

# Peroxi-Electrocoagulation process for the treatment of simulated dye wastewater: A comparison study

**Mohammed Najim Abdullah**

*Department of Chemical Engineering, Faculty of Engineering, University Baghdad, Iraq,  
muhammad.abdullah1607m@coeng.uobaghdad.edu.iq*

**Asrar Abdullah Hassan**

*Department of Chemical Engineering, Faculty of Engineering, University Baghdad, Iraq,  
asrar.hasan@coeng.uobaghdad.edu.*

## Abstract

The present work was conducted to make a comparison among two types of electrochemical processes [peroxi-coagulation (PC), peroxi-electrocoagulation (PEC)] that have been used for the treatment of simulated dye wastewater using a lab-scale batch electrochemical cell. In the peroxi-coagulation (PC), peroxi-electrocoagulation (PEC) processes, stainless steel anode and porous graphite cathode were used in both processes. At the peroxi-coagulation process, Impacts of operating parameters like current density (4-36 mA/cm<sup>2</sup>), air aeration (0.5-2.5 l/min), pH (3-9), and time (20–120min) on the elimination efficiency color were examined with the use of response surface methodology (RSM) combined with Box–Behnken design (BBD). The optimum conditions were found to be an initial value of the pH equal to (3), current density of 36 mA/cm<sup>2</sup>, air aeration equal to 1.5 l/min, and time duration of 120 min, where color removal efficiency of 98.76% was achieved and energy consumption of 10.54 kWh/kg was required. At the peroxi-electrocoagulation process, impact of operating factors like current density (4-36 mA/cm<sup>2</sup>), H<sub>2</sub>O<sub>2</sub> concentration (20-100 g/l), pH (1-5), and time (10–30min) on the color removal were studied using RSM combined with BBD. The optimal operating parameters were determined to be H<sub>2</sub>O<sub>2</sub> concentration of 100 g/l, current density of 20 A/cm<sup>2</sup>, duration of 10 min, and pH of 3., where color removal efficiency of 99.92% was achieved and energy consumption of 0.45 kWh/kg was needed. Results showed that the PEC is more effective than PC where quantity of energy consumption in PEC less than in PC process we can consider the PEC process is the most successful for removal the dye from wastewater.

**Key words:** *Box–Behnken design; Graphite poros; Hydrogen peroxide; Peroxi-coagulation (PC); Reactive Yellow.*

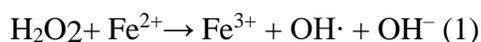
## 1. INTRODUCTION

Recently, the availability of fresh water has become a major issue on a global scale due to ascarcity of surface water and the depletion of groundwater resources. Rapid urbanization, industry, and improved living conditions have led to a global water use that is higher than it has ever been [1]. Four billion people currently experience severe water scarcity for at least one month of the year, and more than two billion people are

currently under severe water stress [2]. Agricultural, household, and commercial sectors consume the most water (municipal), water use is expected to increase by 160 percent globally by 2030 [3] due to population growth, industry, and other factors. One of the largest water consumers, textile companies produce a lot of effluent that is heavy in nutrients, dissolved solids (TDS), and colors that are detrimental to fish and other aquatic life [4]. Wastewater from the textile industry is discharged into surface

waters in developing nations like Bangladesh, India, Vietnam, China, and others after inadequate or no treatment. Because of this, it's essential to design efficient treatment processes that allow for the safe discharge of textile effluent to receiving bodies of water.

The use of adsorption and other common therapeutic techniques is either expensive or ineffective. Researchers explored sophisticated oxidation techniques to eliminate synthetic colors from wastewater streams (AOPs). These methods use electrochemical mechanisms [5] or chemical [6], photochemical [7], or electrophilic addition to systems to increase the production of hydroxyl radicals (OH•). These radicals also interact with pollutants to absorb hydrogen atoms through redox reactions and electrophilic addition [8]. Using advanced oxidation processes (AOPs), which are promising dye removal technologies that are primarily focused on the in situ generation of oxidizing agents such hydroxyl radicals (OH) in solution, will eliminate the limitations of these antiquated procedures. Because of its high oxidative potential ( $E_0 = 2.80 \text{ V vs. NHE}$ ), the hydroxyl radical is able to swiftly and non-selectively oxidize a wide range of chemical dyes [9,10]. Because of how fragile it is, this radical must be continuously created "in situ" using chemical or photochemical methods [11,12]. The OH degrades synthetically colored water, oxidizing the resulting species to produce safe gases such CO<sub>2</sub> and H<sub>2</sub>O [9,12,13]. One of the main AOPs for the oxidative destruction of several refractory chemical substances, including dyes, is the conventional Fenton reaction ( $\text{Fe}^{2+}/\text{H}_2\text{O}_2$ ) [14,15].



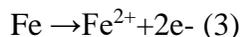
The widespread use of the Fenton reaction in wastewater treatment is prohibited [16,17], despite the reaction's incredible efficacy. More

research has been done on the chemistry of the Fenton's reaction in order to fix acidic waters that include synthetic colors. [18]. Recently, it has been possible to boost reaction power by using the so-called electro-Fenton, a novel AOP generated by chemistry [19,20]. The sacrificial iron anode generates Fe<sup>2+</sup> in the electro-Fenton (EF) process, which involves manually injecting H<sub>2</sub>O<sub>2</sub> [19]. Four different approaches make up the present EF process division. On a sacrificial anode and a cathode, respectively, Fe<sup>2+</sup> and H<sub>2</sub>O<sub>2</sub> are produced using electrical energy in the first method [20,21]. The second strategy [22,23] employs a manual addition of H<sub>2</sub>O<sub>2</sub> while a sacrificial iron anode serves as a source of Fe<sup>2+</sup> electro-generation. In the third method, Fe<sup>2+</sup> ions are manually added, and electrically produced H<sub>2</sub>O<sub>2</sub> is formed by oxygen sparging on a carbon- or a gas-diffusion cathode electrode via Eq (2). The fourth approach employs an electrolytic cell and Fenton's reagent to produce OH, which is subsequently reduced to ferrous ion at the cathode to produce ferrous ions [24].

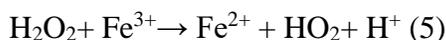


The EF method is a low-cost, environmentally responsible technology that does not produce secondary pollutants in water or wastewater and does not employ any hazardous or toxic ingredients [25,26]. To describe the primary EF process reactions, the following equations have been used: Equation 2 shows that water is reduced as a result of the sacrificial iron anode's discharge of Fe<sup>2+</sup> ions into the solution. When H<sub>2</sub>O<sub>2</sub> is manually added, the Fenton reactions (Eqs. (1) and (4)) subsequently take place, resulting in constant Fe<sup>2+</sup> regeneration at the cathode (Eq. (5)) [19]. The equations below have been used to explain the primary reactions of the (PEC) process: Water is reduced as a result of the release of Fe<sup>2+</sup> ions from the

sacrificial iron anode into the solution (Eq. 2) and the Four simultaneous reduction of water (Eq. 3) at the cathode.



