Removal of antimony and aniline from wastewater by PMS combined with electrocoagulation

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Abstract

Antimony (Sb) and aniline are typical pollutants in printing and dyeing wastewater. This study explored the simultaneous removal of Sb and aniline by peroxymonosulfate (PMS) combined with electrofloculation (EC) and the removal mechanisms were systematically studied. The effects of PMS concentration, NaCl concentration, and initial pH on the removal efficiency were investigated. Under the optimal condition (anode: iron plate, cathode: aluminum plate, current density: 20 A/m², PMS concentration: 2.5 mM, NaCl concentration: 0.1 mol/L, and initial pH: 8), Sb and aniline could be removed entirely after 20 min of reaction. The results showed that PMS facilitated the formation of iron flocs, improving the Sb removal efficiency, and electrical activation of PMS was conducive to the removal of aniline. In addition, electron paramagnetic resonance (EPR) analysis and quenching experiments confirmed that $^1\text{O}_2$ contributed most to the degradation of aniline, followed by •OH and $\text{SO}_4^{\cdot -}$. This study demonstrated that the EC/PMS system could remove heavy metals and organic matter simultaneously, and the system can be extended to treating similar printing and dyeing wastewater.

Introduction

Chinese textile output is the largest in the world, a huge amount of wastewater is discharged into the natural environment [1], resulting in substantial environmental pollution. Sb is widely used as a dyeing agent in the textile processing of polyester bers [2] and mainly exists in Sb(Ⅲ) in comprehensive printing and dyeing wastewater [3]. At the same time, using dyes and additives in the printing and dyeing process leads to a high concentration of organic compounds in wastewater. Aniline is usually produced by the biochemical treatment of dyeing wastewater containing benzidine azo dyes [4]. The US Environmental Protection Agency has listed Sb and aniline as priority pollutants and their permissible concentration is 0.1 mg/L and 1.0 mg/L, respectively, in the latest revision of emission standards for the textile industry. To effectively control and remove these toxic pollutants, various water treatment technologies have been developed, including adsorption, oxidation, and membrane treatment [5]. Compared with physical treatments, chemical methods to remove pollutants are more widely used because they are more effective for synthetic dyes. However, their applications are restricted by the high operation cost, risk of secondary pollution, and unsatisfactory treatment effect. With the development of electric power industry, electrofloculation (EC) treatment technology has emerged owing to the advantages of simple structure, small area, and flexible operation. Verma et al [6] used an electrocoagulation process based on Fe-Al composite electrodes to treat different types of textile wastewater. It is reported that this method is more suitable for wastewater containing heavy metals, but its effect on removing organic compounds needs to be improved.

Advanced oxidation processes (AOPs) based on sulfate radicals ($\text{SO}_4^{\cdot -}$) have received increasing attention, $\text{SO}_4^{\cdot -}$ compared with hydroxyl radical (•OH), has a higher redox potential (2.5–3.1 V versus standard hydrogen electrode, depending on pH) and a longer half-life (30–40 µs), which can degrade organic pollutants more efficiently [7]. In addition, $\text{SO}_4^{\cdot -}$ shows a preference for electron transfer...
reactions and higher reactivity to certain functional groups, such as carboxylic acids, anilines, and phenols. Peroxymonosulfate (PMS) activation is the main approach to produce SO$_4^{\cdot-}$. Traditional methods to activate PMS include metal ion activation, ultraviolet radiation, alkali, and thermal activation. However, these methods have some disadvantages, such as high energy consumption and secondary pollution caused by metal ion leaching. To activate PMS by electrochemical method and combine EC and AOPs, PMS could be added to the EC reactor. In this study, electrical activation of PMS was employed owing to its low energy consumption and environmental friendliness.

Although EC and AOPs are effective ways to remove Sb and aniline from water systems, respectively [8, 9], no comparative study has been carried out on the simultaneous removal of Sb and aniline by PMS combined with electrocoagulation so far. Therefore, this study investigated the simultaneous removal efficiency of Sb and aniline by PMS combined with EC, the removal mechanisms were systematically studied. Considering this method can simultaneously remove heavy metals and organic matter, it shows great potential for the practical treatment of printing and dyeing wastewater.

