Salicylhydroxamic acid is an excellent collector of oxidizing ore, and it has an efficient collection performance for tungsten molybdenum ore. However, the utilization ratio of salicylhydroxamic acid is relatively low in the flotation process, and a large amount of flotation wastewater discharged might cause damage to the water environment. This study mainly compared the effects of natural sunlight degradation, ozonation, and Fenton oxidation processes on the treatment of salicylhydroxamic acid wastewater from W–Mo mineral processing. The results showed after 30 hours degradation by natural sunlight, the CODcr removal rate of wastewater was only 25.99%. When the initial pH was 8, the dosage of O3 was 1.3 mg/L and the reaction time was 60 minutes; O3 oxidation could remove 40.37% CODcr from wastewater, and the BOD5/CODcr value increased to higher than 0.3 after 15 min reaction. Under the Fenton oxidation conditions such as initial pH 3, H2O2 dosage 0.96 g/L, and the molar ratio of H2O2 to Fe2+ 2:1, 90.43% CODcr could be removed from flotation wastewater after 90 min reaction, and the BOD5/CODcr value was obviously improved. Fenton oxidation was a high efficient processing technology for salicylhydroxamic acid wastewater, and the effluent could meet the discharge and reuse emission standard requirements in China.

1. Introduction

W–Mo ore is one of the dominant minerals in China due to abundant reserves, high utilization value, and high economic benefits. According to the data from the China Mineral Resources Report, up to the end of 2016, the national tungsten mineral resource reserves increased by 6% to 101.955 million tons and occupied the first place in the world [1]. A large amount of flotation wastewater was produced during the mineral processing which was the absolutely tache before utilization of mineral resources. Based on statistic data, the water consumption of per ton mineral with flotation is about 4~7 m³, while the gravity separation process is high to 6~15 m³ [2]. Due to the low utilization efficiency of the flotation process, large amount of flotation reagents remained in the flotation wastewater which was certainly toxic to ecological environment.

During the W–Mo ore flotation process, fatty acids, amines, citric acid, and phosphoric acid are the commonly used collectors which have the disadvantage of poor selectivity, low flotation efficiency, and certain toxicity. Salicylhydroxamic acid is an innovative collector, which has lone pair of electrons of oxygen atom and nitrogen atom with the similar positions in the hydroxyl group structure. It is beneficial to coordinate with metal cations on the surface of tungsten ore to form chelate ring. Meanwhile, the stability of the chelate is enhanced by increasing the density of electron clouds of atomic oxygen with the α-conjugation effect, which makes the salicylhydroxamic acid to be strongly adsorbed on the mineral surface [3, 4], thus improving the mineral flotation efficiency. However, the hydroxyamidine group and a stable alkyl benzene ring in the molecular structure of salicylhydroxamic acid causes a certain degree of biological toxicity and poor biodegradability. The common treatment methods for flotation wastewater in practical engineering are natural sunlight degradation, coagulation, and flocculation, which are difficult to achieve the removal effect.

In recent years, advanced oxidation processes (AOPs) were considered as methods with application prospect to
transform nonbiodegradable pollutants into harmless substances [5]. The AOPs can effectively mineralize a variety of organic pollutants by generating highly active and nonselective free radical like hydroxyl radical (·OH) [6]; meanwhile, the AOPs attract a wide spread attention to the treatment of industrial wastewater containing toxic organic pollutants [7]. The reaction mechanism of Fenton oxidation mainly involves the production of ·OH by Fe²⁺ and H₂O₂ under acidic conditions [8]. The oxidation capacity of ·OH is about 10⁶–10⁸ times stronger than O₃ or oxygen. The ·OH oxidation process is nonspecific [9] and can effectively degrade residual organic contaminants in wastewater. Ozone oxidation technology is also based on the hydroxyl radical with a higher redox potential to degrade organic pollutants which can greatly shorten the reaction time [10, 11] and achieve the purpose of harmless mineralization of refractory organics [12]. There are few researches at present on the AOPs applied in salicylhydroxamic acid wastewater from W–Mo mineral processing. This study focused on the removal effect of W–Mo mineral flotation wastewater treatment with different processes such as advanced oxidation and natural photodegradation, moreover optimized process parameters, and provided reference for practical treatment project of salicylhydroxamic acid wastewater from W–Mo mineral processing.

