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Optimization the Effects of Physicochemical Parameters on the Degradation of Cephalexin in Sono-Fenton Reactor by Using Box-Behnken Response Surface Methodology

Tariq J. Al-Musawi[1] · Hossein Kamani[2] · Edris Bazrafshan[3] · Ayat Hossein Panahi[4] · Marcela Fernandes Silva[5] · Gholamreza Abi[2]

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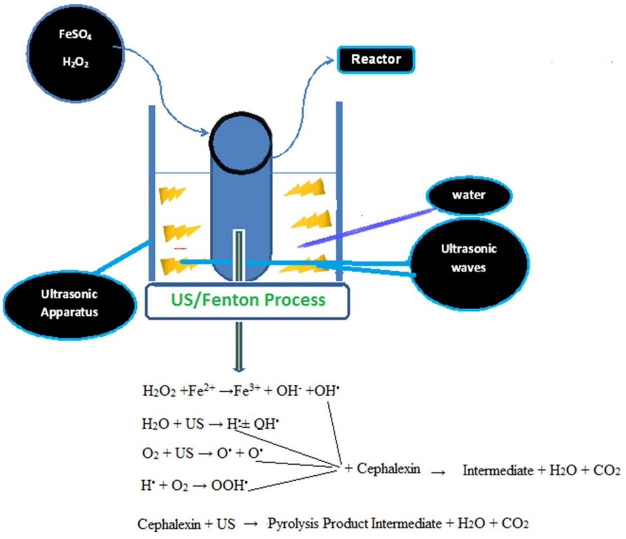
Abstract

This work aims to study the degradation process using Sono-Fenton reactor for the treating of pharmaceutical wastewater loaded with cephalexin. The degradation process was tested as a function of pH (3–11), concentration of degradation agent H_2O_2 (40–80 mg/L), metal catalyst agent Fe^{2+} (4–12 mg/L), reaction time (up to 100 min), and initial cephalexin concentration (50–100 mg/L). The effects of these parameters were tested and optimized by using Box-Behnken response surface methodology (RSM). All the experiments were performed with exposure to ultrasonic irradiation of a frequency of 130 kHz. According to the ANOVA results with a confidence level of 95%, a high regression and fitting values were obtained between the experimental degradation data of cephalexin and the RSM predicted model. This finding suggests that RSM is an extremely significant and accurate methodology to model the degradation process of cephalexin using Sono-Fenton reactor. Accordingly, the optimum degradation efficiency of 90% was obtained at conditions of pH 3, H_2O_2 concentration = 60 mg/L, Fe^{2+} concentration = 8 mg/L, cephalexin concentration = 50 mg/L, and reaction time = 60 min. Thus, the current study demonstrated that the Sono-Fenton reactor can be used effectively as an advanced oxidation treatment unit for degradation of cephalexin under optimized environmental conditions.

Graphical Abstract



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Keywords Advanced oxidation · Sono-Fenton · Cephalexin · Box-Behnken methodology · Physicochemical parameters · Optimization

1 Introduction

At present time, there are more than 3000 of different kinds of chemical compounds as pharmaceuticals medicines are applied in human and veterinary cures [14, 38]. Among medications, antibiotics are important compounds due to their efficacious to treat wide range of bacterial infections [43, 44]. Cephalexin is a well-known antibiotic with a similar structure to penicillin which is considered as a powerful medicine that fights a variety of diseases caused by gram-negative and gram-positive bacteria [2]. Indeed, this type of antibiotic is working primarily by either stopping the growth of bacteria or destroy them. In case of human, this medication normally was prepared as a suspension and taken by mouth. The other application of cephalexin is as an efficacious therapeutic agent in the treatment of large groups of infectious diseases in poultry and fish fields [15, 23, 28]. According to latest studies, it is estimated that between 100,000 and 300,000 tons of antibiotics are consumed annually in the world [15, 37]. Approximately, 30–90% of these consumed compounds are not metabolized in the body of humans and animals and they enter to the environment as active compounds through the urine and faeces [28]. In addition, a significant amount of antibiotics are entering the water bodies through the disposal of wastewater effluents loading antibiotic from pharmaceutical factories as well as from agricultural farms [40].

Despite the high therapeutic value of antibiotics, the contamination of water resources with antibiotics compounds can cause severe risks for humans and biota [5, 35]. Excessive pharmaceutical compounds in aquatic environment are identified as part of the hazardous chemicals that have ability to change the equilibrium status of the natural ecosystem resulting to extremely environmental effects [18]. The frequent consumption of the unused or remained antibiotics compounds especially from drinking water can cause severe health effects for human beings as they carcinogenic, toxic, and mutagenic agents at birth levels. On the other hand, the hazardous and carcinogenetic to human by-product compounds was observed due to the chlorination and ozonation of pharmaceutical compounds-laden water and wastewater [40]. Therefore, developing treatment technology for monitoring and removal of the pharmaceutical compounds especially undesirable antibiotics compounds before being discharged to the ecosystem has gained tremendous interest by researchers and become a hot topic in the environmental engineering field [37]. Recently, the advanced oxidation technique was effectively employed to destroy organic pollutants in the wastewater treatment plants. The principle of this method, is the production of high reactive and powerful hydroxyl radical ($OH^{\cdot}$) from the decomposition reaction of hydrogen peroxide (H_2O_2) [8, 30], as a result, the target pollutants are broken down into low-risk materials [10]. The Fenton process is one of the advanced oxidation treatment techniques that currently used widely in the treatment of pharmaceutical compounds. This process involves the reaction of H_2O_2 as an oxidant agent with ferrous (Fe^{2+}) ions as a metal catalyst to produce the degradation agent of $OH^{\cdot}$ as illustrated in Eq. 1 [11, 29].

