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Photocatalytic decomposition of Metronidazolein aqueous solutions using titanium dioxide nanoparticles

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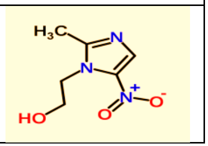
Abstract
The presence of pharmaceuticals drugs in aquatic environment is a growing environmental concern due to their drug-related adverse effects on aquatic ecosystems. In this study the effects of some operational parameters such as pH, concentration of titanium dioxide nanoparticles, exposure time and intensity of UV were evaluated using photo catalytic process by nanoparticles of titanium dioxide (TiO_2). The results showed that the removal of metronidazole and COD have a direct connection with the intensity of the UV lamp and exposure time. Metronidazole removal efficiency at each exposure time decreases with increasing pH. Moreover the results showed that at exposure times of 30 and 60 minutes the removal efficiency for COD and metronidazole were reduced by increasing TiO_2, but they were increased when exposure time was increased to 180 minutes and TiO_2 nanoparticles' concentration increased from 0.5 to 3 $g.L^{-1}$, which this could be related to the presence of more active sites on the catalyst surface and more impact of UV at higher concentrations. According to obtained results, it can be concluded that the photo catalytic process using TiO_2 nanoparticles could be an effective and promising method for treatment of aqueous solutions containing Metronidazole.

Keywords: Metronidazole, Photocatalytic decomposition, Titanium dioxide nanoparticles, COD

Introduction
Every year, about 30 to 50 new drugs are introduced in Europe and the United States [1]. Pharmaceutical compounds such as hormones, antibiotics, antidepressants, heart medicines and etc. are discharged into the sewage system through the residential areas' sewers, hospitals, and commercial areas, medical and veterinary centers [2]. Antibiotics are extensively used for treatment and prevention of diseases among humans and animals. Most antibiotics are metabolized partially in the body but 30% to 90% of them are discharged into municipal sewage system without being metabolized [3, 4]. Antibiotics are stable and lipophilic and they can keep their chemical structure for treatment aims during long times in the body and then they can create environmental pollution via human wastewater and application of related sludge in soil [5, 6]. Metronidazole is among this pharmaceutical drug which widely is used for treating infections that are being caused by anaerobic bacteria and protozoa such as giardia and trichomonas vaginalis and it is among the nitromidazole class antibiotics. Accumulation of metronidazole in body is carcinogenic and mutagenic and results in damage to DNA in human lymphocytes, which finally leads to acute toxicity in freshwater and marine organisms [7, 8]. Table 1 shows the physico-chemical properties of metronidazole. Because these compounds are strongly resistant against biological treatment methods such as activated sludge and also physical and chemical treatment methods (including activated carbon adsorption, reverse osmosis, combustion), so, the application of advanced oxidation processes (AOP) seems more suitable in comparison with other methods [9].
Today, nanoparticles are extensively used for removal of biological contaminants (such as bacteria) and chemical contaminants including organic pollutants [10]. One of the advanced oxidation methods is photocatalyze, a process which is based on the adsorption of radiation energy by nanoparticles. In this process, the nanoparticles play the role of catalyst and absorb the high-energy photons of UV spectra and

subsequently, the active chemicals such as hydroxyl radicals are formed [11, 12]. Catalysts such as SeO2, CdS, ZnS, TiO2, ZnO, WO3, SnO2, and ZrO2 have been used to photocatalytic oxidation of pollutants in water [13, 14].

Table 1: Physico-chemical properties of metronidazole

Molecular formula	**$C_6H_9N_3O_3$**
molecular weight (g/mol)	**171.2**
Solubility in water (g/l)	**9.5**
pKa	**2.55**
Melting point (°C)	**159-163**
Molecule structure	