2. Materials and Methods

2.1. Synthetic Salicylhydroxamic Acid Wastewater. The experimental wastewater prepared with salicylhydroxamic acid simulated the wastewater quality of a tungsten-molybdenum polymetallic ore tailings reservoir in Hunan province. Meanwhile, taking into account the residual ratio of the main flotation reagents in the actual flotation wastewater, the simulated wastewater was prepared with four flotation reagents such as salicylhydroxamic acid 50 mg/L, No. 2 oil 50 mg/L, sodium oleate 100 mg/L, and butyl xanthate 100 mg/L, which brought 300 mg/L CODcr concentration.

The water quality of the simulated salicylhydroxamic acid wastewater, the first-grade discharge standard in the Integrated Wastewater Discharge Standard (GB 8978), and the water quality of the reuse of urban recycling water-water quality standard for industrial uses (GB/T 19923) are listed in Table 1.

2.2. O₃ Treatment Procedure. The experimental scheme of O₃ oxidation is as shown in Figure 1. The reactor setup included a reactor made of high borosilicate glass to prevent oxidation and chemical corrosion and an ozone generator (3S-A5, China). The height, outer diameter, and inner diameter of the reactor was 1000 mm, 70 mm, and 60 mm, respectively, and the effective volume was 2.8 L. The gas distributor in the reactor was a titanium plate with about 20–30% open porosity, and the average pore size of micropores was about 17 μm.

The O₃ treatment procedure was intermittent operation. The simulated wastewater was injected into the reactor through a peristaltic pump, then turned on the ozone generator, and maintained the flow rate of O₃ gas at 100 mL/min by controlling the gas flow meter. Ozone mixture was introduced into the gas distribution plate after the gas flow was stable and then adjusted the power knob of the ozone generator to control the dosage of O₃ in the range of 1–10 mg/L. A series of batch tests were employed to determine the degradation of pollutants under different stepwise reaction times, initial pH value, and O₃ dosages.

2.3. Fenton Treatment Procedure. Samples of 450 mL simulated salicylhydroxamic acid wastewater were adjusted to preselected pH value with 10% H₂SO₄ or NaOH and then put into the reactor. Different dosages of FeSO₄·7H₂O and H₂O₂ (mass concentration was 30%) were added into the former solution. Samples were collected at different reaction times, and the pH was adjusted to 7–9 with 10 mol/L NaOH solution and then settled for 30 minutes. The supernatant was sampled and treated with 50°C water bath and heated for 2 hours to ensure the residual H₂O₂ in the solution completely volatilized [13]. CODcr or BOD₅ of treated supernatant was analyzed to evaluate the treatment effect.

2.4. Chemicals and Analyses. Analytical grade salicylhydroxamic acid and sodium oleate were purchased from Aladdin (Shanghai, China). Industrial grade butyl xanthate sodium and No. 2 oil were purchased from Zhuzhou mineral processing reagent company (Hunan, China). Analytical grade ferrous sulfate heptahydrate, sulfuric acid, sodium hydroxide, potassium iodide, soluble starch, and sodium

| Items                   | pH  | BOD₅ (mg/L) | CODcr (mg/L) | NH₃-N (mg/L) | TP (mg/L) |
|-------------------------|-----|-------------|--------------|--------------|-----------|
| Simulated wastewater    | 9.5–10 | 60–70       | 300–350      | 8.5–9        | <0.01     |
| Discharge standard      | 6–9  | 30          | 100          | 15           | 0.5       |
| Reuse standard          | 6.5–8.5 | 10          | 60           | 10           | 1         |

Table 1: The water quality of simulated flotation wastewater and standard concentration limits.

![Figure 1: Schematic diagram of experimental devices used in O₃ oxidation.](image-url)
thiosulfate were purchased from Sinopharm (Beijing, China). The pH value was measured by pH meter (PHS-3C, Raytheon, China), CODcr was analyzed with UV-Vis spectrophotometer (UV3000PC, Mapada, China), BOD5 was detected with five-day biochemistry culture method, and O3 concentration in gas was measured by iodometry [14].

