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Selective separation of chalcopyrite from jamesonite with guar gum

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Abstract: A novel reagent, guar gum (GG), is investigated as the depressant on the depression of chalcopyrite and jamesonite, when mixed aerofloat (CSU11) is used as the collector in flotation tests. Kinetics, dynamic potential, adsorption and infrared spectra analysis are performed to study the interaction mechanism between GG and minerals. The flotation results display that selective flotation separation of chalcopyrite from jamesonite is achieved under conditions of depressant GG 2.5 mg/dm³, collector CSU11 10 mg/dm³ and frother MIBC (Methyl isobutyl carbinol) 10 mg/dm³ at pH 5.3. As to mixed minerals flotation, the Cu grade and recovery in the concentrate is 21.35 % and 85.12 %, respectively, indicating that GG has a selective depression effect on jamesonite. Flotation kinetics shows that the addition of GG can dramatically reduce the floatability of jamesonite but hardly influences that of chalcopyrite. The zeta potential and adsorption reveal that the depressant GG adsorbs strongly on the surface of jamesonite. Infrared spectra reveal a dominant chemisorption between GG and jamesonite, while GG occurs weak chemisorption on chalcopyrite surface. This is the reason why GG has excellent selectivity for jamesonite and less effect on chalcopyrite.

Keywords: guar gum, chalcopyrite, jamesonite, flotation depressant

1. Introduction

Lead (Pb) is an important metal in modern industries, and it is widely used in the chemical, military and electronics industries. The major sources of Pb are natural minerals, such as galena, cerussite and jamesonite (Wang, 2012; Hu, 2014). Antimony (Sb) is a type of metal as important as Pb in industry and it is commonly used in alloys, printing, chemical and military industries. The major mineral sources of Sb include stibnite, jamesonite, and pyrargyrite (Hu and Feng, 2006). Jamesonite (Pb₄FeSb₆S₁₄) contains 40.15% Pb, 2.71% Fe, 35.39% Sb and 21.75% S, belonging to the low-to-moderate temperature hydrothermal deposits, which mainly come from Cu-Pb-Zn multimetallic deposits and cassiterite-sulfides deposits (Anthony et al., 2005). Jamesonite frequently co-exists with other sulfide minerals, such as chalcopyrite, galena, pyrite, pyrrhotite and marmatite. Problems commonly occur between chalcopyrite and lead-bearing minerals (galena and jamesonite) (Sun and Li, 2007).

Chalcopyrite and lead-bearing minerals have similar floatability in minerals processing. It is difficult to achieve efficient separation of these minerals. Usually, the major methods widely used in the separation of Cu-Pb concentrate are to inhibit chalcopyrite using cyanide or depress galena and jamesonite using dichromate (Huang et al., 2012). However, these inorganic depressants have been known to be toxic and hazardous. Their use is often accompanied with environmental pollution and loss of precious metals in Cu-Pb concentrate (Qin et al., 2012; Huang et al., 2014). In order to avoid these shortcomings, depressants with less cyanide and dichromate emerge as the environmental protection required. Therefore, non-toxic, cyanide-free and dichromate-free flotation depressants with high selectivity will be developed dominantly in the future (Bulatovic, 1999; Zhang et al., 2017). Compared with inorganic depressants, organic depressants have their own advantages of better selectivity and environmental friendliness, and they are designed and synthesized according to practical demands. On

the other hand, they also have defects, cost-efficient and readily available characteristics (Chen et al., 2011a, b).

In recent years, there appear many organic compounds used as lead-bearing mineral depressants. In the flotation separation of sulfide minerals, dichromate sulfite, cyanide or lime were commonly used as depressant. Dichromate or sulfite depresses galena when the galena surface was oxidized, and dichromate also depressed jamesonite at a natural pH (Zhang et al., 2005; Wei and Sun, 2008). Cyanide strongly inhibited the flotation of minerals, such as pyrite, sphalerite and chalcopyrite, but it hardly influenced flotation of galena or jamesonite (Liu et al., 1994; Chen et al., 2005; Lu, 2011). Interestingly, jamesonite was more sensitive to lime than galena (Deng and Xu, 1990). Dextrin was used for depressing galena selectively while chalcopyrite was floated with xanthate collector using NaOH to adjust the pulp pH, and the depressing mechanism also has been studied (Liu and Zhang, 2000; Qin et al., 2013a,b). Carboxymethyl cellulose (CMC) was also widely used in the separation of Cu-Pb concentrate together with silicate (Na_2SiO_3) and sodium sulfite (Na_2SO_3) (Wang and Guo, 2002; Mi et al., 2009; López-Valdivieso et al., 2017). RB-SO₂-starch, a derivative of starch, could also depress galena very well (Bulatovic and Wyslouzil, 1995). Additionally, some organic compounds, such as ferrochrome lignin (FCLS), ASC, sodium humate with ammonium persulfate together, were found to depress galena strongly (Chen et al., 2000, Liu et al., 2009). There were also some new synthesized organic depressants reported for galena. Piao reported two new depressants, sodium 2, 3-dihydroxypropyl dithiocarbonate (SGX) and O, O-bis (2, 3-di-hydroxypropyl) dithiophosphate (DHDTP) (Piao et al., 2014), which showed a good selective depression for galena. Compared with small molecule depressants, macromolecular depressants had stronger depressing ability and were easier to design. A recent study about xanthation-modified polyacrylamide (PAM-X) was conducted by Wang et al. (2012) in the galena flotation separation from sphalerite. It was found that PAM-X exhibited a stronger depression and a better selectivity for galena than PAM in single mineral flotation. A lot of studies have reported on the flotation separation of polymetallic sulfide minerals. However, the separation flotation of chalcopyrite and jamesonite has not been extensively studied. Consequently, it is of significance to carry out experiments on the selective separation of chalcopyrite from jamesonite, especially in low pH media.

