

Article

Effects of Al(III) Ions at Magnetite Flotation from Quartz by Dodecylamine Al(III)

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Abstract: The flotation separation of magnetite and quartz is a long-term challenge for the beneficiation industry. For high-quartz magnetite, conventional flotation shows poor separation effect, resulting in the waste of resources and low flotation efficiency. In this paper, dodecylamine acts as a collector and Al(III) ions in water act as a depressant to selectively separate magnetite and quartz at high alkalinity. The experimental results are analyzed by a micro-flotation experiment, solution chemical calculation, zeta potential, contact angle measurement, and Fourier transform infrared spectroscopy (FTIR). The results of micro-flotation experiments showed that Al(III) ions in water inhibited magnetite more strongly than quartz. The calculation results of solution stoichiometry and zeta potential showed that the phase formed by Al(III) ions on the surface of magnetite and quartz are mainly $\text{Al}(\text{OH})_{3(s)}$, which covers the surface of magnetite and quartz. The contact angle measurement results showed that with the addition of Al(III) ions, the contact angle of magnetite varies significantly than that of quartz, and the floatability of magnetite is lower than that of quartz. The FT-IR results further indicated that the addition of Al(III) ions could hinder the adsorption of dodecylamine on the magnetite surface. Meanwhile, the addition of Al(III) ions has no obvious effect on the adsorption of dodecylamine on the quartz surface.

Keywords: magnetite; quartz; Al(III) ions; dodecylamine; flotation; adsorption



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1. Introduction

Iron resources are important metal materials in life and are widely used in chemical products, the electronic industry, powder metallurgy and the machinery industry, and other fields [1–4]. Cationic reverse flotation is a widely used technology to improve the quality of iron ore concentrates and reduce impurities, depending on the properties and process conditions of iron oxide ore [5–7]. However, magnetite often coexists with the gangue mineral quartz, which hinders the effective utilization of magnetite. Therefore, it is necessary to use metal ions and cationic collectors in water for the reverse flotation of magnetite, which is the most widely used flotation technology in the iron ore industry [8–10].

In the mineral flotation system, process water circulation, mineral dissolution, polyaluminum reagent addition, etc., which all generate a variety of ions, have an important impact on mineral flotation. A large number of studies have shown that the addition of metal ions such as Ca^{2+} , K^{+} , Mg^{2+} , Na^{+} , etc., to water can effectively improve the flotation separation of magnetite and quartz [11–13]. These metal ions in water are mainly low in price. In the case of adding collectors or metal ions, quartz and magnetite were floated, and it was found that amine collectors had stronger collecting performance on quartz than magnetite; therefore, it shows more advantages in reverse flotation. The form of cations adsorbed on the mineral surface increases the active sites on the mineral surface, thereby

promoting the adsorption of cationic collectors on the mineral surface [12,14]. However, these metal ions include Fe^{2+} , Fe^{3+} , Al^{3+} , etc. They not only act as collectors, but also can be adsorbed on the surface of siliceous gangue minerals (quartz). Therefore, metal ions have an inhibitory effect on silica-containing gangue minerals, making it difficult to achieve the ideal index during the flotation process [15–17]. Although these low-valence metal ions have a good separation effect from calcium-containing gangue minerals, high-valence Al(III) ions will dissolve in the circulating water, which may affect the flotation separation effect of magnetite and quartz.

In our previous study, it was mentioned that Al(III) ions have a great influence on iron oxide ore [18–20]. Therefore, the effect of Al(III) ions in water on the flotation separation of magnetite and quartz was investigated. In addition, previous studies have improved the flotation feasibility of magnetite and quartz by using low-valent metal ions in water while ignoring the effect of high-valent metal ions on the flotation separation of magnetite and quartz. Therefore, underestimating the importance of Al(III) ions in water in flotation may lead to different flotation behavior of minerals and potential recovery losses.

For the above reasons, a study was carried out using AlCl_3 solution as the source of Al(III) ions and dodecylamine as the collector. Furthermore, the study set out to determine how high-valence metal ions in water affect the flotation separation of magnetite and quartz. The effects of Al(III) ions in water on the surface properties and adsorption mechanism of magnetite and quartz flotation separation were studied and analyzed by solution chemical calculation, zeta potential analysis, contact angle measurement and Fourier transform infrared spectroscopy (FTIR). The findings provide useful guidance for the flotation separation of magnetite and quartz.

2. Materials and Methods

2.1. Materials and Reagents

The magnetite and quartz samples used in this study were obtained from mines in Yunnan, China. The original ore sample was crushed into 2 mm particles and impure sample impurities were thrown away by hand under an optical microscope. The X-ray diffraction pattern of the pure sample is shown in Figure 1. Analysis showed that these samples were of high purity and could therefore be considered pure minerals. A three-head grinding machine (XPM- $\phi 120 \times 3$, Ganzhou, China) was used for grinding. The ground products were screened and particles in the size range of 38–74 μm were preserved for the micro-flotation experiments and subsequent analysis.

