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ORIGINAL ARTICLE

Wastewater treatment using sono-electrocoagulation process: optimization through response surface methodology

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Abstract

The hybrid treatment processes are one of the hot topics in wastewater and industrial effluent treatment, especially in the highly polluted wastewater can be treated effectively using the combined processes. The present study is to treat the wastewater using a hybrid sono-electrocoagulation process (SEC), and the effects of operating parameters such as current density (0.3 to 1 A/dm^2), initial effluent pH (4 to 10), electrolyte concentration (1 to 6 g/L) and inter-electrode distance (1 to 3 cm) on % chemical oxygen demand (COD) removal, % color removal, and power consumption were studied. The operating parameters used for hybrid SEC for the treatment of wastewater were optimized using response surface methodology (RSM) based on central composite design (CCD). The quadratic regression models with estimated coefficients were developed for the % removal of COD, color, and power consumption. It was observed that the model predictions matched with experimental values with an R^2 for % COD removal, % color removal, and power consumption. The central composite design was selected in this study because of its efficiency concerning the number of runs required for fitting a second-order response surface model. The maximum removal of COD—97.50% and color—100% was observed with the minimum power consumption—0.55 kWh/m^3 for the treatment of wastewater using the hybrid SEC process.

Keywords Sono-electrocoagulation process · Wastewater · Color and COD removal · Power consumption · Central composite design · Optimization

Introduction

Water is essential for the existence of life on the earth; it provides a medium to all biochemical activities and it is used for agriculture, residential, industrial, institutional purposes (Moussavi et al. 2010; Bae et al. 2012; Zhao et al. 2017; Dolatabadi et al. 2021; Li et al. 2021; Son et al. 2021), etc. Due to improper treatment of wastewaters and removal of pollutants, the contaminants are being added to the natural water resources. Therefore, water pollution has become a major problem all over the world. To meet the environmental standards and regulations, the treatment of wastewater is a must before letting it out to the environment.

The conventional techniques of physical and/or chemical processes are applied for the treatment of wastewaters to enhance their removal efficiency and allow further applicability of the treatment process (Ambaye et al. 2021; Upender and Anand Kishore 2021). The treatment techniques such as coagulation, membrane separation, and adsorption have resulted in phase transfer of pollutants and generation of secondary pollution (Bae et al. 2012; Mateen et al. 2020). However, the wastewater having various compositions of the organic/inorganic compounds using conventional methods is becoming inadequate and insufficient. Since the pollutants are refractory to chemical oxidation in an aqueous medium or due to the production of partially oxidized reaction products having greater toxicity (Lahkimi et al. 2007). One of the most important integrated processes for the treatment of wastewater containing toxic and persistent organic pollutants is hybrid process.

Electrocoagulation (EC) is an inexpensive method for the treatment of various wastewater and industrial effluents to eliminate a wide range of pollutants (Al-Shannag et al. 2015; Merma et al. 2020). The metallic electrodes such as iron (Fe)

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and aluminum (Al) are usually used as an anode and cathode (Devlin et al. 2019). The anodic reaction offers oxidation and in situ generations of active adsorbent of metallic hydroxides for the removal of the pollutants, in cathodic reaction H_2 gas evolved which causing flotation of the adsorbents (Akyol et al. 2015; El Allaoui et al. 2020). A combination of EC with advanced oxidation processes (AOPs) is an interesting solution, due to that the synergetic way removal efficiency is maximized with minimal operating costs (Al-Qodah et al. 2018; Ikhlaq et al. 2020). The electrochemical and AOPs provide several advantages for the prevention and remediation of pollution problems because the electron is a clean reagent, economic friendly requirement, versatility, amenability to automation, high energy efficiency, easy handling, and simple equipment set up, etc., (Dizge et al. 2018). The electrochemical and AOPs are characterized by the production of hydroxyl radicals (Asaithambi et al. 2020), it can be generated by a variety of chemical, electrochemical, photocatalysis, photo (UV)-assisted electrochemical (Brillas 2020), Fenton's, ozone(O_3)-based, sono (US)-electrochemical, and radiolytic methods.

The ultrasonic (US) waves is generated with the ultrasonicator are transmitted in the liquid medium. As a result, air cavities are formed and cause molecular disintegrations. In addition, they also generate ions and radicals in the solution from EC technology (Al-Qodah et al. 2018; Prajapati 2021). Indeed, the sonic field increases the rate of formation of coagulants during the EC method (Dizge et al. 2018; Moradi et al. 2021; Patidar and Srivastava 2022). By employing the ultrasonic waves with the EC, the $^{\cdot}OH$ radicals are generated in wastewater which favors the subsequent oxidation of pollutants. Many researchers have confirmed that ultrasound with the various process can be used for the removal of pollutants from wastewater (Mirhosseini et al. 2021; Rashtbari et al. 2021; Torkashvand et al. 2021). However, ultrasound alone cannot be used to oxidize the pollutants present in effluents containing complex organic and inorganic compounds (Asaithambi et al. 2017). A combination of US and EC process is a hybrid technology developed for the treatment of organic/inorganic pollutants. When sonication is combined with other treatment processes such as electrochemical, UV, O_3 and Fenton, there is faster removal of pollutants from wastewater compared to the application of individual process (Raschitor et al. 2014; Al-Qodah et al. 2018).

