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Efficiency Evaluation of the Continuous Flow Electrocoagulation Process for the Treatment of Oily-Contaminated Wastewater

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ABSTRACT

Wastewater generated by edible oil industries is characterized by elevated levels of chemical oxygen demand (COD), oils, and grease (O&G), which poses significant challenges for treatment to comply with environmental standards. This study aims to assess the effectiveness of continuous flow electrocoagulation in treating such wastewater and optimizing water quality to meet these standards. A response surface methodology (RSM) approach is employed to evaluate the influence of critical operational parameters, including pH, electrode distance, electric current, and reaction time, on the removal efficiencies of COD and O&G. Numerous experiments are conducted under various conditions to identify the optimal configuration. The results revealed that under optimal conditions of pH 3.81, electrode spacing of 1.5 cm, an electric current of 5 A, and a contact time of 51.42 minutes, removal efficiencies of 91.2% for COD and 93.7% for O&G are achieved. Additionally, the maximum processing efficiency is reached during the second operational cycle, where the residual concentrations of COD and O&G are found to be 36.6 mg/L and 14.2 mg/L, resulting in removal efficiencies of 99.26% and 99.25%, respectively. These findings underscore that the proposed optimized electrocoagulation method can attain higher removal efficiencies for COD and O&G than those previously noted in comparable studies. Consequently, this method could be adopted by industries aiming to comply with stringent environmental regulations. Furthermore, the novel combination of operational parameters addresses a significant gap in wastewater treatment research, providing a sustainable solution for industries managing oily contaminants. However, further research may be necessary to evaluate large-scale applications' long-term operational stability and cost-effectiveness.

Keywords: electrocoagulation, oily wastewater treatment, response surface methodology, sustainability.

INTRODUCTION

Industrial wastewater poses significant environmental challenges, and the variety of pollutants complicates wastewater treatment efforts. The expansion of the industrial sector and alterations in manufacturing processes have increased the volume and complexity of wastewater released into the environment. This amalgamation of industrial effluents may include hazardous waste, which must be mitigated or eliminated to safeguard environmental integrity and public health (Popat et al., 2019).

Oily-contaminated effluent is produced by various industries, including petrochemical facilities, poultry processing plants, edible oil refineries, and dairy operations (Ayoub, 2022). Edible oil companies generate a significant volume of wastewater due to the large quantities of water required for processing. The composition and characteristics of wastewater from vegetable oil refinery plants depend on the specific crop used for oil extraction (Sharma et al., 2018). These effluents contain substantial amounts of dissolved and suspended organic materials, such as fats, O&G) and nutrients like ammonia, phosphates,

and other minerals. They also exhibit elevated levels of biological and chemical oxygen demand (BOD and COD, respectively). Consequently, it is essential to conduct a thorough assessment before the disposal of such effluent (Benazzi et al., 2016). The presence of organic matter, heavy metals, inorganic substances, and suspended solids in wastewater poses a significant threat to the environment and aquatic life in Egypt. The industrial sector contributes to high levels of impurities and pollutants, which have serious repercussions (Ali, 2022). The removal of these pollutants can be accomplished through chemical, physical, and/or biological methods. However, traditional approaches have proven insufficient in recent decades, as noted by Carmona-Carmona et al. (2021).

Electrocoagulation (EC) is an effective method for treating oil pollution, which involves the electro-dissolution of sacrificial anodes and the formation of hydroxo-metal products that act as coagulants. This technique effectively destabilizes oil-in-water emulsions, presenting a promising alternative for the removal of oil from wastewater (An et al., 2017). The electrocoagulation process offers several advantages, including ease of operation, minimal equipment requirements, shorter treatment times, reduced sludge production, and lower resource consumption (Ahmed et al., 2024). Its rapid adoption as a wastewater treatment technology can be attributed to its efficacy in removing contaminants that are often challenging to eliminate through filtration or chemical treatment systems (Al-Rubaiey and Al-Barazanjy, 2021). Electrocoagulation can remove suspended particles smaller than a micron, break emulsions such as oils and fats, oxidize compounds, and eliminate heavy metals, all without the need for additional chemical substances (Dobrosz-Gómez et al., 2024). In this manner, Mao et al. (2023), Aiyd Jasim and AlJaberi (2023), and Moneer et al. (2023) assessed the influence of various factors on the electrocoagulation process and its efficacy in pollutant removal. The effectiveness of the treated water and its potential applications were not taken into consideration.

This study aims to evaluate the effectiveness of EC in removing O&G as well as COD from wastewater contaminated with oil. It focuses on analyzing the influence of various operational factors, including reaction time, electric current, initial pH, and electrode spacing, on treatment efficiency. Additionally, the research seeks to explore the potential for obtaining treated wastewater suitable for reuse in the irrigation of green areas, based on the optimal conditions identified through the electrocoagulation process.

MATERIALS AND METHODS

Study area

Industrial drainage samples were collected from the crude oil refining phase, as well as from sunflower oil and soybean oil produced at the oil and soap factory located in Karmoz, Alexandria, Egypt. The factory has an average daily output of 7 to 9 tons of crude oil, undergoing processes that include glue removal, fatty acid extraction, neutralization, and finally, deodorization. Experiments and analyses were conducted at the sewage laboratory of the Engineering College of Pharos University in Alexandria, and the Egyptian Foundation for Scientific Services and Water Analysis using the Standard Methods (2017) for Water and Wastewater Examination, 23rd edition, as prepared and published by APHA, AWWA, and WEF in 2017.

Raw oily-contaminated wastewater parameters

When a sodium hydroxide solution (NaOH) is added to crude oil, a chemical reaction occurs between the sodium hydroxide and the free fatty acids present in the oil. This reaction produces soap and water, as the free fatty acids react with sodium hydroxide to generate sodium salts (soap) and water (Saputra et al., 2024).

$$RCOOH + NaOH \rightarrow RCOONa\ (soap) + H_2O \quad (1)$$

The wastewater generated by the oil-refining equivalence process possesses specific chemical and physical properties that must be considered during handling or treatment. These properties are affected by the chemicals utilized in the process, such as sodium hydroxide, as well as by the components extracted from the oil, including fatty acids and soap (Saputra et al., 2024). Table 1 outlines the characteristics of the industrial discharge from the refining process, while Figure 1 illustrates the form of the specimen.