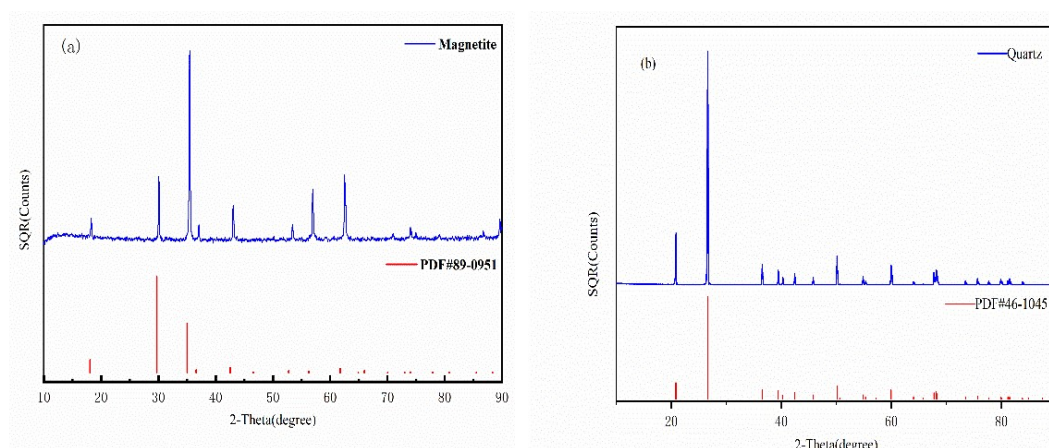


Figure 1. X-ray diffraction patterns of (a) pure magnetite and (b) pure quartz samples.

The cationic collector used in this study was analytical grade dodecylamine($\text{C}_{12}\text{H}_{27}\text{N}$), and other reagents such as aluminum chloride were all analytical grade. Analytical grade dodecylamine and acetic acid were mixed in different mass ratios to help dissolve, and then deionized water was added to prepare a solution with a mass fraction of 0.5%. Hydrochloric

acid (HCl) and sodium hydroxide (NaOH) were used to adjust the pH values, and fresh deionized water was used throughout the experiments (Figure 2).

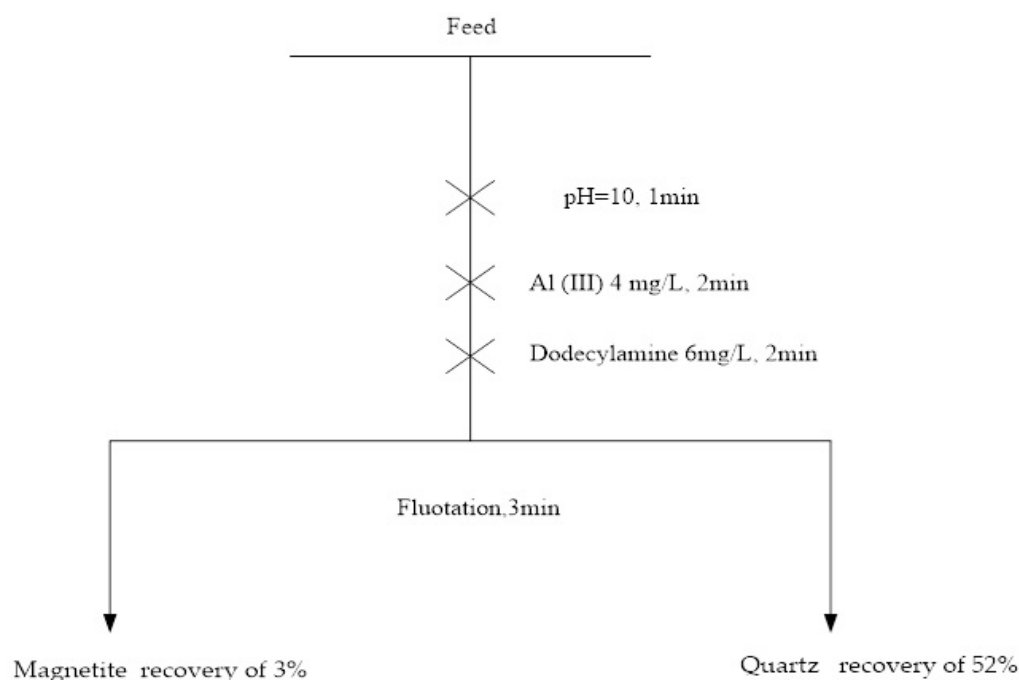


Figure 2. Flowsheet of single flotation test.

2.2. Micro-Flotation Experiments

The micro-flotation experiments were performed using a 50 dm³ cell (XFGC) (Prospecting Machinery Factory, Jilin, China) flotation machine at 25 °C temperature. The impeller speed was fixed at 1800 rpm, and the airflow rate was 0.05 m³/h. The operations involved in the micro-flotation experiment were as follows: (1) 2 g single mineral or binary mixed minerals (1 g magnetite plus 1 g quartz) were placed into the cell with 30 dm³ deionized water, and the pH of the pulp was adjusted by adding pH regulators and agitating for 1 min. (2) High valence metal ions were added and stirred for 2 min. When necessary, the corn starch was added and stirred for 2 min. (3) Dodecylamine was added and stirred for 2 min. After adding each required reagent, it was aerated for three minutes and the concentrate manually scraped. (4) The concentrate was collected and filtered, dried and weighed to calculate flotation recovery. The flotation recovery ε (%) of the single minerals and binary mixed minerals were respectively calculated by

$$\varepsilon = \frac{m1}{m1 + m2} \times 100\% \quad (1)$$

$$\varepsilon = \frac{m1 \times \beta}{(m1 + m2) \times \alpha} \times 100. \quad (2)$$

Formulas (1) and (2) calculate the flotation recovery of single and binary minerals, respectively. The quality of concentrate is represented by $m1$ and $m2$, respectively, the grades of quartz ore and concentrate are represented by α and β , respectively. The experimental tests were performed three times each time and the average results were obtained.

The optimal high-valence metal ion concentration was found in the micro-float experiment for subsequent testing to indicate samples for analysis.

