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Research Article

Degradation and mineralization of tetracycline by Fenton process

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ABSTRACT

In this study, we aimed to systematically optimize the operating parameters in the degradation and mineralization of tetracycline by Fenton process. For this purpose; optimum values were found for Fe^{2+} concentration, H_2O_2 concentration and pH, reaction time, sedimentation times which are effective operating parameters in Fenton process. In this study where initial tetracycline concentration was used as 100 mg/L; optimum values were found as 4 for pH, 30 mg/L for Fe^{2+} concentration, 100 mg/L for H_2O_2 concentration and 10 min for reaction time and 90 min for sedimentation time. Under these conditions, the TC degradation was 100%, while the COD removal efficiency was approximately 94%. As a result of kinetic studies, BMG is the most suitable kinetic model in terms of tetracycline degradation, while it is seen that the most suitable kinetic model for tetracycline mineralization in terms of COD is the first-order kinetic model. The cost of removing 1 kg of tetracycline from the unit costs of chemicals and energy used in the Fenton process was found to be 1.527$.

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INTRODUCTION

Tetracycline (TC) antibiotics are a group of broad-spectrum synthetic antibiotics against a wide range of Gram positive and Gram-negative bacteria, so they are widely used in human and veterinary medicine for controlling diseases and promoting growth [1]. Tetracyclines are the second largest group of antibiotics in terms of production and use [2]. A very small amount of tetracycline taken into human and animal bodies is metabolized or degraded, the remaining tetracycline being excreted into the environment in active form through humans and animals feces or urine [3]. The release of antibiotics to the environment promotes the proliferation of antibiotic-resistant bacteria and genes, and consequently affects human health and ecosystem [4, 5]. Although conventional biological wastewater treatment has advantages such as low cost, high stability and easy operation; tetracyclines cannot be effectively removed because of its chemical stability and biological resistance [6, 7]. Therefore, effective and environmentally friendly alternative technologies are required to effectively degrade and remove these compounds [2]. Advanced oxidation processes are efficient alternative methods for treating organic wastewater pollutants with low biodegradable and high toxicity. Advanced oxidation methods such as Fenton, photo-Fenton, ozonation, electrochemical oxidation and photo catalysis are commonly used in the removal of recalcitrant and non-biodegradable organic contaminants in wastewa-

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ter [8]. Fenton process, which is one of the advanced oxidation processes, is one of the most widely used processes for removing of a wide variety of non-degradable organic contaminants because it has advantages such as high performance, technology simplicity, low cost and low toxicity of the chemicals used [8, 9]. The Fenton process involves the formation of hydroxyl radical formed by the catalytic reaction between hydrogen peroxide and iron ions (Eq. 1). The hydroxyl radical has an oxidation potential of 2.80 V and can degrade and mineralize a wide range of organic matter [10]. The Fenton process is influenced by H_2O_2 and Fe^{2+} and pollutant concentrations. In addition, other factors such as reaction time, pH, temperature are important operating parameters in the Fenton process.

$$Fe^{2+}+H_2O_2 \rightarrow Fe^{3+}+{}^{\bullet}OH+OH^- \quad (1)$$

There are many studies using the Fenton process for the removal of different drugs [11–16]. Also, different processes such as UV, UV/H_2O_2, UV/persulfate, photo-Fenton, solar photo-Fenton, sono-Fenton, ozonation have been tried in tetracycline removal [17–22]. In this study, it was aimed to systematically optimize the operating parameters such as pH, Fe^{2+} concentration, H_2O_2 concentration, reaction time and precipitation time in the degradation and mineralization of tetracycline by Fenton process. The kinetics of tetracycline degradation and mineralization by Fenton process were determined. The cost of tetracycline removal by Fenton process was calculated.

MATERIALS AND METHODS

Experimental System

All experiments were performed in amber colored glass bottles with a total volume of 250 mL to minimize light effect (Fig. 1). Stirring was done with a magnetic stirrer. The pH was initially adjusted with the aid of the Thermo Scientec brand pH meter and no further pH adjustment was made during the reaction. The desired concentrations of Fe^{2+} and H_2O_2 were added to the tetracycline solution prepared at a specific concentration for each experiment. H_2SO_4 and NaOH were used for pH adjustment. At the end of the reaction, the pH was adjusted to 9–10 and the reactions were stopped and settled for 90 min. At the end of sedimentation time, clear liquid was removed from the top of the reactor and tetracycline and COD were analyzed.