Application of catalysts such as titanium dioxide maybe successfully used for degradation of pollutants, due to their untoxic nature and photocatalystic stability and low expenses especially when sun radiation is present [15, 16]. TiO2 is found in three crystalline phase's in nature i.e.anatase, rutile and Brookite with different structure and properties. Anatase and Rutile have photocatalistic properties but it is reported that anatase phase has higher photocatalytic activity [17, 18]. Advantages of TiO2 are including low cost and having same energy gap i.e. 3.2 eV [19-22]. Hydroxyl radical is one of the most important oxidants in the air, water and biological systems and it has a very high oxidation potential (2.8 eV) in comparison with the other antioxidant.
Hydroxyl radicals can convert organic compounds into carbon dioxide, water, inorganic ions, which are biologically degradable compounds with minimal adverse effects [23]. Those catalysts that are used in the photocatalistic process are semiconductors and unlike the metals which have continuous electronic levels, they are associated with two levels of energy: capacity layer which is placed at low energy level and conducting layer at a higher energy level. Energy difference between the conducting layer and capacity layerwhich is known as energy gap is one of the intrinsic properties of semiconductors and control thermal conductivity of semiconductors [24]. OH radical formation and decomposition of pollutants by nanoparticles of titanium dioxide is as follows:

$$\mathbf{TiO_2 + h\nu \rightarrow h{+}vb + e^{-}cb} \qquad (1)$$
$$\mathbf{H_2O + h{+}vb \rightarrow {}^{0}OH + H^{+}} \qquad (2)$$
$$\mathbf{h{+}vb{+}Pollutant(ads) \rightarrow Pollutant^{+}} \qquad (3)$$
$$\mathbf{OH + Pollutant\ (sol) \rightarrow CO_2 + H_2O} \qquad (4)$$
$$\mathbf{O2 + e^{-}cb \rightarrow O^{-2}} \qquad (5)$$

Due to the extensive usage of antibiotics and their related environmental impacts and also the adverse effects of exposure with these compounds with humans and other organisms and being high resistance against biodegradation and ineffectiveness of conventional treatment methods, so evaluation of new methods for coping these problems is considered as a necessity. In present study, removal ratio of metronidazole which has a stable and non-biodegradable structure was evaluated using advanced photocatalistic oxidation method with nanoparticles of titanium dioxide.

2. Experimental details

2.1. Chemicals and analyze method

sulfuric acid and sodium hydroxide were provided from MERCK Company (Germany) and Nano TiO_2 was Degussa P25 (Evonik, Germany). MNZ (99%, Chemical Reagent) was purchased from commercial sources. The commercial product was purchased from Guangzhou Chemical Factory (Guangdong, China). Potassium dehydrogenates phosphate (KH_2PO_4) and acetonitrile (HPLC grade) were purchased from Merck Company, Germany. Two UV radiations with intensity of 8 and 125 W/m^2 were applied for irradiation and quartz sleeve for protection of UV lamps. Also A pH meter (Metrohm 827, Swiss) with glass electrode was used for pH measurement. HPLC (Waters, USA) equipped with a UV detector at 348 nm. A Diamonsil (R) C18 column (5 lm, 250mm long_4.6mm ID) was used. Flow rate was equal to 1 ml/min.

composition of mobile phase was included acetonitrile and distilled water (30/70, v / v). Determination of COD was done using COD reactor model AR851 (HACH, USA).

2.2 Experimental procedure

Synthetic wastewater was prepared by adding 80 grams metronidazole in 1 liter of ionized distilled water. Initial COD of solution was equal to 126 mg.L^{-1} . Synthetic wastewater was poured into the designed steel reactor with a volume of 3 liters and was equipped with a quartz sleeve for protection of UV lamp. The UV lamp is located at the center (Fig. 1). To adjust temperature, the reactor was placed in water bath. The pH was adjusted to the required value by 1N H_2SO_4 or 1N NaOH. Evaluated variables were included the exposure times (30, 60, 90, 180 min), the intensity of UV radiation (8 and 125 W/m^2), pH (3, 7, 10) and nanoparticle concentration (0.5, 1.5, 3 g.L^{-1}), respectively.

All experiments were duplicated. After determining residual metronidazole and COD, regression analysis is performed. Study type in this study was factorial and initial design was full factorial. COD experiment was determined according to Standard Methods [25].

