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Report on Froth Flotation & Other Beneficiation Testing
Lat 65°10' N to 65°20' N; Long 132°45' W to 133°15' W
Claim Sheet # 6
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RESULTS OF CONCENTRATION TESTS MADE ON CRUDE IRON ORE AND JIG CONCENTRATES FROM CREST EXPLORATION LTD. PROPERTIES

by

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SUMMARY OF RESULTS

This is a report of the laboratory metallurgical evaluation performed by the Bureau of Mines at the Minneapolis Metallurgy Research Center under terms of Cooperative Agreement No. 814-4355 with Crest Exploration, Limited. The material treated consisted of an ABC composite crude ore sample and an ABC composite jig concentrate. Batch flotation testing was employed extensively in evaluating both samples. In the later stages of testing, acid leaching of flotation middling products was included in the treatment of the jig concentrate. Additional beneficiation techniques employed in the treatment of the crude ore included reduction roasting and magnetic separation. Both anionic and cationic flotation techniques then were employed to further upgrade the magnetic concentrates.

Acceptable concentrates were made in the treatment of the jig concentrates while only limited success was obtained in treating the crude ore. In treating the jig concentrate, application of a combination of selective flocculation-anionic silica flotation-acid leaching produced a concentrate assaying 65 percent Fe, 6 percent SiO_2, 0.07 percent P, and 0.08 percent S. An iron recovery of 85 percent was obtained from the jig concentrate by this procedure. The best flotation separation obtained on the untreated crude ore yielded a concentrate containing 59 percent Fe, 11 percent SiO_2 and 0.10

1/ Research extractive metallurgist
2/ Research extractive metallurgist

percent P with an iron recovery of 58.6 percent. Selective flocculation-anionic silica flotation techniques were employed in this test on the crude ore.

RAW MATERIAL PREPARATION

Sample description and chemical analyses

Three samples of iron ore, consisting of two ABC composite-jig concentrates and a crude ore sample, were submitted for metallurgical evaluation by Crest Exploration, Limited. The crude ore, code number 9662, consisted of an untreated ABC composite bulk ore sample. The two jig concentrates, which were shipped from Ontario Research Foundation in separate bags and given code numbers 9656 and 9656A, were composites of the concentrates from pilot plant jig tests. The two jig concentrate samples were treated as identical samples in this evaluation with sample 9656 being used in the preliminary flotation work and sample 9656A being used to complete the flotation and leaching work. Code numbers and chemical analyses of the three samples are shown in table 1.

Sample grind time analyses

Each of the three samples, precrushed to minus 8-mesh, was subjected to wet grinding in a 7- by 9-inch laboratory rod mill at 50 percent solids; screen analyses for the various grind times are shown in table 2. Since preliminary microscopic examinations indicated the need for fine grinding of the ores before adequate liberation would be obtained, a grind period was selected in each case to produce a flotation feed approximately 95 percent minus 325-mesh.

TEST PROCEDURE

Standardized testing procedures were employed wherever possible. The basic operations employed in the flotation testing are shown schematically in Figure 1. Sulfuric acid leaching of the flotation middling products was

TABLE 1 - Chemical head sample analyses of Crest ore composites

Code No.	Analyses, percent						
	Fe	SiO_2	P	CO_2	CaO	MgO	Al_2O_3
	ABC composite-jig concentrates						
9656	59.4	11.1	0.19	0.95	1.18	0.56	----
9656A	60.2	9.9	0.19	0.83	1.21	0.52	----
	Crude ore						
9662	44.1	27.1	0.34	2.46	2.73	1.14	1.00

TABLE 2 - Wet screen analyses of Crest ore composites at various grind times[1/]

Code No.	Grind time, minutes	100 percent passing, mesh		
		200	325	400
	ABC composite-jig concentrates			
9656	15	-----	88.9	83.6
	20	-----	96.0	94.2
9656A	15	-----	86.7	81.9
	20	-----	96.0	94.4
	Crude ore			
9662	15	96.0	77.2	73.3
	20	99.7	94.1	91.5
	25	100.0	98.4	97.3

1/ Samples wet ground in laboratory rod mill at 50 percent solids.

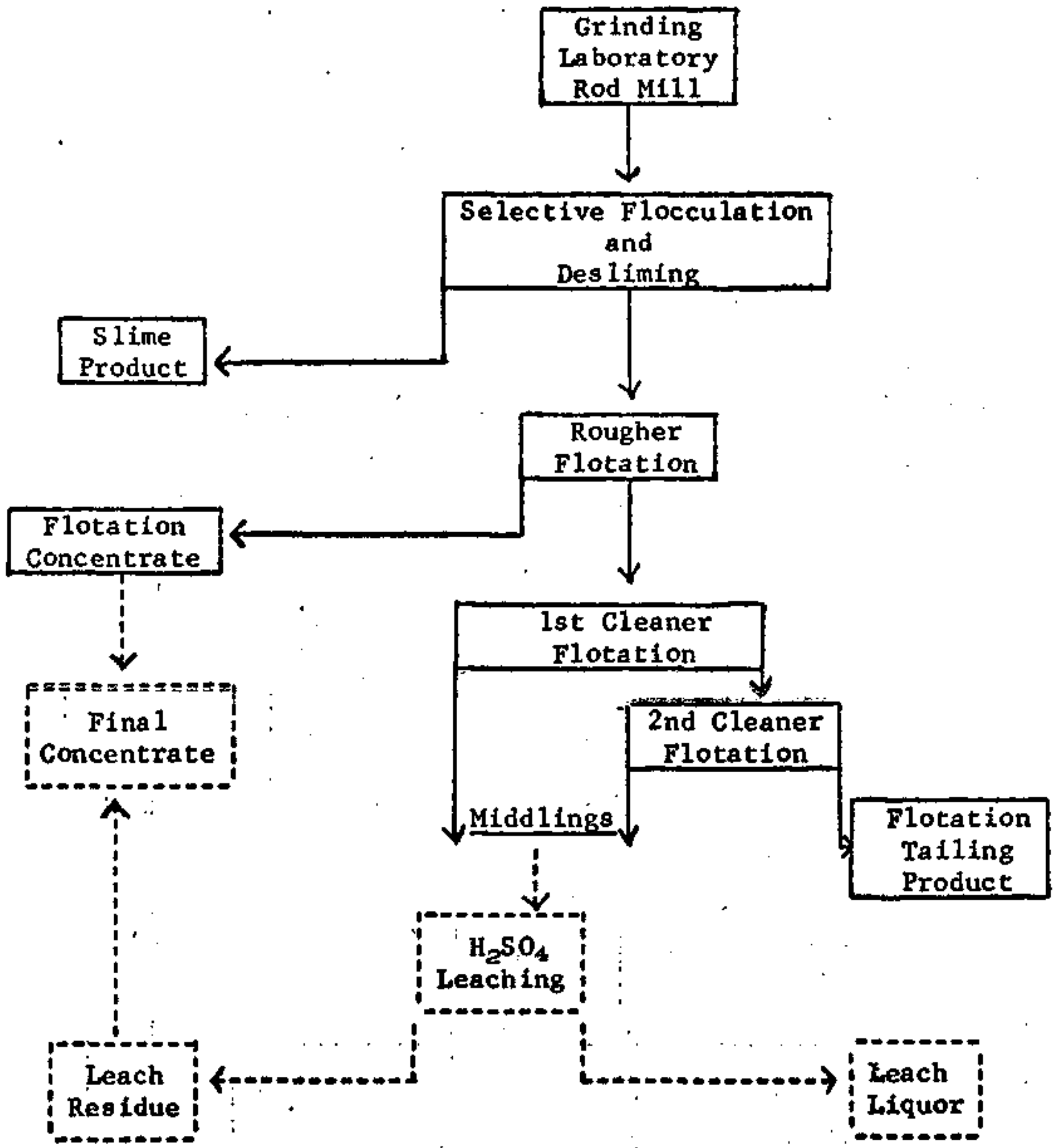


FIGURE 1 - Schematic diagram of flotation test procedures with additional leach treatment of flotation middlings

incorporated in the latter stages of the test work on the jig concentrate.

Batch Flotation Procedure

A standard 600-gram Fagergren flotation cell was used in all of the flotation testing. In preparing the flotation feed, a 600-gram sample was pulped to 50 percent solids and ground in a laboratory rod mill. When desliming was practiced prior to anionic silica flotation, dispersants were added to the grinding mill, after which the pulp was transferred to a 4 liter beaker and the pulp volume adjusted to 17 percent solids. Following the addition of tapioca flour and a two-minute conditioning time, the flocculated material was allowed to settle approximately 4-inches and a slime product was siphoned off. The deslimed pulp was then transferred to the flotation cell, conditioned at about 30 percent solids, and diluted to 20 percent solids for flotation. In all cases where anionic silica procedures were used, sufficient sodium hydroxide was added prior to rougher flotation so that a pH of approximately 11.5 was obtained. In some instances, high solids conditioning in a lightning mixer at 50 to 60 percent solids was employed prior to flotation.

In the flotation operation, the gangue constituents were contained in the froth product, and the concentrate was the underflow from the rougher flotation operation. The froth product from the fougher stage was subjected to two cleaner flotation stages, thereby producing two underflow middling products and a final tailing. In the latter stages of testing on the jig concentrate, the middling products were further treated by leaching in dilute sulfuric acid.

Leaching Test Procedure

Preliminary leaching tests employed to process the middling products from a carbonate flotation test were conducted using a 5 percent sulfuric acid solution. In these tests, a 10-gram sample was agitated in 100 cc of

5 percent H_2SO_4 for 1 hour. The residue was then filtered, washed, and dried. Both the filtrate and residue were submitted for chemical analyses.

The difficulty encountered in determining sulfuric acid consumption in these tests led to the adoption of a standardized test procedure which more closely approximated plant leaching processes and provided for accurate determination of sulfuric acid consumption. In order to establish the effect of leach solution concentration, sulfuric acid solutions were made up to concentrations of approximately 1.0, 2.5, 4.0, 5.5, 7.0, 8.5, and 10 percent which are equivalent to 20-, 50-, 80-, 110-, 140-, 170-, and 200-lbs H_2SO_4 per ton of feed, respectively, when used at 50 percent solids. Leaching tests with each solution concentration were conducted using contact times of 15, 30, 60, 120 and 240 minutes to establish the effect of leaching time on phosphorus removal. The following operational steps outline the procedure followed in the leaching tests:

1. Eight 50-gm samples were weighed into 300 cc erlenmeyer flasks and 50 cc of each H_2SO_4 solution was added to respective flasks, the eighth sample being a replicate of one of the seven solutions.
2. The set of eight samples was agitated on a mechanical shaker for each of the above contact times. Contact time was considered the time elapsed from beginning to end of agitation. Other handling time was assumed constant for all samples.
3. The flasks were removed from the shaker, the leach solution was decanted through filter paper, the pH of the filtrate was measured, and 50 cc of distilled water were added to the residue to stop leaching reactions.

4. The residue and first wash solution were transferred to the filter paper, and the residue was washed with an additional 100 cc of distilled water. The filtrate was diluted to volume in 500 cc volumetric flask.

5. The dried residue and filtrate were submitted for chemical analyses.

Reduction Roast-Magnetic Separation Procedure

The crude ore was subjected to reduction roast-magnetic separation beneficiation using both hydrogen gas and lignite as the reductant. Magnetic concentrates were prepared from the roasted products using both Davis tube and Jeffrey-Steffensen separators. Three different procedures were followed in producing magnetic concentrates in which one or more of the following parameters were varied: (1) Reductant, (2) size of separator feed, (3) roasting apparatus, and (4) magnetic separator.

In the first reduction roast-magnetic separation procedure, 125 grams of minus 8-mesh material were roasted at 500°C in a 3- by 4-inch externally heated rotating drum. Reduction of the iron oxide was accomplished in 30 minutes with a hydrogen gas flow of 2 standard cubic feed per hour. A flow of nitrogen gas was directed through the roasting drum during both prereduction and postreduction periods to protect against oxidation of the ore. After reduction, the ore was wet ground in a laboratory rod mill to minus 400-mesh with 15 grams of this material being subjected to the single stage Davis tube separation.