Response surface methodology (RSM) is used to optimize the operating parameters chosen for the SEC process. It is a regression analysis used to predict the value of the dependent variable based on the controlled values of the independent. In RSM, the most common CCD was extensively used because of its efficiency concerning the number of runs required for fitting a second-order response surface model. In addition, CCD was ideal for sequential experimentation and allows a reasonable amount of information for testing lack of fit while not involving an unusually large number of design points (Nwabueze 2010; Demirel and Kayan 2012) to provide high-quality predictions over the entire design space (Tak et al. 2015).

In this study, the hybrid SEC processes were investigated for the treatment of wastewater. The effects of operating parameters such as current density, initial effluent pH, electrolyte concentration, inter-electrode distance and on % COD and % color removal, and power consumption were studied for the treatment of wastewater. To study the combined effect of parameters using statistical analysis by CCD for the four chosen variables, design of Expert (DoE) version 11 was used to optimize and study the effects of the selected operating variables on the % COD and % color removal efficiency and power consumption. Experimental data were fitted to a second-order polynomial equation and regression coefficients were obtained.

Materials and methods

Wastewater collection and characterization

The sample was collected from domestic wastewater and is near Jimma Institute of Technology (JiT), Jimma University (JU), Jimma, Ethiopia. The wastewater was transferred into clean plastic sampling bottles which were immediately stored at room temperature. The wastewater was analyzed for various water quality parameters and the results are given in the Table 1. The COD was measured by the closed reflux method using potassium dichromate ($K_2Cr_2O_7$), ferrous ammonium sulfate (FAS), etc., and color was determined by UV/Vis-spectrophotometer. The chemicals used in the experiments were sodium chloride (NaCl) as an oxidant reagent, H_2SO_4, and NaOH to adjust the pH value, etc. Only distilled water was used to prepare the entire solution.

Experimental setup

As shown in the Fig. 1, the experimental setup of hybrid SEC and its were conducted in a batch process using an electrochemical cell of 600 mL capacity of the solution.

Table 1 Characteristics of wastewater

Parameters	Range of value
pH	6
COD	1200 mg/L
Turbidity	200 NTU
TSS	150 mg/L
Temperature	27 °C
Color	Dark brown
Sample size	12.5 L

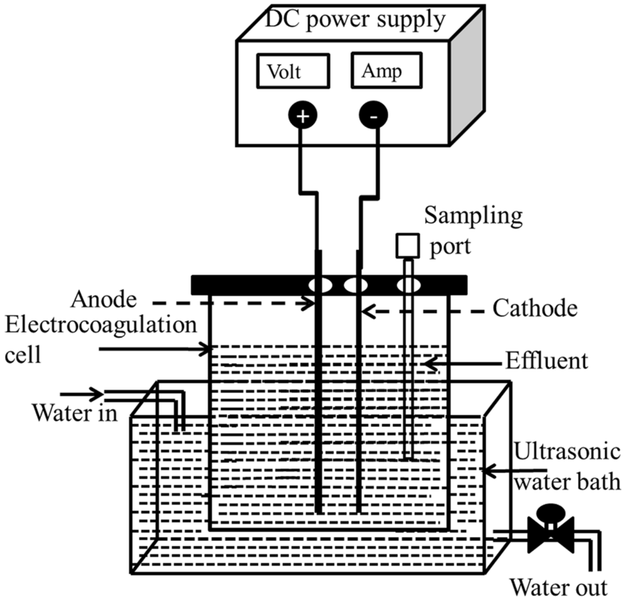

Fig. 1 Hybrid sono-electrocoagulation process setup

The Al electrodes were used as anode and cathode and were positioned vertically and parallel to each other with various inter-electrode distances (1 to 3 cm). The electrochemical cell of volume (500 mL) is filled with the wastewater with the addition of NaCl which increases the conductivity of the solution. A direct current (DC) was applied across the electrodes by using a DC power supply (ANDELI, Model: WYJ-0-15v/15A). The current density was ranged from 0.30 to 1 A/dm^2, while the voltage changed according to the electrolyte concentration and the distance between electrodes. The digital ultrasonic cleaner (Model: CD-480) was filled with distilled water up to an optimum level. The electrochemical cell was placed inside the ultrasonic bath and the electrolysis reaction occurred for a constant time of 45 min.

During the treatment, the samples were taken for the analysis of COD and color, and the COD was determined using the closed reflux method (Spectroquant$^{®}$TR320). The color was measured at the wavelength corresponding to maximum absorbance λ max (400 nm) using UV/Vis-spectrophotometer (Spectroquant$^{®}$TR300). The total energy consumption was calculated for the hybrid SEC in the summation EC and US process.

Analysis

The COD removal

The % COD removal was calculated using the following equation:

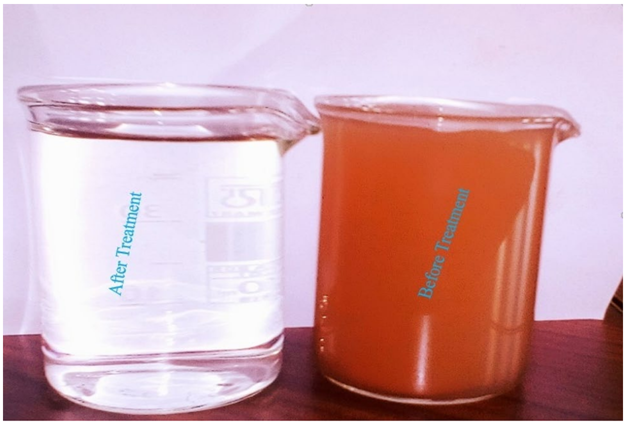

Fig. 2 Color removal before and after treatment of wastewater

$$\%\mathrm{COD\ \ removal} = \left(\frac{\mathrm{COD}_i - \mathrm{COD}_t}{\mathrm{COD}_i}\right)100, \tag{1}$$

where COD$_i$ and COD$_t$ are initial and at time t chemical oxygen demand (mg/L), respectively.