**Experimental**

**Chemicals**

PMS (available as Oxone (2KHSO$_5$·KHSO$_4$·K$_2$SO$_4$,%)), sodium chloride (NaCl, 99%), aniline (C$_6$H$_7$N, 99%), potassium pyroantimonate (K$_2$H$_2$Sb$_2$O$_7$·4H$_2$O, 95%), methanol (MeOH, 99.5%), tert-butyl alcohol (TBA, 99%), L-histidine (C$_6$H$_9$N$_3$O$_2$, 99%), sulfuric acid (H$_2$SO$_4$, >98%), and sodium hydroxide (NaOH, >98%) were purchased from Shanghai Macklin Biochemical Co., Ltd. The chemicals used in the experiments were of analytical grade. Sulfuric acid (H$_2$SO$_4$, >98%) and sodium hydroxide (NaOH, >98%) were used to adjust the pH of the solution before the reaction. Ultrapure water was used throughout the study.

**Electro flocculation apparatus and experiments**

As shown in Fig. S1, the EC device consists of a power supply, a plate, and an electrolytic cell. The programmable power supply (DAHUA Electronics, Beijing) had a voltage regulating range of 0–35 V. Conventional iron and aluminum plates (150 mm × 90 mm × 4 mm) were used as the anode and cathode, respectively. The effective reaction area was 50 cm$^2$. The electrolytic cell was customized by plexiglass, with a volume of 1 L and a dimension of 200 mm × 100 mm × 70 mm. The bottom of the electrolytic cell had two rows of card slots to fix the plate.

Sb( ) (1 mg/L) and aniline (50 mg/L) stock solutions were added to the electrolytic bath and completely mixed. The initial pH of the solution was regulated using dilute H$_2$SO$_4$(50 mM) and NaOH (50 mM) solutions. A certain amount of NaCl and PMS was added, and the experiments were started by electrification. Samples were taken at predesigned time intervals and filtered through a 0.22 µm membrane. Different concentrations of quenching agents were used to determine the free radicals involved in the reaction; for example, methanol (MeOH, 0.2 mol/L) was employed to inhibit •OH and SO$_4^{\cdot-}$
and tert-butyl alcohol (TBA, 0.2 mol/L) was added to suppress •OH [11]. L-Histidine (L-H, 0.6 mol/L) was added to suppress singlet oxygen (1O2). All experiments were performed in triplicate at ambient temperature.

Characterizations

The morphology of the flocs was observed by scanning electron microscopy (SEM, Zeiss Sigma 300). X-ray diffraction (XRD, PANalytical X’Pert’3 Powder) was used to analyze the phase and structure of the flocs. The concentration of Sb was detected using an inductively coupled plasma quantometer (ICP, Perkin Elmer, USA). The aniline concentration was measured by high-performance liquid chromatography (HPLC, Aglient-1260, USA) with a ZORBAX C18 chromatographic column and DAD detector. The intermediates during the degradation of aniline were qualitatively analyzed by HPLC (UPLC, Aglient-1290, USA) with a triple tandem quadrupole mass spectrometer (MS, Aglient-qtof6550, USA). The PMS concentration was determined using spectrophotometry based on a modified iodometric method. The active species were examined by electron paramagnetic resonance (EPR) using a Bruker spectrometer (Bruker EMX PLUS, Germany). 5,5-dimethylpyrroline N-oxide (DMPO) and 2,2,6,6-tetramethylpiperidine (TEMP) were used as spin-trapping agents for •OH, SO4•− and 1O2, respectively. Total organic carbon (TOC) was determined on a Total Organic Carbon Analyzer (Shimadzu, TOC-L CPH).

Results and discussion

Removal efficiency of Sb and aniline

The removal efficiency of Sb (1 mg/L) and aniline (50 mg/L) using different systems, i.e., PMS alone, EC alone, and EC/PMS was studied.

The kinetic parameters of the reaction process were determined, which were consistent with first-order reaction kinetics, and the mathematical expression of the reaction kinetics was shown in Eq. (1), [12]

\[
\frac{1}{[C]_t} = \frac{1}{[C]_0} + K_{obs}t
\]

Where, [C]0 is the concentration of aniline at time t = 0; [C]t is the concentration of aniline at time “t”; t is time in minutes; Kobs is the rate constant.

