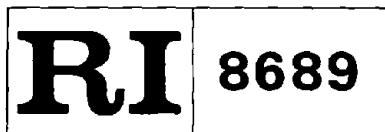


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Flotation of Rare Earths From Bastnäsite Ore

By E. Morrice and M. M. Wong



UNITED STATES DEPARTMENT OF THE INTERIOR

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FLOTATION OF RARE EARTHS FROM BASTNÄSITE ORE

By E. Morrice¹ and M. M. Wong²

ABSTRACT

As part of its efforts to maximize process efficiency and decrease energy requirements in mineral processes, the Federal Bureau of Mines has investigated methods for beneficiating bastnäsite ores from Mountain Pass, Calif. The results of a bench-scale study on the flotation of bastnäsite ore are presented. Flotation at a pulp temperature of 40° to 45° C yielded a cleaner concentrate containing 58.7 pct RE₂O₃ at a rare-earth recovery of 67 pct. These results are comparable to those reported for the commercial beneficiation method in which the pulp is heated to boiling before flotation. An attempt was also made to recover a barite flotation concentrate from the bastnäsite rougher tailing. Concentrates containing only 70 pct barite were obtained.

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INTRODUCTION

In 1949 a large bastnäsite deposit was discovered at Mountain Pass, Calif. Subsequent development of the deposit made the United States the world's largest source of rare-earth minerals. Since 1965, bastnäsite, a fluocarbonate of the cerium-group metals, REFCO_3 , has replaced monazite as the principal source of rare earths; in 1978 it accounted for more than half of the world production (6).³ Rare-earth alloys and compounds are used in petroleum cracking catalysts, ductile iron and high-strength, low-alloy (HSLA) steel production, high-energy permanent magnets, color television picture tubes, glass polishing and decolorizing, and ceramics.

At Mountain Pass, bastnäsite concentrates are produced by froth flotation. In the milling operation the ballmill discharge containing 9.5 pct RE_2O_3 is heated to boiling and conditioned with lignin sulfonate, a gangue depressant, and fatty acid collector (5). Flotation is carried out at a pulp temperature of about 70° C. The rare-earth fluocarbonate is floated from associated gangue minerals which include barite, calcite, silicates, apatite, galena, hematite, and monazite. Cleaner flotation concentrates containing 55 to 60 pct RE_2O_3 are made and are acceptable for processing into higher grade rare-earth products (7).

Rougher tailings containing between 1.5 and 2.5 pct RE_2O_3 are produced.

In 1980 the Mountain Pass mill shipped 16,800 short tons of RE_2O_3 . Bastnäsite, cerium, and lanthanum concentrates are produced. Bastnäsite concentrates representing 43 pct of the rare-earth production are exported (3).

Since the Bureau of Mines is interested in maximizing process efficiency and decreasing energy requirements of mineral processes, research was initiated to improve bastnäsite flotation; although bastnäsite is mined at only one U.S. operation, it is a unique material and whatever can be learned about it is useful in advancing the frontiers of mineral knowledge.

The main objective was to devise a viable method for producing a bastnäsite concentrate containing 55 to 60 pct RE_2O_3 at a lower temperature than is used in commercial practice, thereby conserving energy. Since barite was one of the principal gangue minerals in the bastnäsite ore and was a potential byproduct which could be marketed as a drilling mud additive, research was also performed to evaluate the possibility of producing an acceptable barite concentrate.

ACKNOWLEDGMENT

The authors gratefully acknowledge the assistance of Molycorp., Inc., a subsidiary of Union Oil Co., of California, in providing the ore samples.

DESCRIPTION OF THE SAMPLE

The sample received from the Mountain Pass Mine was minus 8-mesh mill feed.

The analysis of the sample is shown in table 1.

³Underlined numbers in parentheses refer to items in the list of references at the end of this report.

TABLE 1. - Partial chemical analysis
of sample, pct

RE ₂ O ₃ ¹	7.5
BaSO ₄	21.2
SiO ₂	12.6
CaO.....	18.5
SrO.....	4.5
MgO.....	2.7
Fe ₂ O ₃	2.2
Fluorine.....	1.0
CO ₂	19.6
P ₂ O ₅5
Total sulfur.....	3.9
Lead.....	.3
Thorium.....	.02

¹RE₂O₃ contained, in pct: 53 CeO₂; 30 La₂O₃; 11.2 Nd₂O₃; 4.2 Pr₆O₁₁; 0.66 Eu₂O₃; 0.62 Sm₂O₃; 0.21 Y₂O₃; and 0.13 Gd₂O₃.

A screen analysis of the ore was made to determine the grind necessary for liberation of the bastnäsite particles. A sample was crushed to minus 35 mesh with a laboratory rolls and wet-screened through Tyler standard sieves. The sized fractions were examined with an electron microprobe and analyzed for rare-earth and barium sulfate content. Screen analysis results are given in table 2. No appreciable concentration of rare earths or barium sulfate was noted in any of the fractions. The lower rare earth and the higher barium sulfate values in the minus 325-mesh fraction indicated that the barite is more friable than the bastnäsite. Electron microprobe indicated that most of the bastnäsite grains in the minus 150- plus 200-mesh fraction were liberated. Figure 1 shows the liberated bastnäsite grains. Even though the data indicated a liberation size of 150 mesh, flotation tests were made on ore ground to 80 pct minus 150 mesh because a minus 150-mesh grind yielded more than 60 pct minus 325-mesh material, which was difficult to treat.