Reagents

Tetracycline (TC) hydrochloride salt (CAS No. 64-755) was purchased from Sigma-Aldrich and 35% purity Hydrogen peroxide (H_2O_2) was purchased from Merck. Iron sulfate heptahydrate was obtained from Biochem. The pH of the solution was initially adjusted with dilute 98% sulfuric acid (0.2 and 0.02 N H_2SO_4) and sodium hydroxide (0.2 N NaOH).

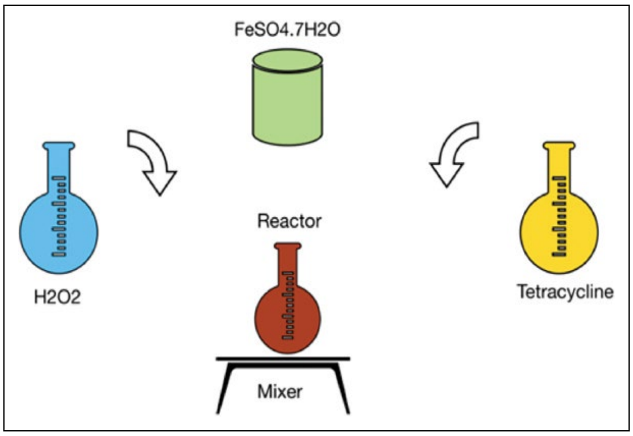

Figure 1. Experimental setup.

Analytical Methods

To determine the performance of Fenton process, tetracycline and COD analyzes were performed on the samples taken at the end of the sedimentation period. Determination of tetracycline was performed by Shimadzu brand High Performance Liquid Chromatography (HPLC). As the mobile phase, a mixture of 20 mM $(NH_4)\ H_2PO_4$ and HPLC grade acetonitrile with pH adjusted to 2.45–2.55 was used and the flow rate was adjusted to 1.2 mL/min and the injection volume to 100 µL. The determination of COD was made with Merck code 114895.

RESULTS AND DISCUSSIONS

Effect of pH

Tetracycline is an amphoteric compound containing two acidic (tricarbonyl amide and phenolic diketone) and one basic functional groups (dimethyl amine) in its structure. Therefore, different forms of TC will occur in the environment depending on the pH. At pH <3.30 (pKa1), TC molecules are available as TC^+ form; at 3.30 <pH <7.68 (pKa2) TC molecules available as TC^0; at 7.68 <pH <9.70 (pKa3) TC molecules are present as TCH^-, and at pH> 9.70, TC molecules are present as TC^{2-} [23]. In the Fenton process, the pH value has an important effect on the formation of hydroxyl radical and therefore on the oxidation efficiency [24]. Hence, pH is important in terms of both tetracycline and Fenton process. Experimental studies were carried out at pH 2, 3 and 4 to determine the effect of pH in Fenton process. Initial TC concentration, Fe^{2+} concentration and H_2O_2 concentration were selected as 100, 30 and 300 mg/L, respectively. At all pH values, the effluent TC concentration were found to be 0 mg/L and the corresponding TC removal efficiencies were 100% (Fig. 2). The COD removal efficiencies were 81%, 74% and 94% mg/L at pH 2, 3 and 4, respectively. Compared to pH 4, the efficiency of COD removal is lower at pH 2 and 3. Because it is stated that TC molecules have hydroxyl groups in ring 1 in undissolved

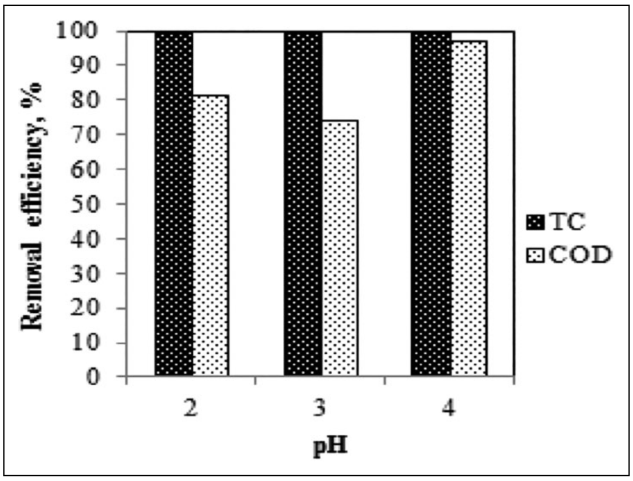

Figure 2. TC and COD removal efficiency at different pH values (TC: 100 mg/L, Fe^{2+}: 30 mg/L, H_2O_2: 300 mg/L).