It was observed from Fig. 1a and Fig. 1b, PMS could effectively remove aniline but not Sb. However, there was almost no degradation of aniline under EC alone. The removal rates of Sb and aniline were significantly improved using EC/PMS, wherein Sb was completely removed at 15 min, and the removal rate of aniline reached approximately 90% at 30 min. Compared with only PMS, removal rates of aniline were increased by 30%. For Sb, the reaction rate constants (Kobs) for PMS and EC are 9.99×10−4 min−1 and 0.05 min−1, respectively. In contrast, the Kobs of EC/PMS reached 0.31 min−1, about 6 times higher than that of EC alone. The results showed that EC played an important role in removing Sb and the
removal rate was accelerated by the addition of PMS. The removal rate of aniline was only 50% when PMS was used alone, and almost no aniline was removed when EC was used alone. When PMS is combined with EC, the removal rate of aniline could reach approximately 90%, indicating EC could effectively activate PMS and for aniline removal. In summary, when combining PMS with EC, a synergistic effect occurred to significantly increase the removal rates of Sb and aniline.

At the same time, the decompositions of PMS with or without electrical activation were also compared (Fig. 2). When PMS was used alone, the PMS decomposed slowly with 80% degradation within 30 min. In contrast, in the EC/PMS system, the decomposition of the PMS was accelerated, and all PMS were broken down in 10 min, suggesting electrical activation could accelerate PMS decomposition. In the EC/PMS system, the removal efficiency of aniline was high when the decomposition rate of PMS was fast in the first 10 min but decreased when the decomposition of PMS was complete after 10 min. Moreover, when PMS was used alone, the decomposition rate of PMS was similar to that of aniline, indicating that PMS played a significant role in the aniline removal process, and the electrical activation of PMS was conducive to the removal of aniline.

**Effects of PMS dosage**

The effect of PMS dosage on the removal of Sb and aniline was studied by increasing the amount of PMS from 0.5 mM to 2.5 mM under the initial pH = 5 and NaCl = 0.1 mol/L. According to Fig. 3a, the Sb removal efficiency increased with an increase in PMS dosage. Adding PMS could promote the conversion of Fe\(^{2+}\) produced at the iron anode to Fe\(^{3+}\), thus accelerating the production of flocs, promoting the flocculation and precipitation of pollutants, and improving the Sb removal rate. However, when the dosage of PMS increased from 1.0 to 2.0 and 2.5 mM, the removal rate was reduced, indicating that excessive PMS restricted the removal of Sb.

It was speculated that the Sb removal process of the EC/PMS system might be divided into two stages. Under the action of an external power supply, the electrolytic iron anode produced Fe\(^{2+}\). At the same time, electrolytic water generated H\(_2\), and Fe\(^{3+}\) and Sb(\(\text{V}\)) were reduced to Fe\(^{2+}\) and Sb(III) at the cathode, respectively. In the first stage, most Fe\(^{2+}\) reacted with PMS to form •OH and SO\(_4^{2-}\)\(^{2-}\), whereas a small amount of Fe\(^{2+}\) reacted with Sb(\(\text{V}\)) to form Sb(III). In the second stage, with the decrease in PMS concentration in the solution, the Fe\(^{2+}\) produced in the system was mainly used to remove Sb(\(\text{V}\)) \([10, 13]\). Therefore, when the PMS concentration was low, increasing the PMS dosage could improve the Sb removal rate. In contrast, when the dosage of PMS was excessive, Fe\(^{2+}\) was first consumed to activate PMS, resulting in a decrease in the removal rate of Sb.

The obtained results are given in Fig. 3b, the removal rate of aniline was improved by increasing the PMS concentration. When the dosage of PMS increased from 0.0 to 2.5 mM, the removal rate of aniline was increased from 3–100%. The results indicated that increasing the concentration of active substances in the solution promoted the degradation of aniline. Increasing the concentration of PMS accelerated the mass transfer of PMS from the bulk solution to the electrode surface, which was conducive to the
electrochemical activation of PMS, resulting in the generation of more active species to oxidize organic matter [14]. Although increasing the dosage of PMS could improve the removal rate of aniline, the dosage of PMS was set at 2.0 mM for the following study, considering chemical consumption and treatment efficiency.

**Effects of NaCl dosage**

The effect of NaCl on the removal of Sb and aniline was studied by increasing the amount of NaCl from 0.00 to 0.20 mol/L under the PMS = 2.00 mM and initial pH = 5. As represented in Fig. 3c and Fig. 3d, when the NaCl concentration was low, the removal efficiency of Sb and aniline increased with increasing NaCl dosage. When the NaCl was 0.10 mol/L, the removal efficiency of Sb and aniline was the highest, i.e., the removal rate of Sb reached 100% at 10 min and the removal rate of aniline reached approximately 90% at 30 min. The Sb and aniline removal efficiencies were not further improved when the NaCl concentration increased from 0.10 to 0.15, and 0.20 mol/L. Therefore, we determined that the optimal concentration of NaCl was 0.10 mol/L.

