Removal of Chemical Oxygen Demand (COD) from Hospital Wastewater by Electro Fenton process using Graphite–Graphite Electrochemical system

Abdulla Y. Ghjair a Ali H. Abbar b

aDepartment of Chemical Engineering, University of Al-Qadisiyah, Iraq
bBiochemical Engineering Department, Al-Khwarizmi College of Engineering, University of Baghdad, Baghdad, Iraq

ABSTRACT

Removal of COD from hospital wastewater generated from Al-Diwaniyah hospital located in Iraq was achieved using graphite–graphite electro-Fenton (EF) system. The effect of various operational parameters on the COD removal efficiency was investigated based on response surface methodology (RSM). Optimal conditions were current density of 20mA/cm², FeSO₄ concentration of 0.697 mM and time of 48.68 min. At these conditions COD elimination efficiency of 97.964 % was achieved at a specific energy consumption of 10.78 kWh/kg. The results indicated that time had the least effect on the COD removal efficiency, while the impact of current density had the greatest effect, followed by the FeSO₄ concentration. The adequacy of the model equation was confirmed by its high R² value (99.62%). The present study shows that graphite–graphite EF system was an efficient tool for removing of COD from hospital wastewaters.

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1. Introduction

Medical wastewater contains a large number of macro and micro-pollutants with a wide range of concentrations such as microorganisms, toxic chemicals, antibiotics, and radioactive elements coming from laboratories, research units, operating rooms, and polyclinics [1]. Recently, the issue of wastewater containing drug residues and their derivatives has taken on a new importance. Numerous studies have been conducted and revealed the detrimental effects of pharmaceutical pollutants on various components of the environment. [2]. Appropriately, scientists are attempting to develop a method of disinfecting wastewater that is successful and meets the standards for practically total removal of contaminants. The latter is because even a trace amount of a medical pollutant has a detrimental effect on the environment’s elements [3]. Many conventional techniques of hospital wastewaters (HWWs) treatment are used such as biological and physiochemical processes [4, 5]. Nevertheless, these methods have not the ability to treatment HWWs perfectly because of the composition and nature of these effluents. It was found that the biological treatment process suffered from many problems in the treatment of HWWs due to the adverse effects of the contaminants on the community of organisms used in the biological treatment [6]. Among advanced techniques, advanced oxidation processes (AOPs), as identified for the first time by Glaze et al. 1987[7], represent potential technology. These techniques are generated by means of strong oxidants in place, primarily radicals’ hydroxyl (HO°), the second most potent oxidizing species (E° = 2.80 V/SHE), capable of oxidizing any organic pollutant non-selectively up to the point of mineralization (conversion to Carbon dioxide and H₂O) (reactions 1st and 1f). HO° might well be created using a variety of activation mechanisms, including chemical (Fenton reaction), Photochemical reactions (Photolysis by

* Corresponding author.
E-mail address: eng.chem.20.post.18@qu.edu.iq (Abdulla Y. Ghjair)
ultraviolet light, photocatalysis on a heterogeneous scale, and photo-Fenton), sonochemistry, and electro-Fenton-reaction. [8-10].

\[ \text{HO}^+ + \text{Organic pollutant} \rightarrow \text{Primary intermediates} \quad (1\alpha) \]

\[ \text{Primary intermediates} + \text{HO}^+ \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{inorganic ions} \quad (1\beta) \]

The most modern AOPOs are electrochemical advanced oxidation processes (EAOPs). They have been created as a non-toxic, environmentally friendly, and cost-effective method of destroying organic compounds in water. [11-13]. The electrochemical oxidation (or anodic oxidation) and electro-Fenton (EF) processes are the most widely used EAOPs [8, 14, 15]. The chemical synthesis of OH° is commonly accomplished using the Fenton reaction (2), which utilizes a combination of H₂O₂ and a soluble ferrous iron salt, dubbed "Fenton's reagent." [8,9]:

\[ \text{H}_2\text{O}_2 + \text{Fe}^{+2} \rightarrow \text{Fe}^{+3} + \text{OH}^- + \text{HO}° \quad (2) \]