The second and third reduction roast-magnetic separation procedures differed from each other in that concentrates were produced with a Jeffrey-Steffensen (one roll) magnetic separator from a minus 35-mesh feed in one; while in the other, concentrates were produced from a minus 400-mesh feed in a Davis tube. Both the last two procedures used a reduced feed prepared in the following manner:

1. 19 pounds of crude ore (minus $\frac{3}{8}$ inch) was blended with 2 pounds of lignite (minus $\frac{1}{4}$ inch) and roasted in a 10- by 24-inch externally heated rotating drum.
2. The reductant and ore were heated from room temperature to 650°C in 1.5 hours, held at 650°C for $\frac{3}{4}$ hour, and then allowed to cool to room temperature. No attempt was made to control the atmosphere in the reacting vessel.
3. After reduction, the ore was roll crushed to minus 14-mesh and further reduced to minus 35-mesh by stage grinding in a pulverizer.

The final concentrate made from the lignite-roasted product by either the Davis tube, or the roll-type separator was a composite of the primary magnetic product, and a secondary magnetic product made by returning the primary nonmagnetics to the separator for scavenging.

PRESENTATION AND DISCUSSION OF RESULTS

Both the jig concentrate and the crude ore were extensively evaluated at essentially the same size consist using anionic silica flotation procedures. In the later stages of the investigation, acid leaching of flotation middlings from the jig concentrate was employed as a means of complementing the flotation metallurgy, while a reduction-roast-magnetic separation-flotation scheme was evaluated as a means of obtaining acceptable concentrates from the crude ore.

The experimental data from the beneficiation evaluation of the jig concentrate and the crude ore are discussed in this section under separate headings. Test data not specifically used in this discussion are tabulated in Appendix I and Appendix II.

Jig Concentrate

The primary objective of this phase of the investigation was to reduce the phosphorus content of the Crest jig concentrate to an acceptable level. Preliminary testing included application of various reagent suites for flotation of phosphorus constituents with only a minor degree of success. However, a relationship between the floatability of phosphorus-bearing minerals and carbonate gangue constituents was observed. A flotation scheme designed to float the carbonate minerals resulted in a concentrate containing only 0.07 percent P, but with an iron recovery of 65 percent. The flotation middling products, containing about 0.11 percent P, were leached in dilute sulfuric acid to lower the phosphorus content to 0.01 percent. Thus, by combination of leaching and flotation, a 94.1 percent recovery of iron was obtained in a product containing 60.2 percent Fe, 11.6 percent SiO_2, and 0.05 percent P (see table 3). Acid consumption was not determined in this leaching test.

While the above treatment was effective in lowering the phosphorus, the high silica content of the concentrate would place the product at a competitive disadvantage. Hence, research efforts were concentrated on developing a flotation system, based on anionic silica flotation, which would effect simultaneous removal of both phosphorus and silica gangue constituents.

In anionic silica flotation, the silica gangue particles are conditioned for adsorption of fatty acid through activation with divalent cations which are supplied to the system either through dissolution of soluble ore constituents or by the addition of divalent calcium ions. Flotation water may be another source of activating ions. Preliminary treatment of the jig concentrate indicated an excess of soluble ions which adversely effected flotation of the gangue constituents. In order to control the soluble ion content, a selective flocculation-desliming operation prior to flotation was incorporated in the testing procedure. Various combinations of complexing and dispersing

TABLE 3 - Results of carbonate flotation and sulfuric acid leaching of Crest jig concentrate

Product	Weight, percent	Analysis, percent				Dist., percent			Reagents, lb/ton of feed			
		Fe	P	CO_2	SiO_2	Fe	P	CO_2	Na_2CO_3*	Na_2SiO_3	FA-2	Aero Promoter 825
Concentrate	64.5	59.2	.07	.22	12.5	65.1	27.5	14.0	2.0	4.0	0.5	1.5
Middling 1	20.1	61.2	.09	.29		21.0	10.8	5.7		2.0		
Middling 2	7.7	61.6	.15	.40		8.0	7.2	3.1		2.0		
Tailing	7.7	44.7	1.18	10.16		5.9	54.5	77.2				
Composite	100.0	58.6	.167	1.01		100.0	100.0	100.0				
Combined and Leached Middlings	27.3	62.3	.01		9.6	29.0	1.8		Leach 5% H_2SO_4 1 hr. contact time			
Leach Solution	0.5		5.5				16.9					
Final Concentrate**	91.8	60.2	.05		11.6	94.1	28.7					

* Flotation at pH 9.9.
**Composite of flotation concentrate and leached middling product.

reagents at several levels of addition were evaluated prior to adopting an addition of 2.0 lb/ton sodium hydroxide and 0.5 lb/ton tetrasodium pyrophosphate to the grind. An addition of 0.25 lb/ton tapioca flour was used in the desliming step for flocculation of the iron minerals. Results of tests at other levels of addition and with other reagents are included in Appendix I.

The selective flocculation-desliming operation proved to be effective in providing a uniform feed for flotation as well as effecting partial removal of phosphorus in the slime product. Subsequent treatment of the deslimed pulp by the anionic silica flotation method, modified by the addition of a sulfonate-type collector (Aero Promoter 825) to effect flotation of carbonates and phosphorus-bearing minerals, proved to be successful in producing concentrates of acceptable grade. The results of a series of tests designed to evaluate various collector levels are shown in table 4. One of the better tests (No. 8) produced a concentrate containing 65.6 percent Fe, 4.9 percent SiO_2 and 0.08 percent P. Iron recovery in this batch test was only 56.2 percent which indicated a need for further treatment to improve recovery.

On the basis of these preliminary tests, a twenty flotation test series was designed to establish optimum levels of collector addition, to add validity to the data by duplication of tests, and to provide a sufficient weight of middling products for subsequent leaching tests. The test series consisted of five replicate tests at each of the following collector levels:

1. FA-2, 0.75 lb/ton; Aero Promoter 825, 0.5 lb/ton
2. FA-2, 1.0 lb/ton; Aero Promoter 825, 0.5 lb/ton
3. FA-2, 0.75 lb/ton; Aero Promoter 825, 1.5 lb/ton
4. FA-2, 1.0 lb/ton; Aero Promoter 825, 1.5 lb/ton

TABLE 4 - Summary of results obtained in modified anionic silica flotation of Crest jig concentrate

Test No.	Product	Weight, percent	Analyses, percent Fe	P	SiO_2	Dist., % Fe	P	Reagents, lbs/ton of feed NaOH	$Na_4P_2O_7$	Tapioca	Aero Promoter 825	FA-2
1	Concentrate	73.1	62.7	.12	7.3	77.7	46.7	2.5		1.25	0.5	0.25
	Middling 1	14.2	55.3	.21		13.3	16.7					
	Middling 2	4.2	41.4	.41		2.9	9.4					
	Tailing	1.5	27.8	.75		0.7	6.1					
	Slime	7.0	45.2	.54		5.4	21.1	2.0*	0.5*	0.25		
	Composite	100.0	59.0	.18		100.0	100.0					
2	Concentrate	63.6	63.1	.10	6.6	67.8	36.8	2.5		1.25	1.0	0.25
	Middling 1	16.4	59.8	.15		16.6	14.3					
	Middling 2	6.7	51.6	.25		5.8	9.8					
	Tailing	5.1	34.3	.53		3.0	15.5					
	Slime	8.2	48.9	.50		6.8	23.6	2.0*	0.5*	0.25		
	Composite	100.0	59.2	.17		100.0	100.0					
3	Concentrate	57.9	64.6	.093	5.8	62.9	30.3	2.5		1.25	1.5	0.25
	Middling 1	17.3	61.9	.125		18.0	12.4					
	Middling 2	7.6	55.5	.196		7.1	8.4					
	Tailing	9.2	37.0	.511		5.7	26.4					
	Slime	8.0	46.9	.495		6.3	22.5	2.0*	0.5*	0.25		
	Composite	100.0	59.5	.178		100.0	100.0					
4	Concentrate	57.8	64.5	.096	5.9	63.2	30.9	2.5		1.25	0.5	0.5
	Middling 1	19.7	60.0	.149		20.0	16.2					
	Middling 2	9.6	52.4	.248		8.5	13.5					
	Tailing	7.3	34.9	.474		4.3	19.7					
	Slime	5.6	41.7	.631		4.0	19.7	2.0*	0.5*	0.25		
	Composite	100.0	59.0	.178		100.0	100.0					
5	Concentrate	60.5	64.8	.088	5.7	66.6	29.8	2.5		1.25	1.0	0.5
	Middling 1	15.3	58.0	.144		15.1	12.3					
	Middling 2	7.5	55.2	.215		7.0	9.0					
	Tailing	9.9	37.6	.472		6.3	26.4					
	Slime	6.8	43.7	.581		5.0	22.5	2.0*	0.5*	0.25		
	Composite	100.0	58.8	.178		100.0	100.0					

*Reagents added to grind.

TABLE 4 - Summary of results obtained in modified anionic silica flotation of Crest jig concentrate (Con'td)

Test No.	Product	Weight, percent	Analyses, percent			Dist., %		Reagents, lbs/ton of feed				
			Fe	P	SiO_2	Fe	P	NaOH	$Na_4P_2O_7$	Tapioca	Aero Promoter 825	FA-2
6	Concentrate	61.3	64.5	.089	5.5	67.5	30.7	2.5		1.25	1.5	0.5
	Middling 1	14.0	58.7	.137		14.0	10.1					
	Middling 2	8.9	54.9	.233		8.3	11.1					
	Tailing	10.3	36.9	.476		6.5	27.4					
	Slime	5.5	39.2	.661		3.7	20.1	2.0*	0.5*	0.25		
	Composite	100.0	58.6	.179		100.0	100.0					
7	Concentrate	59.2	65.2	.085	5.6	65.3	28.4	2.5		1.25	1.0	0.75
	Middling 1	16.0	60.8	.137		16.5	12.5					
	Middling 2	9.0	55.0	.215		8.4	10.8					
	Tailing	11.3	37.0	.467		7.0	30.1					
	Slime	4.5	37.3	.707		2.8	18.2	2.0*	0.5*	0.25		
	Composite	100.0	59.0	.176		100.0	100.0					
8	Concentrate	50.7	65.6	.075	4.9	56.2	21.6	2.5		1.25	0.5	1.0
	Middling 1	19.3	62.5	.120		20.4	13.1					
	Middling 2	10.2	57.4	.187		9.9	10.8					
	Tailing	15.5	41.7	.404		10.9	35.8					
	Slime	4.3	36.4	.762		2.6	18.7	2.0*	0.5*	0.25		
	Composite	100.0	59.2	.176		100.0	100.0					
9	Concentrate	53.0	63.9	.091	6.6	56.9	28.4	2.5		1.25	1.5	0.125
	Middling 1	24.0	61.5	.126		24.8	17.7					
	Middling 2	9.0	56.9	.178		8.6	9.5					
	Tailing	8.7	43.4	.447		6.3	23.1					
	Slime	5.3	38.4	.672		3.4	21.3	2.0*	0.5*	0.25		
	Composite	100.0	59.6	.169		100.0	100.0					
10	Concentrate	69.1	63.0	.11	7.0	73.7	44.2	2.5		1.25		0.5
	Middling	19.5	55.1	.20		18.2	22.7					
	Tailing	8.6	43.2	.41		6.3	20.3					
	Slime	2.8	37.0	.79		1.8	12.8	2.0*	0.5*	0.25		
	Composite	100.0	59.0	.17		100.0	100.0					

*Reagents added to grind.

Other reagent additions were held constant, and the selective flocculation-desliming step prior to flotation was standardized for the test series. Since sample No. 9656 was depleted in the preliminary testing, sample No. 9656A was used for this series.

Flotation test data are presented in tables 5, 6, 7, and 8 with each table containing the data for five replicate tests and the average results of the five tests. The high degree of similarity in the results obtained indicate that varying the levels of the collector combination had little or no effect within the limits tested on the Fe content and recovery of the concentrate. However, there does seem to be a trend towards lower phosphorus content in the concentrate as the amount of total collector increases.

All of the middling products from the twenty flotation tests were composited to provide a uniform feed for the sulfuric acid leaching tests. This combined product had the following analysis in percent: Fe - 61.6; SiO_2 - 8.2; P - 0.16; CaO - 0.98; MgO - 0.45; CO_2 - 0.76; S - 0.13.

The leaching tests were designed to establish the leach solution concentration required to effect suitable leaching of the phosphorus, to determine sulfuric acid consumption, and to determine the effect of contact time on the leaching operation. The standardized leaching procedure previously discussed was used for this leaching test series.

Acid consumption was determined from the difference in H_2SO_4 concentration of the stock leach solutions and the filtrate from the leaching operation. Sulfuric acid concentration of the filtrate was determined by titration to a methyl-orange end-point with a standard NaOH solution. The methyl-orange end-point (pH - 4) was selected to minimize error resulting from NaOH titration of dissolved phosphoric and carbonic acids.