Guar gum (GG) is an environmentally friendly chemical reagent as dextrin and CMC. The interaction mechanism between guar gum and minerals such as talc, mica, galena, sphalerite, pyrite and pyrophyllite has been reported recently (Frollini et al., 1995; Shortridge et al., 2000; Gong et al., 2011; Chen et al., 2012; Castro et al., 2016; Zhao et al., 2017). In this work, guar gum is used as a depressant to inhibit jamesonite using single mineral and mixed mineral flotation experiments. The adsorption mechanism of GG on chalcopyrite and jamesonite is investigated by dynamic potential, adsorption and infrared spectra analysis.

2. Materials and methods

2.1. Pure minerals and reagents

Chalcopyrite and jamesonite pure minerals were purchased from the geological museum of China. Two minerals were both handpicked to obtain high purity samples, and then ground and screened out to collect the $-74\ \mu\text{m}\sim+38\ \mu\text{m}$ size fractions for the following flotation tests. The purity of chalcopyrite and jamesonite could reach 95.54 % and 93.7 % by X-ray diffraction (XRD) analysis and chemical analysis, respectively (shown in Fig. 1 and Table 1).

CSU11 was compound by amino dithiophosphate, ammonium butylenes and soda in a certain ratio used as a collector. The guar gum (GG) shown in Fig. 2, obtained from commercial companies with a purity above 92 % was used as a depressant in the study. Methyl isobutyl carbinol (MIBC) was chosen as a frother bought from Sinopharm Chemical Reagent Co., Ltd, China. Solutions of H_2SO_4 and NaOH were used to adjust the pH of the pulp. All waters used in the experiments were distilled waters.

2.2. Flotation experiments

Single-mineral flotation experiments were carried out in a mechanical agitation flotation machine with a volume of $40\ \text{cm}^3$ at a rotating speed of 1860 r/min (Li and Gao, 2017; Gao et al, 2018). For each test, 2 g of sample was taken, and the mineral surface was cleaned for 5 min using an ultrasonic cleaner to

remove any oxide. The sample was allowed to settle, and the upper liquid layer was decanted. The sample was flushed with 40 cm³ of distilled water, and the solution pH value was adjusted to the desired value by using NaOH or H₂SO₄ stock solutions. Then, the suspension was conditioned with depressant for 3 min, collector for 2 min, and frother for 1 min, followed by flotation for 3 min. The products were filtered, dried, and weighed. The flotation recovery (*R*) was calculated from $R = m_1 / (m_1 + m_2) \times 100\%$, where *m*₁ and *m*₂ were masses of the floated and un-floated fractions, respectively. The flotation tests flowsheet was shown in Fig. 3 and the error bars were based on the standard deviation. For mixed minerals flotation (a chalcopyrite to jamesonite mass ratio of 1:2), the flotation recovery was calculated based on yield and Cu grade between the concentrates and tailings.

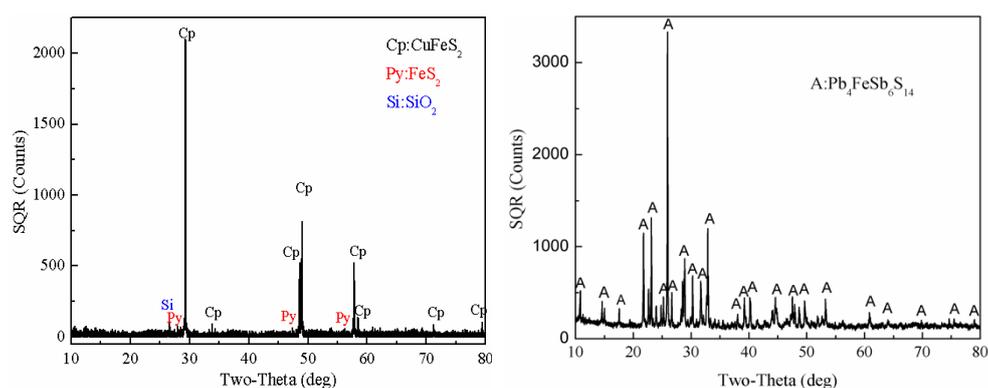


Fig. 1. XRD diagrams of chalcopyrite and jamesonite

Table 1. Chemical analysis of chalcopyrite and jamesonite

Species	Cu	Pb	Fe	Sb	S
Chalcopyrite	32.50	-	30.11	-	32.93
Jamesonite	-	35.68	2.89	33.72	21.41

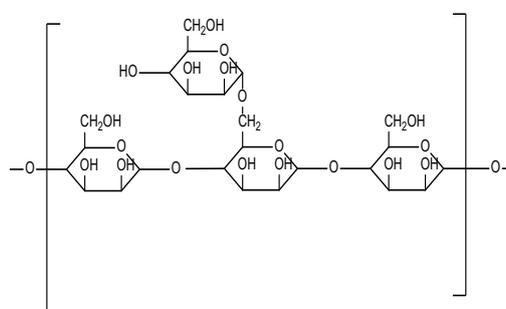


Fig. 2. Structures of guar gum

2.3. Zeta potential measurements

The zeta potential measurements were conducted by using a Malvern Zetasizer Nano ZS90 (England) equipped with a rectangular electrophoresis cell. The suspensions were prepared by adding 20 mg of purified minerals that were ground to -5 μm in an agate mortar and 40 cm³ of KCl electrolyte solution (0.001 mol/dm³). After magnetic stirring for 5 min and settling for 10 min, the supernatant of the dilute fine-particle suspension was obtained for the zeta potential measurement. During stirring, the suspension was conditioned by corresponding reagents at different pH values. Each sample was measured at least three times, and the averages were used as the final result.

2.4. Adsorption analysis

The adsorption measurements were completed on a TU-1810 ultraviolet visible spectrophotometer (Purkinje General, Beijing, China). 2 g of mineral powder and 40 cm³ of distilled water were transferred

into a 100 cm³ Erlenmeyer flask. After the reagent addition to the solution, the Erlenmeyer flask was stirred on a magnetic mixer for 0.5h, allowing the adsorption process to reach equilibrium. After centrifuged, the concentration of GG in the supernatants was determined using UV spectrometry analysis. And the adsorption of the reagent on the mineral surface could be calculated as follows:

$$\Gamma = \frac{(C_0 - C) \times V}{1000 \times 2} \quad (1)$$

where, Γ is the adsorption quantity (mg/g), C_0 is the initial reagent concentration (mg/dm³), C is the tested concentration in the supernatant (mg/dm³), V is the pulp volume (dm³).