2.3. Solution Chemistry Calculations

In order to study the action mechanism of aluminum ions on dodecylamine flotation of magnetite and quartz, Visual MINTEQ (version 3.1) was used to calculate the effects of aluminum ions on magnetite and quartz solutions at different pH values, as well as in the

solution Saturation Index (SI) of concealed minerals. $SI = \log(IAP/K_s)$, where K_s is the solid solubility product and IAP is the ionic activity product, which can be used to characterize the stability of minerals within a thermodynamic system. When $SI > 0$, a solid phase is likely to form; the higher the SI value, the more likely it is that a particular potential mineral is present. Then, the conditional solubility products of Fe_3O_4 , SiO_2 and aluminum ions at different pH values were analyzed using the conditional solubility product theory, and the changes in the solution compositions of magnetite and quartz surfaces were analyzed.

2.4. Zeta Potential Analysis

The zeta potential of minerals was measured using a Malvern high concentration colloidal particle and zeta potential analyzer (Zetasizer Nano ZS90 Zeta, Malvern, England). Use an agate grinder to grind the pure minerals to a particle size of less than $2\ \mu m$, weigh 0.05 g of the sample and place it in a beaker, then add 50 mL of 5×10^{-2} mol/L electrolyte potassium chloride solution, and stir with a stirrer with a rotational speed of 500 r/min for 3 min. Then add the agent according to the agent system of the flotation test, stand still for 3 min, take an appropriate amount of the upper layer suspension and put it into the electric pool for potential measurement. Each sample was measured three times under the same conditions, and the average value was taken as the test result.

2.5. Contact Angle Measurements

The JY-82B contact angle measuring instrument was used in the test to measure the contact angle of minerals. The preselected high-purity block pure minerals need to be sliced, polished and polished again. Before each measurement, it needs to be polished again to ensure that the mineral surface is fresh enough. The sample preparation procedure was the same as the flotation test. First, add the desired agent to the solution containing mineral crystals and stir for 5 min; then adjust the pH of the solution to 10, take out the mineral crystals to dry naturally, and place them on a contact angle measuring instrument for measurement.

2.6. FT-IR Analysis

The magnetite and quartz samples were analyzed by FTIR (740FJ-IR, Niolet Corporation, Waltham, MA USA). The number of scans of the instrument was 10 times, and the spectral resolution was $4\ cm^{-1}$. An appropriate amount of the tested sample and potassium bromide was fully ground in an agate mortar so that the minerals were fully dispersed in the potassium bromide, and the ground sample was pressed into a tablet with the help of a tablet machine, and then placed in an infrared spectrometer for detection.

3. Results and Discussions

3.1. Micro-Flotation Experiments

Figure 3 explores the effect of optimal pulp pH and dodecylamine dosage on the separation of magnetite and quartz when dodecylamine is used as a collector. As shown in Figure 3a, the flotation recovery in the pH range of 6–12 increased first and then decreased with the increase in solution pH. The recovery of quartz flotation decreased with increasing solution pH. However, the inhibitory effect of magnetite was stronger than that of quartz. Figure 3b shows that the recovery of magnetite is lower than that of quartz as the dodecylamine concentration rises from 0 mg/L to 12 mg/L. Excitingly, the recovery of magnetite increased with increasing dodecylamine concentration. Below 6 mg/L, with the increase in dodecylamine concentration, the flotation recovery of quartz increases gradually. When the concentration of dodecylamine is greater than 6 mg/L, the flotation recovery rate of quartz increases rapidly. The difference between the recoveries of magnetite and quartz is about 6 mg/L dodecylamine, which indicates the best separation effect.

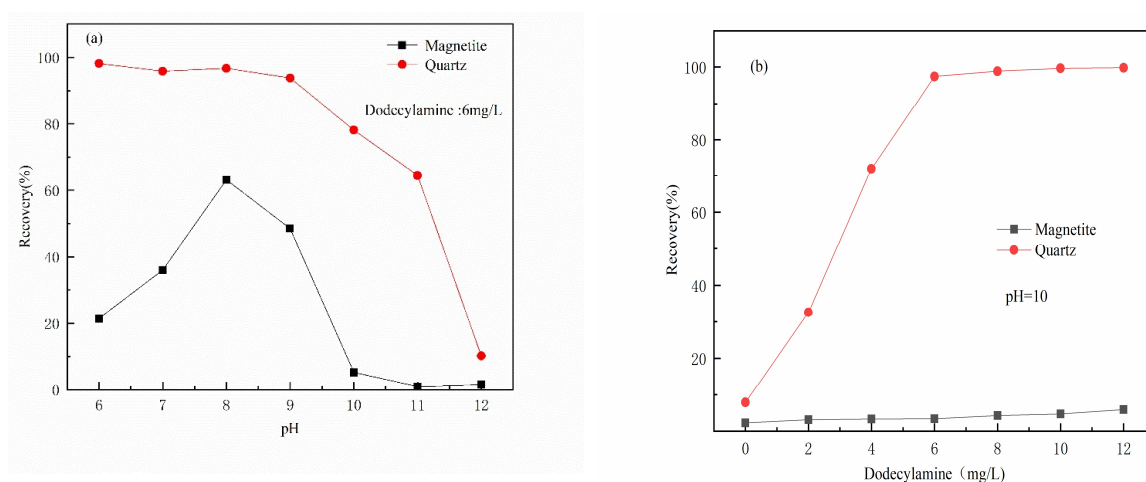


Figure 3. Effect of (a) pH value and (b) dodecylamine concentration on the recovery of magnetite and quartz.