TABLE 5 - Results of batch flotation tests using collector levels of 0.75 lb/ton FA-2 and 0.5 lb/ton Aero Promoter 825

Test No.	Product	Weight, percent	Analyses, percent				Dist., %		Other Reagents, lb/ton		
			Fe	P	SiO_2	S	Fe	P	NaOH	$Na_4P_2O_7$	Tapioca
1	Concentrate	55.6	64.9	.100	5.4	.012	59.9	29.8	2.5		1.25
	Middling 1	19.2	62.4	.158			19.9	15.9	1.0		
	Middling 2	9.7	56.8	.227			9.2	11.1	1.0		
	Tails	11.1	43.2	.444			8.0	26.1			
	Slimes	4.4	41.6	.700			3.0	16.5	2.0*	0.5*	0.25
	Composite	100.0	60.2	.188			100.0	100.0			
8	Concentrate	52.6	64.4	.094	5.2	.034	56.8	27.4	2.5		1.25
	Middling 1	19.9	62.2	.130			20.7	14.5	1.0		
	Middling 2	10.2	58.0	.187			9.9	10.6	1.0		
	Tails	12.3	43.8	.426			9.0	29.1			
	Slimes	5.0	43.0	.664			3.6	18.4	2.0*	0.5*	0.25
	Composite	100.0	59.7	.179			100.0	100.0			
13	Concentrate	49.8	64.9	.101	5.3	.024	53.8	26.5	2.5		1.25
	Middling 1	21.3	63.1	.141			22.4	15.9	1.0		
	Middling 2	10.7	58.2	.206			10.3	11.6	1.0		
	Tails	12.5	45.0	.406			9.4	27.0			
	Slimes	5.7	43.4	.632			4.1	19.0	2.0*	0.5*	0.25
	Composite	100.0	60.1	.189			100.0	100.0			
15	Concentrate	53.2	65.3	.098	5.3	.034	57.7	27.5	2.5		1.25
	Middling 1	18.2	63.2	.144			19.1	13.8	1.0		
	Middling 2	10.2	58.5	.201			9.9	11.1	1.0		
	Tails	13.1	44.1	.417			9.6	29.1			
	Slimes	5.3	42.7	.669			3.7	18.5	2.0*	0.5*	0.25
	Composite	100.0	60.3	.189			100.0	100.0			
20	Concentrate	51.3	64.4	.099	5.3	.039	55.2	27.6	2.5		1.25
	Middling 1	19.7	63.1	.139			20.8	14.6	1.0		
	Middling 2	11.2	58.6	.197			11.0	11.9	1.0		
	Tails	12.4	44.5	.409			9.2	27.5			
	Slimes	5.4	42.1	.637			3.8	18.4	2.0*	0.5*	0.25
	Composite	100.0	59.8	.185			100.0	100.0			
Average	Concentrate	52.5	64.8	.098	5.3	.029	56.7	27.7			
	Middling 1	19.7	63.2	.142			20.6	14.9			
	Middling 2	10.4	58.0	.204			10.1	11.4			
	Tails	12.3	44.1	.420			9.0	27.8			
	Slimes	5.1	42.6	.660			3.6	18.2			
	Composite	100.0	60.0	.186			100.0	100.0			

*Reagents added to grind.

TABLE 6 - Results of batch flotation tests using collector levels of 1.0 lb/ton FA-2 and 0.5 lb/ton Aero Promoter 825

Test No.	Product	Weight, percent	Analyses, percent Fe	P	SiO_2	S	Dist., % Fe	P	Other Reagents, lb/ton NaOH	$Na_4P_2O_7$	Tapioca
2	Concentrate	52.8	64.9	.096	5.2	.010	57.1	26.7	2.5		1.25
	Middling 1	19.8	62.9	.147			20.7	15.2	1.0		
	Middling 2	9.1	58.4	.218			8.8	10.5	1.0		
	Tails	13.5	44.3	.438			10.0	30.9			
	Slimes	4.8	42.5	.670			3.4	16.7	2.0*	0.5*	0.25
	Composite	100.0	60.0	.191			100.0	100.0			
5	Concentrate	47.7	64.7	.091	5.1	.039	52.0	23.1	2.5		1.25
	Middling 1	18.8	62.9	.126			19.9	12.9	1.0		
	Middling 2	10.6	59.7	.173			10.7	9.7	1.0		
	Tails	17.0	45.6	.382			13.1	34.9			
	Slimes	5.9	43.4	.608			4.3	19.4	2.0*	0.5*	0.25
	Composite	100.0	59.3	.186			100.0	100.0			
9	Concentrate	53.1	64.9	.093	5.2	.010	57.5	26.2	2.5		1.25
	Middling 1	19.0	62.6	.140			19.8	14.4	1.0		
	Middling 2	9.7	58.5	.195			9.5	10.2	1.0		
	Tails	12.8	44.1	.427			9.4	29.4			
	Slimes	5.4	41.8	.677			3.8	19.8	2.0*	0.5*	0.25
	Composite	100.0	59.9	.187			100.0	100.0			
12	Concentrate	50.8	65.6	.088	4.9	.018	55.4	24.2	2.5		1.25
	Middling 1	18.3	63.5	.130			19.3	12.9	1.0		
	Middling 2	9.8	58.6	.189			9.5	10.2	1.0		
	Tails	15.1	45.2	.405			11.4	32.8			
	Slimes	6.0	44.1	.611			4.4	19.9	2.0*	0.5*	0.25
	Composite	100.0	60.1	.186			100.0	100.0			
17	Concentrate	53.0	64.2	.090	5.1	.039	57.0	26.5	2.5		1.25
	Middling 1	17.8	61.5	.136			18.4	13.3	1.0		
	Middling 2	9.7	58.2	.198			9.5	10.5	1.0		
	Tails	13.7	47.2	.400			10.8	30.4			
	Slimes	5.8	44.3	.604			4.3	19.3	2.0*	0.5*	0.25
	Composite	100.0	59.7	.181			100.0	100.0			
Average	Concentrate	51.5	64.8	.092	5.1	.023	55.8	25.4			
	Middling 1	18.7	62.7	.136			19.6	13.7			
	Middling 2	9.8	58.7	.195			9.6	10.2			
	Tails	14.4	45.3	.410			10.9	31.7			
	Slimes	5.6	43.2	.634			4.1	19.0			
	Composite	100.0	59.8	.186			100.0	100.0			

*Reagents added to grind.

TABLE 7 - Results of batch flotation tests using collector levels of 0.75 lb/ton FA-2 and 1.5 lb/ton Aero Promoter 825

Test No.	Product	Weight, percent	Analyses, percent Fe	P	SiO_2	S	Dist., % Fe	P	Other Reagents, lb/ton NaOH	$Na_4P_2O_7$	Tapioca
4	Concentrate	56.3	64.9	.089	5.1	.032	60.9	27.8	2.5		1.25
	Middling 1	15.4	63.5	.125			16.3	10.5	1.0		
	Middling 2	8.0	59.7	.188			8.0	8.3	1.0		
	Tails	14.3	43.8	.416			10.4	32.8			
	Slimes	6.0	43.8	.618			4.4	20.6	2.0*	0.5*	0.25
	Composite	100.0	60.0	.180			100.0	100.0			
6	Concentrate	52.3	66.0	.083	4.8	.034	57.0	24.7	2.5		1.25
	Middling 1	16.1	64.0	.121			17.0	10.9	1.0		
	Middling 2	9.3	60.6	.177			9.3	9.2	1.0		
	Tails	16.7	45.4	.373			12.6	35.6			
	Slimes	5.6	44.3	.599			4.1	19.6	2.0*	0.5*	0.25
	Composite	100.0	60.5	.174			100.0	100.0			
10	Concentrate	57.4	65.1	.088	5.0	.010	62.1	27.9	2.5		1.25
	Middling 1	14.5	63.1	.132			15.2	10.4	1.0		
	Middling 2	8.4	59.7	.219			8.4	9.8	1.0		
	Tails	14.7	43.8	.427			10.7	34.4			
	Slimes	5.0	43.1	.633			3.6	17.5	2.0*	0.5*	0.25
	Composite	100.0	60.1	.183			100.0	100.0			
16	Concentrate	56.4	64.9	.092	5.4	.021	61.2	28.6	2.5		1.25
	Middling 1	15.6	63.1	.131			16.5	11.0	1.0		
	Middling-2	8.6	57.3	.199			8.2	9.3	1.0		
	Tails	13.3	43.4	.422			9.7	30.8			
	Slimes	6.1	43.6	.602			4.4	20.3	2.0*	0.5*	0.25
	Composite	100.0	59.8	.182			100.0	100.0			
18	Concentrate	55.3	64.9	.093	5.4	.021	59.9	28.0	2.5		1.25
	Middling 1	16.1	62.9	.129			16.9	11.5	1.0		
	Middling 2	8.2	59.3	.194			8.1	8.8	1.0		
	Tails	14.4	44.3	.409			10.7	32.4			
	Slimes	6.0	43.6	.585			4.4	19.3	2.0*	0.5*	0.25
	Composite	100.0	59.9	.182			100.0	100.0			
Average	Concentrate	55.6	65.2	.089	5.1	.024	60.2	27.4			
	Middling 1	15.5	63.3	.128			16.4	10.8			
	Middling 2	8.5	59.3	.195			8.4	9.1			
	Tails	14.7	44.2	.409			10.8	33.2			
	Slimes	5.7	43.7	.607			4.2	19.5			
	Composite	100.0	60.1	.180			100.0	100.0			

*Reagents added to grind.

TABLE 8 - Results of batch flotation tests using collector levels of 1.0 lb/ton FA-2 and 1.5 lb/ton Aero Promoter 825

Test No.	Product	Weight, percent	Analyses, percent Fe	P	SiO_2	S	Dist., % Fe	P	Other Reagents, lb/ton NaOH	$Na_4P_2O_7$	Tapioca
3	Concentrate	53.0	64.9	.090	5.3	.024	57.4	25.8	2.5		1.25
	Middling 1	17.1	63.8	.125			18.2	11.3	1.0		
	Middling 2	8.2	60.9	.187			8.3	8.1	1.0		
	Tails	16.1	44.8	.419			12.0	36.0			
	Slimes	5.6	43.8	.631			4.1	18.8	2.0*	0.5*	0.25
	Composite	100.0	59.9	.186			100.0	100.0			
7	Concentrate	55.0	64.9	.087	5.2	.016	59.8	26.5	2.5		1.25
	Middling 1	14.6	63.8	.121			15.6	10.0	1.0		
	Middling 2	8.1	60.0	.175			8.1	7.7	1.0		
	Tails	16.3	44.0	.407			12.0	36.5			
	Slimes	6.0	44.5	.580			4.5	19.3	2.0*	0.5*	0.25
	Composite	100.0	59.7	.181			100.0	100.0			
11	Concentrate	56.8	65.6	.083	5.0	.033	62.0	26.0	2.5		1.25
	Middling 1	13.0	63.1	.134			13.7	9.4	1.0		
	Middling 2	7.9	60.4	.170			7.9	7.2	1.0		
	Tails	17.0	44.8	.416			12.7	38.6			
	Slimes	5.3	42.5	.639			3.7	18.8	2.0*	0.5*	0.25
	Composite	100.0	60.1	.181			100.0	100.0			
14	Concentrate	54.0	64.4	.089	5.1	.018	58.0	26.1	2.5		1.25
	Middling 1	15.2	63.8	.126			16.2	10.3	1.0		
	Middling 2	8.0	61.3	.173			8.2	7.6	1.0		
	Tails	16.5	46.5	.403			12.8	35.9			
	Slimes	6.3	45.9	.592			4.8	20.1	2.0*	0.5*	0.25
	Composite	100.0	60.0	.184			100.0	100.0			
19	Concentrate	48.8	65.1	.087	5.0	.035	53.2	22.5	2.5		1.25
	Middling 1	17.1	63.8	.122			18.2	11.2	1.0		
	Middling 2	9.3	60.9	.167			9.5	8.6	1.0		
	Tails	19.3	47.0	.380			15.2	39.0			
	Slimes	5.5	42.7	.632			3.9	18.7	2.0*	0.5*	0.25
	Composite	100.0	59.8	.187			100.0	100.0			
Average	Concentrate	53.5	65.0	.087	5.1	.025	58.1	25.4			
	Middling 1	15.4	63.6	.126			16.4	10.4			
	Middling 2	8.3	60.7	.174			8.4	7.8			
	Tails	17.0	45.4	.405			12.9	37.2			
	Slimes	5.8	43.9	.615			4.2	19.2			
	Composite	100.0	60.0	.184			100.0	100.0			

*Reagents added to grind.