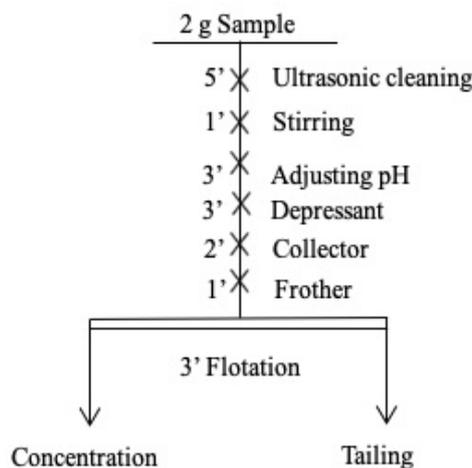


Fig. 3. The flotation tests flowsheet of purity minerals

2.5. Infrared spectroscopy analysis

The infrared spectra were performed with a Spectrum One (Version BM) FT-IR (USA) spectrometer at an environment temperature of 25 °C. The samples were prepared by adding 1 g of pure minerals that were ground to less than 2 μm, and desired reagents were placed in a Plexiglas cell with 40 min of conditioning time. After washing three times using distilled water, the washed samples were vacuum-dried below 30 °C and used for the later FT-IR analysis. The spectra of the solids were taken with KBr pellets. The data were collected from 4000 to 400 cm⁻¹.

3. Results and discussion

3.1. Single mineral flotation

Fig. 4 presents the effect of pH on the floatability of chalcopyrite and jamesonite using CSU11 as the collector. As illustrated in Fig. 4, chalcopyrite shows excellent floatability with recovery above 95 % over the tested pH range. Jamesonite exhibits very good floatability under acid conditions as pH ranges from 4.0 to 6.0. Under neutral to alkaline conditions, the recovery of jamesonite decreases steadily from 88.42 % at a pH of 6.0 to 12.88 % at a pH of 12.0. Clearly, CSU11 shows preferable collecting selectivity to chalcopyrite under high-alkaline pH conditions. However, considering the disadvantage of high alkalinity on flotation as well as the treatment of waste water, much more attention is paid to realize the separation of chalcopyrite from jamesonite at around neutral pH. Thus, selective depressant needs to be added.

Fig. 5 presents the effect of pH on the floatability of chalcopyrite and jamesonite in the presence of depressant GG. As illustrated in Fig. 5, the two minerals exhibit different response to the addition of GG. In the presence of GG, the flotation recovery of jamesonite decreases more obviously and remains constantly below 10 %. On the contrary, the recovery of chalcopyrite is affected slightly by GG. Especially, the chalcopyrite recovery is exceeded 85 % in the pH range of 4.0-6.0; and the max recovery of 94.12 % can be obtained at an optimum pH of approximately 5.3. It is clear that GG has an excellent selective depression on jamesonite.

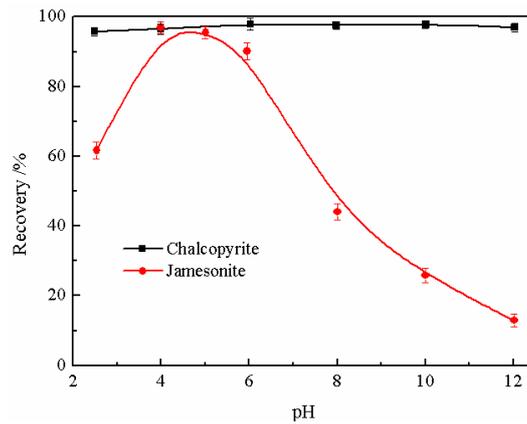


Fig. 4. Flotation recovery of chalcopyrite and jamesonite with CSU11 as a function of pH ([CSU11] = 10 mg/dm³, [MIBC] = 10 mg/dm³)

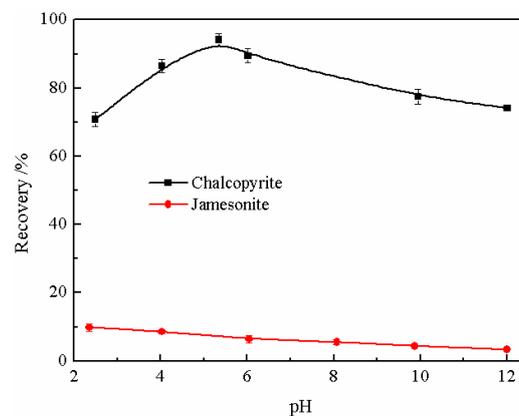


Fig. 5. Flotation recovery of chalcopyrite and jamesonite in the presence of GG as a function of pH ([CSU11] = 10 mg/dm³, [GG] = 2.5 mg/dm³, [MIBC] = 10 mg/dm³)

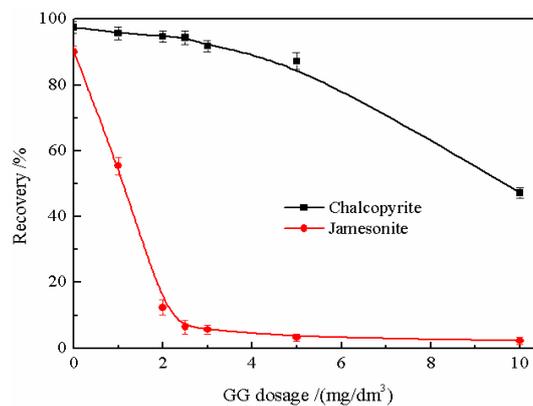


Fig. 6. Effect of GG dosage on the flotation recovery of chalcopyrite and jamesonite (pH 5.3, [CSU11] = 10 mg/dm³, [MIBC] = 10 mg/dm³)

Fig. 6 presents the effect of GG dosage on the floatability of chalcopyrite and jamesonite. It can be seen from Fig. 6 that GG has an excellent selective depression on jamesonite. When GG dosage increases from 0 to 5 mg/dm³, the recovery of jamesonite has dramatically reduced from 90.12 % to 3.27 %. In contrast, GG has slight depression effect on chalcopyrite flotation and the recovery of chalcopyrite maintains above 85 % with a slight drop as GG dosage ranges from 0 to 5 mg/dm³. At a GG dosage of 2.5 mg/dm³, the flotation recovery of chalcopyrite and jamesonite are about 94.38 % and 6.17 % respectively, indicating that the flotation separation of chalcopyrite and jamesonite can be achieved.