Actually, H.J.H. Fenton discovered an increase in the oxidation power of hydrogen peroxide in the presence of (Fe²⁺) at the end of the nineteenth century. [16]. After 4 decades, wise and Haber [17] established the reaction's dynamics and mechanism, establishing the explanation for the increase in oxidation efficiency caused by the production of HO° from Fenton's reagent via processes (1α) and (1β). The Fenton reaction is an easy method of producing HO°. Furthermore, the method requires a large volume of reagent to generate sufficient OH°. This has economic implications additionally to the production of sludge ferric that requires additional processing. Additionally, increased agent concentrations increase sludge processes (3) and (4), resulting in decreased effectiveness:

\[ \text{HO}^+ + \text{H}_2\text{O} \rightarrow \text{H}_2\text{O} + \text{HO}_2^- \quad (3) \]

\[ \text{HO}^+ + \text{Fe}^{+2} \rightarrow \text{Fe}^{+3} + \text{OH}^- \quad (4) \]

These reactions are extremely damaging because they consume reagents and deplete HO°. As a result, the decrease in mineralization efficiency results in the development of potentially hazardous oxidation reaction intermediates. [18]. To eliminate these interactions, it is necessary to carefully manage the amount of Fenton's reagent. The optimum pH for EF is taken as 3. pH value higher than 3 leads to decrease EF oxidation efficiency due to the formation of low active Fe(OH)₃ which has a lower tendency to react with H₂O₂ while a pH value lower than 3 generates less hydroxyl radicals and increases scavenging effect of H⁺ and hydroxyl radicals [19]. Few works have been published which confirmed suggested graphite can be utilized as both electrodes in the EF process. [20]. Nidheesh et al [21] reported that graphite–graphite EF system has been demonstrated to be an effective electrolytic system for the dyes removal [22-24] and salicylic acid [25] from aqueous solution. The advantage of application graphite–graphite EF process as reported by Nidheesh et al [22] is that using graphite–graphite EF system would enhance the efficiency of the system as a result of forming graphite layer on the cathode from anode particles with no affecting on the homogeneity of the system.

The aim of present work is to treat hospital wastewater generated from Al-Diwaniyah hospital in Iraq using an electrochemical cell composed of porous graphite plates as cathode and anode materials. No such research had been conducted in the literatures. On the other hand, this work investigates the feasibility of EF technology in removal of COD from hospital wastewater where hydrogen peroxide is generated in-situ at porous graphite cathode and Fe²⁺ is added externally. The efficiency of COD removal was evaluated using constant-current mode of operation which is the most preferable mode for industrial scale-up. The impacts of three operating parameters namely applied current density, Fe²⁺ concentration, and time on the removal of COD from hospital effluent were investigated and optimized using Box-Behnken design (BBD) based on the response surface methodology (RSM).

2. Experimental work

As a case study, 30L of hospital wastewater was collected from sewage system of the General Diwaniyah hospital (located at Al-Diwaniyah city in Iraq) before mixing with the domestic wastewater of the city. Table 1 shows the properties of the hospital wastewater. This hospital sewage was kept at 4 °C during the period of the experimental program and the required sample (0.25 L) for each experiment was taken from this vessel before the operation.

| Table 1. Characteristics of wastewater from the sewage system at Al-Diwaniyah Hospital |
|------------------------------------------|--------|
| Variable       | value  |
| COD            | 780 (mg/l) |
| pH             | 7 (mg/l)  |
| T.D.S          | 1130 (ppm) |
| Cl             | 1.6 (g/l)  |
| SO₄²⁻         | 0.4 (g/l)  |
| Turbidity      | 11.2 (NTU) |
| Conductivity   | 2.29 (mS/cm) |