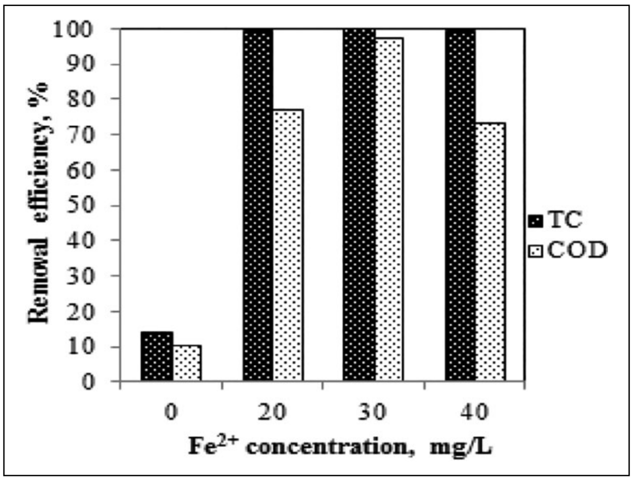

Figure 3. TC and COD removal efficiency at different Fe^{2+} values (TC: 100 mg/L, pH: 4, H_2O_2: 300 mg/L).

form at pH <3.3, while hydroxyl groups in ring 1 in the structure of TC molecules dissolve at pH> 3.3. These experimental results were evaluated and the optimum pH value was selected as 4 in terms of TC and COD removal and pH 4 value was used in the rest of the study. The results of this study were similar with the results of the study in which the degradation of tetracycline with ozonation was investigated [17]. In addition, in the literature, it is stated that the low removal rate in the Fenton process at pH 1 and 2 is due to hydroxyl radical reacting with H^+ ions. Furthermore, H_2O_2 can be dissolved at a high H^+ ion concentration to form an oxonium ion. An oxonium ion makes it electrophilic to increase the stability of hydrogen peroxide and reduces its reactivity with iron ion. On the other hand, it is stated that the oxidation efficiency decreases due to the precipitation of dissolved iron at pH> 4 and the decrease in the disintegration of H_2O_2 to hydroxyl radical [7]. The optimum pH value found in this study was consistent with the pH range in the literature [7, 25].

Effect of Fe^{2+} Concentration

Increased iron concentration leads to the formation of more hydroxyl radical and accelerates the redox reaction. Experimental studies were carried out at 0, 20, 30 and 40 mg/L concentrations in order to determine the effect of Fe^{2+} concentration on TC and COD removal efficiency. Figure 3 shows the TC and COD removal efficiency at different Fe^{2+} concentration. The highest TC and COD removal was achieved at a Fe^{2+} concentration of 30 mg/L, where the removal efficiencies were 100% and 97%, respectively. However, there was a decrease in COD removal in Fe^{2+} concentration of 40 mg/L. The use of a much higher Fe^{2+} concentration causes scavenging of $^{\bullet}OH$, resulting in a decrease in the rate of degradation and mineralization. Furthermore, the use of a lower iron concentration in the Fenton process will result in reduced sludge volume and treatment costs [26]. Therefore, it was seen that Fe^{2+} concentration of 30 mg/L was the most appropriate value. Similarly, it was obtained complete degradation of amoxicillin (AMX) at a concentration of 30 mg/L Fe^{2+} for an initial concentration of AMX of 10 mg/L [16].

