Study on treating old landfill leachate by Ultrasound–Fenton oxidation combined with MAP chemical precipitation

Jing Zhang*, Tao Yang*, Hongyu Wang*, Kai Yang*, Cheng Fang*, Bin Lv* and Xiaojun Yang*

*School of Civil Engineering, Wuhan University, Wuhan, China; bSchool of Environmental Engineering, Wuhan Textile University, Wuhan, China

ABSTRACT
In this study, the “Ultrasound/Fenton oxidation – MAP chemical precipitation” method was used to remove chemical oxygen demand (COD) and ammonia nitrogen from the old landfill leachate which was collected from one sanitary landfill in Wuhan. Firstly, Ultrasound treatment and Fenton oxidation treatment were separately used to treat the old landfill leachate, and under their optimum reaction conditions, the COD concentration was degraded from 842 to 697 mg L⁻¹ and from 842 to 133 mg L⁻¹, respectively. Then, Ultrasound/Fenton oxidation treatment was used to treat the same old landfill leachate. Compared with the single Fenton treatment, Ultrasound/Fenton oxidation treatment could raise the COD removal efficiency from 84.05 to 90.88% with the same H₂O₂ consumption. After the Ultrasound/Fenton oxidation treatment, Na₂HPO₄·12H₂O and MgSO₄·7H₂O were used as precipitation reagents to remove ammonia nitrogen from the old landfill leachate, and the ammonia nitrogen concentration degraded from 910 to 11 mg L⁻¹. The experiment results indicated that “Ultrasound/Fenton oxidation – MAP chemical precipitation” method was an effective and economic method to treat old landfill leachate.

ARTICLE HISTORY
Received 17 September 2015
Accepted 6 November 2015

CONTACT
Hongyu Wang hongyuwang220@126.com

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1. Introduction
During the past several decades, the soaring populations, huge changes in lifestyle, great utilization of resources, and continuing development of the industry and commerce have been accompanied by the rapid generation of municipal solid wastes.[1,2] Because of its technical feasibility, ease of operation, minimum supervision, and low operation expenditure, sanitary landfill is considered as the most perfect method for solid waste disposal.[3] However, it is inevitable to produce secondary pollution in the process of sanitary landfill, such as water, air, and soil pollution.[4] A major drawback of sanitary landfill is the landfill leachate discharged from the sanitary landfill sites, which puts adverse impact on the environment without any treatments before being discharged.[4,5] Therefore, landfill leachate is recognized as a serious environmental problem.[3,6]

Leachates are mainly generated by (i) the natural precipitation and runoff in landfill site, (ii) the original water in the wastes, and (iii) decomposition processes occurring in the wastes.[7] The natural precipitation and runoff in landfill site are the main sources of leachate. It is a specific type of wastewater with a complex composition, containing large amounts of organic pollutants, ammonia nitrogen, inorganic salts, and heavy metals, and so on.[8] Meanwhile, composition of landfill leachate is highly variable and depends on many factors such as the type of waste, site hydrology, waste compaction, amount of precipitation, cover design, particularly, the age of the landfill.[2,9] The old landfill leachate (i.e., >10 years old) contains biorefractory compounds such as humic and fulvic acids, and is characterized by a low chemical oxygen demand (COD < 4000 mg L⁻¹) and biological oxygen demand/chemical oxygen demand ratio (BOD/COD < 0.1), so it is a kind of refractory and high concentrated organic wastewater.[7,10]

At present, the treatments of landfill leachate are mainly physical–chemical method and biological method.[3] Because of their high cost-effectiveness and simplicity, biological treatments such as activated sludge, aerated lagoons, sequencing batch reactors, and upflow anaerobic sludge blanket reactors are widely and effectively used to treat the young leachate.[2] However, it is difficult to remove COD from old landfill leachate with these conventional biological treatments, due to the low BOD/COD ratio (<0.1) and the presence of bio-refractory and toxic contaminants.[7,10] Simultaneously, owing to the potential risks posed by landfill leachates to aquatic ecosystems, especially ground water, the enforcement of environmental rules and regulations...
on the direct discharge of leachate by environmental regulatory agencies are becoming more stringent and restrictive. All those reasons have accelerated the search for a cost-effective and environment friendly attractive treatment for old landfill leachate to meet these stricter standards.