TABLE 2. - Screen analysis
of sample

Screen size, mesh	Analysis, pct		Wt-pct
	RE ₂ O ₃	BaSO ₄	
Minus 35 plus 48..	7.7	17.9	16
Minus 48 plus 65..	8.5	19.5	17
Minus 65 plus 100.	9.3	20.5	12
Minus 100 plus 150	9.5	20.5	8.5
Minus 150 plus 200	8.6	19.9	8.5
Minus 200 plus 270	8.1	19.6	6
Minus 270 plus 325	8.0	20.2	5
Minus 325.....	5.8	23.4	27
Composite....	7.7	20.6	100

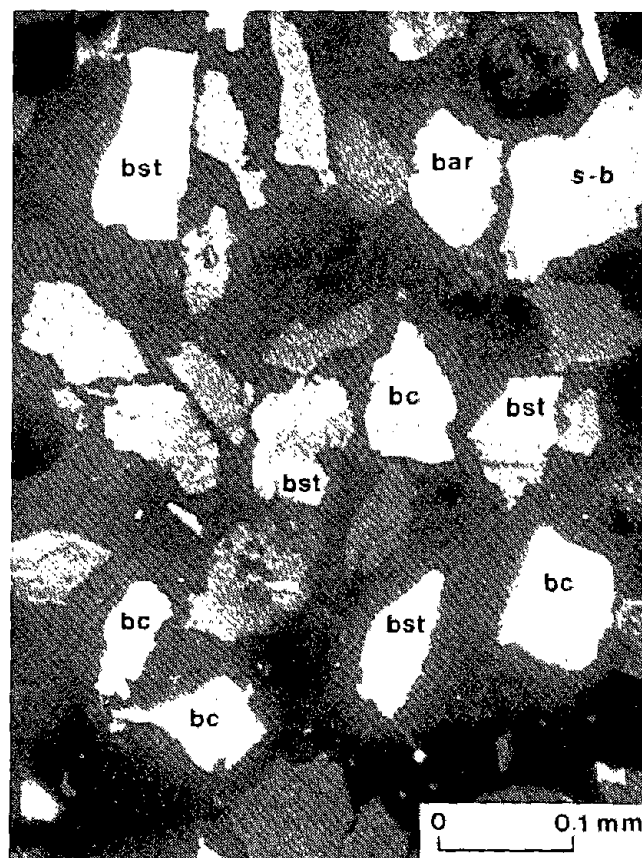


FIGURE 1. - Minus 150- plus 200-mesh fraction. Barytocelestite (bc), bastnäsite (bst), barite (bar), strontianite-barite intergrowth (s-b).

FLOTATION EQUIPMENT AND PROCEDURE

Conditioning and rougher flotation were conducted in a Wemco⁴ model 52-524 flotation cell having a rubber impeller (2-in diameter), a rubber disperser (4-in diameter), and a 3-L (liter) Pyrex bowl. To prepare cleaner concentrates, rougher concentrates were conditioned and floated in a Denver No. 12 laboratory flotation cell fitted with a 2-7/8-in-diam impeller and a 3-1/8-in-diam stainless steel stator in a 1.3-L stainless steel tank.

Pulp pH in all flotation tests was determined with a phenophtazine indicator paper. The pH's were checked with a Corning Digital 109 pH meter.

The ore sample was mixed and split in 30-lb (13.6-kg) lots. Each 30-lb lot was

crushed to approximately 85 pct minus 100 mesh in a rolls crusher and passed through a Sweco vibrating screen operating in closed circuit with the rolls. The 15-pct oversize was dry-ground to minus 100 mesh in a steel ball mill which was operated in closed circuit with the screen. The ground ore was mixed on a large rolling cloth, and 1,000-g charges for flotation tests were split and bagged. Dry crushing and grinding were chosen for comminution because of convenience and easier control in sizing, sampling, and handling of the small quantities of product. Flotation tests using wet-ground ore yielded results similar to those obtained with dry-ground ore.

PRELIMINARY FLOTATION TESTS

The fatty acid collectors evaluated were oleic acid, linoleic acid, linolenic acid, and the fatty acid-resin acid mixtures Westvaco L-1 (1 pct resin acid), Westvaco L-5 (5 pct resin acid), and Westvaco M-28B (28 pct resin acid). The fatty acid portion of the Westvaco products contains approximately equal amounts of oleic and linoleic acids and about 1 pct linolenic acid. The petroleum sulfonate product evaluated was AERO 845.

The gangue depressants screened were lignin sulfonates, sodium fluoride, and sodium fluorosilicate. Lignin sulfonates and sodium fluoride have been used for depressing barite, calcite, and silica in the flotation of fluorspar from barite-fluorspar ore (2). Lignin sulfonates and sodium fluorosilicate are used in the flotation mill at Mountain Pass (7).

Preliminary flotation tests using 1,000-g batches of minus 100-mesh ore

were made. A size distribution of the minus 100-mesh ore is given in table 3. The amount of minus 325-mesh material was 41 pct.

TABLE 3. - Size distribution of minus 100-mesh ore, wt-pct

Screen size, mesh:	
Minus 100 plus 115.....	14
Minus 115 plus 150.....	6
Minus 150 plus 170.....	10
Minus 170 plus 200.....	9
Minus 200 plus 270.....	11
Minus 270 plus 325.....	9
Minus 325.....	41
Composite.....	100

The following experimental conditions were used in the collector screening tests: Solids concentration, 33 pct; collector, 0.4 lb/ton of ore; ammonium lignin sulfonate (Orzan 805) gangue depressant, 5 lb/ton of ore; and sodium carbonate modifier, 12 lb/ton of ore. The pulp pH was 10, and the pulp temperature was ambient (30° C). The depressant

⁴Reference to specific brands is made for identification only and does not imply endorsement by the Bureau of Mines.

and modifier were added to the pulp and conditioned for 5 min. The collector was added, and conditioning was carried out for an additional 5 min. Impeller speed was 1,400 rpm. Results from the collector screening tests are shown in table 4.

TABLE 4. - Collector screening tests

Collector	Rougher concentrate RE ₂ O ₃ , pct	
	Analysis	Recovery
Oleic acid.....	16.6	70
Linoleic acid.....	19.4	67
Linolenic acid.....	13.1	68
Westvaco L-1.....	21.9	63
Westvaco L-5.....	18.7	63
Westvaco M-28B.....	13.5	59
AERO 845.....	14.4	15

Concentrate grades and rare-earth recoveries were comparable with oleic acid, linoleic acid, Westvaco L-1, and Westvaco L-5 collectors. Linolenic acid and Westvaco M-28B gave lower concentrate grades. Westvaco L-5 was used in subsequent investigations because it costs less than the individual fatty acids and Westvaco L-1.

