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Decontamination of Alachlor by Continuously Dosed Sono-Fenton Process: Effects of System Parameters and Kinetics Study

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Abstract: This present work reports a continuous dosing sono-Fenton process that can degrade alachlor and reduce its toxicity. Experimental results indicate that lower pH levels were favorable in enhancing alachlor decontamination; the maximum efficiency was as high as 100% at a pH of 3. The decontamination efficiency of alachlor increased as the Fe^{2+} and H_2O_2 dosages increased; the best result was found at 30 mg/L of Fe^{2+} and 120 mg/L of H_2O_2. The sono-Fenton process was more efficient for alachlor decontamination than either a Fenton process or ultrasound alone, which indicated that combining the ultrasound and Fenton process enhanced the decontamination of alachlor. The toxicity, which was defined by cell viability, decreased after the sono-Fenton process treatment. In conclusion, the continuous sono-Fenton process can effectively decontaminate alachlor with an extremely short reaction time, and the treated wastewater could be passed through a biological treatment unit for further treatment.

Key words: alachlor; cell viability; continuous dosing; decontamination; sono-Fenton process.

1. Introduction

The daily requirement for significant amounts of food due to the increase in the world's population is becoming an important issue because of the excessive amounts of different pesticides that are used to protect the growth of vegetables, fruits and crops from the harmful blight effect in agriculture. Alachlor (2-chloro-2',6'-diethyl-N-methoxymethylacetanilide), which has been commercially used since 1969 [1, 2], is a member of the chloroacetanilide family of herbicides and is used for agricultural and non-agricultural purposes in Taiwan to inhibit the growth of herbaceous plants and weeds in fields growing cotton, brassica, maize, rapeseed, peanuts, radishes, soy beans and sugar cane. The United States Environmental Protection Agency (USEPA) reports that alachlor is the most widespread herbicide used in the USA, Europe and Japan. In France, 1,442 tons of alachlor per year is used for 763,000 hectares of agricultural lands [3]. This herbicide has been proven to be a carcinogen by the USEPA (Group B2), and harmful effects are possible when humans are exposed to levels above the maximum contaminant level (MCL, 0.2 μg/L) of alachlor, such as slight skin, eye irritation and potential damage to the liver, kidneys and spleen. In Europe, the MCL of alachlor in drinking water is only 0.1 μg/L [4]. Improperly treated, alachlor-contaminated wastewater will lead to health risks for humans and the environment. Many ultrasonic technologies, including ultrasound/H_2O_2 [2, 5], hydrodynamic cavitation [6] and the ultrasound/Fenton process [7], and other technologies, such as photo-Fenton [8], visible light/Fe-TiO_2/H_2O_2

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[4], gamma radiolysis [9] and O_3/H_2O_2 [10], have been used to degrade alachlor.

It is well known that the sono-Fenton oxidation involves two mechanisms, i.e., pyrolysis in ultrasonic collapsing bubbles and oxidation of •OH radicals, that degrade organic compounds [11]. Equation 1 shows the well-known Fenton reaction. The generated Fe^{3+} will react with H_2O_2 and produce $Fe\text{-}OOH^{2+}$ (Eq. 2) to reduce the production of •OH [12]. The ultrasonic wave can spontaneously decompose $Fe\text{-}OOH^{2+}$ to Fe^{2+} and •OOH (Eq. 3), and the isolated Fe^{2+} can react with H_2O_2 to produce more •OH [13]. Therefore, the combination of ultrasound and Fenton's reagent (namely, the sono-Fenton process) can be described by Eq. (4).

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

$$Fe^{3+} + H_2O_2 \rightarrow Fe\text{-}OOH^{2+} + H^+ \quad (2)$$

$$Fe\text{-}OOH^{2+} +))) \rightarrow Fe^{2+} + \bullet OOH \text{ (fast)} \quad (3)$$

$$Fe^{2+} + H_2O_2 +))) \rightarrow Fe^{3+} + \bullet OH + OH^- \quad (4)$$

Many researchers have attempted to use the sono-Fenton process to degrade refractory compounds [14-17] and decolorize dyed wastewater [12, 18-20] and have reported satisfactory results. However, those studies were conducted using a batch method, and most of them were performed in small reactors (0.1-0.3 L). Similar results from these studies have shown that additional amounts of H_2O_2 and Fe^{2+} dosed into the treatment pathway did not increase the degradation of pollutants. This finding indicates that the optimal dosages of H_2O_2 and Fe^{2+} in the sono-Fenton system require investigation to reduce operation costs and achieve better treatment efficiency. Therefore, a continuous dosing sono-Fenton system was designed to degrade alachlor wastewater in this study. The objectives were to investigate the effects of different reaction conditions on the degradation of alachlor and to measure the toxicity profiles by counting cells before and after the sono-Fenton treatment.

