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A comparison of sodium silicate and ammonium lignosulfonate effects on xenotime and selected gangue mineral microflotation

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ABSTRACT

Because of their selective depressing power, sodium silicate and lignosulfonate have been widely used as depressants in rare-earth mineral flotation to separate minerals from specific types of gangue minerals. In this project, the microflotation of a xenotime pre-concentrate and pure samples of the selected gangue minerals ilmenite, zircon, schorl and staurolite was carried out. This utilized octano-hydroxamic acid and sodium oleate as the collectors and the research was conducted in a Partridge-Smith microflotation cell. The flotation of the mixed samples (weight ratio = 1:1) of xenotime and each one of its gangue minerals was also investigated at both room temperature and 80 °C, using sodium silicate or ammonium lignosulfonate in the presence of octano-hydroxamic acid and sodium oleate respectively. The flotation results are described and compared with those observed by previous researchers. The effects of sodium silicate and ammonium lignosulfonate on weight recoveries and grade of xenotime are also discussed and compared.

1. Introduction

Sodium silicate, widely used as a depressant in rare earth mineral flotation to separate minimally soluble minerals from siliceous gangue minerals (Sis and Chander, 2003), has been studied through the last five decades.

In 1965, using sodium silicate as depressant in the presence of sodium oleate, Viswanathan et al. selectively separated monazite from its associated gangue minerals (Viswanathan et al., 1965). In 1981, Pradip stated that work by Illie in 1966 also enhanced the recovery of monazite from 77% to 90% by using both sodium silicate and Na_2S as depressants (Pradip, 1981). In 1990, Dho and Iwasaki concluded that the effect of sodium silicate was attributed the higher specific flotation rate of phosphate over silicate minerals, thus enhancing the selectivity of separation (Dho and Iwasaki, 1990). In 2010, Silva et al. investigated the use of sodium silicate with the use of FTIR spectra. It was found that the depressing power of sodium silicate increased correspondingly with its concentration. Almost a complete depression of calcite and quartz was achieved with concentrations above 1500 g/l (Silva et al., 2012). The most successful use of sodium silicate as a depressant is in its application in the mine. There it is used to depress silicates before the Bayan Obo addition of a naphthyl hydroxamic acid collector. At the low alkaline conditions used, the depressing power of sodium silicate helps to upgrade the rare earth minerals concentrate from 9.78–12% to 34–55% TREO content (Li and Yang, 2014).

Lignosulfonate, a byproduct from the production of paper using sulfite pulping, is also well known as a depressant in the flotation of rare earth minerals.

In 1968, Helmut et al. found that lignosulfonate possessed the power to depress silica in froth flotation (Helmut et al., 1968). In 1975, Browning indicated that the adsorption of lignosulfonate on a mineral surface happened by chemical hydrogen bonding (Browning, 1975). Further, in 1981, Pradip found that temperature had little effect on the performance of lignosulfonate as a depressant (Pradip, 1981). In contrast, Anderson in 2015 concluded the opposite in that a sharp increase in recovery and grade occurred by increasing the temperature of a flotation operation from 25 °C to 80 °C (Anderson, 2015).

More importantly, is utilization of the depressing power of lignosulfonate on iron-bearing gangue minerals. In 1986 Weir et al. successfully recovered gold from refractory auriferous iron-containing sulphidic concentrates by using lignosulfonate as a depressant (Weir and Roman, 1986). In 2008 Sun and Yi significantly upgraded limonite by reverse flotation by using lignosulfonate as the depressant (Sun and Yi, 2007). The commercial application of lignosulfonate as a depressant also appears in the industrial flotation of bastnaesite ore at Mountain Pass in California. There ammonium lignosulfonate is added in a steam heated

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conditioning stage before the addition of steam-distilled tall oil C-30, in order to depress barite (Pradip and Fuerstenau, 2013).

While sodium silicate and lignosulfonate have been widely investigated and used in rare-earth mineral flotation, their application in the flotation of xenotime has apparently been minimal, when compared to that of bastnaesite and monazite. So, in order to better understand the effect of sodium silicate and ammonium lignosulfonate on xenotime flotation, in this research, a pre-concentrated xenotime sample and four common gangue minerals (ilmenite, zircon, schorl and staurolite) were used in lab-scale microflotaion tests. These were conducted in a Partridge-Smith microflotation cell. Comparisons were made between the performance of sodium silicate and ammonium lignosulfonate as the depressants in experiments conducted under differing conditions. This was also studied in the presence of octano-hydroxamic acid and sodium oleate collectors.

2. Materials and methods

The pre-concentrated xenotime sample used in this project was obtained from a Chinese rutile mining plant in Hainan Province, China. Xenotime is a byproduct of beach placer deposits and it had been separated and concentrated from rutile ores by washing, Wilfley table concentration, electrostatic separation and finally magnetic separation. As shown in Table 1, Mineral Liberation Analyzer (MLA) analysis on this concentrate indicated that xenotime (YPO_4) was the major phase present at 67.7% by weight. An iron-titanium oxide phase called pseudo-rutile was found to be 12%, followed in abundance by silicates-staurolite 6%, zircon 4%, and schorl 3%. Since pseudo-rutile is a weathering product of ilmenite, and a FeTiO-bearing mineral similar to ilmenite, ilmenite was chosen as one of the four major gangue minerals. The other three minerals utilized were zircon, schorl and staurolite. The proposed formulas for these are shown in Table 1. All four gangue minerals were obtained as crystals. All of the xenotime concentrate and the gangue minerals were pulverized in an Angstrom TE250 Ring Pulverizer to a 200 × 400 US mesh size fraction. These materials were then washed and dried for experimental use.