Any chemicals utilized in this experiment were of analytical degree. Na₂SO₄, 10H₂O (purity 99.0%, Pellets, Sigma-Aldrich), FeSO₄·7H₂O (purity 99.5%, Pellets, Sigma-Aldrich), Na₂SO₃·98 w/w, Sigma-Aldrich, and NaOH (purity 99%, Pellets, Sigma-Aldrich) were used in the Electro-Fenton reaction. Every experiment was performed in a batch manner with the aid of a cylindrical Perspex reactor provided with a cover. It has an internal diameter of 89 mm, a length of 80 mm, and a thickness of 5 mm (Fig. 1). The working volume of the reactor was approximately 0.25 L. The reactor cover was a square plate with 160 mm on the outside length and 10 mm on the thickness. Three holes with inside diameter of 15mm were made in the cover of reactor for inserting probes of conductivity meter, pH-meter, and sampling taking out. A further hole of 10mm for air distribution tube was made on the cover as well as two slots for inserting the electrodes. The anode and cathode were made of porous graphite. Each one of two electrodes has dimensions of 53 mm wide, thickness of 4 mm, and length of 85 mm. The distance between anode and cathode was fixed at 2.0 cm. Porous graphite was provided from Tokai Carbon Co., Ltd. as ARC furnace. It has a surface area of approximately 0.892 m²/g measured based on ISO-9277-2010 method at petroleum R & D center, ministry of oil in Iraq using BET surface area analyzer model No. Quiru9600, Thermo Finnegan Co. USA. An air flow meter (0-5l/min, China) combined with air pump (model-ACO-208,45W, China) were used to supply the air to the reactor. The reactor and its cover were covered by aluminum foil to prevent the effect of light penetration hence dark conditions for the Fenton reaction was maintained.

Each experiment was carried out at a temperature of 25°F 2 °C using a hot plate magnetic stirrer (model number MR HEI-Standard, HEIDOLPH) at a rotation speed of 250 rpm. The electrolyte pH was measured using a smart pH meter “HNNA Equipment Inc.PH211, Romania”, pH was changed using 0.1 M sodium Hydroxide or 0.1M sulfuric acid solutions. Constant current was supplied via a DC power supply type (UNI-208,45W, China) were used to supply the air to the reactor. The reactor and its cover were covered by aluminum foil to prevent the effect of light penetration hence dark conditions for the Fenton reaction was maintained.

The aim of present work is to treat hospital wastewater generated from Al-Diwaniyah hospital in Iraq using an electrochemical cell composed of porous graphite plates as cathode and anode materials. No such research had been conducted in the literatures. On the other hand, this work investigates the feasibility of EF technology in removal of COD from hospital wastewater where hydrogen peroxide is generated in-situ at porous graphite cathode and Fe²⁺ is added externally. The efficiency of COD removal was evaluated using constant-current mode of operation which is the most preferable mode for industrial scale-up. The impacts of three operating parameters namely applied current density, Fe²⁺ concentration, and time on the removal of COD from hospital effluent were investigated and optimized using Box-Behnken design (BBD) based on the response surface methodology (RSM).
2.1. Design of experiments

Response surface methodology (RSM) summarized as a collection of mathematical and statistical tools for determining a regression model equation that correlate an objective function with its independent variables [28]. The present study used a three-level, three-factor Box–Behnken design (BBD) to investigate the effects of process variables on COD elimination. "Current density (X1)"; "time (X2)"; and "concentration of FeSO4(X3)" were considered as process factors, while the COD removal efficiency (RE %) will be used as a responding. Process factor scales were classified into three levels namely (-1), (0), (+1) for low, intermediate and high value, respectively [29]. Table 2 depicts the process variables at their selected levels, while Table 3 depicts the experiments array recommended by BBD for this work using Minitab-17 software.

Table 2. Variables in the process of hospital wastewater treatment along with their level.

| Variables of the process | Box– Behnken level |
|-------------------------|--------------------|
| Levels that are coded   | Low (-1) | Middle (0) | High (+1) |
| X1-current density (mA/cm²) | 10        | 15        | 20        |
| X2-Time(min)            | 20        | 40        | 60        |
| X3-Fe SO₄(mM)           | 0.2       | 0.5       | 0.8       |

Correlation between the response and its independent variables was determined in this study using the following second-order model and least-squares approach [30]:

\[
Y = a_0 + \sum a_i x_i + \sum a_{ij} x_i^2 + \sum a_{ij} x_i x_j
\]  

(7)

Where Y is the response (Removal %), i and j denote the index numbers for the pattern, a₀ denotes the intercept term, and x₁, x₂, ... xₙ denote the parameters used in the operation in coded form. The primary influence of the first order (linear) is denoted by aᵢ, the second-order main effect is denoted by aᵢⱼ, and the interaction effect is denoted by aᵢ₂. After doing an analysis of variance, For the purpose of demonstrating the model's suitability, the regression coefficient (R²) was computed.