2. Materials and Methods

2.1 Standards and Reagents

Analytical grade alachlor (99.8%) was purchased from Sigma-Aldrich. Other chemical reagents used in this study were H_2SO_4 (> 97%), NaOH (> 97%), $FeSO_4 \cdot 7H_2O$ (> 99.5%) and an aqueous solution of the purest grade hydrogen peroxide (H_2O_2, 30%, w/w in water) that is commercially available, which was used without further purification. During the analytical process, potassium hydrogen phthalate ($C_8H_5KO_4$) (KHP) and n-hexane (C_6H_{14}) were used as standard chemicals to determine the total organic carbon (TOC) concentration and isolate alachlor from the aqueous solution via a liquid-liquid extraction procedure.

More problematic is the fact that each gallon of gas burned to power these vehicles releases 55 pounds of carbon into the air, which, when combined with oxygen, creates 20 pounds of carbon dioxide contributing to global warming.

2.2 Experimental Apparatus and Design

A schematic drawing of the reactor has been proposed by Ma and Sung [21], and a sonicator (Microson VCX 750, USA, 0-750 W) operated at 20 kHz was used in this study, where the output energy of the sonicator was maintained at 100 W. Oxidation of alachlor by a continuous mode sono-Fenton process was first performed in a cylindrical reactor (working volume of 1 L with a cooling jacket and a circulating temperature controller to maintain the reaction temperature) to determine the degradation kinetics at various pH values (3-9), H_2O_2 dosages (60-240 mg/L), Fe^{2+} dosages (5-30 mg/L), temperatures (15-50°C) and in the presence of various anions (SO_4^{2-}, NO_3^-, CO_3^{2-}, CH_3COO^-, SO_3^{2-} and Cl^-). The degradation of 1,000 mL of aqueous alachlor (initial concentration of 50 mg/L, i.e., 1.85×10^{-4} M) was conducted in the reactor, and the reaction pH was adjusted using 0.1 N H_2SO_4 and 0.1 N NaOH. The concentration of every anion was 50 mg/L. The reagents of H_2O_2 and Fe^{2+}

were pre-adjusted at desired concentrations and dosages in the reactor by individual micro-pumps with flow rates of 0.5 mL/min (the total added volume of H_2O_2 and Fe^{2+} for a 60-min reaction was 60 mL); hence, as 60 mg/L H_2O_2 was dosed into the solution within 60 min, the dosing rate of H_2O_2 was determined to be 1 mg/min. Aeration of the reactor during the reaction was maintained at 0.2 L/min to provide a sufficient amount of dissolved oxygen. The reactor was equipped with an oxidation-reduction potential (ORP) and pH meters (Suntex PC-3200, Taiwan). Prior to the experiment, the ORP meter was checked with an ORP standard solution of 220 mV.

2.3 Analytical Methods

Alachlor contamination was determined using a gas chromatography/flame ionization detector (GC/FID-Varian GC 3400, Mulgarve, Victoria, Australia) equipped with a DB-1 column (30 m×0.53 mm, i.d. of 1.50 μm). Before the GC/FID analysis, each 10-mL alachlor sample was shaken and extracted with 1 mL of n-hexane for 30 min at a mixing speed of 150 rpm. After the extraction procedure, 1 μL of the upper solvent layer was collected and injected into the GC/FID in splitless mode. The GC oven temperature was programmed to increase from 50°C (holding time 10 min) to 250°C (holding time 3 min) at a rate of 10°C/min. The injector and detector temperatures were 200 and 290°C, respectively. Nitrogen gas was used as a carrier gas (15 mL/min); hydrogen gas (33 mL/min) and air (400 mL/min) were used for the GC/FID. Prior to sample analysis, a calibration curve was plotted using known concentrations of alachlor (between 0 and 50 mg/L) and an area response with an R^2 value of 0.995; the method detection limit (MDL) of alachlor was 0.003 mg/L for seven measurement trials. The hydrogen peroxide concentration was measured using titration with KI. The mineralization of alachlor was investigated by determining the total organic carbon (TOC) using a total organic carbon analyser (TOC-500, Shimadzu, Japan); the MDL of the TOC was 0.04 mg/L.