$$H_2O_2 + Fe^{2+} \rightarrow Fe^{3+} + OH^{-} + OH^{\cdot} \tag{1}$$

Ultrasonic irradiation (US) as a treatment agent has advantages of being green technology, safe, easy to apply, and does not produce secondary or by-product contaminations [4, 20, 34]. However, the application only US is limited in the wastewater treatment systems as it requires a long reaction time and consumes considerable energy. Combining this techniques with other processes such as Fenton process appears to be a promising method not only to overcome the technical bottlenecks of using pure US, but also give a major boost to promote the effectiveness of Fenton process by speeding up the destruction of the toxic organic compounds associated with the formation of additional high reactive radicals of $OOH^{\cdot}$, $H^{\cdot}$ and $O^{\cdot}$ [7, 25]. This improved treatment technology is denoted in the literature with Sono-Fenton process, where the chemical reactions given by equations from 2 to 6 show the mechanism of this method [4, 16; 16].

$$H_2O + US \rightarrow H^{\cdot} + OH^{\cdot} \tag{2}$$

$$O_2 + US \rightarrow O^{\cdot} + O^{\cdot} \tag{3}$$

$$O^{\cdot} + H_2O \rightarrow 2OH^{\cdot} \tag{4}$$

$$H^{\cdot} + O^{2} \rightarrow OOH^{\cdot} \tag{5}$$

$$H_2O + O_2 \rightarrow OH^{\cdot} + OOH^{\cdot} \tag{6}$$

The Sono-Fenton process has been applied to degrade many undesirable organic pollutants in wastewater such as metronidazole [1]; reactive yellow dye 145 [33]; lignin [32]; 2, 4 dichloro phenoxy acetic acid [9], and alachlor herbicide [45]. However, a few investigations have reported the treatment of wastewater loaded with cephalexin antibiotic [6], by utilizing this treatment method. In addition, it is necessary to conduct an investigation about the mechanism and the competition effects of physicochemical parameters on the cephalexin degradation using engineered Sono-Fenton reactor. Therefore, this study aims to assess the Sono-Fenton reactor as an advanced treatment method for the eradication of cephalexin antibiotic wastewater. Several laboratory tests were carried out to examine the cephalexin degradation efficiency under different environmental factors such as (i) solution pH, (ii) the concentration of H_2O_2, cephalexin, and Fe^{2+}, (iii) and reaction time, on the degradation of cephalexin. Ultimately, a comprehensive study was presented, describing the detailed methodology of using Box-Behnken statistical design as useful technique to optimize the experimental independent parameters.

2 Materials and Methods

2.1 Chemicals and Apparatuses

A specific quantity of analytical grade and high purity of cephalexin antibiotic powder (chemical formula: $C_{16}H_{17}N_3O_4S$, the chemical structure: see Fig. 1, purity: 99%, molecular weight: 347.389 g/mol, origin: Sigma-Aldrich company, Germany) was used to prepare the stock solutions of concentration = 1000 mg/L. Further, from the stock solution, working cephalexin solutions were prepared, via dilution using deionized water. Moreover, ferrous sulfate heptahydrate ($FeSO_4 \cdot 7H_2O$) and Hydrogen peroxide (30% v/v) were obtained from Merck Company (Germany). The sulphuric acid and sodium hydroxide solutions of 0.1 N enabled the adjustment of the pH of the working solutions throughout the experimental work by using a pH meter model (UB-10, USA). Ultrasonic apparatus (model Elma Transsonic TI-H 5, MF3, Scotland) was used for the sonolysis process that applied at 130 kHz intensity. All the experimental samples were analyzed for the concentration of cephalexin using Spectrophotometric equipment (model LUV-100, Japan) at wavelength of 258 nm.

