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Degradation of atrazine by a novel Fenton-like process and assessment the influence on the treated soil

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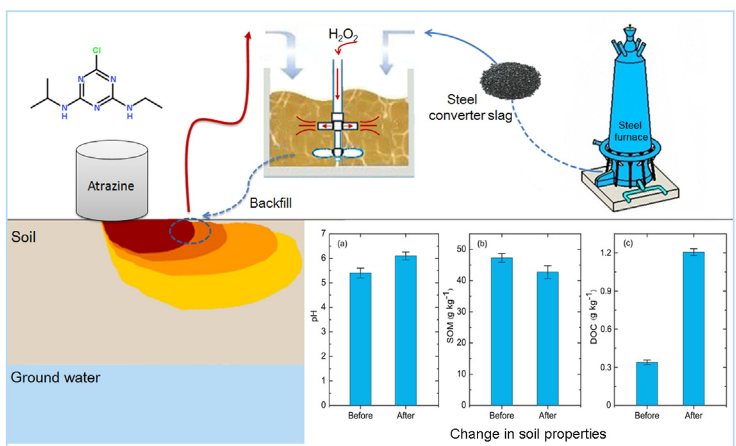
HIGHLIGHTS

- The optimal steel converter slag load was determined as 80 g kg^{-1}.
- High initial H_2O_2 concentrations caused a sharp increase in soil temperature.
- 93.7% of atrazine in the soil was degraded with a 3-time addition of 10% H_2O_2.
- Steel converter slag catalyzed Fenton-like oxidation slightly increased soil pH.
- A considerable amount of dissolved organic carbon released during the treatment.

GRAPHICAL ABSTRACT



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ABSTRACT

This is the premier study reporting the remediation of atrazine contaminated soil with steel converter slag (SCS) catalyzed Fenton-like process. The effects of various operating parameters, such as SCS loads and H_2O_2 concentrations were evaluated with respect to the removal efficiency of atrazine. Results show the optimal SCS load and H_2O_2 concentration were 80 g kg^{-1} and 10%, respectably. The graded modified Fenton's oxidation with a 3-time addition of 10% H_2O_2 was able to remove 93.7% of total atrazine in the contaminated soil and maintain soil temperature within 50 °C. In contrast to traditional Fenton treatment, a slight pH increase has been observed due to the addition of SCS. More importantly, experiment conducted at natural conditions with SCS gave the similar atrazine removal to the experiments with the other catalysts (e.g., $FeSO_4$ and Fe_2O_3). One thing should be noted that after the treatment, dissolved organic carbon (DOC) content increased to 1.206 g kg^{-1} from an initial value of 0.339 g kg^{-1}.

1. Introduction

Atrazine (2-chloro-4-ethylamino-6-isopropylamino-*S*-triazine) have been used for over 50 years to control broad-leaved and grassy

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Table 1
The main physicochemical properties of the soil.

pH	SOM (%)	TOC (%)	Fe (%)	Amorphous iron (%)	Free iron (%)	Sand (%)	Silt (%)	Clay (%)	Atrazine mg kg^{-1}
5.4	4.72	2.56	2.14	0.16	0.43	27.5	24.6	47.9	617.5

Table 2
The major compositions of the steel converter slag.

pH	CaO (%)	SiO_2 (%)	MgO (%)	Al_2O_3 (%)	MnO (%)	FeO (%)	Fe_2O_3 (%)	Total iron (%)	Amorphous iron (%)	Free iron (%)
12.3	45.7	10.4	7.5	3.4	2.4	13.4	9.7	18.2	5.6	9.5

weeds especially in corn and sorghum production [1]. It is the second highly consumed herbicide in the world [2] and also one of the most common pesticides detected in groundwater in the United States [3] and Europe [4]. This widespread distribution is of particular concern because atrazine appears to be a potent disrupter of cell chromosome structure [5,6] and estrogen metabolism [7,8]. Although atrazine has been included in the list of priority substances by the European Union and banned in the European Union [9], it is still in use in many countries including America and China.

Atrazine is relatively persistent in soil. Biodegradation is the principal process controlling its fate, which occurs through slow *N*-dealkylation with reported half-lives of 41–231 days [10]. Although agricultural use results in relatively low soil contamination (2 mg kg^{-1} in the surface 5 cm), much higher concentrations (up to 29,000 mg kg^{-1}) are found due the intentional dumping to disposal ponds or accidental spillage during pesticide mixing and loading [11]. Due to its low adsorption to soil particles, there is a need to clean up the contaminated soils quickly to prevent the dispersion of atrazine to ground and surface water [12].

Chemical oxidation by Fenton's reagents is a well-developed technology for the remediation of organic compounds contaminated soils [13,14]. Fenton reaction is based on the generation of reactive hydroxyl radicals ($^{\bullet}OH$), which can oxidize nearly all types of organic contaminants into harmless products. [15]. The production of $^{\bullet}OH$ by Fenton reagents occurs by means of addition of H_2O_2 to Fe^{2+} salts (Eq. (1)) [16]. Moreover, the newly formed Fe^{3+} can catalyse H_2O_2 (Eq. (2)), the reaction of H_2O_2 with Fe^{3+} is known as a Fenton-like reaction [17].