Product 501 (calcium lignin sulfonate), product 512 (sodium lignin sulfonate), and Orzan 805 (ammonium lignin sulfonate), all products of Crown Zellerbach, were evaluated as gangue depressants. Experimental conditions were the same as those used in screening the collectors, except that the collector used was Westvaco L-5. Results are shown in table 5. Concentrate grade and recovery were higher with Orzan 805 than with the other lignin sulfonates, were unacceptable in the absence of lignin sulfonate, and indicated the lack of selectivity of the fatty acid collector.

TABLE 5. - Screening tests using lignin sulfonate depressants

Depressant	Rougher concentrate RE ₂ O ₃ , pct	
	Analysis	Recovery
Product 501.....	13.2	64
Product 512.....	12.1	59
Orzan 805.....	19.5	70
None.....	5.2	36

Tests using Westvaco L-5 collector, Orzan 805 depressant, and either sodium fluoride or sodium fluorosilicate were made to improve the grade of concentrate and RE₂O₃ recovery. The fluoride reagents were added in the amount of 4 lb/ton of ore. Other experimental conditions were the same as those used in the screening tests. Rougher concentrate prepared with sodium fluoride contained 24 pct RE₂O₃ and had a rare-earth recovery of 69 pct. The result showed a significant improvement in concentrate grade. When sodium fluorosilicate was used instead of sodium fluoride, a pulp pH of 8.5 was obtained. Flotation gave a concentrate containing 71 pct of the rare earths in the feed and having a grade of 15 pct RE₂O₃. An additional 9 lb Na₂CO₃/ton (total 21 lb/ton) was required to increase the pH to 10. Flotation at pH 10 gave a concentrate containing 28 pct RE₂O₃ and a rare-earth recovery of only 31 pct. Since NaF gave markedly better results than sodium fluorosilicate, NaF was used in subsequent investigations.

In the preliminary flotation tests the addition of 12 lb of sodium carbonate per ton of ore gave a pulp pH of 10. Tests using sodium hydroxide rather than sodium carbonate to attain the desired pH yielded rare-earth recoveries of <25 pct and concentrates containing approximately 7 pct RE₂O₃.

OPTIMIZATION OF ROUGHER FLOTATION PARAMETERS

Preliminary tests showed that a combination of Westvaco L-5, Orzan 805, sodium fluoride, and sodium carbonate

was effective in concentrating the rare earths in bastnäsité. Tests were made to determine the best chemical

environment and mechanical operating technique for the reagents. The parameters investigated were--

Pulp temperature during conditioning and flotation.

Amount of Westvaco L-5.

Amount of Orzan 805.

Amount of sodium fluoride.

Amount of sodium carbonate.

Flotation time.

Conditioning time with Orzan 805, sodium fluoride, and sodium carbonate.

Conditioning time with Westvaco L-5.

Percent solids in pulp.

Impeller speed.

Ten series of tests were made to investigate the parameters. One-thousand-gram charges of minus 100-mesh ore (table 3) were used. Thirty-six percent solids in the pulp was used in series 1 through 8. In series 1, the conditions were Westvaco L-5, 0.4 lb/ton of ore; Orzan 805, 5 lb/ton of ore; sodium carbonate, 12 lb/ton of ore; and sodium fluoride, 4 lb/ton of ore; conditioning time with Orzan 805, sodium carbonate, and sodium fluoride, 5 min; conditioning time with Westvaco L-5, 5 min; flotation time, 5 min; and impeller speed, 1,400 rpm. Tapwater was heated to the desired temperature and added to the ore charge. Pulp temperature was maintained during flotation by an immersion heater. Air was introduced carefully to promote selectivity. In each subsequent series (2-10), the best conditions as determined in the preceding series were used. Results are shown in figures 2-11.

Up to 45° C, rare-earth recovery and concentrate grade increased significantly with an increase in flotation pulp temperature (fig. 2). The rare-earth content of the concentrate increased at

temperature >45° C, but recovery decreased markedly. The best temperature was between 40° and 45° C. Rougher concentrates ranging from 31 to 33 pct RE₂O₃ and rare-earth recoveries of 74 to 78 pct were obtained. Flotation at ambient temperature (30° C) was less selective and gave 27-pct-RE₂O₃ concentrate. A pulp temperature of 43°±2° C was maintained during conditioning and flotation in subsequent tests.

The addition of more than 0.4 lb of Westvaco L-5 per ton of ore resulted in increased rare-earth recovery and an appreciable decrease in concentrate grade (fig. 3). Both grade and recovery decreased markedly when less than 0.4 lb of Westvaco L-5 per ton of ore was added.

The amount of Orzan 805 required was from 5 to 7 lb/ton of ore (fig. 4). Rare-earth recovery decreased significantly at greater than 8 lb of Orzan 805 per ton.

Sodium fluoride additions of more than 6 lb/ton of ore yielded higher grade rare-earth concentrates and a marked decrease in recovery (fig. 5). A gradual decrease in concentrate grade and a pronounced decrease in recovery were observed when NaF was decreased from 6 lb/ton of ore. The addition of more or less than 12 lb of sodium carbonate per ton of ore resulted in a marked decrease in both grade and recovery (fig. 6).

Concentrate grade was higher and rare-earth recovery was considerably lower with flotation times of less than 5 min (fig. 7). Recovery leveled off between 8- and 12-min flotation time, and the grade remained at approximately 30 pct RE₂O₃.

Conditioning with Orzan 805, sodium fluoride, and sodium carbonate modifiers for more than 10 min with Westvaco L-5 collector for more than 15 min resulted in a marked decrease in concentrate grade and rare-earth recovery (figs. 8-9). Conditioning with Westvaco L-5 collector for less than 5 min resulted in a decrease in rare-earth recovery.