Following the continual injection of H<sub>2</sub>O<sub>2</sub> manually or in situ, the Fenton reactions (Eqs.(1) and (4)) take place, and the regeneration of Fe<sup>2+</sup> by the continuing reduction of Fe<sup>3+</sup> at the cathode (Eq. (5)) occurs. [19] .different approaches make up the present EF process division. On a sacrificial anode and a



This reaction (Eqs. (6) and (7)) does not efficiently support the oxidation process, despite the possibility that some hydroxyl radicals may mix with iron and oxygen to create HO<sub>2</sub> [27].



The aim of the present work was to investigate the decolorization of reactive yellow (RY) dye, an azo dye, by PEC in a batch reactor utilizing iron and graphite electrodes. Further research was done into the effects of pH, current density, working time, and H<sub>2</sub>O<sub>2</sub> dosage on the PEC process in order to determine the best operating conditions. Additionally, under ideal conditions, measurements of energy consumption and color removal effectiveness were done. Centrifuging materials for three minutes at 4000 rpm before analysis reduced the interference of interfering elements such iron and created sludge in reading [28]. TDS,

conductivity, and final pH values for each sample were evaluated. A spectrophotometer (Hach-DR5000) with a 420 nm wavelength was used to measure the absorbance at the dyes' maximum wavelength (max=420) in order to track the decolorization of the Reactive Yellow solution. Eq. (10) was used to determine the dye's decolorization % [29].

$$R = \frac{C_0 - C_t * 10^3}{C_0} \quad (10)$$

Where R is the removal ratio while C<sub>0</sub> and C<sub>t</sub> are the dye concentrations in mg/l initially and at a given time t, respectively [30]. In addition, to evaluate the effectiveness of PC and PEC electrodes, energy consumption (EC), which was computed using the modified Eq (11), was utilized.

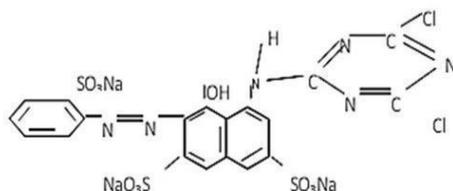
In addition, to evaluate the effectiveness of PC and PEC electrodes, energy consumption (EC), which was computed using the modified Eq (11), was utilized [30].

$$EC = \frac{U * I * t * 1000}{M * V} \quad (11)$$

where M is concentration of dye removal (mg/L), t is the duration (hr), I is the electrical current(A), U is the voltage (V) and V is the cell's volume (L).

## 2. Experimental

Reactive Yellow (anionic dye) was obtained from, the AL-kut textile factory, south of Baghdad. Table. 1 shows the chemical structure and specifications of this azo dye . Na<sub>2</sub>SO<sub>4</sub> (Merck) was utilized as an electrolyte in the experimental cell to produce conductivity. All additional reagents, including H<sub>2</sub>O<sub>2</sub> (50 wt%), were obtained from Market , and the room temperature was used for the setup and testing.

**Figure 1. The Chemical Structure Of Reactive Yellow****Table 1. Characteristics Of Reactive Yellow**

Item	Reactive Yellow (RY)
Trade name	Yellow FG
Origin	Swiss
Phase	Solid
Wavelength (nm)	420
Solubility g/l in 250C	150
pH	7.2± 0.3
Molecular Weight	717

0.1M H<sub>2</sub>SO<sub>4</sub> or 0.1M NaOH were employed to adjust the pH of the solution. All of the substances employed in this experiment were of analytical purity, which is crucial to mention. A rectangular Stain steel plate and graphite plate with dimensions of 2 cm in length, 5 mm in depth, and changeable width served as the electrode material, which was obtained locally.

Using a 400 ml beaker with a 300 ml working volume, experiments were conducted. The anodeelectrodes were constructed of iron plates, and the cathode was composed of graphite and situated 2 cm away from the anode. An air pump (R-5010) was also used to provide air close to the cathode, increasing the amount of soluble oxygen in the solution and maximizing hydrogen peroxide production. A flowmeter was also used to control the airflow

(Dwy, V-23). The solution was homogenized by swirling it with a magnetic stirrer at 1000 rpm (MS-500). A pH meter (Jenway 3540) was used to determine the starting pH of the solutions, and the energy was supplied by a power supply (PS-305).

To create the stock solution for the dye concentration samples (100 mg/L), one gram of each dye was dissolved in one thousand milliliters of double-distilled water. A 400 mL cylindrical glass cell made up the PC batch reactor that contained 300 mL of samples with the necessary dye standard concentrations. Two plate steel and graphite electrodes (anode and cathode) with dimensions of (100 mm 50 mm 4 mm) were submerged in the solution. The electrodes were spaced 20 millimeters apart. An air pump (shown in Figure 2-a) was placed next to the cathodic electrode. For 20 to 30 minutes, compressed bubbled air was added into the mixture to maintain O<sub>2</sub> saturation in aqueous media during all tests in the (PC) procedure before to electrolysis and stayed there throughout all experiments, whereas H<sub>2</sub>O<sub>2</sub> concentrations were manually inserted into the electrolytic reactor during the (PEC) procedure. To a digital DC Power Supply, To enable monopolar operation, the electrodes were linked (PS-305 DM, USA) [26]. H<sub>2</sub>SO<sub>4</sub> and NaOH were used to alter the pH of the solutions at first (0.1 M). To enhance the conductivity and ionic strength of the water, 50 mM of Na<sub>2</sub>SO<sub>4</sub> was added to the (PC) process and 7 mM of Na<sub>2</sub>SO<sub>4</sub> to the (PEC) process, in all experiments as a supporting electrolyte.

**Figure 2. Schematic diagram of electrochemical (PC and PEC methods) experimental rig, 1. Beaker, 2. Electrodes, 3. Magnetic Stirrer, 4. Power supply, 5. Ammeter, 6. Air pump, 7- flowrate control. from the left (PC) with (Air pump, flowrate control) cell, from the right (PEC) cell without (Air pump, flowrate control)**



PC (a)

PEC (b)

To choose the most important parameters that affected the process performance and to narrow the range of each parameter, a preliminary set of experiments (screening trials) was carried out. The chosen research parameters are shown in Tables 2 and 3.