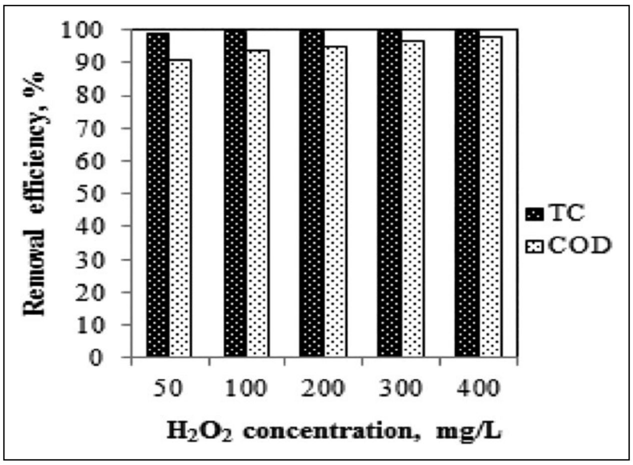

Figure 4. TC and COD removal efficiency at different H_2O_2 values (TC: 100 mg/L, pH: 4, Fe^{2+}: 30 mg/L).

Effect of H_2O_2 Concentration

Figure 4 shows the TC and COD removal efficiency at different H_2O_2 concentrations. Based on TC and COD removal efficiencies, 100 mg/L H_2O_2 concentration could be considered as the optimum value. The TC and COD removal efficiencies at this H_2O_2 concentration were 100% and 94%, respectively. When the optimum H_2O_2 concentration was evaluated in terms of TC and COD removal efficiencies; higher H_2O_2 concentration was not necessary. In the literature, it is stated that the rate of degradation increases as H_2O_2 concentration increases until critical H_2O_2 concentration is obtained. The reduction in the rate of degradation at

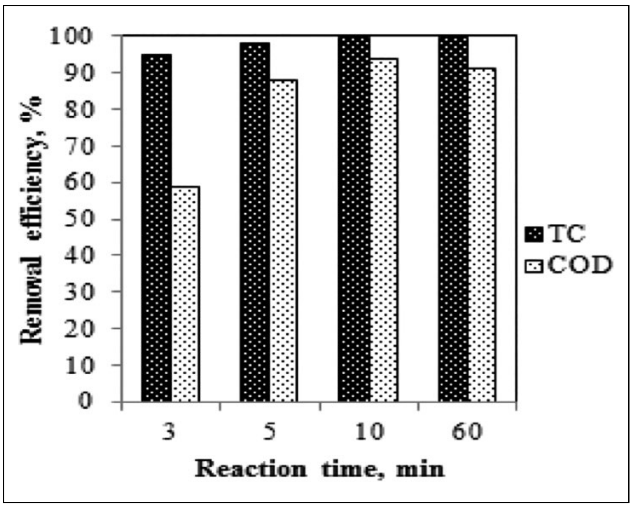

Figure 5. TC and COD removal efficiency at different reaction time (TC: 100 mg/L, pH: 4, Fe^{2+}: 30 mg/L, H_2O_2: 100 mg/L).

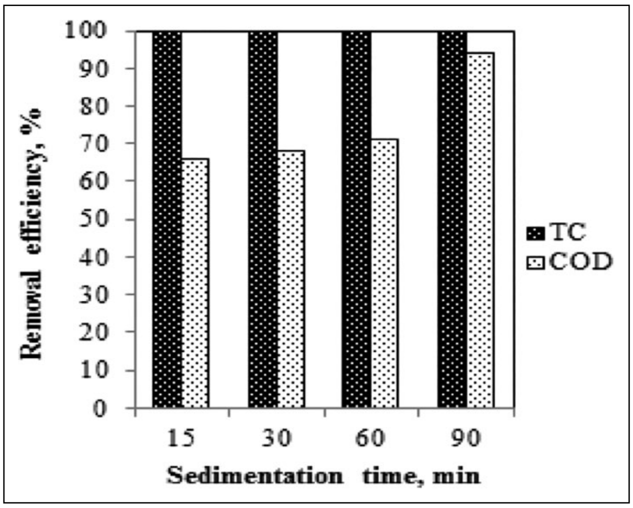

Figure 6. TC and COD removal efficiency at different sedimentation time (TC: 100 mg/L, pH: 4, Fe^{2+}: 30 mg/L, H_2O_2: 100 mg/L, Reaction time: 10 min).

