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Interactions between fine and coarse hematite particles in aqueous suspension and their implications for flotation

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ABSTRACT

The interactions between fine and coarse hematite particles were investigated, and their effects on the flotation of the hematite using sodium oleate as a collector were studied through micro-flotation tests, supplemented by optical microscopic analysis, extended Derjaguin-Landau-Verwey-Overbeek (EDLVO) theoretical analysis, and focused beam reflectance measurement (FBRM) particle/aggregate size analysis. The micro-flotation results show that the recovery of hematite from fine-coarse hematite mixtures did not decrease monotonously with increasing the fine hematite mass ratio. The highest recovery was obtained when the fine and coarse hematite were approximately equal in mass ratio, indicating that the interactions between fine and coarse hematite particles could promote the overall flotation recovery. The results of optical microscopy analysis, EDLVO calculation, and FBRM measurements showed that the interaction energies and aggregation tendencies between fine and coarse hematite particles were stronger than that among the fine hematite particles, and the aggregation would weaken when the coarse and fine fractions were mixed in extreme mass ratios, which explained the observed effects of different mixing ratios of fine and coarse hematite particles on their flotation.

1. Introduction

Flotation is regarded as one of the most important techniques for the separation of minerals, especially for the finely disseminated ores, where fine grind is essential to achieve the liberation of the value minerals from the gangue (Bagster and Mcllvenny, 1985; Sivamohan, 1990; Song and Lu, 1994). The flotation process of fine particles is plagued with losses of recovery and selectivity. Increasing the apparent sizes of the fine particles, and/or decreasing the sizes of the collecting bubbles are the main methods to improve the flotation performance of fine mineral particles, which aim to enhance the collision and attachment efficiency of particles with bubbles, or lower their entrainment when the sizes of gangue particles are enlarged (Song et al., 2000; Cao and Liu, 2006; Liu et al., 2010; Gong et al., 2010; Zhang et al., 2013; Ahmadi et al., 2014; Liang et al., 2015).

The low collision efficiencies of fine particles with bubbles are generally caused by the small mass of the particles and consequently their low momentum in the flotation pulp, resulting in a low rate of flotation recovery (Bloom and Heindel, 2002; Wang et al., 2016). The fine gangue particles with the detrimental nature of mechanical/hydraulic entrainment into froth and/or slime coating on value minerals reduce the separation efficiency of the flotation process (Xu et al., 2003; Yianatos and Contreras, 2010; Wang et al., 2015; Yin et al., 2016). In addition, the specific surface areas of fine particles are high, which increase the consumption of reagents per unit particle mass and increase unselective adsorption of reagents compared with coarse particles. Hence, the results of flotation can be influenced by even small amounts of fines.

In the case of iron ores, fine and ultrafine hematite particles are inevitably produced during the process of dressing finely disseminated iron ores (Trahar and Warren, 1976; Subrahmanyam and Forssberg, 1990; Filippov et al., 2014). Methods such as carrier flotation, hydrophobic (shear) flocculation, and selective polymer flocculation have been studied to improve the recoveries of iron ore fines (Akdemir, 1997; Shibata and Fuerstenau, 2003; Yin et al., 2011; Ng et al., 2015). In practice, especially for the finely disseminated iron ores, the optimum size (coarse) hematite and fine hematite always co-exist in the pulp and float together into the concentrate. While the available literature is rich in information on the recovery of fine hematite particles, the authors are unaware of any reported data on the effect of fine hematite on the flotation of coarse hematite, or the effect of fine hematite on the overall flotation of the hematite.

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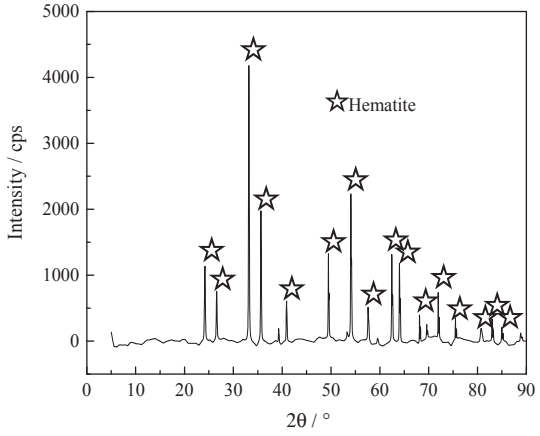

Fig. 1. X-ray diffraction pattern of the studied hematite sample.

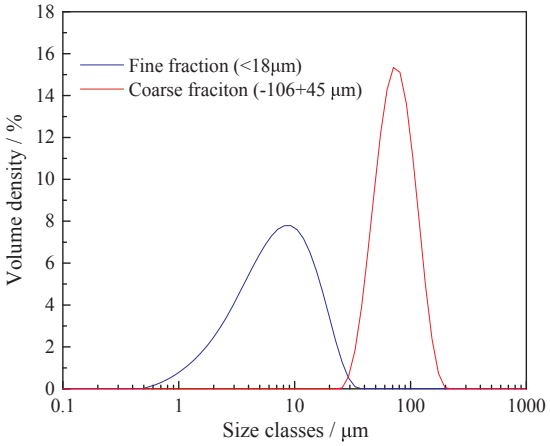

Fig. 2. Particle size distribution of hematite fine and coarse fractions.

