



Removal of Tetracycline Antibiotic from Wastewater by Fenton Oxidation Process

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Submitted: 05/11/2020

Accepted: 11/12/2020

Published: 25/02/2021

KEY WORDS

Advanced oxidation processes, Fenton's reagent, Tetracycline.

ABSTRACT

This study aimed to remove the antibiotic tetracycline from a sample of synthetic wastewater using an advanced oxidation process by Fenton's reagent treatment. Central Composite Design (CCD) software was used to reduce the number of tests required to remove tetracycline. The independent variables identified in batch oxidation experiments are the concentrations of tetracycline (40–250 mg / L), hydrogen peroxide (20–600 mg / L), and Fe(II) (0–60 mg / L). The rate of tetracycline degradation was significantly influenced by the concentration of hydrogen peroxide and tetracycline. The reaction time required for tetracycline removal was determined to be 15 minutes. The optimal ratio of independent variants leading to complete degradation 100% of tetracycline was hydrogen peroxide / Fe²⁺ / tetracycline 310/30/145 mg / l.

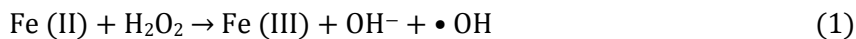
How to cite this article: M. H. Mahdi, T. J., Mohammed, and J. A. Al-Najar, "Removal of tetracycline antibiotic from wastewater by Fenton oxidation process," Engineering and Technology Journal, Vol. 39, Part A, No. 02, pp. 260-267, 2021.
DOI: <https://doi.org/10.30684/etj.v39i2A.1915>

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1. INTRODUCTION

Human and veterinary drugs are one of the main causes of pollution of natural water systems due to their frequent use today [1-6]. Many antibiotics are discharged into the river environment with medical waste and wastewater from pharmaceutical plants [3]. The presence of antibiotics in the aquatic environment is a major source of environmental pollution. Several researchers have reported the risks of the presence of these pharmaceutically active compounds (PhACs) in aquatic environments [3-6]. Tetracycline (TC) is one of the most widely used antibiotics in the world, and due to its frequent use, it is often present in wastewater [7, 8]. It is difficult to very effectively remove TC from aqueous media due to its complex chemical structure and antibacterial properties. The accumulation of tetracycline in river water leads to the development of bacteria resistant to

antibiotics, which poses a serious threat to human health and ecosystems [9, 10, and 11]. To get rid of this type of pollutant, more sustainable and efficient technologies need to be developed. Fenton's reagent, consisting of H₂O₂ and Fe (II), is one of the most oxidation agents most effective in removing the most hazardous organic compounds that affect water quality. The following mechanism is acceptable for the activity of Fenton's reagent [12].



Due to the high oxidation potential (2.8 V) of hydroxyl ($\bullet\text{OH}$) radicals, Fenton's reagent is widely used to decompose slowly decomposing chemicals [13, 14]. Fenton reagent can be used to remove drug residues from wastewater and industrial wastewater from pollutants. Some of the advantages that led to the use of the Fenton method are its high ability to remove pollutants, as well as the oxidizing agent and catalyst in this method, are available at a low cost.

Several previous studies have been investigated the advanced oxidation process of various types of antibiotics and pharmaceutical compounds [3, 7, 8, 10, 15-17]. A relatively high rate of tetracycline removal (TC) was obtained by the Fenton method using the most efficient catalyst in the batch samples, Morphology-tunable WMoO-1 nanowire, as a typical TC removal material, In which unsaturated metal atoms acted together with oxygen defects as sites for TC chemical absorption and the transfer of electrons. As a result, the degree of TC removal of 91.75% was obtained within an hour after the reaction for an initial TC concentration of 400 μM [18].

The applicability of Fenton's oxidation has been investigated to improve the biodegradability of biologically treated medical wastewater. Treatability studies were carried out under known conditions for all chemicals (COD 900 to 7000 mg / l) to determine the optimum operating conditions for their widespread use in wastewater treatment plants. The optimum pH for the oxidation and coagulation phases of the Fenton process was determined as 3.5 and 7.0, respectively, Higher COD removal efficiency for all chemicals was obtained at a H₂O₂ / Fe²⁺ molar ratio of 150-250. With a H₂O₂ / Fe²⁺ ratio of 155, 0.3 M H₂O₂ and 0.002 M Fe²⁺, 45% to 65% COD is removed. [19].