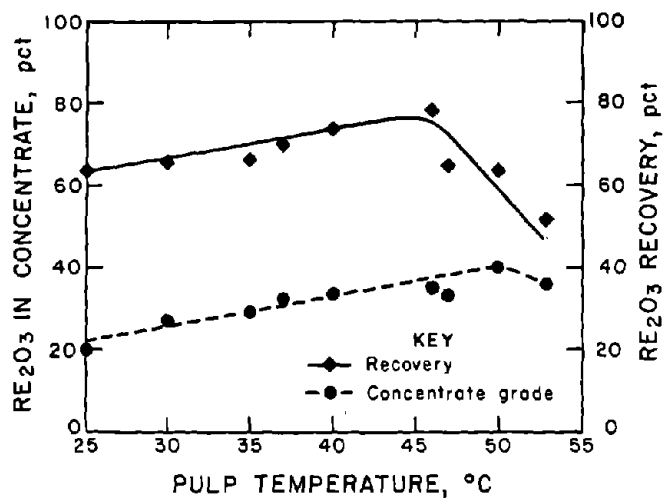


FIGURE 2. - Effect of pulp temperature on rougher flotation.

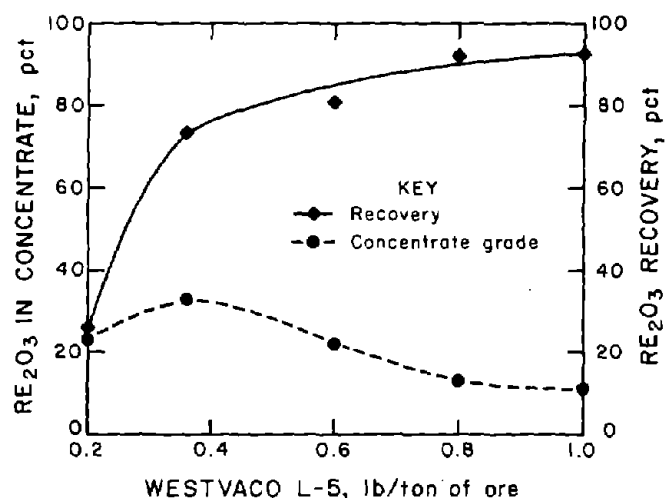


FIGURE 3. - Effect of Westvaco L-5 on rougher flotation.

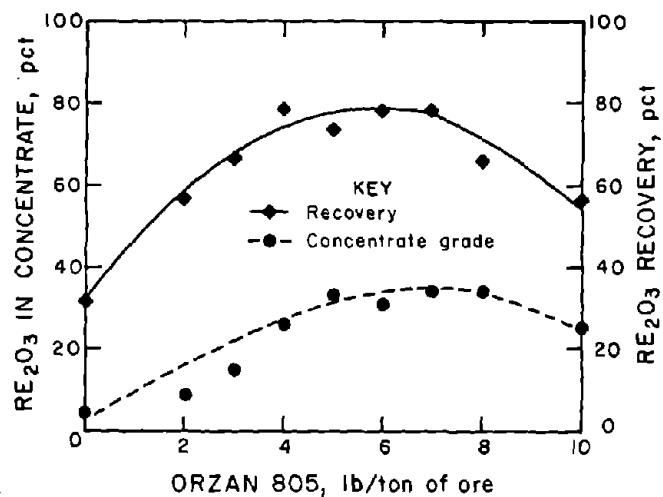


FIGURE 4. - Effect of Orzan 805 on rougher flotation.

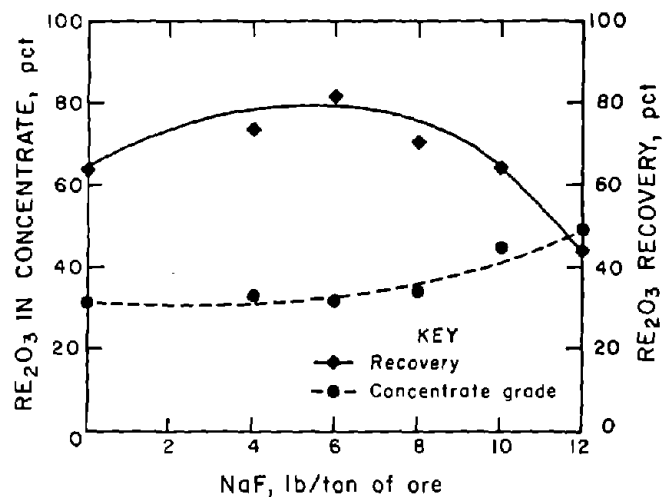


FIGURE 5. - Effect of sodium fluoride on rougher flotation.

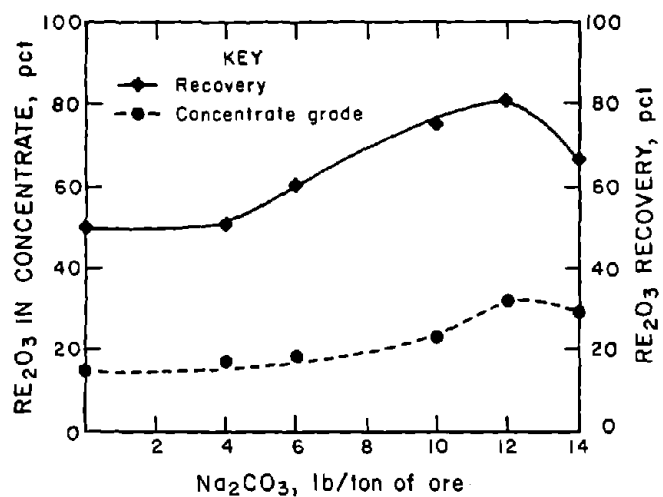


FIGURE 6. - Effect of sodium carbonate on rougher flotation.

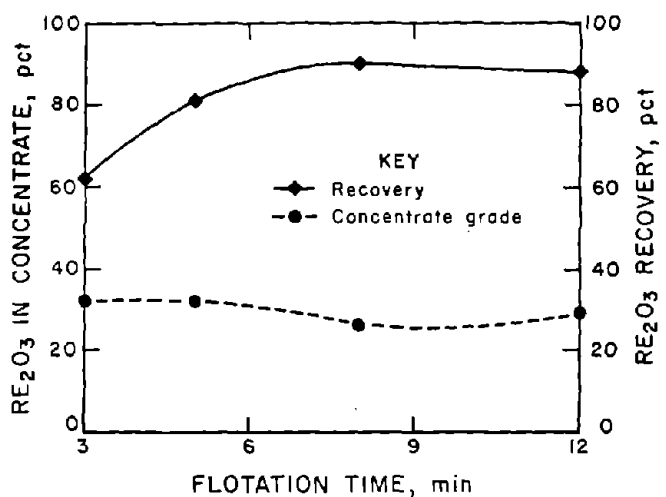


FIGURE 7. - Effect of flotation time on rougher flotation.