Table 1. The parameters of kinetic models and correlation coefficients (R^2) for the degradation of tetracycline

	First-order kinetic model		Second-order kinetic model		BMG kinetic model		
	k_1 (1/min)	R^2	k_2 (L/mg.min)	R^2	1/m	1/b	R^2
R TC	0.6989	0.57	3.0014	0.88	Undefined	1.0	1.00
COD	0.422	0.99	0.0342	0.83	1.1	1.0395	0.95

higher concentrations results from both the recombination of hydroxyl radical and the scavenging effect of the ${}^{\bullet}OH$ of H_2O_2 [27]. However, such a critical H_2O_2 concentration value was not found in this study. In another study, the optimum H_2O_2 concentration was found to be 375 mg/L in the degradation of amoxycillin (initial concentration: 10 mg/L) with Fenton process [16].

Effect of Reaction Time

As could be seen in Figure 5, the degradation of tetracycline was completed in 10 min. The tetracycline removal efficiency was increased until the reaction time of 10 min. In the Fenton process, it can be said that the effect of the reaction time on the process efficiency is important since the degradation efficiency increases with increasing reaction time [8]. However, the further increase in reaction time (>10 min) did not show a positive effect on the efficiency of the Fenton process. Besides, the increase in reaction time would increase the operating cost. So, the reaction time of 10 min was considered optimum. In a similar study, complete degradation of amoxycillin by the Fenton process took place at a reaction time of 12 min [16].

Effect of Sedimentation Time

The TC and COD removal efficiency depending on the sedimentation time is given in Figure 6. The TC removal efficiencies were found to be 100% after 15, 30, 60 and 90 min of sedimentation time. The highest COD removal efficiency was obtained at the end of the 90 min of sedimentation time which has a value of 94%. Therefore, the sedimentation time of 90 min was found to be the optimum value when the COD removal efficiencies were considered. The reason why the COD removal efficiency is lower than the TC removal efficiency is due to the formation of intermediates and the incomplete mineralization of TC and intermediates to CO_2 and H_2O.

Kinetic Study

The kinetics of the degradation of tetracycline with Fenton process was evaluated using first-order, second-order and Behnajady-Modirshahla-Ghanbery (BMG) [28]. For this purpose, the change in tetracycline concentration and the value of tetracycline in terms of COD depending on the reaction time was investigated. Kinetic calculations were made according to the reaction time of 10 minutes. R^2 value is taken into account in determining the suitability of the kinetic model. For the tetracycline concentration, the R^2 value for the first-order was 0.57, the R^2 value for the second-order was 0.88, and the R^2 value for BMG was 1 (Fig. 7 and Table 1). In the degradation of tetracycline in terms of COD, R^2 value is 0.99 for first-order, R^2 value is 0.83 for second-order and 0.95 for BMG. When R^2 values