Figure 4a shows the recoveries of magnetite and quartz under high-valent metal ion concentrations. As the Al(III) ion concentration increases, the recovery of quartz first drops sharply and then tends to a stable equilibrium. However, with the increase in Al(III) ion concentration, the recovery of magnetite tends to be stable. This may be due to the coverage of Al(III) or its hydrolyzate on the surface of magnetite, which strongly depresses the floatability of magnetite [21,22]. In particular, at Al(III) ions concentration above 4 mg/L, the recovery of quartz is below 55%, but the depression effect on quartz is not so obvious. The effect of pH on the flotation recoveries of magnetite and quartz in the presence of 4 mg/L Al(III) ions using dodecylamine as a collector is shown in Figure 4b. As the pH value increases from 6 to 10, the flotation recovery of quartz increases from 20% to 52%, and then it changes to decrease to 16% at pH 12. However, pH has little effect on the flotation of magnetite as the flotation recovery of magnetite over the entire pH range is less than 10%. It follows that the preferred pH for the flotation separation of magnetite and quartz is 10.0 with Al(III) ions as the depressant.

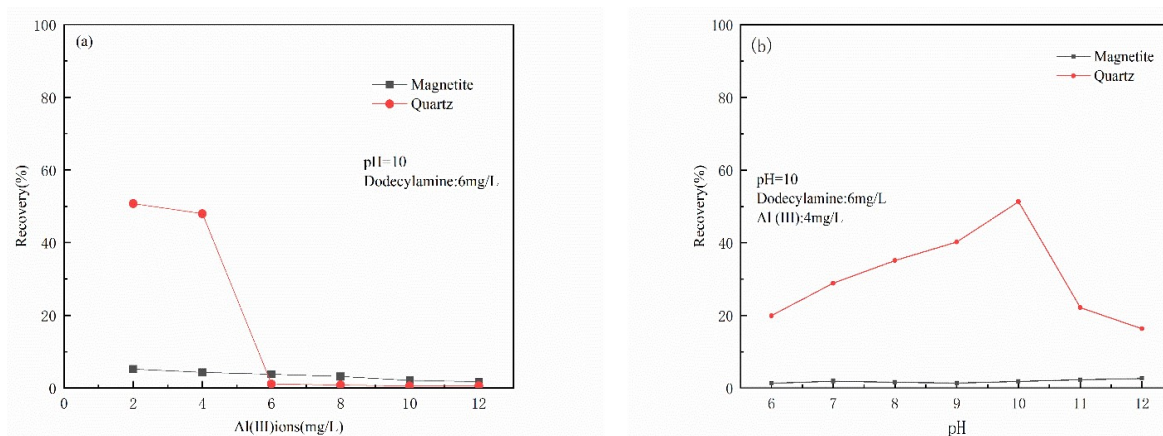


Figure 4. Effect of (a) Al(III) ions concentration (at pH 10.0) and (b) pH values (at Al(III) ions concentration of 4 mg/L) on floatability of magnetite and quartz.

In order to define whether magnetite could be separated from quartz with Al(III) ions as a depressant, magnetite and quartz were mixed by 1:1 (mass ratio) and floated at pH 10.0 using dodecylamine as a collector. The effect of Al(III) ions dosage on the Fe grade and recovery of the unfloated particles are plotted in Figure 5. When the Al(III) ion concentration is greater than 4 mg/L, the Fe grade decreases and the recovery of unfloated particles increases continuously. By using a depressant with 4 mg/L Al(III) ions and a

collector with 6 mg/L dodecylamine, the unfloated particles with Fe grade of 65.14% and recovery of 85% are obtained. These results suggest that the separation of magnetite and quartz can be achieved by reverse flotation using Al(III) ions as the depressant.

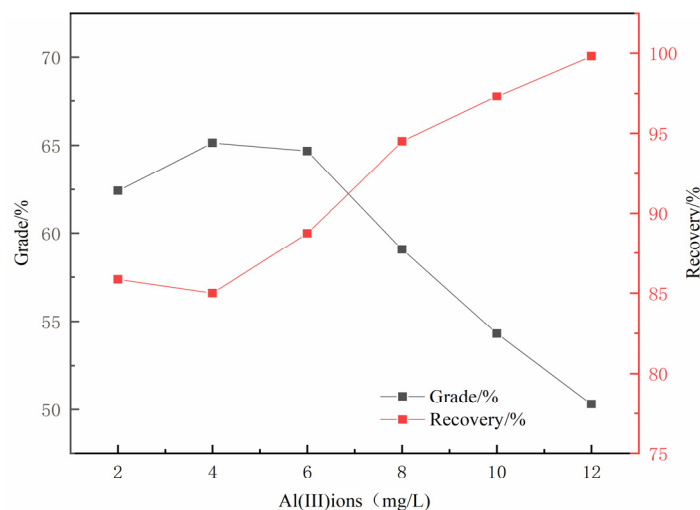
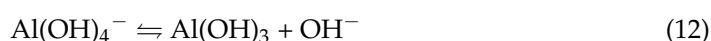
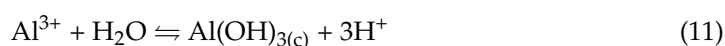
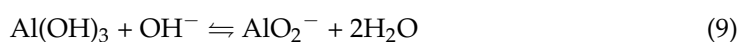
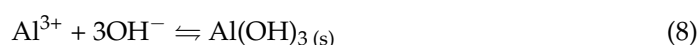
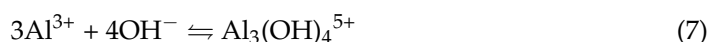
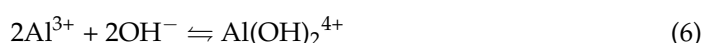


Figure 5. Effect of Al(III) ions concentration on Fe grade and recovery of unfloated particles (at pH 10.0 and dodecylamine concentration of 6 mg/L).