Two advanced oxidation methods have been used, namely, the Fenton process (Fe²⁺ / H₂O₂) and photo-oxidation processes (UV-A / TiO₂) to remove amoxicillin (AMO) and chemical oxygen antibiotics (COD) from the aqueous solution. Many factors affect the removal ratio as pH, antibiotic, Fe²⁺, H₂O₂, TiO₂ concentrations, and reaction time. The removal efficiency of AMO and COD in the Fenton process was obtained at 83% and 66, respectively, and the optimal ratio for Fe²⁺ / H₂O₂ was 1/15. While the percentage of removal was obtained in the photocatalytic process, AMO and COD were 62% and 52%, respectively [20].

Oxidation with Electro Fenton has proven to be very effective for the treatment of aqueous solution containing tetracyclines. Hydrolysis of tetracycline proceeds by 84.6% at pH 3 [21]. Adsorption and Fenton-like catalyst degradation of tetracycline were investigated by using nanoparticles ferric iron oxide (AC@Fe₃O₄) coated on activated carbon with which acts as a green oxidizer. The removal efficiency and total organic carbon (TOC) of 99.8% and 50.6% respectively were obtained under optimal conditions [22].

The removal of tetracycline (TC) from aqueous solutions was studied by oxidation of the UV-Fenton system with a heterogeneous synthetic catalyst consisting of magnetite Fe₃O₄ nanoparticles deposited on activated carbon powder (Fe₃O₄ @ C). The influence of reaction time, catalyst, H₂O₂ concentration, and pH on TC removal was studied to determine the optimum condition. The removal efficiency under optimal conditions was 79% in 44 minutes, and the decomposition reaction followed the pseudo-first-order kinetic model [23].

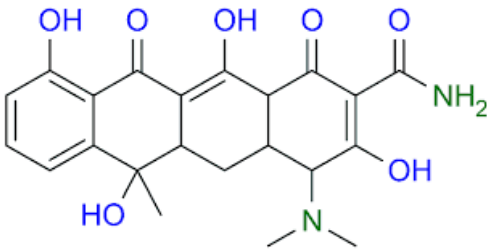
In this study and after reviewing the previous studies above, the Fenton reagent was used to degrade tetracycline. The central compound design (CCD) approach was used by looking at independent variables such as tetracycline, hydrogen peroxide, and iron concentrations. As well, the optimal conditions that increase the degradation of tetracycline have been identified.

2. MATERIALS AND METHODS

I. Chemicals

Tetracycline was obtained from commercial source Wadi Alrafidain company pharmaceutical products. Baghdad, Iraq. Table 1 summarizes some of the main properties of tetracycline. Hydrogen peroxide (35% w / w, solution) and ferrous sulfate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$) were obtained from Sigma Aldrich, USA. Hydrochloric acid (HCl) and Sodium hydroxide (NaOH) used for pH adjustments were obtained from Merck(Germany). Acetonitrile and methanol (HPLC grade) were purchased from Merck for HPLC analyzes.

TABLE I: Basic characteristics of tetracycline

Name of antibiotic	Tetracycline
<i>Molecular formula</i>	$\text{C}_{22}\text{H}_{24}\text{N}_2\text{O}_8$
<i>Chemical structure</i>	
<i>Molecular weigh</i>	444.43g
<i>Solubility</i>	Light
<i>Colour</i>	Yellow

II. Experimental system

A jar apparatus was used to mix the wastewater synthetic tetracycline at a constant speed (300 rpm). The required amount of iron in the form of $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ was added to the aqueous solution. Specific amounts of the oxidizing agent hydrogen peroxide were then added at the beginning of the experiment with the pH adjusted to the desired value with either HCl or NaOH. The ferrous sulfate catalyst was well mixed with tetracycline solution before hydrogen peroxide was added. All experiments were performed at ambient temperature ($25 \pm 2^\circ \text{C}$). The pH was adjusted to 3.5, as it is more suitable for treating Fenton reagent [24]. A $0.22 \mu\text{m}$ filter was used for filtering samples before performing HPLC analysis.

III. Analytical methods

After the completion of the mixing process through the jar apparatus, the samples go through several stages, including placing these samples on a centrifuge at 4500 rpm for 10 minutes, after that the samples were filtered with a $0.22 \mu\text{m}$ filter. Also, the samples were placed in a high-performance liquid chromatography (HPLC) device to measure residual tetracycline concentration in water. This HPLC is equipped with UV-vis detector (Waters 2998) at $\lambda = 285 \text{ nm}$ using a non-end capped high strength silica C18 column (4.6 mm \times 250 mm, 5mm, Waters, USA). Also, contains a mixture of Milli-Q water: methanol (30:70 v/v) and 0.1% formic acid at a flow rate of 1 ml/min. This mixture was used as a mobile phase for elution purposes. The column temperature was maintained throughout the analysis at 25°C .

