



Influence of depressant foenum-graecum on the flotation of a sulfide ore which contains hydrophobic gangue



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ABSTRACT

In this paper, the influence of the depressant foenum-graecum (FGM) on the flotation of a nickel sulfide ore which contains hydrophobic talc and chlorite was systematically investigated through single mineral flotation, bench-scale and industrial-scale flotation tests. The flotation results indicated that FGM had excellent depression selectivity for talc and chlorite minerals and little depression effect on copper–nickel minerals. Compared with the conventional depressant carboxymethyl cellulose, the FGM scheme increased the recovery of copper in Cu–Ni concentrates over 25% and nickel in Cu–Ni concentrates over 16% as well as simplified the structure of flotation process. In addition, the adsorption mechanisms of FGM on talc and copper–nickel minerals were studied by adsorption, zeta-potential and FTIR measurements, which further demonstrated that the adsorption of FGM on talc was much stronger than that on pentlandite, FGM could selectively adsorb on talc surfaces through chemical adsorption while a weak hydrogen bond or electrostatic attraction occurred between FGM and copper–nickel minerals.

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1. Introduction

Carboxymethyl cellulose (CMC), guar gum and other polysaccharide polymers have been widely used in the processing of many Cu/Ni sulfide ores to depress hydrophobic gangue minerals (Beattie et al., 2006; Cawood et al., 2005; Feng et al., 2012a; Huang et al., 2014; Khraishah et al., 2005; Laskowski et al., 1991; Leung et al., 2011; Ma and Pawlik, 2007; McFadzean et al., 2011; Mierczynska and Beattie, 2013; Morris et al., 2002; Parolis et al., 2008; Senior et al., 1995; Shortridge et al., 2000; Wang et al., 2005; Wiese et al., 2007). However, their selectivity may be low when dealing with low-grade Cu/Ni sulfide ores of complicated nature or fine dissemination (He and Liu, 2006; Ma and Liu, 2005; Peng et al., 2011). Although some hydrophobic talc and chlorite could be removed without the use of depressant owing to its physical in nature, it could lead to the loss of copper (over 10%) and nickel (over 5%) (Dong et al., 2003; Feng and Tang, 2011; Li, 1998; Liu et al., 2005). In addition, guar gum has been one of the most widely used industrial depressants for talc and chlorite minerals in the flotation of sulfide ores (Leung et al., 2011; McFadzean et al., 2011; Senior et al., 1995; Wang et al., 2005; Wiese et al., 2007), but it suffered the disadvantage of limited availability and high cost (Zhao et al., 2015), and

the cost of buying guar gum in the Chinese Market over triple that of foenum seed. Therefore, there is a demand to develop easily available, cheap and high performance depressants for depression of hydrophobic talc and chlorite.

In the present study, a type of foenum-graecum product was introduced in the Cu/Ni sulfide ore (containing talc and chlorite) flotation. Foenum-graecum (FGM) is taken from the endosperm of the common foenum seed and is a high molecular weight polysaccharide. It owes its blood sugar and blood lipid controlling action to the presence of a unique galactomannan polysaccharide gum, often used in medicine, food additives, chemicals, etc. (Madzlan et al., 2013; Song et al., 2000; Youssef et al., 2009). Foenum plants are widely grown in China, other Asian countries and Africa (Jiang et al., 2012). Thus, compared with guar gum, FGM was the advantage of being an abundant resource and low in price. Meantime, FGM was very good quality and wide application, which could completely take the place of imported guar gum in some considerable application areas (Xu et al., 2008). However, FGM used as a commercial depressant for the depression of hydrophobic gangue minerals in practice has not been studied, and the investigation on the selective adsorption between FGM and hydrophobic minerals has not previously been considered.

In this investigation, the depressant FGM was simply used to depress talc and other magnesia-bearing minerals. The depressing performance of FGM was compared with CMC and guar gum in the flotation separation of copper–nickel minerals from a complex Cu/Ni sulfide ore

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(containing hydrophobic talc and chlorite), in the Yanbian Copper–nickel Mine. The experimental part included flotation tests on single and mixed model minerals as well as a real ore sample. Meanwhile, the selective adsorption mechanism of FGM on both sulfide and gangue minerals were investigated by adsorption, zeta-potential and FTIR spectroscopy.

2. Experimental

2.1. Samples and reagents

2.1.1. Samples

The pure chalcopyrite (CuFeS_2), pentlandite $[(\text{Fe},\text{Ni})_9\text{S}_8]$ and talc $\{\text{Mg}^3[\text{Si}_4\text{O}_{10}](\text{OH})_2\}$ samples were obtained from the Yanbian Copper–nickel Mine of Jilin Province, China. The samples were crushed, handpicked and then dry-ground with a porcelain ball mill and dry-sieved to obtain different size fractions. The $(-100 + 75) \mu\text{m}$ fraction was used for micro-flotation tests. The $-26 \mu\text{m}$ fraction was used for adsorption, zeta-potential and infrared spectra measurements. The minerals were stored in a desiccator with nitrogen atmosphere. The results of chemical analysis of the pure samples are listed in Table 1, which indicated that the purities of chalcopyrite, pentlandite and talc were 90.45%, 92.26% and 97.06% respectively.

The Cu/Ni sulfide ore for bench-scale flotation was from the Yanbian Copper–nickel Mine. The results of chemical analysis of the ore are listed in Table 2. It showed that the main composition of the ore for bench-scale flotation is as follows: 27.81% MgO, 38.91% SiO_2 , 12.38% Fe_2O_3 and 6.02% CaO, which only contained 0.20% Cu, 0.43% Ni in this low-grade Cu/Ni sulfide ore. The Cu/Ni sulfide ore for industrial-scale tests was also from the Yanbian Copper–nickel Mine (high-grade ore), and the results of chemical analysis are listed in Table 2. The mineralogical data confirmed that in these Cu/Ni sulfide ores, the main minerals were pyrrhotite, chalcopyrite, pentlandite, talc, chlorite and pyroxene, copper and nickel mainly existed in the form of chalcopyrite and pentlandite, respectively, and the liberation size of the desired minerals (copper–nickel minerals) was below 0.1 mm. In addition, the predominant gangue minerals were hydrophobic talc and chlorite, they accounted for 29.5% and 15.4% of the total minerals respectively.

