

# Chemical Oxygen Demand Removal from Synthetic Wastewater Containing Non-beta Lactam Antibiotics Using Advanced Oxidation Processes: A Comparative Study

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## A-R-T-I-C-L-E I-N-F-O

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## A-B-S-T-R-A-C-T

**Background & Aims of the Study:** Pharmaceuticals are considered as an emerging environmental problem due to their continuous discharge and persistence to the aquatic ecosystem even at low concentrations. The purpose of this research was the investigation of advanced oxidation processes (Fenton and Fenton-like) efficiency for the removal of non-beta lactam Antibiotics of azithromycin and clarithromycin from synthetic wastewater.

**Materials & Methods:** In this laboratory scale study, samples of synthetic wastewater were prepared from azithromycin and clarithromycin antibiotics. Concentration of samples was 200 mg/L. Chemical oxygen demand (COD) index was selected as the parameter for evaluation in this study. Fenton and Fenton-like oxidation processes were done on synthetic wastewater of azithromycin and clarithromycin. In Fenton ( $\text{Fe}^{2+}/\text{H}_2\text{O}_2$ ) and Fenton-like ( $\text{Fe}^0/\text{H}_2\text{O}_2$ ) processes the influence of pH, iron and hydrogen peroxide on the removal efficiency of the antibiotics were studied and the optimum values for each parameter were determined.

**Results:** The optimum condition for Fenton in removal of azithromycin and clarithromycin were pH= 7 and 7,  $\text{Fe}^{2+}$  0.45 mmol/L and 0.45 mmol/L, hydrogen peroxide 0.16 mmol/L and 0.2 mmol/L, and contact time of 1 h and 1 h, respectively. The optimum condition for Fenton-like in removal of clarithromycin and azithromycin were pH= 7 and 7,  $\text{Fe}^0$  0.3 mmol/L and 0.36 mmol/L, hydrogen peroxide 0.3 mmol/L and 0.38 mmol/L, contact time of 30 min and 30 min.

**Conclusions:** The findings of this study demonstrate that the Fenton and Fenton-like processes under optimum conditions can play an important role in the removal of azithromycin and clarithromycin antibiotics from industrial wastewater.

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## Background

Pharmaceuticals continuously discharge to the aquatic ecosystem. Their persistence in the environment emerges environmental issues and impact the human and veterinary health (1).

Studies have shown after passing through wastewater treatment, pharmaceuticals are released directly into the environment. Microbial resistant is one of the greatest concerns related to antibiotics use and their disposal in environment.

Antibiotics have been widely used in human and veterinary medicine to prevent or treat

microbial infections. Thus, large quantities of these pharmaceutical agents are metabolized in the body and the rest are excreted in their native form or as metabolites. These pharmaceuticals may accumulate in soil and may be mobile in soil and can contaminate ground water (2-4). They are present in the effluent of sewage treatment plants, indicating their poor biodegradability in municipal sewage and sewage treatment plants that can be emitted into the receiving water systems. Hence, biological treatment process of wastewater for removal antibiotic is insufficient and a pretreatment process is often required.

One of the new technologies used in the pretreatment of water supplies and industrial sewage containing toxic material is "advanced oxidation processes (AOPs)". The reason for the use of AOPs is due to production of hydroxyl radicals ( $\cdot\text{OH}$ ) which have high efficacy in breaking down organic material because  $\cdot\text{OH}$  is capable of mineralizing them ultimately to  $\text{CO}_2$  and  $\text{H}_2\text{O}$  (5-7).