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

$$K_1 = 70\,M^{-1}\,s^{-1}$$

$$Fe^{3+} + H_2O_2 \rightarrow Fe^{2+} + H^+ + HO_2^{\bullet} \quad (2)$$

$$K_2 = 0.001\text{–}0.1\,M^{-1}s^{-1}$$

Studies have demonstrated that Fenton/Fenton-like reaction can not only be catalyzed by free iron ions (Fe^{3+} and Fe^{2+}), but also by native or synthesized iron oxide (FeO, Fe_2O_3 and Fe_3O_4) [18–20]. In this study, steel converter slag (SCS)—a by-product of iron and steel manufacturing is employed as the catalyst. The weight content of iron oxides in SCS might exceed 20% [21]. Iron materials can be dissociated in water to produce Fe^{3+} and Fe^{2+}, therefore, SCS can act as an iron sink to supply iron continuously for Fenton/Fenton-like reaction. Furthermore, SCS can increase soil fertility since it contains fertilizer components including CaO, SiO_2, and MgO [22]. On the other hand, in order to prevent a sharp increase in soil temperature and undesired soil sterilization when large amounts of H_2O_2 was added to the soil in one time, graded modified Fenton's oxidation was studied, in which H_2O_2 is added intermittently [23].

In this paper we evaluated the efficiency of a cost-effective Fenton-like process based on the utilization of SCS for the remediation of atrazine contaminated soil. The optimal reagents doses were determined. The variation in soil temperature was monitored during the chemical process. Our research work also focused on the influences of the treatment on soil properties including soil pH, soil organic matter (SOM) content and dissolved organic carbon (DOC) content.

2. Materials and methods

2.1. Preparation of contaminated soil and materials

The soil was collected (0–20 cm) from a contaminated load site in Hunan pesticide manufacturing plant in Xiangtan, China (27°57′N, 113°01′E). The soil was naturally dried in air and then grinded. After that, the soil was sieved with a 0.25 mm mesh to remove plant debris and homogenized to obtain laboratory soil sample. The main physicochemical properties of the soil are indicated in Table 1. The SCS was obtained from Valin Iron and Steel Corp (VISTC), Xiangtan, China, and it was sieved with a 0.25 mm mesh sieve to remove large slag. SCS was dried at 80 °C in an oven after washing with ultrapure water, and collected in a desiccator. The main constituents of SCS including CaO, MgO, Al_2O_3, MnO, FeO, Fe_2O_3, total iron, extractable iron, amorphous iron, free iron, and pH are shown in Table 2. H_2O_2 solution (30% w/w) was purchased from Sinopharm Chemical Reagent, China. All other chemicals used were of analytical grade or chromatographic grade. Ultrapure water (18.2 Ω, Milli-Q Millipore) was used in all experiments.

The pH was measured with a pH electrode (Mettler Toledo FE 20) in 1:3 soil (slag)/water suspensions. The SOM content was measured by incineration of a known weight of soil sample in a muffle for 4 h at 550 °C, and the corresponding SOM content was obtained by the mass difference [24]. Total organic carbon (TOC) were determined according to Romero et al. [25] using a TOC analyzer (Shimadzu 1020A, Japan). 2 g of soil and 10 ml of Milli-Q water were shaking at 200 rpm and then centrifugation for 15 min at 4500 rpm. The filtrate was used to detect soil DOC with a Shimadzu TOC analyzer. The contents of SiO_2, Al_2O_3, CaO, MgO Fe_2O_3, FeO, total iron and MnO were acquired from VISTC. Total Fe content in the soil was determined by acid extraction/atomic absorption spectroscopy (AAS, Agilent 3510, USA) with a Fe hollow cathode lamp. Amorphous iron concentration was quantified by ammonium oxalate extraction method [26]. Free iron concentration was quantified by dithionite–citrate–bicarbonate extraction method [27]. Soluble iron concentration was measured according to Tsai and Kao [28] using the AAS. The determination of the percent of clay (<0.002 mm), silt (0.002–0.05 mm), and sand (0.05–2 mm) was according to Gee and Bauder [29].

2.2. Fenton-like treatment

The effect of SCS dosage on atrazine degradation efficiencies was tested. The oxidation reaction was conducted in 200-mL glass tubes with Teflon caps. Each tube contains 20 g of atrazine contaminated soil, 40 mL of Milli-Q water and 20 mL of H_2O_2 solution (15% w/w) and different dosage (0, 2, 4, 6, 8, 10, 20 g) of SCS. The experiments