Therefore, in this work, the interactions between fine and coarse hematite particles and the resulting flotation of the fine-coarse hematite mixtures using sodium oleate as a collector were investigated through micro-flotation tests, supplemented by optical microscopy analysis, extended Derjaguin-Landau-Verwey-Overbeek (EDLVO) theoretical analysis, and focused beam reflectance measurement (FBRM) particle/aggregate size analysis.

2. Experimental

2.1. Mineral and reagents

The hematite samples used in this study were obtained from Anshan (Liaoning Province, China). Hand-picked hematite lumps were crushed, ground, and then enriched by using a shaking table to remove light gangue minerals. Two size fractions were generated for the experiments. A fine (< 18 μm) and a coarse (−106 + 45 μm) fraction were obtained by elutriation and sieving, respectively. The results of X-ray diffraction (Fig. 1) and multi-element chemical analyses (Table 1) confirmed that the purity of the hematite sample was more than 95%. The particle size distribution of hematite samples measured by Mastersizer 3000 is shown in Fig. 2. The results indicate that the dominant sizes of the fine and coarse hematite were about 9.2 μm and 71.3 μm, respectively.

Sodium oleate (NaOl) which was used as the collector in this study was chemical pure. Hydrochloric acid (HCl) and sodium hydroxide (NaOH) of analytical grade were used as pH regulators. Distilled water was used in all the experiments.

2.2. Micro-flotation tests

The schematic diagram of the micro-flotation apparatus is shown in Fig. 3. The top of the micro-flotation cell used in this study was modeled after Siwek et al. (1981), and the base was a sintered glass frit on which a magnetic stirring bar was used to agitate the flotation pulp. No frother was used in the flotation tests as NaOl has the natural frothing ability. During flotation, the narrow throat between the vertical flotation tube and the side collection bulb only allows several gas bubbles to pass at a time. Hence, only the particles attached to the gas bubble can pass through the throat and enter the collection bulb, resulting in low mechanical entrainment.

Table 1
Multi-element chemical analysis of the hematite sample.

Names	Fe (total)	FeO	SiO_2	Al_2O_3	MgO	CaO	P	S
Contents (wt%)	68.17	0.43	1.65	0.28	0.04	0.08	0.02	0.05

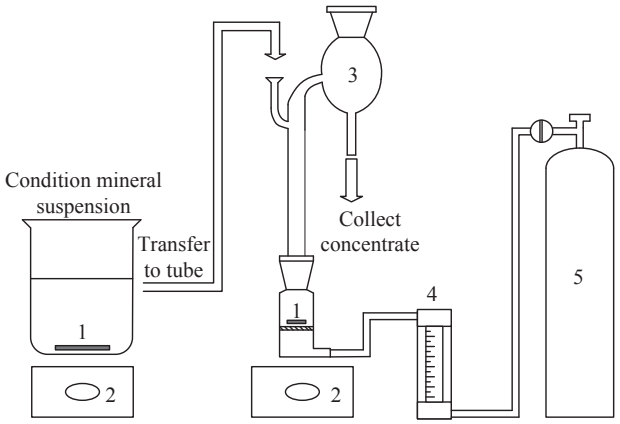

Fig. 3. Schematic diagram of the micro-flotation apparatus.

In a typical flotation test, 2 g of mineral particles were placed in a 250-mL beaker in which 150 mL distilled water were added. The pulp was stirred for 2 min at a rotating speed of 600 rpm (or 400 rpm as indicated), followed by 3 min of conditioning after the suspension pH was adjusted to the desired value using HCl or NaOH solution. Then, NaOl was added with 3 min of conditioning. Afterwards, the conditioned pulp was transferred to the micro-flotation cell and floated for 5 min with high purity nitrogen at a flow rate of 30 mL/min. The froth products and tailings were weighed to calculate the recovery after filtration and drying. For each condition, an average of at least three individual flotation tests was calculated and reported

2.3. Optical microscopy analysis

The mineral particles (1 g) were mixed with 100 mL distilled water in a 250-mL beaker. The pulp was stirred for 2 min at a rotating speed of 600 rpm, then the suspension pH was adjusted to 9.0 using NaOH solution and conditioned for 2 min, followed by 5 min of conditioning after adding a given concentration of NaOl. After settling for about 5 min, 2 mL of sediments near the bottom of the beaker was siphoned by a syringe and transferred to a glass dish, followed by the optical microscopy examination using the Fisher Scientific Stereomaster Zoom microscope with a WF 15× eyepiece and a 4× object lens (i.e., 60× magnification).