Additionally, when the dosage of GG increases higher than 10 mg/dm³, the floatability of chalcopyrite is also strongly inhibited.

3.2. Mixed mineral flotation

Pure minerals flotation results suggest that it may be possible to separate chalcopyrite from jamesonite using GG as depressant. Therefore, flotation separation of mixed minerals (a chalcopyrite to jamesonite mass ratio of 1:2) was conducted under the condition of MIBC 10 mg/dm³ and CSU11 10 mg/dm³ at pH 5.3, and the results are shown in Table 2. It can be seen from Table 2 that a concentrate with Cu grade of 21.35 % and recovery of 85.12 % is achieved with the addition of 2.5 mg/dm³ GG. When the GG dosage increases to 5 mg/dm³, the Cu concentrate grade increases but the recovery decreases from 85.12 % to 81.35 %. The results in Table 2 illustrate that GG has a straining influence on the depression of jamesonite in the mixed minerals flotation and the flotation separation between chalcopyrite and jamesonite can be achieved using GG as the depressant.

Table 2. The results of flotation separation of mixed minerals

Dosage of GG (mg/dm ³)	Product	Ratio (w/%)	Cu grade (%)	Cu recovery (%)
2.5	Cu concentrations	44.30	21.35	85.12
	Tailings	55.70	2.97	14.88
	Feed	100	11.11	100
5	Cu concentrations	39.05	23.08	81.35
	Tailings	60.95	3.39	18.65
	Feed	100	11.08	100

3.3. Flotation kinetics analysis

In general, concentration of valuable minerals through bubble flotation is considered to follow first-order kinetics model (Yalcin and Kelebek, 2011). The rate equation in its simple form may be written as

$$\varepsilon = \varepsilon_{\infty} (1 - e^{-Kt}) \quad (2)$$

where, ε is the recovery in the flotation, t is time, K is the flotation rate constant, ε_{∞} is the max concentrate recovery in infinitely flotation time. The first-order flotation kinetics of chalcopyrite and jamesonite is shown in Fig. 7, and the flotation rate constant and correlation coefficient are shown in Table 3.

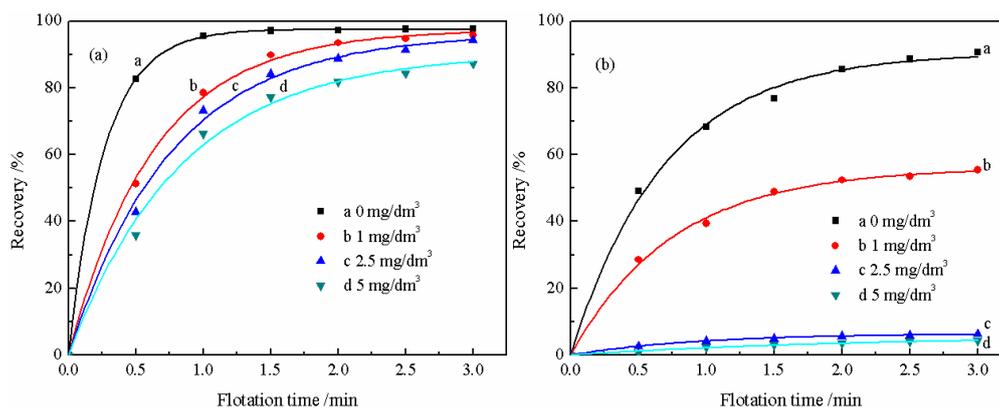


Fig. 7. Effect of GG dosage on chalcopyrite (a) and jamesonite (b) recovery versus flotation time (pH 5.3, [CSU11] = 10 mg/dm³, [MIBC] = 10 mg/dm³)

From Fig. 7 and Table 3 that with the increasing GG dosage, the max concentrate recovery reduces from 90.40 % to 5.91 %, and the recovery rate constant of jamesonite reduces from 1.45 % to 0.45 %. While chalcopyrite still maintains a good recovery (above 90 %), although the flotation rate constant of chalcopyrite decreases from 3.76 to 1.19. This illustrates that GG has stronger depressing effect on jamesonite.

Table 3. Effect of GG dosage on parameters of first-order flotation rate model of chalcopyrite and jamesonite

Species	GG dosage / (mg/dm ³)	K / (min ⁻¹)	ε_{∞}	R ²
Chalcopyrite	0	3.76	97.55	0.999
	1	1.58	97.36	0.998
	2.5	1.32	96.21	0.997
	5	1.19	90.33	0.992
Jamesonite	0	1.45	90.40	0.996
	1	1.33	56.00	0.997
	2.5	1.06	6.45	0.999
	5	0.45	5.91	0.987

3.4. Zeta potential measurement results

The zeta potentials of chalcopyrite and jamesonite in the absence and presence of reagents are shown in Fig. 8. Without any reagents, the IEP (isoelectric point) at about 3.4 is observed for jamesonite, which is slightly smaller than the reported value of 3.9 (Zhang and Qing, 2015). While the IEP of chalcopyrite cannot be found over the tested pH range, which is different from the values (2.7, 3.4, 3.9, 4.8) reported by other researchers (Wanget al., 2015; Huang et al., 2017; Liu et al., 2017; Yin et al., 2017). According to the literature, the IEP of elemental sulfur is at pH 1.6 (Fairthorne et al., 1998) and IEP values for copperoxide/hydroxide and ferric oxide/hydroxide is close to pH 9.5 and 6.5, respectively (Healy and Moignard, 1976; Fullston et al., 1999). The observed IEP lying between the IEP of elemental sulfur and the corresponding metaloxide/hydroxide species may result from the oxidation of the mineral surface.