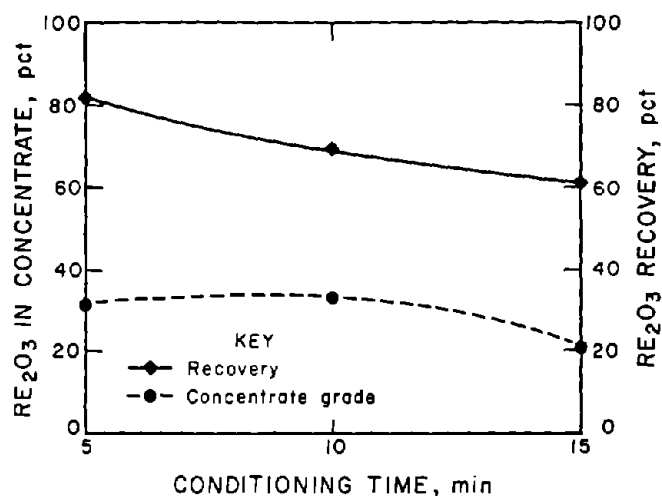


FIGURE 8. - Effect of conditioning time with Orzan 805, sodium fluoride, and sodium carbonate on rougher flotation.

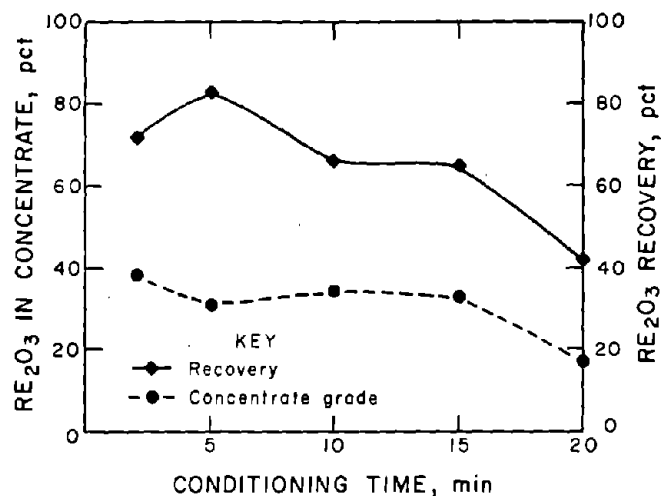


FIGURE 9. - Effect of conditioning time with Westvaco L-5 on rougher flotation.

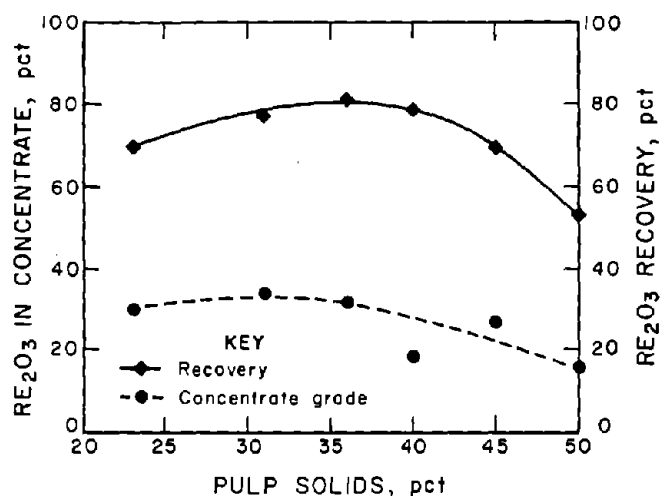


FIGURE 10. - Effect of solids content on rougher flotation.

A solids content of 36 pct was best (fig. 10). Lower or higher solids content resulted in appreciable decreases in rare-earth recovery and concentrate grade.

Decreasing the impeller speed from 1,400 to 1,000 rpm resulted in a lower rare-earth recovery, but the concentrate grade increased markedly (fig. 11). Increasing the impeller speed above 1,400 rpm resulted in an increase in concentrate grade and a decrease in rare-earth recovery.

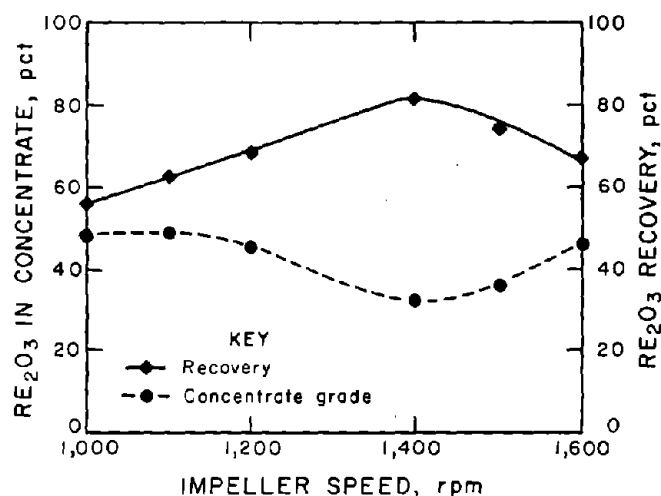


FIGURE 11. - Effect of impeller speed on rougher flotation.

Best conditions from all tests were pulp temperature, 40° to 45° C; Westvaco L-5, 0.4 lb/ton of ore; Orzan 805, 6 lb/ton of ore; sodium fluoride, 6 lb/ton of ore; sodium carbonate, 12 lb/ton of ore; conditioning time with Orzan 805, sodium fluoride, and sodium carbonate, 10 min; conditioning time with Westvaco L-5, 6 min; solids concentration, 36 pct; flotation time, 6 min; and impeller speed, 1,400 rpm. Average results from 16 tests made under these conditions are presented in table 6.