Oily-contaminated wastewater treatment steps resulting from the refining process

Given the presence of these characteristics, it is essential to treat the oily-contaminated wastewater

Table 1. Characteristics of collected oily-contaminated wastewater

Parameter	Value	
	Average	Standard deviation
pH	11.04	1.45
COD (mg/L)	4945	90.3
Oil and grease – O&G (mg/L)	1903	279
Total suspended solids - TSS (mg/L)	4866	125.9
Conductivity (mS/cm)	50.64	2.1

Figure 1. Raw oily-contaminated wastewater after product of the crude edible oil refining process

produced during the refining process before its discharge into the environment or its use in other applications. Potential interventions may include: dispose of the soap appropriately, reducing the degree of Alkalinity, electrocoagulation process.

Dispose of the soap appropriately

The water generated by the refining process contains soap (R-COONA) in as shown in Equation 1. The liquid soap is removed by sedimentation or centrifugation and a large part of it can be disposed of (Kaya and Hung, 2020). The presence of soap influences the water's viscosity, its foaming capacity, Furthermore, soap adversely impacts the efficacy of treatment. The sedimentation process takes place within 8 hours, where the soap floats to the top as shown in Figure 2, and its percentage in the sample is approximately 25%. After that, it is completely separated from oily-contaminated wastewater

Reducing the degree of alkalinity

At high alkalinity levels (pH: 9.5–12.5), electrification treatment is ineffective; the reaction proceeds slowly, and the properties of the sample

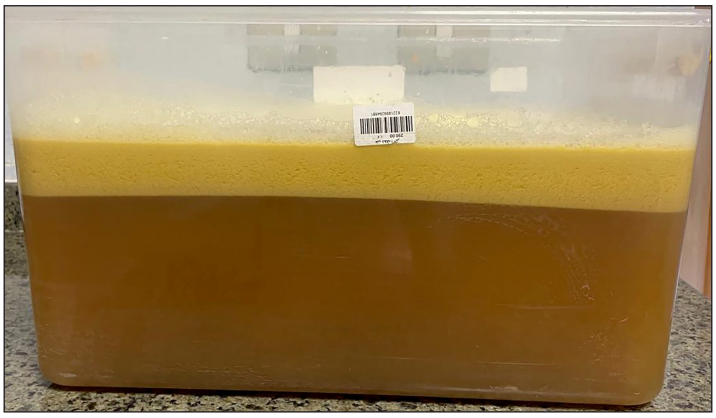

Figure 2. Separation of the soap from the sample

requiring removal remain unaltered. Hydrochloric acid was employed to accelerate the reaction and regulate the pH level. The presence of sodium hydroxide (NaOH) in water contributes to alkalinity, which hydrochloric acid (HCl) neutralizes. The reaction between HCl and NaOH results in the formation of sodium chloride (NaCl) and water (H_2O) (Acharyya et al., 2023).

$$HCl + NaOH \rightarrow NaCl + H_2O \quad (2)$$

Figure 3 illustrates the formation of a fatty acid layer on the surface of the sample. Upon the addition of HCl, the soap contained in (R-COONa) undergoes decomposition, reacting with the liquid soap to yield fatty acid (R-COOH) and sodium chloride (NaCl) (Zhang et al., 2021).

$$R\text{-}COONa + HCl \rightarrow R\text{-}COOH + NaCl \quad (3)$$

Electrocoagulation process

The electrocoagulation (EC) process was implemented using a glass reactor with a capacity of 7.2 liters, connected to a direct current power supply (XY6008; 0–60 V, 0–8 A). The cell was continuously supplied with oily-contaminated wastewater via a peristaltic pump (Tbest1f32u-5ws4e 0–250 mL/min), operating at flow rates designed to achieve nominal retention times of 30, 40, and 60 minutes. The system featured six aluminum electrodes (three cathodes and three anodes), each measuring 100 × 40 × 3 mm, with inter-electrode distances of 1.5 cm, 2.5 cm, and 3.5 cm, as illustrated in Figure 4.

Experiment Equipment

The model, specifically designed for this purpose, illustrates the experiment in its entirety, as detailed in Table 2 and Figure 5.

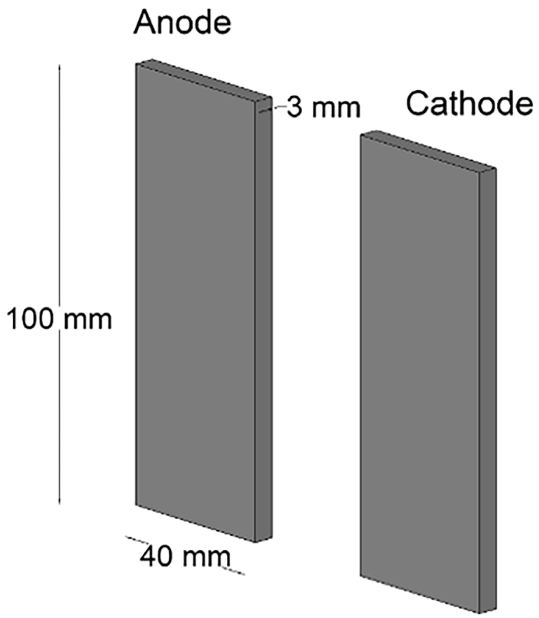

Figure 4. Dimensions of aluminum electrodes

EC container

The EC container is a clear acrylic unit with a working volume of 7.2 liters and dimensions of 30 × 20 × 12 cm, as illustrated in Figure 6. Figures 7a and 7b show the shape of the device during testing. Figures 8a and 8b depict the sample's form during the sedimentation phase and its subsequent arrangement for laboratory transport.