Based on the characteristic of old landfill leachate, there exist many ways to decrease the COD,[11] for example, ultrasound technology (US) and advanced oxidation processes (AOPs). Ultrasound technology integrates the characteristics of many kinds of water treatment technology, such as advanced oxidation technology, incineration, supercritical oxidation, and so on.[12] Besides, due to its mild degradation condition, quick degradation speed, and wide applicability, it could be used alone or combined with other water treatment technologies. Hence, ultrasound technology which is used to degrade the chemical pollutants in water, especially refractory organic pollutants (POPs), is a new and popular water treatment technology in recent years. In addition, compared with the traditional water treatment technology, the AOPs,[13] which could generate the extremely reactive and non-selective hydroxyl radicals to remove organic matter from solutions, are a kind of high efficient and classic chemical oxidation method and widely used in wastewater treatment. Fenton's oxidation is one of these AOPs processes. There are many reports on Fenton’s reaction treating landfill leachate.[14,15] At present, the treatment of ammonia nitrogen wastewater could be divided into physical method, chemical method, and biological method.[16,17] A large number of studies have shown that the magnesium ammonium phosphate (MAP) precipitation could effectively remove ammonia nitrogen from wastewater.

In this study, we used the “Ultrasound/Fenton oxidation – MAP chemical precipitation” method to remove COD and ammonia nitrogen from the old landfill leachate, which collected from one sanitary landfills in Wuhan. The property of landfill in this experiment is that the COD concentration and ammonia nitrogen concentration are 800–900 mg L\(^{-1}\) and 900–1200 mg L\(^{-1}\), respectively. The experiment results indicated that the treatment of “Ultrasound/Fenton oxidation – chemical precipitation” was fast, effective, and did not have secondary pollution. After being treated by this method, COD concentration of the landfill decreased from 842 to 77 mg L\(^{-1}\), and the ammonia nitrogen concentration was declined from 910 to 11 mg L\(^{-1}\) at the same time, which met the demand of GB16889-2008.

2. Materials and methods

2.1. Landfill leachate characteristics

The landfill leachate was collected from Erfeishan landfill, which was in operation of 8 years and located in Wuhan. Leachate samples were collected in precleaned brown glass amber bottles. The samples were stored at 4 °C to keep the wastewater characteristics unaltered, and they were used without any pre-treatment. In all experiments, concentrations of COD and ammonia nitrogen were determined using potassium dichromate method and sodium reagent colorimetric method, respectively. The main parameters of landfill leachates were pH of 8.20, the COD concentration of 820 mg L\(^{-1}\), the ammonia nitrogen concentration of 913 mg L\(^{-1}\), 0.22 < BOD/COD < 0.27, and the chromaticity of raw landfill leachate was tawny.

2.2. Experimental unit and method

The reactor used in experiment was a cylinder with an inner diameter of 150 mm, height of 250 mm, and
effective volume of 4.416 L. Experimental apparatus was shown in the following Figure 1. Ultrasonic generator (LT-300A) used in experiment has two powers (125 and 250 W). Its reaction time control panel could be set up to 60 min and could automatically disconnect.

2.3. Ultrasound treatment experiment

Ultrasound treatment experiments were carried out in the reactor containing 2000 mL landfill leachate without Fenton reagent. In these experiments, the main influenced factors such as radiation time, initial pH, and ultrasonic power were studied.

2.4. Fenton oxidation treatment experiment

Fenton oxidation is one of the AOPs and popular in treating landfill leachate. In these experiments, Fenton oxidation was used to treat landfill leachate in a 500-mL beaker, and the influence of different factors (such as radiation time, initial pH, the additive amount of H$_2$O$_2$, and the mole ratio of H$_2$O$_2$ and Fe$^{2+}$) on the treatment effect were studied. All glassware and apparatuses were rinsed with sulfuric-dichromate cleaning solution and dried at 100 °C to use.

2.5. Ultrasound/Fenton oxidation treatment experiment

Based on above experiments, the Ultrasound/Fenton oxidation treatment experiments were carried out in this reactor. And the main influence factors, such as radiation time, initial pH, the amount of H$_2$O$_2$, and the mole ratio of H$_2$O$_2$ and Fe$^{2+}$ were studied.