TABLE 6. - Rougher flotation of bastnäsite ore¹

Product	Wt-pct	Analysis, pct		Distribution, pct	
		RE ₂ O ₃	BaSO ₄	RE ₂ O ₃	BaSO ₄
Tailing.....	83	1.8	22.9	19	89
Concentrate...	17	38.2	13.7	81	11
Composite	100	8.0	21.3	100	100

¹Average values of 16 tests.

CLEANING OF ROUGHER CONCENTRATES

Because of the desirability of producing a concentrate with >55 pct RE₂O₃ for subsequent processing, six series of flotation tests were made to determine the best conditions for the cleaner circuit. For these tests, rougher concentrates were prepared by using the best conditions previously described. Rougher concentrates from several flotation tests were combined and mixed to provide sufficient material. Filtered, but not dried, mixtures were repulped with water from the rougher circuit. In series 1, investigation of pulp temperature, flotation was carried out for 5 min at 20 pct solids and a pulp pH of 10. Impeller speed in all tests was 1,400 rpm. No additional reagents were added. Series 2-6 each used the best conditions determined in the preceding series. When reagents were added, a conditioning time of 5 min was used.

Parameters investigated were--

Temperature during conditioning and flotation.

Amount of Orzan 805.

Amount of sodium carbonate.

Amount of sodium fluoride.

Percent solids in pulp.

Flotation time.

Results are shown in Figures 12-17. The best conditions were pulp temperature, 40°-45° C; and flotation time, 5 min. Because of the importance of preparing a concentrate containing >55 pct RE₂O₃, 20 pct solids was chosen as best. There was no advantage in adding reagents to the cleaner circuit. The addition of sodium carbonate had a deleterious effect on flotation. Average results from five tests made under the best conditions are shown in table 7.

TABLE 7. - Cleaner flotation¹

Product	Wt-pct	Analysis, pct		Distribution, pct	
		RE ₂ O ₃	BaSO ₄	RE ₂ O ₃	BaSO ₄
Tailing....	42	17.0	17.7	18	77
Concentrate	58	55.5	3.8	82	23
Composite	100	39.3	9.6	100	100

¹Average values of 5 tests.

SCAVENGING OF CLEANER TAILING

Tailings from 15 cleaner flotation tests contained an average of 18 pct RE₂O₃ and represented a loss of about 16 pct of the rare earths in the ore. Scavenger flotation tests on the cleaner tailing were made to prepare a marketable rare-earth product and to minimize the rare-earth loss. Since approximately

10 pct of the tailing was plus 150 mesh and electron microprobe analysis indicated locked bastnäsite grains, regrinding of the cleaner tailing to minus 150 mesh would be advantageous.

Cleaner tailings from several flotation tests made under the best conditions

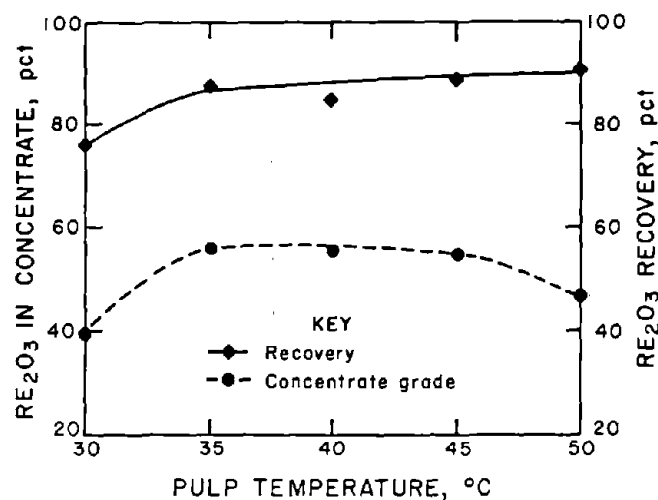


FIGURE 12. - Effect of pulp temperature on cleaner flotation.

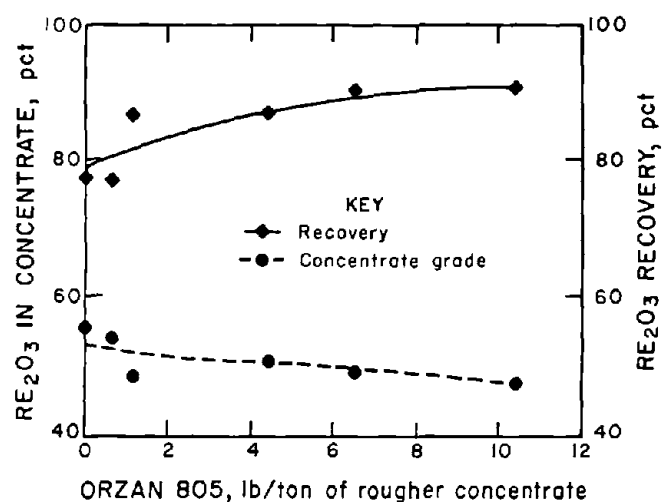


FIGURE 13. - Effect of Orzan 805 on cleaner flotation.

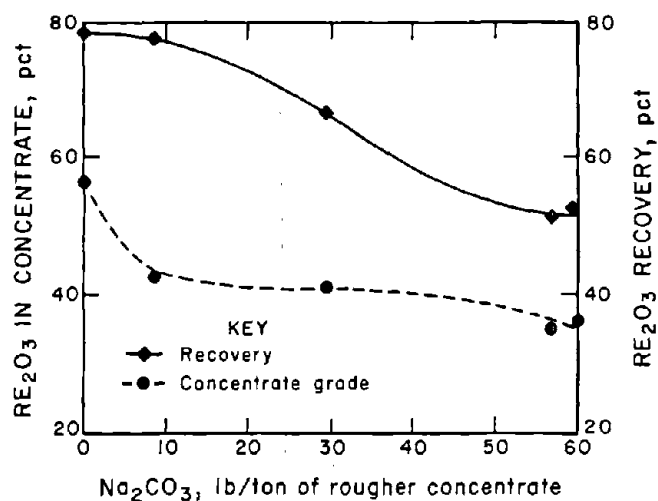


FIGURE 14. - Effect of sodium carbonate on cleaner flotation.