3. Results and Discussion

3.1. Results of experimental design

According to BBD design, fifteen runs were performed to investigate the optimum conditions for COD removal. The experimental results for Removal efficiencies (RE percent) and specific energy consumption (SEC) are summarized in Table 4.

Results showed that efficiency of COD removal was in the range of 81.38-97.3% while the specific energy consumption ranged between (1.970-14.294) (kWh/kg COD). As a preliminary inspection, a comparison between run (6) and run (7) demonstrated that the concentration of FeSO₄ has a significant effect on COD removal efficiency where RE% increased from 81.38 to 92.465 % making a difference of 11.085 % as FeSO₄ concentration increased from 0.2 to 0.8 mM at constant current density of 10mA/cm² and time of 40 min. While the comparison between running (7) and (12) demonstrated that the density of current followed the concentration of FeSO₄ in its impact on the COD removal efficiency where the RE% increased from 92.465 to 97.3% which made a difference of 4.835% as the current density increased from 10 to 20 mA/cm² at constant FeSO₄ concentration of 0.8 mM and time of 40 minutes.
The findings of the Removal effectiveness were evaluated using the ANOVA results. The removal effectiveness was quantified in terms of real units of process parameters, as shown by eq. (8)

\[ RE\% = 50.85 + 1.685X_1 + 0.3406X_2 + 55.47X_3 - 0.0268(X_1)^2 - 0.003583(X_2)^2 - 38.61(X_3)^2 - 0.00203X_1X_2 - 0.302X_1X_3 + 0.0914X_2X_3 \]  

In which X1, X2, and X3 are the model parameters' interaction effects. X1^2, X2^2, and X3^2 each constitute a parameter's principal influence. Using equation 8, the predicted values of the COD removal efficiency was estimated and tabulated in Table 4.

In eq. 8, the positive coefficient in front of any parameter reveals that RE% increases with its increasing and vice versa. Analysis of variance (ANOVA) was used to determine the acceptability of BBD. It really is an analytical technique that utilizes Fisher's F-test and P-test to estimate the model's and its parameters' significance [31]. In principle, bigger F-values and lower p-values indicate that the coefficient terms are more important [32]. Table 5 illustrates an ANOVA using the response surface model. In this table, Contr.% denotes percentage of contribution of each variable, DF represents degree of freedom of the model and their parameters, and the statistical terms are represented by sum of the square (Seq. SS), adjusted sum of the square (Adj. SS), and adjusted mean of the square (Adj. MS) respectively. P-value of (0.0001) and F-value of (145.59) were obtained which elucidate that regression model is highly significant. The model's multiple correlation coefficient (R^2) was 0.9962, indicating that the regression is statistically significant and only (0.0038) of the overall variation is not confirm by the model. The adjusted multiple correlation coefficient (adj. R^2) = 0.9894 and the predicted multiple correlation coefficient (pred. R^2) = 0.9435 in this model were well-matched since the difference between them less than 0.2 [33].

Results of Table 5 showed that FeSO4 concentration has the major effect followed by current density with contributions of 56.78% and 23.46% respectively. While time has a lower effect with contribution of 3.23%. The high contributions of current density and FeSO4 concentration confirm that EF governed by these two variables. The result is expected since EF process is governed by Eq.2 where Fe^{2+} is furnished externally and H2O2 is generated internally based FeSO4 and current density. The squared interactions are significant with a contribution of 15.43% in which squared interaction of FeSO4 concentration and current density confirm that this interaction is not confirm by the pure error in this investigation [34]. As a result, the model can generate an adequate prediction that corresponds to the response values.