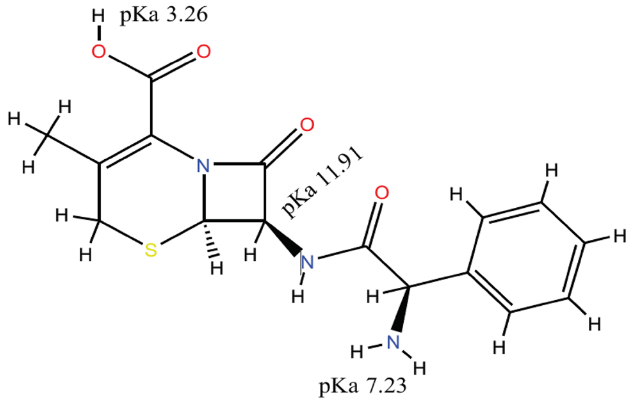

Fig. 1 Chemical structure of cephalexin

2.2 Experimental Procedure

In the current study, all the experiments were conducted using several glass beakers of 250 mL volume. The beakers were filled up with 0.1 L of the pre-prepared cephalexin solutions of different concentrations. The degradation process of cephalexin was investigated at various environmental parameters by varying; (a) pH (3–11); (b) H_2O_2 concentration (40–80 mg/L); (c) Fe^{2+} concentration (4–12 mg/L); (d) reaction time (up to 100 min), and (e) cephalexin concentration (50–100 mg/L). During the degradation process and at specific reaction time period, aliquots of 3 mL from each solution were withdrawn, filtered, centrifuged, and followed by analysis of any remaining cephalexin. Predominantly, samples taken were analyzed in thrice, thereby determining the average results. The actual removal percentage (degradation %) of the cephalexin in the aqueous solution could be calculated using Eq. 1 [46], which is written as:

$$\%\ \text{Actual removal} = \frac{(C_0 - C_t) \times 100}{C_0} \tag{7}$$

where C_o and C_t are the cephalexin concentrations (mg/L) at initial and sampling reaction time interval (min), respectively.

2.3 Statistical Methods

The Box-Behnken response surface methodology (RSM) as proved to be a popular, easy, and efficient statistical expression design tool [12, 17] was applied to model and optimize the values of process parameters including pH (A), concentration of H_2O_2 (B), concentration of Fe^{2+} (C), initial concentration of antibiotic (D) and reaction time (E) on the cephalexin removal in Sono-Fenton process. In fact, the main advantage point of employing RSM as an experimental design methodology is that this technique is rapid and needs a short time to execute the optimization problem compared with the other methods. Therefore, the number of experimental tests required to identify the interaction degree of multiple factors and their effects in a system can be reduced [17, 47]. Normally, this methodology is applied when only few experimental parameters are involved in the process. The employment of RSM provides a mathematical relationship between various factors and the experimental results that can be fitted to a second-order polynomial equation. Consequently, Eq. [8] is suggested to develop a mathematical correlation between the degradation efficiency of cephalexin (% Predicted removal) and the selected five independent parameters [36]. This equation is very helpful to evaluate the effects and finding the optimum values of five selected experimental parameters on the cephalexin degradation efficiency.

$$\begin{aligned}\%\ \text{Predicted removal} = {} & \beta_0 + \beta_1 A + \beta_2 B + \beta_3 C + \beta_4 D \\ & + \beta_5 E + \beta_6 AB + \beta_7 AC + \beta_8 AD \\ & + \beta_9 AE + \beta_{10} BC + \beta_{11} BD \\ & + \beta_{12} BE + \beta_{13} CD + \beta_{14} CE \\ & + \beta_{15} DE + \beta_{16} A^2 + \beta_{17} B^2 \\ & + \beta_{18} C^2 + \beta_{19} D^2 + \beta_{20} E^2\end{aligned} \tag{8}$$

where β_0 is a constant; β_1 to β_{10} are the first-order main effect constants, and β_{11} to β_{20} are the second-order main effect constants, of the regression equation.

Notably, Design-Expert Software (version 7) was employed for the determination of these constants. Further for the judgment of the goodness of the suggested model with the experimental data of cephalexin degradation in Sono-Fenton reactor, the coefficient of determination (R^2) and adjusted coefficient of determination ($R^2_{Adjusted}$), were determined. Besides, the normal distribution of the residuals and the plot of actual values versus predicted values, were employed. Analysis of variance (ANOVA) was applied as a method of statistical analysis of responses, where probability critical level (p-value) of 0.05 was considered to reflect the statistical significance of the parameters of the proposed model. The range and levels of the factors based on experimental design are presented in Table 1.

3 Results and Discussion

3.1 Statistical Analysis

Using the RSM and experiments of design of five variables and ten central points, a total of 50 Runs (experiments) were employed according to (Eq. 9) [49]. Table 2 listed the detailed input values of Box-Behnken matrix with the actual values of degradation efficiency.

$$N = 2k(k - 1) + C0 \tag{9}$$

where N; k, and C0 are denoted to the number of experimental runs; variables, and center points, respectively.

Table 3 listed the results of ANOVA for the degradation efficiency of cephalexin using Sono-Fenton process. Significant parameters with p value < 0.05 have been obtained in the present study for the input response variables, indicating that the experimental data can be adequately describe the proposed model obtained by RSM. In addition, the determined R^2 value was found to be equal to 0.98 which has a logical fit with $R^2_{adjusted}$ as determined to be equal to 0.99. Also, the validity of the model is confirmed by the insignificantly of the p-value of lack of fit which was found to be 0.83, this value is greater than the lowest limit of fit as recommended to be (0.05) [39]. As a result, the model developed in this work for predicting the degradation efficiency (% Predicted removal) of cephalexin in Sono-Fenton reactor was considered to be satisfactory. This model can be written as shown in Eq. [10] with coded five factors.

$$\begin{aligned}\%\ \text{Predicted removal} = {} & 89 - 23.3A + 2.46B - 4.86C - 5.29D \\ & + 4.5E + 4.85AC + 3.08AD - 3.68BD \\ & + 4.53CD - 3.98CE + 3.17DE - 9.6A^2 \\ & - 4.5B^2 - 21.52C^2 - 11.02D^2 - 8.8E^2\end{aligned} \tag{10}$$

Figure 2 depicts graphically the normal probability plot of residuals from the least-squares fitting for the response percentage of cephalexin removal. As can be observed, this figure shows that the points on the plot are lie reasonably close to a straight line as well as the residuals follow a normal distribution pattern. Figure 3 is a random scatter plot of the actual values (Eq. 7) and predicted results (Eq. 10) of cephalexin removal efficiency. It can be seen that both the predicted and actual results are randomly scattered around the 45° straight line, which confirms that the error values between the actual and predicted values have zero mean. This finding indicates high correlation and adequacy of the proposed model to predict the degradation process of cephalexin using the Sono-Fenton process.