The two collectors used, sodium oleate ($C_{18}H_{33}NaO_2$) and Octano-hydroxamic acid ($C_8H_{17}NO_2$) were both supplied by Tokyo Chemicals Inc. One depressant used, pentahydrate sodium silicate ($Na_2SiO_3{\cdot}5H_2O$) was obtained from unknown supplier; the other depressant used, ammonium lignosulfonate ($C_{20}H_{26}O_{10}S_2$ for lignin sulfonate) was supplied by HBC Chem Inc.

In this research, zeta potential measurement was conducted with the Stabino, produced by Microtrac. Before performing Stabino testing, the equilibrium time of samples in solution was determined first through adsorption tests. Then the samples for Stabino tests were prepared for a longer time. In this case, the samples for zeta potential measurements were first ground in a pulverizer to 200 × 400 mesh. Then 0.02 g of each mineral was added in 40 mL distilled water. The pH was adjusted as required with NaOH and HCl.

In the research more than 300 microflotation tests were conducted using a Partridge-Smith microflotation cell. Replicate tests were conducted on each benchmarking test and the reproducibility was excellent. In each benchmarking test, 0.5 g of mineral sample (or a mixed sample of xenotime and the gangue minerals) was stirred with 40 ml of collector solution with the concentration ranging from 0.0005 M to 0.002 M, in a 100 ml beaker for 15 min at set pH values. After conditioning, the sample was transferred to the microflotation cell. 10 ml of the collector with the correct concentration and pH was added and also used to wash down any residual material in the beaker to the cell.

Table 1
MLA mineral content of the xenotime concentrate.

Mineral	Formula	Modal (wt%)
Xenotime	YPO_4	67.7
Pseudorutile	$Fe_2Ti_3O_9$	11.6
Staurolite	$Fe_2Al_9Si_4O_{20}(OH)_4$	5.94
Zircon	$ZrSiO_4$	4.00
Schorl	$NaFe_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$	3.05
Others	/	7.71

In each test with depressant addition, 0.5 g of sample was conditioned with 25 ml of 0.001 M depressant first for 5 min and then for 15 min after the addition of 15 ml of collector solution with concentrations ranging from 0.001 M to 0.004 M. After conditioning, the sample was transferred to the cell and 10 ml of the collector with the correct concentration and pH was used to wash down any residual material in the beaker to the cell.

The pH in the tests was modified with either NaOH or HCl. The pH was measured before conditioning with a pH meter. Elevated temperature tests were performed by heating the samples to 80 °C during conditioning.

After the pulp was transferred, it was stirred with a magnetic bar in the cell at 600 rpm. The compressed air flow addition rate was maintained at 30 cc per minute. After 2 min of flotation, the concentrate and tailings were filtered and dried for weighing. Then the dried concentrate was prepared for XRF analysis, in order to determine the content.

Using different reagents, the experimental variables evaluated in the microflotation tests included pH, temperature and reagent concentration. Other variables like gas flow rate and particle size were not tested in this project.

The error bars presented represent the standard deviation of the experimental data gained from the benchmarking tests. The magnitude of experimental error was within the allowable range, having no effect on qualitative analysis.

3. Results and discussion

In benchmarking tests, no depressants were used. Octano-hydroxamic acid (HXM) and sodium oleate (SOT) collectors were tested with varying conditions. Fig. 1 shows that the weight recovery of xenotime increased when the concentration of HXM was increased from 0.0001 M to 0.0005 M. The weight recovery was constant above 96% even when the concentration of HXM was increased to 0.002 M. This likely indicates that the concentration of HXM has already reached its adsorption equilibrium at 0.0005 M.

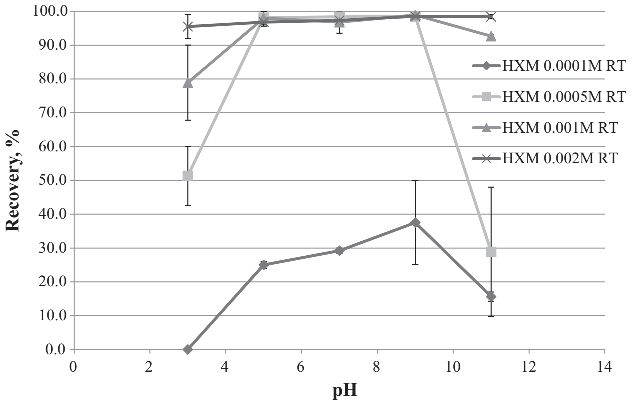

Fig. 1. Microflotation recoveries of xenotime with different concentrations of octano-hydroxamic acid as a function of pH at room temperature.