Fenton-like and Fenton are advanced oxidation processes that use  $\text{Fe}^\circ$  and  $\text{Fe}^{2+}$  in reaction with  $\text{H}_2\text{O}_2$ , respectively, to produce  $\cdot\text{OH}$  as follows:

- (1)  $\text{Fe}^\circ \rightarrow \text{Fe}^{2+} + 2\text{e}^-$
- (2)  $\text{Fe}^{2+} + \text{H}_2\text{O}_2 \rightarrow \text{Fe}^{3+} + \text{OH}^- + \cdot\text{OH}$

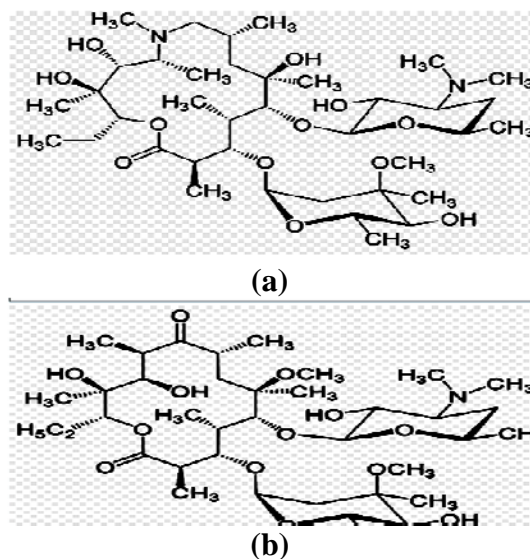
**Aims of the study:** In this study Fenton and Fenton-like oxidation processes were done on synthetic wastewater of azithromycin and clarithromycin and the effects of important variables such as  $\text{H}_2\text{O}_2$  and  $\text{Fe}^\circ$  dosage, pH and reaction time in these processes on antibiotics removal were examined.

## Materials & Methods

This study was performed to determine the optimum conditions, including  $\text{Fe}^{2+}$  and  $\text{H}_2\text{O}_2$  dosages, and pH for the Fenton process; and  $\text{Fe}^\circ$  and  $\text{H}_2\text{O}_2$  dosages and pH for Fenton-like process, for obtaining maximum "chemical oxygen demand (COD)" removal.

For all experiments, the synthetic wastewater was produced by dissolving 0.2 g antibiotic in 1000 mL distilled water.

Based on our analysis 1 mg/L of azithromycin is equivalent to 1.95 mg/L COD and 1 mg/L of clarithromycin is equivalent to 1.75 mg/L COD. Figure 1 shows molecular structure of azithromycin and clarithromycin.



**Figure 1) Molecular structure of azithromycin (a) and clarithromycin (b)**

The iron powder (95%) with particle size of 70-100  $\mu\text{m}$ ,  $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$  (98%), Sulfuric acid (96%) and  $\text{NaOH}$  (98%) (in order to pH adjustment), and hydrogen peroxide with the technical grade (30% w/w and density of 1.13 kg/L) were purchased from the Merck Company. COD measurements were performed by the closed reflux titrimetric method (8). The COD samples were measured after filtration through a Millipore membrane filter with a pore size of 0.45  $\mu\text{m}$ . Initial and residual  $\text{H}_2\text{O}_2$  amounts were determined by the spectrophotometry method (presence of  $\text{H}_2\text{O}_2$  leads to overestimating COD) (9).

Each experiment was conducted three times. The Fenton and Fenton-like oxidation experiments were performed in a cylindrical glass reactor with a magnetic stirrer using a constant speed of 200 rpm. The stages of experiments for Fenton-like process were similar to Fenton process. The only difference between these processes was use of  $\text{Fe}^\circ$  for Fenton-like and  $\text{Fe}^{2+}$  for Fenton.

The experiments were performed in three stages. In the first stage, the initial concentrations of ( $\text{Fe}^0$  or  $\text{Fe}^{2+}$  and  $\text{H}_2\text{O}_2$ ) were kept the same from run to run to determine the optimum pH for the solution. While maintaining the optimum pH determined during the first stage and the same  $\text{Fe}^0$  or  $\text{Fe}^{2+}$  concentration, the optimum level for  $\text{H}_2\text{O}_2$  was measured and determined during the second stage. Finally, while maintaining the optimum pH from the first stage and the  $\text{H}_2\text{O}_2$  optimum concentration from the second stage, the optimum concentration for the  $\text{Fe}^0$  or  $\text{Fe}^{2+}$  was measured and determined in the third stage. All experiments were performed at  $20^\circ\text{C}$ .