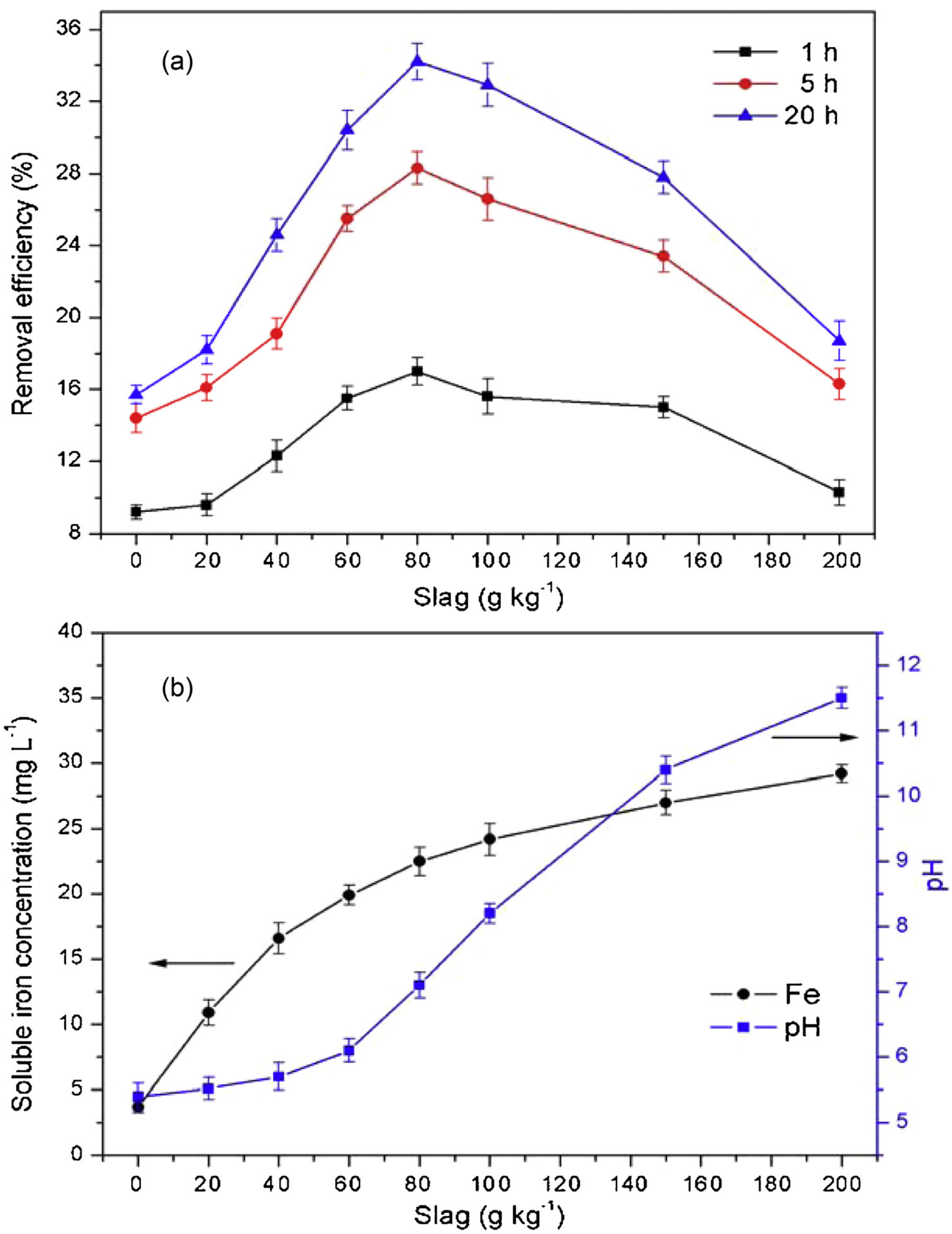

Fig 1. Variations in atrazine removal efficiency (a), the pH value and soluble iron concentration (b) versus converter slag dosage. Conditions: atrazine initial concentration = 617.5 mg kg^{-1}; initial H_2O_2 concentration = 15%.The bars represent the standard deviations of the means (n = 3).

were conducted at natural pH and 25 °C and the glass tubes were mechanically shaken at 120 rpm. The soil samples were collected at different time points for the analysis of atrazine and H_2O_2 concentrations. All batch experiments were performed in duplicates.

2.3. Atrazine extraction and analysis

Atrazine extraction from soil samples was carried out using the procedure reported by Navarro et al. [30]. Briefly, atrazine was extracted by adding dichloromethane and acetonitrile to the soil samples, and sonicating the mixture. After setting, the organic phase was filtered and then evaporated to dryness. The residue was dissolved in acetone, atrazine concentration in the solution was determined by high performance liquid chromatography (HPLC, Agilent 1100, USA) equipped with an Agilent TC-C18 column (150 mm × 4.6 mm, 5 μm) and an UV–vis photodiode array detector [31].

2.4. H_2O_2 decomposition

The concentration of H_2O_2 in the suspension was determined by titration with a solution of potassium permanganate ($KMnO_4$), of known concentration, in sulphuric acid by using a potentiometric titration analyzer [32].

3. Results

3.1. Effect of converter slag dosage on atrazine degradation

To obtain the optimal SCS dosage for the treatment, experiments with different catalyst between 0 and 200 g kg^{-1} were conducted. Atrazine (initial concentration = 617.5 mg kg^{-1}) removal efficiencies with 15% H_2O_2 and different SCS dosage were reported in Fig. 1a. The similar trends were observed on the curves of atrazine removal in 1, 5 and 20 h in general. It is obvious that atrazine