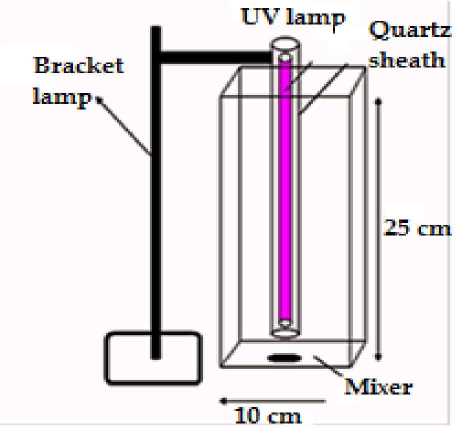


Figure 1: Photocatalytic reactor

3. Results and discussion

3.1. Evaluating the effect of UV radiation intensity and exposure time

the effect of UV radiation intensity and radiation time on the elimination of metronidazole and COD was evaluated using following items: metronidazole with initial concentration of 80 mg.L^{-1} and initial COD concentration of 126 mg.L^{-1} at 30, 60, 90 and 180 minutes together with application of two UV lamp with intensity of 8 and 125 W/m^2 and dioxide titanium nanoparticle concentration of 3 g.L^{-1} at pH 10. Effects were shown in fig. 2 and 3. As it can be seen in Figure 2, the minimum and maximum removal ratio of metronidazole by both UV lamps with intensity of 8 and 125 W/m^2 are related to exposure times of 30 and 180 minutes, respectively. The minimum and maximum removal ratio of metronidazole by UV lamp with intensity of 8 W/m^2 was equal to 18.86% and 76.19%, respectively. Also the minimum and maximum removal ratio of metronidazole by UV lamp with intensity of 125 W/m^2 was obtained equal to 47.56% and 99.55%, respectively. Therefore, over time from 30 to 180 minutes, removal efficiency is become higher about 2 to 4 times and with changing radiation intensity from 8 to 125 W/m^2, it was increased about 1.5 to 2.5 times.

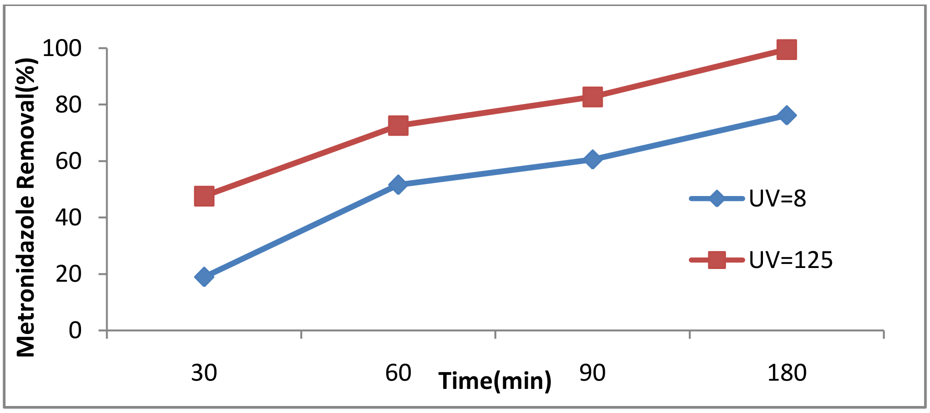


Figure 2: Effect of UV irradiation intensity and time on the removal of metronidazole