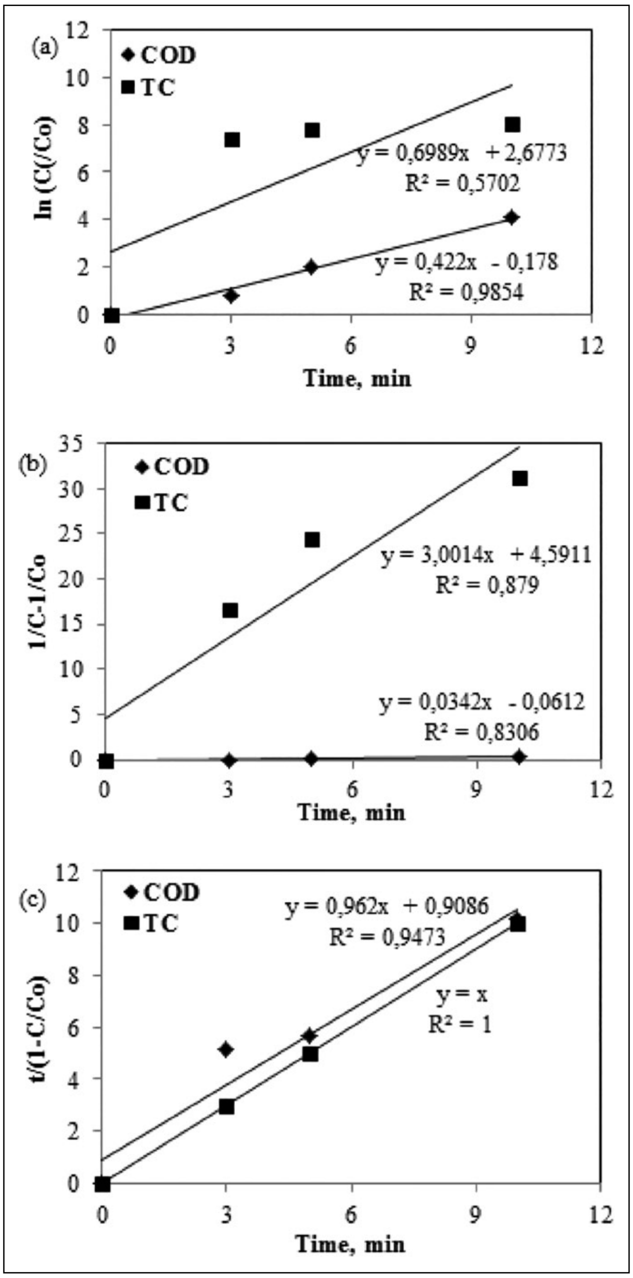

Figure 7. **(a)** First-order, **(b)** second-order, **(c)** BMG kinetics of the degradation of tetracycline with Fenton process.

are taken into consideration, when mineralization is evaluated in terms of COD concentration, it is seen that it fits the first-order kinetics. In terms of tetracycline concentration, it is seen that the BMG kinetic model is suitable. This is due to the fact that the tetracycline concentration decreases very quickly at the beginning and then slows down. The fact that the decrease in tetracycline in terms of COD concentration corresponds to first-order kinetics is due to the intermediate products originally formed during oxidation. It has been reported that the degradation of tetracycline in the schorl/H_2O_2 system fits first-order kinetics [1].

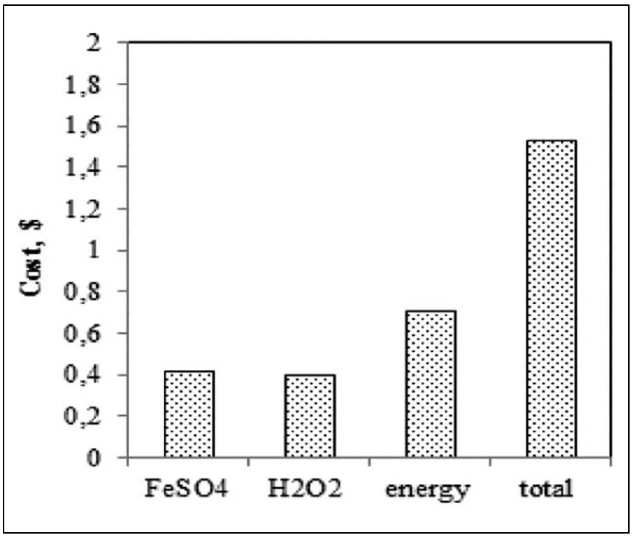

Figure 8. The operating cost in Fenton process (in $ per kg tetracycline removal).

Operating Cost Analysis

The factors affecting the operating cost in Fenton process are chemicals and the energy cost spent for the mixer. The calculation was made by taking $FeSO_4.7H_2O$ cost as 0.28$/kg, H_2O_2 cost as 0.4$/kg and mixer power as 3 W and unit energy cost as 0.071$. For 1 kg tetracycline removal, $FeSO_4$ cost was calculated as 0.417$, H_2O_2 cost was 0.4$ and energy cost was 0.71$. The total cost is 1.527$ (Fig. 8). In the study in which phenol removal was done with the Fenton and electro-Fenton method, the calculation using the same numbers found that the removal cost of 1 kg phenol was 1.337$ with the Fenton process [29]. It was stated that the operating cost for 1 kg of tetracycline removal was 330.06$ for the ozone method, 405.59$ for the ozone+ultrasound method, 193.63$ for the ozone+Fenton method, and 229.71$ for the ozone+ultrasound+Fenton method [30]. It was seen that the Fenton process had lower operating costs compared to other methods.