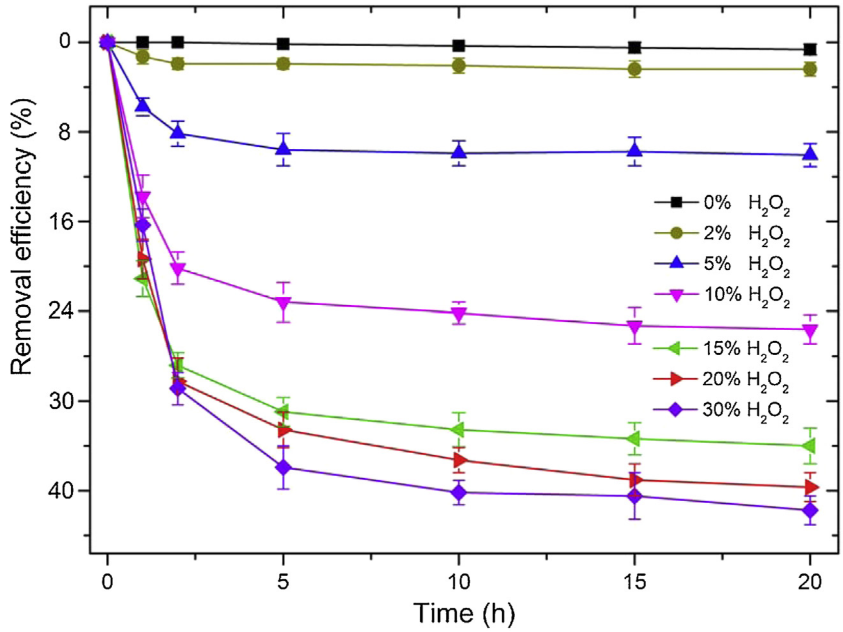

Fig. 2. Effects of H_2O_2 concentrations (0–30%) on atrazine removal. Conditions: atrazine initial concentration = 617.5 mg kg^{-1}; converter slag dosage = 80 g kg $^{-1}$. The bars represent the standard deviations of the means (n = 3).

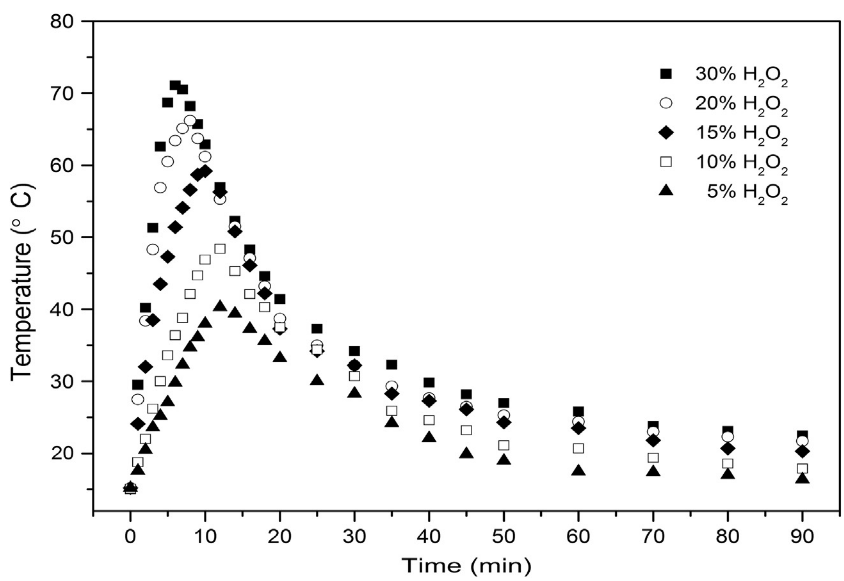

Fig. 3. Variations in temperature during Fenton-like treatments with different H_2O_2 concentrations (5–30%). Conditions: atrazine initial concentration = 617.5 mg kg^{-1}; converter slag dosage = 80 g kg $^{-1}$.The bars represent the standard deviations of the means (n = 3).

removal increased with the addition of SCS, but decreased with the further addition of SCS. Results also show atrazine removal increased rapidly from 0 h to 5 h and slowed down from 5 h to 20 h regardless the amounts of SCS were added. We also found that 15.7% of the total atrazine was removed after 20 hours treatment in the system without SCS. This is because natural iron oxide minerals (e.g., hematite and goethite) present in the soil can also catalyze H_2O_2 oxidation of the pollutant [33]. Natural soils generally contain 0.5–5% (5–50 g kg^{-1}) of iron minerals. As for the studied soil, the contents of total iron, amorphous iron and free iron content of the studied soil are 2.14%, 0.16% and 0.43%, respectively (Table 1). Fig. 1a demonstrates that addition of SCS with a dosage of just 2% can largely enhance atrazine degradation, compared with the control reactor. This observation suggest that SCS can effectively promote the generation of •OH for atrazine oxidation. This comes about because SCS contains much higher iron minerals than the soil. As we shall see, the free iron content of SCS is 20 times over that of the soil.

Results indicate that increasing SCS dosage from 20 to 80 g kg^{-1} caused the increase in the atrazine removals. The atrazine removals after 20 h reaction were 18.2% and 34.3% with 20 and 80 g kg^{-1} of SCS, respectively. This indicates that the increase in SCS dosage would accelerate atrazine removal. It is probably because more SCS can provide more soluble iron for the Fenton/Fenton-like reaction. As shown in Fig. 1b, the soluble iron concentration increased with the increase of SCS dosage. And especially fast increasing rates were observed when SCS dosages were under 60 g kg^{-1}. Fig. 1a also reveals that atrazine removal was significantly decreased with SCS dosages increased from 80 to 200 g kg^{-1}. Two mechanisms, indeed, can be responsible for this phenomenon. On the one hand, the