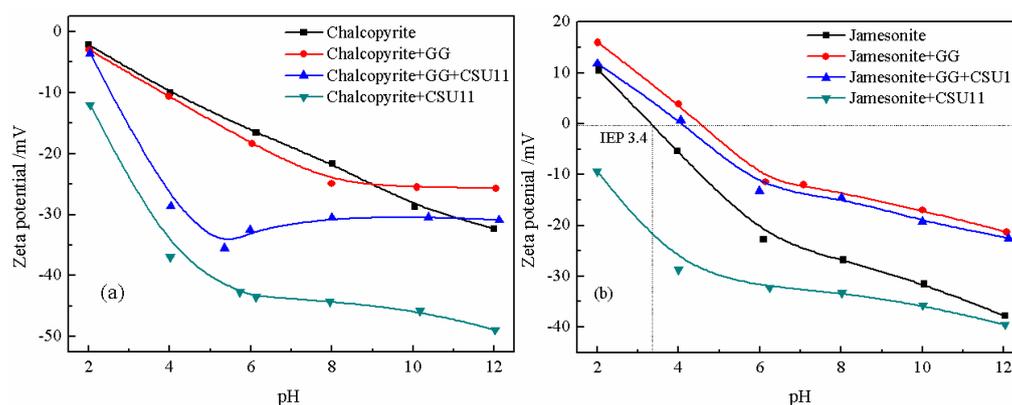


Fig. 8. Zeta potentials of chalcopyrite (a) and jamesonite (b) as a function of pH ([CSU11] = 10 mg/dm³, [GG] = 2.5 mg/dm³)

From Fig. 8(a), in the presence of depressant GG, the zeta potential of chalcopyrite decreases by approximately 2 mV, suggesting a minor amount of the depressant GG is adsorbed on the negatively charged chalcopyrite surface. While the zeta potential of chalcopyrite has a drop of near 20 mV at the optimal pH range of 4.0-6.0 as the depressant GG and collector CSU11 are both added, which may be due to the strong chemisorption between CSU11 and chalcopyrite. It can be concluded that the pre-adsorption of GG has less effect on CSU11 adsorption on chalcopyrite surface.

From Fig. 8(b), the addition of the depressant GG significantly alters the zeta potentials of jamesonite, and the zeta potentials vary by an average of 12 mV within the flotation pH of 4.0-6.0, indicating strong adsorption of GG on jamesonite surface. In contrast, in the presence of the depressant GG and collector CSU11, the zeta potentials of jamesonite are almost the same as the zeta potentials in the presence of GG alone within the flotation pH of 4.0-6.0. This implies that the absorption CSU11 on the jamesonite surface may be greatly hindered by the presence of the depressant GG (Zeng et al., 2017).

3.5. Adsorption measurement results

The adsorption amount may be related to depression performance. The adsorption capacities of GG on chalcopyrite and jamesonite with different dosage of GG at pH 5.3 are shown in Fig. 9. It is found that

the adsorption dosage of GG on jamesonite increases rapidly with the increasing GG dosage. The adsorption ability of GG on jamesonite surface is significantly higher than that on chalcopyrite surface. While the adsorption of GG on chalcopyrite surface is very weak and the adsorption dosage of chalcopyrite grows slowly. The results obtained in the dosage range of GG 2-5 mg/dm³, is consistent with the flotation results presented in Fig. 6. These results may be attributed to the chemisorption between GG and jamesonite (Piao et al., 2013; Liu et al., 2016).

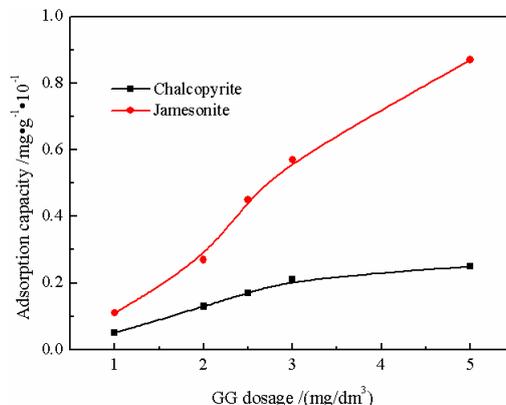


Fig. 9. Effect of GG dosage on the adsorption of chalcopyrite and jamesonite (pH 5.3)

3.6. FTIR spectra analysis

Above results demonstrate that the depressant GG can selectively adsorb on jamesonite, but the adsorption mechanism still unclear. The subsequent FTIR spectra analysis will further uncover the underlying adsorption mechanism.

Fig. 10 presents the FTIR spectra of flotation reagents and two minerals. In the FTIR spectrum of CSU11, the characteristic bands of -SH stretching vibrations are present at 2561.23 cm⁻¹ and 2512.60 cm⁻¹, the peak at 1279.21 cm⁻¹ belongs to stretching vibrations of -P=S, and peaks at approximately 648.90 cm⁻¹ and 542.78 cm⁻¹ are assigned to the anti-symmetric stretching vibration of -P-S₂ (Lin et al., 2015; Buckley et al., 2017). For the FTIR spectrum of guar gum (GG), the peak at 3445.32 cm⁻¹ stands for the stretching vibration of O-H, the peak at 2927.84 cm⁻¹ represents the stretching vibration of -CH₂, the peak at 1654.74 cm⁻¹ means the stretching vibration of hexatomic ring of carbon and oxygen, and peaks at 1111.10 cm⁻¹ and 1049.72 cm⁻¹ are attributed to the stretching vibration of C-O (Rath et al., 2000; Messali et al., 2017). In the FTIR spectrum of chalcopyrite, the broad band at 3424.37 cm⁻¹ may be attributed to hydrogen bonded hydroxyl groups. The bands between 1094 -1200 cm⁻¹ are characteristic peaks of chalcopyrite (Gadsden, 1975). The peaks between 500 -700 cm⁻¹ may be assigned to sulphate ions. For the FTIR spectrum of jamesonite, the peaks at 1080.1 cm⁻¹, 977.35 cm⁻¹ and 421 cm⁻¹ are characteristic peaks of jamesonite.