The toxicity of the alachlor samples (before and after treatments) was determined by assessing the cell viability, where the viability was defined by cell counting. The steps for cell counting are described next. The water samples were first sterilized by filtration through a 0.25-μm Millipore membrane filter (Millipore, Bedford, USA). The rat liver cell line, Clone-9, was maintained in Dulbecco's modified Eagle's medium (DMEM) supplemented with 10% (v/v) foetal bovine serum, 100 U/mL penicillin and 100 μg/mL streptomycin at 37°C in a humidified incubator under 5% CO_2. Confluent cultures were passaged by trypsinization. The cells were washed twice with warm DMEM (without phenol red) and then treated in a serum-free medium. In all experiments, cells were treated with alachlor water samples for 24 hours before and after the sono-Fenton-like treatment. Cell viability was determined using a blue formazan assay, in which colourless 3-(4,5-dimethyl-thiazol-2-yl)-2,5-diphenyl tetrazolium bromide (MTT) is metabolised to a blue product by mitochondrial dehydrogenases. Absorbance was recorded at 540 nm using a SpectraMAX 340 reader. The data are expressed as the mean percent of viable cells compared with that of the control.

3. Results and Discussion

3.1 Effect of pH

To understand the effect of pH on the degradation and mineralization of alachlor wastewater, the reaction temperature, Fe^{2+} dosage and H_2O_2 dosage were controlled at 25°C, 5 mg/L and 2 mg/min, respectively, and the results are shown in Fig. 1a. As shown, the degradation and mineralization efficiencies of alachlor at a pH of 3 after 60 min reaction were 43.8% and 14.9%, respectively, which were higher than at other pH levels. As the initial pH increased to 9, the degradation and mineralization efficiencies of alachlor decreased to 20.3% and 6.2%, respectively. This result is comparable with other studies in which lower pH levels increased the degradation of organic compounds by the sono-Fenton process or other AOPs [6, 8, 16, 22]. Although pH did not have any direct effect on the cavitational intensity in terms of the number of cavitation events or the pressure/temperature generated due to cavity collapse, Chakinala et al. proposed that a lower pH helps to increase the concentration of the hydrophobic compounds at the bubble interface, which leads to exposure of a higher quantum of compounds to the cavitation conditions [23]. Thus, higher rates of oxidation of compounds are expected at lower operating pH values.

Fig. 1b shows the profiles of the ORP values during the reaction at different pH levels. At a pH of 3, the maximum ORP value was 592 mV, which occurred at a reaction time of 10 min and was much higher than the data observed for other pH levels. Higher ORP values indicate a higher oxidation potential for the oxidation system; thus, the optimal degradation and mineralization efficiencies of alachlor occurred at a pH of 3. Katsumata et al. [8] and Bagal and Gogate [7] found that the differences in organic compound degradation were insignificant when the pH levels were higher than 6 or 7. At pH values between 5 and 8, a greater number of hydroxyl radicals recombine to form H_2O_2, which decreases the number of hydroxyl radicals available for the desired degradation reaction. This study also found that the degradations of alachlor at a pH of 5 and 7 were both approximately 30%, which was similar to the results found in literature.

