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The influence of temperature on rare earth flotation with naphthyl hydroxamic acid[☆]

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ABSTRACT

The influence of temperature on the complex process of Bayan Obo rare earth (RE) ore flotation with a collector of naphthyl hydroxamic acid (LF8#) was investigated. Industrial test data shows that the grade and recovery of RE increase with the temperature. However, the proportion of bastnaesite in the bulk concentrate increases as the RE grade improves. Adsorption mechanism of LF8# on the surfaces of bastnaesite and monazite were confirmed via zeta potential, UV/Vis Spectrophotometer (UV/Vis), Fourier transform infrared (FTIR), and X-ray photoelectron spectroscopy analyses (XPS). Although the results indicate that the total amount of the LF8# adsorption on the surface of bastnaesite and monazite decreases with increasing the temperature, the amount of stable adsorbed predominance of characteristic bonds (−C(═O)N−) from LF8# uptake on bastnaesite surfaces increases significantly at high temperatures. This conclusion indicates that the adsorption stability increases with increasing the temperature. For monazite, the amount of characteristic elements C and N in LF8# does not increase as the temperature increases on the mineral surface, but the proportion of characteristic bonds increases, which shows that the adsorption stability of LF8# on the surface of monazite also increases, but it is not as significant as bastnaesite, which may be one of the reasons that the floatability of bastnaesite is better than those of monazite. Pulp dispersion results show that the temperature improve the dispersions of both the gangue and RE minerals. This improved the flotation selectivity so that it favored RE minerals. The calculated bubble size distribution confirms that higher temperatures generate smaller bubbles, thereby increasing the bubble-particle collision probability and the recovery of RE minerals.

1. Introduction

The Bayan Obo iron–rare earth (RE)–niobium deposit, located in the Inner Mongolia region of northern China, is the largest RE body in the world.[1] The principal industrial RE minerals in the deposit are bastnaesite and monazite, which are present in ratios of 1:1 or 9:1.[2] In most flotation processes, bastnaesite and monazite are recovered together in the form of a bulk concentrate as a by-product of iron ore extraction.[3] Over the past three decades, flotation of the Bayan Obo RE minerals using hydroxamates as collectors has been quite successful,[4] generating approximately 54% of global RE production.[5] However, the desired flotation has not been achieved at room temperature. The process involved clearly lags behind those used with fluorite, iron ore, sulfide ore, etc., which have long benefited from high-efficiency flotation at room temperature.

Earlier studies have suggested that the floatability and selectivity of RE ores increase with temperature when fatty acids or hydroxamic acids are used. According to Pradip et al.,[6,7] the commercial bastnaesite deposit in Mountain Pass, USA, is processed via froth flotation using fatty acids and lignin sulfonate to selectively float bastnaesite from calcite and barite at elevated temperatures. The process even uses six sequential stirring barrels to enhance the

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effect of the high temperature. The researchers also calculated that the free energy of adsorption of octyl hydroxamate onto the bastnaesite surface increases significantly with the temperature.[8] Pavez et al.[9] reported that monazite recovery increased slightly with the temperature (20–70 °C) in the presence of sodium oleate. Recent researchers have tried to avoid using high temperature RE flotation processes. Fuerstenau showed that alkyl hydroxamates can achieve the desired bastnaesite flotation selectivity at room temperature.[10] Furthermore, considerable research shows that a hydroxamate collector can react with the RE cations from lattice sites via a chelation reaction at room temperature in the weak alkaline pulp,[11–17] and some studies even indicate that elevated temperatures have negative effects on flotation.[18,19]

Changes in temperature may affect flotation performance via differences in mineral surface chemistry, reagent adsorption properties, or hydrodynamics. However, the actual flotation process is highly complex, and the flotation behaviors of the target minerals depend largely on the gangue composition of the ore and the impurities present in the mineral itself. The same mineral may exhibit differences in floatability when sourced from different mines. There are more than 170 minerals have been identified in the deposit, some of which exhibit thesimilar floatabilities to those of RE minerals such as barite, fluorite, phosphorite, etc,[3,4] and these minerals are extremely fine grained. In Bayan Obo ore, RE minerals are closely correlated with these minerals, whose grain sizes are in the range of 10–74 μm and particles smaller than 40 μm account for 70–80%. All the reasons above make the RE flotation of Bayan Obo ore difficult.[3,4] At present, there is few study carried out to investigate the flotation of Bayan Obo RE ore at the room temperature, that is why such a process have not been applied to the Bayan Obo RE dressing plant, which is the largest dressing plant in the world.

