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Enhanced separation of pyrite from high-sulfur bauxite using 2-mercaptobenzimidazole as chelate collector: Flotation optimization and interaction mechanisms

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ABSTRACT

The existence of sulfide minerals (mainly pyrite) limits the use of high-sulfur bauxite in the production of Bayer alumina. In this work, the reverse flotation desulfurization using 2-mercaptobenzimidazole (MBI) as the collector was studied by $L_9(3^4)$ orthogonal tests. The interaction mechanisms of MBI with pyrite were investigated by advanced analysis technologies including scanning electron microscopy, Fourier transform infrared spectroscopy (FTIR), X-ray photoelectron spectroscopy (XPS), contact angle testing and zeta potential analysis. Results indicate that the sulfur content of bauxite is decreased from 2.87% to 0.26% by one roughing and one cleaning flotation under the optimized conditions of collector dosage of 100 g/t, activator dosage of 60 g/t, frother dosage of 200 g/t and pulp pH at 3. MBI exhibits superior hydrophobic behavior on the pyrite surface under the acid solution than under the alkaline solution, which favors the flotation of pyrite under the acidic condition. The zeta potential, FTIR and XPS results reveal that the interaction mechanisms of MBI with pyrite are electrostatic forces and chelation by forming N—Fe—S coordination bonds. MBI is an efficient collector of pyrite in the flotation desulfurization of high-sulfur bauxite and is expected to be used in other oxide or sulfide ores to separate pyrite.

1. Introduction

Diasporic bauxite is the primary mineral resource of alumina production in China. The development of the alumina industry has considerably increased the supply problems of high-quality bauxite resources. To ensure the stable, healthy and continuous development of the alumina industry, the utilization of the high-sulfur bauxite (sulfur content is higher than 0.7%) has elicited special concern. The resource reserve of high-sulfur bauxite is over 0.8 billion tons and is mostly found in the provinces of Henan, Guizhou, Guangxi and Shandong (Daoling et al., 2012; Xin and Liye, 2010; Yin et al., 2011). However, the sulfur in high-sulfur bauxite cannot be used directly in Bayer process because several harmful effects will be brought, such as corroding the equipment, increasing the consumption of alkali, declining the dissolution of alumina and reducing the yield and quality of alumina production. Therefore, high-sulfur bauxite must be desulfurized before being used in the manufacture of alumina products.

Many studies have been conducted on the desulfurization of bauxite, including wet desulfurization (Hu and Chen, 2011; Liu et al., 2017a, 2017b), calcination (Liu et al., 2017a, 2017b; Lou et al., 2016), microwave (Li et al., 2015; Zhang et al., 2012), electrolysis (Gong et al., 2017a, 2017b) and bio-desulfurization (Li et al., 2016, 2017). These technologies have disadvantages, such as costly desulfurization reagent, complicated operation, harsh or dangerous reaction conditions and requirement of SO_2 processing units for calcination (Dong, 2017; Liu et al., 2015; Yin et al., 2011; Zheng et al., 2017). Flotation desulfurization has been proven to be a particularly suitable method in virtue of flexible operation, low cost and pollution and comprehensive utilization of resources (Fan, 2013; Ma et al., 2017; Xie et al., 2017). However, water used in the flotation should be recycled and reused to conserve water resources and protect the environment (Fang et al., 2017; Fu et al., 2017).

Sulfur in the high sulfur-containing bauxite mainly exists in the form of pyrite (Li, 2013). Xanthates are the frequently used collectors of pyrite in the flotation desulfurization of high-sulfur bauxite (Fan, 2013; Ma et al., 2016, 2017; Xie et al., 2017). However, they suffer from disadvantages, including unstable chemical properties, water coloring and neurovirulence (Okibe and Johnson, 2002; Webb et al., 1976). Consequently, the research on the development of an efficient and green collector of pyrite has important expectations.

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Mercaptobenzo derivatives, a type of heterocyclic organic compounds that contain N and S atoms as electron donor atoms, have been used as chelating collectors of some low-grade sulfide minerals (Jiao et al., 2015; Numata et al., 1998). Furthermore, 2-mercaptobenzimidazole (MBI) derivatives have high selectivity for sulfide minerals, such as galena, sphalerite and argentite, by forming a four-membered ring by N and S atoms (Qin et al., 2013, 2016). In our previous work, the modified MBI was used as the collector to separate pyrite from high-sulfur bauxite, which was suitable to desulfurize at the alkaline conditions (Chai et al., 2018). Given that the natural pulp pH of high-sulfur bauxite is acidic (pH = 4–6), developing desulfurizing reagents suitable to the acidic conditions is important and necessary. To the best of our knowledge, the utilization of MBI in the flotation desulfurization of high-sulfur bauxite has not been recently reported, and the desulfurization mechanisms of MBI are unclear.

In this work, we used MBI without modification as the collector of pyrite to desulfurize the high-sulfur bauxite. The interaction mechanisms of MBI and pyrite were investigated by advanced analysis techniques including scanning electron microscopy (SEM), Fourier transform infrared spectroscopy (FTIR), X-ray photoelectron spectroscopy (XPS), contact angles testing and zeta potential analysis. The flotation factors including pulp pH, collector dosage, activator dosage and frother dosage were optimized by orthogonal experimental designs.