Electrode plate

Electrode plates play a vital role in electrocoagulation systems by generating coagulants and conducting electrical current. Composed of materials such as aluminum, iron, and stainless steel, these plates require regular maintenance to manage wear and tear. Optimal design and placement

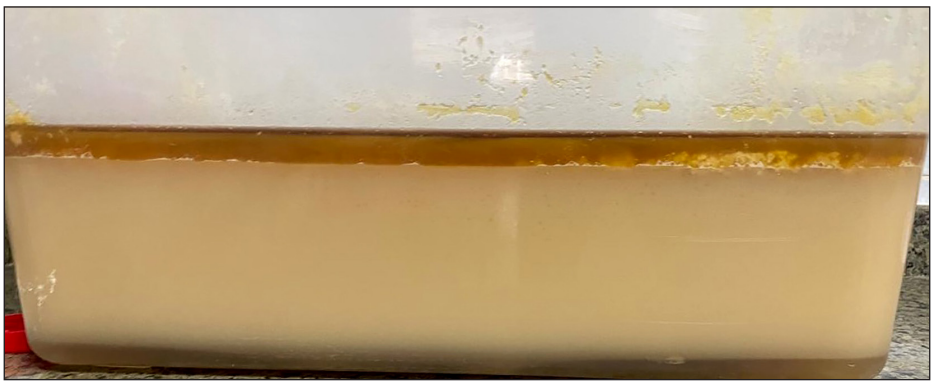

Figure 3. Fatty acid from HCL reaction

Table 2. Model of the experiment

EC setup	Volume of container	7.2 L (7200 cm³)
	Dimensions of container	30·20·12 cm
	Material of container	fiberglass
	Electrode plate type	Aluminum
	Dimensions of electrode	100·40·3 mm
	Number of electrodes	(3 cathodes and 3 anodes)
	dc power supply	XY6008; 0–60 V, 0–8 A
	Peristaltic Pump	Tbest1f32u5ws4e 0-250 ml/min
	Influent tank	80L (8000 cm³)
	Final storage.	15L (1500 cm³)
Constant parameters	electrode type	Aluminum
Variable parameters	Contact times	30/45/60 min
	Inter-electrode spacing	1.5/2.5/3.5 cm
	pH	3/7/5
	Electric current	1/3/5 A

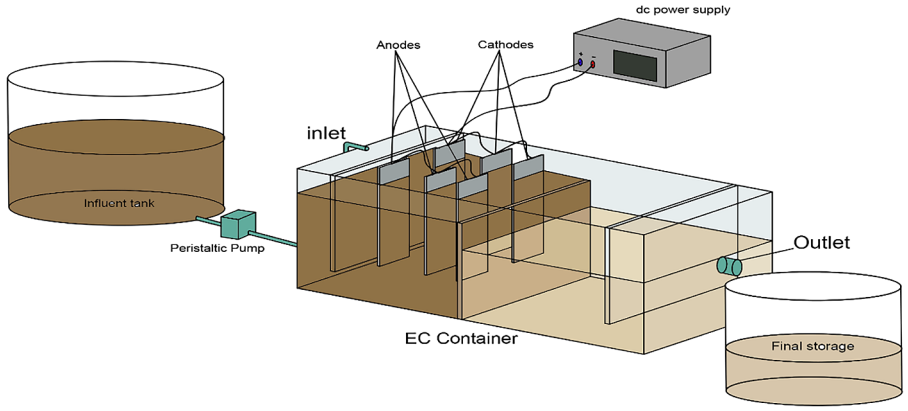

Figure 5. Electrocoagulation setup

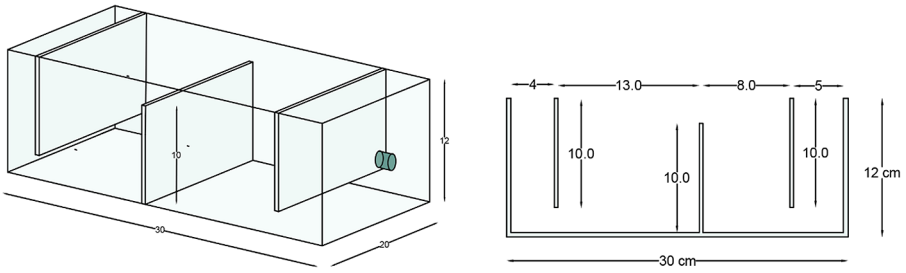

Figure 6. Dimensions of electrocoagulation container

can further improve current efficiency and flocculation processes. Research conducted by Bharath et al. (2020), Igwegbe et al. (2021), Chezeau et al. 2020), Rusdianasari et al. (2019) illustrates that aluminum electrodes demonstrate superior efficiency compared to iron electrodes in treatment applications, showing a greater capacity to reduce the percentages of COD, total suspended solids (TSS), total dissolved solids (TDS), and oil and grease. Consequently, aluminum electrodes were utilized. The dimensions of the electrode plates are 100 × 40 × 3 mm. Aluminum (Al) is commonly employed as electrode material, with cations generated through the dissolution of sacrificial anodes when direct current is applied. Metal ions are produced at the anode, while the cathode

(a) (b)

Figure 7. The devices during the testing (a) Sample during processing and (b) Foam volume formed

(a) (b)

Figure 8. Portion of the specimens (a) Sample sedimentation (b) Final sample

yields hydrogen gas, as illustrated in reaction Equations 3, 4, and 5 (Benazzi et al., 2016b).

- At the anode:

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

- At the cathode:

$$3H_2O \rightarrow 3/2\ H_2(g) + 3OH^- \quad (4)$$

$$Al_3 + 3H_2O \rightarrow Al(OH)_3 + 3H^+ \quad (5)$$

Factors affecting electrocoagulation process

Initial pH

The initial pH at the commencement of the electrocoagulation process is crucial for several reasons. The pH of the solution significantly impacts the efficacy of electrocoagulation. Maintaining an appropriate pH range in wastewater treatment is essential for optimizing the performance of coagulants and ensuring the efficient removal of suspended particles and contaminants. The electrocoagulation process relies on the formation of flocs, which are aggregates of particles that can be subsequently removed from the solution. The pH level directly affects the electrical charge of both the particles and the coagulant components, thereby influencing the development and stability of the flocs. For instance, excessively high or low pH levels can hinder floc formation or result in inadequate coagulation.

The research conducted by Prasetyaningrum et al. (2019), İrdemez et al. (2006), and Yıldız et al. (2008) indicates that a pH value between 3 and 7 is most effective in the electrocoagulation process. This pH range facilitates optimal electrical conductivity and the efficient removal of COD, TSS, and O&G. The selected experimental pH values were 3, 5, and 7, which were adjusted by administering hydrochloric acid (HCl) in varying doses. Table 3 presents the calculations necessary for adjusting the pH of 80 liters of wastewater from an initial pH of 10.5 to the target levels of 3, 5, and 7.