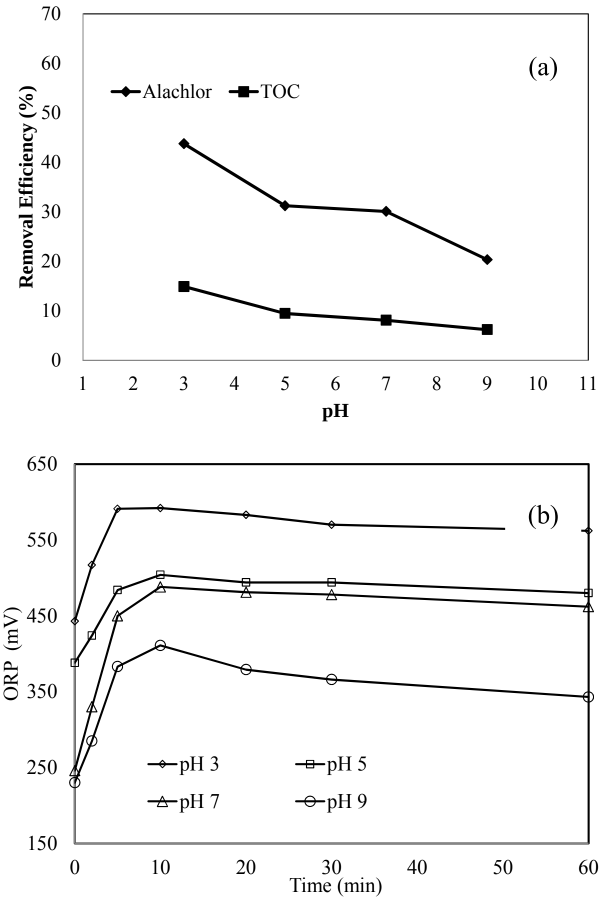

Fig. 1 (a) Degradation and Mineralization of Alachlor and (b) Profiles of ORP Values for the Sono-Fenton Process at Different Initial pH Values.

3.2 Effect of H_2O_2 Addition

The addition of H_2O_2 in ultrasound, Fenton or sono-Fenton processes increases the •OH in the aqueous system, which thus enhances the degradation of organic pollutants. Sun et al. [12] used the sono-Fenton process to decolorize Acid black 1 (AB1)-dyed wastewater and found that the decolourization efficiency within a reaction time of 10 min increased from 67% to 92.4% when the H_2O_2 dosages increased from 0.5 to 8.0 mM. As the H_2O_2 dosage increased to 32.0 mM, decolourization of AB1 slightly decreased, which could be the result of •OH self-competition during the oxidation reaction (including the recombination of two •OH to form H_2O_2). Babuponnusami and Muthukumar [24] used the Fenton, sono-Fenton and sono-photo-Fenton processes to degrade phenol under different H_2O_2 concentrations (between 500 to 1,000 mg/L) and found that increasing the H_2O_2 concentration increased the degradation of phenol and that the optimal H_2O_2 concentration was 700 mg/L for the sono-photo-Fenton process, in which the degradation and mineralization efficiencies of phenol were 84.2% and 76.6%, respectively. This result indicated that the application of UV radiation increased the formation of

•OH in the solution; thus, the amount of H_2O_2 could be decreased. In addition, if the H_2O_2 concentration was greater than 700 mg/L, the degradation efficiency of phenol decreased.

In this study, the degradation of alachlor by individual ultrasound was only 7% (data not shown) after 60 min and increased to 28.9% by adding Fe^{2+} in the ultrasonic process (without H_2O_2 addition). It was clear that the degradation of alachlor increased to more than 92.8% when the H_2O_2 dosages were between 1 and 3 mg/min (Fig. 2). The addition of H_2O_2 resulted in sufficient •OH production. However, as the H_2O_2 dosage increased to 4 mg/min, the degradation of alachlor decreased to 81.7%, which is comparable to other studies. As the individual Fenton reaction proceeded, degradations of alachlor were 44% and 71%, respectively, whereas the additions of Fe^{2+} were 5 mg/L and 20 mg/L with an H_2O_2 addition of 2 mg/min. Therefore, comparing the results of alachlor degradation between the individual ultrasound, Fenton and sono-Fenton process, it was found that the sono-Fenton process can effectively increase the degradation efficiency of alachlor. The removal rates of TOC were in contrast with those from alachlor degradation. As the H_2O_2 dosages increased from 0 to 2 mg/min, the removal of TOC increased from 21.1% to 46.8%. Increases in the H_2O_2 dosage were ineffective for enhancing TOC removal; when the H_2O_2 dosages were 3 and 4 mg/min, the TOC removal decreased to 28.9% and 27.9%, respectively, which are lower than the removal at an H_2O_2 dosage of 2 mg/min.

