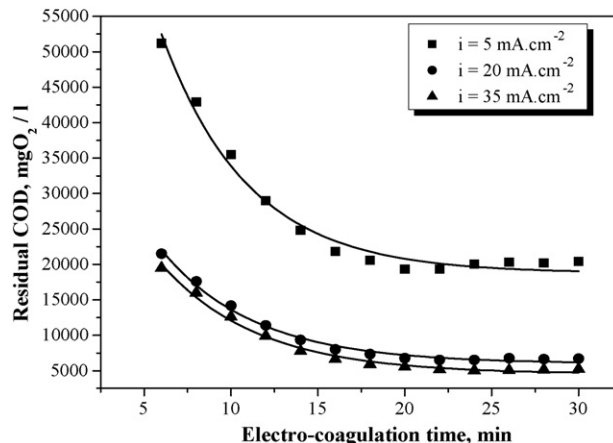


Fig. 4. Effect of current density on the residual COD, $\text{pH } 6\text{--}7$, $T = 20\text{--}22^\circ\text{C}$, $C_0 = 5\%$ in wt.

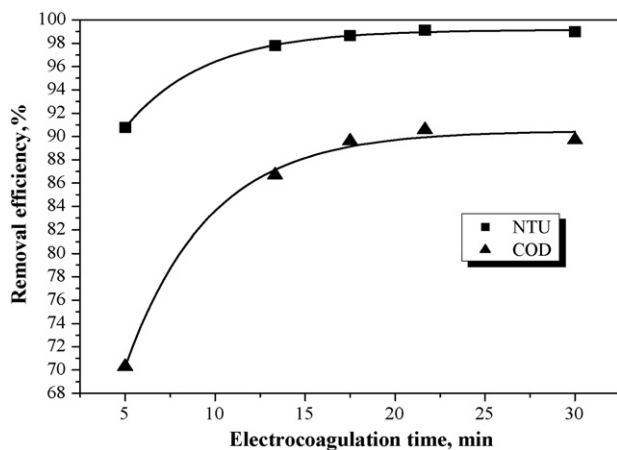


Fig. 5. Effect of EC time on the turbidity and COD removal efficiencies, $i = 20 \text{ mA cm}^{-2}$, $T = 20\text{--}22^\circ\text{C}$, $\text{pH } 6\text{--}7$, $C_0 = 5\%$ in wt.

an increase in the amount of coagulant (Al^{3+}) produced by the electrochemical dissolution of the aluminium anode. Indeed, the amount of coagulant generated at fixed time, within the electrocoagulation cell is related to the current flow, using Faraday's law. The presence of coagulant in solution contributes to an increase of oil removal efficiency by flotation. This phenomenon can be attributed to different mechanisms: flocculation of the oil droplets, reduction of electrostatic repulsion between the air bubble and oil droplets and an increase of oil droplets hydrophobicity. In the present investigation experiments, a current density around 25 mA cm^{-2} seem to be sufficient for a better electrolytic flocculation and consequently a maximum of removal efficiency (99% turbidity and 89% COD).

As seen in Fig. 5, the removal efficiencies of turbidity and COD increase according to time. The first 6 min of the EC process give a considerable removal of turbidity and COD (89–67.4%) of the initial emulsion. The increase in the EC time gives better results in removal efficiency to reach 99% turbidity and 90% COD, just after 20 min. However further increase of the EC time; the removal efficiency remains constant, when the emulsion becomes visually very clear. Therefore, the optimal EC time is around 20 min for this equipment where the electrocoagulation process is effective in reducing turbidity and amount of pollutants (COD) in the emulsion. The trend of this result is similar to those obtained by Xu and Zhu [10].