3. Results and Discussion

3.1. Degradation of Simulated Wastewater by Natural Sunlight.

A beaker containing 500 mL simulated wastewater was put in natural sunshine outside and irradiated for different times. A control group was put in a place without natural light exposure. The CODcr removal ratio of the wastewater is shown in Figure 2. Natural light degradation had a limited removal effect on organic pollutants in simulated wastewater. The CODcr removal ratio increased gradually with the extension of the sun illumination time. When the sun illumination time was 30 h, the CODcr removal ratio reached the highest 25.99% mainly due to easy degradation of butyl xanthate under sunshine which was in accordance with the phenomena recorded in the literature [15]. Without sunshine radiation, the CODcr removal ratio of the control group increased to about 5% within 6 h.

In order to further explore the change in organic matter structure in the wastewater illuminated by sunlight, infrared spectrum analysis was performed on the simulated wastewater before and after sunlight degradation and the results are shown in Figure 3. Compared the infrared spectra of the wastewater before and after degradation with sunlight, the characteristic absorption peak positions did not change obviously, no new absorption peaks appeared, and the intensity of the absorption peak of the benzene ring C–C skeleton was almost unchanged; it meant that sunlight degradation could not greatly change the molecular structures of organic matters in simulated wastewater, especially the benzene ring structure could not be destroyed. Thus, natural sunlight has limited ability to degrade pollutants in the flotation wastewater, and the treated effluent could not meet the discharge or reuse standard requirements.

3.2. O3 Oxidation Degradation of Simulated Wastewater

3.2.1. Effect of Reaction Time on Treatment. The experimental conditions were set as O3 dosage = 2.4 mg/L and pH = 4, 6, and 10, respectively; the CODCr removal ratio of simulated wastewater by O3 oxidation is shown in Figure 4.

The removal ratios of CODCr all rose rapidly under different pH conditions within the first 15 min of ozone oxidation reaction, and it was mainly due to the higher initial concentration of aromatic compounds, unsaturated bond-containing compounds, and heterocyclic compounds capable of providing electron groups (–OH and –NH2) in the wastewater. Meanwhile, O3 molecules and ·OH were electrophilic to easily oxidize the pollutants; thus, the removal ratio of CODCr increased rapidly. Prolonging the reaction time from 15 to 60 min, the CODCr removal ratio increased less than 10%. Continuously increasing the reaction time could not change the CODCr removal ratio significantly.
because of the residual organic pollutants in the wastewater mainly being small organic molecules such as formaldehyde and formic acid which were difficult to be mineralized by O₃.

3.2.2. Effect of Initial pH on Treatment. The treatment of ozone oxidation on COD₅₉ removal was explored by controlling the dosage of O₃ 2.4 mg/L, reaction time 60 min, and adjusting pH 2, 4, 6, 8, and 10, respectively, as the results in Figure 5.

The initial pH of the wastewater had a significant effect on COD₅₉ removal by O₃ oxidation. The COD₅₉ removal ratio reached the maximum 51.19% when pH increased from 2 to 8, but it decreased when the initial pH rose to 10. In acidic conditions, ·OH generation was inhibited, and O₃ molecules played an active role in the oxidation process which was selective and low reaction to make the organic pollutants degradation rate slower. Under weak alkaline condition, it was more conducive to the oxidation degradation of organic pollutants in wastewater by ozone, and it should owe to the increase in the concentration of hydroxide ion as the pH value enhanced which acted as the initiator to promote O₃ molecule and generated the ·OH through the reactions as follows:

\[
O_3 + \text{OH}^- \rightarrow \text{HO}_2^- + \cdot \text{O}_2^- \quad (1)
\]

\[
O_3 + \text{HO}_2^- \rightarrow \text{HO}^- + 2\text{O}_2 \quad (2)
\]

Under the weak alkaline condition, the organic pollutants’ degradation reaction is mainly based on the indirect oxidation of ·OH, the reaction rate was faster, and the oxidation ability was stronger, thus improving the removal effect of organic pollutants. When pH was higher to 10, on the one hand, the generation rate of ·OH by ozone decomposition was too higher, which resulted in quenching reaction occurred among the excessive generation of radicals as ·OH to reduce the removal efficiency of ozone on organic pollutants. On the other hand, CO₂ generated from organic pollutants mineralized could not effectively overflow from wastewater in the strong basic condition; therefore, HCO₃⁻ and CO₃²⁻ were the main existence forms which could quickly consume the radicals as ·OH. Meanwhile, some of the decomposition products of organic pollutants like aromatic group might inhibit the radicals generated. These factors led to the decrease in COD₅₉ removal efficiency.