Table 3. Experimentation with the Box-Behnken style

| Run | Blk | Coded levels | Real value |
|-----|-----|--------------|------------|
| 1   | 1   | X1 = 1      | 20         |
| 2   | 1   | X1 = 0      | 60         |
| 3   | 1   | X1 = 0      | 40         |
| 4   | 1   | X1 = 0      | 60         |
| 5   | 1   | X1 = 0      | 20         |
| 6   | 1   | X1 = 0      | 40         |
| 7   | 1   | X1 = 0      | 40         |
| 8   | 1   | X1 = 0      | 40         |
| 9   | 1   | X1 = 0      | 60         |
| 10  | 1   | X1 = 0      | 20         |
| 11  | 1   | X1 = 0      | 60         |
| 12  | 1   | X1 = 0      | 40         |
| 13  | 1   | X1 = 0      | 40         |
| 14  | 1   | X1 = 0      | 40         |
| 15  | 1   | X1 = 0      | 20         |

Table 4. Box–Behnken design (BBD) for COD elimination experimental results

| Run | Parameters | E (vol) | RE% | SEC kW h/kg COD |
|-----|------------|--------|-----|----------------|
| 1   | X1 = 20    | 6.52   | 0.565 |               |
| 2   | X1 = 60    | 5.656  | 9.804 |               |
| 3   | X1 = 40    | 5.305  | 6.0333|               |
| 4   | X1 = 60    | 4.525  | 5.569 |               |
| 5   | X1 = 20    | 6.43   | 4.242 |               |
| 6   | X1 = 40    | 4.53   | 4.9996|               |
| 7   | X1 = 60    | 4.885  | 3.816 |               |
| 8   | X1 = 40    | 6.49   | 10.974|               |
| 9   | X1 = 60    | 6.22   | 14.294|               |
| 10  | X1 = 40    | 6.465  | 10.351|               |
| 11  | X1 = 60    | 5.265  | 10.351|               |
| 12  | X1 = 40    | 6.05   | 10.953|               |
| 13  | X1 = 60    | 5.32   | 6.252 |               |
| 14  | X1 = 40    | 5.305  | 6.269 |               |
| 15  | X1 = 60    | 5.335  | 3.247 |               |

However, the precise effect of these parameters and their interactions can be observed via ANOVA results. The findings of the Removal effectiveness were evaluated using the Minitab-17 program, and a quadratic model of the Removal efficiencies (RE percent) in terms of real units of process parameters was developed as follows:

\[ RE\% = 50.85 + 1.685X_1 + 0.3406X_2 + 55.47X_3 - 0.0268(X_1)^2 - 0.003583(X_2)^2 - 38.61(X_3)^2 - 0.00203X_1X_2 - 0.302X_1X_3 + 0.0914X_2X_3 \]
Table 5. Analysis of variance for chemical oxygen demanded reduction

| Source      | DF | Seq. ss   | Contr. % | Adj. ss   | Adj. Ms | F-value | P-value |
|-------------|----|-----------|----------|-----------|---------|---------|---------|
| Model       | 9  | 322.981   | 99.62    | 322.981   | 35.887  | 145.59  | 0.001   |
| Linear      | 3  | 270.615   | 83.47    | 270.615   | 90.205  | 365.95  | 0.001   |
| (X1)        | 1  | 76.070    | 23.46    | 76.070    | 76.070  | 308.61  | 0.001   |
| (X2)        | 1  | 10.465    | 3.23     | 10.465    | 10.465  | 42.46   | 0.001   |
| (X3)        | 1  | 184.080   | 56.78    | 184.080   | 184.080 | 746.80  | 0.001   |
| Square      | 3  | 50.022    | 15.43    | 50.022    | 16.674  | 67.64   | 0.001   |
| "X1 * X1"   | 1  | 0.381     | 0.12     | 1.658     | 1.658   | 6.73    | 0.049   |
| "X2 * X2"   | 1  | 5.050     | 1.56     | 7.586     | 7.586   | 30.78   | 0.003   |
| "X3 * X3"   | 1  | 44.590    | 13.75    | 44.590    | 44.590  | 180.90  | 0.001   |
| 2-Way Inter.| 3  | 2.344     | 0.72     | 2.344     | 0.781   | 3.17    | 0.123   |
| X1 * X2     | 1  | 0.320     | 0.10     | 0.320     | 0.320   | 1.30    | 0.306   |
| X1 * X3     | 1  | 0.820     | 0.25     | 0.820     | 0.820   | 3.33    | 0.138   |
| X2 * X3     | 1  | 1.203     | 0.37     | 1.203     | 1.203   | 4.88    | 0.078   |
| Error       | 5  | 1.232     | 0.38     | 1.232     | 1.232   | 0.246   |         |
| Lack of Fit | 3  | 1.132     | 0.35     | 1.132     | 0.377   | 7.48    | 0.120   |
| "Pure-Error"| 2  | 0.101     | 0.03     | 0.101     | 0.050   |         |         |
| Total       | 14 | 324.213   | 100.00   |           |         |         |         |