**Table 2: Parameters Tested in This Study For PC Process**

Process parameters	range in Box–Behnken design		
	Low(-1)	Middle(0)	High (+1)
Coded levels	Low(-1)	Middle(0)	High (+1)
Current density (mA/cm <sup>2</sup> )	4	20	36
Aeration Rate (L/min)	0.5	1.5	2.5
initial pH	3	6	9
Time(min)	20	70	120

**Table 3: Parameters Tested in This Study For PEC Process**

Process parameters	range in Box–Behnken design		
	Low(-1)	Middle(0)	High (+1)
Coded levels	Low(-1)	Middle(0)	High (+1)
Current density (mA/cm <sup>2</sup> )	4	20	36
H <sub>2</sub> O <sub>2</sub> Concentration (mg/l)	20	60	100
initial pH	1	3	5
Time(min)	10	20	30

### 3. Results and Discussion

#### 3.1. Design of Experiments

One of the best statistical techniques for optimization and design is response surface methodology (RSM). The current work used a four factor, three level full factorial Box-Behnken design (BBD) with RSM, optimize a variety of process factors, including current density (4 -36 mA/cm<sup>2</sup>), initial pH (3-9), air

aeration rate (0.5-2.5 l/min), and time (20-120 min) during the process (PC) and were investigated current density (4-36 mA/cm<sup>2</sup>), initial pH (1-5), and H<sub>2</sub>O<sub>2</sub> concentration (20-100 mg/l), time (10-30 min ) through (PEC).

The full quadratic models are provided by Eqs. (12) and (13) based on the experimental results of removal for Peroxi-coagulation (PC), and Peroxi-electrocoagulation (PEC), regression analysis for BBD:

$$\begin{aligned} \text{Removal\%} = & 0.9 + 1.668 \text{ Current density} + 22.96 \text{ Aeration Rate} + 0.24 \text{ pH} + 0.956 \text{ Time} \\ & - 0.01997 \text{ Current density} * \text{Current density} - 7.15 \text{ Aeration Rate} * \text{Aeration Rate} \\ & - 0.453 \text{ pH} * \text{pH} - 0.004052 \text{ Time} * \text{Time} \end{aligned} \quad (12)$$

$$\begin{aligned} \text{Removal\%} = & 40.4 + 0.537 \text{ Current density} + 0.365 \text{ H}_2\text{O}_2 + 18.34 \text{ pH} - 0.337 \text{ Time} \\ & - 0.01817 \text{ Current density} * \text{Current density} - 0.00105 \text{ H}_2\text{O}_2 * \text{H}_2\text{O}_2 \\ & - 2.741 \text{ pH} * \text{pH} + 0.0025 \text{ Time} * \text{Time} \end{aligned} \quad (13)$$

The P-test and Fisher F-test are used to determine the model's acceptance in ANOVA analysis. When Fisher's value is high, the bulk of response variation can be shown using an equation of regression. The F must be large enough to recognize the statistical significance of the model, and this is done using the P-value when the P-value is less than 0.05, 90% of the model's variability can be explained (0.05) [27].

In addition to the F-value, the P-value, adjusted average of square (Adj. MS), an adjusted average of square (Adj. SS), degree of freedom (DOF), and adjusted average of the square (Adj. SS) were investigated. For PC and PEC, the F-values are (23.13) and (22.07), respectively. P- values of (0.0001) were found for both processes, indicating a significant regression model has been used. Multiple correlation coefficient with model (R<sup>2</sup>) has been (89.50% 89.05% ) for PC and PEC the

agreement with the regression is statistically significant. Multiple correlation coefficient that has been altered (adj. R<sup>2</sup> is equal to 89.02%, 85.63% for PC, PEC process) was not as expected given the multiple correlation coefficient's forecasted value (pred. R<sup>2</sup>= 78.17 %, 77.11 % for PC & PEC ) in the model.

Tables 4 and 5 display the results of the analysis of variance (ANOVA) for the removal efficiency for each method.

#### 3.2. Effect of Studied Parameters on Removal Efficiency for peroxi-coagulation (PC) process

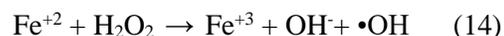
The interaction between current density and pH was presented in Fig.3, at pH (3), The results demonstrate that raising the current density from 4 mA/cm<sup>2</sup> to 36 mA/cm<sup>2</sup> increases color removal efficiency significantly. In an acidic medium at pH 3 , In the aqueous solution, anionic contaminants are bound by Fe<sup>2+</sup> ions produced at the anode surface. With the acidic

solution at pH 3, Fe(OH)<sub>3</sub> metal hydroxide concentration rises, This in favor of enhancing the rate of pollutant adsorption on metal hydroxide precipitates, increased removal as a result. then starting Fe(OH)<sub>4</sub> flocs by formation, which are extremely soluble and poorly able to bind with pollutant ions, when at high initial pH access to 6, leading to decreased removal, Contrarily, in an alkaline pH the system at 9, the Fe<sup>3+</sup> precipitates as Fe(OH)<sub>3</sub> and FeOOH<sub>2</sub>, which reduces the process' effectiveness and which is replaced by coagulation decreasing removal in both circumstances. The related contour plot reveals that the removal effectiveness of 90% is found in a limited area where the current density was between 19-36 mA/cm<sup>2</sup> and the pH was between (3-3.7).

Fig. 4 shows a surface plot and contour plot that show how current density and time interact to affect the effectiveness of color removal at constant pH and aeration rate. When the current was increased from 22.5 to 36 mA/cm<sup>2</sup> and time between 50 and 120 minutes, it was found that the efficiency of color removal increased rapidly with increasing time. resulting in high removal efficiencies with increases the reaction time leads to enhanced color removal efficiency for dye degradation when from 70 to 120 min, this phenomenon occurs because the OH has a larger chance to react with impurities when the reaction time is raised .The increased H<sub>2</sub>O<sub>2</sub> generation results in the production of more •OH.

Fig. 5 shows the effect of aeration rate on the effectiveness of color removal at various current densities (4-36 mA/cm<sup>2</sup>) and constant pH (6) through time (70 min). Surface map of the response demonstrates that as aeration increases, color removal efficiency increases linearly at the current density (4-20 mA/cm<sup>2</sup>), a similar tendency exists (36 mA/cm<sup>2</sup>). When

increasing current density with aeration rate increasing from 0.5 to 1.5 L/min effectiveness of removal will increasing will be increased from 80% to 95% as the amount of hydrogen peroxide produced increases as a result of the increased formation of hydrogen-free radicals (•OH) as a result of the Fenton (Eq. 14), the mineralization of organic compounds in the reaction media increased.



When increasing air aeration of 2.5 L/min a reverse phenomenon was observed, as indicated in (Eq. 15), the reaction of excess hydrogen peroxide with the formation of •OH in an undesired reaction to generate HO<sub>2</sub>• (which is less effective than •OH) will result in a drop in removal efficiency [28].



The related contour plot demonstrates that the color removal effectiveness of 80% is found in a small region with current densities ranging between 22.5 to 36 mA/cm<sup>2</sup> and additional aeration rate ranging from 0.7 to 2.3 L/min.