**Data analysis:** The data were analyzed using one-way analysis of variance (ANOVA). P-values less than 0.5 were considered as statistically significant.

## Results

Fenton and Fenton-like oxidation processes were done on synthetic wastewater of azithromycin and clarithromycin.

In Fenton ( $\text{Fe}^{2+}/\text{H}_2\text{O}_2$ ) and Fenton-like ( $\text{Fe}^0/\text{H}_2\text{O}_2$ ) processes, the influence of pH, iron and hydrogen peroxide on the removal efficiency of antibiotics were studied and the optimum values for each parameter were determined.

Figure 2 compares the effects of the pH value on the Fenton and Fenton-like processes in removal of azithromycin COD (2-a) and clarithromycin COD (2-b). To elucidate the role of pH on final COD, pH was altered within a range of 3 to 11 for each process, and  $\text{H}_2\text{O}_2$  and  $\text{Fe}$  ( $\text{Fe}^0$  or  $\text{Fe}^{2+}$ ) concentrations for each process were fixed at 0.1 mM/L and 0.1 mM/L, respectively.

The minimum final COD (each tow antibiotics) for each tow processes of Fenton and Fenton-like was obtained at  $\text{pH}=7.0$ , while at  $\text{pH}<7.0$  and  $\text{pH}>7.0$ , higher values of final COD was observed. Considering the above

indicated results, optimum pH for each process was selected as 7.0.

Figure 3 shows the effect of the initial  $\text{H}_2\text{O}_2$  on the decreasing of final COD. As presented in Figure 3a, azithromycin COD removal efficiency was increased (the final COD was decreased) by increasing the  $\text{H}_2\text{O}_2$  concentration from 0.1 to 0.38 mM/L and 0.05 to 0.2 mM/L for Fenton-like and Fenton, respectively, and increase in the concentration of  $\text{H}_2\text{O}_2$  up to 0.38 mM/L for Fenton-like and 0.2 for Fenton did not significantly affect the removal of COD.

Also according to figure 3b, the clarithromycin final COD was decreased by increasing of  $\text{H}_2\text{O}_2$  added (increasing the  $\text{H}_2\text{O}_2$  concentration from 0.1 to 0.3 mM/L and 0.04 to 0.16 mM/L), while clarithromycin final COD remained constant with increasing  $\text{H}_2\text{O}_2$  up to 0.3 mM/L and 0.16 for Fenton-like and Fenton processes, respectively (in each process for removal of antibiotics, pH controlled at 7.0 and the  $\text{Fe}^0$  or  $\text{Fe}^{2+}$  dosage was Fixed at 0.1 mM/L).

Conclusively, the optimal doses for removal azithromycin and clarithromycin COD by the Fenton were 0.2 and 0.16, and by the Fenton-like process were 0.38 and 0.3, respectively.

To obtain the optimum concentration of  $\text{Fe}^0$  or  $\text{Fe}^{2+}$  for COD removal from solution, the investigation was carried out with various amounts of the  $\text{Fe}^0$  or  $\text{Fe}^{2+}$ .

Figure 4 shows that the increase of either  $\text{Fe}^0$  or  $\text{Fe}^{2+}$  enhanced the efficiency of Fenton-like and Fenton processes for COD removal of azithromycin and clarithromycin. Experiments show that COD removal efficiency significantly increases (final COD decreased) in dosages of 0.36 mM/L and 0.42 mM/L ( $\text{Fe}^0$  and  $\text{Fe}^{2+}$ , respectively) for azithromycin and 0.3 mM/L and 0.45 mM /l ( $\text{Fe}^0$  and  $\text{Fe}^{2+}$ , respectively) for clarithromycin.