The method involves the use of hydrochloric acid (HCl) at a concentration of 37%, combined with an equal volume of water to achieve the necessary dilution. This adjustment aims to bring the wastewater to the required pH range for effective treatment and subsequent discharge.

Table 3. Calculations required for pH adjustment

Target pH	Quantity of HCl (37% concentration)	Quantity of water
pH 7	1.25 liters	1.25 liters
pH 5	1.5 liters	1.5 liters
pH 3	1.9 liters	1.9 liters

Inter-electrode spacing

The distance between electrodes in an electrocoagulation system is critical for its efficiency and effectiveness. It influences electric field strength, current distribution, solution resistance, electrolyte contact, floc formation and removal, as well as electrode wear and maintenance. A reduced distance results in a more intense electric field, whereas an increased distance diminishes it. Appropriate spacing guarantees uniform current flow, minimizes solution resistance, and sustains effective floc formation and removal.

Inefficient spacing can result in overheating or degradation of the electrodes, while excessive spacing may lead to inadequate floc formation and removal. Therefore, optimizing electrode spacing is crucial for achieving optimal coagulation efficiency (Alam et al., 2024) (Akhtar et al., 2020). Based on the aforementioned studies, electrode distances of 1.5, 2.5, and 3.5 cm were selected for evaluation of the results.

Contact times

Contact time is a critical parameter in electrocoagulation treatment, significantly impacting both the efficiency and effectiveness of the process. This time frame facilitates more comprehensive interactions between contaminants and coagulant agents, enhancing removal efficiency. Sufficient contact time is vital for floc formation and growth, electrochemical reactions, and pollutant removal. Extended contact times guarantee uniform treatment across the entire solution volume, while a careful consideration of contact time alongside other parameters optimizes the process for effectiveness and cost-efficiency. Inadequate contact time can lead to diminishing returns and increased energy consumption, whereas excessively brief contact times may result in incomplete treatment. The contact durations selected during the electrocoagulation process were 30, 45, and 60 minutes, in alignment with the findings from each source (Moradi et al., 2021; Aljaleeland and Alwan, 2021).

Electric current

Current is a crucial factor in electrocoagulation, as it directly affects the efficiency and efficacy of the treatment process. It influences the production of coagulants, the occurrence of electrochemical reactions, the effectiveness of flocculation, the distribution of current, energy usage efficiency, electrode performance, process optimization, operational monitoring and control, and regulatory compliance. Increasing the amperage leads to a higher rate of coagulant formation, enhances electrochemical reactions, and ensures optimal reaction conditions. The appropriate amperage influences the creation and growth of flocs in treated water, facilitating faster and more effective pollutant separation. The current distribution system ensures uniform treatment, maximizing energy efficiency. High amperage also affects electrode performance, impacting their durability, wear, and heat generation. Continuous monitoring and regulation of amperage allow for necessary adjustments to maintain ideal operating conditions.

Experimental design using response surface methodology

Response surface methodology (RSM) comprises a collection of statistical and mathematical techniques utilized to optimize processes, evaluate the relationships among multiple factors, and improve outcomes. It is particularly advantageous for designing and refining experiments in scenarios where various factors impact a response variable (Mirshahghassemi et al., 2017).

The experimental design, analysis of variance (ANOVA), mathematical modeling, and response surface contour plots were carried out using Minitab statistical software (Minitab, version 18). The four essential functional parameters include contact time, electrode spacing, initial pH, and current. The Box-Behnken model (BBM) was employed to explore and establish the experimental protocols (Moneer et al., 2023).

$$Y(\%) = \sum_{i-1}^{n} BiXi + \sum_{i-1}^{n} B_{1i} x_i^2 \, i_1^{-r^1 \Sigma 0} \quad (6)$$

The equation comprises several terms. β0 denotes the offset term, βi indicates the first-order or linear effect, βii signifies the second-order or quadratic effect, and βij represents the interaction effect among the coded variables. Xi refers to the experimental variables, n denotes the number of components, and Y (%) is the output provided by the model. Three values were chosen for each operational variable. The specifics of the inputs necessary to construct the experimental matrix are detailed in Table 4.

RESULTS AND DISCUSSION

Model development and validation

Table 5 presents empirical data on the percentage of COD removal (Y1) and O&G removal (Y2) achieved under various independent

Table 4. The experimental matrix for the four operational variables for RSM based on the Box–Behnken model

N	Variable	Unit	-1	0	+1
X1	Electric current	A	1	3	5
X2	pH	–	3	5	7
X3	Distance	cm	1.5	2.5	3.5
X4	Contact time	min	30	45	60

Table 5. The independent variables and the observed and expected values of the removal efficiencies of COD, and O&G

NO	current	pH	Distance	Contact time	Y1 (RE COD%)	Predicted Y1 (RE COD%)	Y2 (RE O&G%)	Predicted Y2 (RE O&G%)
1	5	5	3.5	45	85.4398	84.8338	93.3263	93.2212
2	5	7	2.5	45	80.9282	79.7747	90.4887	89.1421
3	3	5	2.5	45	82.2042	82.4065	93.1161	92.7658
4	3	5	1.5	30	84.4287	83.7262	89.8056	91.3492
5	5	5	2.5	30	79.9798	82.2891	90.1209	90.6704
6	3	7	1.5	45	80.7887	79.7613	90.5938	87.9291
7	3	3	3.5	45	80.9909	82.9062	93.6416	94.3138
8	5	3	2.5	45	90.0910	88.0403	94.5875	94.0730
9	1	3	2.5	45	80.3842	79.6608	89.8056	90.2369
10	3	5	2.5	45	82.8109	82.4065	93.6416	92.7658
11	5	5	1.5	45	85.4398	86.0808	94.0620	94.9991
12	3	5	3.5	60	84.6309	83.4565	92.3805	89.9216
13	5	5	2.5	60	85.6421	86.5021	93.7993	94.2788
14	3	5	3.5	30	82.6087	81.4680	89.9107	89.5713
15	1	5	2.5	60	80.1820	78.7606	86.4950	83.9530
16	1	5	3.5	45	78.3620	78.7101	85.9695	87.9401
17	1	7	2.5	45	77.3509	77.5246	81.0300	80.6293
18	3	7	2.5	60	79.1709	80.5870	81.8707	85.0412
19	3	7	3.5	45	80.3842	81.0420	83.1844	83.4450
20	3	5	1.5	60	86.0465	85.3102	90.4887	89.9129
21	3	5	2.5	45	82.2042	82.4065	91.5397	92.7658
22	3	3	2.5	30	84.4287	84.0016	93.1161	92.8534
23	3	7	2.5	30	78.1598	78.0929	82.0809	83.0618
24	3	3	1.5	45	88.0688	88.2989	93.8518	91.5988
25	1	5	1.5	45	79.9798	81.5749	84.9185	87.9313
26	3	3	2.5	60	84.0243	85.0801	87.8613	89.7881
27	1	5	2.5	30	79.3731	79.4010	91.1193	88.6473