Increasing the RE concentrate grade can reduce the amount of impurities taken into the hydrometallurgy process from the source and is conductive to the development of a cleaner and more efficient hydrometallurgical technologies. In this respect, the RE concentrate grade (REO) was improved from 50% to 65% over the past 1–2 years via the joint efforts of our group and the China Northern Rare Earth (Group) Hi-Tech Co. Ltd. dressing plant.[20–24] However, this achievement was not enough to avoid heating of the pulp. In this study, industrial experiments were performed to determine the effect of temperature on mixed RE flotation. The mechanism by which naphthyl hydroxamicacid (LF8#) adsorbs onto bastnaesite and monazite was investigated using zeta potential measurements, UV/Vis Spectrophotometer (UV/Vis), Fourier transform infrared spectroscopy (FTIR), and X-ray photoelectron spectroscopy (XPS). The study, which examines the effects of pulp dispersion and bubble size distribution on flotation performance, indirectly explains the influence of temperature on flotation selectivity and recovery. The experimental results will aid in further development of exciting new technology for Bayan Obo RE ore flotation at room temperature.

2. Materials and methods

2.1. Materials

Industrial test pulp was obtained from the Baotou Iron & Steel (Group) Co. Ltd. (BIS) dressing plant, and REO was enriched to 9.85% in the pulp after a "low magnetic separation – high magnetic separation – reverse flotation" process was applied to iron oxide ore (the average REO grade was 6%).[25,26] The iron tailings were ground to 85% of them passed through a 74 μm mesh, and particles smaller than 20 μm accounted for 55% of the total. The degree of RE mineral liberation was only 77%. The gangue minerals were fluorite, barite, and silicate minerals. Furthermore, the pulp contained significant amounts of ionic calcium-magnesium and iron flotation reagents. The main sample compositions are given in Table 1.

To avoid the complexity imposed by the varying floatabilities of diverse sources, the samples were obtained from the Bayan obo deposit, and high purity bastnaesite and monazite was selectively separated by flotation using potassium alum as a depressant. The details of the experimental procedure can be found elsewhere.[27] To remove potential residue and other impurities from the sample surfaces, the powder samples were screened to leave only coarse fractions (45–75 μm), and washed with reagent grade ethanol followed by de-ionized water. The coarse fractions were then ground to approximately 5 μm using an agate ball mill for Zeta potential measurements, UV/Vis, as well as FTIR and XPS analyses. Based on their mineralogical analyses, the purities of bastnaesite and monazite were at least 97% and 92%, respectively. The X-ray diffraction (XRD) results and elemental analyses of the mineral samples are shown in Fig. 1 and Table 2. Naphthyl hydroxamic acid (LF8#) and water glass were used in the industrial experiments. These reagents were obtained from Ling Feng Rare Earth Chemical Co., LTD. in Baotou, China. Other reagents such as HCl, NaOH, and KCl were pure.

2.2. Methods

2.2.1. Industrial experiments

To determine the influence of temperature on mixed RE ore flotation, flotation data were acquired from a China Northern Rare

Table 1
Chemical composition of the RE ore (wt%).

Composition	REO	TFe	CaO	SiO_2	K_2O	Na_2O
Quantity	9.85	14.92	28.95	9.22	0.21	0.93
Composition	ThO_2	MgO	MnO	BaO	Nb_2O_5	Al_2O_3
Quantity	0.11	1.52	2.88	3.47	0.27	0.62

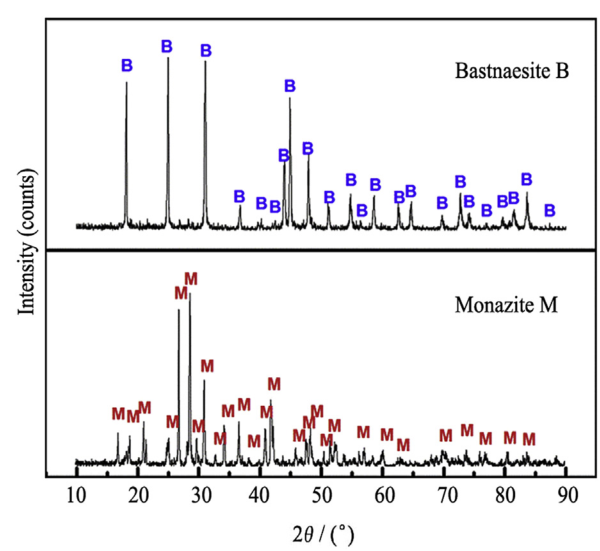

Fig. 1. XRD spectra of bastnaesite and monazite.

Table 2
The elemental compositions of bastnaesite and monazite (wt%).

Element	REO	TFe	F	P_2O_5	SiO_2	MgO	Na_2O	CaO
Bastnaesite	74.08	1.32	8.94	0.98	0.20	0.19	0.13	2.12
Monazite	69.73	1.30	0.43	13.83	0.40	0.11	0.05	0.17