2.5.1. The effect of the initial pH

At room temperature, 2000 mL landfill leachate was added in the reactor. In the mixture, the dosage of Fe$^{2+}$ and H$_2$O$_2$ was 0.05 and 0.15 mol L$^{-1}$, respectively, and the Ultrasonic generator’s power was 125 W. The initial pH (2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, and 9.0) was adjusted using 1N H$_2$SO$_4$ and 1N NaOH. Then, the reaction was conducted for 40 min. After 2-h standing, the supernatant was removed to measure the residual concentration of COD.

2.5.2. The effect of the amount of Fe$^{2+}$

The influence of the amount of Fe$^{2+}$ was studied by changing the mole ratio of H$_2$O$_2$/Fe$^{2+}$, while H$_2$O$_2$ dosage was 0.15 mol L$^{-1}$, the pH was 4, and the Ultrasonic generator’s power was 125 W.

2.5.3. The effect of the concentration of H$_2$O$_2$

Based on above experiments, the influence of the concentration of H$_2$O$_2$ on the removal rate of COD was studied by changing the amount of H$_2$O$_2$.

2.6. Chemical precipitation experiment

After Ultrasound/Fenton treatment, the COD in landfill leachate had been better treated, and the COD concentration of the effluent met the national discharge standard. But the NH$_3$-N concentration of the effluent after Ultrasound/Fenton system treatment was still high. The effluent discharged without any treatment would cause serious harm to the environment. Hence, in this study, chemical precipitation was used to remove the ammonia nitrogen from landfill leachate. The main influencing factors, such as the kind of precipitation agent, initial pH, the ratio of the additive amount of precipitant, were investigated.

2.7. Analytical methods

In this study, the COD and ammonia nitrogen were determined by the potassium dichromate method and the colorimetric method using Nessler’s reagent in accordance with a procedure from the National Standard of the People’s Republic of China (GB 7479-87) (SEPA, 1987), respectively.

3. Results and discussion

3.1. Treatment effect comparison among Ultrasound (US), Fenton, and Ultrasound/Fenton reaction system

As shown in Figure 2, the most effective treatment method was Ultrasound/Fenton treatment method. After reacting for 40 min, the COD removal efficiency of Ultrasound/Fenton, Ultrasound treatment, and Fenton oxidation treatment was 88.26, 13.65, and 70.88%, respectively. The COD removal efficiency of Ultrasound/Fenton was higher than the sum of the removal efficiency of Ultrasound treatment and Fenton oxidation treatment. Meanwhile, compared with the Fenton oxidation treatment, the Ultrasound/Fenton oxidation treatment required less reaction time to achieve the same removal efficiency. Therefore, Ultrasound and Fenton oxidation had a synergistic effect. But with the extension of reaction time, COD removal efficiency of Fenton and Ultrasound/Fenton treatment gently fluctuated. The synergy effect between Ultrasound and Fenton oxidation became smaller and smaller. The reason was that hydrogen peroxide decomposed completely as the reaction progressed, hydroxyl radicals generated in reaction system became less and less and could not mineralized macromolecular organic.

3.2. The effect of Fenton reagent’s influence factors

3.2.1. The effect of the initial pH

As seen from Figure 3(A), at 40th min of treatment time, the highest COD removal efficiency (88.12%)
was observed in the experiment with initial pH of 4. When the initial pH ranged from 4 to 7, COD removal efficiency decreased with the increase of pH. While the initial pH was higher than 7, COD removal efficiency raised slightly. Thus, the optimal pH is 7. Under the condition of the optimal pH, the COD removal efficiency nearly increased by 14.72% for Ultrasound/Fenton method, when it was compared with Fenton treatment.