3.2.3. Effect of O₃ Dosage on Treatment. At the optimum conditions such as reaction time 60 min, pH 8, and O₃ mixture flow 100 mL/min, O₃ dosage was controlled within 1–10 mg/L by regulating the power of the O₃ generator and influent COD₅₉ concentration 300–350 mg/L; the removal of COD₅₉ from wastewater by ozone oxidation is displayed in Figure 6.

As the dosage of O₃ increased from 1.3 mg/L to 5.5 mg/L, the removal ratio of COD₅₉ gradually improved from 40.37% to 55.46% and then tended to be stable by continuously adding O₃ dosage. Low dosage of O₃ produced less strong oxidation substances such as ·OH in the wastewater which caused poorer oxidation effect and longer reaction time. With the increase in O₃ dosage, more ·OH was produced and the oxidation rate increased. Until the O₃ dosage was added to 5.5 mg/L, the dissolved amount of O₃ molecules in the wastewater tended to be saturated, the excess O₃ gas could not be used effectively, and the effluent still could not meet the discharge or reuse standard requirements. Ozone oxidation might be an assistant treatment for flotation wastewater.

3.2.4. Effect of O₃ Oxidation on the Biodegradability of Wastewater. The biodegradability of simulated wastewater by O₃ oxidation at different times was discussed based on the experimental conditions such as O₃ dosage 1.3 mg/L and pH 8; the results are shown as Figure 7. O₃ oxidation could obviously increase BOD₅/COD₅₉ value of wastewater to higher than 0.3 when the reaction time was 15 min and reached the maximum value 0.549 as the reaction time prolonged to 30 min. O₃ and ·OH had a strong oxidation effect and could break down the hard-degradable organics.
into small-molecule intermediates by chain-breaking and ring-opening to increase the biodegradability of wastewater. As the reaction time was up to 60 min, the intermediate product from oxidative degradation played the dominant role which lead to faster degradation of BOD₅ and a corresponding decrease of BOD₅/CODcr value in the wastewater.

### 3.3. Fenton Oxidation of Simulated Wastewater

#### 3.3.1. Effect of Reaction Time on Treatment

The experimental conditions of Fenton oxidation were initial pH = 4, H₂O₂ dosage = 0.48 g/L, and FeSO₄·7H₂O dosage = 0.196 g/L (the molar ratio of H₂O₂ to Fe²⁺ was 5:1); the reaction time was 15 min, 30 min, 60 min, 90 min, and 120 min, respectively. The experimental results of CODcr concentration and the removal ratio are shown in Figure 8.

According to the reaction time, the CODcr removal effect of Fenton oxidation was obviously divided into two stages: CODcr removal ratio rapidly increased to more than 60% within 15 min, while the increasing trend was slowly during 15 to 120 min. In the initial stage of Fenton reaction, the catalytic reaction rate was faster and the production of ·OH was more due to the high concentration of H₂O₂ and Fe²⁺; most of the organic pollutants in the wastewater were effectively degraded. With increasing reaction time, the H₂O₂ concentration decreased which caused the reduction of ·OH generation and the degradation rate slowed down gradually. Based on comprehensive consideration of economy and efficiency, the optimum reaction time was selected as 90 min, and CODcr removal ratio reached 79%.

#### 3.3.2. Effect of Molar Ratio of H₂O₂ to Fe²⁺ on Treatment

The initial conditions were set as pH = 4 and H₂O₂ dosage = 0.48 g/L; the dosage of FeSO₄·7H₂O was changed to different molar ratios of H₂O₂ to Fe²⁺: 1:1, 2:1, 5:1, 10:1, and 20:1, respectively. The effect of reaction time on CODcr removal ratio by Fenton oxidation is shown in Figure 9. The changing trends of the CODcr removal ratio with the reaction time at different molar ratios of H₂O₂ to Fe²⁺ had almost the similar tendency, within the first of 15 min reaction time; the removal ratio of CODcr increased rapidly and then improved slowly during 15 to 120 min reaction time. When the molar ratio of H₂O₂ to Fe²⁺ was 2:1 and the reaction time was 90 min, the CODcr removal ratio reached the maximum value of more than 80%.