According to previous literature [15], when the conductivity of a solution was low, an additional electrolyte was required to improve the conductivity and maintain the current efficiency, but the energy consumption was increased. In addition, when the applied voltage was too high, rapid polarization and passivation of the plate might reduce the treatment efficiency and increase the operating cost of EC. Adding NaCl could improve the conductivity of the solution. At the same time, an oxide film was easily formed on the anode surface during the EC process, which hindered further dissolution of the anode. When NaCl was added to the solution, owing to the intense penetration of Cl\(^-\), the passivation film formed on the anode surface during the electrolytic process could be destroyed, and the blocking effect of the passivation film on the plate dissolution was alleviated. Therefore, Cl\(^-\) activated the anode, which indirectly improved the treatment efficiency of Sb and aniline in the EC/PMS system.

**Effects of initial pH**

Due to pH plays a vital role in controlling the corrosion of iron and the formation and activity of free radicals, the effect of the initial pH on the removal of Sb and aniline was investigated by changing the initial pH in the EC/PMS system from 3 to 11 under the PMS = 2.0 mM and NaCl = 0.1 mol/L.

Figure 3e shows the removal rate of Sb gradually increased as the initial pH value increased from 3 to 7. When the initial pH value was 7, the Sb removal rate reached 100% in 10 min. Then, the removal rate gradually decreased as the initial pH value increased to 11. This was because the removal of Sb from wastewater by EC was related to the forms of Sb in aqueous solutions and their zeta potential under different pH values [16, 17]. When the solution was acidic or neutral, Sb (V) mainly existed as negatively charged Sb(OH)\(_6\)^-. At this time, the EC product with a positive charge could absorb the negatively charged Sb(OH)\(_6\)^-, and the removal rate of Sb gradually increased. When the solution was basic, Sb(V) mainly existed in the form of negatively charged ions. The floc surface generated by the EC reaction was also
negatively charged. The repulsion between the floc surface and the Sb anion led to a decrease in the Sb removal efficiency. Therefore, an increase in pH became unfavorable for Sb removal.

The aniline removal rate increased from 85–95% as the initial pH value increased from 3 to 7 with the results shown in Fig. 3f. When the initial pH value was 7, the aniline removal rate reached 95% in 30 min. Subsequently, the aniline removal rate gradually decreased as the initial pH value further increased to 11. According to Ao et al., acid catalysis could produce additional free radicals under acidic conditions, which were conducive to the degradation of aniline. Under alkaline conditions, when hydroxyl and sulfate radicals coexisted, the reaction between them might inhibit aniline degradation [18]. Considering the maximum removal of Sb and degradation of aniline, the optimal pH for the EC/PMS system was 7.

**Identification of involved reactive species**

As mentioned in Section 3.1, the decomposition rate of PMS was similar to that of aniline. Our preliminary inference is that the electrical activation of PMS was conducive to the decomposition of PMS to produce active substances, thus promoting the degradation of aniline.

To investigate the aniline removal mechanism in the EC/PMS system, EPR analysis was performed using DMPO as a collector [19]. A typical quartet spectrum of DMPO-•OH (1:2:2:1) was observed in 3 min, and DMPO-SO$_4$$^{•−}$ (1:1:1:1:1) was also observed, confirming the presence of •OH and SO$_4$$^{•−}$ (Fig. 4a). Moreover, the signal of •OH was significantly stronger than that of SO$_4$$^{•−}$, indicating that •OH played a more important role in the EC/PMS system. Figure 4b shows DMPO-•OH was observed in 5 min, but DMPO-SO$_4$$^{•−}$ was not detected. This was because nucleophilic substitution resulted in the rapid conversion of DMPO-SO$_4$$^{•−}$ to DMPO-•OH [20, 21]. However, after 20 min of the experiment, DMPO-•OH and DMPO-SO$_4$$^{•−}$ signals could not be detected (Fig. 4c), indicating that •OH and SO$_4$$^{•−}$ were no longer present in the reaction.