Model-summary

| S.          | R²          | R²(adj.) | PRESS | R²(pred.) |
|-------------|-------------|----------|--------|-----------|
| 0.496481    | 99.62%      | 98.94%   | 18.333 | 94.35%    |

3.2. The Influence of process factors on the efficiency of COD removal

Graphical representations of RSM can be used to demonstrate the influences of specified variables on the response. The Figs. (2-i and 2-j) illustrate the effect of FeSO₄ concentration on the RE percent at different current densities (10-20 mA/cm²) during a constant time period (40 min.). Fig. 2-i depicts the surface response plot, while Fig 2-j depicts the contour plot. The surface plot revealed that, at the same current density (10 mA/cm²), an increase in COD removal efficiency occurs as the Fe⁺² intensity rises from 0.2 to 0.8 mM. The increasing in RE% occurs rapidly at the first stage then tends to be sluggish at final stage. Similar observation was identified at higher current density (20mA/cm²). This behavior can be interpreted as increasing Fe⁺² concentration improved the hydrogen peroxide’s oxidizing ability to degrade big molecules, therefor increasing concentration of Fe⁺² leads to more degradation of organic compounds in wastewater [29]. Previous studies showed that Fe⁺² has the ability to destroyed big molecule in wastewater such as dyestuffs, in real dyeing wastewater [35].

At any concentration of FeSO₄, RE% increases linearly with increasing of current density from 10 to 20 mA/cm². This behavior of the effect of current density on RE% is in agreement with previous work [36, 37] and could be explained as the current considers as the driving force for the reduction of oxygen on the cathode surface leading to generate H₂O₂ hence, by increasing the current density, more generation of ‘OH would be happened due to reaction of H₂O₂ with ferrous ions.

The corresponding contour plot indicates that the ≥96 percent COD removal efficiency value is contained inside a limited area with a current density of (16-20 mA/cm²) and FeSO4 concentration of (0.5-0.8 mM). The shape of control plot indicates the nature and extent of the interaction. The Figs. (3-i and 3-j) explain the impact of time on the RE percent at varied current densities (10-20 mA/cm²) and constant FeSO₄ concentration (0.5mM).

Figure 2. Display of the impact of FeSO₄ concentration and current density on the percent of RE in a three-dimensional surface plot
As illustrated in Fig. 3-i, the effectiveness of COD elimination is exponentially grown in proportion to the growth of time then started to be approximately constant beyond 40 min for any values of current density. These findings agree those seen in the previous studies [38-41]. The findings indicate that the reaction time has a positive impact on the progress of the EF process for a limited period. The corresponding contour plot (3-j) indicates that the ≥96 percent COD elimination efficiency occurs in a limited area with a current density of (19-20 mA/cm$^2$) and a time range of 35-55 minutes.