3.2. Solution Chemical Calculations and Analysis

The Visual MINTEQ model is widely used to calculate the speciation, solubility equilibrium and adsorption of ions in solution [23–26]. This analysis can be used to computationally analyze the presence of minerals or reagents at a specific pH and possible reaction mechanisms. The effects of pH on the form and content of Al(III) ions in the quartz magnetite solution systems are shown in Figure 6a. In these two solutions, Al(III) ions have pH less than 5.1; when pH > 5.1, Al(OH)_2^+ , $\text{Al(OH)}_{3(s)}$, Al(OH)_4^- and Al(OH)_2^+ are dominant. Al(OH)_4^- dominates when pH = 10.0. The main chemical reactions of the ions in solution are as follows



Solution chemical analysis is useful in determining the mechanism of action between minerals and agents. The effects of pH on the SI values of potential minerals in the magnetite and quartz solution system are shown in Figure 6b. Minerals that were saturated after the interaction include $\text{Al(OH)}_{3(s)}$, $\text{Al}_2\text{O}_{3(s)}$ and $\text{Al(OH)}_{3(c)}$. The SI values of these three minerals increased with increasing pH to maxima of 4.078, 5.083 and 4.628, respectively, after which the SI values decreased with a further increase in pH. The minerals that are saturated after interaction include $\text{Al(OH)}_{3(s)}$, $\text{Al}_2\text{O}_{3(s)}$ and $\text{Al(OH)}_{3(c)}$. The SI values of these three minerals increase with pH, and the maximum values are, respectively, 4.078,

5.083 and 4.628; after that, the SI value decreases with a further increase in pH. This means that when pH = 10.0, $\text{Al}(\text{OH})_{3(s)}$ precipitates may exist on the quartz and magnetite surface. This indicates that the presence of Al(III) ions is not conducive to the dissolution of minerals, thereby increasing the precipitation of $\text{Al}(\text{OH})_{3(s)}$ on the quartz and magnetite surface, and hindering the dissolution of quartz and magnetite due to the common ion effect.

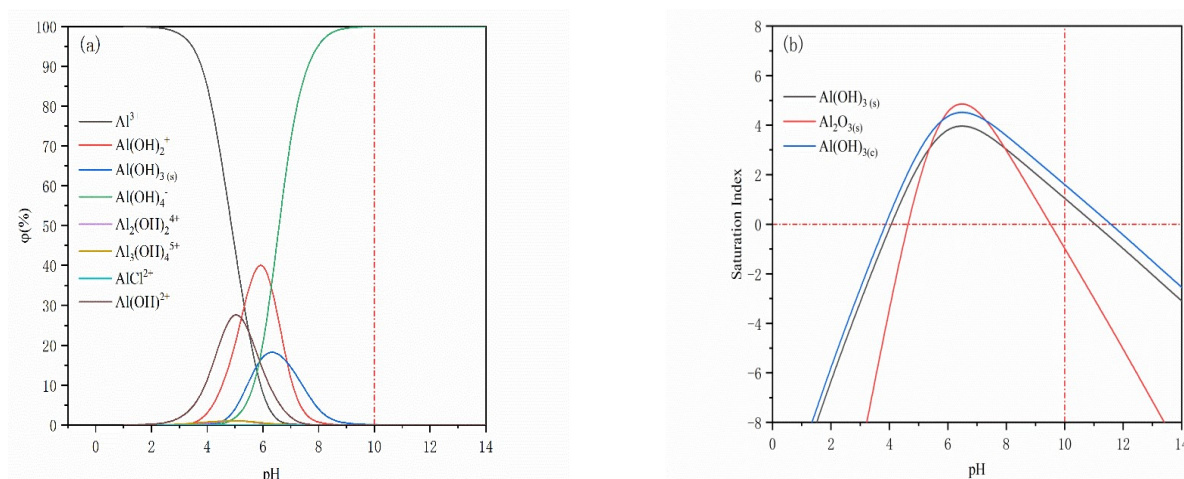


Figure 6. The effect of pH on Al(III) ionic solution composition (a) and the saturation index (SI) of potential aluminous minerals in a quartz and magnetite solution system (b).

The results of solution stoichiometry and analysis show that when the pH value is 10, Al(III) ions can react with OH^- in solution or dissociate from $\text{Al}(\text{OH})_4^-$ to form $\text{Al}(\text{OH})_{3(s)}$ precipitation, and this leads to the formation of thin films on the surfaces of quartz and magnetite, and hindering of the adsorption of dodecylamine on magnetite and quartz.

3.3. Zeta Potential Analysis

In order to study the action mechanism of Al(III) ions on the surface of magnetite and quartz, the function relationship between the zeta potential of the mineral surface and the pH value of the magnetite and quartz under the addition of chemicals and ions was measured. The results are shown in Figure 7.

Figure 7a shows the test results of the zeta potential of the magnetite surface before and after the action of the agent. The zeta potential of magnetite decreases with increasing solution pH. After magnetite was treated with cationic collectors, the zeta potential shifted positively. In the range of pH = 9–10, the zeta potential of both is positive and changes significantly, and the adsorption capacity of the collector will increase. The surface potential of magnetite indicates that the positively charged cation collector twelve is adsorbed on the surface of magnetite in small amounts depending on the composition. However, the positive zeta potential shift of magnetite decreases after the addition of Al(III) ions, which may be due to the fact that Al(III) ions in the form of $\text{Al}(\text{OH})_3$ under strong alkaline conditions are not fully neutralized, and OH^- in water, or Al(III) ions will generate hydroxide precipitation, resulting in the reduction in Al(III) ions electrostatically adsorbed with minerals, and thus the surface potential of minerals also tends to decrease. Therefore, the precipitation of $\text{Al}(\text{OH})_3$ will cover the surface of magnetite, hindering the direct interaction between minerals and collectors, resulting in a decrease in the floatability of magnetite.