variables, reflecting different operating parameters. This data was utilized to develop comprehensive quadratic regression models that illustrate the relationship between operating parameters and the responses Y1 and Y2. The close alignment between the experimental and predicted values of Y1 and Y2 demonstrates that the model has been successfully validated. Equations 7 and 8 were derived using Minitab®18 software to calculate the removal percentages of COD (Y1) and O&G (Y2).

$$Y1 = 102.2 + 1.94 \times C\text{-}1.57 \times P\text{-}11.47 \times \times D\text{-}0.142 \times T\text{-}0.170 \times C \times C\text{-}0.119 P\times P + 1.073\ D \times D + 0.00005\ T \times T\text{-}0.383\ C \times P + 0.202\ C \times D + 0.0404\ C \times T + + 0.834\ P \times D + 0.0118\ P \times T + 0.0067\ D \times T \quad (7)$$

$$Y2 = 69.4 - 0.56\ C + 5.10\ P + 5.74\ D + + 0.332\ T\text{-}0.318\ C \times C\text{-}0.743\ P \times P\text{-}0.47 D \times D - 0.00936\ T \times T + 0.292\ current \times \times P\text{-}0.223\ C \times D + 0.0692\ C \times T\text{-}0.900 P \times D + 0.0420\ P \times T + 0.0298\ D \times C \quad (8)$$

where: *Y*1 – COD removal%, *Y*2 – O&G removal%, *C* – current, *P* – pH, *D* – distance, *T* – contact time.

The regression models for Y1 and Y2 were evaluated by calculating the coefficient of determination (R^2) between the experimental and predicted values. The R^2 values were determined to be 88.45% for Y1 and 84.75% for Y2, indicating a high significance level. Consequently, the R^2 values exceeding 80% underscore the relevance of the response surface models for Y1 and Y2. Conversely, Table 6 presents the ANOVA results for each response of Y1 and Y2. The significance of the response models becomes particularly evident as the P-values decrease and the F-values increase. When assessing the overall significance of the results, it is crucial to consider both the F and P-values.

The significant influence of various operational parameters on the responses of Y1 and Y2 was ranked in the following order, as determined by the Pareto charts generated from the outputs after analysis using Minitab®18 software Figure 9 and the F-values presented in Table 6. Electric current had the greatest impact, followed by pH as the second most influential factor. with distance ranking third and contact time ranking fourth.

The impact of operating parameters on the removal efficiencies of COD and O&G

The contour plots of COD removal (Y1) and O&G removal (Y2) presented in Figures 10 and 11 depict their respective regression Equations 6 and 7. These contour plots demonstrate the relative impacts of two variables while keeping the other two variables constant. Figures 10 and 11 at (a) pH and contact duration as the hold values, whereas current and distance are the variables. According to (b), the hold values are Distance and contact time, whereas the variables are current and pH. According to (c), the hold values are pH and distance, whereas the variables are current and contact time. According to (d), the hold values are Current and contact time, whereas the variables are pH and Distance. According to (e), the hold values are Current and Distance, whereas the variables are pH and contact time. According to (f), the hold values represent the current pH, whereas the variables are distance and contact time.

The pH level in the electrocoagulation process is crucial in determining the results. It was adjusted between 3 and 7 to evaluate its effect on the removal efficiencies of COD and O&G. The experimental findings reveal that a pH of 3 is optimal, achieving a maximum COD removal rate of 90% and an O&G removal rate of 94.58%. Additionally, at pH 5, the removal rates for COD and O&G dropped below 81% and 90%, respectively, and at pH 7, these rates further decreased to 79% and 84%. The adjusted reaction time (t) ranging from 30

Table 6. ANOVA is used to analyze response surface models of COD and O&G percent removals

Parameter	DF		Adj SS		Adj MS		F-Value		P-Value	
Source	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2
Error	12	12	30.106	68.139	2.5088	5.678				
Lack-of-fit	10	10	29.860	65.745	2.9860	6.575	24.34	5.49	0.040	0.164
Pure error	2	2	0.245	2.393	0.1227	1.197				
Total	26	26	260.571	446.761						