2. Experimental

2.1. Materials

The high-sulfur bauxite was collected from Henan province, China, and this sample was also used in our previous work (Chai et al., 2018). The typical chemical and mineralogical compositions are given in Table 1 and Fig. 1, respectively. We find from Table 1 that the A/S (the mass ratio of Al_2O_3 and SiO_2) is 3.36, and the content of sulfur is 2.87%. Fig. 1 shows that it mainly consists of diaspore (valuable mineral), pyrite (sulfur-contained mineral) and muscovite (gangue). The single mineral pyrite with the purity of 98% was obtained from Hebei province, China. The typical chemical and mineralogical compositions of pyrite sample are presented in Table 2 and Fig. 2, respectively. The molar ratio of S and Fe atoms for pyrite sample is 1.99, and the main phase of pyrite sample is pyrite (Table 2 and Fig. 2). The purity of the pyrite sample is more than 90%, which meets the requirement for single minerals.

Unless specifically noted, all chemicals used in the experiments were analytical reagents and purchased from Tianjin Kermel Reagent Technologies Co., Ltd., China. The MBI collector was bought from Aladdin Industrial Corporation, China. Terpenic oil and copper sulfate were respectively used as frother and activator. Hydrochloric acid and sodium carbonate were used as regulators to adjust pH.

2.2. Batch flotation tests

The batch flotation tests were performed in a flotation cell (1.5 L, RK/FD III, China). The flotation parameters, such as grinding density and fineness, slurry concentration, air flow rate, stirring rate, flotation time and dosage range, were chosen on the basis of the investigative tests and flotation control theory (Bartolacci et al., 2006; Shean and Cilliers, 2011). The samples of 150 g with the particle size below 3 mm were first wet ground to 75% and passed through a 74 μm sieve with a grinding density of 60 wt% in an RK/ZQM ball mill. The mean particle size D_{50} of the fine ground sample is 1.99 μm, as shown in the size distribution of Fig. 3. Then, the slurry was transferred into the flotation cell, and water was added for a total volume of 1.5 L. After the pulp was stirred for 1 min at 2200 rpm at 30 ± 0.1 °C, the desired pH was adjusted from 3 to 11 with hydrochloric acid and sodium carbonate solutions and stabilized for 3 min. The activator, collector and frother were added in succession and mixed for 3 min. Finally, flotation was conducted for 10 min with an air flow rate at 220 L/h after the froth amassed for 0.5 min. The concentrates and tailings were collected, filtered, dried and weighted. Each flotation test was repeated three times with good reproducibility, and the mean results were reported. The results with a standard error less than 5% are considered accurate. Fig. 4 shows the schematic diagram of flotation.

Table 1
Typical chemical composition of high-sulfur bauxite sample.

Composition	Al_2O_3[a]	SiO_2[a]	K_2O	TiO_2	Fe_2O_3	CaO	S[a]
Content/wt%	54.65	16.26	4.65	3.15	2.81	0.55	−2.87

[a] Based on chemical analysis.

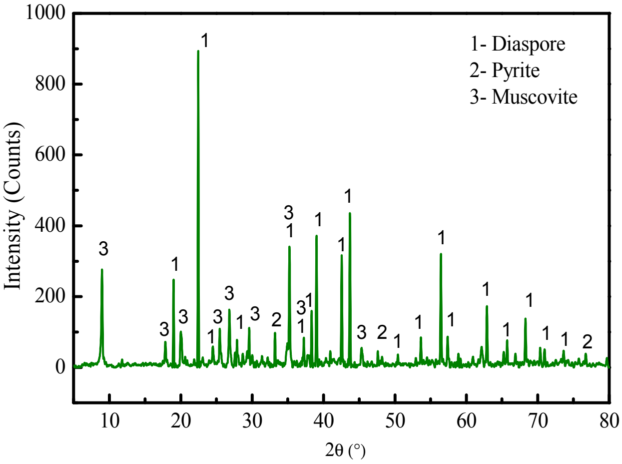

Fig. 1. XRD patterns of high-sulfur bauxite sample.

Table 2
Typical chemical composition of pyrite sample.

Composition	Fe	S	Al	Si	K	Ca	Others
Content/wt%	42.27	48.12	2.59	4.51	0.81	0.83	0.87

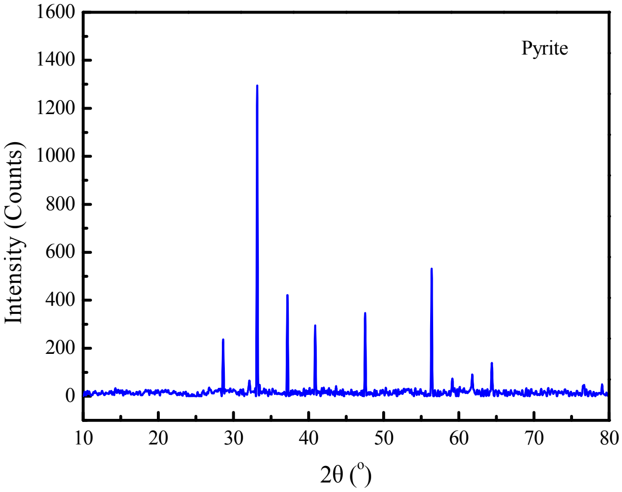

Fig. 2. XRD patterns of pyrite sample.

The Al_2O_3 content of the samples was analyzed by the industry standard 'YS/T575.1-2007', methods for chemical analysis of bauxite