The principle of Fenton treatment method is that Fe$^{2+}$ is used as a catalyst to produce large amounts of hydroxyl radicals in the reaction process to degrade the organic pollutants. The main reactions are as follows:

1. \( \text{Fe}^{2+} + \text{H}_2\text{O}_2 \rightarrow \text{Fe}^{3+} + \text{OH}^- + \cdot\text{OH} \)  
2. \( \cdot\text{OH} + \text{RH(organics)} \rightarrow \text{P(degradation products)} \)  
3. \( \text{Fe}^{3+} + \text{H}_2\text{O}_2 \rightarrow \text{Fe}^{2+} + \text{H}^+ + \cdot\text{H}_2\text{O} \)

Higher pH would restrain reaction (1), and the reaction (3) would be in the forward direction; thus the generation of hydroxyl radicals was inhibited. At high pH values (>5.0), the rate of auto-decomposition of \( \text{H}_2\text{O}_2 \) would increase, and iron ion was deactivated into iron oxyhydroxides\[11,18\] thus COD removal efficiency was reduced. On the other hand, low pH values (<3.0) prompted the formation of \( [\text{Fe(II)(H}_2\text{O})_6]^{2+} \). The reaction speed of this complex compounds with \( \text{H}_2\text{O}_2 \) was slower than that of this complex compounds with \( [\text{Fe(II)(OH)(H}_2\text{O})_5]^+ \).[11] So the generation of \( \cdot\text{OH} \) was reduced, and the removal of organic matter was inhibited.

### 3.2.2. The effect of the amount of Fe$^{2+}$

As seen from Figure 3(B), the low concentration of Fe$^{2+}$ was not enough to catalyze \( \text{H}_2\text{O}_2 \), so the amount of hydroxyl radicals was small. As a consequence, the oxidizability of Fenton reagent would decrease. When the concentration was too high, the \( \text{H}_2\text{O}_2 \) was catalyzed at a fast speed and produced larger amount of hydroxyl radicals; the excessive hydroxyl radicals would reacted with each other. At last, the effect of catalytic oxidation was reduced. Meanwhile, excess Fe$^{2+}$ reacted with \( \cdot\text{OH} \) as reaction (4). Thereby, the degradation effect was no longer apparent.

\[
\text{Fe}^{2+} + \cdot\text{OH} \rightarrow \text{Fe}^{3+} + \text{OH}^- \tag{4}
\]

In addition, with the increasing ferrous ions, there would produce a large brown precipitate in the process of the experiment. But when the concentration of ferrous ions was low, the quantity of brown precipitate was small. Therefore, the amount of ferrous ions cannot be too much. This experiment found the optimum mole ratio of \( \text{H}_2\text{O}_2/\text{Fe}^{2+} \) was 4:1.

As shown in Figure 3(B), when the mole ratio of \( \text{H}_2\text{O}_2/\text{Fe}^{2+} \) was 1:1, 2:1, 3:1, 4:1, and 5:1, compared with Fenton treatment, the COD removal rate of Ultrasound/Fenton treatment increased by 2.34, 3.07, 7.33, 16.51, and 21.52%, respectively. experiments showed that the effect of Ultrasound/Fenton was superior to Fenton effect when concentration of ferrous ion was low. The reason for this phenomenon was that the cavitation formed by Ultrasound not only could speed up the reaction rate, but also could promote the decomposition of \( \text{H}_2\text{O}_2 \). At the same time, the cavitation of Ultrasound produced free radicals which were helpful to increase the COD removal rate.

### 3.2.3. The effect of the concentration of \( \text{H}_2\text{O}_2 \)

As shown in Figure 3(C), when the concentration of \( \text{H}_2\text{O}_2 \) was less than 0.10 mol L$^{-1}$, the removal rate of COD increased with the increasing concentration of \( \text{H}_2\text{O}_2 \). However, when the amount of \( \text{H}_2\text{O}_2 \) was more than 0.10 mol L$^{-1}$, the COD removal rate tended to be stable. The reason for this phenomenon was that when the concentration of \( \cdot\text{OH} \) was too high, Fe$^{2+}$ was oxidized to Fe$^{3+}$, which consumed hydrogen peroxide and suppressed the generation of \( \cdot\text{OH} \).[19]

