

## Interaction of reactive oily bubble in flotation of bastnaesite

ZHOU Fang (周芳)<sup>1,2</sup>, WANG Louxiang (王娄翔)<sup>3</sup>, XU Zhenghe (徐政和)<sup>3</sup>, LIU Qingxia (刘青侠)<sup>3</sup>, CHI Ru'an (池汝安)<sup>1,2,\*</sup>

(1. School of Minerals Processing & Bioengineering, Central South University, Changsha 410083, China; 2. School of Chemical Engineering and Pharmacy, Wuhan Institute of Technology, Wuhan 430073, China; 3. Department of Chemical and Materials Engineering, University of Alberta, Edmonton, Alberta T6G 2V4, Canada)

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**Abstract:** To understand the flotation mechanism of bastnaesite using reactive oily bubble, the interaction between bastnaesite particles and reactive oily bubbles was investigated by electro-kinetic studies, induction time measurements and small-scale flotation experiments. The bastnaesite flotation could be seen as a hetero-coagulation between bastnaesite particles and reactive oily bubbles which was confirmed by the zeta potential distribution and induction time measurements from pH 4.8 to pH 9.0. The small-scale flotation tests were consistent with the hetero-coagulation results, and showed a better flotation of reactive oily bubble than air bubble among all pH range. The interaction force between bastnaesite particles and reactive oily bubbles was evaluated by the classical DLVO theory. It indicated that the attachment could be predicted well by the DLVO theory only in a restricted pH range due to the absence of hydrophilic interaction repulsion force and chemical interaction force.

**Keywords:** bastnaesite; reactive oily bubble; flotation; hetero-coagulation; DLVO theory; rare earths

The rare earth elements are a group of fifteen elements from 57 La to 71 Lu. Because of their unique fluorescent and chemical properties, rare earth elements are used in many technological devices such as catalysts, high-strength permanent magnets, glass, polishing, TV color components and so on<sup>[1]</sup>. The increasing world demand for rare earth elements led to the high-efficiency exploitation and recovery of rare earth ores. The found minerals containing rare earth in the world has reached more than 250. Bastnaesite, monazite and weathered crust elution-deposited rare earth ore are the main rare earth elements bearing industry minerals. Bastnaesite as the main source of Ce group rare earth elements has important industrial value such as polishing powder, catalyst and phosphor<sup>[2]</sup>. Bastnaesite is normally associated with calcium and barium gangue mineral such as barite, calcite and fluorite et al.. This kind of mineral may be beneficiated using gravity, magnetic, electrostatic and flotation separation techniques<sup>[3]</sup>. The common approach for separating bastnaesite is froth flotation which is according to the differences of the surface properties of minerals. In the bastnaesite flotation process, the ore is usually crushed and ground to less than 200  $\mu\text{m}$  to liberate the minerals before flotation. The surface of bastnaesite is hydrophilic and then rendered to hydrophobic by added reagents like collector so as to attach them to air bubbles. The gangue mineral particles are unattachable to air bub-

bles and can be separated from the valuable mineral by the bubble rise<sup>[4]</sup>.

A novel flotation technique was raised which used reactive oily bubble instead of conventional air bubble. The reactive oily bubble was prepared by coating a thin layer of kerosene containing 100 ppm fatty acid on the surface of air bubble which shows a better mineral flotation performance in sulphide ore flotation<sup>[5,6]</sup>. The novel technique can avoid the high temperature process, reduce the amount of fatty acid and increase the collecting power of fatty acid due to a higher localized concentration of collector molecules at the oil/water interface. In my previous work, the superiority of the novel technique of reactive oily bubble in the bastnaesite flotation was confirmed by the induction time measurement and zeta potential distribution measurement.

The reactive oily bubble flotation of bastnaesite is controlled by the interactions between a bastnaesite particle and a reactive oily bubble, which further determines the flotation kinetics and bastnaesite recovery. This flotation process can be seen as a colloidal system, where bastnaesite particles and reactive oily bubbles suspended in an aqueous media. All of particles and reactive oily bubbles randomly collide with each other as a result of Brownian motion, or from external force such as thermal and gravitation, and result in a hetero-coagulation between bastnaesite particles and reactive oily bubbles. It is easy

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\* **Corresponding author:** CHI Ru'an (E-mail: [rac@mail.wit.edu.cn](mailto:rac@mail.wit.edu.cn); Tel.: +86-27-87195682)

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for the occurrence of the term hetero-coagulation among dissimilar surfaces in a number of ways such as composition, size, surface charge, etc.<sup>[7]</sup>. The existing interaction in a colloidal system usually includes the electrostatic double-layer forces and the van der Waals force, which can be calculated by the classical DLVO theory. With the popularization of surface force apparatus and the atomic force microscope, many researches on the interaction in colloidal system were completed<sup>[8]</sup>. In this study, the interaction between bastnaesite particles and reactive oily bubbles was evaluated by the classical DLVO theory to theoretically illustrate the flotation mechanism of reactive oily bubble.