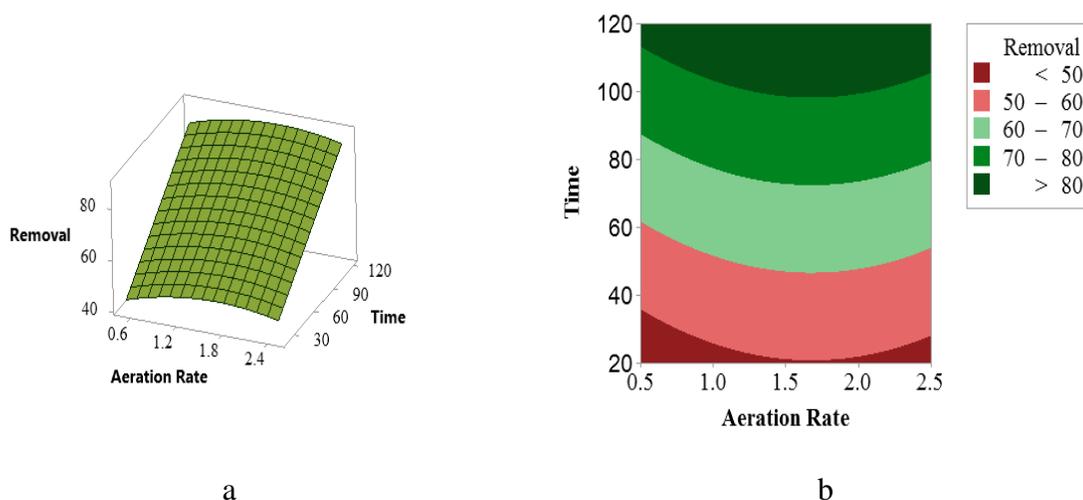
Fig.6 shows the relationship between aeration rate and reaction time that affects color removal efficiency. The color removal efficiency increased from 55 to 90% with an increase in aeration rate from 0.5 to 1.5 L /min at a long reaction time of 120 min at constant pH and current intensity and the amount of dye was 100 ppm. This indicates that when there is a lot of aeration rate present, the reaction produces more •OH and the initial deterioration happens more quickly.

The interaction between current density and pH was presented in Fig.7, at pH (3), The results demonstrate that raising the current density from 4 mA/cm<sup>2</sup> to 36 mA/cm<sup>2</sup> increases color removal efficiency significantly. The reaction rate will be accelerated by using more Fe<sup>2+</sup>

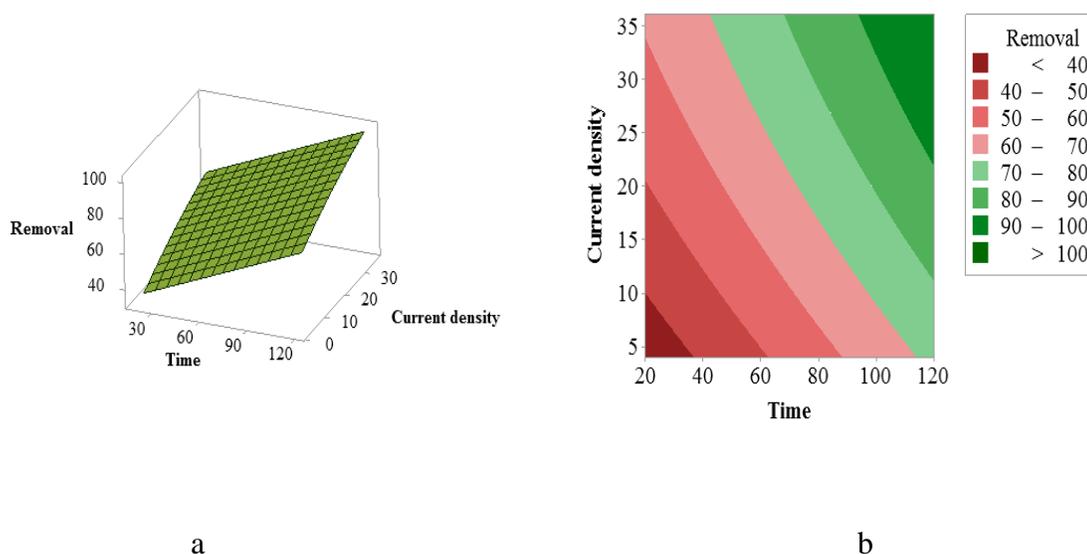
ions and generation of hydroxyl radicals, resulting in high removal efficiencies that raise the reaction time leads to enhanced color removal efficiency for dye degradation at higher current density 36 mA/cm<sup>2</sup>. Increasing current density with increasing pH at 9, this

can prevent the production of •OH and result in lower elimination effectiveness. The related contour plot reveals that the removal effectiveness of 90% is found in a limited area where the current density was between 19-36 mA/cm<sup>2</sup> and the pH was between (3-3.7).

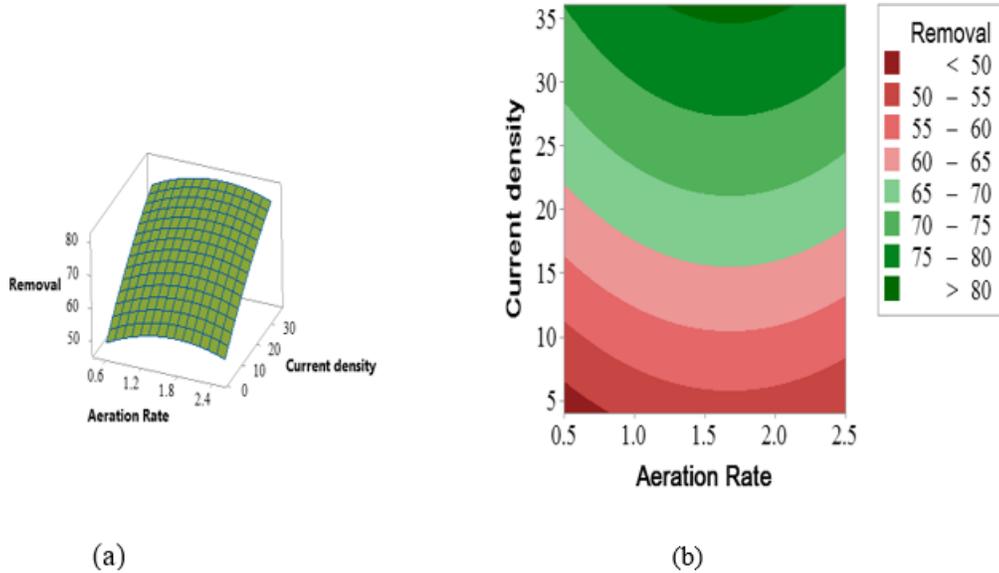
**Fig. 3: Plots for the Response Surface and the Contour for the Effect of the Aeration Rate and Time on Color Removal Efficiency (RE%) in PC. (Constant Values: pH= 6 , Current Density =20 mA/cm<sup>2</sup>)**