In addition, as shown in Figure 3(C), when the concentration of \( \text{H}_2\text{O}_2 \) was 0.05, 0.075, 0.100, 0.125, 0.150, and 0.175 mol L$^{-1}$, compared with Fenton treatment, the COD removal rate of Ultrasound/Fenton treatment increased by 19.65, 12.93, 11.88, 10.23, 9.15, and 9.44%, respectively. That illustrated that the ultrasonic power strengthened the Fenton reagent’s effect of oxidative degradation. But with the increase in concentration of \( \text{H}_2\text{O}_2 \) and its reinforcement, effect was not obvious and tended to be stable. The main reason was that in these experiments, COD was used as the evaluation index of oxidation degradation, but the composition of landfill leachates was very complex, and contained a mass of refractory macromolecular organic matter. Under the ultrasonic reinforcement, refractory macromolecular organic matters were
likely to be degraded into small molecular substances, which was difficult to be mineralized.

### 3.2.4. The effect of ultrasonic power

The influence of ultrasonic power on the removal rate of COD was studied by changing electrical power of the ultrasonic generator. The test results were shown in Figure 3(D).

As shown in Figure 3(D), when the ultrasonic power was 125 and 250 W, the removal rate of COD was 90.08 and 92.66%, respectively. The COD removal rate of Ultrasound/Fenton treatment increased with the increase in ultrasonic power. In other words, high electric power was beneficial to the degradation of organic matter in landfill leachate. In general, the sound energy density of ultrasonic always needed larger electric power consumption; as a consequence, the degradation rate of organic matter increased, and the removal rate of organic matter in landfill leachate was high.[20–23] But when negative phase of sound waves was great, excessive power would cause cavitation bubble form a sound shielding and produced strong scattering attenuation to irradiation velocity, leading to available acoustic energy reduce, thereby degradation rate would decline. Besides, with the increase of power, energy consumption also increased, and the cavitation corrosion speed of the ultrasonic probe tip was also accelerated. This experiment determined the best power was 125 W.

### 3.3. MAP chemical precipitation experiment

#### 3.3.1. Selection of precipitant

For MAP precipitation treatment, the precipitants containing Mg2+ usually are MgO, MgCl2·6H2O, and MgSO4·7H2O, and the precipitants contained PO4− mainly are H3PO4, Na2HPO4·12H2O, MgHPO4·3H2O, and K2HPO4·12H2O. Above the precipitants, the operation for MgHPO4·3H2O was simple. But, the landfill leachate used in experiments was alkaline, and the solubility of MgHPO4·3H2O was low in alkaline solution, so MgHPO4·3H2O was not appropriate in this experiments. MgO should be dissolved by H3PO4 before adding in mixture, which was time-consuming. So its ammonia nitrogen removal effect was poor. The removal efficiency of ammonia nitrogen of MgCl2·6H2O and MgSO4·7H2O were compared in those experiments. Na2HPO4·12H2O and K2HPO4·12H2O were relatively easy to dissociate ions in solution, but the price of K2HPO4·12H2O was more expensive than that of Na2HPO4·12H2O. Therefore, Na2HPO4·12H2O was chosen to provide H3PO4.

At room temperature, 400 mL landfill leachate treated by Ultrasound/Fenton treatment was, respectively, added
in six 500-mL beakers. In each mixture, the \([\text{Mg}^{2+}] : [\text{NH}_4^+] : [\text{PO}_4^{3-}] = 1 : 1 : 1\), the mixing speed was 200 \(\text{r min}^{-1}\), and the pH was 8.5. The test results were shown in Figure 4(A).

As shown in the Figure 4(A), for the two kinds of different combinations of precipitants, the removal of ammonia nitrogen in the leachate was both good. And ammonia nitrogen removal rate of precipitant combined by \(\text{Na}_2\text{HPO}_4 \cdot 12\text{H}_2\text{O}\) and \(\text{MgSO}_4 \cdot 7\text{H}_2\text{O}\) was a bit high. Besides, the price of \(\text{MgCl}_2 \cdot 6\text{H}_2\text{O}\) was more expensive than that of \(\text{MgSO}_4 \cdot 7\text{H}_2\text{O}\). Therefore, the precipitant combined \(\text{Na}_2\text{HPO}_4 \cdot 12\text{H}_2\text{O}\) and \(\text{MgSO}_4 \cdot 7\text{H}_2\text{O}\) and was selected to use in experiments.