## 1 Materials and methods

### 1.1 Materials

Kerosene, reagent grade HCl and NaOH as pH modifiers were purchased from Fisher Scientific. Ultra-high purity KCl (>99.999%) from Fisher Scientific was used to prepare 10 mmol/L KCl solutions as supporting electrolytes. A bastnaesite concentrate with REO content of 75.02% was used in this study, which has been characterized by XRD, XRF, SEM and XPS. The chemical analyses of bastnaesite concentrate are shown in Table 1.

### 1.2 Electrokinetic studies

Zeta potentials and zeta potential distributions were measured using a SEPHY/CAD Zetaphorometer III. The bastnaesite particles of  $-25\ \mu\text{m}$  were used to prepare bastnaesite suspension by placing 0.1 g bastnaesite into 50 mL 10 mmol/L KCl solutions under a 550 Sonic Dismemberator (Fisher) for 15 min. The emulsion of reactive oily bubble was prepared by dropping 5 droplets of kerosene with 100 ppm fatty acid into 80 mL of 10 mmol/L KCl solutions and then ultrasonic dispersed for 15 min, too. Before every measurement, the upper layer

of bastnaesite suspension and reactive oily bubble emulsion were diluted into 0.01 wt.%–0.1 wt.% by testing 10 mmol/L KCl solution to obtain a solution with right concentration suitable for zeta potential measurement. The pH of the emulsion and suspension were adjusted by HCl and NaOH solution. At least five zeta potentials readings were taken and averaged as well as the standard deviations were reported. The environmental temperature was maintained at  $22\pm 0.1\ ^\circ\text{C}$ .

### 1.3 Determination of hetero-coagulation

The hetero-coagulation between bastnaesite particles and reactive oily bubbles was evaluated by the efficiency of particle-bubble attachment under a macro lens connected to a CCD camera, which is presented by induction time. The theory and specific method of induction time can be seen in literatures<sup>[9,10]</sup>. The induction time measurement was conducted by an in house-built induction timer. The bastnaesite was ground in a mortar and pestle and sieved to different ranges, where  $+150\text{--}212\ \mu\text{m}$  of bastnaesite particle was used in this part. Fig.1 shows the induction time measurement. A silica wafer cleaned by sulfuric acid was put onto a plastic platform on the bottom of a glass cell, where an even thickness of bastnaesite particle bed was formed by a plastic pipette transferring the bastnaesite suspension. A reactive oily bubble was generated by a clean capillary tube for every touch, firstly a small volume of the kerosene with 100 ppm fatty acid was sucked. The contact time and attachment of the reactive oily bubble to the bastnaesite particle bed was monitored by the macro lens. The reactive oily bubble approach and retract velocity was fixed at 40 mm/s, and the temperature was maintained at  $22\pm 0.1\ ^\circ\text{C}$ .

### 1.4 Small-scale flotation measurements

The small-scale flotation was measured in a home-made flotation cell which is similar to the microflotation cell reported by Liu et al.<sup>[5]</sup>. The only difference was that

**Table 1 Results of chemical analyses of bastnaesite concentrate**

Elements	Si	P	S	Pd	K	Ca	Ba	La	Ce	Fe	Sr	Zr
Contents/(wt.%)	2.16	0.26	3.87	6.94	0.23	1.48	13.27	29.44	38.64	3.11	0.23	0.16

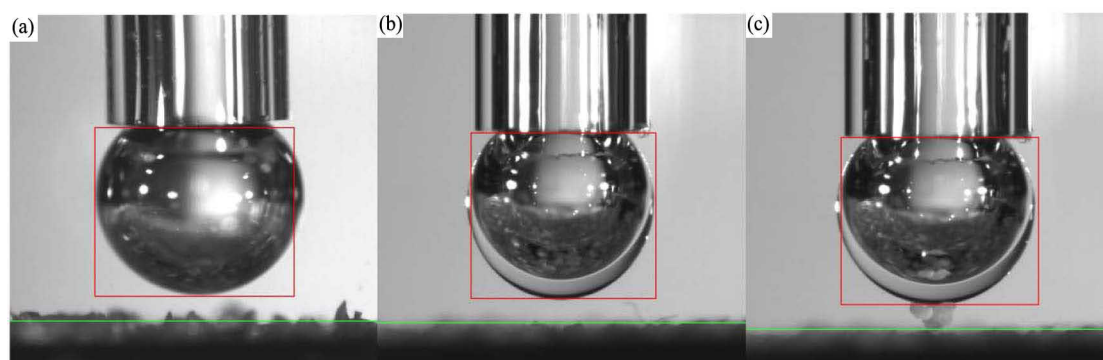


Fig. 1 Schematic illustration of induction time

(a) Air bubble; (b) Reactive oily bubble; (c) Reactive oily bubble attached with bastnaesite particles

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