Table 1 Variables, levels of design experiments, and RSM Design

Variable	Code	Range and level		
		Low level (− 1)	Central point (0)	High level (+ 1)
pH	A	3	7	11
Concentration of H_2O_2 (mg/L)	B	40	60	80
Concentration of Fe^{2+} (mg/L)	C	4	8	12
Concentration of cephalexin (mg/L)	D	50	75	100
Reaction time (min)	E	20	40	60

Table 2 The experimental design matrix of RSM and the actual and predicted cephalexin degradation efficiency

Run	A	B	C	D	E	% Actual removal
1	3	40	8	75	40	92.70
2	7	60	8	75	40	88.90
3	11	60	8	75	60	46.00
4	11	60	8	75	20	44.90
5	7	40	8	50	40	75.00
6	3	60	8	75	20	86.50
7	7	60	8	75	40	86.10
8	7	80	8	75	60	89.90
9	3	60	8	100	40	85.00
10	7	60	12	75	20	51.00
11	7	60	8	75	40	85.00
12	7	80	4	75	40	72.50
13	3	60	8	50	40	95.60
14	7	60	8	50	20	70.10
15	7	60	8	75	40	70.00
16	7	60	8	75	400	86.90
17	7	40	4	75	40	67.70
18	3	60	12	75	40	52.00
19	11	60	12	75	40	41.00
20	7	60	12	100	40	50.20
21	7	60	8	75	40	83.90
22	7	40	12	75	40	52.20
23	7	80	12	75	40	48.00
24	7	40	8	75	20	66.00
25	7	60	8	100	20	51.10
26	7	60	8	50	60	90.30
27	7	60	4	50	40	53.90
28	7	60	8	75	40	88.00
29	7	80	8	50	40	87.40
30	7	60	8	75	40	85.50
31	11	60	4	75	40	44.10
32	11	60	8	100	40	42.20
33	7	40	8	75	60	71.00
34	7	80	8	75	20	82.00
35	11	40	8	75	40	42.00
36	7	40	8	100	40	65.90
37	11	60	8	50	40	43.50
38	7	60	12	50	40	49.90
39	7	60	4	75	20	54.0
40	3	60	4	75	40	84.40
41	7	60	8	75	40	85.10
42	7	60	4	75	60	64.30
43	7	60	8	75	40	87.70
44	7	80	8	100	40	63.20
45	7	60	12	75	60	48.90
46	3	60	8	75	60	94.90
47	7	60	8	100	60	70.10
48	11	80	8	75	40	44.00
49	3	80	8	75	40	97.50
50	7	60	4	100	40	51.10

Table 3 Results of ANOVA for cephalexin removal using Sono-Fenton process

Model	Sum of squares	Mean square	F value	p value
Theoretical model (Eq. 10)	15967.00	998.00	1111	<0.0001
A	8487.00	8487.00	108.2	<0.0001
B	97.17	97.17	421.2	<0.0001
C	378.30	378.30	498.5	<0.0001
D	447.60	447.60	376.8	<0.0001
E	330.30	330.30	104.80	<0.0001
A^2	940.00	940.00	1047.00	<0.0001
B^2	206.00	206.00	230.40	<0.0001
C^2	4730.00	4730.00	5267.00	<0.0001
D^2	1240.00	1240.00	1381.00	<0.0001
E^2	802.00	802.00	893.20	<0.0001
C × A	94.00	94.00	104.80	0.0001
A × D	37.80	37.80	42.12	0.001
B × D	54.00	54.00	60.40	0.001
C × D	81.00	81.00	91.20	0.001
C × E	63.00	63.00	70.38	0.001
D × E	40.30	40.30	44.90	0.001
Residual	29.64	0.90	–	–
Lack of fit	18.39	0.77	0.61	0.83
Pure error	11.25	1.25	–	–
Cor. total	15997.00	–	–	–

3.2 Effect of pH

Solution pH is the most important experimental factor that affecting on the chemical reactions of Sono-Fenton process as it can effect on the contaminant structure, mechanism of radical hydroxyl production, and reaction kinetics [19, 29]. In the present study the effects of pH in Sono-Fenton process was examined as a function of cephalexin concentrations and the results are depicted in Fig. 4. Clearly, high cephalexin degradation values were occurred at acidic pH values and vice versa. The reason behind this behavior is the increase in the solubility degree of ferrous ions at the acidic medium leading to increase in the rate of hydrogen peroxide decomposition and thereby increasing in the rate of radicals' formation. Besides, the oxidation power of the formed radicals increases in acidic state leading to more degradation percent in cephalexin molecules in aqueous solution. Keep in mind that the production of $H^{\cdot}$ and $OH^{\cdot}$ radicals is increased under ultrasound effects, thus the degradation efficiency was enhanced notably.