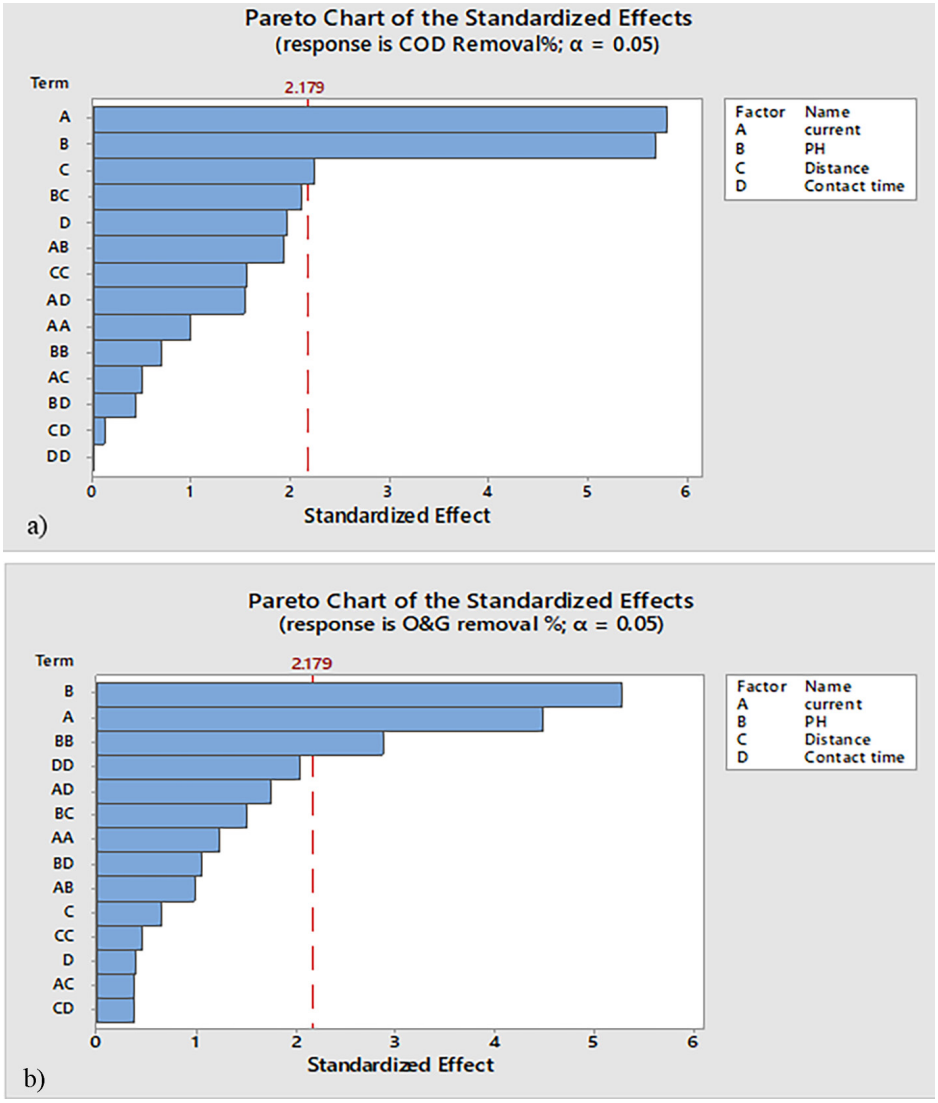

Figure 9. Pareto charts will be created for each operating model to display (a) percentage of COD removal and (b) percentage of O&G removal

to 60 minutes was evaluated for its effect on COD and O&G elimination percentages. It is clear that an increase in reaction time is associated with higher removal percentages for COD and O&G. At a maximum reaction time of 60 minutes, the elimination rates for COD and O&G were recorded at 86% and 93.79%, respectively, a reaction time of 45 minutes yielded a maximum COD removal of 90% and a maximum O&G removal of 94.58%, with electrode spacing varying between 1.5 and 3.5 cm. Generally, a decrease in distance enhances the removal efficiencies of COD and O&G. At a distance between 1.5 and 2.5 cm, the removal efficiencies for COD and O&G exceeded 85% and 92.5%, respectively.

The electric current varied between 1 to 5 A during the electrocoagulation reaction to assess its impact on the removal efficiencies of COD and O&G. At a minimum electric current of 1 A, the reductions in COD and O&G were less than 78% and 82%, respectively. Conversely, at a maximum current of 5 A, the removal efficiencies for COD and O&G reached 90% and 94.58%, respectively.

Optimization of the COD and O&G removal efficiencies

The response optimizer in Minitab®18 software was utilized to ascertain the optimal values for Electric Current, pH, distance, and contact times. Figure 12 illustrates the

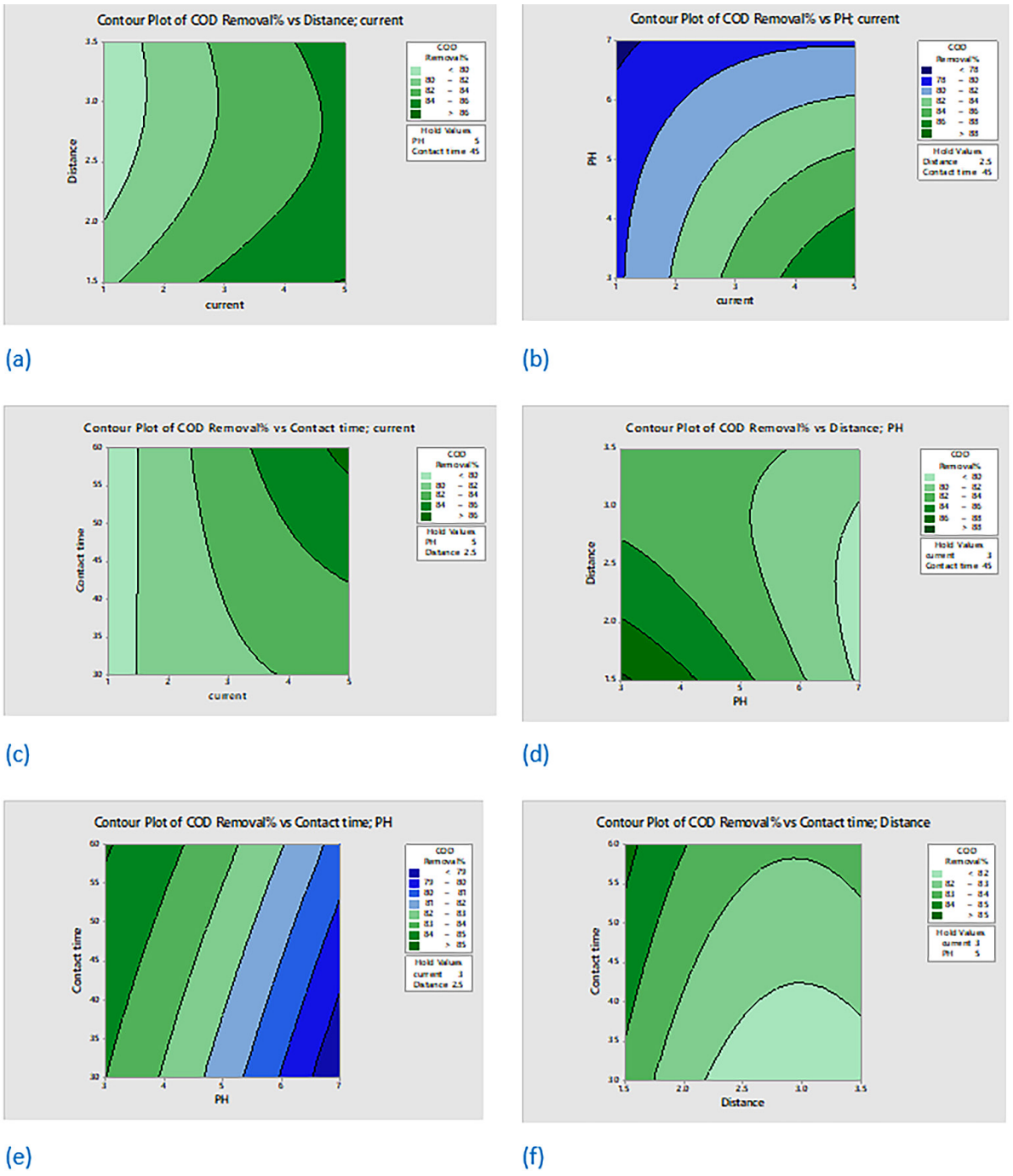

Figure 10. Response surface contour plots illustrating the impact of operational parameters on the removal of COD