Fig. 11(a) shows the FTIR spectrum of chalcopyrite after interacting with GG and CSU11. It is clear that there appear new absorption peaks at 2543.29 cm⁻¹, 2488.79 cm⁻¹ and 1263.56 cm⁻¹ due to the stretching vibrations of -SH and -P=S respectively, which may be attributed to chemical adsorption of CSU11 on the chalcopyrite surface. GG has slight effect on the spectrum of chalcopyrite. After interacting with GG, the characteristic bands of chalcopyrite have no obvious changes and no new bands appear. However, the new absorption peaks of CSU11 at about 2546.69 cm⁻¹, 2492.8 cm⁻¹ and 1266.53 cm⁻¹ still can be observed on chalcopyrite surface after interacting with GG before CSU11. These results illustrate that the chemisorption of GG on chalcopyrite surface is weak, resulting in slight influence on the adsorption of CSU11.

The FTIR spectrum of jamesonite after interacting with GG and CSU11 is shown in Fig. 11(b). After interacting with CSU11, there appears a new band at 1486.6 cm⁻¹ resulted from the vibration of benzene ring; the peak at 864.52 cm⁻¹ by the formation of bi-dithiophosphate; and the peak at 661.53 cm⁻¹ from the anti-symmetric stretching vibration of -P-S₂. These signals indicate that CSU11 chemisorbs on jamesonite. After interacting with GG, new bands appear at 3429.50 cm⁻¹ and 1029.28 cm⁻¹. The characteristic sharp band of near 3445.32 cm⁻¹ shifts to 3429.50 cm⁻¹ due to -OH stretching vibration, and

the band near 1049.72 cm^{-1} shifts to 1029.28 cm^{-1} due to C-O stretching vibration. These changes are results of the strong chemisorption of GG on jamesonite. Additionally, there still exist several absorption peaks of GG at 3430.29 cm^{-1} and 1031.73 cm^{-1} , and the characteristic peaks of CSU11 disappear after conditioning jamesonite with GG prior to CSU11, illustrating that GG strongly interferes the adsorption of CSU11 on jamesonite surface.

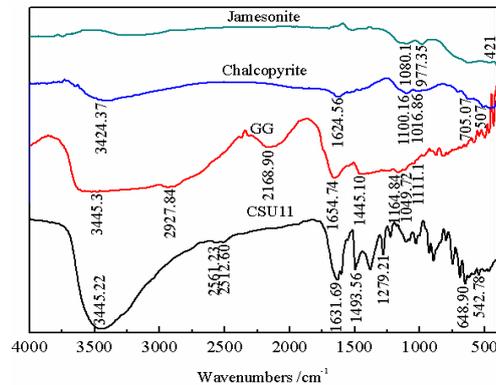


Fig. 10. Infrared spectra of the two minerals and flotation reagents

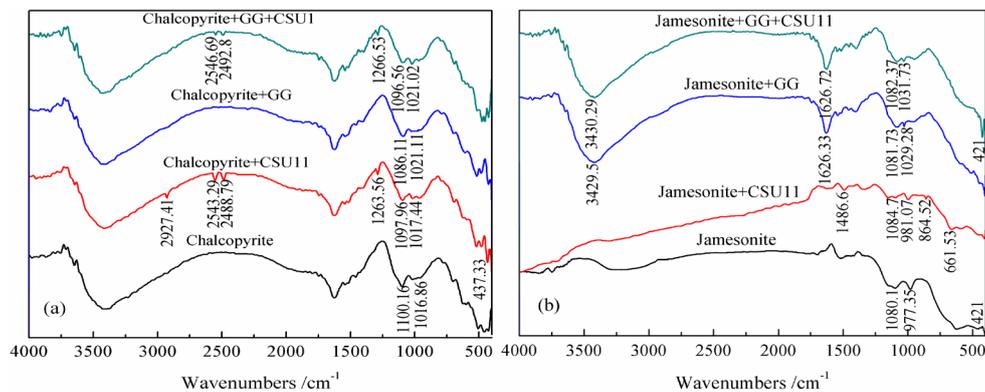


Fig. 11. The IR spectra of chalcopyrite (a) and jamesonite (b) conditioned with different reagents

4. Conclusions

In this work, guar gum (GG) is used as a depressant in flotation separation of chalcopyrite and jamesonite. The separation cannot be realized without the addition of depressant as jamesonite has a good floatability under weak acid conditions. GG has good depression ability and high depression selectivity to jamesonite within the preferable flotation pH range from 4.0 to 6.0. At pH 5.3, large difference in the floatability between chalcopyrite and jamesonite can be obtained with a variation of 86.21%. Based on this, a concentrate containing 21.35 % Cu can be obtained from an artificially mixed sample containing 11.1 % Cu, with a recovery of 85.12 %. The addition of GG can dramatically reduce the floatability of jamesonite but hardly influences chalcopyrite. Furthermore, through analyzing the dynamic potential, adsorption and IR spectra measurements, it is concluded that GG has stronger adsorption on jamesonite surface than that on chalcopyrite surface, and chemical adsorption process may dominate the interaction between GG and jamesonite, which explains the flotation results.

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References

ANTHONY, J.W., BIDEAUX, R.A., BLADH, K.W., NICHOLS, M.C., 2005. *Handbook of Mineralogy*. Mineralogical Society of Amer.