The color removal

The % color removal was calculated using the following equation:

$$\%\mathrm{Color\ \ removal} = \left(\frac{\mathrm{Abs}_i - \mathrm{Abs}_t}{\mathrm{Abs}_i}\right)100, \tag{2}$$

where Abs$_i$ and Abs$_t$ are the initial and after time t maximum absorbance to corresponding wavelength λ max, respectively.

Figure 2 shows that the color removal of wastewater before and after treatment using SEC process. From Fig. 2, it is observed that the complete color removal is achieved within the process of time.

Power consumption, (kWh/m^3)

Power consumption is a very important economical parameter in electrochemical and AOPs (He et al. 2007, 2018; Dizge et al. 2018). It is directly proportional to the operating cost and it is the major source for the electrochemical and US process. The total power consumption was calculated using the following equation:

$$E_{\mathrm{Total}} = \frac{IVt}{V_{\mathrm{R}}} + E_{\mathrm{US}}, \tag{3}$$

where E_{total} (kWh/m^3) is electrical energy consumption, V is applied potential or voltage (V), I is applied current (A), t is treatment time (h), V_{R} is the net reactor volume (wastewater volume in the reactor) (m^3) and E_{US} (kWh/m^3) is energy consumption during the US process ($E_{US} = 0.07$ kW).

Results and discussion

The SEC process on the outcomes such as the % COD and % color removal efficiency, and power consumption, a 4-factor and 3-level CCD were used to optimize the operating parameters. The total number of experiment combinations was 30 with 6 replications at the design central to determine the pure error. The experimental conditions, the responses of % COD removal, % color removal, and power consumption with the predicted values are given in the Table 2.

Effect of operating parameters

Current density

The current density determines the dosage of coagulants, bubble production rate, size, and growth of flocs which can influence the removal efficiency of pollutants in the SEC process (Secula et al. 2011; Moradi et al. 2021). Results are given in Table 2 and shown in Fig. 3a, the % color (95 to 100%) and COD removal (62.50 to 91.75%) were increased with increasing the current density from 0.30 to 1 A/dm^2, respectively. According to Faraday's Law, the charge passed to the solution was directly proportional to the amount of electrode (Fe or Al) dissolved (Kobya et al. 2006). This implies that the % color and % COD removal by SEC may be governed by the formation of hydroxyl radicals. Therefore, when higher current densities were applied, the coagulation

Table 2 Measured result for each run

Run	*A* (–)	*B* (g/L)	*C* (cm)	*D* (A/dm^2)	COD removal, (%)		Color removal, (%)		Power consumption, (kWh/m^3)	
					Actual	Predicted	Actual	Predicted	Actual	Predicted
1	5.00	2.00	1.00	0.30	62.50	63.70	95	95.36	0.20	0.24
2	9.00	2.00	1.00	0.30	65.25	66.80	100	99.32	0.45	0.41
3	5.00	6.00	1.00	0.30	70.50	71.63	100	98.65	0.08	0.11
4	9.00	6.00	1.00	0.30	72.50	73.65	100	100	0.10	0.21
5	5.00	2.00	3.00	0.30	55	56.06	92	92.44	0.5	0.49
6	9.00	2.00	3.00	0.30	60	61.20	97	96.15	0.6	0.24
7	5.00	6.00	3.00	0.30	64.56	65.69	99	98.48	0.35	0.37
8	9.00	6.00	3.00	0.30	68.50	69.75	100	100	0.5	0.52
9	5.00	2.00	1.00	1.00	91.75	90.63	100	99.65	0.85	0.91
10	9.00	2.00	1.00	1.00	93	92.05	100	100	1.01	1.06
11	5.00	6.00	1.00	1.00	98.5	97.48	100	100	0.6	0.54
12	9.00	6.00	1.00	1.00	98.75	97.82	100	99.65	0.57	0.61
13	5.00	2.00	3.00	1.00	87	86.03	98	96.98	1.25	1.20
14	9.00	2.00	3.00	1.00	90.50	89.50	96	97.44	1.35	1.61
15	5.00	6.00	3.00	1.00	96	94.59	100	100	0.70	0.79
16	9.00	6.00	3.00	1.00	98	96.98	100	99.48	0.86	0.89
17	5.00	4.00	2.00	0.65	87	87.00	95	95.98	1.35	1.61
18	9.00	4.00	2.00	0.65	91	89.74	98	97.31	1.65	1.32
19	7.00	2.00	2.00	0.65	90	89.02	97	97.31	1.81	1.58
20	7.00	6.00	2.00	0.65	97	96.72	100	99.98	1.54	1.28
21	7.00	4.00	1.00	0.65	97	95.99	100	100	1.59	1.36
22	7.00	4.00	3.00	0.65	92	91.75	99	98.82	1.91	1.64
23	7.00	4.00	2.00	0.30	83	73.33	96	97.31	1.35	1.04
24	7.00	4.00	2.00	1.00	92	100	100	98.98	1.77	1.58
25	7.00	4.00	2.00	0.65	93.50	94.13	97.8	98.16	1.54	1.61
26	7.00	4.00	2.00	0.65	93.50	94.13	98	98.16	1.27	1.61
27	7.00	4.00	2.00	0.65	93.50	94.13	98.50	98.16	1.35	1.37
28	7.00	4.00	2.00	0.65	93.5	94.13	98.5	98.16	1.35	1.61
29	7.00	4.00	2.00	0.65	93.5	94.13	98.5	98.16	1.35	1.61
30	7.00	4.00	2.00	0.65	93.5	94.13	98.5	98.16	1.35	1.61