penalties associated with the D-optimization dimension. The COD elimination response was validated at 93.06% under the optimal settings of electric current, pH, distance, and contact duration, which were recorded as 5 A, 3, 1.5 cm, and 60 min, respectively. Additionally, the optimal response for the removal of O&G reached 95.31%, achieved using the optimal parameters of electric current, pH, distance, and contact duration of 5 A, 4.41, 2.26 cm, and 49.6 min, respectively. The optimal removal efficiencies for COD and O&G are 90% and 94.24%, respectively. These efficiencies were achieved using optimal parameters of electric current, pH, distance, and contact duration of 5 A, 3.82, 1.5 cm, and 51.42 minutes, respectively.

The experiment was conducted under identical conditions, as reflected by the values in Figure 13. The removal efficiencies for

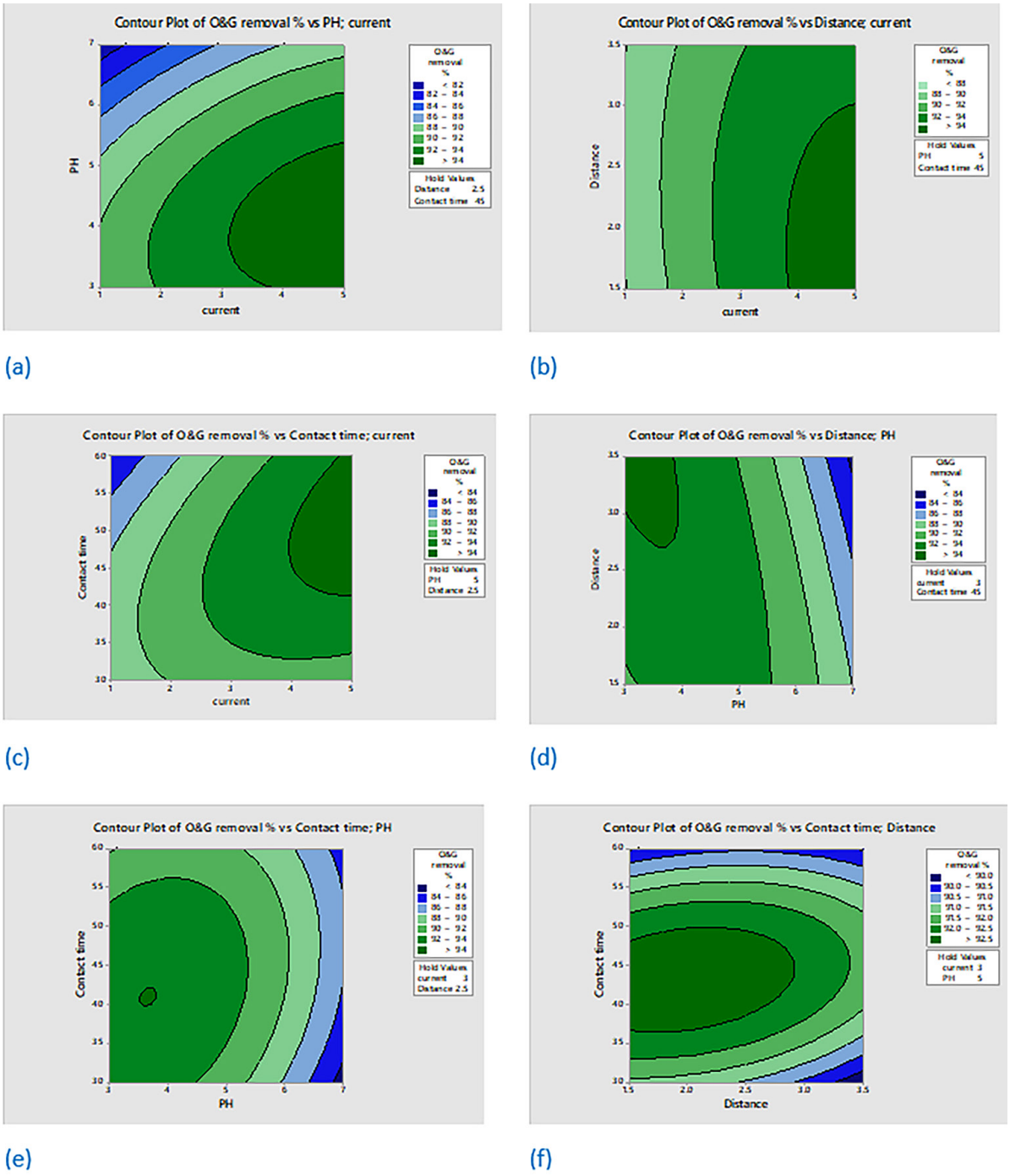

Figure 11. Response surface contour plots illustrating the impact of operational parameters on the removal of O&G

COD and O&G were found to be 91.2% and 93.7%, respectively. The experiment was replicated using the treated sample, resulting in a colorless and clearer appearance, as shown in Figure 14. The residual COD and O&G levels post-treatment were 36.6 mg/L and 14.2 mg/L, respectively. These findings indicate that this water is suitable for irrigating non-fruit trees.