Figure 5 presents changes in COD values of azithromycin and clarithromycin during Fenton-like and Fenton oxidation as a function of treatment time. Degradation of azithromycin and clarithromycin by Fenton-like and Fenton

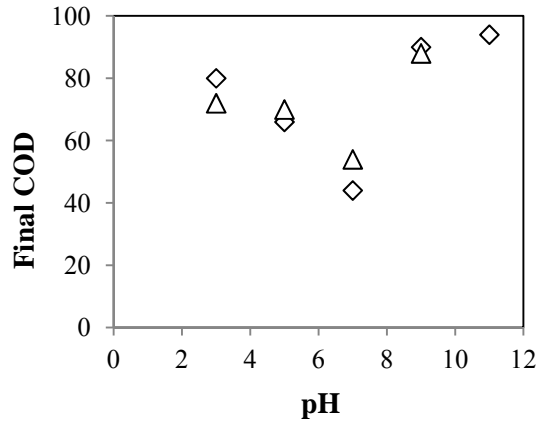
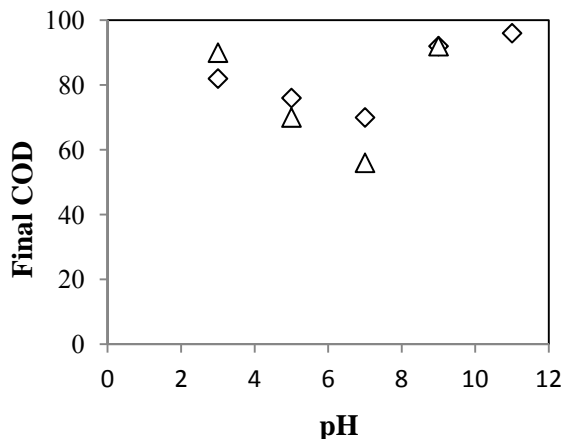
oxidation could be expressed as first order reaction according to the following equation:

$$d\text{COD}/dt = -k_{\text{COD}} \times \text{COD}$$

Where  $k_{\text{COD}}$  ( $\text{min}^{-1}$ ) is the first-order COD abatement rate constant for azithromycin or clarithromycin by Fenton-like and Fenton.

**Table 1) Rate constants of mineralization in antibiotics by Fenton and Fenton-like**

Process	Azithromycin		Clarithromycin	
	K( $\text{s}^{-1}$ )	$t_{1/2}(\text{min})$	k( $\text{s}^{-1}$ )	$t_{1/2}(\text{min})$
Fenton-like	0.074	9.3	0.079	8.7
Fenton	0.028	24.7	0.027	25.6



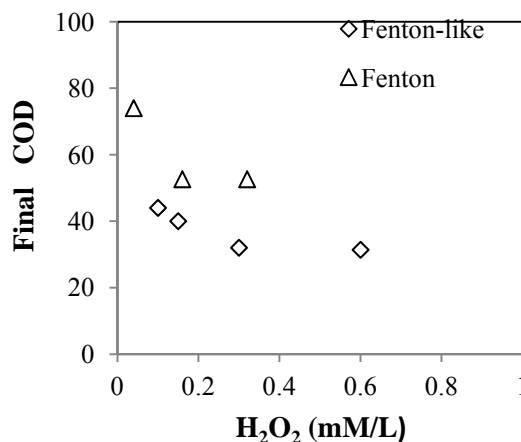
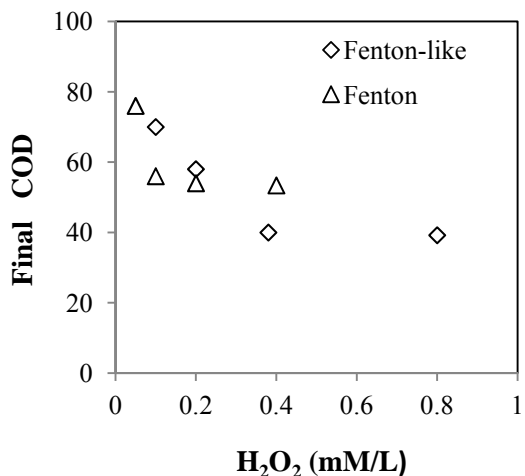
◇Fenton-like    △Fenton

◇Fenton-like    △Fenton

(a)

(b)

**Figure 2) Effects of pH on chemical oxygen demand (COD) removal rates obtained for azithromycin (a) and clarithromycin (b) antibiotics by “Fenton” and “Fenton-like” processes**