From an energetic point of view, energy consumption during EC is a function of current and operating time. Fig. 6 shows the variation of the electrical energy consumed per cubic-meter of the treated emulsion against as a function of current density and electrocoagulation time at initial pH values varied within the range of 6–7. An increase in current density from 5 to 35 mA cm^{-2} causes an increase in voltage between electrodes from 2.3 to 6.5 V and an increase in power requirement from 0.115 to 11.38 kWh m^{-3} . Thus, the energy consumption increases with current density. For example, for EC time = 30 min, the system consumed an energy of 0.58, 4.3, 11.38 kWh m^{-3} when current density values were 5, 20 and 35 mA cm^{-2} , respectively. At EC time = 6 min, thus the lowest

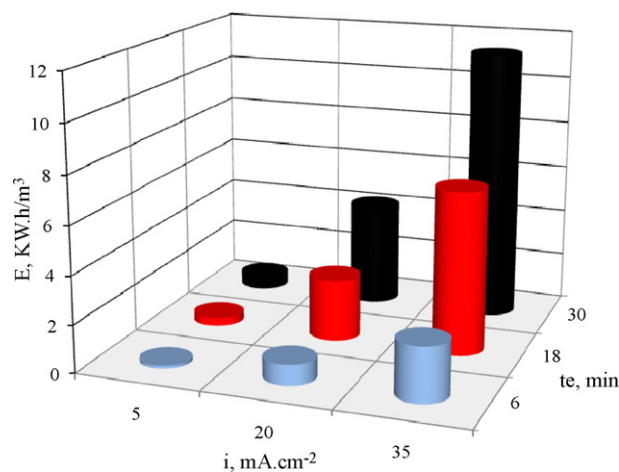


Fig. 6. Variation of energy consumption as function of current density and EC time $\text{pH } 6\text{--}7$, $T = 20\text{--}22^\circ\text{C}$, $C_0 = 5\%$ in wt.

energy consumption values were achievable (0.12 kWh m^{-3}) at a current density of 5 mA cm^{-2} .

For the treatment of an emulsion of 5% in wt. and under the optimal operation conditions, the power consumption is usually equal to 3 kWh m^{-3} . Previous works showed that energy consumption could range from 2 to 4 kWh m^{-3} [31]; the process seems competitive in comparison to incineration or water evaporation.

3.2. D-optimal experiments

The arrangements of D-optimal experiments are listed in Table 3, which include 16 sets of electrocoagulation experiments. By using multiple regression analysis, the responses (turbidity and COD removals) were correlated with the three design factors using the second-order polynomial (Eq. (6)). The quadratic regression model for turbidity removal (Y_1 , %) and COD removal (Y_2 , %) in terms of coded factors are given by Eqs. (7) and (8), respectively:

$$Y_1 = 98.6225 + 11.4138 X_1 - 10.9707 X_2 + 21.3454 X_3 - 14.0451 X_1^2 - 10.3814 X_2^2 - 19.837 X_3^2 - 1.8935 X_1 X_2 - 1.1739 X_1 X_3 - 1.9514 X_2 X_3 \quad (7)$$

$$Y_2 = 89.4575 + 11.3876 X_1 - 10.9872 X_2 + 22.0024 X_3 - 13.289 X_1^2 - 10.4034 X_2^2 - 20.2716 X_3^2 - 1.6465 X_1 X_2 + 1.6741 X_1 X_3 - 2.7659 X_2 X_3 \quad (8)$$

The second-order regression model obtained for the operating variables of turbidity and COD removals are satisfied as the predicted versus observed value plot approximates along a straight line as shown in Fig. 7. The high R^2 value, close to 1, is desirable and the predicted R^2 must be in reasonable agreement with the adjusted R^2 for a significant model. The value of R^2 for turbidity and COD removals are 0.998 and 0.991, respectively.