- BULATOVIC, S., WYSLOUZIL, D.M., 1995. *Selection and evaluation of different depressants systems for flotation of complex sulphide ores*. Miner. Eng. 8(1), 63-76.
- BULATOVIC, S., 1999. *Use of organic polymers in the flotation of polymetallic ores: a review*. Miner. Eng. 12(4), 314-354.
- BUCKLEY, A.N., HOPE, G.A., PARKER, G.K., STEYN, J., WOODS, R., 2017. *Mechanism of mixed dithiophosphate and mercaptobenzothiazole collectors for cu sulfide ore minerals*. Minerals Engineering, 109, 80-97.
- CHEN, J.H., FENG, Q.M., LU, Y.P., 2000. *Research on a new organic depressant ASC for separation chalcopyrite and galena*. Conserve. Util. Miner. Resour. 5, 39-42.
- CHEN, J.H., WU, B.Z., CHEN, B., 2005. *Fundamental flotation behaviors of the jamesonite and marmatite and the depressing mechanism of NaCN*. Conserv.Util. Miner. Resour. 4, 27-30.
- CHEN, J.H., LI, Y.Q., CHEN, Y., 2011a. *Cu-S flotation separation via the combination of sodium humate and lime in a low pH medium*. Miner. Eng. 24, 58-63.
- CHEN, J.H., WANG, L., CHEN, Y., GUO, J., 2011b. *A DFT study of the effect of natural impurities on the electronic structure of galena*. Int. J. Miner. Process. 98, 132-136.
- CHEN, F.S., XU, H.F., WANG, S.L., ZHENG, L., 2012. *A study on preparation of low viscosity guar gum and its strengthening performance*. China Pulp Pap. Ind. 33(2), 13-16.
- CASTRO, R.R., SILVA, C.M.M., NUNES, R.M., PAULA, R.C., FEITOSA, J.P., 2016. *Structural characteristics are crucial to the benefits of guar gum in experimental osteoarthritis*. Carbohydr. Polym. 150,392-399.
- DENG, H.B., XU, S., 1990. *Flotation mechanism of jamesonite and its separation from marmatite*. Nonferr. Met.6, 15-18.
- FROLLINI, E., REED, W.F., MILAS, M., RINAUDO, M., 1995. *Polyelectrolytes from polysaccharides: selective oxidation of guar gum-a revisited reaction*. Carbohydr. Polym. 27(2), 129-135.
- FAIRTHORNE, G., BRINEN, J.S., FORNASIERO, D., NAGARAJ, D.R., RALSTON, J., 1998. *Spectroscopic and electrokinetic study of the adsorption of butyl ethoxycarbonyl thiourea on chalcopyrite*. International Journal of Mineral Processing. 54(3-4), 147-163.
- FULLSTON, D., FORNASIERO, D., RALSTON, J., 1999. *Zeta potential study of the oxidation of copper sulfide minerals*. Colloids and Surfaces A: Physicochemical and Engineering Aspects. 146(1/3), 113-121.
- GADSDEN, J.A., 1975. *Infrared spectra of minerals and related inorganic compounds*. Infrared Spectra of Minerals & Related Inorganic Compounds.
- GAO, Y.S., GAO, Z.Y., SUN, W., YIN, Z.G., WANG, J.J., HU Y.H., 2018. *Adsorption of a novel reagent scheme on scheelite and calcite causing an effective flotation separation*. J. Colloid Interface Sci., 512, 39-46.
- GONG, H.H., LIU, M.Z., ZHANG, B., CUI, D., GAO, C., NI, B., 2011. *Synthesis of oxidized guar gumby drymethod and its application in reactive dye printing*. Int. J. Biol. Macromol. 49 (5), 1083-1091.
- HEALY, T.W., MOIGNARD, M.S., 1976. *A review of electrokinetic studies of metal sulphides*. In: Flotation. New York: Gaudin Memorial. 275-297.
- HU, Y.H., FENG, Q.M., 2006. *Mineral Processing Technology and Equipment*. Science Press, Beijing.
- HUANG, P., CAO, M.L., LIU, Q., 2012. *Using chitosan as a selective depressant in the differential flotation of Cu-Pb sulfides*. Int. J. Miner. Process. 106-109(2), 8-15.
- HU, Y.H., 2014. *Mineral Flotation*. Central South University Press, Changsha.
- HUANG, P., WANG, L., LIU, Q., 2014. *Depressant function of high molecular weight poly-acrylamide in the xanthate flotation of chalcopyrite and galena*. Int. J. Miner. Process. 128, 6-15.
- HUANG, Y.G., LIU, G.Y., MA, L.Q., LIU, J., 2017. *5-Heptyl-1, 3, 4-oxadiazole-2-thione: Synthesis and flotation mechanism to chalcopyrite*. Journal of Industrial and Engineering Chemistry. 3787, 9-18.
- LI, C., GAO Z., 2017. *Effect of grinding media on the surface property and flotation behavior of scheelite particles*. Powder Technol, 322, 386-392.
- LIU, R.Y., LI, W.J., HE, X.C., ZHOU, W.J., HAN, M.Q., 1994. *Study of Sb-Pb-Zn sulfide minerals comprehensive utilization*. Nonferrous Met. (Miner. Process. Sect.) 04, 1-6.
- LIU, Q., ZHANG, Y.H., 2000. *Effect of calcium ions and citric acid on the flotation separation of chalcopyrite from galena using dextrin*. Miner. Eng. 13, 1405-1416.
- LIU, R.Q., SUN, W., HU, Y.H., 2009. *Study on organic depressant FCLS for separation of chalcopyrite and galena*. Min. Metall. Eng. 29(3), 30-35.
- LU, Y.S., 2011. *Research status and progress of copper-lead mixed concentrates*. World Nonferrous Met. 03, 44-47.
- LIN, W., TIAN, J., REN, J., XU, P., DAI, Y., SUN, S., 2015. *Oxidation of aniline aerofloat in flotation wastewater by sodium hypochlorite solution*. Environmental Science & Pollution Research International. 23(1), 1-8.
- LIU, R.Z., QIN, W.Q., JIAO, F., WANG, X.J., PEI, B., YANG, Y.J., 2016. *Flotation separation of chalcopyrite from galena*