(a)

(b)

**Figure 3) Effects of H<sub>2</sub>O<sub>2</sub> on chemical oxygen demand (COD) rates obtained for azithromycin (a) and clarithromycin (b) antibiotics by “Fenton” and “Fenton-like” processes**

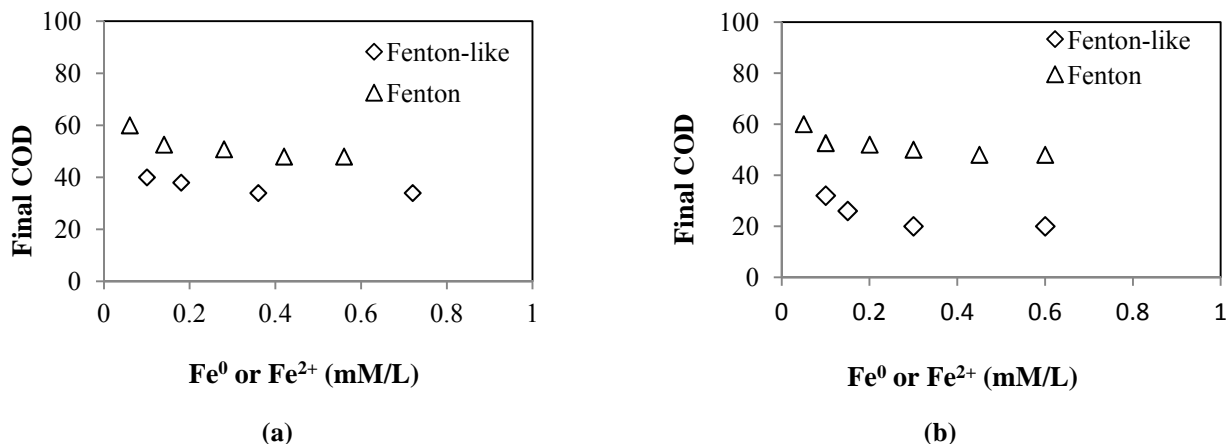


Figure 4) Effects of Fe<sup>0</sup> or Fe<sup>2+</sup> on chemical oxygen demand (COD) removal rates obtained for azithromycin (a) and clarithromycin (b) antibiotics by “Fenton” and “Fenton-like processes”

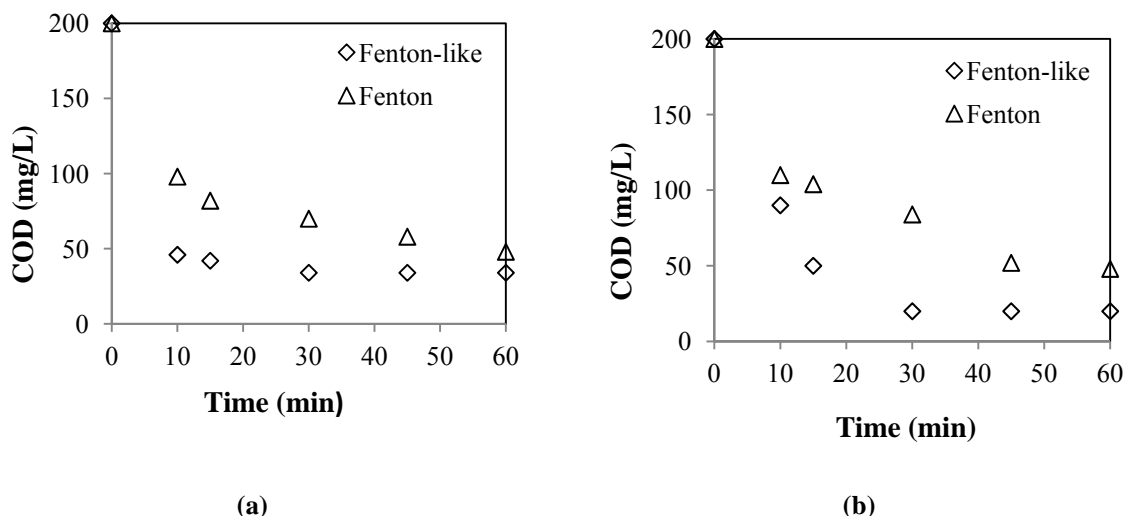


Figure 5) Chemical oxygen demand (COD) abatement rates for “Fenton” and “Fenton-like” experiments