Results of the leaching tests are tabulated in table 9. These results show complete consumption of H_2SO_4 and only slight leaching of phosphorus for the H_2SO_4 leach solution strength of 19.2 lb/ton, insufficient leaching of phosphorus with the 48 lb/ton solution, achievement of a suitable phosphorus grade for the leach product treated with the 78 lb/ton solution, and a leveling off of the phosphorus grade of the products from leaching tests with solution concentrations greater than 78 lb/ton H_2SO_4. This relationship of phosphorus grade of the leach product to leach solution concentration is shown graphically in figure 2. Thus, it appears that the optimum H_2SO_4 leach solution concentration was around 80 lb/ton of middling.

The data in table 9 is presented graphically in figure 3 to show the effect of leach solution concentration and leaching time on sulfuric acid consumption. Acid consumption increased as the leach solution concentration was increased; and for each solution, acid consumption increased as the leach time was increased. In order to maintain minimum acid consumption, solution concentration should be maintained at the optimum level; and since leaching time has no apparent effect on the phosphorus grade of the leach product, contact time should also be kept at a minimum. In all cases, the sulfuric acid consumption was less than the theoretical value of 80 lb/ton which would be required to leach all of the P, Ca, and Mg contained in the middling product. Hence, increased acid consumption for the longer leach times and increased solution concentration, probably results from further dissolution of the Ca and Mg constituents as well as from leaching of soluble iron.

Leach solution concentrations in lb/ton as discussed above, were based on a ton of middling product. Basing acid consumption on a ton of jig concentrate gives a much more favorable value. For example, an acid consumption of 45 lb/ton based on a ton of middling product would be 12.2 lb/ton when based on a ton of jig concentrate.

TABLE 9 - Summary of data for sulfuric-acid leaching of flotation middling products

Sample No.	Leach Solution Concentration, lb/ton H_2SO_4	Leach time, minutes	H_2SO_4 Consumed lb/ton	Residue Analyses, percent				Filtrate Analyses, gm/liter		Composite	Residue	Final pH
				Fe	SiO_2	S	P	P	Fe	% P	Wt. gm.	
121	19.2	15	19.2	61.6	8.3	.08	.132	.018	.01	.150	49.7	4.5
131	19.2	30	19.2	61.6	7.9	.09	.134	.013	.00	.147	49.8	4.6
141	19.2	60	19.2	61.8	8.1	.12	.132	.012	.01	.144	49.7	4.6
151	19.2	120	19.2	61.8	8.0	.06	.129	.011	.01	.140	49.6	5.0
161	19.2	240	19.2	62.0	8.1	.06	.134	.012	.01	.146	49.6	5.0
Averages				61.8	8.1	.08	.132	.013	.01	.145	49.7	
122	48.3	15	39.4	61.6	8.1	.32	.040	.100	.03	.140	49.7	2.0
132	48.3	30	39.6	61.6	8.1	.33	.040	.096	.03	.136	49.8	2.0
142	48.3	60	40.3	61.8	8.1	.33	.043	.099	.04	.142	49.7	1.8
152	48.3	120	41.3	61.8	8.0	.33	.046	.096	.04	.142	49.8	1.8
162	48.3	240	42.9	61.8	8.0	.30	.046	.090	.06	.136	49.7	2.0
Averages				61.7	8.1	.32	.043	.096	.04	.139	49.7	
123	77.9	15	42.0	61.6	8.1	.31	.020	.129	.14	.149	49.6	1.4
133	77.9	30	45.3	61.6	8.0	.37	.024	.120	.20	.144	48.5	1.2
143	77.9	60	45.6	61.3	8.0	.37	.023	.120	.14	.143	49.7	1.1
153	77.9	120	46.8	61.8	8.0	.28	.020	.122	.16	.142	49.4	1.2
163	77.9	240	47.2	61.3	8.0	.31	.025	.115	.19	.140	49.6	1.2
Averages				61.5	8.0	.33	.022	.121	.17	.143	49.4	
124	105.8	15	43.6	61.1	8.0	.31	.017	.130	.15	.147	49.6	1.2
134	105.8	30	46.8	61.6	8.1	.39	.018	.121	.16	.139	----	1.0
144	105.8	60	47.6	61.6	8.0	.36	.022	.122	.24	.144	49.6	0.8
154	105.8	120	48.8	61.6	8.0	.36	.021	.122	.23	.143	49.6	0.8
164	105.8	240	53.6	62.0	8.0	.40	.028	.116	.27	.144	49.8	1.0
Averages				61.6	8.0	.36	.021	.126	.21	.147	49.6	
125	135.1	15	44.4	61.6	8.1	.32	.016	.131	.17	.147	49.6	1.0
135	135.1	30	47.2	61.6	8.0	.39	.015	.144	.36	.159	----	0.8
145	135.1	60	48.0	61.6	8.0	.35	.019	.122	.20	.141	49.6	0.7
155	135.1	120	52.8	61.8	8.0	.33	.017	.126	.24	.143	49.5	0.7
165	135.1	240	56.0	62.0	7.9	.41	.014	.120	.33	.134	49.7	0.7
Averages				61.7	8.0	.36	.016	.129	.26	.144	49.6	

TABLE 9 - Summary of data for sulfuric-acid leaching of flotation middling products (Continued)

Sample No.	Leach Solution Concentration, lb/ton H_2SO_4	Leach time, minutes	H_2SO_4 Consumed lb/ton	Residue Analyses, percent: Fe	SiO_2	S	P	Filtrate Analyses, gm/liter: P	Fe	Composite % P	Residue Wt. gm.	Final pH
126	164.3	15	46.0	61.6	8.1	.35	.015	.129	.22	.144	49.6	0.9
136	164.3	30	48.0	62.0	8.2	.25	.016	.133	.23	.149	----	0.7
146	164.3	60	50.8	61.6	8.0	.33	.014	.129	.23	.143	49.5	0.6
156	164.3	120	57.2	61.6	8.0	.36	.014	.125	.30	.149	49.7	0.6
166	164.3	240	61.2	62.2	7.9	.35	.012	.125	.36	.137	49.7	0.7
Averages				61.8	8.0	.33	.014	.128	.27	.142	49.6	
127	196.8	15	51.6	61.6	8.0	.44	.016	.122	.19	.138	49.8	0.8
137	196.8	30	54.8	62.0	8.0	.38	.018	.124	.47	.142	49.7	0.5
147	196.8	60	57.6	62.0	8.0	.35	.011	.130	.31	.141	49.5	0.5
157	196.8	120	62.0	62.0	8.0	.33	.012	.128	.32	.140	49.4	0.5
167	196.8	240	67.2	62.2	8.0	.32	.014	.126	.43	.140	49.5	0.6
Averages				61.9	8.0	.36	.014	.126	.34	.140	49.6	
			REPLICATE TESTS 1/									
128	105.8	15	43.8	61.6	8.1	.32	.016	.130	.15	.146	49.5	1.2
138	77.9	30	43.1	61.8	8.2	.39	.025	.120	.14	.145	49.8	1.2
148	196.8	60	62.4	61.8	7.9	.40	.016	.122	.24	.138	49.8	0.5
158	135.1	120	52.3	62.0	8.1	.35	.017	.147	.25	.146	49.6	0.7
168	19.2	240	19.2	62.0	8.2	.09	.125	.013	.01	.138	49.6	5.0

1/ One duplicate test was included for each leach time.

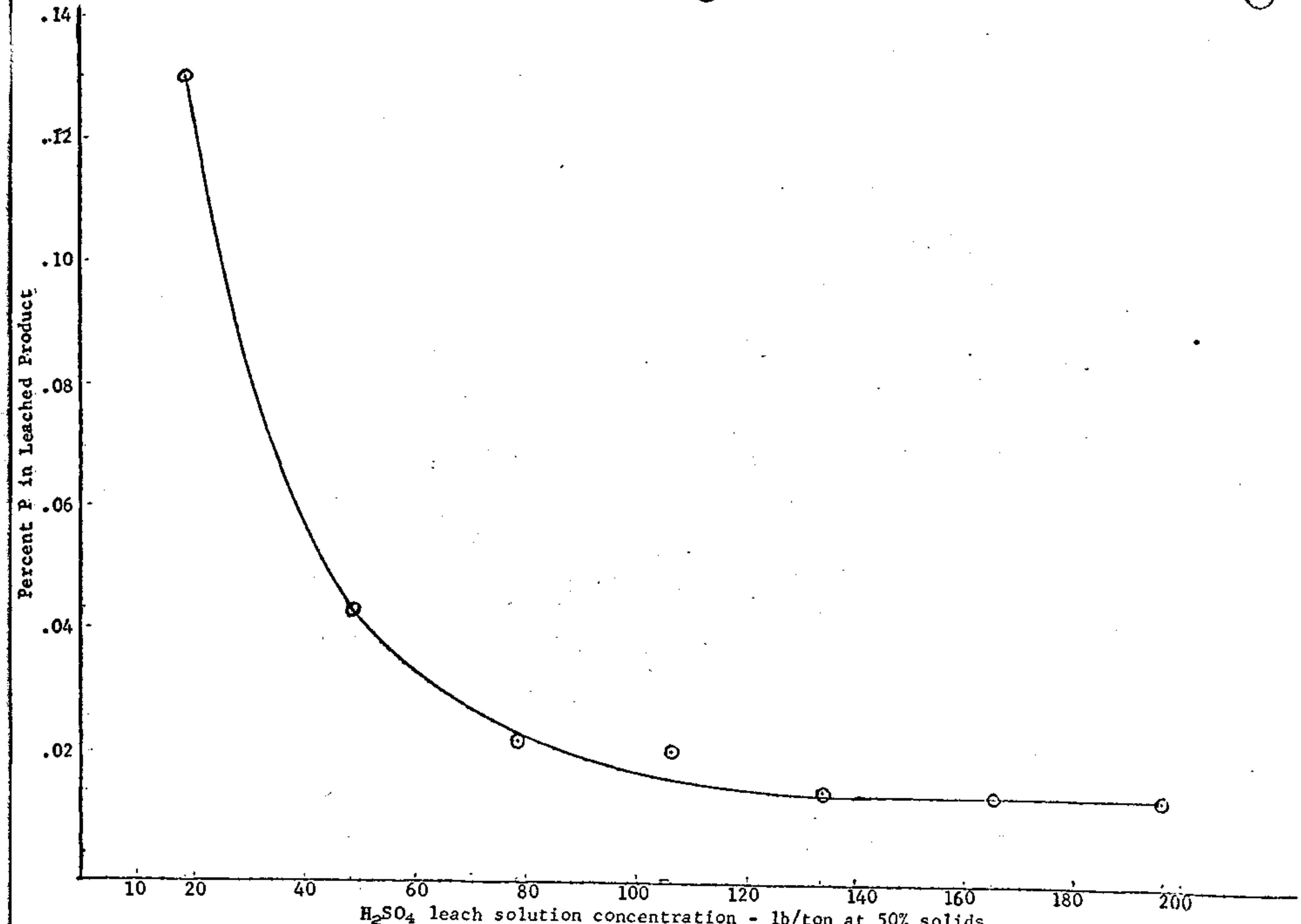
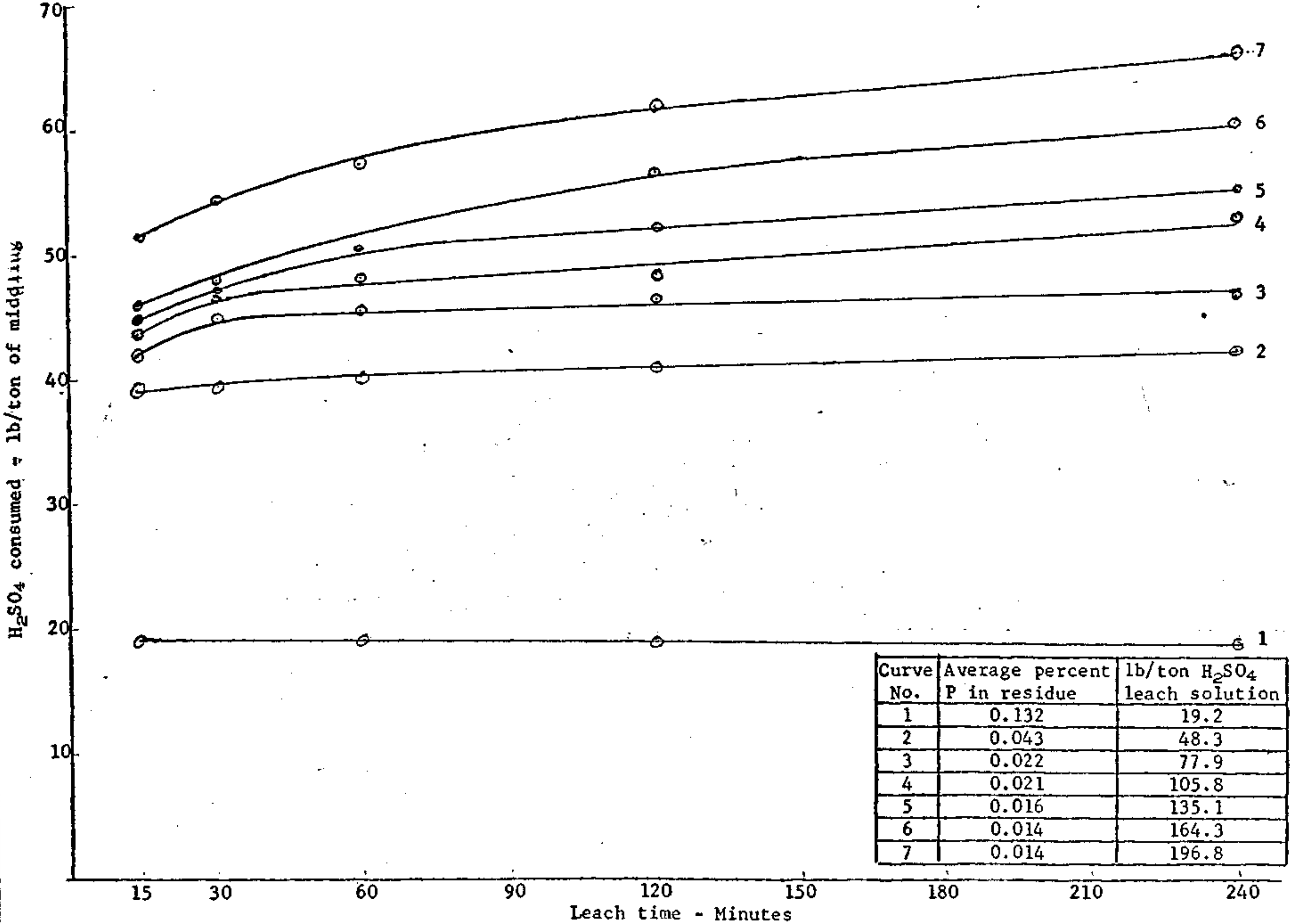