As a $^{1}$O$_2$ trapping agent, TEMPO could react with $^{1}$O$_2$ to generate spin adducts, which could be detected by EPR. The results are given in Fig. 4d, TEMP-$^{1}$O$_2$ (1:1:1) showed distinct $^{1}$O$_2$ signals [22], confirming $^{1}$O$_2$ might play a leading role in the reaction process. $^{1}$O$_2$ is a unique non-free radical oxygen derivative [23] and is considered the most potent reactive oxygen species (ROS) [24]. Importantly, $^{1}$O$_2$ is highly selective for oxidizing electron-rich pollutants, such as pharmaceuticals, unsaturated biomolecules, and aromatic organic compounds [25]. Mi et al. found that the $^{1}$O$_2$ produced by oxidation of PMS effectively degraded several organic pollutants over a wide pH range [26].

Electrically activated PMS decomposed to produce active substances, such as •OH and SO$_4$$^{•−}$ (Eq. (2)). In the EC/PMS system, EC effectively activated PMS and promoted the formation of free radicals, contributing to the removal of aniline.

$$Fe^{2+} + PMS + H_2O \rightarrow Fe^{3+} + •OH + SO_4^{•−}$$
To further verify the effect of EC/PMS on aniline degradation, quenching experiments were carried out. MeOH is a very effective quenching agent for •OH and SO$_4^{2-}$. Its second-order reaction rate constants with •OH and SO$_4^{2-}$ are $9.7 \times 10^8$ M$^{-1}$s$^{-1}$ and $2.5 \times 10^7$ M$^{-1}$s$^{-1}$ [10], respectively. TBA has a high quenching effect on •OH with a second-order reaction rate constant of $6.0 \times 10^8$ M$^{-1}$s$^{-1}$, but a poor quenching effect on SO$_4^{2-}$ with a second-order reaction rate constant of $8.0 \times 10^5$ M$^{-1}$s$^{-1}$ [11]. Based on these properties, MeOH and TBA were added to the EC/PMS system to determine the main active substances [27]. Figure 5 depicts that, adding MeOH and TBA inhibited aniline removal, suggesting that •OH and SO$_4^{2-}$ both played essential roles in the removal of aniline and •OH was the primary active radical in the synergistic process. In addition, 65% of aniline was still removed after MeOH was added, indicating that non-free radical oxidation, such as direct anodic oxidation of non-free radicals and the $^{1}$O$_2$ pathway, could occur during the reaction.

Active species are other than •OH and SO$_4^{2-}$ might be produced by the electrochemical activation of PMS. According to previous reports, $^{1}$O$_2$ was produced by activating PMS, and electrochemical activation could prompt $^{1}$O$_2$ production [28]. To verify the role of $^{1}$O$_2$ in the reaction, L-H was selected as the quenching agent of $^{1}$O$_2$ to carry out the quenching experiment, and the results are shown in Fig. 5. After L-H was added, the aniline removal efficiency decreased to approximately 53%, suggesting that $^{1}$O$_2$ was the main contributor to aniline degradation in the EC/PMS system, followed by •OH and SO$_4^{2-}$.

According to the quenching and EPR experiment results, free radical oxidation and non-free radical oxidation pathways [29] were proposed in the EC/PMS system. Both •OH and SO$_4^{2-}$ played essential roles in the radical oxidation process, and •OH was the prominent active radical in the synergistic process. And $^{1}$O$_2$ was mainly involved in the non-free radical oxidation process.

**Possible pathway of aniline in the EC/PMS system**

A possible route for aniline degradation is inferred in Fig. S2. Hydroxylation and oxidation of aniline groups are the two main possible degradation pathways. Combined with the mechanism reported in a previous study [30], hydroxylation occurred on the benzene ring of aniline, which was vulnerable to attack. It was reported that aniline groups could be oxidized repeatedly to form nitrobenzene groups [31]. EC activated PMS to generate •OH, SO$_4^{2-}$ and $^{1}$O$_2$, degraded aniline to produce intermediates, such as nimbidiol, nitrobenzene, phenyl succinic acid, o-aminophenol, and 4-hydroxydiphenylamine were identified by LC-MS and confirmed to be present. Then, the benzene rings of these intermediates were cracked under the action of •OH and degraded to small molecular organic matters and finally to CO$_2$ and H$_2$O.