CONCLUSIONS

Experimental study results showed the optimum values for pH, Fe^{2+}, H_2O_2, reaction time and sedimentation time in Fenton process were found to be 3, 30 mg/L, 100 mg/L, 10 min and 90 min, respectively. Under these conditions, TC degradation is 100%. The COD removal efficiency was about 94%. As a result of kinetic studies, it was the most appropriate kinetic model BMG in tetracycline degradation and first-order in tetracycline mineralization. The cost of tetracycline removal by Fenton process was calculated as 1.527$ per 1 kg. The operating cost of the Fenton process for tetracycline removal was lower compared to other methods.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

REFERENCES

[1] Y. Zhang, J. Shi, Z. Xu, Y. Chen, and D. Song, "Degradation of tetracycline in a schorl/H2O2 system: Proposed mechanism and intermediates," Chemosphere, Vol. 202, pp. 661–668, 2018. [CrossRef]

[2] J. Jeong, W. Song, W. J. Cooper, J. Jung, and J. Greaves, "Degradation of tetracycline antibiotics: mechanisms and kinetic studies for advanced oxidation/reduction processes," Chemosphere, Vol. 78(5), pp. 533–540, 2010. [CrossRef]

[3] M. K. Liu, Y. Y. Liu, D. D. Bao, G. Zhu, G. H. Yang, J. F. Geng, and H. T. Li, "Effective removal of tetracycline antibiotics from water using hybrid carbon membranes," Scientific Reports, Vol. 7(1), pp. 1–8, 2017. [CrossRef]

[4] Y. Zhang, J. Geng, H. Ma, H. Ren, K. Xu, and L. Ding, "Characterization of microbial community and antibiotic resistance genes in activated sludge under tetracycline and sulfamethoxazole selection pressure," Science of the Total Environment, Vol. 571, pp. 479–486, 2016. [CrossRef]

[5] E. Aydın, M. Şahin, E. Taşkan, H. Hasar, and M. Erdem, "Chlortetracycline removal by using hydrogen based membrane biofilm reactor," Journal of Hazardous Materials, Vol. 320, pp. 88–95, 2016. [CrossRef]

[6] M. G. Alalm, A. Tawfik, and S. Ookawara, "Degradation of four pharmaceuticals by solar photo-Fenton process: kinetics and costs estimation," Journal of Environmental Chemical Engineering, Vol. 3(1), pp. 46–51, 2015. [CrossRef]

[7] M. Zouanti, M. Bezzina, and R. Dhib, "Experimental study of degradation and biodegradability of oxytetracycline antibiotic in aqueous solution using Fenton process," Environmental Engineering Research, Vol. 25(3), pp. 316–323, 2020. [CrossRef]

[8] S. A. Mousavi, F. Farrokhi, N. Kianirad, and F. Falahi, "Degradation of aniline from aqueous solution by Fenton process: modeling and optimization," Desalination and Water Treatment, Vol. 125, pp. 68–74, 2018. [CrossRef]

[9] E. Gürtekin, and N. Şekerdağ, "An advanced oxidation process: Fenton process," Pamukkale University Journal of Engineering Sciences, Vol. 14(3), pp. 229–236, 2008.

[10] V. Kavitha, and K. Palanivelu, "Destruction of cresols by Fenton oxidation process," Water Research, Vol. 39(13), pp. 3062–3072, 2005. [CrossRef]

[11] E. Elmolla, and M. Chaudhuri, "Optimization of Fenton process for treatment of amoxicillin, ampicillin and cloxacillin antibiotics in aqueous solution," Journal of Hazardous Materials, Vol. 170(2-3), pp. 666–672, 2009. [CrossRef]

[12] S. P. Sun, H. Q. Guo, Q. Ke, J.H. Sun, S. H. Shi, M. L. Zhang, and Q. Zhou, "Degradation of antibiotic ciprofloxacin hydrochloride by photo-Fenton oxidation process," Environmental Engineering Science, Vol. 26(4), pp. 753–759, 2009. [CrossRef]

[13] O. Rozas, D. Contreras, M. A. Mondaca, M. Pérez-Moya, and H. D. Mansilla, "Experimental design of Fenton and photo-Fenton reactions for the treatment of ampicillin solutions," Journal of Hazardous Materials, Vol. 177(1–3), pp. 1025–1030, 2010. [CrossRef]

[14] A. S. Giri, and A. K. Golder, "Ciprofloxacin degradation from aqueous solution by Fenton oxidation: reaction kinetics and degradation mechanisms," RSC Advances, Vol. 4(13), pp. 6738–6745, 2014. [CrossRef]

[15] G. Dalgic, I. F. Turkdogan, K. Yetilmezsoy, and E. Kocak, "Treatment of real paracetamol wastewater by Fenton process," Chemical Industry and Chemical Engineering Quarterly, Vol. 23(2), pp. 177–186, 2017. [CrossRef]