FIGURE 2 - Effect of sulfuric acid concentration of leach solution on phosphorus grade of leached product



Curve No.	Average percent P in residue	lb/ton H_2SO_4 leach solution
1	0.132	19.2
2	0.043	48.3
3	0.022	77.9
4	0.021	105.8
5	0.016	135.1
6	0.014	164.3
7	0.014	196.8

FIGURE 3 - Effect of leach time and leach solution concentration on sulfuric acid consumption in leaching flotation middlings

Sulfur content of the leach residues also showed a tendency to increase as the leach solution concentration was increased (table 9). The seemingly high sulfur content of the leach residues may not be a serious factor since the leach residue only makes up about 37 percent of the final concentrate when recombined with the flotation concentrate.

Table 10 gives the average metallurgical balance for each of the four sets of five replicate tests in the twenty flotation test series (tables 5, 6, 7, and 8) as well as the final concentrates obtained by combining the leached middling products and the flotation concentrates. Since leaching time had no apparent effect on the chemical analysis of the leach residues, the average analyses of the leach products from tests conducted using the 78 lb/ton H_2SO_4 leach solution were used in computing chemical analyses of the final concentrates. These composite results (table 10) show that it is possible to produce a final concentrate assaying approximately 65 percent Fe, 6 percent SiO_2, 0.07 percent P, and 0.08 percent S with an iron recovery of approximately 85 percent through a combination flotation-leaching process. Iron losses to the leach solution were assumed to be negligible and were not accounted for in these calculations.

Crude Ore

The crude ore as received contains approximately 45 percent Fe, 27 percent SiO_2, 0.34 percent P, 5 percent carbonates, and 1 percent Al_2O_3. The objective of this phase of the investigation was to reduce both the SiO_2 and P to sufficiently low levels so that the resulting iron oxide concentrates would be merchantable. Some degree of success was attained, although, acceptable concentrates were never produced. The best concentrates produced by selective flocculation-anionic silica flotation were chemically similar to the jig concentrates.

TABLE 10 - Composite results of anionic silica flotation and sulfuric-acid leaching of Crest jig concentrate

Product	Weight, percent	Analyses, percent				Distribution percent		Reagents, lb/ton of feed				
		Fe	P	SiO_2	S	Fe	P	NaOH	$Na_4P_2O_7$	Tapioca	FA-2	Aero Promoter 825
Concentrate	52.5	64.8	.098	5.3	.029	56.7	27.7	2.5		1.25	0.75	0.5
Middling 1	19.7	63.2	.142			20.6	14.9	1.0				
Middling 2	10.4	58.0	.204			10.1	11.4	1.0				
Tailing	12.3	44.1	.420			9.0	27.8					
Slimes	5.1	42.6	.660			3.6	18.2	2.0*	0.5*	0.25		
Composite	100.0	60.0	.186			100.0	100.0					
Combined Leached Middlings	29.7	61.5	.022	8.0	.33	30.7	3.8	H_2SO_4 concentration leach solution 77.9 lb/ton of middling product .				
Leach Solution	0.4		10.5				22.5	H_2SO_4 consumption 46 lb/ton of middling product				
Final Concentrate**	82.2	63.6	.069	6.3	.14	86.4	31.5					
Concentrate	51.5	64.8	.092	5.1	.023	55.8	25.4	2.5		1.25	1.0	0.5
Middling 1	18.7	62.7	.136			19.6	13.7	1.0				
Middling 2	9.8	58.7	.195			9.6	10.2	1.0				
Tailing	14.4	45.3	.410			10.9	31.7					
Slimes	5.6	43.2	.634			4.1	19.0	2.0*	0.5*	0.25		
Composite	100.0	59.8	.186			100.0	100.0					
Combined Leached Middlings	28.1	61.5	.022	8.0	.33	29.2	3.2	H_2SO_4 concentration leach solution 77.9 lb/ton of middling product				
Leach Solution	0.4		9.8				20.7	H_2SO_4 consumption 46 lb/ton of middling product				
Final Concentrate**	79.6	63.6	.066	6.1	.13	85.0	28.6					

* Reagents added to grind.
**Composite of flotation concentrate and leached middling product.

TABLE 10 - Composite results of anionic silica flotation and sulfuric-acid leaching of Crest jig concentrates (Con'td)

Product	Weight, percent	Analyses, percent: Fe	Analyses, percent: P	Analyses, percent: SiO_2	Analyses, percent: S	Distribution percent: Fe	Distribution percent: P	Reagents, lb/ton of feed: NaOH	Reagents, lb/ton of feed: $Na_4P_2O_7$	Reagents, lb/ton of feed: Tapioca	Reagents, lb/ton of feed: FA-2	Reagents, lb/ton of feed: Aero Promoter 825
Concentrate	55.6	65.2	.089	5.1	.024	60.2	27.4	2.5		1.25	0.75	1.5
Middling 1	15.5	63.3	.128			16.4	10.8	1.0				
Middling 2	8.5	59.3	.195			8.4	9.1	1.0				
Tailing	14.7	44.2	.409			10.8	33.2					
Slimes	5.7	43.7	.607			4.2	19.5	2.0*	0.5*	0.25		
Composite	100.0	60.1	.180			100.0	100.0					
Combined Leached Middlings	23.7	61.5	0.22	8.0	.33	24.8	2.8	H_2SO_4 concentration leach solution 77.9 lb/ton of middling product				
Leach Solution	0.3		10.3				17.1	H_2SO_4 consumption 46 lb/ton of middling product				
Final Concentrate**	79.3	64.4	.067	6.0	.082	85.0	30.2					
Concentrate	53.5	65.0	.087	5.1	.025	58.1	25.4	2.5		1.25	1.0	1.5
Middling 1	15.4	63.6	.126			16.4	10.4	1.0				
Middling 2	8.3	60.7	.174			8.4	7.8	1.0				
Tailing	17.0	45.4	.405			12.9	37.2					
Slimes	5.8	43.9	.615			4.2	19.2	2.0*	0.5*	0.25		
Composite	100.0	60.0	.184			100.0	100.0					
Combined Leached Middlings	23.4	61.5	.022	8.0	.33	24.8	2.6	H_2SO_4 concentration leach solution 77.9 lb/ton of middling product				
Leach Solution	.3		9.6				15.6	H_2SO_4 consumption 46 lb/ton of middling product				
Final Concentrate**	76.9	63.9	.067	6.0	.12	82.9	28.0					

* Reagents added to grind.

**Composite of flotation concentrate and leached middling product.

Various approaches were investigated as possible means of upgrading the crude ore. The following is a summary of the various methods that were evaluated in the course of the investigation: (1) selective flocculation-anionic silica flotation with both low and high solids conditioning, (2) carbonate flotation with and without a concentrate cleaner, (3) anionic iron oxide flotation, (4) reduction roast-magnetic separation, and (5) reduction roast-magnetic separation with either anionic or cationic flotation of the magnetic concentrates. Other than the selective flocculation-anionic silica flotation method, the remaining beneficiation approaches were only briefly evaluated.

The application of the selective flocculation-anionic silica flotation method was thoroughly evaluated on the crude ore. A grind time of 20 minutes, giving a product 94 percent minus 325-mesh, was used throughout the flotation test work. In the initial phase of the evaluation the level of sodium silicate, a dispersing agent, was varied in the grind to adjust the slime weight removed in the deslime step. Sufficient sodium hydroxide was also added to the grind to give a pH between 10.5 and 11.0. After running a series of three tests, a sodium silicate level of 2.0 lbs/ton of feed was chosen as giving the desired level of dispersion (see table 11, test No. 1, 2, and 3). These data indicate that the highest sodium silicate addition to the grind hindered selective flocculation. Apparently the pulp was over dispersed and could not be selectively flocculated.

It became evident in the early stages of the evaluation that the concentration of polyvalent cations supplied by the crude ore would be sufficient for activation of the quartz minerals. In comparing test No. 4 and 5, table 11, it is evident that an addition of activating ion in the form of calcium chloride is detrimental to flotation of both silica and phosphorus minerals.

TABLE 11 - Crest crude ore 9662, Summary of flotation results[1/]

Test No.	Product	Weight, percent	Analysis, percent Fe	Analysis, percent SiO_2	Analysis, percent P	Dist., % Fe	Dist., % P	Reagents, lbs/S. ton feed Na_2SiO_3	NaOH	Tapioca	$CaCl_2 \cdot 2H_2O$	FA-2
1	Concentrate	57.2	53.75	16.60	.25	68.1	45.3		2.0	1.0	1.0	1.5
	Middling 1	22.8	41.59	34.10	.36	21.0	25.9					
	Middling 2	11.9	29.77	47.26	.39	7.8	14.6					
	Tails	6.0	18.63	58.90	.59	2.5	11.0					
	Slime	2.1	12.16	69.88	.48	0.6	3.2	1.0*	2.0*	0.25		
	Composite	100.0	45.15	27.89	.32	100.0	100.0					
2	Concentrate	65.5	53.18	15.28	.32	77.1	65.2		2.5	1.0	1.0	1.0
	Middling 1	15.4	41.36		.34	14.1	16.2		0.5			
	Middling 2	7.1	26.14		.24	4.1	5.3		0.5			
	Tails	5.9	17.27		.18	2.2	3.4					
	Slime	6.1	18.41		.53	2.5	9.9	2.0*	2.0*	0.25		
	Composite	100.0	45.20		.32	100.0	100.0					
3	Concentrate	60.7	53.41	16.13	.26	71.8	53.0		2.5	0.5	1.0	1.0
	Middling 1	10.6	40.91		.26	9.6	9.4		0.5			
	Tails	7.1	21.82		.18	3.4	4.4					
	Slime	21.6	31.82		.46	15.2	33.2	3.0*	2.0*	0.25		
	Composite	100.0	45.18		.30	100.0	100.0					
4	Concentrate	52.5	49.22	20.85	.283	62.5	40.4		2.5	0.5	0.5	1.0
	Middling 1	19.6	43.31		.354	20.5	18.7					
	Tails	19.1	26.79		.537	12.4	27.9					
	Slime	8.8	21.32		.542	4.6	13.0	2.0*	2.0*	0.5		
	Composite	100.0	41.33		.369	100.0	100.0					
5	Concentrate	47.7	56.25	13.79	.16	60.2	23.0		2.5	0.5		1.0
	Middling 1	17.1	45.54		.35	17.5	18.1		1.0			
	Middling 2	8.3	38.62		.51	7.2	12.7		1.5			
	Tails	16.6	26.56		.59	9.9	29.6					
	Slime	10.3	22.77		.53	5.2	16.6	2.0*	2.0*	0.5		
	Composite	100.0	44.59		.33	100.0	100.0					

1/ Ore given 20-minute grind for each test.