As shown in Fig. 3, when the H_2O_2 dosage was 1 mg/min, only 65% of the alachlor degraded in the first 2 min, though eventually increased to 92.8%, which indicated that the addition of H_2O_2 was insufficient to produce •OH at the beginning of the sono-Fenton oxidation and that continuous dosing of H_2O_2 was required to produce •OH. When the H_2O_2 dosages were 2 and 3 mg/min, the majority of alachlor degradation occurred in the first 2 min of the reaction (approximately 93% to 95% of the final degradation); the degradation that occurred after 2 min was insignificant. This result indicated that these H_2O_2 dosages should be suitable for the degradation of alachlor because alachlor was effectively degraded under these conditions. When the H_2O_2 dosage was 4 mg/min, degradation of alachlor was lower than that at H_2O_2 dosages of 2 and 3 mg/min, which could be explained by the scavenging action of H_2O_2 on the hydroxyl radicals [23]. However, comparing the results from the degradation and mineralization of alachlor and the economic considerations of different H_2O_2 dosages, 2 mg/min of H_2O_2 should be considered as the optimal choice.

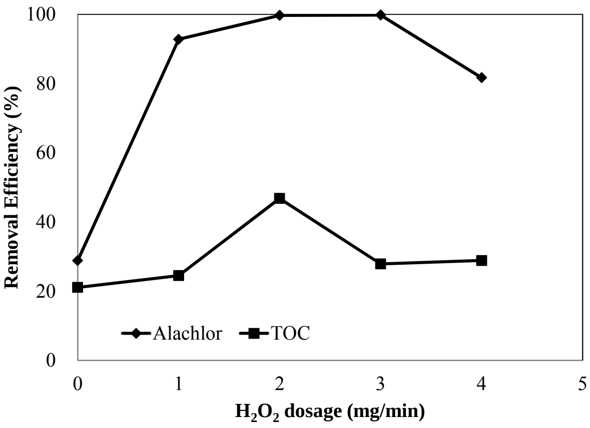

Fig. 2 Degradation and Mineralization of Alachlor by the Sono-Fenton Process at Different H_2O_2 Dosages.

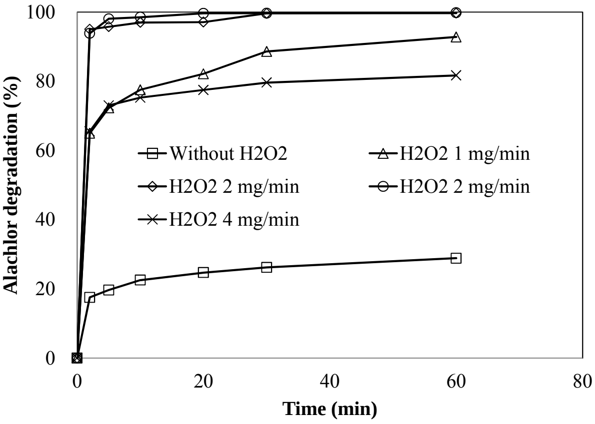

Fig. 3 Profiles of Alachlor Degradation by the Sono-Fenton Process at Different H_2O_2 Dosages.

3.3 Effect of Fe^{2+} Addition

Fig. 4 shows the results of alachlor degradation and mineralization by the sono-Fenton process at different Fe^{2+} dosages at a pH of 3 with 2 mg/min H_2O_2. It was found that the degradation and mineralization efficiencies of alachlor increased with an increase in Fe^{2+} dosages; when the Fe^{2+} dosage was greater than 20 mg/L, the degradation efficiency reached almost 100% after 60 min. The mineralization of alachlor also increased with increasing Fe^{2+} dosages but slightly decreased when the Fe^{2+} dosage was 30 mg/L. Many studies have shown that increases in Fe^{2+}/Fe^{3+} and H_2O_2 in an ultrasonic system provide a higher oxidation capacity and enhance the degradation efficiency of 2-chlorophenol (2-CP), its intermediate [25], 2,4-dinitrophenol [26] and AB1 dye [12] or dye reactive brilliant red [19]. The increase in organic pollutant degradation by increasing the amount of iron salts in the sono-Fenton system proved that the $Fe\text{-}OOH^{2+}$ formed during the Fenton process easily decomposed to Fe^{2+} and •OOH (Eq. 3) by ultrasonic irradiation and that cycling the Fenton process (Eq. 1) enhanced the treatment efficiency, which could be due to a synergistic effect from the ultrasound and Fenton processes. However, the excessive addition of iron salts will decrease the treatment efficiency because •OH will be reduced by Fe^{2+} [20, 27, 28], which decreases the efficiency of organic compound degradation. Therefore, reasonably high iron dosages will only be beneficial under certain conditions.