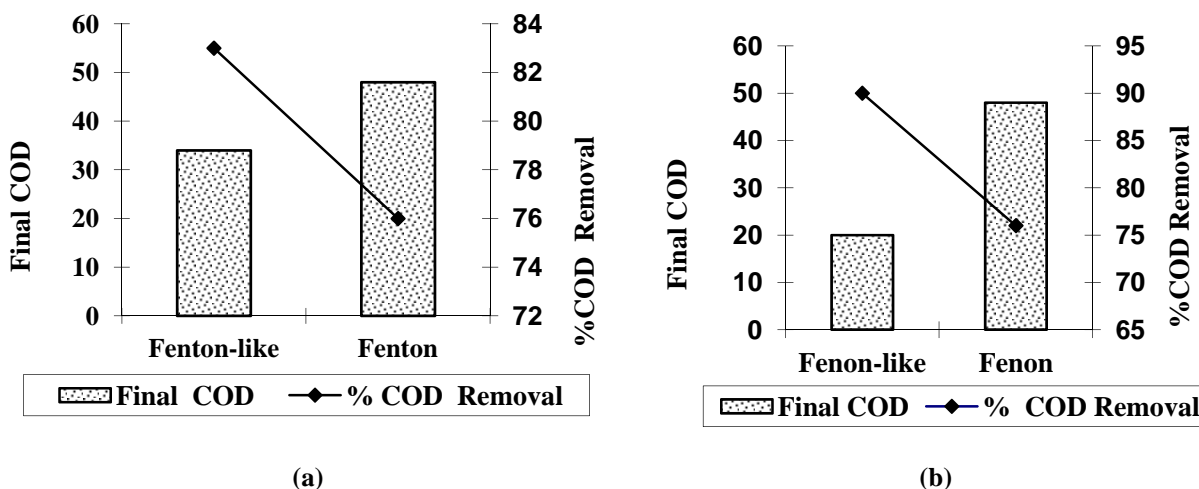
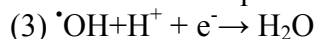


Figure 6) Comparison of “Fenton” and “Fenton-like” processes for chemical oxygen demand (COD) removal: azithromycin (a) and clarithromycin (b)

## Discussion

The pH value affects the final COD and AOPS processes are strongly affected by pH. It was observed that the minimum final COD for each antibiotic at pH 7.0 that can be compared to pH >7.0 and pH <7.0. The high removal efficiency of COD was achieved at pH 7.0 which might be due to:

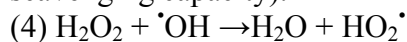
a) The generation of OH radicals according to Equations 1 and 2; b) at this pH, the amount of the dissolved Fe<sup>2+</sup> increases. At pH values higher than 7.0, the degradation strongly decreases because of: 1- iron precipitates as hydrous oxyhydroxide (Fe<sub>2</sub>O<sub>3</sub>. nH<sub>2</sub>O) 2- at alkaline solutions H<sub>2</sub>O<sub>2</sub> is unstable and decomposes to give O<sub>2</sub> and H<sub>2</sub>O. The decrease in the COD removal efficiency at pH <7 could be because of the scavenging effect of <sup>•</sup>OH by H<sup>+</sup> as shown in Equation 12 (10, 11).



Xing *et al.* for removal of the antibiotic fermentation wastewater COD used a combination of coagulation and Fenton-like processes. The pH of the wastewater entering the Fenton-like process was set to 4 and the COD removal efficiency after combined process was measured as %93.5 (12).

The degradation of antibiotics was increased by augmenting the concentration of H<sub>2</sub>O<sub>2</sub> added to optimum dosage that, and this can be due to produced <sup>•</sup>OH radicals (ferrous ions completely oxidized; consequently, the generation of hydroxyl radicals increased).