Table 3
RSM design and its observed and predicted values

Run	X_1 , (mA cm ⁻²)	X_2	X_3 , (min)	Experimental turbidity removal (%)	Predicted turbidity removal (%)	Experimental COD removal (%)	Predicted COD removal (%)
1	-1	-1	-1	26.86	27.5514	14.72	16.4422
2	1	-1	-1	58.19	56.5141	42.94	39.1623
3	-1	1	-1	14.16	13.3001	5.12	3.29284
4	1	-1	1	99.9	100.76	90.22	92.0472
5	-1	1	1	52.76	54.4359	34.64	38.4177
6	1	1	1	71.82	71.1286	62.97	61.2478
7	-1	-1	0.333	77.12	77.812	64.14	65.2538
8	-1	-0.333	1	80.63	78.3685	68.86	63.8073
9	1	1	-0.333	65.16	64.4681	52.5	51.3862
10	1	0.333	-1	48.93	51.1916	30.2	35.2527
11	-0.333	-1	1	96.88	97.0665	83.45	84.2488
12	0.333	1	-1	40.23	40.0435	26.66	25.8612
13	0	0	0	98.92	98.6225	85.06	85.5475
14	0	0	0	99.81	98.6225	83.24	85.5475
15	0	0	0	97.26	98.6225	85.45	85.5475
16	0	0	0	98.5	98.6225	88.44	85.5475

In this case it indicates that only 0.2–0.9% of the total variation is not explained by the model. The values of the adjusted R^2 of 0.995 and 0.977, respectively, for turbidity removal and COD removal are also high to advocate a high significance of the model.

Statistical testing of the model was performed with the Fisher’s statistical test for analysis of variance (ANOVA). The results of the ANOVA for turbidity and COD removals are shown in Table 4. The ANOVA of these responses demonstrated that the model is highly significant as is evident from the value of $F_{\text{statistic}}$ (the ratio of mean square due to regression to mean square to real error), ($F_{\text{model(a)}} = 347.096$ and $F_{\text{model(b)}} = 72.955$) and a very low probability value ($P = 0.0001$). P value lower than 0.01 indicated that the model is considered to be statistical significant [32].

3.3. Optimization of operating conditions

The response surface contour plots to estimate the oil recovery efficiency (COD and turbidity removals) over independent variables current density and time electrolysis are shown in

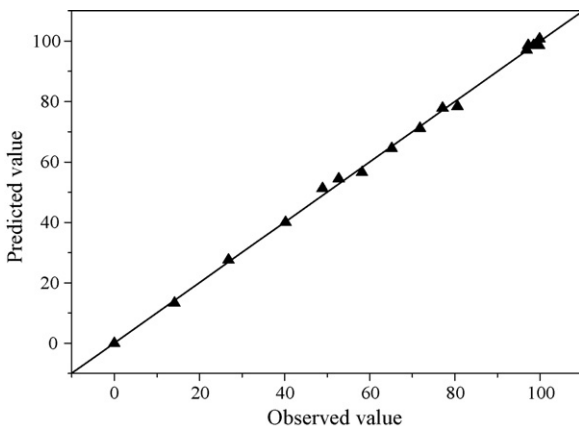


Fig. 7. Predicted (–) vs. observed values (▲).

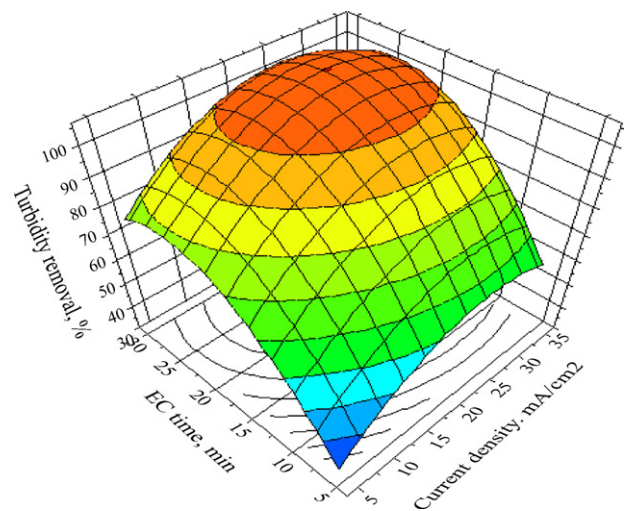


Fig. 8. Effect of current density and EC time on turbidity removal (%); 3D surface graph and contour plots.