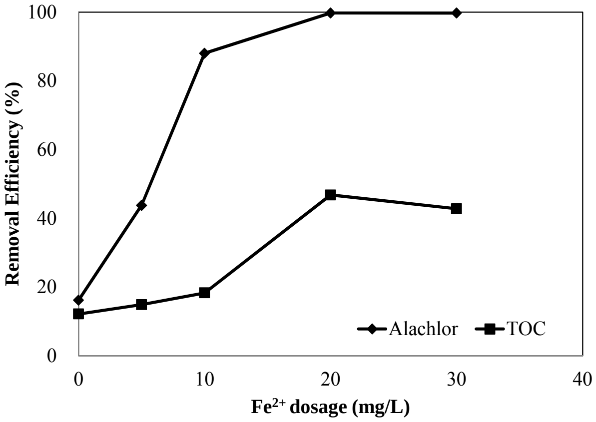

Fig. 4 Degradation and mineralization of alachlor by the sono-Fenton process at different Fe^{2+} dosages.

3.3 Effect of Temperature

The reaction temperature, which affects the reaction rates and operation costs, is a key parameter in organic pollutant treatment by AOPs. Gogate et al. [29] proposed that the liquid temperature affects the intensity of collapse, rate of the reaction, threshold/nucleation and almost all physical properties. In an ultrasonic oxidation system, much heat is produced, and most researchers must use a water bath or a water jacket reactor to maintain a constant temperature and avoid generating high temperatures during the solution phase [30-32]. Grčić et al. [33] also noted that the increase in solution temperature was 3°C/min in small reactors (100 mL) or 1.0-1.5°C/min in large reactors (500 mL). This temperature increase is beneficial for increasing the production of cavitation bubbles in ultrasonic systems such that the thermal cleavage of organic compounds is more effective. However, extremely high temperatures lead to negative effects, such as the sedimentation of Fe^{2+} and self-decomposition of H_2O_2, which lower the reaction rate or degradation efficiency of the oxidation process [34, 35].

Fig. 5 shows the results of alachlor degradation and mineralization by the sono-Fenton process at temperatures of 15 to 50°C; the data indicate that the degradation and mineralization efficiencies of alachlor at 15°C were lower than at other temperatures and that 20°C was the optimal choice for this system. In addition, the degradation efficiencies of alachlor were between 92.4 and 99.7% when the reaction temperatures were between 20 and 40°C, and the differences among these temperatures was insignificant. Psillakis et al. [36], Ma [17] and Golash and Gogate [22] all showed that although the higher reaction temperatures were useful for forming more cavitation bubbles to degrade organic pollutants, the temperature increase also led to the collapse of bubbles;

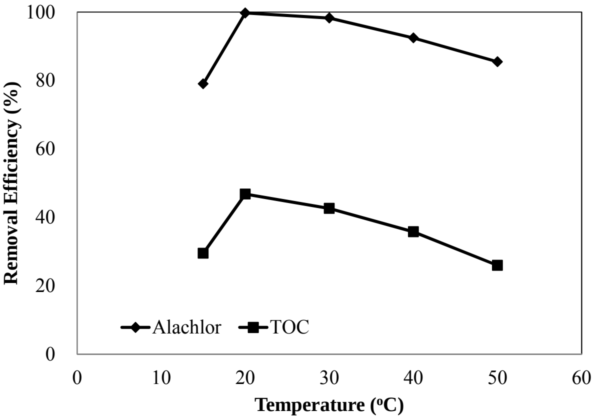

Fig. 5 Degradation and mineralization of alachlor by the sono-Fenton process at different temperatures.

thus, the increase in temperature would decrease the degradation efficiency for organic pollutants.