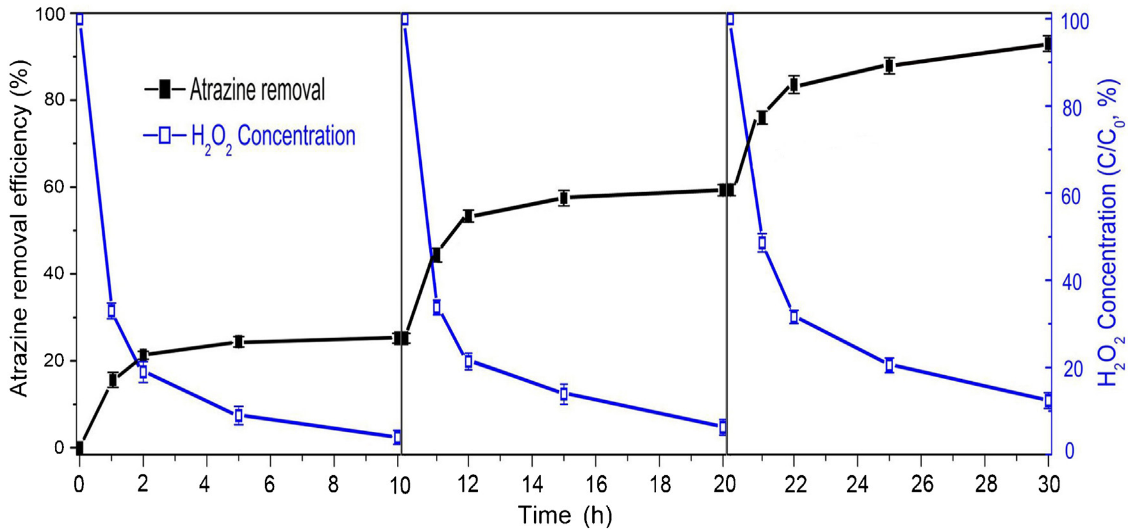

Fig. 4. Variations in atrazine removal and H_2O_2 concentration during the graded modified Fenton-like treatment. Conditions: atrazine initial concentration = 617.5 mg kg^{-1}; converter slag dosage = 80 g kg $^{-1}$; H_2O_2 concentrations = 10%. C_0 represents H_2O_2 concentration in the system immediately after each addition of H_2O_2 solution. The bars represent the standard deviations of the means (n = 3).

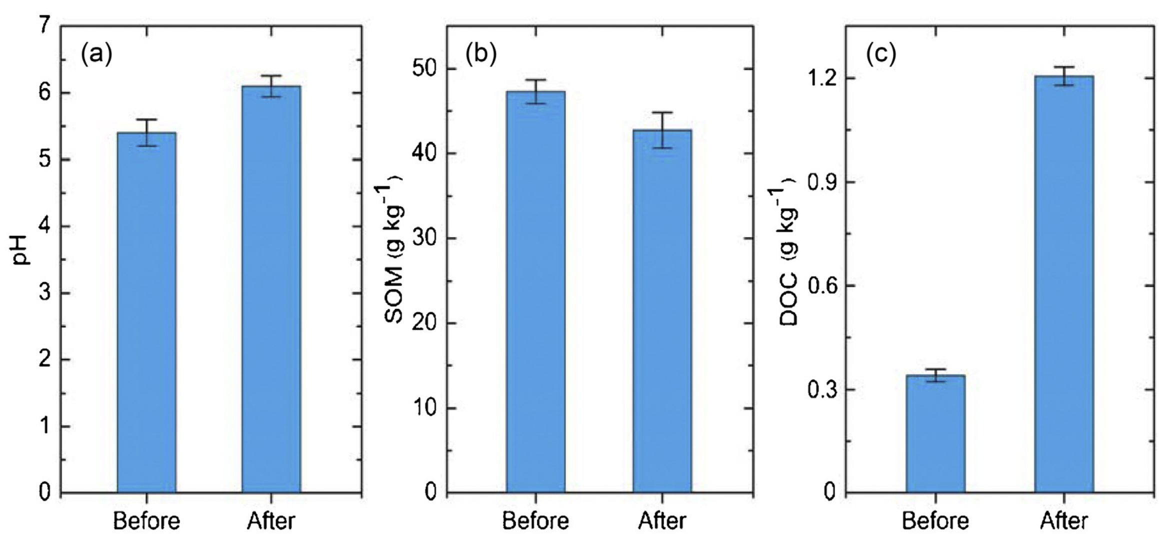

Fig. 5. Effects of the Fenton-like treatment on soil properties including pH, SOM, and DOC. Conditions: atrazine initial concentration = 617.5 mg kg^{-1}; converter slag dosage = 80 g kg $^{-1}$; H_2O_2 concentrations = 10%. The bars represent the standard deviations of the means (n = 3).

increased SCS dosage would cause superfluous fresh iron surfaces. The extra iron surfaces would then cause the consumption of oxidants (e.g., H_2O_2 and $^{\bullet}OH$) rapidly [28]. On the other hand, more efficient Fenton-like reaction would occur under acidic condition [34,35]. Under alkali conditions, the iron ions would precipitate as hydroxides, and instead of generating the $^{\bullet}OH$, the H_2O_2 would decompose into oxygen [36]. Results from this study show the pH values increased from 7.1 to 11.5 with the increase of SCS dosage from 80 to 200 g kg^{-1} (Fig. 1b). The significant increase in slurry pH was caused by the hydrolyzation of alkaline metal oxide (e.g., CaO, MgO) which make up over 50% of SCS.