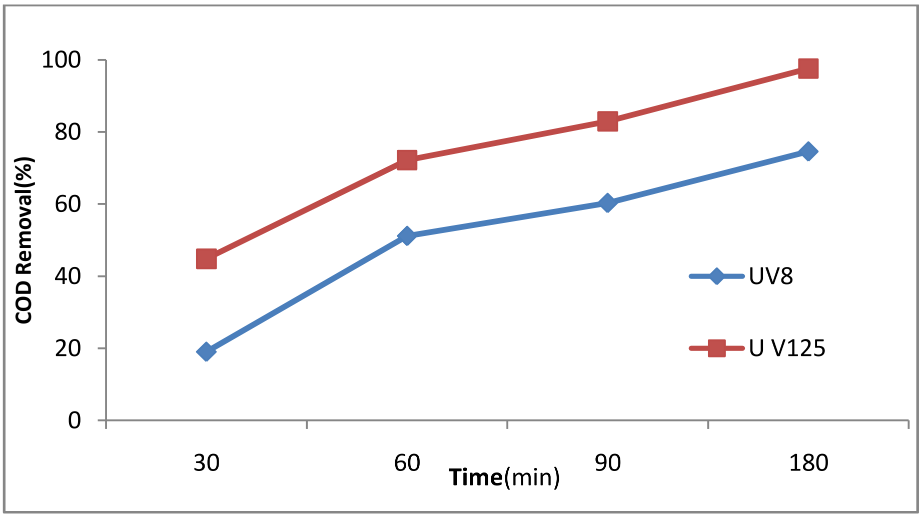


Figure 3: Effect of UV irradiation intensity and time on the removal COD

The results indicate that there is a significant relationship between UV radiation intensity and exposure time and metronidazole removal ratio and COD (P-value <0/05). According to Figures 2 and 3, metronidazole removal ratios using UV radiation with an intensity of 8 W/m2 at 30, 60, 90 and 180 minutes were obtained equal to 18.86%, 51.56 %, 60.53% and76.19 %, respectively. These percentages for UV radiation with an intensity of 125 W/m2 at 30, 60, 90 and 180 minutes were obtained equal to 47.56% , 72.61 %, 82.75% and 99.55 %, respectively. The Highest efficiency for application of UV lamp with an intensity of 8 W/m2 was 76.19 % and since the efficiency has been considered to be more than 90%, therefore the removal efficiency by using UV lamp with an intensity of 8 W/m2 is not acceptable.

As it was shown in figure 2, during application of UV lamp with an intensity of 125 W/m2, efficiency of metronidazole removal ratio was more than 70% at 60 minutes of exposure time, but this efficiency for UV lamp with an intensity of 8 W/m2 was obtained at 180 minutes. Therefore, for saving time and funding for construction of larger ponds and from economic and technical point of view, the efficiency of removal by UV radiation with an intensity of 125 W/m2 is optimal (according to figures 2 and 3). Technically, the highest efficiency for metronidazole removal ratio was related to 180 minutes (Figures 2 and 3), but depending on the desired efficiency, because the efficiency is 82.75% at 90 minutes, therefore for time and expenses saving, a exposure time of 90 minutes was considered as the optimal time . Under optimum conditions, the efficiency of metronidazole removal ratio by UV radiation intensity of 125 W/m2 and exposure time of 180 minutes was equal to 99.55% and the COD was eliminated about 97.61%. Increasing exposure time and intensity significantly increased removal efficiency, mainly due to more penetration for higher radiation intensity and break down of Metronidazole.

According to a study which was conducted in 2009 by Masumbeigi et al. [26] on the Photocatalytic degradation of methylene blue using zinc oxide nanoparticles, it was shown that color removal has a direct relationship with intensity of the radiation, so that the higher the intensity radiation, the higher efficiency of color removal ratio . These findings are consistent with Elmolla and Chaudhuri who used the process of UV / TiO2 [27] and Fenton [28] and Photocatalytic processes of ZnO / UV [29] for removal of amoxicillin, ampicillin, cloxacillin from wastewater. That study results showed that with increasing exposure time, the removal efficiency for antibiotics was increased [29].

3.2 Evaluating the effect of TiO2 concentration

the effect of TiO2 concentration on the elimination of metronidazole and COD were evaluated using following items: metronidazole with initial concentration of 80 mg.L-1 and initial COD concentration of 126 mg.L-1 and initial BOD5 was zero, exposure times of 30, 60, 90 and 180 minutes together with application of UV lamp with intensity of 125 W/m2 and dioxide titanium nanoparticle concentrations of 0.5, 1.5 and 3 g.L-1 at pH 10. All effects were shown in fig. 4 to 5. The minimum removal ratio of metronidazole is related to exposure time of 30 minutes which was obtained equal to 47.56% and the maximum removal ratio of metronidazole is related to exposure time of 180 minutes which was equal to 99.55%.