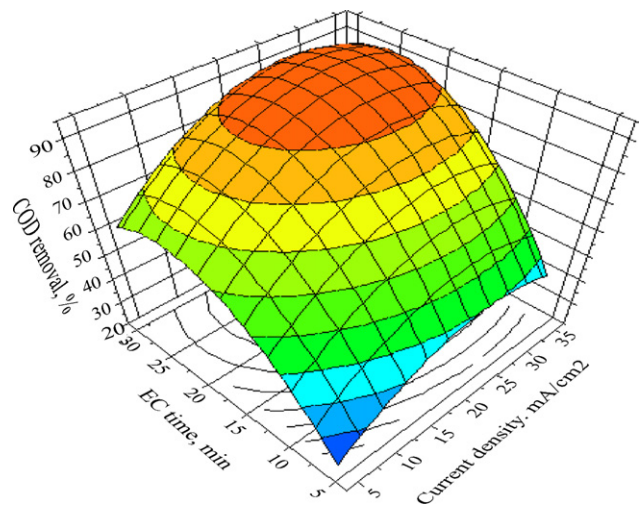


Fig. 9. Effect of current density and EC time on COD removal (%); 3D surface graph and contour plots.

Table 4
Analysis of variance (ANOVA) for the RSM model of turbidity and COD removals

Source	Sum of squares	Degrees of freedom	Mean square	F-value	P
Turbidity removal ^a					
Model (regression)	11807.6	9	1311.3	347.096	0.0001
Residual	22.6787	6	3.779		
Lack of fit	19.3087	3	6.4362	5.7295	0.093
Pur error	3.3701	3	1.1233		
COD removal ^b					
Model (regression)	12027.4	9	1336.38	72.9552	0.0001
Residual	109.907	6	18.3178		
Lack of fit	95.9683	3	31.9894	6.8852	0.074
Pur error	13.9383	3	4.6461		

^a $R^2 = 0.998$; $R^2_{\text{adj}} = 0.995$.

^b $R^2 = 0.991$; $R^2_{\text{adj}} = 0.977$.

Figs. 8 and 9. These graphical representations are derived from the models of Eqs. (7) and (8).

The contour plots given in these figures shown the relative effects of two variables when pH value is kept constant in its zero level. It was be noted that the oil removal efficiencies increase with increasing current density and electrolysis time. However, the response surface of turbidity and COD show a clear peak, suggesting that optimum conditions for maximum turbidity and COD removals are well inside the design boundary. As can be seen from Figs. 2 and 3, the maximum percentage of turbidity and COD removals of more than 99% and 89%, respectively, are achieved at the current density of 25 mA cm^{-2} and pH between 5 and 8.

Based on the overlay plot, the optimum conditions for current density, pH and EC time are, respectively, 25 mA cm^{-2} , 7 and 22 min. These values were also experimentally validated, as shown in Table 5. Therefore, the initial pH of the emulsion was adjusted in the optimum range by added sulphuric acid during electrolysis since it was expected to increase during the treatment.

Table 5
Confirmation experiments for optimum conditions

	Responses	
	Turbidity removal (%)	COD removal (%)
Experimental value	99.37	89.63
Predicted value	99.78	90.12

As we can see, these results closely agree with the experimental results, confirming that the RSM could be effectively used to optimize the process parameters in complex process using the statistical design of experiments.

3.4. Electrochemical destabilization mechanism

The process of emulsion destabilization by electrocoagulation was examined. Microscopic analysis before, during and after the operation of treatment was proceeded (Fig. 10). Fig. 10a, shows that the initial emulsion contains a significant number of oil droplets dispersed in the aqueous phase.