The ·OH generation during the reaction process mainly included two stages as follows:

\[
\text{Fe}^{2+} + \text{H}_2\text{O}_2 \rightarrow \text{Fe}^{3+} + \cdot\text{OH} + \text{OH}^- \quad (3)
\]

\[
\text{Fe}^{3+} + \text{H}_2\text{O}_2 \rightarrow \text{Fe}^{2+} + \cdot\text{HO}_2 + \text{H}^+ \quad (4)
\]

Fe²⁺ in the wastewater acted as catalyst. When molar ratio of H₂O₂ to Fe²⁺ was 2:1, it just met the theoretical demand for Fe²⁺ in the ·OH generation reaction, and the catalytic efficiency of Fe²⁺ and the production of ·OH could achieve...
the highest level. If the molar ratio was greater than 2:1, the concentration of Fe$^{2+}$ in the system was lower to decrease the rate of catalysis, the ·OH yield, and the removal rate in the wastewater. When the molar ratio decreased to 1:1, the concentration of Fe$^{2+}$ in the system was too high, the excess Fe$^{2+}$ would also react with ·OH to cause redox reaction which promoted the decomposition of H$_2$O$_2$ and declined the removal efficiency of organic pollutants.

3.3.3. Effect of Initial pH on Treatment. The initial pH was one of the important factors indirectly affecting the activity and production of ·OH and resulting in a certain limitation on the oxidative capacity of Fenton reaction [16]. The initial conditions were set as H$_2$O$_2$ dosage = 0.48 g/L, the molar ratio of H$_2$O$_2$ to Fe$^{2+}$ = 2:1, and reaction time = 90 min; pH was adjusted to 2, 3, 4, 5, and 6, respectively. The experimental results are displayed in Figure 10. Fenton oxidation generally possessed a better treatment effect on wastewater with the decrease in pH. The best removal ratio of COD$_{Cr}$ was 84.4% at initial pH = 3, and the concentration of COD$_{Cr}$ was lower than 48.36 mg/L. As the pH value was higher than 3, the concentration of hydroxide in the wastewater increased gradually and the generation of ·OH was inhibited; meanwhile, Fe$^{2+}$ precipitated and affected catalytic efficiency. When the pH was lower than 3, the H$^+$ concentration in the system increased which inhibited the reduction of Fe$^{3+}$ to Fe$^{2+}$ and hindered the conversion equilibrium between Fe$^{3+}$ and Fe$^{2+}$ and thus reduced the efficiency of the catalytic reaction [17].

3.3.4. Effect of H$_2$O$_2$ Dosage on Treatment. The experimental conditions were selected as follows: pH = 3, the molar ratio of H$_2$O$_2$ to Fe$^{2+}$ = 2:1, and reaction time = 90 min; the dosage of H$_2$O$_2$ was 0.24 g/L, 0.48 g/L, 0.72 g/L, 0.96 g/L, and 1.2 g/L, respectively. The effect of Fenton oxidation on COD$_{Cr}$ is shown in Figure 11. When the dosage of H$_2$O$_2$ was increased from 0.24 to 0.96 g/L, the COD$_{Cr}$ removal ratio increased rapidly from 71.63% to 90.43% and the COD$_{Cr}$ was decreased from 85.1 mg/L to 28.7 mg/L. When the dosage of H$_2$O$_2$ was continuously increased to 1.2 g/L, COD$_{Cr}$ removal ratio decreased obviously. When the dosage of H$_2$O$_2$ was less than 0.96 g/L, the reaction rates of equations (5) and (6) became slower and the amount of ·OH produced decreased and reduced the removal ratio of COD$_{Cr}$. With the increase in H$_2$O$_2$ dosage, the concentration of ·OH in the system increased and the degradation rate of organic pollutants accelerated. The oxidation reaction of ·OH was not selective, the excess dosage of H$_2$O$_2$ resulted in reaction equations (3) and (4) which became the dominant reactions in the system, and H$_2$O$_2$ acted as a scavenger to reduce the concentration of ·OH [18]:

- ·OH + H$_2$O$_2$ $\rightarrow$ H$_2$O + HO$_2$; (5)
- ·OH + HO$_2$ $\rightarrow$ H$_2$O + O$_2$ (6)

3.3.5. Effect of Fenton Oxidation on Biodegradability of Wastewater. The concentrations of COD$_{Cr}$ and BOD$_5$ of the simulated wastewater were 320 mg/L and 61.18 mg/L; the BOD$_5$/COD$_{Cr}$ was 0.19. The effect of Fenton oxidation on the biodegradability of wastewater was discussed under the experimental conditions as pH = 3, the molar ratio of H$_2$O$_2$ to Fe$^{2+}$ = 2:1, and the dosage of H$_2$O$_2$ = 0.96 g/L; reaction time was 15 min, 30 min, 45 min, 60 min, and 90 min, respectively. The results are exhibited in Figure 12.

With the increase in reaction time, the concentrations of COD$_{Cr}$ and BOD$_5$ in wastewater declined continuously. Within 60 min reaction time, the declining rate of COD$_{Cr}$ concentration was significantly faster than BOD$_5$, BOD$_5$/COD$_{Cr}$ value increased rapidly from 0.19 to 0.382, and the biodegradability of wastewater was improved. While the reaction time was prolonged to 90 min, BOD$_5$/COD$_{Cr}$ value dropped off rapidly to 0.17. Within the first 60 min reaction, difficult-to-biodegrade pollutants in the wastewater were rapidly degraded to biodegradable intermediates, and a
portion was directly mineralized to CO₂ and H₂O which resulted in increased BOD₅/CODCr. Due to prolonged reaction time, the concentration of strong oxidation substances and macromolecular organic pollutants decreased, and the reaction in the system was dominated by the oxidative decomposition of intermediate products. The removal rate of CODCr was lower than the BOD₅; thus, the BOD₅/CODCr value declined.

4. Conclusions

Salicylhydroxamic acid wastewater from the W–Mo ore flotation process is difficult to be treated by coagulation-settlement technology, and the effluent is difficult to meet the requirements of the first-grade discharge standard in the Integrated Wastewater Discharge Standard (GB 8978) and the water quality of the reuse of urban recycling water-water quality standard for industrial uses (GB/T 19923). In practical engineering, tailing reservoir is generally used for a final section to treat the flotation wastewater by natural sunlight degradation, but it was proved in this paper that the degradation of natural sunlight had a limited effect on the simulated flotation wastewater, the CODcr removal ratio could reach the highest 25.99% after 48 h sun illumination, and sunlight could not degrade the mineral processing reagent with benzene ring structure. Sunlight degradation was not an effective treatment method for practical flotation wastewater. Under varied operation parameters of reaction time, initial pH, and O₃ dosage, ozonation was proved to be effective for simulated salicylhydroxamic acid wastewater, the CODcr removal ratio could reach the maximum 55.46% at the optimum experimental conditions, and the BOD₅/CODcr value increased to 0.549 after 30 min reaction. But the effluent could not reach the discharge or reuse standard, and ozonation could be the prepositional disposal combined with biochemical treatment. Ozonation is a high-power consumption treatment method, treatment cost was necessary to be considered in actual engineering, and the BOD₅/CODcr value could be controlled as 0.35 after 15 min reaction to meet the demand of biochemical treatment. Fenton oxidation was more effective than sunlight and ozonation process, under the experimental conditions such as pH 3, H₂O₂ dosage 0.96 g/L, the molar ratio of H₂O₂ to Fe²⁺ 2:1, and the reaction time 90 min; CODCr concentration and the removal ratio in the flotation wastewater were 30.07 mg/L and 90.43%, which was far below the prescribed emission or reuse standards. Fenton oxidation could be of single-use to treat the salicylhydroxamic acid wastewater which was more simple than the ozonation process, but the consumption of H₂O₂ and Fe₂(SO₄)₃·7H₂O was large, and massive precipitate was generated which brought inconvenient operation in practical engineering.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was supported by the National Key Research and Development Project (2018YFC0406403-1).