**Possible mechanism of Sb removal in the EC/PMS system**
Sb removal in the EC/PMS system was probably due to the adsorption of the \( \text{Fe(OH)}_3 \) colloid. Environmental SEM and energy dispersive X-Ray analyzer (EDX) were used to study the surface morphology and elemental composition of the EC products based on Fe-Al composite electrodes. Figure 6a and Fig. 6b represent the apparent morphology of the product after 5 min of wastewater treatment using EC technology based on the Fe-Al composite electrode, and Fig. 6c and Fig. 6d show the apparent morphology of the product after 30 min of wastewater treatment. SEM images represent that the EC products had a fishbone structure at 5 min and a large irregular structure at 30 min. Sb was transferred from the solution to the floc (Fig. S3), indicating that the floc could adsorb Sb and contribute to Sb removal during the sedimentation process.

According to previous studies, heavy metal was mainly removed through iron oxide adsorption or co-precipitation [16]. XRD was used to further characterize the flocs generated by the reaction. As represented in Fig. S4, the EC products exhibited the phase characteristics of \( \text{Al(OH)}_3 \), \( \text{Fe(OH)}_3 \), and \( \text{Fe}_3\text{O}_4 \), confirming that the phase composition of the EC product was Fe/Al oxide. Some of the ferric hydroxide produced by the EC reaction might be converted to ferric oxide, with abundant adsorption and co-precipitation sites.

**Conclusion**

This study investigated the simultaneous removal of aniline and Sb from wastewater by PMS combined with EC. The removal process of aniline requires the participation of oxidizing active species and the removal mechanism of Sb depends on the adsorption of flocs. Under these circumstances, the removal rate of aniline was not significant and it was not helpful to remove Sb when PMS was used alone, and there was almost no degradation of aniline and a low removal rate of Sb under EC alone. However, the EC/PMS system could remove Sb and aniline simultaneously and significantly increase their reaction rates. By investigating the effect of PMS and NaCl dosage and initial pH in the EC/PMS system, it is concluded that increasing the concentration of PMS can promote the conversion of \( \text{Fe}^{2+} \) to \( \text{Fe}^{3+} \), thus accelerating the formation of floc. SEM and XRD analyses showed that Sb in wastewater was removed by the adsorption and precipitation of flocs. EPR analysis confirmed that •OH, \( \text{SO}_4^{2-} \) and \( ^1\text{O}_2 \) were present in the EC/PMS system. The quenching experiment further showed that both free and non-free radicals contributed to aniline degradation in varying degrees. Based on the results of this research, it can be inferred that the EC/PMS system is a wastewater treatment system with a small area, simple operation and remarkable removal efficiency. This study provides a theoretical basis for the simultaneous removal of organic matter and heavy metals.

**Declarations**

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**Conflicts of interest** There are no conflicts of interest to be declared.

**Authors' contributions** Wenjie Dong: Conceptualization, Investigation, Writing-review & editing; Yu Shu: Data curation, Methodology, Writing-original draft; Ao Cai: Investigation, Resources, Writing-review & editing; Yuehong Huang: Investigation, Resources; Beimeng Qi: Investigation, Resources; Jingrao Zhao: Investigation, Resources; Hailu Fu: Project administration, Supervision.

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**References**


Figures
Figure 1

Removal rate of (a) Sb and (b) aniline by PMS, EC and PMS Conditions: [PMS]=2mM, [NaCl]=0.09mol/L, and [pH]=8

Figure 2

Decompositions of PMS with or without electrical activation. Conditions: [PMS]=2mM, [NaCl]=0.09mol/L, and [pH]=8
Figure 3

Removal of (a) Sb and (b) aniline by EC/PMS under different concentrations of PMS. Conditions: [NaCl]=0.1mol/L, and [pH]=5. Removal of (c) Sb and (d) aniline by EC/PMS under different concentrations of NaCl. Conditions: [PMS]=2mM, and [pH]=5. Removal of (e) Sb and (f) aniline by EC/PMS under different pH values. Conditions: [PMS]=2mM, and [NaCl]=0.1mol/L
Figure 4

EPR spectra obtained using (a), (b) and (c) DMPO as spin-trapping agent, and (d) TEMP as spin-trapping agent

Figure 5

Removal of aniline by EC/PMS under different scavengers. Conditions: \([\text{PMS}]=2\text{mM}, [\text{NaCl}]=0.09\text{mol/L},\) and \([\text{pH}]=8\)
Figure 6

SEM images of the flocs after wastewater treatment using EC/PMS (a and b) after 5 min, and (c and d) after 30 min

Supplementary Files

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