3.2. Effect of H_2O_2 concentrations on atrazine degradation

Previous studies indicated that the degradation efficiencies of organic pollutants with Fenton reagents related oxidations are strongly facilitated by higher H_2O_2 concentrations [37]. However, there is also evidence that higher H_2O_2 concentrations can restrain contaminant removal [38]. Fig. 2 shows atrazine removals after 20 h treatment with different initial H_2O_2 concentrations (0%, 2%, 5%, 10%, 15%, 20%, and 30%). As we can see in Fig. 2, almost no atrazine removal was obtained in the system without H_2O_2. And the improvement in atrazine removal was not obvious as 2% H_2O_2 was applied, which is probably because the organic matters in the soil quenched most of the H_2O_2.

Results indicate that atrazine removal can be significantly increased with the further addition of H_2O_2. In the experiment with H_2O_2 concentrations of 5%, the atrazine concentrations dropped from 617.5 to 554.5 mg kg^{-1} (10.2% of atrazine removal) after 20 h of reaction. And approximately 25.6% and 36.0% of atrazine were removed in experiments with H_2O_2 concentrations of 10% and 15%, respectively. This suggests that the atrazine oxidation can be enhanced under conditions of higher H_2O_2 concentration. However, the increase in atrazine removal was not obvious when H_2O_2 concentration increased from 15% to 30% (Fig. 2). Similar trends have been observed in several other Fenton/Fenton-like systems, it was reported that the oxidation efficiency increases significantly with H_2O_2 dose till a certain concentration, but does not increase

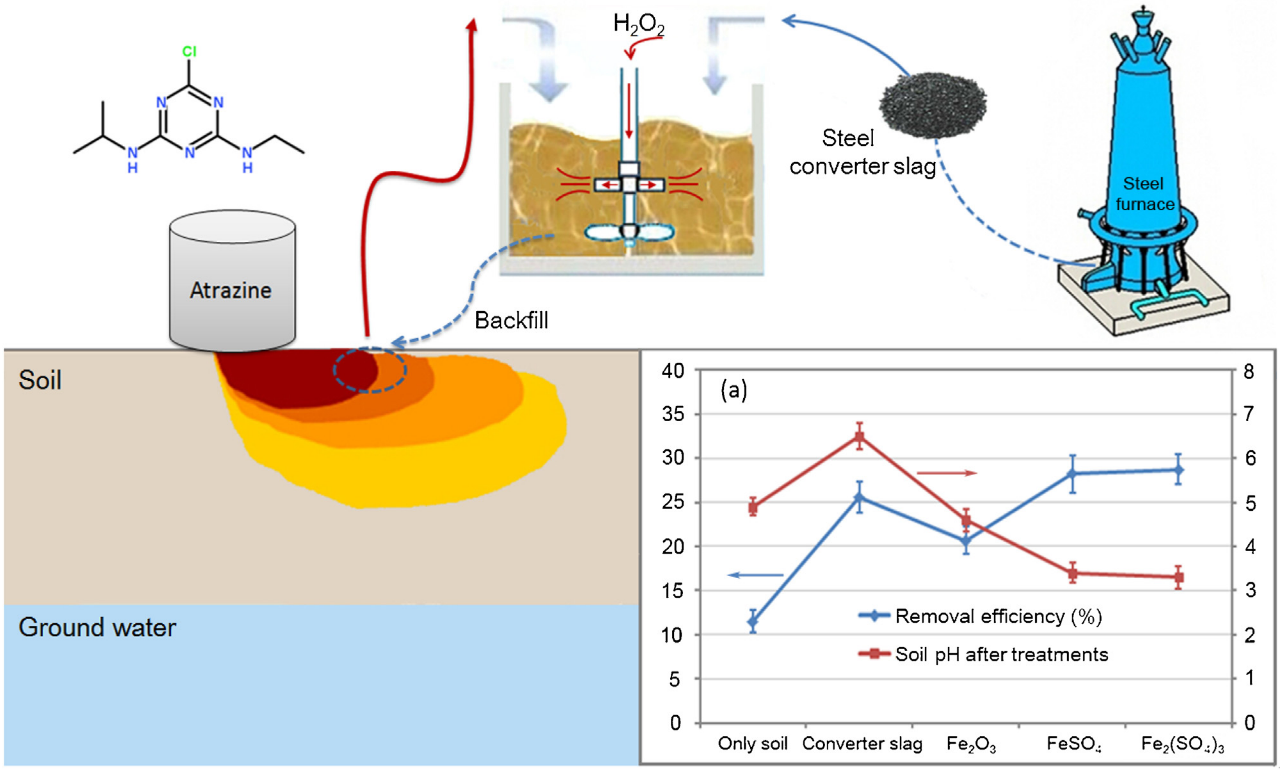

Fig. 6. A scheme for the treatment of atrazine contaminated soil by steel converter slag catalyzed Fenton-like oxidation. (a) The removal efficiency and soil pH after the treatment with different types of catalysts. Conditions: atrazine initial concentration = 617.5 mg kg^{-1}; catalysts dosage = 80 g kg $^{-1}$; H_2O_2 concentrations = 10%. The bars represent the standard deviations of the means (n = 3).

appreciable afterwards [39], very high H_2O_2 concentrations may even decrease the oxidation efficiency [40]. This is due to the scavenging effects of $^{\bullet}OH$ by excess H_2O_2 and consequent formation of the less reactive $HO_2\bullet$ as presented by the following reactions:

$$HO^{\bullet} + H_2O_2 \rightarrow H_2O + HO_2^{\bullet} \quad (3)$$

$$HO^{\bullet} + HO_2^{\bullet} \rightarrow H_2O + O_2 (4)$$

when H_2O_2 is present at high concentrations, Reaction (3) will become more significant.