Addition of H<sub>2</sub>O<sub>2</sub> exceeding optimum dosage for Fenton and Fenton-like processes did not improve removal of COD, because H<sub>2</sub>O<sub>2</sub> acts as a scavenger of the <sup>•</sup>OH to produce the perhydroxyl radical (HO<sub>2</sub><sup>•</sup>) according to reaction 4 (H<sub>2</sub>O<sub>2</sub> itself contributes to the OH scavenging capacity).

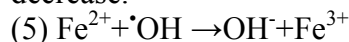


The decrease in COD removal efficiency with reduction of H<sub>2</sub>O<sub>2</sub> concentration can be explained by partial oxidation of Fe<sup>2+</sup> in H<sub>2</sub>O<sub>2</sub>

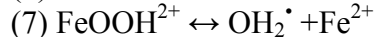
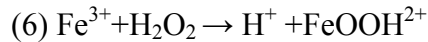
concentrations lower than optimum values (13,14). Arslan-Alaton *et al.* used Fenton-like process for removal of penicillin COD from the wastewater. The optimum H<sub>2</sub>O<sub>2</sub> amount for the COD removal was achieved at 1.5 mM (15).

As presented in figure 4, increasing the iron in its Fe<sup>2+</sup> or Fe<sup>•</sup> form has a significant effect on the removal efficiency of azithromycin or clarithromycin COD. Experiments show that in the optimum dosage of Fe<sup>2+</sup> or Fe<sup>•</sup>, final COD significantly decreases (in the other hand the removal efficiency of COD distinctly increased with higher amounts of Fe<sup>2+</sup> or Fe<sup>•</sup>).

The best result of antibiotics removal were achieved at optimum dosages of Fe<sup>•</sup> (0.36 mM/L) or Fe<sup>2+</sup> (0.42 mM/L) for azithromycin, and at optimum dosages of Fe<sup>•</sup> (0.3 mM/L) or Fe<sup>2+</sup> (0.45 mM/L). Addition of Fe<sup>•</sup> or Fe<sup>2+</sup> above mentioned optimum dosage did not affect the removal efficiency (a slight increase in removal efficiency was observed). Because in overdoses of Fe<sup>2+</sup> ions or Fe<sup>•</sup>, ferrous ions reacted with OH radicals as a scavenger as observed in reaction 5 (the formation of orange-brown iron precipitate (Fe(OH)<sub>3</sub> flocculates), consequently, the COD removal could decrease.



According to equations 6 and 7, it must be noted that the formed Fe<sup>3+</sup> again enters a reaction with hydrogen peroxide that leads to an increase in the removal efficiency (16, 17).



Fana *et al.* study used a Fenton-like process in the removal of sulfasalazine from wastewater. The amount of the iron used was 0.35 mM and a COD removal efficiency of 84.2% was achieved (18).

The experimental data were fitted by first order kinetics. Table 1 presents the Pseudo-first-order kinetic constants for the Fenton-like and Fenton processes studied and the experimental half-life time.

Major COD mineralization occurred for the Fenton-like process (each tow antibiotics) in 30 min and Fenton process (each tow antibiotics) in 60 min and Fenton-like process showed more COD mineralization rate than the Fenton process. According to table 1 Fenton-like process has significant role on mineralization of azithromycin an clarithromycin in comparison with the Fenton process (15).

Figure 6 shows comparison of Fenton-like and Fenton oxidation efficiency for removal of azithromycin or clarithromycin antibiotics from synthetic wastewater. According to Figure 6 (a) and 6 (b), Fenton-like oxidation shows the best efficiency for removal of azithromycin or clarithromycin, whereas Fenton oxidation shows a slow degradation.

At optimum reaction conditions for azithromycin or clarithromycin COD<sub>0</sub> adjusted to 200 mg/L, 83 and 76% azithromycin COD removals were achieved by Fenton-like (after 30 min) and Fenton (after 60 min), respectively, also 90 and 76% clarithromycin COD removals were achieved by Fenton-like (after 30 min) and Fenton (after 60 min), respectively.