References

[1] W. Liu, C. J. Moran, and S. Vink, “A review of the effect of water quality on flotation,” Minerals Engineering, vol. 53, no. 10, pp. 91–100, 2013.
[2] Z. G. Wang, C. H. E. N. Xiang-xiang, Y. W. Zhang et al., “New process of treatment wastewater from Lead -Zinc concentrator of Jindong mining company,” Metal Mine, vol. 31, no. 6, pp. 126–128, 2013.
[3] L. Che, Y. Yu, J. Pang et al., “Synthesis, properties and role mechanism of hydroximic acid as co-lectors of RE mineral flotation,” Chinese Rare Earths, vol. 25, no. 6, pp. 74–79, 2004.
[4] W. Liu, B. Wang, and S. Dai, “Current application and development prospect of hydroximic acid in flotation,” Non-Ferrous Mining and Metallurgy, vol. 22, no. 4, pp. 25–27, 2006.
[5] S. Esplugas, P. L. Yue, and M. I. Pervez, “Degradation of 4-chlorophenol by photolytic oxidation,” Water Research, vol. 28, no. 6, pp. 1323–1328, 1994.
[6] M. I. Litter, Introduction to Photochemical Advanced Oxidation Processes for Water Treatment Environmental Photochemistry Part II, pp. 325–366, Springer, Berlin, Heidelberg, Germany, 2005.
[7] L. R. Rad, I. Haririan, and F. Divsar, “Comparison of adsorption and photo-Fenton processes for phenol and para-cetamol removing from aqueous solutions: single and binary systems,” Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, vol. 136, pp. 423–428, 2015.
[8] P. T. Almazán-Sánchez, I. Linares-Hernández, V. Martínez-Miranda, V. Lugo-Lugo, and R. M. Guadalupe, “Wastewater treatment of methyl methacrylate (MMA) by Fenton’s reagent and adsorption,” Catalysis Today, vol. 220-222, pp. 39–48, 2014.
[9] D. O. Energy, “Airborne laser induced fluorescence imaging: innovative technology summary report,” Technical Reports, Office of Scientific & Technical Information, Denton, TX, USA, 1999.

[10] S. Dai, J. Liu, W. Song et al., “Application of advanced treatment for refractory organic wastewater with ozone oxidation method,” Water Sciences and Engineering Technology, vol. 136, no. 2, pp. 24–26, 2007.

[11] S. Deng, M. Bai, X. Bai et al., “Characteristics and chemical reaction of hydroxyl radical,” Journal of Dalian Maritime University, vol. 30, no. 3, pp. 62–64, 2004.

[12] W. Jiang, X. Peng, L. Zhang et al., “Research progress in treatment of xanthate in mineral concentration wastewater by advanced oxidation technology,” Metal Mine, vol. 498, no. 12, pp. 123–129, 2017.

[13] X. Zhu, J. Tian, R. Liu, and L. Chen, “Optimization of Fenton and electro-Fenton oxidation of biologically treated coking wastewater using response surface methodology,” Separation and Purification Technology, vol. 81, no. 3, pp. 444–450, 2011.

[14] D. Zhang, Y. Wen, and X. Gao, “A comparative study on the calibration of ozone concentration with three potassium iodide methods,” Journal of Beijing University of Technology, vol. 11, no. 1, pp. 97–103, 1985.

[15] Z. Zhang, T. Zeng, Y. Nie et al., “Natural photolysis and photocatalytic degradation characteristics of reagent for beneficiation in gannan region,” Nonferrous Metals Engineering, vol. 8, no. 5, pp. 50–56, 2018.

[16] W. A. Simon, E. Sturm, H.-J. Hartmann, and U. Weser, “Hydroxyl radical scavenging reactivity of proton pump inhibitors,” Biochemical Pharmacology, vol. 71, no. 9, pp. 1337–1341, 2006.

[17] E. Lipczynska-Kochany, G. Sprah, and S. Harms, “Influence of some groundwater and surface waters constituents on the degradation of 4-chlorophenol by the Fenton reaction,” Chemosphere, vol. 30, no. 1, pp. 9–20, 1995.

[18] E. C. Catalkaya and F. Kargi, “Effects of operating parameters on advanced oxidation of diuron by the fenton’s reagent: a statistical design approach,” Chemosphere, vol. 69, no. 3, pp. 485–492, 2007.