3.5 Effect of the Addition of Anions

The effect of anions on the degradation of organic pollutants has been investigated in several studies. Son et al. [14] used ultrasound coupled with Fe^0, Fe^{2+} and $S_2O_8^{2-}$ to degrade 1,4-dioxane and reported that HCO_3^- competed with 1,4-dioxane for the available free radicals in the interfacial and bulk regions and decreased the decomposition efficiency of 1,4-dioxane. In addition, the effects of various inorganic anions exhibited the following order: $SO_3^{2-} > CH_3COO^- > Cl^- > CO_3^{2-} > HCO_3^- > SO_4^{2-} > NO_3^-$, which indicated that SO_3^{2-} resulted in a dramatic inhibition of the degradation of pollutants. The effect of various inorganic anions can be explained by the chemical reactions described by Eq. (5) to Eq. (11).

$$SO_3^{2-} + H_2O_2 \rightarrow SO_4^{2-} + H_2O \quad (5)$$

$$SO_3^{2-} + \cdot OH \rightarrow \cdot SO_3^- + OH^- \quad (6)$$

$$CH_3COO^- + \cdot OH \rightarrow CH_3COO\cdot + OH^- \quad (7)$$

$$Cl^- + \cdot OH \rightarrow \cdot ClOH^- \quad (8)$$

$$ClOH^- + Fe^{2+} \rightarrow Cl^- + OH^- + Fe^{3+} \quad (9)$$

$$CO_3^{2-} + \cdot OH \rightarrow \cdot CO_3^{2-} + OH^- \quad (10)$$

$$SO_4^{2-} + \cdot OH \rightarrow \cdot SO_4^{2-} + OH^- \quad (11)$$

Bhatkhande et al. [37] summarized the effect of four anions on the degradation of organic compounds and reported the following order: $SO_4^{2-} < HCO_3^- < NO_3^- < Cl^-$. In this study, six anions, SO_3^{2-}, CH_3COO^-, Cl^-, CO_3^{2-}, SO_4^{2-} and NO_3^-, were added to the solution to investigate the effect of anions on the degradation of alachlor by the sono-Fenton process. Figure 6 shows that the presence of CO_3^{2-} significantly decreases the alachlor degradation efficiency to 14.9%. This finding is comparable to previous studies [10, 38, 39] and can be explained by Eq. (10), i.e., CO_3^{2-} rapidly reacts with •OH to directly reduce •OH production such that the inhibition of alachlor degradation is significant. The effect of various inorganic anions in this study exhibited the following order: $CO_3^{2-} > NO_3^- > CH_3COO^- > Cl^- > SO_3^{2-} > SO_4^{2-}$, which is slightly different from that reported by Sun et al. [12] but comparable to that from Bhatkhande et al. [37] because of the different oxidants used in their system.

Sun et al. [12] proposed that SO_3^{2-} either reacted with H_2O_2 to decrease the formation of •OH or reduce •OH directly, as described by Eq. (5) and Eq. (6), such that the SO_3^{2-} had a drastic inhibition on the degradation of dye. In this study, the H_2O_2 dosage was placed into the reactor drop by drop such that the H_2O_2 easily reacted with Fe^{2+} to produce •OH; thus, the effect of Eq. (10) might be ignored. Additionally, this study used $FeSO_4$ to prepare the Fe^{2+} in the sono-Fenton system, which indicated that the anion, SO_4^{2-}, was always present in the water sample, which might be the reason that the effect of adding more SO_3^{2-} and SO_4^{2-} on the inhibition of alachlor degradation was lower than that with other anions.

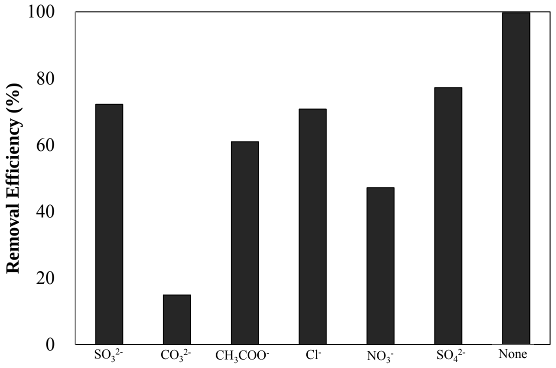

Fig. 6 Effect of anion addition on the degradation of alachlor in the sono-Fenton process.