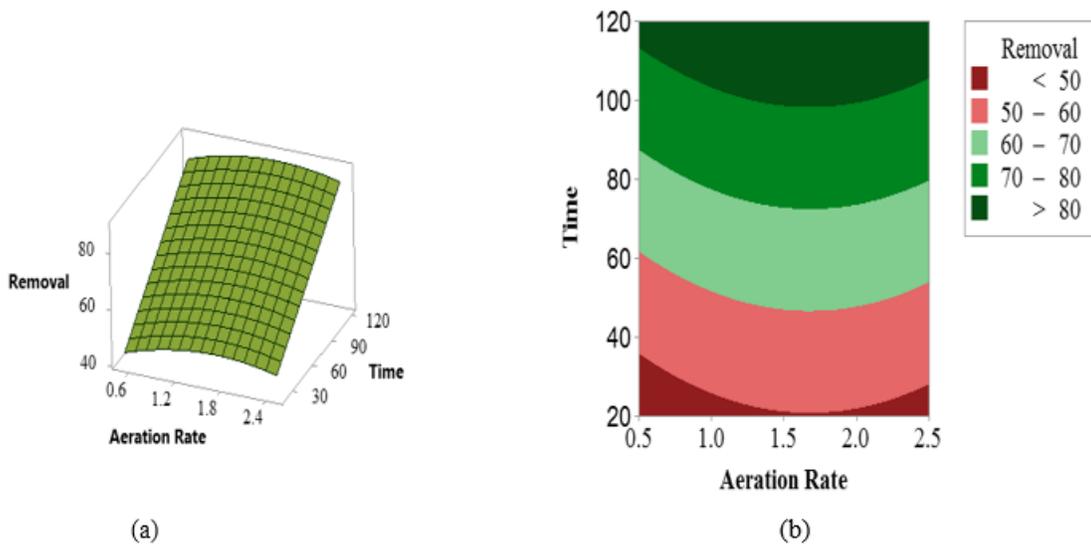
**Fig. 4: Plots for the Response Surface and the Contour for the Effect of the Time and Current Density on Color Removal Efficiency (RE%) in PC. (Constant Values: pH= 6 , Aeration Rate =1.5 L/min)**



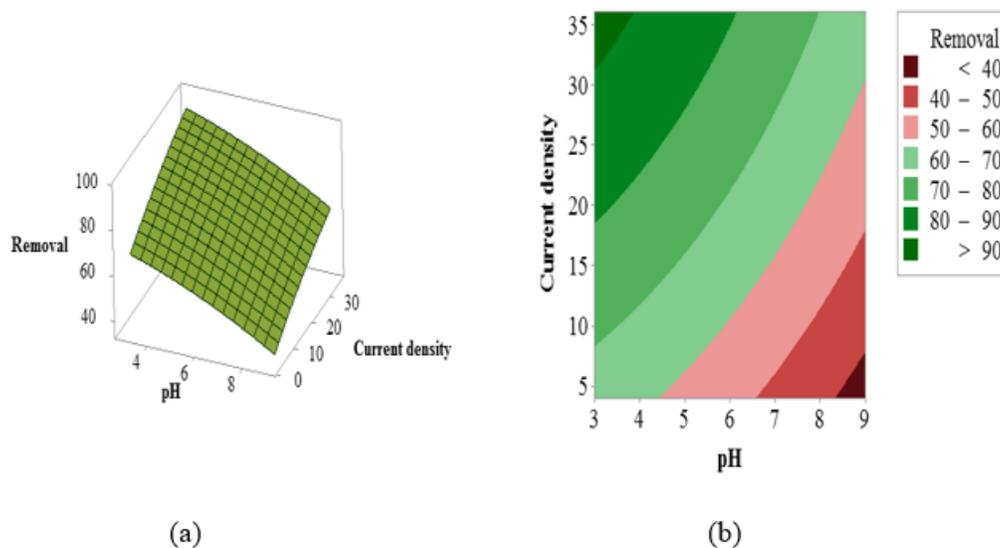
**Fig. 5: Plots for the Response Surface and the Contour for the Effect of the Aeration Rate and Current Density on Color Removal Efficiency (RE%) in PC. (Constant Values: pH= 6 , Time =70 min)**



**Fig. 6: Plots for the Response Surface and the Contour for the Effect of the Aeration Rate and Time on Color Removal Efficiency (RE%) in PC. (Constant Values: pH= 6 , Current Density =20 mA/cm2)**



**Fig. 7: Plots for the Response Surface and the Contour for the Effect of the pH and Current Density on Color Removal Efficiency (RE%) in PC. (Constant Values: Air Aeration =1.5 L/min, Time =70 min)**



### 3.3. Effect of Studied Parameters on Removal Efficiency for Peroxi- electrocoagulation PEC process

The interaction between current density and H<sub>2</sub>O<sub>2</sub> concentrations was presented in Fig. 8, a surface plot and contour plot represent the efficiency of color removal increases exponentially as current density increases from 4 mA/cm<sup>2</sup> to 20 mA/cm<sup>2</sup>, where an increase in initial H<sub>2</sub>O<sub>2</sub> concentration from 60 to 100 mg/L would also increase the formation of hydroxyl radicals, which might react with organic pollutants in the solution; hence, raising H<sub>2</sub>O<sub>2</sub> concentration can be said to increase pollution removal and increase removal efficiency from 70% to 90%, but it decreases at 36 mA/cm<sup>2</sup> due to a reduction in color removal efficiency. When the current density was raised to 36 A/cm<sup>2</sup>, the removal efficiency decreased. This decrease could be attributed to hydrogen peroxide decomposition at greater current densities. The resulting contour map reveals that the color removal

efficacy of 90% is concentrated in a narrow area with current densities ranging from 4-29 mA/cm<sup>2</sup> and H<sub>2</sub>O<sub>2</sub> concentrations ranging from 75- 100 mg/l.

Figure 9, shows the interaction between pH and reaction time that effect on removal efficiency and it found that color removal efficiency increase to > 95% at pH 3 at time about 10 min, this because of the degradation of most organics in the solution, and the OH is more likely to react with pollutants. When starting pH increase about 5 will color removal efficiency decreasing due to the decrease in the generation of pollutant adsorbents and their consumption with the passage of time and the conversion to the basic medium at increase the reaction time from 20 to 30 min. The accompanying contour plot reveals that the color removal efficacy of 88% is concentrated in a narrow area with pH ranging from 2 to 4.7 and times between 10 and 27 min.

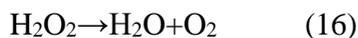
Figure 10, shows the relationship between H<sub>2</sub>O<sub>2</sub> concentration and reaction time that

affects color removal efficiency. The color removal efficiency increased from 75 to 95% with an increase in concentration from 60 to 100 mg/L at a long reaction time of 10 min at constant pH and current intensity. This shows that the reaction produces more  $\bullet\text{OH}$  and that the first degradation of the process happens more quickly in the presence of a substantial concentration of  $\text{H}_2\text{O}_2$ .