IV. Design of experiments

Statistical experiment design methods and Response Surface Methodology (RSM) have become widely used to identify factors affecting the treatment process [25, 26]. RSM designs have different

types such as 3-level factorial design, central composite design (CCD) [27, 28], Box–Behnken design (BBD) [29] and D-optimal design [30]. Among all the designs mentioned above for the Response Surface Method (RSM), the central composite design (CCD) requires the least number of experiments compared to the other types [31]. The advantage of this design allows for the identification of important factors and reactive factors to be quantified. It also works to discover the nonlinear behavior of the effect and to determine the best set of experimental factors that lead to producing the maximum result. While it covers the same experimental space as the traditional array design used in the primary study, in economic terms the CCD is more economical and requires fewer experiments. In this work, the Design Expert 11 edition was used. There are three types of CCD design points: (i) Center points (0, 0): These points are detected in the center and are also used to detect curvature in the response; (ii) Axial points ((+ α , 0), (0, + α), (- α , 0), (0, - α)): The Axial points are detected at a distance α from the center point and are also used to estimate coefficients Quadratic terms (iii) Factorial points ((-1, -1), (+1, -1), (-1, +1), (+1, +1)): Factorial points are located at the corners. These points are mostly used to evaluate linear terminology coefficients and two-way interactions (Expert 2016) [26].

The optimization procedure includes studying the response of statistically designed experiments, evaluating the coefficients by comparing experimental data with response functions, predicting the response of the prepared model, and checking the adequacy of the model [31]. The effect of three factors affecting the removal rate of tetracycline, which are the concentrations of tetracycline antibiotic (X1), hydrogen peroxide (X2), and iron ion (X3) was studied as shown in Table II.

TABLE II: The experimental results of Central Composite Design (CCD)

Run	Variables			Experimental percent removals
	Tetracycline, X1 (mg / l)	H2O2, X2 (mg / l)	Fe(II), X3 (mg / l)	Tetracycline removal (%)
1	145	20	60	16
2	145	310	30	100
3	40	600	30	100
4	250	600	30	90
5	250	310	0	40
6	145	600	60	100
7	40	310	0	92
8	40	310	60	87
9	145	310	30	100
10	250	20	30	7
11	145	600	0	100
12	250	310	60	52
13	145	310	30	100
14	40	20	30	22
15	145	20	0	12

The experimental results were correlated with a second-order polynomial as described below

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 \quad (3)$$

Where Y is the predicted response; b_0 is a model constant; X1, X2, and X3 are independent variants; Linear coefficients b_1 , b_2 , and b_3 ; interaction coefficients b_{12} , b_{13} , and b_{23} ; And b_{11} , b_{22} , and b_{33} are the quadratic coefficients. In this study, 15 experiments were designed based on CCD (Table II), and all experiments were analyzed by analysis of variance (ANOVA). The accuracy of the appropriate model was evaluated based on the coefficient of determination and its adjusted value. Also, the significance of the linear and quadratic terms was verified by the F-test. Besides, the final subset of variables is determined based on the p-value.

V. Results and discussion

Many experiments were carried out under different experimental conditions according to Central Composite Design (CCD) as shown in Table II. A complete removal rate of tetracycline was obtained under the following operating conditions (tetracycline, 145 mg / l, H₂O₂ dose, 310 mg / l, Fe (II), 30 mg / l, pH 3.5) over a 15 min time.

The coefficients were determined through a regression analysis depending on the experimental results shown in Table II that were associated with the quadratic response functions. Response functions to remove the percentage of tetracycline (Y) after 15 minutes of reaction time are presented in Eq. (4) with the determined coefficients

$$Y = 100 - 14X_1 + 41.75X_2 + 1.25X_3 + 1.50 X_1X_2 + 4.50X_1X_3 - 1X_2X_3 - 17X_1^2 - 28X_2^2 - 15X_3^2 \quad (R^2 = 0.97) \quad (4)$$

Eqn. (4) was used to predict the removal efficiency of tetracycline at the experimental points. The obtained predictions of the response function are in agreement with the experimental results. To determine the quality of fit, the ANOVA test was used. Table III shows a presentation of the results obtained from the ANOVA test based on the removal efficiency of tetracycline. Have been concluded from the F-value of 21.01 shown in Table III that the model is significant. In addition, a p-value of less than 0.05 indicates that the model conditions are important. The factors that had a major influence on the removal efficiency of tetracycline were the hydrogen peroxide dose and the tetracycline concentration.