* Reagents added to grind.

Several modifying chemicals were examined that would reduce the soluble cation pulp concentrations in the flotation pulps. They included the tetrasodium salts of both pyrophosphate and ethylenediaminetetraacetic acid (EDTA), which chelate soluble cations, and sodium carbonate, which precipitates soluble calcium. These modifier additions were made in the flotation conditioning step. Sodium carbonate and EDTA improved the flotation selectivity, indicating an excessive concentration of activating ions was liberated in grinding the crude ore. The third modifying reagent, tetrasodium pyrophosphate, did little to improve the mineral separations as it produced foamy froths. Comparison of tests No. 1, 2, 3, and 4, tables 12, with tests 5 and 6 which had no modifier addition, shows the effect the modifying chemicals had on the flotation selectivity. In Test 7, table 12, sodium pyrophosphate was employed in a manner similar to that used in the treatment of jig concentrate. The net effect was a high-weight slime product, but with no noticeable improvement in concentrate grade.

The use of a petroleum sulfonate-fatty acid collector combination did not improve the flotation separation of the crude ore using 30 percent solids conditioning, but some advantages were observed using 65 percent solids. A comparison between tests 1 and 8 and 9 and 10 in table 12 show the effect of both low and high solids conditioning with various collector combinations. Other data from tests using the sulfonate-fatty acid collector combination are tabulated in Appendix II.

The effect of grind time is shown by comparison of the results from tests No. 6, 11, and 12, table 12, in which the ore was ground 20, 25, and 30 minutes, respectively. An additional 0.5 lb/ton of sodium silicate was added to the 30-minute grind to produce a sufficient level of dispersion. There appears to be little advantage in the longer grind times although it is possible that some adjustment of reagents might improve the separation.

TABLE 12 - Crest crude ore-9662, Summary of flotation results[1]

Test No.	Product	Weight, percent	Analyses, percent				Distribution, %			Reagents, lbs/S. ton feed				
			Fe	SiO_2	P	CO_2	Fe	P	CO_2	Na_2SiO_3	NaOH	Tapioca	Miscellaneous	FA-2
1	Concentrate	43.2	59.38	11.44	.10	0.55	58.6	13.1	10.6		2.5	1.0	1.0[2]	1.5
	Middling 1	13.9	48.89		.29	1.72	15.5	12.2	10.6		1.0			
	Middling 2	7.8	38.17		.45	4.58	6.8	10.6	15.9		1.5			
	Tails	21.2	23.44		.64	5.17	11.4	41.3	48.7					
	Slime	13.9	24.33		.54	2.27	7.7	22.8	14.2	2.0*	2.0*	0.5		
	Composite	100.0	43.78		.33	2.26	100.0	100.0	100.0					
2	Concentrate	44.2	58.49	12.20	.12	0.80	60.5	15.9	14.0		2.5	1.0	1.0[3]	1.5
	Middling 1	16.8	42.41		.33	3.22	16.6	16.4	21.6		1.0			
	Middling 2	9.0	36.16		.50	5.54	7.6	13.5	20.0		1.5			
	Tails	22.0	22.32		.65	4.70	11.4	42.8	41.2					
	Slime	8.0	20.98		.48	1.06	3.9	11.4	3.2	2.0*	2.0*	0.5		
	Composite	100.0	42.81		.33	2.50	100.0	100.0	100.0					
3	Concentrate	42.6	54.69	14.82	.22	1.26	52.5	26.9	23.6		2.5	1.0	0.5[4]	1.0
	Middling 1	30.0	45.98		.32	2.82	31.0	27.4	37.1		1.0			
	Middling 2	10.3	35.27		.50	4.18	8.2	14.8	18.8		1.5			
	Tails	9.9	19.87		.72	3.74	4.4	20.3	16.1					
	Slime	7.2	23.88		.52	1.43	3.9	10.6	4.4	2.0*	2.0*	0.5		
	Composite	100.0	44.41		.35	2.29	100.0	100.0	100.0					
4	Concentrate	42.4	56.80	13.45	.20	1.36	54.9	25.4			2.5	1.0	0.25[4]	1.0
	Middling 1	26.0	44.87		.30		26.6	23.3			1.0			
	Middling 2	10.3	33.48		.49		7.9	14.9			1.5			
	Tails	11.0	20.98		.65		5.2	21.5						
	Slime	10.3	22.99		.49		5.4	14.9		2.0*	2.0*	0.5		
	Composite	100.0	43.88		.34		100.0	100.0						
5	Concentrate	48.2	56.48	13.38	.16	1.25	62.4	23.6	24.7		2.5	1.0	----	1.5
	Middling 1	16.7	43.31		.43	4.55	16.6	22.0	31.3		1.0			
	Middling 2	7.8	35.94		.42	4.88	6.4	10.1	15.6		1.5			
	Tails	16.4	23.33		.53	2.64	8.8	26.6	17.7					
	Slime	10.9	22.99		.53	2.39	5.8	17.7	10.7	2.0*	2.0*	0.5		
	Composite	100.0	43.59		.33	2.43	100.0	100.0	100.0					
6	Concentrate	57.9	54.92	13.42	.19		71.9	32.9			2.5	1.0	----	1.0
	Middling 1	14.5	41.63		.47		13.7	20.3			1.0			
	Middling 2	6.6	31.20		.63		4.7	12.5			1.5			
	Tails	12.7	20.31		.56		5.8	21.2						
	Slime	8.3	20.76		.53		3.9	13.1		2.0*	2.0*	0.5		
	Composite	100.0	44.23		.34		100.0	100.0						

See footnotes at end of table.

TABLE 12 - Crest crude ore-9662, Summary of flotation results[1] (Continued)

Test No.	Product	Weight, percent	Analyses, percent				Distribution, %			Reagents, lbs/S. ton feed				
			Fe	SiO_2	P	CO_2	Fe	P	CO_2	Na_2SiO_3	NaOH	Tapioca	Miscellaneous	FA-2
7	Concentrate	44.3	57.82	13.14	.14	0.55	58.5	17.9	9.7		2.5	1.0		1.0
	Middling 1	18.3	41.97		.32	2.56	17.5	17.1	19.0		1.0			
	Middling 2	8.9	31.25		.48	6.53	6.4	12.4	23.4		1.5			
	Tails	9.0	19.86		.68	5.24	4.1	17.6	18.9	*				
	Slime	19.5	30.36		.62	3.71	13.5	35.0	29.0	0.75[4]	2.0*	0.5	0.25[5]	
	Composite	100.0	43.78		.35	2.48	100.0	100.0	100.0					
8[6]	Concentrate	51.8	57.35	13.90	.126		68.5	19.3			2.5	1.0	1.0[2]	1.5
	Middling 1	13.0	46.66		.339		14.0	13.0			1.0			
	Middling 2	6.7	35.46		.553		5.5	11.0			1.5			
	Tails	21.6	17.88		.712		8.9	45.7						
	Slime	6.9	19.73		.534		3.1	11.0		2.0*	2.0*	0.5		
	Composite	100.0	43.38		.337		100.0	100.0						
9	Concentrate	57.0	55.50	16.04	.121		72.3	20.8			2.5	1.0	1.0[2]	1.5+[7]
	Middling 1	9.8	45.74		.387		10.2	11.5			1.0			
	Middling 2	7.0	33.30		.612		5.3	13.0			1.5			
	Tails	18.2	20.14		.749		8.4	41.1						
	Slime	8.0	20.55		.561		3.8	13.6		2.0*	2.0*	0.5		
	Composite	100.0	43.76		.331		100.0	100.0						
10[6]	Concentrate	43.6	58.27	12.85	.109	0.39	58.3	14.5	6.7		2.5	1.0	1.0[2]	1.5+[7]
	Middling 1	15.1	52.00		.235	0.92	18.0	10.5	5.5		1.0			
	Middling 2	8.0	42.04		.439	2.23	7.8	10.9	7.0		1.5			
	Tails	26.3	20.96		.678	7.16	12.7	53.6	73.4					
	Slime	7.0	19.94		.497	2.72	3.2	10.5	7.4	2.0*	2.0*	0.5		
	Composite	100.0	43.58		.332	2.56	100.0	100.0	100.0					
11[8]	Concentrate	50.5	54.47	13.75	.19		62.7	28.6			2.5	1.0	---	1.0
	Middling 1	19.7	42.75		.45		19.2	26.5			1.0			
	Middling 2	9.5	36.16		.57		7.8	16.1			1.5			
	Tails	14.9	23.44		.51		8.0	22.6						
	Slime	5.4	18.31		.39		2.3	6.2		2.0*	2.0*	0.5		
	Composite	100.0	43.85		.34		100.0	100.0						
12[9]	Concentrate	49.3	54.47	12.37	.23		60.8	33.4			2.5	1.0	---	1.0
	Middling 1	19.2	45.21		.47		19.6	26.6			1.0			
	Middling 2	8.4	38.84		.51		7.4	12.7			1.5			
	Tails	11.7	25.45		.45		6.7	15.7						
	Slime	11.4	21.10		.34		5.5	11.6		2.5*	2.0*	0.5	0.25[5]	
	Composite	100.0	44.18		.34		100.0	100.0						

1/ Ore in each test ground for 20 minutes unless otherwise noted.
2/ Na_2CO_3
3/ Tetrasodium ethylene diaminetetra acetic acid
4/ Tetrasodium pyrophosphate
5/ $CaCl_2 \cdot 2H_2O$

* Reagents added to grind.

6/ Subsequent to desliming, the pulp conditioned at 50 to 60 percent solids.
7/ 0.75 lbs/s. ton Aero Promoter 825
8/ Ore given 25 minute grind
9/ Ore given 30 minute grind

An attempt at treating the crude ore using anionic iron oxide flotation methods was unsuccessful. The failure of the fuel oil-fatty acid float at a neutral pH was probably the result of the fineness and slimy nature of the ground crude ore. This method also has the added disadvantage of floating both iron oxides and phosphorus minerals while depressing the silica.

Flotation of carbonate minerals proved to be an effective means of reducing the phosphorus content of the ore to near an acceptable level. It is apparent from table 13 that excellent phosphorus removal could be obtained with maximum flotation of carbonate minerals. A correlation seems to exist between product carbon dioxide and phosphorus analyses. This relationship is probably the result of both phosphorus and carbonate minerals being equally floatable and/or a carbonate-phosphorus mineral being present. A single anionic silica flotation test on a product, which combined the concentrate and first and second middlings from a carbonate float similar to the test in table 13, proved unsuccessful.

The best flotation separation obtained on the untreated crude ore yielded concentrates containing 59 percent Fe, 11 percent SiO_2, and 0.10 percent P (test No. 1, table 12). Since prospects of obtaining both better grade and higher recoveries with flotation of the untreated ore seemed remote, a beneficiation scheme incorporating a reduction roasting-magnetic separation-flotation sequence was investigated.

A preliminary reduction roast test involving hydrogen gas reduction in a small bench scale drum, followed by fine grinding (100 percent minus 400-mesh) and magnetic separation in a Davis tube, produced a concentrate very similar in composition to the jig concentrates. This concentrate containing 61 percent Fe, 12 percent SiO_2, and 0.17 percent P was produced with an Fe recovery of 82 percent, while rejecting 72 and 69 percent SiO_2 and P respectively. Results of the hydrogen reduction roast are shown in table 14. Due

TABLE 13 - Crest crude ore-9662, Summary of carbonate flotation results[1/]

Metallurgical Results

Product	Weight, percent	Analyses, percent				Distribution, %		
		Fe	SiO_2	P	CO_2	Fe	P	CO_2
Concentrate	56.6	41.97	35.50	0.08	0.25	54.9	12.4	5.8
Middling 1	20.3	51.34		0.14	0.33	24.1	7.6	2.9
Middling 2	8.0	54.47		0.27	1.43	10.1	6.0	4.5
Tails (froth)	15.1	31.15		1.81	13.98	10.9	74.0	86.8
Composite	100.0	43.24		0.37	2.43	100.0	100.0	100.0
Conc. + M-1 + M-2	84.9	45.39		0.11	0.38	89.1	13.2	26.0

Test Variables

Stages	Reagents, lbs/S. ton feed	Conditioning time	pH
Rougher	Na_2CO_3 - 1.0 Na_2SiO_3 - 4.0 FA-2 - 1.0 Aero Promoter 825 - 2.5	7 minutes	9.5
Cleaner 1	Na_2SiO_3 - 2.0	30 seconds	9.5
Cleaner 2	Na_2SiO_3 - 2.0	30 seconds	9.5

1/ Ore ground 20 minutes for test.