The interaction between current density and pH was presented in Fig., at pH (3), The results demonstrate that raising the current density from 4 mA/cm<sup>2</sup> to 20 mA/cm<sup>2</sup> increases color removal efficiency significantly. While decreases color removal efficiency significantly occur at 36 mA/cm<sup>2</sup>, This might be explained as a result of an increase in current density anodic dissolution of  $\text{Fe}^{2+}$  ions increases with current density, and therefore which causes the increased speed of transformation of solution from the acidic medium to the alkaline medium due to the increase in pH during because of the conversion of  $\text{Fe}^{2+}$  and  $\text{Fe}^{3+}$  to  $\text{Fe}(\text{OH})_3$ , electrocoagulation and pollution are reduced as a result of the electrostatic attraction of

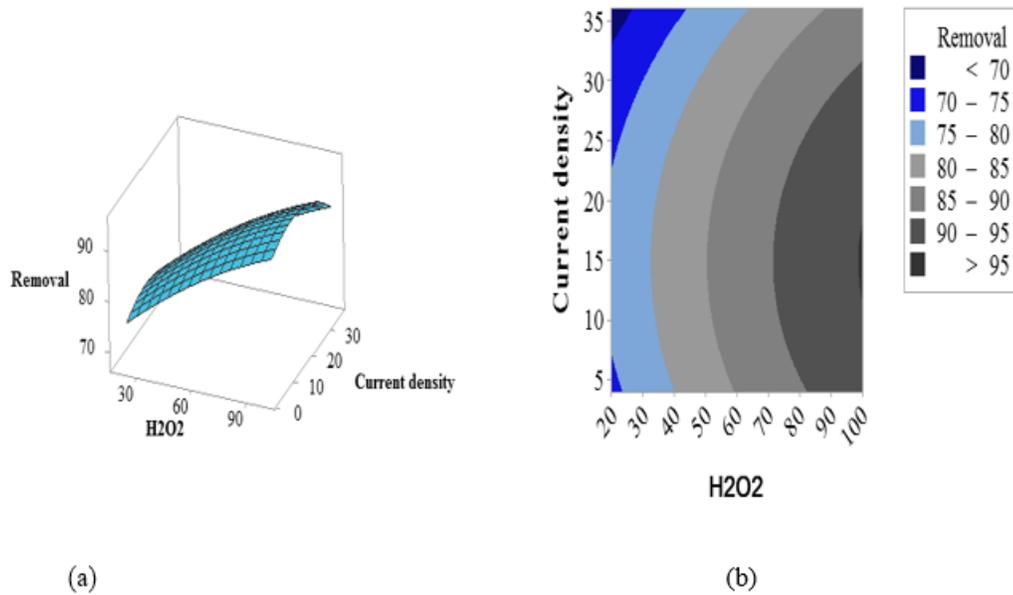
reactions [31]. The related contour plot Fig. 11 b reveals that the removal effectiveness of 85% is found in a limited area where the current density was between 4-27 mA/cm<sup>2</sup> and the pH was between (2.5- 4.3).

Fig.12 shows the interaction between  $\text{H}_2\text{O}_2$  concentration and pH, it found that when the  $\text{H}_2\text{O}_2$  concentration increase from 60 to 100 the color removal efficiency increase from 70% to 90% at pH= 3, at pH range from 1 and 5 the color removal efficiency decrease to 65% with increases  $\text{H}_2\text{O}_2$  concentration from 60 to 100 mg/L. Under highly acidic conditions at pH 1, the formation of oxonium ion ( $\text{H}_3\text{O}_2^+$ ) occurs instead of hydroxyl radicals, and under high basic conditions more than pH 10 will decomposition of  $\text{H}_2\text{O}_2$  occurs (Eq.16) [32].

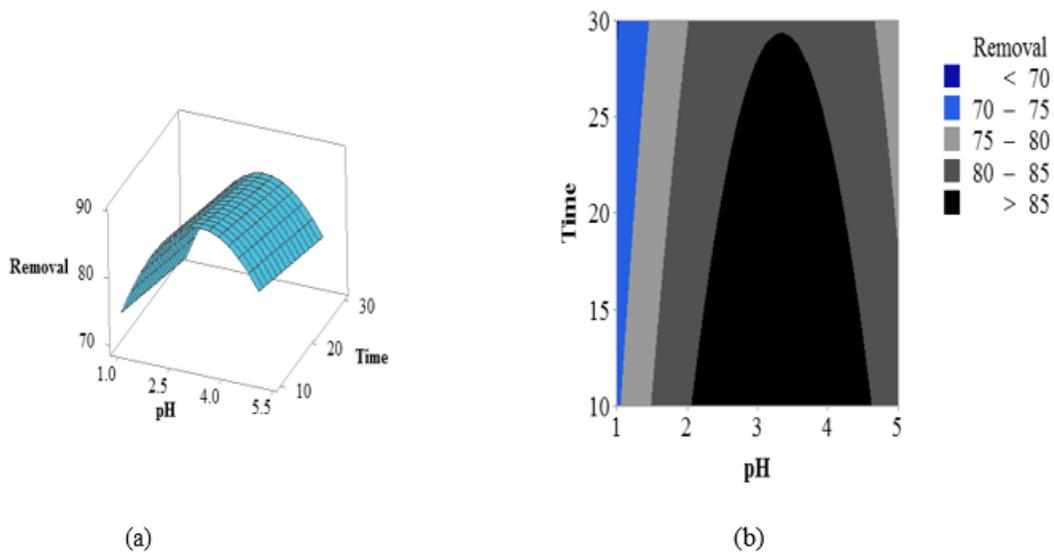


The accompanying contour plot reveals that the color removal efficacy of 90 % is concentrated in a narrow area with  $\text{H}_2\text{O}_2$  concentration ranging from 78 to 100 mg/L and pH between 3 and 4.7.

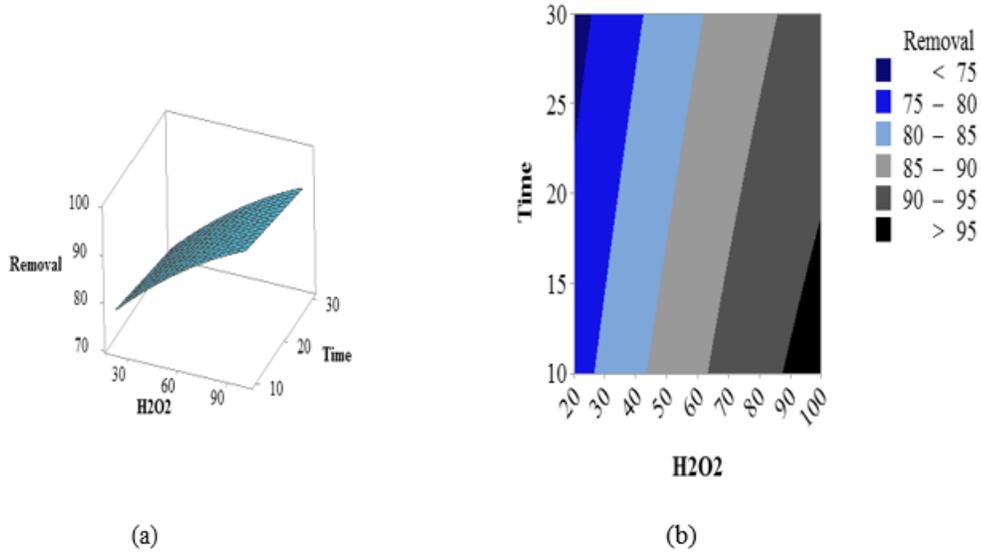
**Fig. 8: Plots for the Response Surface and the Contour for the Effect of the H<sub>2</sub>O<sub>2</sub> Concentration and Current Density on Color Removal Efficiency (RE%) in PEC. (Constant Values: pH=3, Time =20 min)**