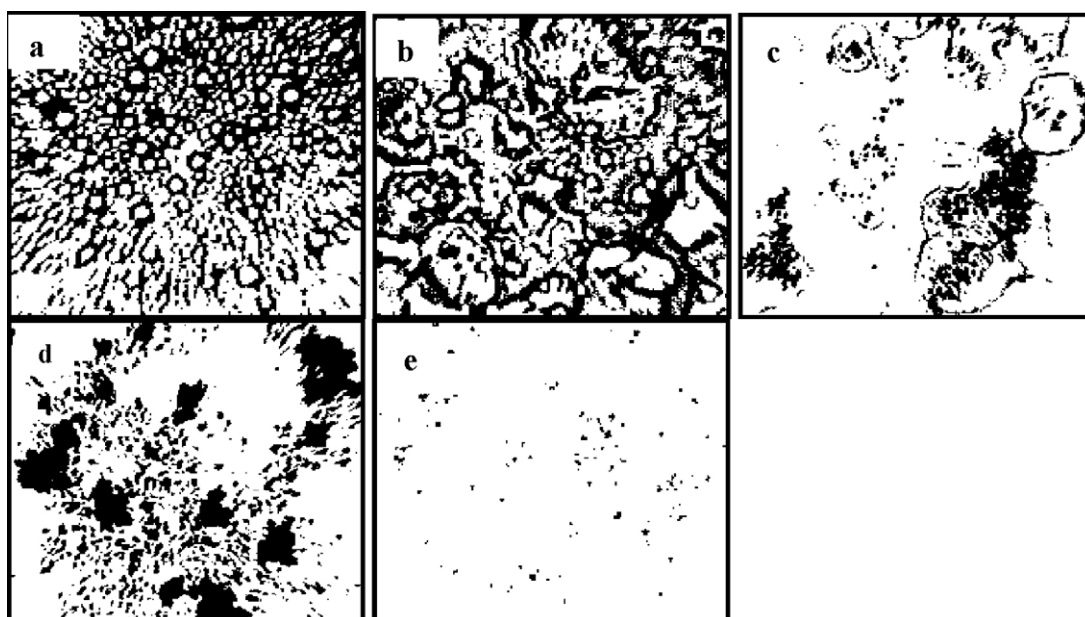


Fig. 10. Microscopic analysis: (a) initial emulsion (5% in wt.); (b) destabilization step; (c) aggregation step; (d) aluminium flocs; (e) final treated solution.

When direct current is applied to emulsion through the electrodes, the anode is dissolved and metal ions (Al^{3+}) are produced instead of oxygen generation. These coagulants promote the break-up of the emulsion due to the reduction of the superficial charge of the droplets, and destroy the protective action of emulsifying agent, overcoming the repulsive effect of the electrical double layer to allow the finally sized oil droplets to form larger droplets through coalescence (Fig. 10b). During electrolysis in wastewater treatment, the coagulated oil droplets are imprisoned into the highly dispersed aluminium hydroxide $\{Al(OH)_3\}$ to form flocs of large size (Fig. 10c) easy to be attached to the gas bubbles to involve them with the cell of the engine. At the end of the operation, a perfect separation of oil from oil-in-water emulsion is obtained (Fig. 10e), which the oil phase floats on the surface and can be removed by a simple decantation.

4. Conclusion

In this study, the efficiency of electrocoagulation process applied to the treatment of a oily wastewater emulsion was investigated. It was shown that electrocoagulation treatment achieves a fast and effective removal of turbidity and chemical oxygen demand. The treatment efficiency was found to be function of the initial pH, applied current density and electrolysis time.

The microscopic analysis confirmed the destabilization of the emulsion by the coagulant (Al^{3+}) coming from the dissolution of aluminium anode, with the formation of large flocs size.

The quadratic model developed in this study shows the presence of a high correlation between experimental and predicted values. Analysis of variance showed a high coefficient of determination value ($R^2 = 0.998$), thus ensuring a satisfactory adjustment of the second-order regression model with the experimental data. Under optimal values of process parameters (current density = 25 mA cm^{-2} , initial pH 7, electrolysis time = 22 min) more than 99% removal turbidity and 89.63% removal COD were obtained.

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