TABLE 14 - Summary of results from magnetic separation of reduction roasted Crest crude ore-9662[1/]

Product	Weight, percent	Analyses, percent								Distribution, percent						
		Fe°	Fe^{2+}	Fe^{3+}	Total Fe	SiO_2	P	CaO	MgO	Fe^{2+}	Fe^{3+}	Total Fe	SiO_2	P	CaO	MgO
Head sample	----	<.05	12.64	32.49	45.43	27.20	.346	1.84	0.68	----	----	----	----	----	----	----
Magnetic	61.2	<.05	19.32	41.73	61.05	12.26	.168	0.43	0.13	94.6	76.9	81.7	28.0	31.4	11.7	10.1
Nonmagnetic	38.8	<.01	1.75	19.83	21.58	49.76	.579	5.09	1.82	5.4	23.1	18.3	72.0	68.6	88.3	89.9
Composite	100.0	---	12.50	33.23	45.73	26.81	.328	2.23	0.79	100.0	100.0	100.0	100.0	100.0	100.0	100.0

1/ Ore was roasted for 30 minutes at 500°C in H_2 atmosphere. A 15-gram sample of reduced ore was ground to minus 400-mesh and magnetically separated in a Davis tube.

to the high silica and phosphorus levels of the magnetic concentrate, it was deemed necessary to further upgrade this material by flotation methods.

In preparing a magnetic concentrate for flotation testing, a large sample of crude ore was roasted using lignite as the reductant. A sample of the lignite reduced ore was ground to minus 400-mesh and a Davis tube separation was made (see table 15). The resulting concentrates, although somewhat over-reduced, were similar in composition to the magnetic concentrate prepared from the hydrogen reduced sample.

The remaining bulk sample of lignite roasted ore was crushed to minus 35-mesh and treated in a Jeffrey-Steffensen magnetic separator. The final magnetic concentrate from this operation analyzed 57.7 percent Fe, 19.0 percent SiO_2, and 0.27 percent P with a recovery of 87.4 percent Fe, while rejecting 53.2 and 44.4 percent SiO_2 and P, respectively (see table 16). The lower grade magnetic concentrate from the Jeffrey-Steffensen separator can be attributed mainly to the poor liberation achieved at minus 35-mesh.

Both cationic and anionic flotation systems were evaluated as methods for upgrading the magnetic concentrates. Prior to flotation, the magnetic concentrates were ground 17 minutes in a laboratory rod mill producing a flotation feed 92 percent minus 325-mesh. Results obtained from the two flotation methods are shown in table 17. The desliming step preceding the two anionic silica flotation tests failed because of the high residual magnetism remaining in the feed. Even at high dispersant levels a small flocculant addition produced complete pulp flocculation. Although concentrates with low silica levels were produced by the reduction roast-magnetic separation-flotation procedure (test 4, table 17), phosphorus removal was inadequate. The increased difficulty in effecting phosphorus removal probably results from both chemical and physical alteration of the phosphorus minerals at the high temperatures and reducing conditions encountered in roasting.

TABLE 15 - Summary of results from magnetic separation of lignite roasted crude ore-9662[1/]

Product[2/]	Weight, percent	Analyses, percent							Distribution, percent						
		Fe^{2+}	Total Fe	P	SiO_2	C	CaO	MgO	Fe^{2+}	Total Fe	P	SiO_2	C	CaO	MgO
Reduced feed	----	29.31	44.97	.340	26.54	3.98	2.70	1.48	----	----	----	----	----	----	----
Primary magnetic	41.1	44.75	64.44	.157	10.82	0.18	.61	.51	61.6	58.6	20.1	16.9	1.8	8.9	15.2
Primary nonmagnetic	58.9	19.47	31.77	.439	37.04	6.45	4.35	1.99	38.4	41.4	79.9	83.1	98.2	91.1	84.8
Composite	100.0	29.16	45.20	.324	26.27	3.87	2.81	1.38	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Secondary magnetic	33.0	43.86	62.65	.172	13.38	0.18	.62	.59	93.5	64.2	13.3	12.1	0.9	3.9	9.9
Final tail	67.0	<1.50	17.23	.555	48.10	9.76	6.49	2.28	6.5	35.8	86.7	87.9	99.1	96.1	90.1
Composite	100.0	15.48	32.21	.429	36.65	6.60	5.13	1.92	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Final Concentrate	62.0	44.48	63.85	.159	11.63	0.18	.62	.54	97.9	85.1	30.6	27.1	2.8	13.3	27.5
Final tail	38.0	<1.50	17.23	.555	48.10	9.76	6.49	2.28	2.1	14.9	69.4	72.9	97.2	86.7	72.5
Composite	100.0	28.15	46.44	.310	25.49	3.82	2.85	1.20	100.0	100.0	100.0	100.0	100.0	100.0	100.0

1/ Ore was roasted with lignite at 650°C for 3/4 hour. A 40-gram sample of reduced ore was ground to minus 400-mesh and separated in Davis tube.

2/ Magnetic separation involved primary separation of the reduced feed with retreatment of the primary nonmagnetic to produce a secondary concentrate and a final tail. The final concentrate is a composite of the primary and secondary magnetic products.

TABLE 16 - Summary of results from magnetic separation of lignite roasted crude ore-9662[1/]

Product[2/]	Weight, percent	Analyses, percent			Distribution, percent		
		Fe	SiO_2	P	Fe	SiO_2	P
Reduced head	----	44.97	26.54	.340	----	----	----
Primary magnetic	61.8	58.62	18.10	.264	81.3	40.4	49.4
Primary nonmagnetic	38.2	21.81	43.19	.436	18.7	59.6	50.6
Composite	100.0	44.56	27.69	.330	100.0	100.0	100.0
Secondary magnetic	15.2	48.10	28.89	.346	33.1	10.3	12.2
Final tails	84.8	17.45	45.20	.451	66.9	89.7	87.8
Composite	100.0	22.11	42.72	.435	100.0	100.0	100.0
Final Concentrate	67.6	57.72	19.04	.267	87.4	46.8	55.6
Final tails	32.4	17.45	45.20	.451	12.6	53.2	44.4
Composite	100.0	44.67	27.51	.329	100.0	100.0	100.0

1/ Ore was roasted with lignite at 650°C for 3/4 hour. Products were produced in a Jeffrey-Steffensen magnetic separator from a minus 35-mesh feed.

2/ Magnetic separation involved primary separation of the reduced feed with retreatment of the primary nonmagnetics to produce a secondary magnetic and a final tail. The final concentrate is a composite of the primary and secondary magnetic products.

TABLE 17 - Summary of results from anionic and cationic flotation tests on the final Jeffrey-Steffensen magnetic concentrate[1]

Test No.	Product	Weight, percent	Analyses, percent Fe	SiO_2	P	Distribution, percent[2] Fe	P	Reagents, lbs/S. ton feed
1	Concentrate	84.9	60.88	14.85	.239	90.1	74.9	Grinding
	Middling	12.8	39.82		.450	8.9	21.4	Na_2SiO_3 - 3.0, NaOH - 2.0
	Tails	2.1	27.23		.416	1.0	3.3	Deslime
	Slime	0.2	11.44		.506	----	0.4	Tapioca - 0.25
	Composite	100.0	57.31		.271	100.0	100.0	Rougher flotation
								Tapioca - 1.0, NaOH - 2.0, $CaCl_2 \cdot 2H_2O$ - 0.5, FA-2 - 0.75, Aero Promoter 825 - 1.0
								Cleaner flotation
								NaOH - 1.5
2	Concentrate	62.0	65.68	9.94	.157	70.2	38.2	Grinding
	Middling 1	18.1	56.30		.206	17.6	14.6	$Na_4P_2O_7$ - 0.5, NaOH - 2.0
	Middling 2	8.7	43.25		.473	6.5	16.1	Deslime
	Tails	11.0	30.21		.688	5.7	29.9	Tapioca - 0.25
	Slime	0.2	8.47		1.277	----	1.2	Rougher flotation
	Composite	100.0	58.01		.254	100.0	100.0	Tapioca - 0.5, NaOH - 2.0, FA-2 - 0.75, Aero Promoter 825 - 1.0
								Cleaner flotation
								NaOH - 1.5
3	Concentrate	71.8	64.77	9.92	.242	81.2	63.7	Rougher flotation
	Middling	9.3	55.84		.379	9.1	12.8	Tapioca - 0.75, NaOH - 0.5, Aerofrother 65 - 0.06, Armac 12D - 0.9
	Tails	18.9	29.52		.338	9.7	23.5	
	Composite	100.0	57.28		.273	100.0	100.0	
4	Concentrate	46.1	67.29	6.56	.193	54.5	32.8	Rougher flotation
	Conc. Cleaner	21.7	59.73		.304	22.8	24.4	Tapioca - 0.5, NaOH - 0.5, Armac 12D - 1.0, Aerofrother 65 - 0.16
	Middling	7.3	59.28		.343	7.6	9.2	Concentrate cleaner flotation
	Tails	24.9	34.56		.364	15.1	33.6	Armac 12D - 0.3
	Composite	100.0	56.92		.271	100.0	100.0	
	Conc. + Conc. Cl. + Mid.	75.1	64.33	10.20	.239	84.9	66.4	

1/ Magnetic concentrate ground 17 minutes in laboratory rod mill to produce a 93 percent minus 325-mesh flotation feed.

2/ Multiply Fe distribution values by 0.874 to obtain recoveries based on crude ore; overall P distribution values obtained by multiplying given values by 0.556.

APPENDIX I

Data obtained in flotation testing on the jig concentrate 9656 which does not appear in the main body of the report is summarized herein. For convenience, the data is presented in two tables. Table 1A summarizes the data obtained using a flotation scheme designed for flotation of phosphorus-bearing minerals, and data obtained using anionic silica flotation techniques is presented in table 2A.

TABLE 1A - Crest jig concentrate, summary of flotation test results

Test No.	Product	Weight, percent	Analyses, percent Fe	P	SiO_2	Dist., percent Fe	P	Reagents lb/ton of feed Na_2CO_3	Na_2SiO_3	NaOH	$Na_4P_2O_7$	Tapioca	Sodium Oleate
1[1/]	Concentrate	85.0	61.8	0.13	11.5	85.6	64.7	2.0	2.0				0.5
	Middling	13.0	60.2	0.31		12.7	23.5						
	Tailing	2.0	52.5	0.95		1.7	11.8						
	Composite	100.0	61.4	0.17		100.0	100.0						
2[1/]	Concentrate	84.1	61.0	0.13	10.8	85.6	66.5	2.0	1.0				0.5
	Middling	7.0	60.4	0.22		7.0	9.1						
	Tailing	1.9	53.9	1.17		1.7	13.4						
	Slime	7.0	48.7	0.26		5.7	11.0		3.0*	2.0*		0.25	
	Composite	100.0	60.0	0.16		100.0	100.0						
3[2/]	Concentrate	74.5	57.4	0.156	12.6	73.5	60.8	2.0	2.0		0.5		0.5
	Middling	18.8	60.3	0.234		19.5	23.0						
	Tailing	6.7	60.1	0.461		7.0	16.2						
	Composite	100.0	58.1	0.191		100.0	100.0						
4[2/]	Concentrate	72.9	58.0	0.158	12.8	72.3	58.4	2.0	2.0		1.0		0.5
	Middling	21.6	59.5	0.263		22.0	28.9						
	Tailing	5.5	60.5	0.450		5.7	12.7						
	Composite	100.0	58.5	0.197		100.0	100.0						
5[2/]	Concentrate	51.2	58.5	0.15	11.4	50.7	41.6	2.0	2.0				1.0
	Middling	16.9	61.4	0.18		17.9	16.2						
	Tailing	5.1	60.9	0.33		5.3	9.2						
	Slimes	26.7	57.8	0.23		26.1	33.0			2.0*	1.0*	0.5	
	Composite	100.0	59.0	0.18		100.0	100.0						
6[2/]	Concentrate	58.1	58.9	0.16	11.7	57.8	49.8	1.0			0.5		1.0
	Middling	26.0	60.3	0.18		26.5	25.1						
	Tailing	14.7	61.2	0.26		15.2	20.3						
	Slimes	1.2	24.3	0.73		0.5	4.8	2.0*			0.5*	0.25	
	Composite	100.0	59.2	0.19		100.0	100.0						
7[2/]	Concentrate	66.4	58.5	0.17	11.3	66.2	58.2	1.0			0.5		0.5
	Middling	24.2	60.0	0.20		24.8	24.7						
	Tailing	8.1	60.9	0.28		8.4	11.9						
	Slime	1.3	27.5	0.76		0.6	5.2	3.0*			0.5*	0.25	
	Composite	100.0	58.7	0.19		100.0	100.0						

* Reagents added to grind.