3.6 Toxicity

For alachlor-contaminated wastewater treatment by AOPs, the changes in toxicity must be investigated in addition to the degradation efficiencies. Several tools, such as the average oxidation state (AOS), carbon oxidation state (COS) and the ratio of biochemical oxygen demand/chemical oxygen demand (BOD_5/COD), have been proven to be suitable indicators for evaluating the biodegradability of wastewater pretreated by AOPs [17, 40, 41]. In this study, cell viability was used evaluate the changes in the toxicity of wastewater.

Fig. 7a shows the results of cell viability for the blank (RO water), untreated alachlor wastewater and treated wastewater after 30 min and 60 min. The sono-Fenton process was conducted at a pH of 3, a Fe^{2+} dosage of 20 mg/L, an H_2O_2 flow rate of 2 mg/min and at 20°C. It was found that the sono-Fenton process increased cell viability as the treatment time increased. After a 60-min treatment, the cell viability increased from 78% to 100% (based on the blank test).

As shown in Fig. 3, almost 95% of the alachlor was degraded within 2 min, which indicated that the toxicity caused by alachlor should be significantly decreased within an extremely short time. However, the increase in cell viability occurred with 30 min of treatment, which was related to the removal of TOC, and is shown in Fig. 7b. In this figure, a linear relationship was observed, and the increase in cell viability clearly resulted from the removal of TOC, which indicates that the mineralization of alachlor was the key reaction for toxicity reduction. Therefore, based on the results shown in Fig. 7, after the toxicity of alachlor wastewater is reduced or the biodegradability is enhanced by the Sono-Fenton process, this wastewater can be further treated with biological methods and can be considered “green technology”.

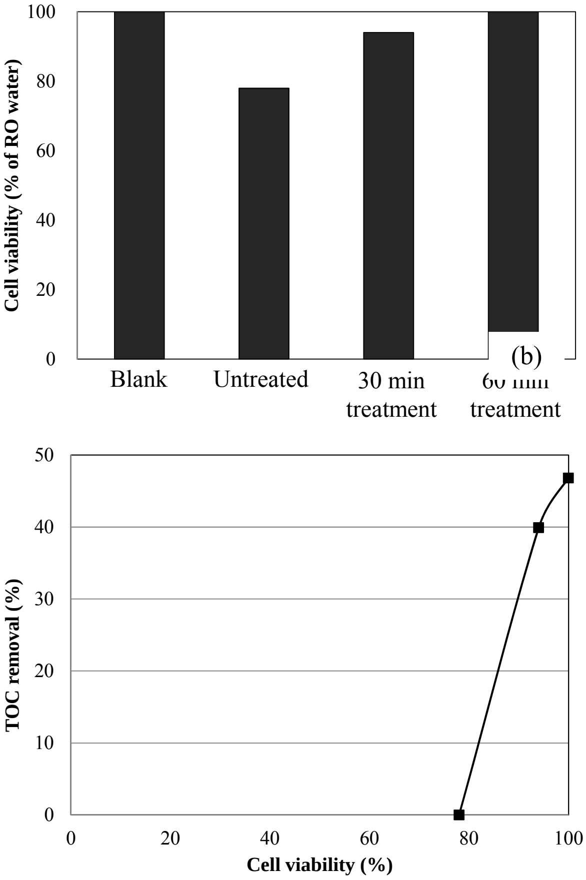

Fig. 7 (a) Enhancement of cell viability and (b) relationship between TOC removal and cell viability of alachlor wastewater treated by the sono-Fenton process.

4. Conclusion

This study investigated the application of a continuous dosing sono-Fenton process to treat alachlor wastewater and discussed the effects of the reaction parameters. In the sono-Fenton system, a lower pH level and reasonable Fe^{2+} and H_2O_2 dosages and reaction temperatures were optimal to obtain satisfactory levels of alachlor degradation and mineralization. Additional Fe^{2+} and H_2O_2 dosages served as a scavenger for •OH radicals, which lead to lower degradation efficiencies of alachlor. When anions were present in the solution, CO_3^{2-} significantly repressed the degradation of alachlor, as did NO_3^- and other anions to a lesser extent. Cell viability was used to examine the toxicity profiles of alachlor wastewater before and after sono-Fenton treatment. The experimental results certified that the sono-Fenton process could reduce the toxicity of alachlor wastewater and can also be used as a pre-treatment method prior to biological treatment.

Acknowledgement

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