[16] M. Verma, and A. K. Haritash, "Degradation of amoxicillin by Fenton and Fenton-integrated hybrid oxidation processes," Journal of Environmental Chemical Engineering, Vol. 7(1), Article 102886, 2019. [CrossRef]

[17] M. H. Khan, H. Bae, and J. Y. Jung, "Tetracycline degradation by ozonation in the aqueous phase: proposed degradation intermediates and pathway," Journal of Hazardous Materials, Vol. 181(1–3), 659–665, 2010. [CrossRef]

[18] J. J. López-Peñalver, M. Sánchez-Polo, C. V. Gómez-Pacheco, and J. Rivera-Utrilla, "Photodegradation of tetracyclines in aqueous solution by using UV and UV/H2O2 oxidation processes," Journal of Chemical Technology and Biotechnology, Vol. 85(10), pp. 1325–1333, 2010. [CrossRef]

[19] A. M. Cahino, M. M. A. de Andrade, E. S. de Araújo, E. L. Silva, C.D.O. Cunha, and E.M.R. Rocha, "Degradation of tetracycline by solar photo-Fenton:

Optimization and application in pilot photoreactor," Environmental Quality Management, Vol. 28(1), pp. 101–106, 2018. [CrossRef]

[20] C. H. Han, H. D. Park, S. B. Kim, V. Yargeau, J.W. Choi, S.H. Lee, J.A. Park, "Oxidation of tetracycline and oxytetracycline for the photo-Fenton process: Their transformation products and toxicity assessment," Water Research, Vol. 172, Article 115514, 2020. [CrossRef]

[21] M. Xu, J. Deng, A. Cai, X. Ma, J. Li, Q. Li, and X. Li, "Comparison of UVC and UVC/persulfate processes for tetracycline removal in water," Chemical Engineering Journal, Vol. 384, Article 123320, 2020. [CrossRef]

[22] Y. Aşcı, The effect of pH on the removal of tetracycline antibiotic from aqueous solutions by ultrasound/H2O2 and sono-fenton methods, In Y. Aşcı, (Ed.). "Engineering sciences innovative approaches," pp. 136–145, 2021.

[23] Y. Y. Chen, Y. L. Ma, J. Yang, L. Q. Wang, J. M. Lv, and C. J. Ren, "Aqueous tetracycline degradation by H2O2 alone: removal and transformation pathway," Chemical Engineering Journal, Vol. 307, pp. 15–23, 2017. [CrossRef]

[24] G. K. Turkay, and H. Kumbur, "Investigation of amoxicillin removal from aqueous solution by Fenton and photocatalytic oxidation processes," Kuwait Journal of Science, Vol. 46(2), pp. 85–93, 2019.

[25] N. Modirshahla, M. A. Behnajady, and F. Ghanbary, "Decolorization and mineralization of CI Acid Yellow 23 by Fenton and photo-Fenton processes," Dyes and Pigments, Vol. 73(3), pp. 305–310, 2007. [CrossRef]

[26] L. V. de Souza Santos, A. M. Meireles, and L. C. Lange, "Degradation of antibiotics norfloxacin by Fenton, UV and UV/H2O2," Journal of Environmental Management, Vol. 154, pp. 8–12, 2015. [CrossRef]

[27] M. Y. Ghaly, G. Härtel, R. Mayer, and R. Haseneder, "Photochemical oxidation of p-chlorophenol by UV/H2O2 and photo-Fenton process. A comparative study," Waste Management, Vol. 21(1), pp. 41–47, 2001. [CrossRef]

[28] M. A. Behnajady, N. Modirshahla, and F. Ghanbary, "A kinetic model for the decolorization of CI Acid Yellow 23 by Fenton process," Journal of Hazardous Materials, Vol. 148(1–2), pp. 98–102, 2007. [CrossRef]

[29] D. Gümüş, and F. Akbal, "Comparison of Fenton and electro-Fenton processes for oxidation of phenol," Process Safety and Environmental Protection, Vol. 103, pp. 252–258, 2016. [CrossRef]

[30] C. K. Wang, and B.M. Huang, "Degradation, of tetracycline by advanced oxidation processes: Sono-Fenton and ozonation processes," Desalination and Water Treatment, Vol. 96, pp. 161–168, 2017. [CrossRef]