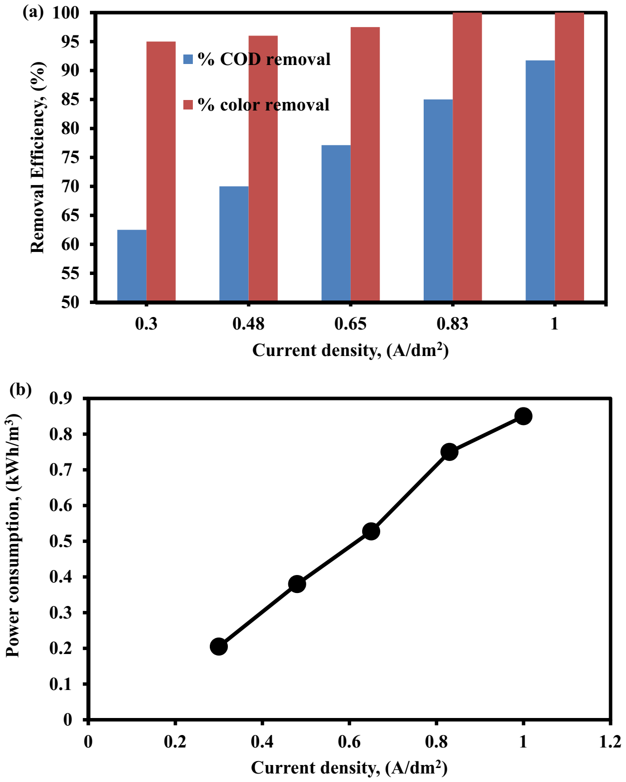

Fig. 3 Effect of current density on **a** % COD and color removal, and **b** power consumption

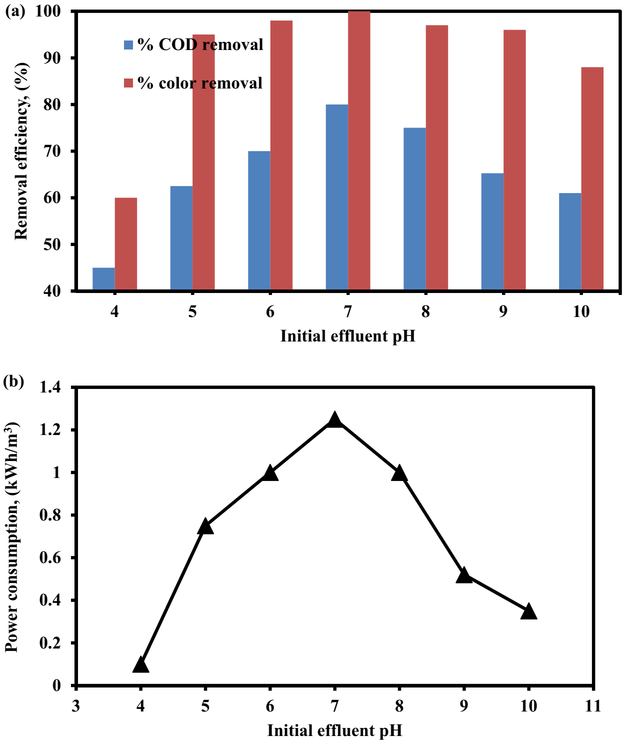

Fig. 4 Effect of initial effluent pH on **a** COD and color removal, and **b** power consumption

and removal of the time of the pollutants were improved. However, the current density should be kept at the optimum level due to reducing the power consumption and operating cost. Therefore, a compromise of the current density and electrolysis time was necessary to optimize the treatment efficiency with the lowest cost. Considering this cost factor, all experiments were carried out at a constant electrolysis time of 45 min.

The effect of current density on power consumption was studied for SEC and the result is shown Fig. 3b, the power consumption was increased from 0.21 to 0.85 kWh/m^3 with an increasing current density from 0.30 to 1 A/dm^2. The current density, cell voltage, and electrolysis time were directly proportional to power consumption.

Effluent pH

In the SEC process, the solution pH can influence the pollutant removal efficiency for the treatment of wastewater (Wang et al. 2009; Moradi et al. 2021). To study the effect of wastewater pH on % COD and % color removal efficiency, the pH of the wastewater was adjusted between 4 and 10. The removal efficiency of % color and COD as a function of initial pH is given in Table 2 and shown in Fig. 4a. When the initial pH of wastewater was changed from 4 to 7, the % color and COD removal efficiencies were increased from 60 to 100% and 45 to 80%, respectively. However, when the initial pH of wastewater was changed from 7 to 10, the removal efficiencies were decreased from 100 to 88% and 80 to 61%, respectively. The results indicated that, at high effluent pH, some of the hydroxide ions might be oxidized at the anode, reducing the production of aluminum ions, and consequently the color and COD removal efficiency was decreased. Moreover, $Al(OH)_3$ ions might be present at high pH reducing the color and COD removal efficiencies. At lower effluent pH, the proton in the solution reduced H_2 at the cathode and the same proportion of hydroxide ions could not be produced. At lower effluent pH, $Al(OH)_3$ was generated which was disadvantageous for colorant precipitation. The higher % color and % COD removal efficiencies were obtained in neutral media, as reported by several research studies (Saravanan et al. 2010).