### 3.3.2. The influence of the initial pH

In the mixture, the initial pH (7.5, 8.0, 8.5, 9.0, 9.5, 10.0, and 10.5) was adjusted using 1N NaOH to study the influence of the initial pH.

The pH is the main driving force for MAP precipitation, and its variation could affect the formation and solubility of MAP crystals.[24] As shown in the Figure 4(B), with the increasing of the initial pH, the ammonia nitrogen removal rate increased, and then declined. When the pH was 9.5, the ammonia nitrogen removal rate was 94.32%, which was the maximum. When the initial pH ranged from 8.5 to 9.5, the ammonia nitrogen removal rate was high.[24] Based on comprehensive consideration of ammonia nitrogen removal efficiency and the cost, the optimal initial pH was 9.0.

The main reaction of MAP precipitation is ionic reaction as reaction (5).

\[
\text{Mg}^{2+} + \text{PO}_4^{3-} + \text{NH}_4^+ + 6\text{H}_2\text{O} \rightarrow \text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O} \ (5)
\]

Na\(_2\)HPO\(_4\) \(\cdot 12\)H\(_2\)O and MgSO\(_4\) \(\cdot 7\)H\(_2\)O are strong electrolyte, which can be completely ionized. So the ionization balance of NH\(_4\)\(^+\) and PO\(_4\)\(^{3-}\) as reactions (6 and 7) showed become controlling factors for MAP precipitation reaction.

\[
\text{NH}_3 + \text{H}_2\text{O} \rightarrow \text{NH}_4^+ + \text{OH}^- \quad (6)
\]

\[
\text{HPO}_4^{2-} \rightarrow \text{H}^+ + \text{PO}_4^{3-} \quad (7)
\]

The reaction (6) showed that higher pH would restrain reaction (6), the concentration of ammonia nitrogen was reduced, which inhibited the precipitation of MgNH\(_4\)PO\(_4\) \(\cdot 6\)H\(_2\)O and the removal of ammonia nitrogen. On the contrary, lower pH would promote the reaction (6), which was not beneficial for the precipitation of MgNH\(_4\)PO\(_4\) \(\cdot 6\)H\(_2\)O and the removal of ammonia nitrogen. But, for the reaction (7), higher pH would promote that reaction, while lower pH would restrain that reaction. Hence, there was an optimal range for the initial pH, in which the concentration of NH\(_4\)\(^+\) and PO\(_4\)\(^{3-}\) was the most
beneficial for the precipitation of MgNH₄PO₄·6H₂O and the removal of ammonia nitrogen. That was consistent with the experimental results.

3.3.3. The influence of the amount of MgSO₄·7H₂O

The reaction mechanism of MAP precipitation indicates that the theoretical molar ratio of Mg²⁺, NH₄⁺, and PO₄³⁻ should be 1:1:1. However, due to the complex composition of garbage leachate, the presence of anion and various types of material which could form complex with Mg²⁺, so part of Mg²⁺ was consumed. On the other hand, landfill leachate also contains many metal ions which may be consumed part of PO₄³⁻. Hence, the influence of the theoretical molar ratio of Mg²⁺, NH₄⁺, and PO₄³⁻ on the removal of ammonia nitrogen was studied.

To study the influence of the amount of MgSO₄·7H₂O, the molar ratio of Mg²⁺, NH₄⁺, and PO₄³⁻ was 0.8:1:1, 0.9:1:1, 1:1:1, 1.1:1:1, and 1.2:1:1 by changing the amount of MgSO₄·7H₂O, while the pH was 9.0, the [NH₄⁺]:[PO₄³⁻] = 1:1, and the mixing speed was 200 r min⁻¹. The test results were shown in Figure 4(C).

As shown in the Figure 4(C), with the increasing amount of MgSO₄·7H₂O, the ammonia nitrogen removal rate increased, and then declined. When the molar ratio of Mg²⁺, NH₄⁺, and PO₄³⁻ was 1:1:1, the ammonia nitrogen removal rate was 95.91%, which was the maximum.

3.3.4. The influence of the amount of MgNH₄PO₄·6H₂O

Based on above experiments, the influence of the amount of MgNH₄PO₄·6H₂O on the removal of ammonia nitrogen was studied by changing the amount of MgNH₄PO₄·6H₂O.