3.3. Variations in temperature

Fenton/Fenton-like reaction in the subsurface is in fact highly exothermic and could lead to a significant increase in soil temperature [38]. Excessive heat generation and gas formation are quite dangerous because they can lead to undesired soil sterilisation, explosions and instability of reactants [38]. Fig. 3 illustrates the variations in slurry temperature versus reaction time with different concentrations of H_2O_2. Results depict that temperature increased rapidly in the first 10 min followed by the fast decline along with the time shift, and come close to initial value (25 °C) after 90 min reaction. This quick temperature rising in the experiments was attributable to the accumulation of heat which continuously generated from the chemical reactions after H_2O_2 was added to the soil. The followed reduction in slurry temperature was likely due to the fast decline in H_2O_2 concentrations. According to the previous work, H_2O_2 decomposition rates decreased rapidly with time [32].

The temperature was found affected by the initial H_2O_2 concentrations to a large extent. Our data indicate that high initial H_2O_2 concentrations caused an increase in the levels of temperature during the experiments, particularly in the peak values. The maximum temperature values were 40.3, 48.4, 59.5, 66.2 and 71.1 °C correspond to initial H_2O_2 concentrations of 5, 10, 15, 20 and 30%, respectively. As shown in Fig. 2, atrazine removals were 10.2, 25.6, 36.0, 39.7 and 41.8% with the initial H_2O_2 concentrations of 5, 10, 15, 20 and 30%. Although there is a considerable enhancement in atrazine removal with H_2O_2 concentrations increased from 10% to 15%. However, the higher H_2O_2 concentration also led to much higher soil temperature. Thus, H_2O_2 concentration of 10% was selected in the following batch study of the degradation experiments because of the cost and environmental safety reasons.

3.4. Graded modified Fenton-like treatment

In this part of work, the same dosage of H_2O_2 (10%) was added to the substrate every 10 h. The concentration of H_2O_2 and the removal efficiency of atrazine versus reaction time are presented in Fig. 4. H_2O_2 concentration was found depleted rapidly after each addition. More than 50% of the total H_2O_2 was consumed in the first hour, and the similar trends were observed in the followed processes, despite that the initial H_2O_2 concentrations were not exactly the same. Experiments performed on the aqueous phase without soil and SCS at 25 °C showed that the H_2O_2 concentration (10%) almost remains constant at 10 h (data not shown); therefore the decrease of H_2O_2 concentration is due to the reduction reactions. On the one hand, the natural reducing species of soil such as peroxidase enzymes and organic matters play important roles in H_2O_2 decomposition and are responsible for the “non-productive” H_2O_2 decomposition pathways [32]. On the other hand, the addition of H_2O_2 to the system causes Fenton/Fenton-like reaction, which lead to the decomposition of atrazine [17].

The variation trends of atrazine removal were in consistent with the variation trends of H_2O_2 concentration. Results from Fig. 4 show atrazine content quickly declined after each addition of H_2O_2, and the degradation was mostly occurred in the first 2 hours after H_2O_2 addition. The findings are in agreement with the other researchers' observations when studying the remediation of contaminated soils by Fenton/Fenton-like process [25,39]. This is because the decomposition of atrazine is mainly rely on the •OH formed by Fenton/Fenton-like process. And the H_2O_2 concentration is the critical factor of the production of •OH. This notion is also supported by the results obtained in an aqueous solution, only a slight oxidation of atrazine occurred at the lower concentration of H_2O_2 [38]. As can be seen in Fig. 4, the total removal percentage of atrazine was not simply in proportion to the addition times of H_2O_2. The atrazine removals in 10, 20 and 30 h were 25.2%, 60.8%, and 93.7%, respectively. The mechanisms underlie this need further studied. Nevertheless, our data confirmed the feasibility of this modified Fenton-like process for the remediation of atrazine contaminated soils.

3.5. Effects of the treatment on soil properties

To elucidate the effect of the Fenton treatment on soil properties, the changes of soil pH, SOM and DOC contents were examined. The results in Fig. 5 show a slight increase of the soil pH after the treatment. Due to the alkaline SCS (pH = 12.3) was applied as the catalyst in this Fenton-like system, no reduction in soil pH after the addition of H_2O_2 was observed. This is because the alkaline oxides (CaO, MgO) in SCS have a strong buffering capacity. The soil pH after the treatment was about 6.2 (Fig. 5a). This is different from traditional Fenton treatment, in which the soil pH significantly decreased since the Fenton reagents (H_2O_2 and Fe^{2+}) and the variety of oxidation products are intrinsically acidic [36]. In fact, the reduction in soil pH is the main disadvantage of Fenton based treatment. The pH value of soil may decrease to about 3 after the treatment, and thus failed to meet the revegetation purpose [35]. Our results here suggest that using SCS as the catalyst can avoid the adverse impact of reduction in soil pH.