The effect of wastewater pH on the power consumption was calculated and the results are depicted in Fig. 4b. The maximum power consumption was observed at higher % COD and % color removal efficiency at initial wastewater pH of 7 while charge loading was the minimum.

Electrolyte concentration

The cell voltage, current efficiency, and power consumption were affected by the conductivity of wastewater for the treatment using an electrochemical process (Moradi et al. 2021). For saving electricity and operating costs in an electrochemical process, the conductivity of a solution is an important parameter. More energy is required for overcoming a high solution resistance between an anode and a cathode when the electrical conductivity of the solution is low. The effect of electrolyte concentration on the % COD and % color removal efficiency and power consumption were examined by varying electrolyte concentrations in the range of 1–6 g/L for a constant 45 min on the system of SEC process. The results are shown in Table 2 and presented in Fig. 5a, b. It was found that an increased amount of NaCl concentration from 1 to 6 g/L increased the COD (37 to 68.25%) and color (73 to 100%) removal efficiency and decreased the power consumption from 0.65 to 0.50 kWh/m^3. This may be attributed that to more Cl$^-$ ions act as a better oxidizing agent upon oxychloride (OCl$^-$) and chlorine gas production. As chloride ion scavenges oxygen to form OCl$^-$ ions at the electrode (Sridhar et al. 2011), it reduces the passivation effect and increases the current efficiency.

Inter-electrode distance

The inter-electrode distance between the anode and cathode was varied by keeping all other parameters was constant for the treatment of wastewater using the SEC process(Moradi et al. 2021). The results are given in Table 2 and presented in Fig. 6a. It can be ascertained from Fig. 6a, when the inter-electrode distance between the anode and cathode was increased from 1 to 3 cm, the % COD and % color removal efficiency was decreased from 80 to 62% and 100 to 95%, respectively. On the other hand, the power consumption was increased from 0.15 to 0.55 kWh/m^3, respectively. The inter-electrode distance between the anode and cathode increases, the electrical current decreases, the voltage must be increased. There is less interaction of ions and electrostatic attraction with an increasing inter-electrode distance between the anode and cathode and also it should be minimized to achieve the acceptable power consumption and the desired removal level of pollutants (Dalvand et al. 2011).

Analysis of variance

The most important factors that affect the SEC process are current density, electrolyte concentration, initial effluent pH, and

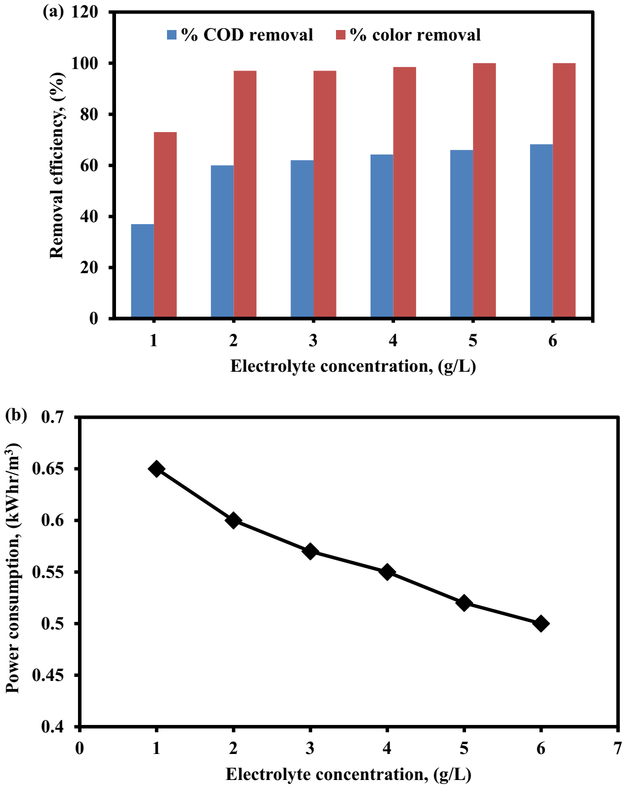

Fig. 5 Effect of electrolyte concentration on **a** COD and color removal, and **b** power consumption

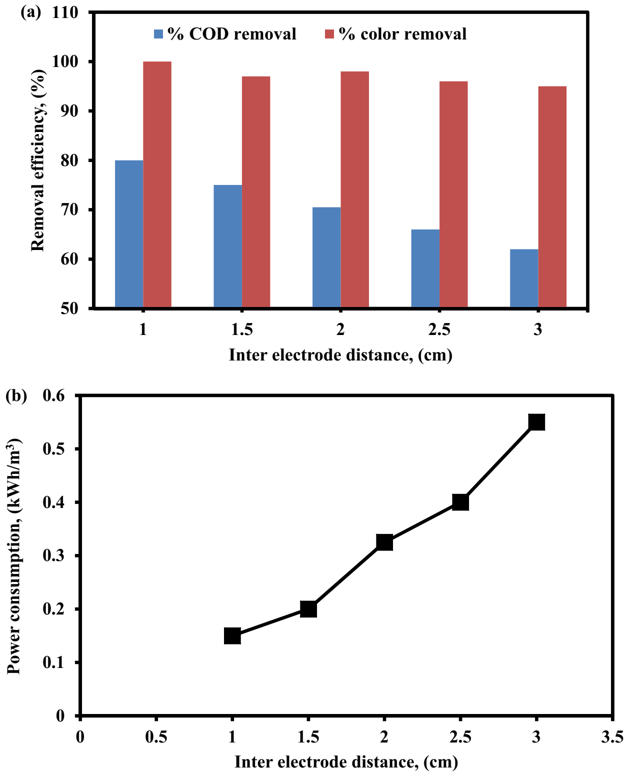

Fig. 6 Effect of inter-electrode distance on **a** COD and color removal, and **b** power consumption