On the contrary, the degradation process was slowed down in a gradual manner with the increase of pH values above 7. The occurrence of this phenomenon attributable to ferrous ion solubility decreased in the alkaline pH values leading to form ferric ions. These ions may precipitate in aqueous solution by clotting of ferric hydroxide ($Fe(OH)_3$), causing a reduction in the number of iron ions that essential for the production of hydroxyl radicals. In addition, the hydrogen peroxide is rapidly decomposed by pre-formed hydrogen radicals into water and oxygen. On the other hand, it is well known that the sonolysis process at alkaline pH is ineffective to produce hydroxyl radicals. Under these circumstances the degradation rate of cephalexin is hampered. The above findings found to be in line with those given by studies of Ninomiya et al. [32]; Li et al. [25], and Özdemir et al. [33].

3.3 Effect of H_2O_2 Concentration

According to the variance analysis, H_2O_2 concentration with p value <0.0001 is another significant process parameter to be studied in the Sono-Fenton process. In this direction, the

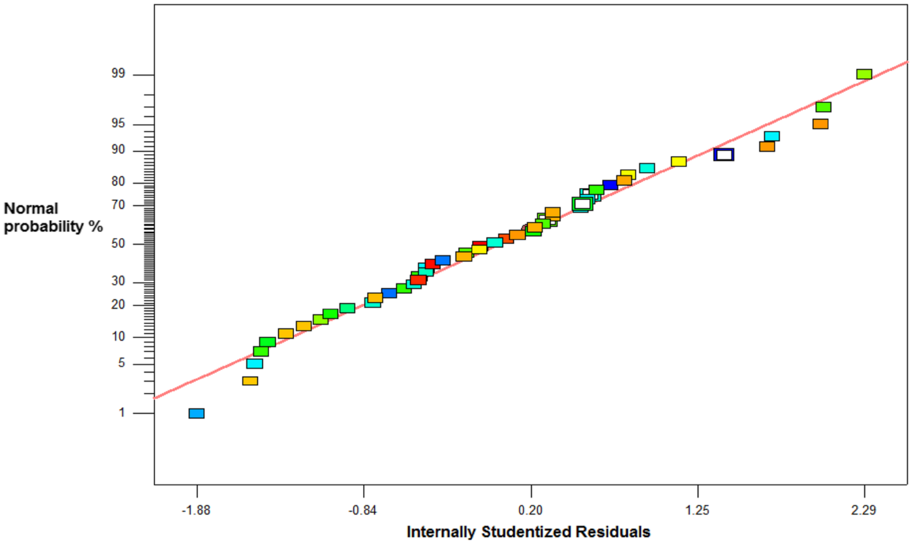

Fig. 2 Normal probability plot of residuals obtained by ANOVA for degradation of cephalexin degradation using Sono-Fenton reactor

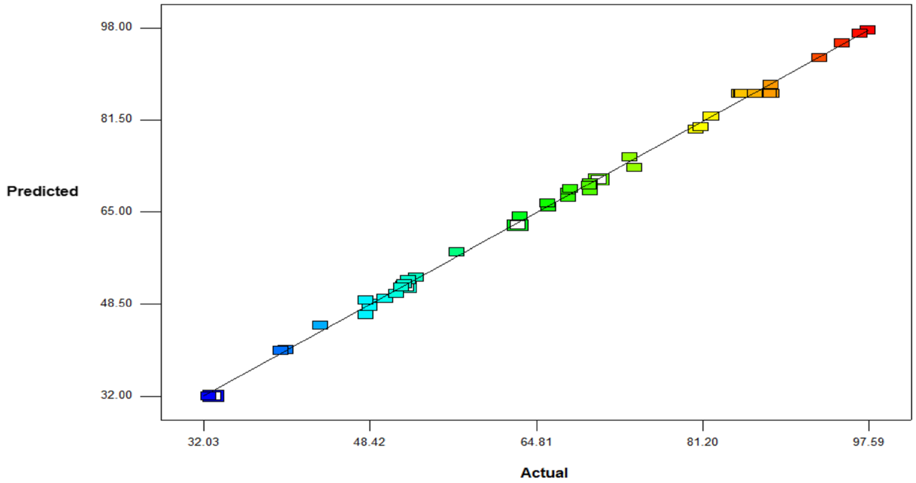

Fig. 3 Correlations between the experimental with predicted values of cephalexin removal efficiency