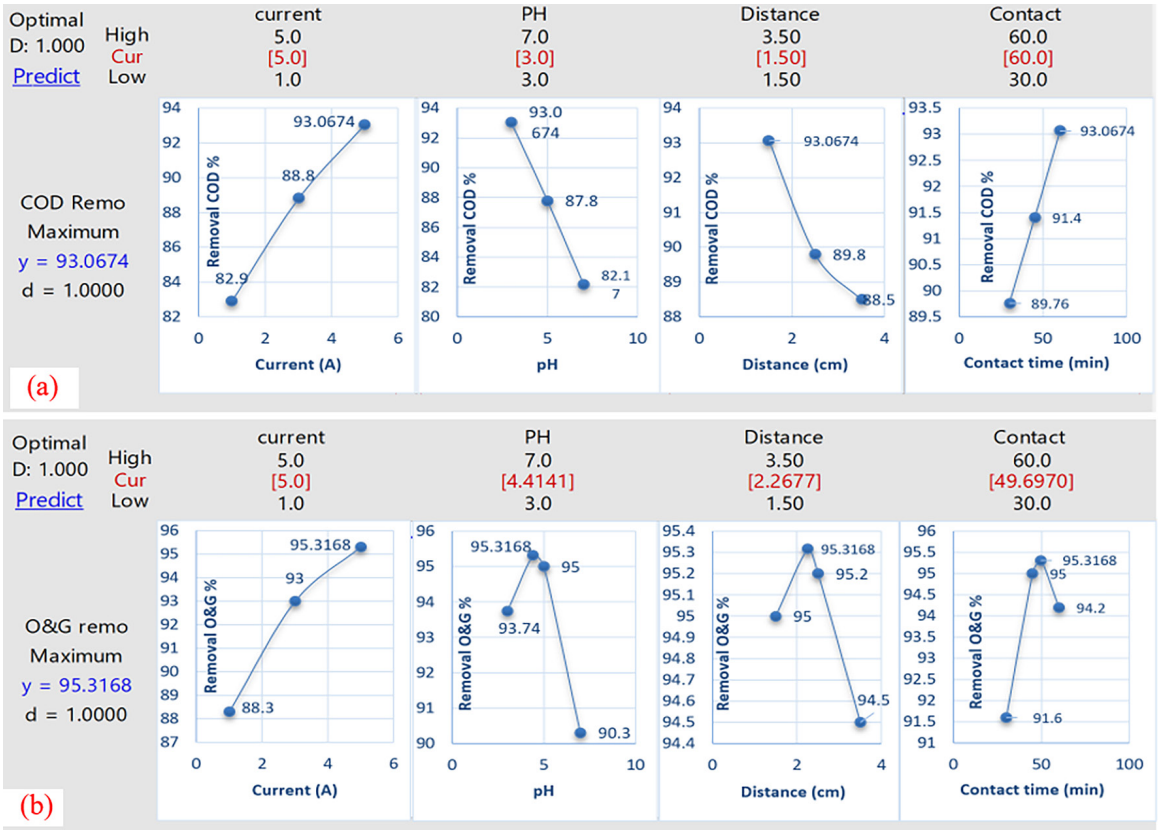

Figure 12. Response optimization of operating parameters on the percentage removal of (a) COD, (b) O&G

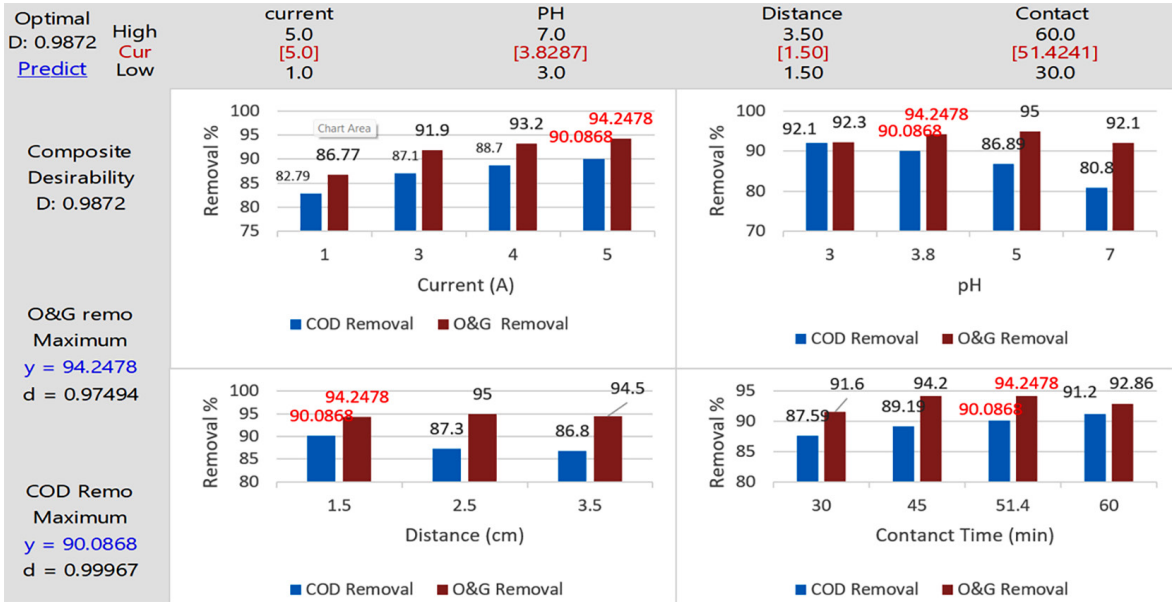

Figure 13. Optimization of operating parameters for the combined removal of COD and O&G

Figure 14. The optimal specimens (a) first cycle (b) second cycle

CONCLUSIONS

This study aims to assess the factors influencing the reaction and examine the effectiveness of the electrocoagulation process in treating wastewater effluent from the edible oil sector. Several notable outcomes were obtained as follows:

- The significant influence of various operational parameters on the removal rates of COD and O&G was ranked as follows: first, electric current; second, pH; third, distance; and lastly, contact time, which exhibited minimal effect.
- The remaining COD and O&G concentrations after final treatment were 36.6 mg/L and 14.2 mg/L, respectively, with removal rates of 99.26% and 99.25%, respectively. The results indicate that the obtained water quality adequately covers the irrigation water deficit, albeit only for non-fruit trees, resulting in a positive impact on the environment.
- This study attained sustainability by using all treatment phases and the resulting trash. During the sedimentation phase, soap was created, which is repurposed as liquid soap for floor cleaning. Fatty acids produced by the HCL addition procedure are efficiently used in the production of candles and cosmetics. The aluminum hydroxide generated by the electrocoagulation method used in water treatment for impurity removal, as an intermediary in the chemical industry, and in skincare cosmetics.

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