inter-electrode distance in the batch reactor were investigated. To study the combined effect of these factors, the experiments were conducted at different combinations of operating parameters. The encoded values and the corresponding % of COD removal, % color removal, and power consumption along with predicated values are given in the Table 2.

The regression method was used to fit the second-order polynomial to the experimental data and to identify the relevant model term. The final equations obtained in terms of coded factors for % COD removal, % color removal, and power consumption are given by Eqs. (4), (5), and (6), respectively:

$$\begin{aligned}\text{COD removal, }(\%) = {} & 94.13 + 1.37A + 3.85B \\ & - 2.12C + 13.54D - 0.27AB \\ & + 0.51AC - 0.42AD + 0.43BC \\ & - 0.27BD + 0.76CD - 5.76A^2 \\ & - 1.26B^2 - 0.26C^2 - 7.26D^2\end{aligned} \tag{4}$$

$$\begin{aligned}\text{Color removal, }(\%) = {} & 98.16 + 0.67A + 1.33B \\ & - 0.77C + 0.83D - 0.44AB \\ & - 0.062AC - 0.81AD + 0.69BC \\ & - 0.56BD + 0.063CD - 1.52A^2 \\ & + 0.48B^2 + 1.43C^2 - 0.016D^2,\end{aligned} \tag{5}$$

$$\begin{aligned}& \text{Power consumption, }\left(\text{kWh/m}^3\right) = \\ & 1.61 + 0.068A - 0.15B + 0.14C \\ & \quad + 0.27D - 0.018AB + 7.000E \\ & \quad - 003AC - 8.000E - 003AD \\ & \quad - 8.000E - 003BC - 0.063BD + 7.500E \\ & \quad - 004CD - 0.36A^2 - 0.18B^2 - 0.11C^2 - 0.31D^2.\end{aligned} \tag{6}$$

The statistical significance of the ratio of mean square variation due to regression and mean square residual error was tested using analysis of variance (ANOVA). The ANOVA for the second-order equation fitted for % COD, % color removal, and power consumption by the SEC process (F value) were 27.90, 7.35, and 8.47, respectively. The large value of F indicates that most of the variation in the response can be explained by the regression equation. The associated p value is used to estimate whether F is large enough to indicate statistical significance. Any factor or interaction of factors with $p < 0.05$ is considered to be significant. The probability ($p \sim 0.0001$) is less than 0.05. This indicates that the model is statistically significant. The ANOVA indicated that the equation adequately represented the relationship between the response (the % COD removal, % color removal, and power consumption) and a significant variable, and the results are tabulated in Tables 3, 4, and 5. The model gave the coefficient of determination (R^2) values of 0.96, 0.87, and 0.89 adjusted R^2 values of 0.93, 0.75, and 0.78 for % COD removal, % color removal, and power consumption, respectively.

The response surface contour plots of % COD and % color removal efficiency and power consumption over independent variables such as current density, electrolyte concentration, initial effluent pH, and inter-electrode distance are shown in Figs. 7, 8, 9. These graphical representations are derived from the models of equations from (4) to (6), respectively.

Optimization

One of the main purposes of this investigation is to obtain the optimal conditions for the removal of % COD, % color, and power consumption from wastewater using a hybrid SEC process. The results were optimized using the regression equation of RSM based on the CCD. In the optimization of initial effluent pH (A), electrolyte concentration (B), inter-electrode

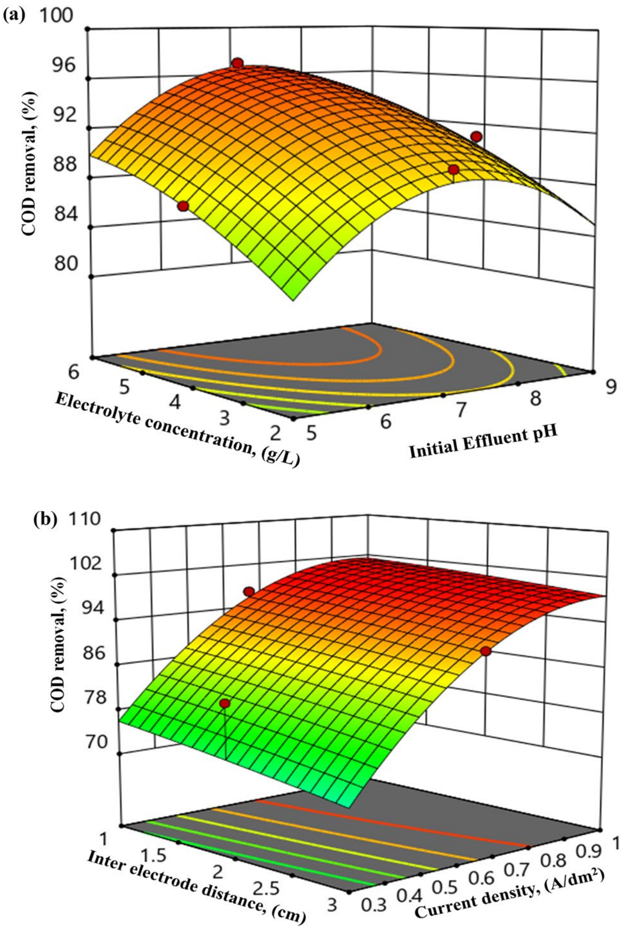

Fig. 7 3D response surface graphs for % COD removal **a** electrolyte concentration versus initial effluent, and **b** current density versus inter-electrode distance