Figure 7b shows that under the same reagent addition conditions, the zeta potential of quartz is shown as a function of pH, and the zeta potentials of magnetite and quartz in solution have the same trend. It can be seen that untreated quartz is negatively charged in the pH range tested and no isoelectric point is observed, which is consistent with the values reported by other laboratories [27–29]. The zeta potential of quartz shifted to the positive direction after the dodecamin treatment, which indicated that the positively charged dodecylamine component was adsorbed on the quartz surface. However, after

Al(III) ions treatment, the degree of positive shift of the zeta potential of quartz was not obvious, which may be due to the positively charged Al(III) ions and dodecylamine that were both adsorbed on the surface of quartz [30].

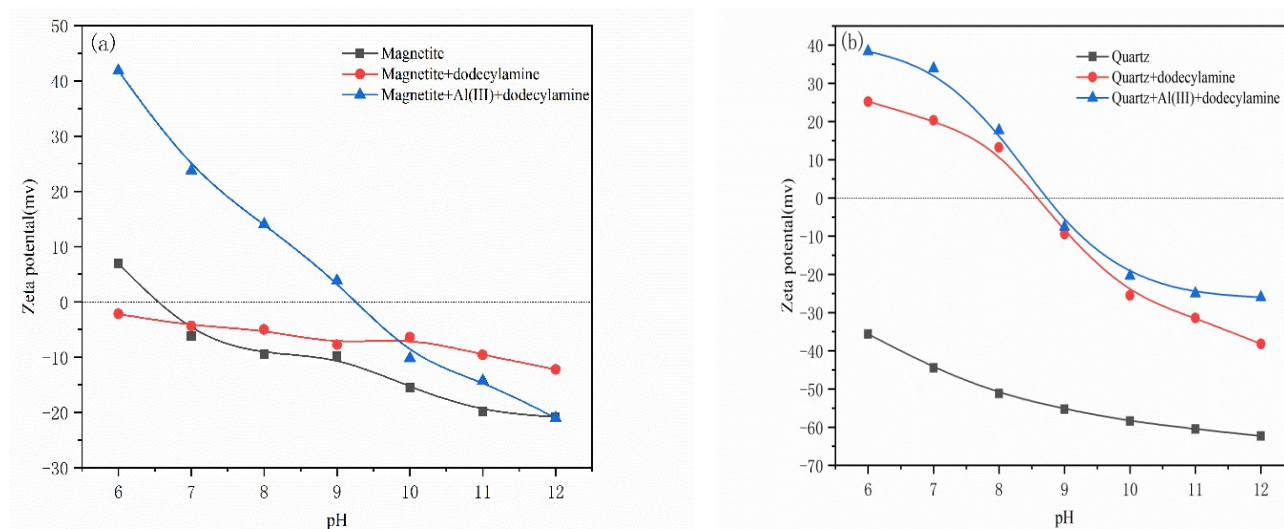


Figure 7. Zeta potentials of (a) magnetite and (b) quartz in different solutions as a function of the solution pH value.

3.4. Contact Angle Measurements

The wettability of the mineral surface depends on the contact angle of the mineral surface. The larger the contact angle θ , the smaller the wettability $\cos \theta$, indicating that the hydrophobicity of the mineral surface is better; conversely, the smaller the contact angle θ , the larger the wettability $\cos \theta$, indicating that the mineral surface is more hydrophilic [31,32]. Figure 8 shows the contact angle measurements for magnetite and quartz under different conditions.

As shown in Figure 8, at pH = 10, the contact angle of magnetite was measured to be 27.1° in deionized water, and that of quartz was 42.98° , indicating that their buoyancy is different in the natural state. After dodecylamine treatment, the contact angle of the magnetite sample increased to 31.3° , and the contact angle of the quartz sample increased to 63.15° , indicating that the hydrophobic group of the agent played an adsorption role on the mineral surface, and the quartz was more hydrophobic than magnetite; it is easier to float [32]. After Al(III) ions and dodecylamine treatment, the contact angle of magnetite decreased to 21.2° and the floatability changed little; the contact angle of quartz decreased to 53.88° , and the floatability significantly decreased. It can be seen from the variation range of the contact angle between magnetite and quartz that after adding Al(III) ions, the contact angle of magnetite decreases more than that of quartz.

3.5. FTIR Analysis

Figure 9 analyzes the infrared spectrum (magnetite) and the interaction of Al(III) ions on the mineral surface with mixed collectors. In Figure 9a, the FTIR spectrum between 1002.69 cm^{-1} and 574.29 cm^{-1} shows a strong absorption band attributable to the characteristic absorption peaks of Fe-O vibrations [33–35]. In Figure 9b, the wavelengths of 2922.09 cm^{-1} and 2851.46 cm^{-1} are the stretching vibration absorption peaks of $-\text{CH}_3$, and the wavelength of 3428.06 cm^{-1} is the stretching vibration absorption peak of $-\text{NH}_2$. However, the new characteristic absorption band of dodecylamine does not appear in Figure 9c. These results indicate that Al(III) ions hinder the adsorption of dodecylamine on magnetite.