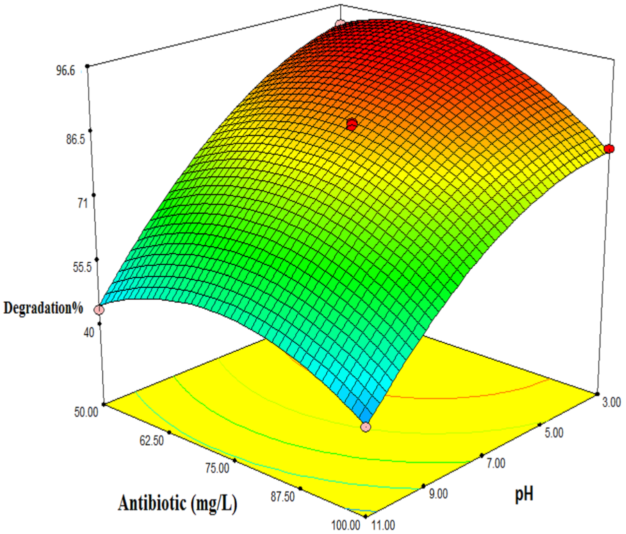

Fig. 4 Degradation efficiency of cephalexin using Sono-Fenton reactor as a function of pH and cephalexin concentration

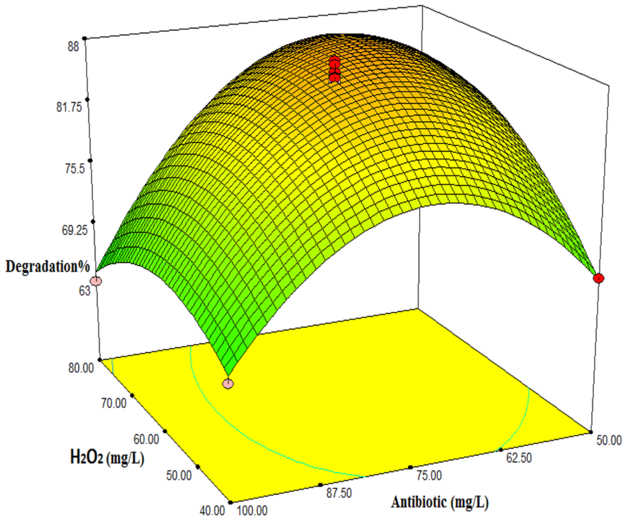

Fig. 5 Effect of H_2O_2 on the degradation efficiency of cephalexin at different concentrations using Sono-Fenton reactor

current study makes an attempt to ascertain the percentage efficiency of Sono-Fenton process in the degradation of cephalexin at H_2O_2 concentration ranging from 40 to 80 mg/L. The results of this experiment are plotted in Fig. 5, which is indicated that the increase of H_2O_2 concentration from 40 to 60 mg/L increased remarkably the percentage degradation of cephalexin. This is due to the addition of H_2O_2 in the presence of iron catalyst produced high radical hydroxyl concentration, thereby enabling degradation of cephalexin in a sizeable amount. On the other hand pyrolysis reaction in cavitation bubbles and radical reactions by hydroxyl and hydrogen radicals are other responsible reason for enhancing the decomposing pollutants in the Sono-Fenton process as shown in reactions Eqs. 11–14 [22, 31].

$$H_2O_2 + Fe^{2+} \rightarrow Fe^{3+} + OH^- + OH^{\cdot} \quad (11)$$

$$\text{cephalexin} + \text{US} \rightarrow \text{Pyrolysis product} \quad (12)$$

$$H_2O + \text{US} \rightarrow H^{\cdot} + HO^{\cdot} \quad (13)$$

$$HO^{\cdot} + \text{cephalexin} + \text{US} \rightarrow \text{Product} \quad (14)$$

However, further increase in the hydrogen peroxide concentration above 60 mg/L had reduced the process efficiency. This behavior is due to the fact that at high concentrations of hydrogen peroxide, this oxidizer acts as a radical hydroxyl consumer (scavenger), and this phenomenon participates to reduce and lowering the degradation agent concentration in aqueous solution (see the chemical reaction Eq. 15) and therefore process efficiency was remarkably reduced. Similar finding was obtained in the study conducted by Ku et al.

[22], which investigated the removal of monochlorophenols with US/H_2O_2 process, as well as the study of Liang et al. [26] which is studied the removal of chlorinated aromatic hydrocarbons by US and Fenton processes. These researchers reported the occurrence of the scavenger phenomenon cause of reducing process efficiency with increase in H_2O_2 concentration above a specific limit.

$$H_2O_2 + OH^{\cdot} \rightarrow OH_2^{\cdot} + H_2O \tag{15}$$

3.4 Effect of Fe^{2+} Concentration

In the reaction of Fenton, the reaction of H_2O_2 as an oxidant agent to produce radicals is considered very slow. But in case of addition of Fe^{2+} ions which act as a catalyst, the radical production process can be faster than using only H_2O_2. Therefore, it is an important, for a particular use, to determine the optimum Fe^{2+} concentration required for the antibiotic degradation using Sono-Fenton process [3]. Also, the p value was <0.0001 as shown in Table 3, which was confirm that the concentration of Fe^{2+} had a great impact on the Sono-Fenton mechanism. In the present study, the effect of the variation of Fe^{2+} ions concentration on the cephalexin degradation was examined in the range of 4–12 mg/L and as a function of pH (Fig. 6a) and antibiotic concentration (Fig. 6b). These two figures showed that the increasing the concentration of Fe^{2+} ions up to 8 mg/L led to increasing the process efficiency due to the acceleration of hydroxyl radical production [41]. However, increase of Fe^{2+} concentration above 8 mg/L resulted in reducing efficiency because excessive Fe^{2+} concentration leads to the production of Fe^{3+} ions, which in turn react with hydroxyl radicals and decrease the reaction rate of $OH^{\cdot}$ with cephalexin molecules, therefore reduced the degradation efficiency as shown in Eq. (16). This finding is similar to this obtained for degradation other organic pollutants [21, 24, 27].