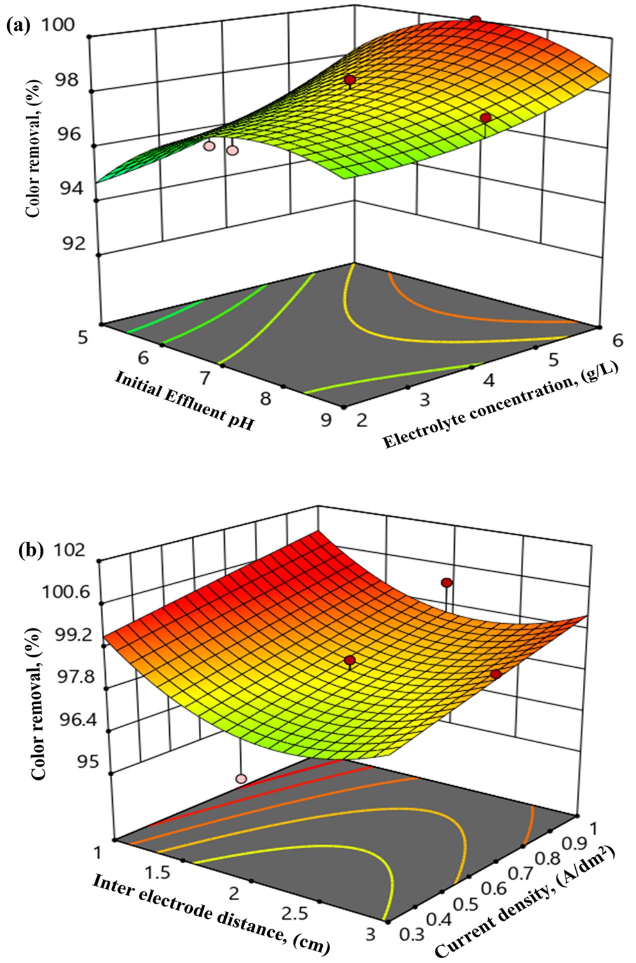

Fig. 8 3D response surface graphs for % color removal **a** electrolyte concentration versus initial effluent, and **b** current density versus inter-electrode distance

distance (C), and current density (D) were selected as within range and the responses such as % COD and % color removal efficiency were maximized and power consumption was minimized.

Under these optimum experimental conditions such as initial effluent pH (A)—5, electrolyte concentration (B)—6 g/L, inter-electrode distance (C)—1 cm with current density (D)—1 A/dm^2 and the % COD and color removal of 97.50% and 100%, respectively, power consumption was found to be 0.55 kWh/m^3 with desirability of 0.89 which was selected. The good correlation between these actual and predicted results indicates that the reliability of the CCD incorporates the desirability function method and it could be effectively used to optimize the hybrid SEC process parameters for any type of wastewater.

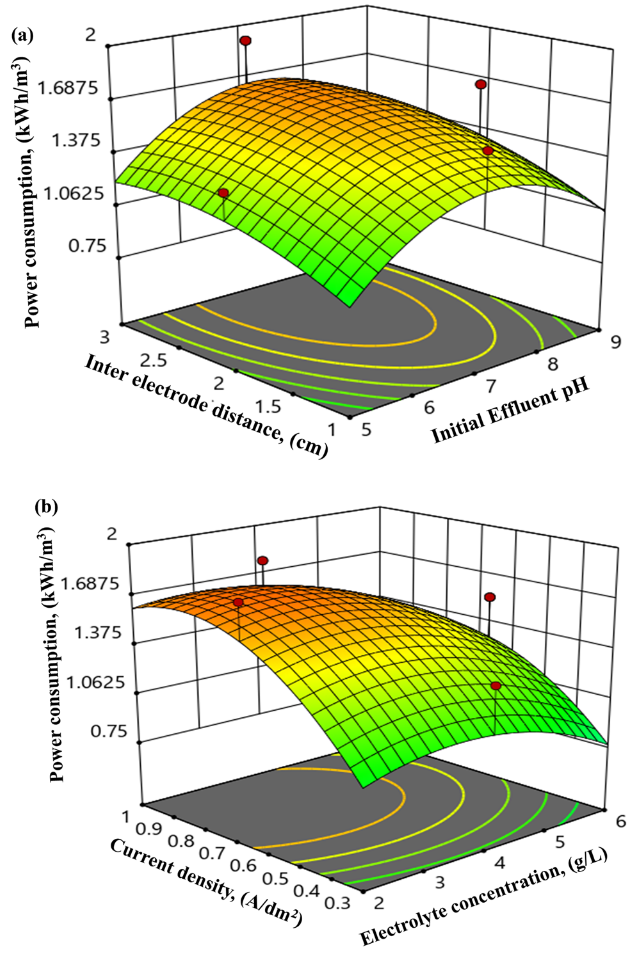

Fig. 9 3D response surface graphs for power consumption **a** electrolyte concentration versus initial effluent, and **b** current density versus inter-electrode distance