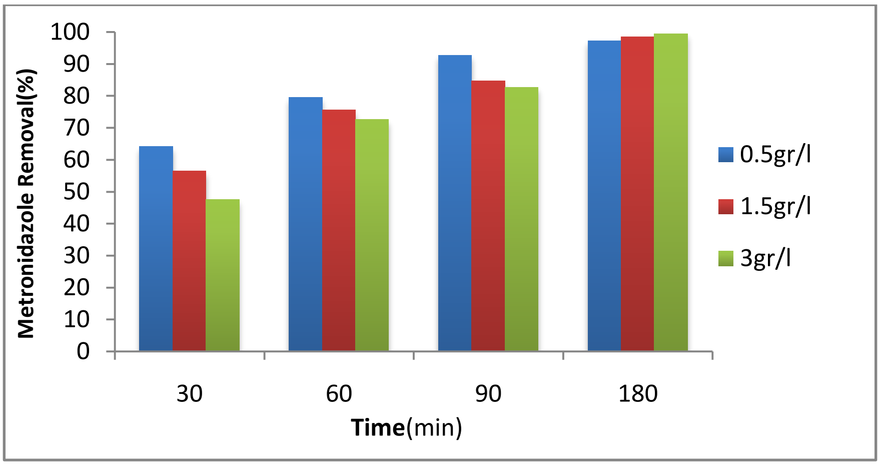


Figure 4: Effect of TiO2 concentration on the removal efficiency of metronidazole

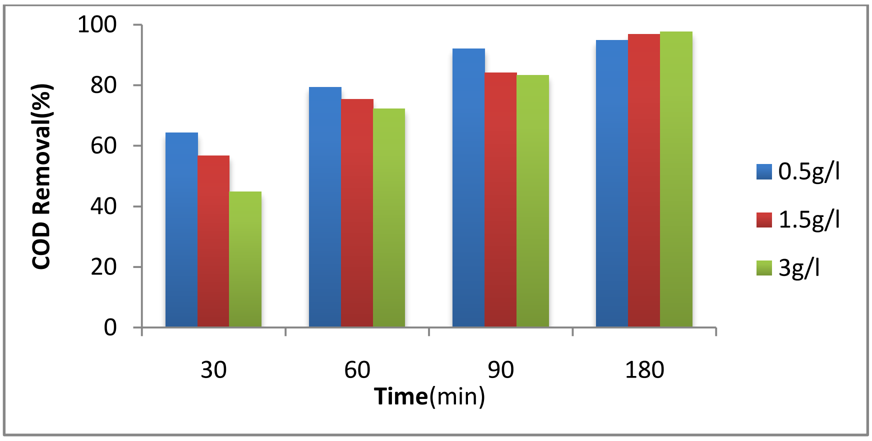


Figure 5: Effect of TiO2 concentration on COD removal

The removal efficiency was evaluated where initial metronidazole concentration was 80 mg.L-1 , initial COD concentration was 126 mg.L-1 and dioxide titanium nanoparticle concentrations was 0.5, 1.5 and 3 g.L-1 at pH 10. According to ANOVA test results, concentration changes in selected range were not statistically effective on the elimination of metronidazole (p> 0/05). Figures 4 and 5 show that at exposure times of 30 and 60 minutes, removal efficiency was less than 80% which is not acceptable. But at exposure times of 90 and 180 minutes, removal efficiency is more than 80%, so that related values at 90 minutes of exposure time using dioxide titanium nanoparticle concentrations of 0.5, 1.5 and 3 g.L-1 were equal to 92.78%, 84.7% and 82.75%, respectively at exposure time of 180 minutes they were equal to 97.28%, 98.58% and 99.55%, respectively. Technically, concentration of 3g.L-1 at 180 minutes and COD removal efficiencies of 99.55% and 97.61% constitute the optimal conditions. The reason for this improvement may be related to more active sites on catalyst surface and higher effect of UV radiation at higher concentrations [11, 12]. These findings are consistent with Masumbeigi et al. [26] about the removal of color, So that related results of that study showed that increasing the nanoparticle concentration increased the efficiency of color removal.

Due to lower consumption of nanoparticles and saving time and reducing costs of investment, the removal efficiency is optimum at 90 minutes exposure time and nanoparticle concentrations of 0.5 g.L-1 .At 90 minutes exposure time, as it is shown in figures 4 and 5, removal efficiency has been reduced due to an increase in concentration. This may be related to higher turbidity, which is due to nanoparticle concentration increase and consequently reduction of the UV penetration power. These findings are consistent with Elmolla and Chaudhuri [29].