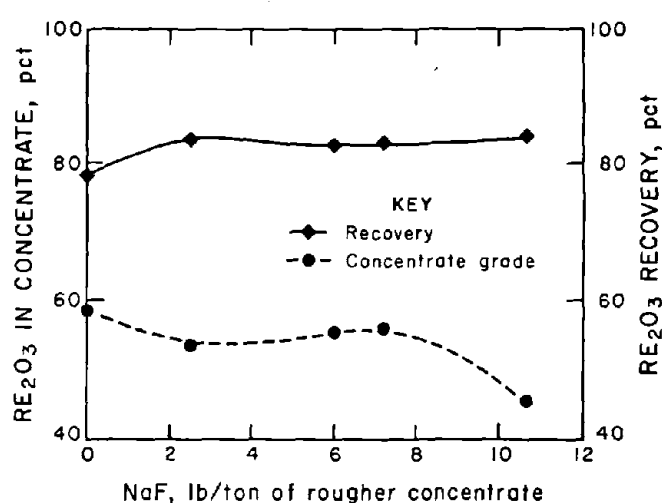


FIGURE 15. - Effect of sodium fluoride on cleaner flotation.

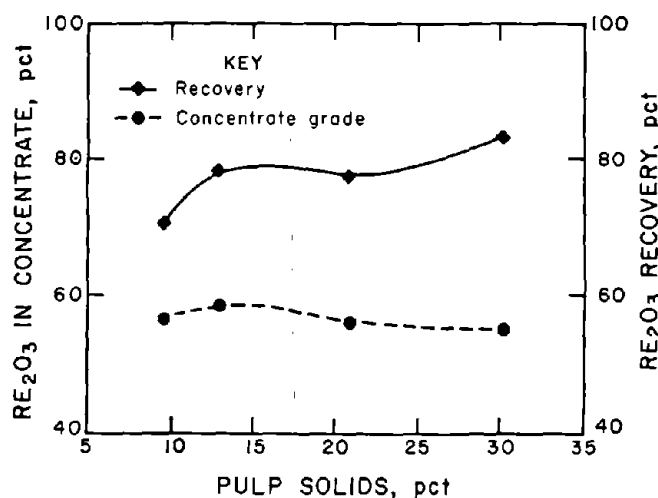


FIGURE 16. - Effect of solids content on cleaner flotation.

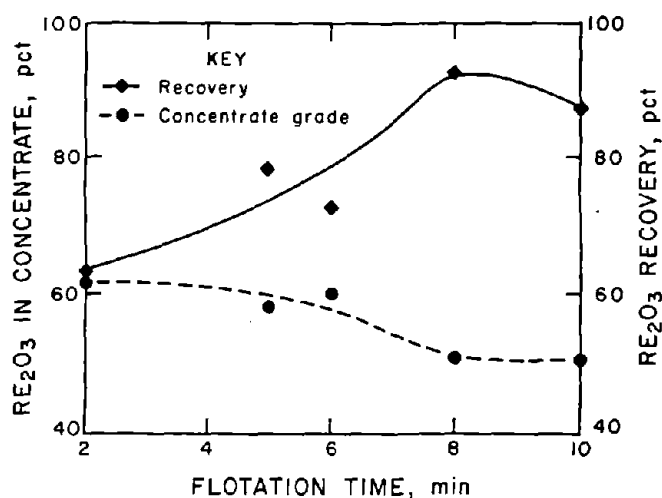


FIGURE 17. - Effect of flotation time on cleaner flotation.

previously described were wet-screened through a 150-mesh sieve. The oversize was ground in a porcelain mortar to minus 150 mesh and added to the minus 150-mesh fraction. The tailings were mixed with water from the rougher circuit. Reagents and flotation conditions were the same as those used in the best rougher circuit. Because the cleaner tailing grades were between the ore (≈ 8 pct RE_2O_3) and the rougher concentrate (≈ 38 pct RE_2O_3), tests were made at cleaner circuit solids of 20 pct and at rougher circuit solids of 36 pct. Average values from four tests in each series are shown in table 8. A higher grade concentrate was obtained at 36 pct solids than at 20 pct solids.

INTEGRATION OF ROUGHER, CLEANER, AND SCAVENGER FLOTATION CIRCUITS

Larger scale tests using the best conditions for floating rare-earth minerals were made. In these tests ore charges to the rougher flotation circuit were increased to 4,000 g so that sufficient material was obtained in one test for subsequent cleaner and scavenger circuits. A Denver No. 12 flotation cell with a 10-L stainless steel tank and fitted with a 3-3/4-in-diam impeller and a 4-1/4-in-diam stator was used. Impeller speed was 1,400 rpm. Results of an integrated flotation test are given in table 9. A detailed analysis of a cleaner concentrate is given in table 10.

TABLE 9. - Integrated flotation of bastnäsite ore with 4,000-g charge

Product	Wt-pct	Analysis, pct		Distribution, pct	
		RE_2O_3	BaSO_4	RE_2O_3	BaSO_4
Rougher tailing....	85	1.6	21.3	17	95
Cleaner concentrate...	9	58.7	2.4	67	1
Scavenger tailing....	3	12.3	18.4	5	3
Scavenger concentrate	3	29.9	7.2	11	1
Composite	100	7.9	19.1	100	100

TABLE 8. - Effect of percent solids in pulp on scavenger flotation of cleaner tailing¹

Product	Wt-pct	Analysis, pct		Distribution, pct	
		RE ₂ O ₃	BaSO ₄	RE ₂ O ₃	BaSO ₄
20 PERCENT SOLIDS					
Tailing....	48	13.3	16.0	31	56
Concentrate	52	26.8	11.4	69	44
Composite	100	20.3	13.6	100	100
36 PERCENT SOLIDS					
Tailing....	57	12.4	18.2	34	72
Concentrate	43	31.4	9.6	66	28
Composite	100	20.6	14.5	100	100

¹Average values of 4 tests for each solids concentration.