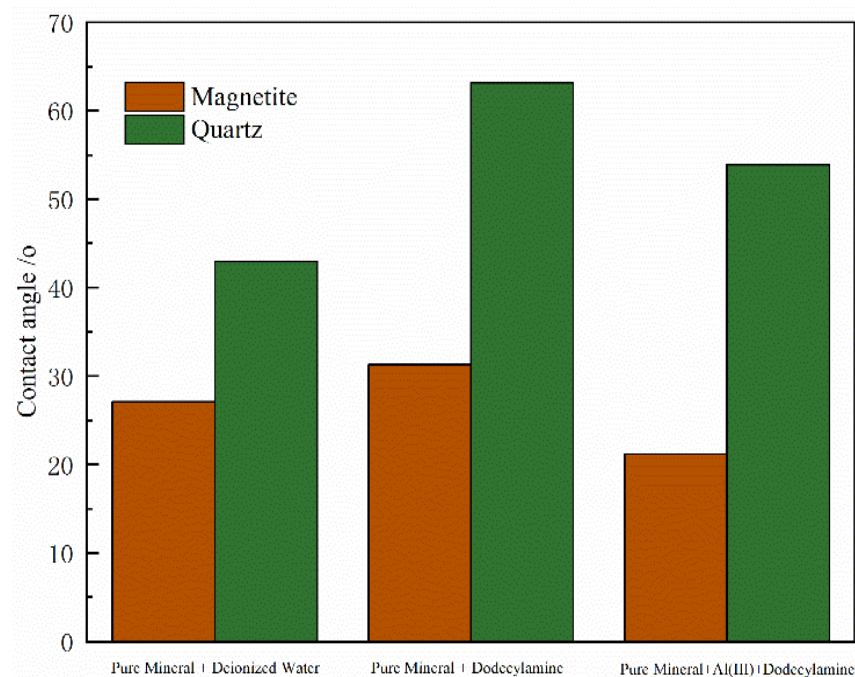


Figure 8. Contact angle between magnetite surface and quartz surface treated with different reagents.

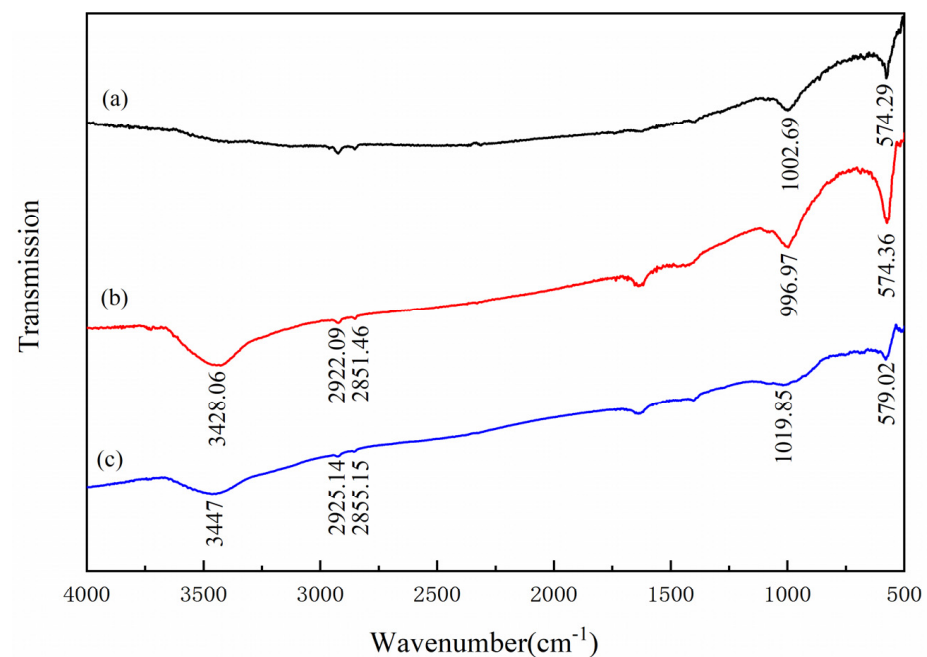


Figure 9. FTIR spectra of: (a) magnetite; (b) magnetite conditioned with mixed collector; (c) magnetite conditioned with Al(III) ions and mixed collector.

Figure 10 presents the reference infrared spectra of quartz and the interaction of the quartz with dodecylamine and Al(III) ions on the mineral surface with the mixed collectors. The strong absorption bands at wavenumbers of 1084.32 cm^{-1} and 463.51 cm^{-1} in Figure 9a can be attributed to Si-O-Si band [36,37]. The Si-O-Si peaks at 1084.32 cm^{-1} and 463.51 cm^{-1} of the infrared spectra of quartz after dodecylamine adsorption in Figure 10a,b move to lower frequencies, 1083.12 cm^{-1} and 461.55 cm^{-1} , respectively, indicating that the polar group ($-\text{NH}_2$) hydrogen bond of dodecylamine is adsorbed on the quartz surface [37–39].

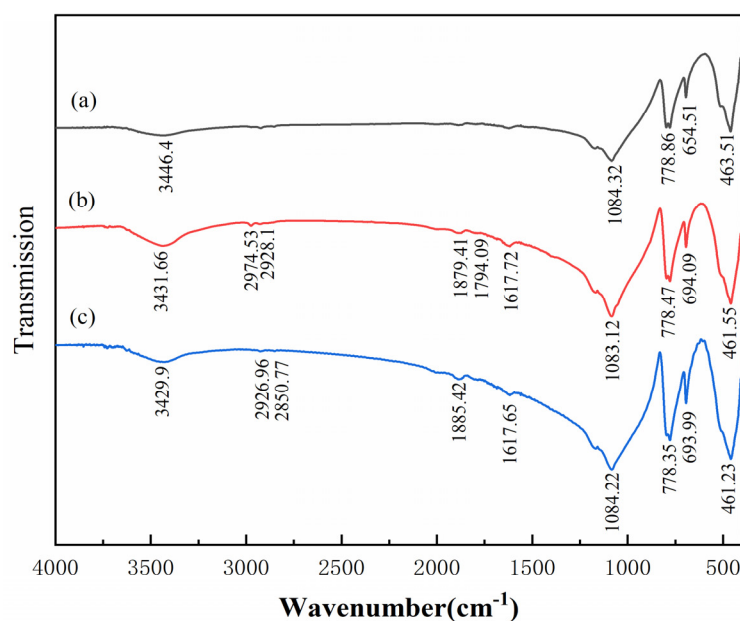


Figure 10. FTIR spectra of: (a) quartz; (b) quartz conditioned with mixed collector; (c) quartz conditioned with Al(III) ions and mixed collector.