The figs. (4-i and 4-j) illustrate the impact of time on the RE percent for varied FeSO$_4$ concentrations (0.2-0.8 mM) and a constant current density of 15mA/cm$^2$. At any FeSO$_4$ concentration, Fig. (4-i) demonstrates that the COD removal efficiency increases exponentially with increasing time. The reaction time has a positive effect on the progress of the electro-Fenton process up to 40min then start to sluggish. At any time, the results show that the increasing in RE% occurs rapidly at the first stage then tends to be sluggish at the final stage when concentration of FeSO$_4$ increased from 0.2 to 0.8mM. The corresponding contour Fig. (4-j) demonstrates that the ≥95 percent COD removal efficiency value is contained within a limited area with FeSO$_4$ concentrations ranging from (0.6-0.8 mM) and times ranging from (35-60 min). As a result, the application of RSM enabled the identification of feasible optimum values for the researched parameters, as well as its function in providing valuable information about the interactions among variables.
Improve of an electrochemical system is essential to reduce energy losses. Numerous criteria should be considered when optimizing the system in order to achieve the desired target via maximization of the desirability function (D_f) [28]. The target function choices could be “maximized”, “objective”, “minimize”, inside the limit, and neither one. The target of COD removal was designated as the ‘maximum’ with D_f=1.0. The process factors studied in the present work were recognized within current at range of (10-20 mA/cm²), FeSO₄ concentration at range of (0.2-0.8 mM), and time at range of (20-60 min). A COD elimination effectiveness of 81.38 percent was chosen as the lower limit value, while the upper limit value was allocated at 97.3%. Under these boundaries and settings, optimization was conducted and the results are shown in Table 6. Two confirmative runs were conducted under the optimized settings to verify them; the results are shown in Table 7. After electrolysis of approximately 49 min, COD removal efficiency of 97.83% as average value was achieved at pH=3 that is consistent with optimization analysis limiting range of the optimal value (Table 6). As a result, BBD is effective and useful at optimizing Removal efficiencies via the porous graphite–graphite EF system.

Table 8 shows a comparison between untreated and treated sewage based on the results of this study. As can be seen, treated wastewater has improved characteristics and conforms to the standard limits for effluent discharge (100 ppm) [26]. Chemical oxygen demanded removal efficiency of 97.96%, phenol removal efficiency of 96.58%, and turbidity removal efficiency of 97.83% was achieved in the present work approving the activity of EF process in treatment wastewater generated from Al-Diwaniyah hospital in removal both of COD and turbidity. The increase in sulfate ions in the treated effluent is due to the using of ferrous sulphate while the decreasing in Cl ions is due to the generation of some chlorine on the anode which has another benefit for decreasing COD due to indirect oxidation of pollutant by Cl₂ [27]. The present work demonstrates that the graphite–graphite EF system may be effectively utilized to the treatment of Al-Diwaniyah hospital wastewater. Starting from an initial COD of 786 ppm, it could be achieved a COD removal efficiency of 97.964% at operating time of approximately 49 min with an energy consumption not exceeded 10.78 kWh/kg COD. In comparison with our previous work [27], using the same source of wastewater and applying an electrocoagulation method, the present system is more efficient in term of time and energy consumption where in our previous work by beginning with an initial chemical oxygen demand (745 ppm), The effectiveness of COD elimination of 99.3% was achieved at electrolysis time of 90 min with energy consumption of 26.079 kWh/kg COD, while in present work, approximately the same removal efficiency of COD was obtained at 49 min and 10.78 kWh/kg COD. This an indication that EF process oxidizes the refractory natural or organic compounds that existing in hospital wastewater in a more proficient way. Moreover, the present system could be considered as an economic one since it used electrodes made from cheap materials and its specific energy consumption is approximately lower and suitable in comparison with previous studies [27].

4. Conclusions

The present work examined the reduction of chemical oxygen demand from hospital sewage by electro-Fenton process using an electrochemical cell.
having cathode and anode made from porous graphite. Impacts of Current density, FeSO₄ concentration on the chemical oxygen demand reduction from the hospital wastewater generated at Al-Diwaniyah hospital located in Iraq were investigated using RSM. Based on RSM, the optimal conditions were current density of 20mA/cm², FeSO₄ concentration of 0.697 mM and time of 48.7 min, in which COD removal and specific energy consumption were 97.964% and 10.78 kWh/kg. COD respectively. The high value of R², adj.R² and pred. R² value indicate that the model fitted very well to the experiment data and RSM was successfully applied to analyze the impact of various operating factors at lower number of runs and lower cost of chemicals. The efficiency of graphite–graphite EF system was found to be influenced by two main parameters current density and FeSO₄ concentration in which FeSO₄ concentration has the main effect followed by current density. The present system gave better performance and lower energy consumption in comparison with previous works due to the powerful oxidation mechanism adopted in the present system. Graphite–Graphite EF technique for the removal of COD from sewage water was shown to be an environmentally beneficial procedure, according to the findings of current study.

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