TABLE III: ANOVA test for the response function Y (%tetracycline removal)

Source	Sum of squares	df	Mean square	F-Value	p-Value
Model	19851.00	9	2205.67	21.01	0.0019
A- Tetracycline (mg/L)	1568.00	1	1568.00	14.93	0.0118
B- H ₂ O ₂ (mg/L)	13944.50	1	13944.50	132.80	< 0.0001
C- Fe ²⁺ (mg/L)	12.50	1	12.50	0.1190	0.7441
AB	9.00	1	9.00	0.0857	0.7815
AC	81.00	1	81.00	0.7714	0.4200
BC	4.00	1	4.00	0.0381	0.8529
A ²	1067.08	1	1067.08	10.16	0.0243
B ²	2894.77	1	2894.77	27.57	0.0033
C ²	830.77	1	830.77	7.91	0.0374
Residual	525.00	5	105.00		
Lack of Fit	525.00	3	175.00		
Pure Error	0.0000	2	0.0000		
Cor Total	20376.00	14			

Parameters X₁, X₂, X₃, X₁₂, X₂₂, and X₃₂ were identified as important model parameters with p-values less than 0.05. It can be concluded from the results obtained from the ANOVA test to removal efficiency of tetracycline that the variants X₂, X₃, X₂₂, and X₃₂ were important model terms with a p-value less than 0.05.

Figure. (1-a, b, c) shows the effect of influencing factors on the removal efficiency of tetracycline.

Figure. (1-a) illustrates the effect of both the tetracycline concentration and the hydrogen peroxide dose on the removal efficiency. An increase in the tetracycline concentration reduces the removal efficiency. Therefore, a higher concentration of tetracycline requires a high peroxide dose to generate sufficient hydroxyl radicals to attack the tetracycline. Whereas, the removal efficiency of 16% was obtained at a concentration of 145 mg / l tetracycline and a hydrogen peroxide dose of 20 mg / l. When the hydrogen peroxide concentration was increased to 600 mg / l and with the same concentration of tetracycline, complete removal efficiency of 100% was obtained. The reason for the

complete removal is due to the generation of hydroxyl radicals that were formed upon increasing the dose of hydrogen peroxide.

Figure. (1-b) shows the effect of both tetracycline concentration and Fe (II) dose on removal efficiency. The high removal efficiency of 90% was obtained at a Fe (II) dose of 30 mg / l at a concentration of 250 mg / l tetracycline. The removal efficiency decreased to 52% when increasing the dose of Fe (II) to 60 mg / l at a concentration of tetracycline of 250 mg / l. The reason for the decrease in removal efficiency could be attributed to the scavenging of the hydroxyl radicals due to the high doses of Fe (II) [32].

In addition, Figure.(1-c) shows the effect of both the hydrogen peroxide dose and Fe (II) dose. From the removal results obtained, conclude that low doses of Fe (II) require high doses of hydrogen peroxide to generate sufficient hydroxyl radicals capable of attacking the organic compound and degradation it in water.

The removal of tetracycline that was only accomplished by oxidation of H₂O₂ was lower than that of Fenton oxide (Fe (II)+ H₂O₂).

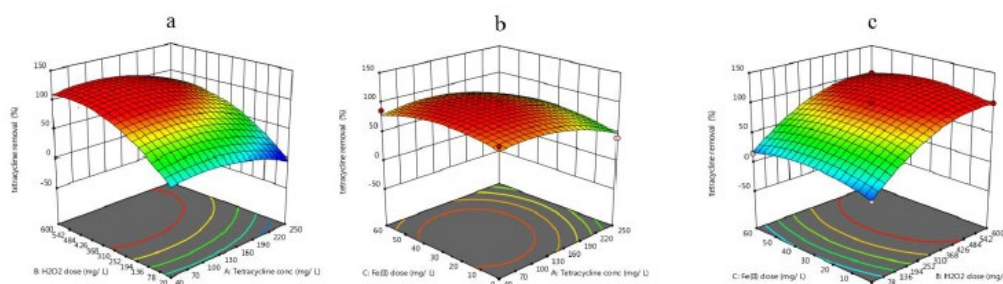


Figure 1: 3D response surface and contour plots: interactive effects of (a) Tetracycline conc. and H₂O₂ dose, (b) Tetracycline conc. and Fe²⁺ dose (c) H₂O₂ dose and Fe²⁺ dose.

3. CONCLUSIONS

Total removal of tetracycline was obtained by using the Fenton method. The effect of independent variables including tetracycline concentration, hydrogen peroxide dose, and Fe (II) dose on tetracycline removal efficiency was studied. It was found that the most influencing factors on removal efficiency were hydrogen peroxide dose and tetracycline concentration. It can be concluded that higher concentrations of tetracycline require higher doses of hydrogen peroxide, but they do not necessarily require high Fe (II) doses because sometimes an increase in Fe (II) doses leads to the scavenging of the hydroxyl radical.

The optimum ratio of hydrogen peroxide / Fe (II) / tetracycline to achieve complete removal of tetracycline is 310/30/145 mg / l.

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