Figure 10c shows the infrared spectra of quartz treated with aluminum ions and dodecylamine. The absorption peaks at 2926.96 cm^{-1} , 2850.77 cm^{-1} and 1617.65 cm^{-1} correspond to the asymmetric stretching vibration of -CH_2 , respectively, and the absorption peaks of -NH_2 , stretching vibration and bending vibration are not remarkable. The results of the FTIR analysis show that the Al(III) ions provide new adsorption sites on the surface of quartz, which is not apparent to the adsorption of dodecylamine on the surface of quartz.

3.6. Discussion

A schematic diagram of the influence of Al(III) ion on dodecylamine adsorption on the surface of quartz is proposed in Figure 10 to explain the decreased recovery of quartz after adding Al(III) ions. As shown in Figure 11, Oxygen and silicon ions are alternately arranged on the quartz surface when Al(III) ion is added first; it interact with hydroxide ions in solution to form Al(OH)_3 precipitates, which then coat the quartz surface. After adding dodecylamine, Al(OH)_3 forms a covering layer on the quartz surface, which hinders the adsorption of dodecylamine on the quartz surface and reduces the recovery rate of quartz.

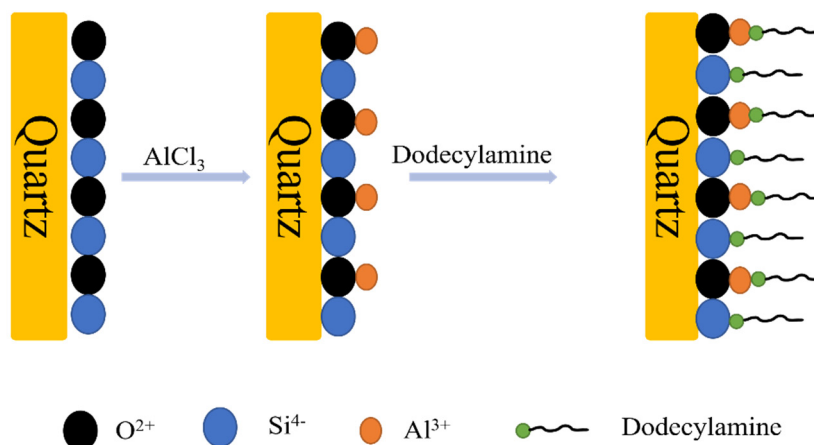


Figure 11. Schematic diagram of effect of Al(III) ion on dodecylamine adsorption on quartz surface.

4. Conclusions

According to micro-flotation experiments, solution chemical calculation, zeta calculation and analysis, contact angle measurement, and FTIR analysis, the effect of Al(III) ions in water on the flotation separation of magnetite and quartz was studied; the following conclusions are drawn:

- (1) The results of micro-flotation experiments show that Al(III) ions in water have a strong inhibitory effect on magnetite, and the inhibitory effect on quartz is not very obvious.
- (2) The solution stoichiometry results show that the phases formed by Al(III) ions on the surface of magnetite and quartz are mainly $\text{Al}(\text{OH})_{3(s)}$ and $\text{Al}(\text{OH})_4^-$.
- (3) The results of zeta calculation and analysis show that the precipitation of $\text{Al}(\text{OH})_3$ produced by Al(III) ions will cover the surface of magnetite and hinder the direct interaction between minerals and collectors, resulting in a decrease in the floatability of magnetite. However, the subsequent adsorption of dodecylamine was hindered due to the precipitation of Al(III) ions and covering the active sites on the mineral surface.
- (4) The contact angle measurement results showed that Al(III) ions weakened the hydrophobicity of magnetite and quartz by reducing the contact angle of magnetite and quartz, and the floatability of magnetite and quartz after treatment decreased. Therefore, with the addition of Al(III) ions, the floatability of magnetite is lower than that of quartz.
- (5) The results of FTIR analysis showed that the addition of Al(III) ions could hinder the adsorption of dodecylamine on the magnetite surface. Meanwhile, the addition of Al(III) ions has no obvious effect on the adsorption of dodecylamine on the quartz surface.

According to micro-flotation experiments, solution chemical calculation, zeta calculation and analysis, contact angle measurement, and FTIR analysis, the effect of Al(III) ions in water on the flotation separation of magnetite and quartz was studied. The results of micro-flotation experiments show that Al(III) ions in water have a strong inhibitory effect on magnetite, and the inhibitory effect on quartz is not very obvious. The solution stoichiometry results show that the phases formed by Al(III) ions on the surface of magnetite and quartz are mainly $\text{Al}(\text{OH})_{3(s)}$ and $\text{Al}(\text{OH})_4^-$. The results of zeta calculation and analysis show that the precipitation of $\text{Al}(\text{OH})_3$ produced by Al(III) ions will cover the surface of magnetite and hinder the direct interaction between minerals and collectors, resulting in a decrease in the floatability of magnetite. However, the subsequent adsorption of dodecylamine was hindered due to the precipitation of Al(III) ions and covering the active sites on the mineral surface. The contact angle measurement results showed that Al(III) ions weakened the hydrophobicity of magnetite and quartz by reducing the contact angle of magnetite and quartz, and the floatability of magnetite and quartz after treatment decreased. Therefore, with the addition of Al(III) ions, the floatability of magnetite is lower than that of quartz. The results of FTIR analysis showed that the addition of Al(III) ions could hinder the adsorption of dodecylamine on the magnetite surface. Meanwhile, the addition of Al(III) ions has no obvious effect on the adsorption of dodecylamine on the quartz surface.

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