$$Fe^{3+} + OH^{-} + 2HO^{\cdot} \rightarrow Fe^{2+} + H_2O + O_2 \tag{16}$$

3.5 Effect of Reaction Time

Since the chemical reactions in treatment systems is significantly depending on the reaction time between the solid and liquid phases, the investigation of this an important parameter, in the Sono-Fenton process applications, must be carried out under different reaction time values. This finding is also confirmed in the current study by the results of ANOVA which demonstrated that the reaction time with p value <0.0001 has a statistical significance effect on the degradation rate of cephalexin (Table 3). Upon varying the reaction time, the variation in the degradation efficiency of

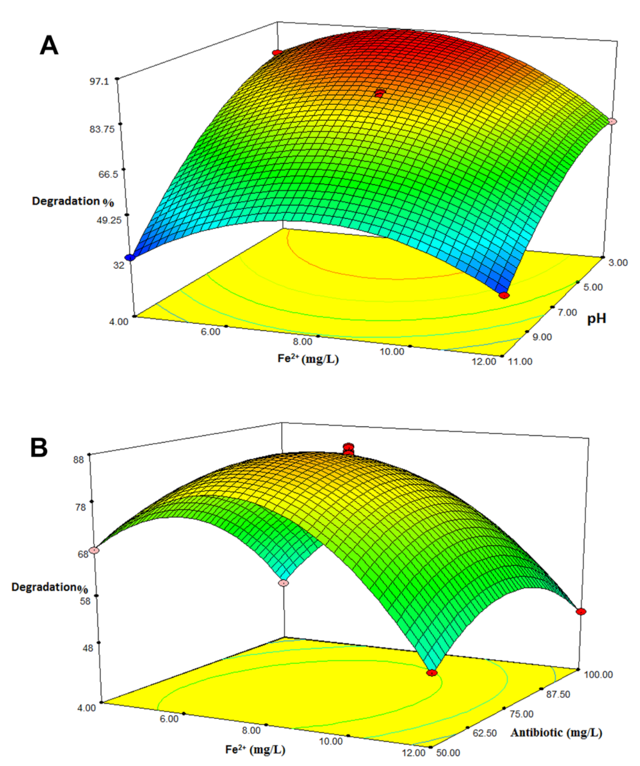

Fig. 6 Effect of Fe^{2+} concentration at different pH values (**a**) and antibiotic concentrations (**b**) on the degradation efficiency of cephalexin using Sono-Fenton reactor

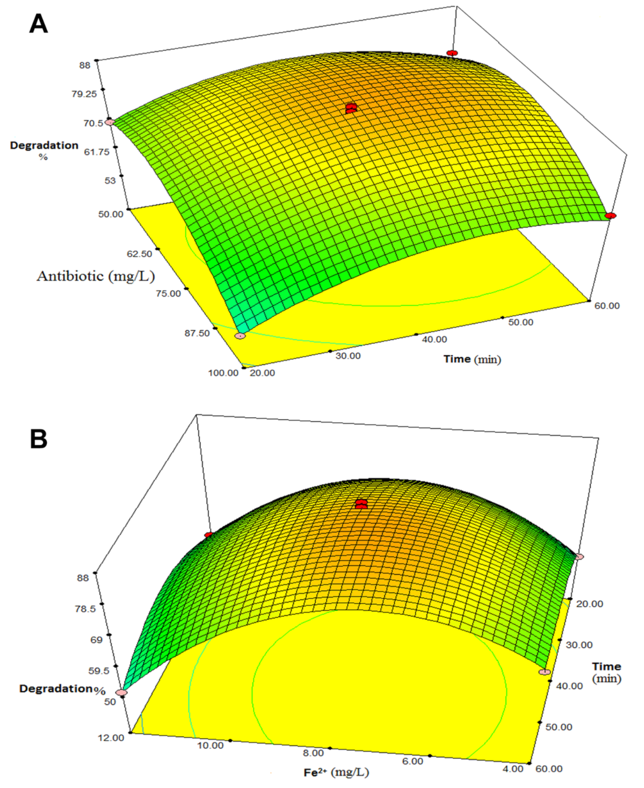

Fig. 7 Effect of reaction time at different antibiotic (**a**) and Fe^{2+} (**b**) concentrations on the degradation efficiency of cephalexin using Sono-Fenton reactor