2.1.2. Reagents

The depressant foenum-graecum [FGM, structure $(\text{C}_{12}\text{H}_{20}\text{O}_5)_n$] was a new generation of polysaccharide gum. The molecular weight of FGM was about 300,000. The FGM solution was prepared by dispersing a known weight of sample in cold distilled water and then dissolving it in hot distilled water (80 °C). The viscosity of aqueous solutions of 1% (by weight) FGM is higher than galactomannan, guar gum or locust bean gum (Jiang et al., 2012; Zhao et al., 2015). The solutions were prepared fresh each day.

Single mineral flotation tests were conducted with FGM as depressant (purity >93%), with sodium isobutyl xanthate (SIBX) as collector, with methyl isobutyl carbinol (MIBC) as frother, and with hydrochloric acid (HCl) and sodium hydroxide (NaOH) used as pH regulators. All reagents used in micro-flotation tests were of analytical grade. Deionized double distilled water was used for micro-flotation, zeta-potential and infrared spectra measurements.

Bench-scale flotation tests used FGM, dextrin, guar gum and CMC as depressants, sulfuric acid and sulfurous acid as pH regulators, SIBX and

ammonium dibutyl dithiophosphate (ABDTP) as collectors, and terpenic oil was used as frother. All reagents used in bench-scale flotation tests were of industrial grade. Tap water was used for the flotation tests.

2.2. Flotation tests

Single mineral flotation tests were carried out in a mechanical agitation flotation machine. The impeller speed was fixed at 1800 r/min. The mineral suspension was prepared by adding 2.0 g of minerals to 40 mL of solutions. After adding the desired amount of reagents, the froth flotation was continued during which a concentrate was collected. The floated and unfloatable particles were collected, filtered and dried. The flotation recovery was calculated based on solid weight distributions between the two products. The 40 mL mechanical agitation flotation machine was also used in mineral mixture flotation, 1.5 g each of pentlandite and talc was taken. Then they were mixed to float. Products were filtrated, dried and weighed for assessing the recovery by multi-elemental chemical analysis. The pH of the mineral suspension was adjusted to a desired value by adding NaOH or HCl stock solutions. The general reagent addition scheme involved depressant, collector and then frother addition with each stage having a 2 min conditioning period prior to the next reagent addition. The flotation was conducted for a total of 5 min. The errors of the recovery were found to be within 2.0% after at least three tests at each condition, and the average values are reported (Zhao et al., 2015).

In the bench-scale flotation tests (Zhao et al., 2015), the ore (1000 g, crushed to -3 mm during sampling) was ground to 78.5% passing 0.074 mm in a closed steel XMQ-240 \times 90 mm ball mill at a pulp density of 66% by weight. The flotation tests were performed in XFD-63 flotation cell (self aeration) whose volume for rougher flotation was 3.0 dm^3 , for the first and second cleaners flotation were 1.0 dm^3 and third cleaner flotation was 0.5 dm^3 , for Cu/Ni separation rougher was 1.0 dm^3 and for cleaner flotation was 0.5 dm^3 , respectively. After grinding, the desired amounts of reagents were added to the slurry and the slurry was conditioned for 6 min. At the end of the 6 min conditioning, air was then fed and the froth flotation was continued for 5.5 min during which a rougher concentrate was collected. The rougher concentrates and tailings were filtered, dried, weighted and assayed for copper and nickel. In order to assess the accuracy of flotation tests, the calculated grade of feed was compared with the head assay. The flotation flowsheet and corresponding flotation conditions of the locked cycle tests are shown in Fig. 1. The experimental system M1 used FGM as depressant (the total dosage of FGM was 510 g/t), the comparative system M2 used guar gum as depressant (the total dosage of guar gum was 1000 g/t), and the comparative system M3 used CMC as depressant (the total dosage of CMC was about 1100 g/t).

2.3. Adsorption tests

For the adsorption tests, 1.0 g of single mineral was taken and made up to 100 mL after addition of desired concentration of FGM solution in 250 mL Erlenmeyer flasks. The suspension was mixed and placed on a rotator for 5 min. The sample was then centrifuged and the concentration of FGM left in solution was analyzed using the TU1810 UV–Vis spectrophotometer absorbance at 487 nm (Dubois et al., 1956). It was assumed that the amount of FGM depleted from solution had adsorbed onto the particular mineral phase.

2.4. Zeta-potential measurements

The zeta-potential measurements on chalcopyrite, pentlandite and talc were carried out using a Coulter DELSA440S II Type electro-kinetic instrument. KNO_3 (potassium nitrate) was used to maintain the ionic strength at 0.1 mol/L. 1.0 g mineral powder was added to the desired amounts of solution and ultrasonicated for 3 min, magnetically stirred for 10 min and the pH adjusted using HCl or NaOH. Pulp pH was

Table 1

The results of chemical analysis of the pure minerals.

Samples	Grade (mass fraction)/%							
	Cu	Fe	S	Ni	MgO	SiO_2	Zn	Co
Chalcopyrite	31.26	29.51	34.39	0.78	0.082	0.34	0.11	0.023
Pentlandite	0.65	30.03	32.18	31.05	0.012	0.94	0.09	0.81
talc	–	–	–	–	30.75	61.60	–	–

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