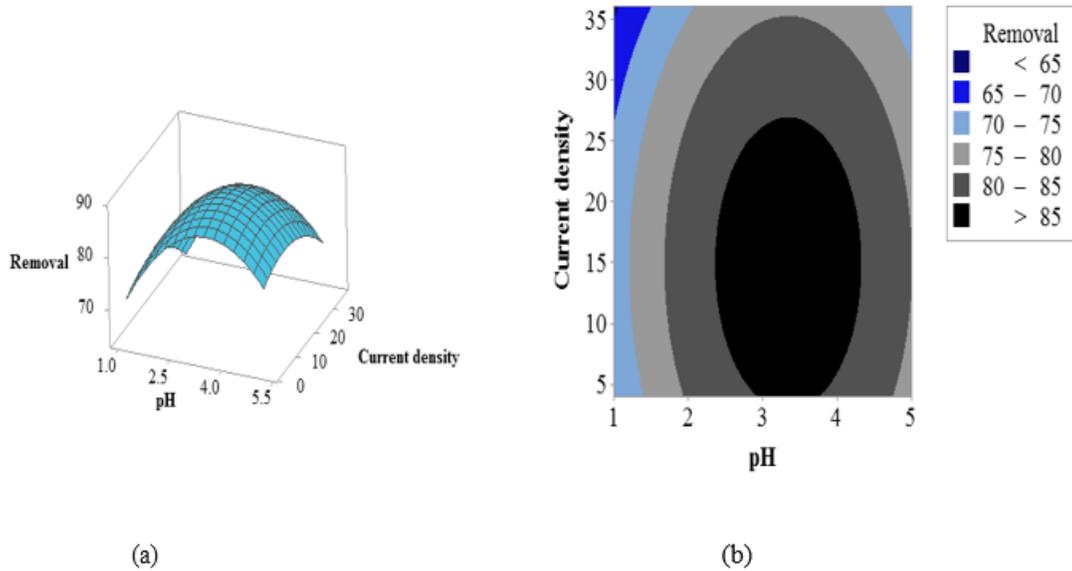
**Fig. 9: Plots for the Response Surface and the Contour for the Effect of the pH and Time on Color Removal Efficiency (RE%) in PEC. (Constant Values: H<sub>2</sub>O<sub>2</sub> Concentration = 60 mg/L, Current Density =20 mA/cm<sup>2</sup>)**



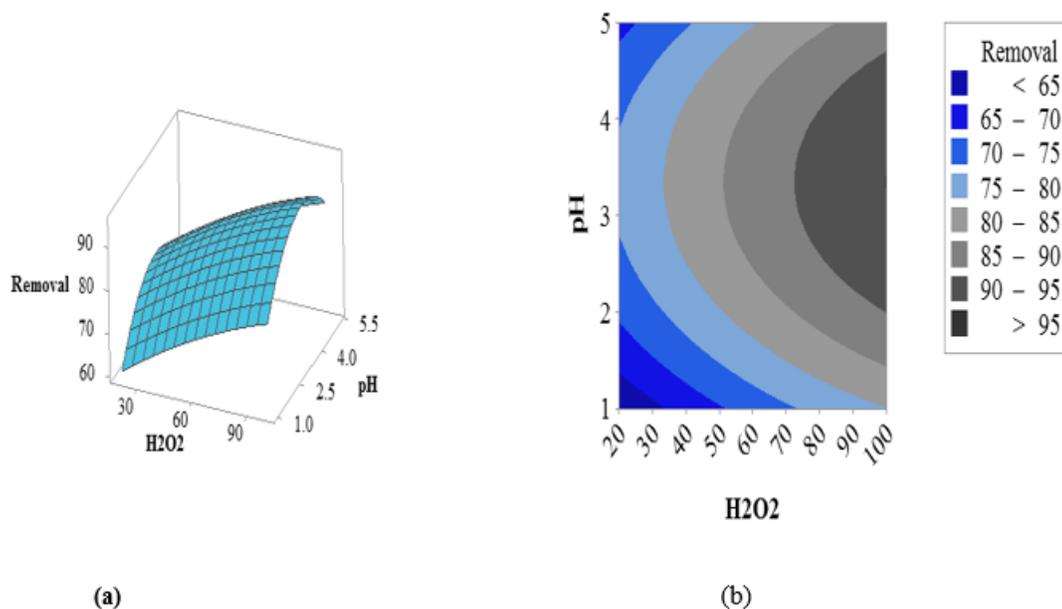
**Fig. 10: Plots for the Response Surface and the Contour for the Effect of the H2O2 Concentration and Time on Color Removal Efficiency (RE%) in PEC. (Constant Values: pH=3, Current Density =20 mA/cm2)**



**Fig. 11: Plots for the Response Surface and the Contour for the Effect of the pH and Current Density on Color Removal Efficiency (RE%) in PEC. (Constant Values: H2O2 Concentration = 60 mg/L, Time =20 min)**



**Fig. 12: Plots for the Response Surface and the Contour for the Effect of the H<sub>2</sub>O<sub>2</sub> Concentration and pH on Color Removal Efficiency (RE%) in PEC. (Constant Values: Current Density =20 mA/cm<sup>2</sup>, Time =20 min)**



**Table 4 : Analysis of Variance Table for the Model of (RE%) Removal Efficiency for (PC) Process**

Source	DOF	Adj. SS	Adj. MS	F-Value	P-value
Model	7	10061.7	1437.38	23.13	0.001
Linear	4	9969.8	2492.44	40.11	0.001
Error	19	1180.8	62.15		
Lack-of-Fit	17	1180.7	69.45	1700.93	0.001
Pure Error	2	0.1	0.04		
Total	26	11242.5			

**Table 5: Analysis of Variance Table for the Model of (RE%) Removal Efficiency for PEC Process**

Source	DOF	Adj. SS	Adj. MS	F-Value	P-value
Model	7	2224.15	317.74	22.07	0.0001
Linear	4	1453.69	363.42	25.25	0.0001
Error	19	273.51	14.40		

Lack-of-Fit	17	273.51	16.09	120664.54	0.000
Pure Error	2	0.00	0.00		
Total	26	2497.66			

#### 4. Comparison with earlier works

The optimum conditions showed that steel anode and porous graphite cathode may be used for peroxi-coagulation (PC) and peroxi-electrocoagulation (PEC), respectively, for dye removal from water, with color-removing effectiveness of 98.78 % and 99.92 % for PC and PEC processes, after 120 minutes and 10 minutes of electrolysis.