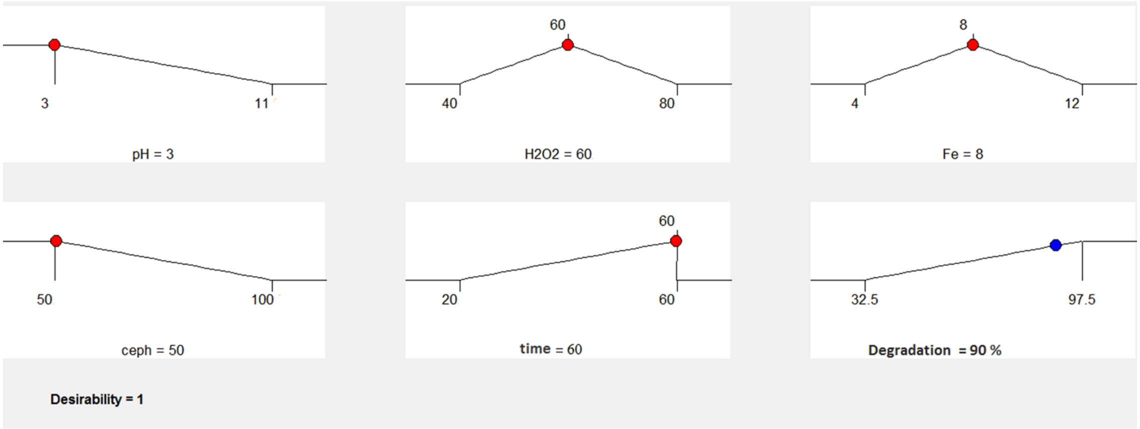

Fig. 8 Plot of optimal conditions designed using RSM

cephalexin was examined at different antibiotic and Fe^{2+} concentration.

The results of this experiment, presented in Fig. 7, reveal that in the case of increasing the reaction time, the degradation percentage of cephalexin was considerably increased. The occurrence of this phenomenon can be attributed to the available an adequate time to permit Fe^{2+} ions to be reacted with hydrogen peroxide and generate more radical hydroxyl, thereby directing these radical to degrade more cephalexin molecules [32, 48]. These results are consistent with those obtained by Wang and Liu [45] who studied the decontamination of alachlor herbicide by ultrasound Fe^{2+}/H_2O_2 process. Their results illustrated that the degradation rate of the studied pollutant was low at the first part of reaction time but the highest degradation efficiency was determined after 60 min reaction time (alachlor concentration = 50 mg/L, pH 3, Fe^{2+} concentration = 20 mg/L, H_2O_2 concentration = 2 mg/L, and temperature = 20 °C).

3.6 Effect of Initial Concentration of Cephalexin

As well described by several studies, the initial concentration of pollutants is another effective parameter in Sono-Fenton reactor [13, 42]. Actually, this parameter was tested in the studies of effects of pH, H_2O_2, and Fe^{2+} concentration as shown in Figs. 3, 4, 5 which indicated that the increased of cephalexin from 50 to 100 mg/L reduced its degradation efficiency abruptly. This is due to the increase the antibiotic concentration can increase the competition of hydroxyl radicals to degrade the antibiotic molecules [24, 33].

3.7 Optimization of Studied Parameters

In the optimization study, the purpose of such study is to find a combination of levels of variables that maximally eliminate antibiotic cephalexin. The response surface methodology selects and predicts the best operating mode in the range of used variables. The model estimated 90% of cephalexin elimination under optimal conditions and desirability factor was expressed 1 for these situations (Fig. 8).

4 Conclusions

The present study provided a comprehensive description regarding the application of the Sono-Fenton process as an efficient treatment process for degradation of cephalexin in aqueous solutions at different pH (3–11), concentration of degradation agent H_2O_2 (40–80 mg/L), metal catalyst agent Fe^{2+} (4–12 mg/L), reaction time (0–100 min), and initial cephalexin concentration (50–100 mg/L). It was found that the degradation rate was remarkably varied by the changing the experimental conditions such as pH, reaction time, antibiotic, H_2O_2, and Fe^{2+} concentrations. The cephalexin degradation data were verified and optimized using Box-Behnken Response Surface Methodology (RSM). The results showed that the RSM is an accurate tool to represent the effects of the five experimental independent parameters on the cephalexin degradation process. The maximum degradation efficiency of 90% was occurred at pH 3.0, H_2O_2 concentration = 60 mg/L, Fe^{2+}concentration = 8 mg/L, initial concentration of cephalexin = 50.0 mg/L, reaction time = 60 min. Thus, the results obtained from the present study indicates that the Sono-Fenton reactor can be used effectively for removing cephalexin molecules from pharmaceutical wastewater and the degradation process can be adequately modeled by RSM.

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Affiliations

Tariq J. Al-Musawi[1] · Hossein Kamani[2] · Edris Bazrafshan[3] · Ayat Hossein Panahi[4] · Marcela Fernandes Silva[5] · Gholamreza Abi[2]

✉ Ayat Hossein Panahi
ayatpanahi@yahoo.com

Tariq J. Al-Musawi
tariq.almusawi@iu.edu.jo

[1] Department of Civil Engineering, Faculty of Engineering, Isra University, Amman, Jordan

[2] Department of Environmental Health, Faculty of Health, Zahedan University of Medical Sciences, Zahedan, Iran

[3] Health Sciences Research Center, Torbat Heydariyeh University of Medical Sciences, Torbat Heydariyeh, Iran

[4] Social Determinants of Health Research Center, Birjand University of Medical Sciences, Birjand, Iran

[5] Chemical Engineering Department, Universidade Estadual de Maringà Av. Colombo n°5790, Maringà-PR, Brazil