**Conclusions:** In conclusion, COD removal rates obtained for Fenton-like process were higher than Fenton process.

## Footnotes

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None declared.

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### Conflict of Interest:

The authors declare no conflict of interest.

## References

1. Elmolla ES, Chaudhuri M. The feasibility of using combined Fenton-SBR for antibiotic wastewater treatment. *Desalination* 2012;285:14-21.
2. Kulik N, Trapido M, Goi A, Veressinita Y, Munter R. Combined chemical treatment of pharmaceutical effluents from medical ointment production. *Chemosphere* 2008;70(8):1525-31.
3. Elmolla ES, Chaudhuri M. Combined photo-Fenton-SBR process for antibiotic wastewater treatment. *J Hazard Mater* 2011;192(3):1418-26.
4. Farabi Pharmaceutical Co. Properties of Azithromycin. Available from: <http://www.Farabipharma.ir>. Accessed 6 May, 2012. (Full Text in Persian)
5. Arsene D, Musteret CP, Catrinescu C, Apopei P, Barjoveanu G, Teodosiu C. Combined oxidation and ultrafiltration processes for the removal of priority organic pollutants from wastewaters. *Environ Eng Manag J* 2011;10(12):1967-76.
6. Zaharia C, Suteu D, Muresan A, Muresan R, Popescu A. Textile wastewater treatment by homogeneous oxidation with hydrogen peroxide. *Environl Eng Manage J* 2009;8(6):1359-69.
7. Ayyasamy PM, Shunthi K, et al. Two-stage removal of nitrate from grand water using biological and chemical treatments. *J Biosci Bioeng* 2007;104(2):129-134.
8. APHA, AWWA, WPCF. Standard Methods for the Examination of Water and Wastewater. 21<sup>st</sup> ed. Washington DC: American Public Health Association; 2005.
9. Lee E, Lee H, Kim YK, Sohn K, Lee K. Hydrogen peroxide interference in chemical oxygen demand during ozone-based advanced oxidation of anaerobically digested livestock wastewater. *Int J Environ Sci Technol* 2011;8(2):381-8.
10. Hang S, Kwon B, Lee J, Kim I. Degradation of 2-chlorophenol by Fenton & Photo Fenton Processes. *Korean J Chem Eng* 2008;25(1):46-52.
11. Wang S. A comparative study of Fenton and Fenton-like reaction kinetics in decolourisation of wastewater. *Dyes Pigm* 2008;76(3):714-20.
12. Xing Z, Sun D, Yu X. Treatment of antibiotic Fermentation wastewater using the combined Polyferric Sulfate coagulation with Fenton-like oxidation. *J Environ Prog Sustain Energy* 2010;29(1):42-51.

13. Ai Z, Yang P, Lu X. Degradation of 4-chlorophenol by a microwave assisted photocatalysis method. *J Hazard Mater* 2005;124(1-3):147-52.
14. Ciner F, Akal Solmaz SK. Decolorization of reactive dye containing wastewater using fenton, fenton-like and chemical coagulation. *Proceedings of the 10<sup>th</sup> International Conference of Environmental Science and Technology 5-7 September 2007, Kos Island, Greece. Greece; 2007.*
15. Arslan-Alaton I, Gurses F. Photo-Fenton-like and photo-Fenton-like oxidation of Procaine Penicillin formulation effluent. *J Photochem Photobiol A Chem* 2004;165(1-3):165-75.
16. Elmolla ES, Chaudhuri M. Photo-Fenton treatment of antibiotic wastewater. *Nature Environ Pollut Technol* 2010;9(2):365-70.
17. Barbusinski K, Majewski J. Discoloration of azo dye Acid Red 18 by Fenton reagent in the presence of iron powder. *Polish J Environ Stud* 2003;12(2):151-55.
18. Fan X, Hao H, Shen X, Chen F, Zhang J. Removal and degradation pathway study of sulfasalazine with Fenton-like reaction. *J Hazard Mater* 2011;190(1-3):493-500.