3.3 pH effect

the effect of pH on the elimination of metronidazoleand COD were evaluated using following items: metronidazole with initial concentration of 80 mg.L-1 and initial COD concentration of 126 mg.L-1 and initial BOD5 was zero, exposure times of 30, 60, 90 and 180 minutes together with application of UV lamp with intensity of 125 W/m2 and dioxide titanium nanoparticle concentrations of 3 g.L-1 at pH values equal to 3, 7 and 10. All effects were shown in fig. 6 and 7. According to figure 6 the minimum removal ratio of metronidazole is related to exposure time of 30 minutes which was obtained equal to 47.56% and the maximum removal ratio of metronidazole is related to exposure time of 180 minutes which was equal to 99.55%.

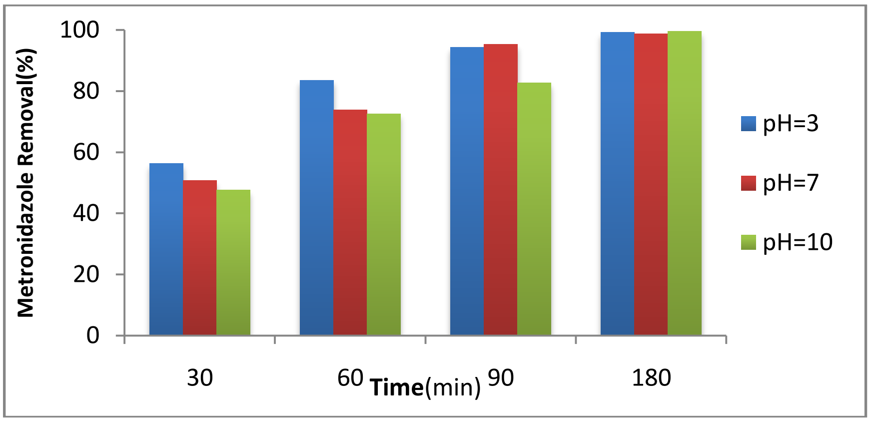


Figure 6: Effect of pH on the removal of metronidazole

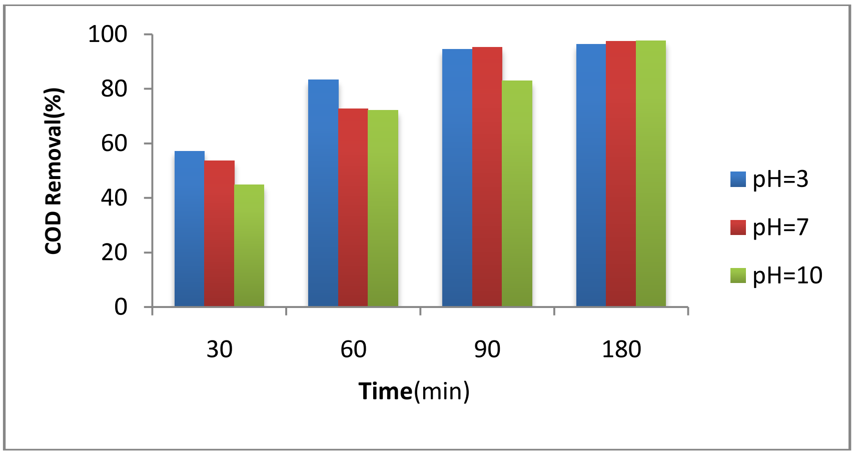


Figure 7: Effect of pH on COD removal

The removal efficiency at 180 minutes of exposure time was evaluated where initial metronidazole concentration was 80 $mg.L^{-1}$, initial COD concentration was 126 mg.L-1 and pH values were equal to 3, 7 and 10. According to results, differences of removal efficiency and reduction for COD at different PH values were not statistically significant (P-value> 0/05).