As shown in the Figure 4(D), with the increase in the amount of MgNH₄PO₄·6H₂O, the ammonia nitrogen removal rate also increased. When the molar ratio of NH₄⁺ and PO₄³⁻ ranged from 0.8:10 to 1.2:1.0, the ammonia nitrogen removal rate increased from 75.03 to 99.18%, the concentration of ammonia nitrogen was reduced from 910 to 7 mg L⁻¹, which reached the national discharge standard. When the molar ratio of Mg²⁺, NH₄⁺, and PO₄³⁻ ranged from 1.1:1:1 to 1.1:1:2, the removal rate of ammonia nitrogen increased from 98.94 to 99.18% which did not change significantly, and the MAP precipitation was not completely carried out.[24] Moreover, the amount of total phosphorus in the treated effluent was increased from 33 to 241 mg L⁻¹, which caused phosphorus secondary pollution for water. Therefore, the optimal molar ratio of Mg²⁺, NH₄⁺, and PO₄³⁻ was 1.1:1:1.1.

4. Conclusion

This experiment indicated that the "Ultrasound/Fenton oxidation – MAP chemical precipitation" method was an effective method to remove COD and ammonia nitrogen from old landfill leachate. The COD concentration of the treated effluent decreased from 842 to 77 mg L⁻¹, while the ammonia nitrogen decreased from 910 to 11 mg L⁻¹. When pH was 4, the Fe²⁺ dosage was 0.10 mol L⁻¹, the mole ratio of H₂O₂/Fe²⁺ was 4:1, ultrasonic power was 125 W, and the COD removal rate of Ultrasound/Fenton oxidation was 90.88%. And the effect of Ultrasound/ Fenton oxidation treatment was better than the superposition of the effect of the two treatments. Besides under the optimum condition ([Mg²⁺]:[NH₄⁺]:[PO₄³⁻] = 1:1:1:1, initial pH = 9.0), the concentration of ammonia nitrogen of the effluent treated by MAP precipitation met the national primary emission standards.

Notes on Contributors

Jing Zhang is a PhD scholar at School of Civil Engineering, Wuhan University, Wuhan 430072, China. Her research interests spanned from the landfill leachate treatment, absorption, sludge dewatering to anaerobic digestion. Born in China, educated in China, and living in China.

Tao Yang is a graduate student of School of Civil Engineering, Wuhan University, Wuhan 430072, China. Her research interests spanned from the landfill leachate treatment, absorption to Sludge dewatering. Born in China, educated in China, and living in China.

Hongyu Wang is an associate professor of School of Civil Engineering, Wuhan University, Wuhan 430072, China. Her research interests spanned from the landfill leachate treatment, Sludge dewatering, nitrogen and phosphorus removal, anaerobic granular sludge to absorption to anaerobic digestion. Born in China, educated in China, and living in China.

Kai Yang is a professor of School of Civil Engineering, Wuhan University, Wuhan 430072, China. Her research interests spanned from the landfill leachate treatment, absorption, sewage treatment, nitrogen and phosphorus removal, anaerobic granular sludge to anaerobic digestion. Born in China, educated in China, and living in China.

Cheng Fang is a graduate student of School of Civil Engineering, Wuhan University, Wuhan 430072, China. Her research interests spanned from the landfill leachate treatment, absorption to sludge dewatering. Born in China, educated in China, and living in China.

Bin Lv is an associate professor of School of School of Environmental Engineering, Wuhan Textile University, Wuhan 430073, China. Her research interests spanned from the landfill leachate treatment, absorption, anaerobic digestion to sludge dewatering. Born in China, educated in China, and living in China.

Xiaojun Yang is an associate professor of School of School of Environmental Engineering, Wuhan Textile University, Wuhan 430073, China. Her research interests spanned from the landfill leachate treatment, absorption...
to sludge dewatering. Born in China, educated in China, and living in China.

Disclosure statement
No potential conflict of interest was reported by the authors.

Funding
This work was financially supported by the Natural Science Foundation of Hubei Province, China [grant number 2013CFB289], [grant number 2013CFB308].

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