In this instance, the energy consumption of 10.5 kWh/kg and 0.45 kWh/kg for both processes is required. In Tables (7&9), a comparison was conducted between the current work and other relevant works for dye removal from water degradation using the (PC), (PEC) method with different electrode types used in different settings.

**Table 6. The Experimental Results Related To Box–Behnken Design About Decolorization Removal In (PC) Process**

NO.	Current density (mA/cm <sup>2</sup> )(X1)	Aeration Rate (L/min)(X2)	pH (X3)	Time (min)(X4)	Removal (%)		EC (Kwh/kg)
					Actual	Predict	
1	20	0.5	3	70	80.07	75.66	1.2767
2	20	2.5	3	70	84.22	78.70	1.3920
3	20	0.5	9	70	47.24	46.15	0.8083
4	20	2.5	9	70	43.17	49.19	0.7219
5	4	1.5	6	20	30.78	33.54	0.0133
6	36	1.5	6	20	45.99	61.38	0.7036
7	4	1.5	6	120	68.51	72.30	0.1918
8	36	1.5	3	120	98.76	112.52	10.5476
9	20	0.5	6	20	37.06	43.90	0.1832
10	20	2.5	6	20	47.08	46.94	0.4331

11	20	0.5	6	120	81.87	82.66	2.4561
12	20	2.5	6	120	83.35	85.70	2.4449
13	4	1.5	3	70	71.18	65.30	0.1301
14	4	1.5	9	70	42.85	35.79	0.0717
15	36	1.5	6	70	90.07	80.76	5.2646
16	36	1.5	9	70	72.19	63.63	4.3206
17	4	0.5	6	70	41.09	47.21	0.0735
18	4	2.5	6	70	49.97	50.25	0.0777
19	36	0.5	6	70	83.24	75.05	4.8362
20	36	2.5	6	70	81.03	78.09	4.8496
21	20	1.5	3	20	66.07	61.99	0.3193
22	20	1.5	9	20	24.08	32.48	0.1137
23	20	1.5	3	120	94.46	100.75	2.8023
24	20	1.5	9	120	69.01	71.24	2.0703
25	20	1.5	6	70	75.08	68.99	1.2409
26	20	1.5	6	70	74.73	68.99	1.2642
27	20	1.5	6	70	74.73	68.99	1.2497

**Table 7. Comparisons of dye wastewater degradation research using PC a computer and employing various electrode types with literature under various circumstances**

Electrodes type	pH	Current density (mA/cm <sup>2</sup> )	Time (min)	RE(%)	EC (Kwh/Kg)	Ref.
Aluminum-graphite	7	0.9 A	120	93	-----	[29]
Iron-carbon-PTFE	3	100 mA	300	92	-----	[36]
Pt-Carbon nano tube	3	250 mA	300	90	400	[37]

Steel - Porous Graphite	3	36	120	98.78	10.5	This work
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**Table 8. The Experimental Results Related To Box–Behnken Design About Decolorization Removal In (PEC) Process**

NO.	Current density (mA/cm <sup>2</sup> ) (X1)	H <sub>2</sub> O <sub>2</sub> Concentration (mg/l) (X2)	pH (X3)	Time (min) (X4)	Removal (%)		EC (Kwh/kg)
					Actual	Predict	
1	20	20	1	20	63.12	60.68	0.28755
2	20	100	1	20	78.43	79.89	0.37036
3	20	20	5	20	67.13	68.28	0.32819
4	20	100	5	20	88.15	87.49	0.42116
5	4	60	3	10	83.32	87.55	0.01805
6	36	60	3	10	87.90	81.47	0.67244
7	4	60	3	30	82.13	82.83	0.05749
8	36	60	3	30	76.44	76.75	2.04095
9	20	20	3	10	80.19	77.89	0.19825
10	20	100	3	10	99.92	97.10	0.45963
11	20	20	3	30	79.68	73.17	0.59760
12	20	100	3	30	91.23	92.38	0.66902
13	4	60	1	20	72.40	70.35	0.03781
14	4	60	5	20	82.51	77.94	0.03942
15	36	60	1	20	67.97	64.27	1.13510
16	36	60	5	20	71.36	71.86	1.22026
17	4	20	3	20	71.00	73.83	0.03629

18	4	100	3	20	94.11	93.04	0.04183
19	36	20	3	20	60.49	67.75	1.00413
20	36	100	3	20	84.85	86.9	1.45093
21	20	60	1	10	68.74	74.41	0.16612
22	20	60	5	10	80.93	82.00	0.19108
23	20	60	1	30	68.57	69.69	0.50856
24	20	60	5	30	74.66	77.28	0.55995
25	20	60	3	20	86.64	86.89	0.40913
26	20	60	3	20	86.66	86.89	0.41886
27	20	60	3	20	86.66	86.89	0.41404

**Table 9. Comparisons of dye wastewater degradation study using PEC and utilizing various types of the electrode with literature under different conditions**

Electrodes type	H <sub>2</sub> O <sub>2</sub> Conc.(mgl <sup>-</sup> )	Current density (mA/cm <sup>2</sup> )	Time (min)	RE (%)	EC (Kwh/Kg)	Ref.
Iron-Iron	1ml/l	30 V	15	90-99	-----	[33]
Iron-Graphite	1mM	21.31	60	98	1.14	[34]
Iron- Iron	500	25	30	84	0.9	[35]
Steel-Porous Graphite	100	20	10	99.92	0.45	This work

## 5. Conclusion

The performance of PC and PEC processes in the decolorization of dye from simulated water was investigated in a comparative study. For PEC and PC treatment, the effects of various parameters such as pH, CD, H<sub>2</sub>O<sub>2</sub> concentration, and electrolysis time were explored, and maximum removal was reached at 98.76 % and 99.92 %, respectively, with

energy consumption (kWh/kg) of 10.2 and 0.45. The closeness of the experimental and BBD estimated findings demonstrates that the BBD-developed model is optimal and effective. High R<sup>2</sup> values govern deterioration during PEC and PC procedures. Based on removal efficiencies and energy usage, PEC treatment was shown to be the most efficient in this study. In future investigations, alternative

types of electrodes, such as Al, and different amounts of iron for addition in both systems should be investigated. It is also recommended that the formation of H<sub>2</sub>O<sub>2</sub> be assessed and the produced sludge be studied to better understand the fundamental mechanism driving the removal in both systems.

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