TABLE 10. - Analysis of a cleaner concentrate, pct

RE_2O_3 ¹	58.71
BaSO_4	2.30
SiO_2	1.8
CaO	6.0
SrO	1.6
MgO75
Fe_2O_35
Fluorine.....	7.85
CO_2	20.3
P_2O_5	<.02
Total sulfur.....	.8
Lead.....	.12
Thorium.....	.08

¹ RE_2O_3 contained, in pct: 52 CeO_2 ; 31 La_2O_3 ; 11.4 Nd_2O_3 ; 4.0 Pr_6O_{11} ; 0.71 Eu_2O_3 ; 0.51 Sm_2O_3 ; 0.10 Y_2O_3 ; and 0.06 Gd_2O_3 .

Overall rare-earth recovery was 67 pct, and the cleaner concentrate contained 58.7 pct RE_2O_3 . A scavenger concentrate containing 22.9 pct RE_2O_3 and 11 pct of the rare earth in the feed was prepared by grinding and refloating the cleaner tailing. Additional rare-earth recovery could be obtained by cycling the scavenger concentrate to the cleaner circuit. The scavenger tailing would probably be added to the rougher tailing. Because of

its slimy nature, recycling the scavenger tailing to the rougher circuit

could be detrimental. Tests on cycling the scavenger concentrate were not made.

FLOTATION OF BARITE FROM BASTNÄSITE ROUGHER TAILING

Agey (1) reported that sodium cetyl sulfate collector was more selective for barite than oleic acid and petroleum sulfonate. Preliminary tests showed that sodium cetyl sulfate (EC-111) was effective in concentrating barite from bastnäsite rougher tailing (≈ 23 pct BaSO_4).

Barite flotation was investigated using 1,000-g charges of rougher tailing from the bastnäsite flotation. Flotation was carried out in the Wemco model 52-524 cell. Rougher tailing was diluted to 40 pct solids with water recycled from the bastnäsite flotation circuit. Since 40 pct solids is typical for floating barite ores (2) and is close to the best solids content for the bastnäsite rougher circuit, this parameter was not investigated.

The following parameters were investigated:

Amount of EC-111 added.

Amount of sodium carbonate added.

Temperature during conditioning and flotation.

Flotation time.

Conditioning time for Na_2CO_3 .

Conditioning time for EC-111.

for EC-111, 7 min; and flotation time, 6 min.

Barite rougher concentrates (≈ 50 pct BaSO_4) were cleaned in the Wemco cell by pulping to 40 pct solids with recycled bastnäsite rougher circuit water and floating at 40°C . No additional reagents were added, and the pulp pH was 10. Results of an average of three tests incorporating the rougher and cleaner circuits are shown in table 11. In these tests the rougher concentrate was cleaned one time. Composition of the cleaner concentrate was BaSO_4 , 70.3 pct; Sr, 7.2 pct; Th, 0.01 pct; and CaO, 1.7 pct. Specific gravity was 4.24. Barite concentrates were cleaned a second time in an attempt to prepare a higher grade barite product. These products also contained approximately 70 pct BaSO_4 .

TABLE 11. - Flotation of barite from bastnäsite rougher tailing

Product	Wt-pct	Analysis, pct		Distribution, pct	
		BaSO_4	RE_2O_3	BaSO_4	RE_2O_3
Rougher tailing....	68	8.6	3.0	26	84
Cleaner tailing....	21	44.1	1.6	41	14
Cleaner concentrate...	11	70.3	.5	33	2
Composite	100	22.8	2.4	100	100

In the first series, no sodium carbonate was added, the pulp temperature was maintained at 40°C , conditioning time was 5 min, and flotation time was 5 min. In each subsequent series (2-5), the best conditions determined in the preceding series were used. Best conditions determined were EC-111, 5 lb/ton of bastnäsite rougher tailing; amount of sodium carbonate, 3 lb/ton of bastnäsite rougher tailing; temperature during conditioning and flotation, 30° to 40°C ; conditioning time for Na_2CO_3 , 5 min; conditioning time

Electron microprobe analysis of barite concentrates showed that strontium was present in the form of barytocelestite. Barite has a specific gravity of 4.3 to 4.6, whereas celestite has a specific gravity of 3.95 to 3.97. Because of the difference in specific gravity between celestite and barite, a barite concentrate more than marginally meeting American Petroleum Institute (API) specification for drilling mud (4.20 minimum specific gravity) cannot be prepared by beneficiation.

Eisele and Bauer (4) treated a barite flotation concentrate (72 pct BaSO_4) from the Mountain Pass operation with concentrated sulfuric acid and obtained a product having a specific gravity of 4.15 to 4.23, which is marginally acceptable for drilling mud formulation. They also prepared individual barium and strontium products from the sulfate mixture by metathesis with sodium carbonate and precipitation.

Precipitation of drilling mud grade barite from bastnäs site tailing is not technically promising because--

1. The presence of strontium decreases the specific gravity of the concentrate so that API specification are barely met.

2. Slight radioactivity associated with the presence of thorium may interfere with the use of concentrate in drill holes that are logged by a gamma-ray probe.

3. Residual flotation reagents must be removed by calcination, because API specifications state that barite cannot exhibit frothing characteristics.

SUMMARY AND CONCLUSIONS

A method using flotation at a pulp temperature of 40° to 45° C was devised for preparing a commercial-grade, rare-earth concentrate from Mountain Pass, Calif., bastnäs site ore. Bench-scale experiments showed that a concentrate containing 58.7 pct RE_2O_3 could be obtained at a rare-earth recovery of 67 pct. Best results were obtained with the following suite of reagents: Westvaco L-5 collector, Orzan 805 and sodium fluoride depressants, and sodium carbonate modifier. In comparison to commercial practice

requiring heating the pulp to boiling before flotation, the results indicate an energy savings.

Barite products containing approximately 70 pct BaSO_4 were prepared by flotation of the bastnäs site rougher tailing. Because of the presence of strontium and residual flotation reagents, the barite concentrate did not meet American Petroleum Institute specifications for drilling mud.

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