SOM is an important component of soil; it has extremely important significance on the soil formation, soil fertility, environmental protection and sustainable development of agroforestry. A slight decrease of SOM was observed after the treatment (Fig. 5b). It was reported that SOM can be oxidized by H_2O_2 [36], and co-oxidized together with the organic contaminants due to the non-selective nature of •OH produced by the Fenton/Fenton-like reaction [32,41]. Despite that SOM can be oxidized by both H_2O_2 and •OH, more than 90% of the total SOM still remained in the system after the treatment. This is in agreement with the results in other reports [25,42]. One proposed mechanism is that humin as the main content of SOM is difficult to be oxidized [42]. Although the oxidation of larger molecules of SOM led to release of smaller parts to the slurry filtrates, most SOM was still bound to the soil during Fenton/Fenton-like oxidation. Another mechanism is that a certain amount of oxygen was introduced by the oxidation of the original SOM, the SOM was oxidized but not mineralized [25].

We also monitored the DOC to make an evaluation of macroscopic changes in organic matter in terms of water solubility. DOC is the main energy source of soil microbial and also an important material in the geochemical circulation between terrestrial and aquatic ecosystems [43]. As shown in Fig. 5c, from an initial value of 0.339 g kg^{-1}, the treatment increased DOC content to 1.206 g kg^{-1} of soil. The DOC increase can be attributed to the release of natural soil organics. Solubilization of organic matter commonly occurs after Fenton/Fenton-like treatment [33]. As also observed by R Mecozzi and co-workers [38], the oxidation process resulted in the release of a smaller part of organic matters from larger molecules and the change of natural organic matter to a less hydrophobic status. This was due to the •OH reaction mechanism, which generally involves electrophilic addition to alkenes or aromatic rings [38]. Moreover, the oxidation of SOM by H_2O_2 could create more hydrophilic sites and thus decreases the sorption ability [25]. The release of atrazine by-products may also account for this phenomenon; previous studies have shown that the extracted quantities of atrazine's principal metabolites counted for more than 20% of the degraded atrazine mass [38].

3.6. Environmental implications

Fenton's reagents and related processes are widely accepted for soils remediation, and mainly focus on the ex-situ Fenton treatments. Compared to the in-situ Fenton treatments, ex-situ Fenton treatments can deliver the oxidant to the contaminated zones more easily and achieve higher oxidation efficiency. To reduce the cost of time and labor, the processes can be operated near the contaminated sites. As shown in Fig. 6, after the treatment, the decontaminated soil could be back filled to the site. Due to the utilization of alkaline SCS as the catalyst, soil pH increased from 5.4 to 6.2, which meets the revegetation purpose. By comparison, when using $FeSO_4$, $Fe_2(SO_4)_3$ and Fe_2O_3 as catalysts, the pH values of the treated soils decreased to 3.4, 3.3, and 4.6, respectively (Fig. 6a). The reduction in soil pH is not only unfavorable for the revegetation, but also a disaster to the soil microorganism. More importantly, experiments conducted at natural conditions with SCS gave comparable atrazine removal with the experiments carried out with the other catalysts (Fig. 6a). The atrazine removals were in the order of 80 g kg^{-1} of $Fe_2(SO_4)_3$ (28.7%) >80 g kg^{-1} of $FeSO_4$ (28.2%) >80 g kg^{-1} of SCS (25.6%) > 80 g kg^{-1} of Fe_2O_3 (20.7%) > only contaminated soil (11.5%) after 20 h of reaction. The results show that the SCS system can provide stronger oxidation condition than Fe_2O_3 system. This is probably because SCS contains significant amounts of extractable iron such as amorphous iron and soluble iron.

The versatility of SCS system is also enhanced by the fact that SCS is one of the main by-products of steel manufacturing. About 100 million tons of SCS is produced in China every year and a considerable part of it is not put into good use. This could be a problem as a large amount of SCS has been accumulated through the years, which occupies hectares of land. On the other hand, several studies have documented that SCS can be utilized as a good soil amendment since it contains fertilizer components including CaO, SiO_2, and MgO [22]. If the studied process can be applied in the field, it may provide a feasible way to utilize SCS and also achieve good environmental benefit.

4. Conclusions

In this study, SCS was applied to activate Fenton-like oxidation to remediate atrazine contaminated soil. Results suggest that addition of SCS is able to catalyze the Fenton-like oxidation process and improve the removal efficiencies of atrazine. The optimal SCS load was determined as 80 g kg^{-1}. Results show that higher H_2O_2 concentrations could lead to the higher atrazine removals and soil temperatures. The graded modified Fenton's oxidation with 10% H_2O_2 was adopted since it could maintain soil temperature within 50 °C and also provide high atrazine removal efficiency. The graded modified Fenton's oxidation with a 3-time addition of 10% H_2O_2 was able to remove 93.7% of total atrazine in the contaminated soil. This research also highlighted the influence of the chemical treatment on the soil. It was found that soil pH increased from 5.4 to 6.2, which is of benefit to the revegetation. Meanwhile, it must be noted that a considerable amount of DOC may release to the environment during the treatment. These results are very encouraging for the application of the SCS catalyzed Fenton-like process in natural conditions.

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