According to Figures 6 and 7 show that at exposure times of 30 and 60 minutes, removal efficiency for metronidazole and COD were at their highest level, so that related values for 30 minutes at pH 3, 7 and 10 were equal to 56.28%, 50.7% and 47.56%, respectively. These values for 60 minutes exposure time were equal to 83.54%, 73.85% and 72.61%, respectively. This indicates that hydrolysis of antibiotics at exposure times of 30 and 60 minutes were higher in acidic pH conditions. Depending on industrial kind of project and treatment plants, it may be possible to remove metronidazole about 50 to 70 percent and rest of operation would be performed in biological treatment. Technically, COD and metronidazole removal efficiency is optimal at pH 10 and 180 minutes of exposure time. Related removal values are 99.55% and 97.61 % respectively (Figure 6 and 7). Because at pH 7 and 90 minutes exposure time, metronidazole and COD efficiency ratio is higher than 90%, so, to saving acid and alkaline consumption for pH adjustment and less time, economically pH 7 and exposure time equal to 90 minutes may be considered as optimum condition. The reason of removal efficiency (which is changing with pH swings) may be attributed to surface charge of catalyst and antibiotics [27]. Since the dominant functional groups of titanium dioxide in water i.e. TiOH2+ are more than TiOH and TiO- and the isoelectric level of TiO2 in water is occurred at pH 6 , so , at lower pH levels, it is expected that surface charge be positive and at higher pH levels, surface charge be negative. Therefore, in weak neutral and alkaline conditions, TiO- is dominant species of TiO2 in water and the antibiotic remains in molecular form. As a

result, antibiotics and TiO- are bonded by a hydrogen bond and this increases the absorption of antibiotics. In alkaline conditions, TiO2 has a negative surface charge, whereas metronidazole might be positive which this leads to simple adsorption [30].
These findings are consistent with Elamolla and Chaudhuri [27] who used UV/TiO2 process for removal of amoxicillin, ampicillin and cloxacillin from wastewater. Also these results are consistent with Devipriya and Yesodharan (2010) who used TiO2 and ZnO for phenol removal. The study showed that degradation by TiO2 is effective at pH 4 to 10, complete degradation was occurred at pH 10 [30].
Elimination of metronidazole and COD is directly related to radiation intensity and exposure time and changes of pH and nanoparticle concentration on the removal efficiency of metronidazole and COD are not statistically significant.

3.4. Real wastewater

Real wastewater samples were taken from Faghihi hospital and the concentration of metronidazole in wastewater was measured. Metronidazole was not detected in wastewater. For this reason 80mg/l metronidazole was added to the real wastewater sample. Based on the actual results of wastewater, COD value was reported equal to 900 mg.L^{-1}.
Before attempting to use any of the advanced oxidation process, suspended COD was should be separated by centrifuge or filter paper Whatman. Efficiency removal ratio for metronidazole in the photocatalytic reactor at optimum conditions was obtained equal to 58.32% in following conditions: exposure time of 180 minutes, radiation intensity of 125 W / m^2, pH 10, and the concentration of TiO_2 nanoparticle was 3g.L^{-1} and efficiency removal ratio for COD by UV/TiO_2 process was equal to 34.32%.

Conclusion

Over the past few years, antibiotics such as metronidazole have been concerned because of their constant and sustainable entrance into aquatic ecosystems. Over the years, various methods of removal for metronidazole for prevention of their entrance into aquatic ecosystems were evaluated. In this study, the application of photo catalytic process using nanoparticles of TiO_2 and effect of some factors such as pH, intensity of UV, exposure time and concentration of TiO_2 were investigated on removal of COD and metronidazole. The results showed that removal efficiency for COD and metronidazole is increased as with UV light intensity and exposure time increases, So that the maximum removal efficiency was related to pH =10 and exposure time equal to 180 minutes , UV intensity of 125 w/m2 and TiO_2 concentration of 3 g.L-1. The results showed that the removal rate of COD and metronidazole were decreased by increasing TiO_2 concentration at exposure times of 30, 60 and 90 minutes. This decrease can be attributed to increased turbidity caused by the increasing concentration of TiO_2 nanoparticles, while removal rate of COD and metronidazole were increased with exposure time of 180 minutes and increasing concentrations of TiO_2 which is due to the presence of active sites on the catalyst surface. According to the results of statistical analysis (One way ANOVA), the changes of TiO_2 concentration and pH on the removal efficiency of metronidazole and COD ratio is not significant ($P> 0.05$). Results on real wastewater (containing metronidazole 80 mg/L and COD equal to 900 mg/L) showed that metronidazole and COD removal efficiency at optimal condition through photo catalytic process using TiO_2 nanoparticles were obtained equal to 58.32% and 34.32 %, respectively.

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