- by sodium humate and ammonium persulfate. Transactions of Nonferrous Metals Society of China. 26(1), 265-271.
- LIU, S., LIU, G.Y., ZHONG, H., YANG, X.L., 2017. The role of HABTC's hydroxamate and dithiocarbamate groups in chalcopyrite flotation. Journal of Industrial and Engineering Chemistry. 52, 359-368
- LÓPEZ-VALDIVIESO, A., LOZANO-LEDESMA, L.A., ROBLEDÓ-CABRERA, A., OROZCO-NAVARRO, O.A., 2017. Carboxymethylcellulose (CMC) as PbS depressant in the processing of Pb-Cu bulk concentrates. adsorption and floatability studies. Minerals Engineering. 112, 77-83.
- MI, L.P., SUN, C.B., LI, Q., XU, T., LIU, X.W., 2009. Experimental study on copper-lead separation with the combinatorial depressant. Met. Mine. 8, 53-55.
- MESSALI, M., LGAZ, H., DASSANAYAKE, R., SALGHI, R., JODEH, S., ABIDI, N., 2017. Guar gum as efficient non-toxic inhibitor of carbon steel corrosion in phosphoric acid medium: electrochemical, surface, DFT and MD simulations studies. Journal of Molecular Structure. 1145(9), 43-54.
- PIAO, Z.J., WEI, D.Z., LIU, Z.L., LIU, W.G., GAO, S.L., LI, M.Y., 2013. Selective depression of galena and chalcopyrite by O, O-bis (2,3-dihydroxypropyl) dithiophosphate. Trans. Nonferr. Met. Soc. China. 23, 3063-3067.
- PIAO, Z.J., WEI, D.Z., LIU, Z.L., 2014. Influence of sodium 2, 3-dihydroxypropyl dithiocarbonate on floatability of chalcopyrite and galena. Trans. Nonferr. Met. Soc. China. 24, 3343-3347.
- QIN, W.Q., WEI, Q., JIAO, F., LI, N., WANG, P.P., KE, L.F., 2012. Effect of sodium pyrophosphate on the flotation separation of chalcopyrite from galena. Int. J. Min. Sci. Technol. 22, 345-349.
- QIN, W.Q., JIAO, F., SUN, W., WANG, X.J., LIU, B., WANG, J., ZENG, K., WEI, Q., LIU, K., 2013a. Effects of sodium salt of N, N-dimethyl-di-thiocarbamate on floatability of chalcopyrite, sphalerite, marmatite and its adsorption properties. Colloids Surf. A: Physicochem. Eng. Aspects. 421, 181-192.
- QIN, W.Q., WEI, Q., JIAO, F., YANG, C.R., LIU, R.Z., WANG, P.P., KE, L.F., 2013b. Utilization of polysaccharides as depressants for the flotation separation of copper/lead concentrate. Int. J. Min. Sci. Technol. 23, 179-186.
- RATH, R. K., SUBRAMANIAN, S., PRADEEP, T., 2000. Surface chemical studies on pyrite in the presence of polysaccharide-based flotation depressants. Journal of Colloid & Interface Science. 229(1), 82.
- SHORTRIDGE, P.G., HARRIS, P.J., BRADSHAW, D.J., KOOPAL, L.K., 2000. The effect of chemical composition and molecular weight of polysaccharide depressants on the flotation of talc. Int. J. Miner. Process. 59, 215-224.
- SUN, Y.L., LI, F.L., 2007. Mineral processing flowsheet for Long Zixin Pb-Zn-Sb-Ag polymetallic ores. Gansu Metall. 29(4), 30-32.
- WANG, Z.S., GUO, Y.Q., 2002. Application of CMC in the flotation separation of Cu-Pb. Conserv. Util. Miner. Resour. 1, 31-34.
- WEI, M.A., SUN, C.Y., 2008. Review and development tendency of the copper and lead sulfides flotation separations. Ming Metall. 02, 6-16.
- WANG, X.L., 2012. Mineral Process and Mechanism Study of Qi Baoshan Copper-Lead-Zinc Ores. Jiangxi University of Science and Technology, Ganzhou.
- WANG, K.P., WANG, L., CAO, M.L., LIU, Q., 2012. Xanthation-modified polyacrylamide spectroscopic investigation of its adsorption onto mineral surfaces. Miner. Eng. 39, 1-8.
- WANG, Z., QIAN, Y., XU, L.H., DAI, B., XIAO, J.H., & FU, K., 2015. Selective chalcopyrite flotation from pyrite with glycerine-xanthate as depressant. Minerals Engineering. 74, 86-90.
- YALCIN, E., KELEBEK, S. 2011. Flotation kinetics of a pyritic gold ore. International Journal of Mineral Processing. 98(1-2), 48-54.
- YIN, Z.G., SUN, W., HU, Y.H., GUAN, Q.J., ZHANG, C.H., GAO, Y.S., 2017. Depressing behaviors and mechanism of disodium bis (carboxymethyl) trithiocarbonate on separation of chalcopyrite and molybdenite. Transactions of Nonferrous Metals Society of China. 27(4), 883-890.
- ZHANG, Q., HU, Y.H., XU, J., CHEN, T.J., 2005. Study of the collectorless flotation of jamesonite. Nonferrous Met. (Min. Process.) 3, 44-46.
- ZHANG, T., QING, W.Q., 2015. Floc flotation of jamesonite fines in aqueous suspensions induced by ammonium dibutyl dithiophosphate. Journal of Central South University (English). 22(4), 1232-1240.
- ZHANG, X., QIAN, Z., ZHENG, G., ZHU, Y., WU, W., 2017. The design of a macromolecular depressant for galena based on dft studies and its application. Minerals Engineering. 112, 50-56.
- ZHAO, K., YAN, W., WANG, X., HUI, B., GU, G., WANG, H., 2017. The flotation separation of pyrite from pyrophyllite using oxidized guar gum as depressant. International Journal of Mineral Processing. 161, 78-82.
- ZENG, X., XU, L., TIAN, J., YIN, W., YANG, Y., DENG, W. 2017. Effect of a CA depressant on flotation separation of celestite from fluorite and calcite using SDS as a collector. Minerals Engineering. 111, 201-208.