Conclusion

The following conclusions can be drawn from this research work. The SEC processes for the treatment of wastewater were successfully carried out in terms of % COD removal and % color removal with the determination of power consumption. The results showed that the hybrid SEC process was effective. The effect of operating parameters such as current density (0.3 to 1 A/dm^2), initial effluent pH (4 to 10), electrolyte concentration (1 to 6 g/L) and inter-electrode distance (1 to 3 cm) on % color and % COD removal, and power consumption were studied. The hybrid SEC process was optimized to maximize % COD and % color removal with minimum power consumption. The maximum % COD and % color removal of 97.50 and 100% were observed at the current density of 1 A/dm^2, effluent pH of 5, electrolyte concentration of 6 g/L, an inter-electrode distance of 1 cm, and reaction time of 45 min, respectively. Finally, this research work is suitable to be applied for the treatment of residential

Table 3 ANOVA of the quadratic model equation for % COD removal

Source	Sum of Square	*df**	Mean square	*F* value	*p* value Prob > *F*	Remark
Model	4975.34	14	355.38	27.90	< 0.0001	Highly significant
A-Initial effluent pH	33.87	1	33.87	2.66	0.1238	
B-Electrolyte concentration	266.88	1	266.88	20.95	0.0004	Significant
C-Inter-electrode distance	81.03	1	81.03	6.36	0.0235	Significant
D-Current density	3299.16	1	3299.16	258.97	< 0.0001	Highly significant
AB	1.16	1	1.16	0.091	0.7669	
AC	4.19	1	4.19	0.33	0.5747	
AD	2.80	1	2.80	0.22	0.6461	
BC	2.90	1	2.90	0.23	0.6402	
BD	1.16	1	1.16	0.091	0.7669	
CD	9.29	1	9.29	0.73	0.4066	
A^2	85.89	1	85.89	6.74	0.0202	Significant
B^2	4.10	1	4.10	0.32	0.5790	
C^2	0.17	1	0.17	0.014	0.9090	
D^2	136.47	1	136.47	10.71	0.0051	Significant
Residual	191.09	15	12.74			
Lack of fit	191.09	10	19.11			
Pure error	0.000	5	0.000			
Cor total	5166.43	29				

**df* degrees of freedom

Table 4 ANOVA of the quadratic model equation for % color removal

Source	Sum of Squares	*df**	Mean square	*F* value	*p* value Prob > *F*	Remark
Model	99.57	14	7.11	7.35	0.0002	Significant
A-Initial effluent pH	8.00	1	8.00	8.26	0.0116	Significant
B-Electrolyte concentration	32.00	1	32.00	33.05	< 0.0001	Highly significant
C-Inter-electrode distance	10.73	1	10.73	11.09	0.0046	Significant
D-Current density	12.50	1	12.50	12.91	0.0027	Significant
AB	3.06	1	3.06	3.16	0.0956	
AC	0.063	1	0.063	0.065	0.8029	
AD	10.56	1	10.56	10.91	0.0048	Significant
BC	7.56	1	7.56	7.81	0.0136	Significant
BD	5.06	1	5.06	5.23	0.0372	Significant
CD	0.063	1	0.063	0.065	0.8029	
A^2	5.95	1	5.95	6.15	0.0255	Significant
B^2	0.61	1	0.61	0.63	0.4406	
C^2	5.33	1	5.33	5.51	0.0331	Significant
D^2	6.459E−004	1	6.459E−004	6.672E−004	0.9797	
Residual	14.52	15	0.97			
Lack of fit	14.02	10	1.40	14.02	0.0047	Significant
Pure error	0.50	5	0.100			
Cor total	114.09	29				

**df* degrees of freedom

Table 5 ANOVA of the quadratic model equation for power consumption

Source	Sum of squares	*df**	Mean square	*F* value	*p* value Prob > *F*	Remark
Model	7.55	14	0.54	8.47	< 0.0001	Significant
A-Initial effluent pH	0.084	1	0.084	1.31	0.2699	
B-Electrolayte concentration	0.41	1	0.41	6.49	0.0223	Significant
C-Inter electrode distance	0.36	1	0.36	5.70	0.0306	Significant
D-Current density	1.30	1	1.30	20.38	0.0004	Significant
AB	5.184E−003	1	5.184E−003	0.081	0.7794	
AC	7.840E−004	1	7.840E−004	0.012	0.9131	
AD	1.024E−003	1	1.024E−003	0.016	0.9008	
BC	1.024E−003	1	1.024E−003	0.016	0.9008	
BD	0.064	1	0.064	1.00	0.3340	
CD	9.000E−006	1	9.000E−006	1.412E−004	0.9907	
A^2	0.34	1	0.34	5.28	0.0364	Significant
B^2	0.086	1	0.086	1.36	0.2622	
C^2	0.031	1	0.031	0.49	0.4930	
D^2	0.24	1	0.24	3.81	0.0698	
Residual	0.96	15	0.064			
Lack of Fit	0.92	10	0.092	11.36	0.0076	Significant
Pure Error	0.040	5	8.058E−003			
Cor Total	8.51	29				

**df* degrees of freedom

effluent as it has higher treatment efficiency compared to the conventional treatment process.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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