1/ 15 min. grind time.
2/ 20 min. grind time.

TABLE 2A - Crest jig concentrate, summary of flotation test results

Test No.	Product	Weight, percent	Analyses, percent Fe	P	SiO_2	Dist., percent Fe	P	Reagents, lb/ton of feed NaOH	$Na_4P_2O_7$	Na_2SiO_3	Tapioca	$CaCl_2 \cdot 2H_2O$	FA-2
1[1]	Concentrate	75.1	63.6	0.15	7.4	78.7	67.7	4.0			1.5	0.5	0.5
	Middling	15.6	58.4	0.20		15.0	18.5						
	Tailing	9.3	41.4	0.25		6.3	13.8						
	Composite	100.0	60.7	0.17		100.0	100.0						
2[1]	Concentrate	84.9	62.2	0.17	8.1	89.3	84.7	2.0			1.0	0.5	0.5
	Middling	9.9	44.2	0.17		7.4	10.0						
	Tailing	3.3	35.3	0.12		2.0	2.4						
	Slimes	1.9	41.0	0.24		1.3	2.9	2.0*		2.0*	0.5		
	Composite	100.0	59.2	0.17		100.0	100.0						
3[1]	Concentrate	86.0	61.8	0.17	8.2	88.6	86.4	2.0			1.25	0.5	0.5
	Middling	8.5	55.4	0.17		7.8	8.3						
	Tailing	3.2	36.5	0.10		2.0	1.8						
	Slimes	2.3	41.2	0.28		1.6	3.5	2.0*		2.0*	0.25		
	Composite	100.0	60.0	0.17		100.0	100.0						
4[2]	Concentrate	73.5	62.3	0.145	6.5	77.3	57.9	2.0			1.25		0.5
	Middling	14.6	57.4	0.230		14.2	21.1						
	Tailing	6.4	44.0	0.315		4.7	10.8						
	Slimes	5.5	40.8	0.352		3.8	10.2	2.0*		3.0*	0.25		
	Composite	100.0	59.2	0.185		100.0	100.0						
5[2]	Concentrate	61.5	63.7	0.10	6.2	66.5	34.1	2.5			1.25		0.5
	Middling	23.3	57.4	0.20		22.7	25.8						
	Tailing	8.2	45.8	0.36		6.4	15.9						
	Slimes	7.0	37.5	0.63		4.4	24.2	2.0*	0.75*		0.25		
	Composite	100.0	59.0	0.18		100.0	100.0						
6[2]	Concentrate	55.3	62.1	0.10	7.6	58.9	30.9	2.5	1.0		1.25		0.5
	Middling	22.8	58.9	0.17		23.1	21.9	1.0					
	Tailing	12.8	53.8	0.28		11.8	20.2						
	Slimes	9.1	40.0	0.53		6.2	27.0	2.0*	0.75*		0.75	0.25	
	Composite	100.0	58.3	0.18		100.0	100.0						
7[2]	Concentrate	28.2	57.2	0.17	12.0	27.7	24.0	2.5	2.0				0.5
	Middling	25.0	59.6	0.17		25.6	21.0						
	Tailing	43.2	59.8	0.19		44.4	41.0						
	Slimes	3.6	37.0	0.78		2.3	14.0	2.0*	0.5*		0.25		
	Composite	100.0	58.2	0.20		100.0	100.0						

See footnotes at end of table.

TABLE 2A- Crest jig concentrate, Summary of flotation results (Continued)

Test No.	Product	Weight, percent	Analyses, percent Fe	P	SiO_2	Dist., percent Fe	P	Reagents, lb/ton of feed NaOH	$Na_4P_2O_7$	Na_2SiO_3	Tapioca	Versene 100	FA-2
8[2]	Concentrate	47.1	64.3	0.091	5.5	51.4	24.3	3.5			1.25		0.5
	Middling	20.0	59.8	0.152		20.3	16.9						
	Tailing	11.3	47.1	0.31		9.0	19.8						
	Slimes	21.6	52.8	0.32		19.3	39.0	1.0*	1.0*		0.5		
	Composite	100.0	59.0	0.177		100.0	100.0						
9[2]	Concentrate	28.8	60.8	0.14	8.6	29.7	22.8	4.0			1.25		0.5
	Middling 1	25.9	61.0	0.15		26.8	22.3						
	Middling 2	22.8	60.2	0.17		23.3	22.3						
	Tailing	17.4	55.9	0.24		16.5	24.0						
	Slimes	5.1	42.3	0.30		3.7	8.6		1.0*		0.5		
	Composite	100.0	59.0	0.18		100.0	100.0						
10[2]	Concentrate	45.8	61.9	0.14	8.1	48.0	35.6	4.0			1.25		0.5[3]
	Middling 1	27.7	60.0	0.16		28.2	24.4						
	Middling 2	14.0	58.0	0.22		13.7	17.2						
	Tailing	6.6	50.6	0.34		5.7	12.2						
	Slimes	5.9	44.5	0.32		4.4	10.6		1.0*		0.25		
	Composite	100.0	59.0	0.18		100.0	100.0						
11[2]	Concentrate	63.6	63.3	0.10	6.3	68.4	36.4	2.5			1.25		0.5[3]
	Middling	18.5	58.6	0.16		18.4	17.0						
	Tailing	11.6	42.8	0.40		8.4	26.1						
	Slime	6.3	44.4	0.57		4.8	20.5	2.0	0.5*		0.25		
	Composite	100.0	58.9	0.18		100.0	100.0						
12[2]	Concentrate	57.8	63.9	0.089	5.7	62.7	29.6	2.5			1.25	0.5	0.5
	Middling	21.1	59.6	0.15		21.3	18.6						
	Tailing	16.0	45.6	0.35		12.4	32.6						
	Slimes	5.1	42.1	0.64		3.6	19.2	2.0*	0.5*		0.25		
	Composite	100.0	59.0	0.17		100.0	100.0						

See footnotes at end of table.

TABLE 2A- Crest jig concentrate, Summary of flotation results (Continued)

Test No.	Product	Weight, percent	Analyses, percent: Fe	Analyses, percent: P	Analyses, percent: SiO_2	Dist., percent: Fe	Dist., percent: P	Reagents, lb/ton of feed: NaOH	$Na_4P_2O_7$	Na_2SiO_3	Tapioca	Aero Promoter 825	FA-2
13 2/	Concentrate	56.5	65.0	0.085	5.3	62.0	27.0	2.5			1.75	1.5	0.5
	Middling 1	16.7	62.5	0.118		17.6	11.2	1.0					
	Middling 2	7.2	57.1	0.177		7.0	7.3	1.0					
	Tailing	13.1	39.5	0.446		8.7	32.6						
	Slimes	6.5	43.2	0.596		4.7	21.9	2.0*	0.5*		0.25		
	Composite	100.0	59.2	0.178		100.0	100.0						
14 2/	Concentrate	64.4	61.0	0.123	9.1	66.5	46.7	2.5			1.25	1.5	
	Middling 1	18.4	60.2	0.114		18.8	12.4						
	Middling 2	5.2	58.2	0.198		5.1	5.9						
	Tailing	4.1	51.0	0.445		3.5	10.7						
	Slimes	7.9	45.8	0.523		6.1	24.3	2.0*	0.5*		0.25		
	Composite	100.0	59.1	0.169		100.0	100.0						
15 2/	Concentrate	58.0	64.1	0.102	5.4	63.1	35.5	2.5			1.25	1.0	0.7
	Middling 1	14.8	60.6	0.152		15.2	13.3						
	Middling 2	9.6	56.7	0.213		9.3	12.1						
	Tailing	13.9	43.2	0.383		10.2	31.9						
	Slimes	3.7	34.9	0.313		2.2	7.2	2.0*		3.0*	0.25		
	Composite	100.0	58.9	0.166		100.0	100.0						

* Reagents added to grind.

1/ 15 min. grind.
2/ 20 min. grind.
3/ 0.5 lb/ton $CaCl_2 \cdot 2H_2O$ added to rougher flotation.

APPENDIX II

Table 3A is a summary of data compiled from flotation tests completed on the crude ore-9662 which does not appear in the main body of the report.

TABLE 3A - Crest crude ore-9662, Summary of flotation results 1/

Test No.	Product	Weight, percent	Analysis, percent Fe	SiO₂	P	Dist., percent Fe	P	Reagents, lbs/S. ton feed Na_2SiO_3	NaOH	Tapioca		FA-2	Aero Promoter 825
1	Concentrate	50.2	54.25	13.87	.256	61.7	37.6		2.5	0.5	0.5 2/	1.0	
	Middling 1	13.5	42.41		.368	13.0	14.6		0.5				
	Tails	11.9	24.78		.435	6.7	15.2						
	Slime	24.4	33.71		.457	18.6	32.6	2.5 *	2.0 *	0.5			
	Composite	100.0	44.14		.341	100.0	100.0						
2	Concentrate	50.9	56.48	13.28	.14	65.7	22.1		2.5	1.0	0.5 3/	1.0	
	Middling 1	15.6	41.07		.44	14.6	21.5		1.0				
	Middling 2	7.8	31.70		.59	5.6	14.3		1.5				
	Tails	11.4	21.09		.58	5.5	20.6						
	Slime	14.3	26.36		.48	8.6	21.5	2.0 *	2.0 *	0.5			
	Composite	100.0	43.80		.32	100.0	100.0						
3	Concentrate	53.2	55.50	16.73	.109	68.1	19.5		2.5	1.0	2.0 3/	1.5	
	Middling 1	13.5	44.60		.354	13.9	16.1		1.0				
	Middling 2	7.7	34.12		.563	6.0	14.4		1.5				
	Tails	18.0	20.14		.613	8.4	36.9						
	Slime	7.6	20.55		.509	3.6	13.1	2.0 *	2.0 *	0.5			
	Composite	100.0	43.37		.298	100.0	100.0						
4	Concentrate	57.6	54.47	16.11	.163	71.7	30.0		2.5	1.0		0.75	1.5
	Middling 1	10.6	44.19		.261	10.7	8.9		1.0				
	Middling 2	8.2	35.35		.557	6.6	14.7		1.5				
	Tails	16.4	20.14		.670	7.6	35.2						
	Slime	7.2	20.55		.486	3.4	11.2	2.0 *	2.0 *	0.5			
	Composite	100.0	43.73		.313	100.0	100.0						
5	Concentrate	57.5	54.26	17.52	.132	71.7	23.5		2.5	1.0	1.0 4/	0.75	1.5
	Middling 1	10.3	46.66		.304	11.0	9.6		1.0				
	Middling 2	8.1	34.33		.543	6.4	13.6		1.5				
	Tails	17.2	19.73		.815	7.8	43.4						
	Slime	6.9	19.73		.462	3.1	9.9	2.0 *	2.0 *	0.5			
	Composite	100.0	43.54		.323	100.0	100.0						

See footnotes at end of table.

TABLE 3A - Crest crude ore-9662, Summary of flotation results[1/] (Continued)

Test No.	Product	Weight, percent	Analysis, percent Fe	SiO_2	P	Dist., percent Fe	P	Reagents, lbs/S. ton feed Na_2SiO_3	NaOH	Tapioca	Na_2CO_3	FA-2	Aero Promoter 825
6[2/]	Concentrate	47.5	57.76	13.63	.107	62.7	15.3		2.5	1.0	1.0	1.5	0.25
	Middling 1	12.8	51.39		.247	15.0	9.6		1.0				
	Middling 2	6.2	39.46		.475	5.6	8.7		1.5				
	Tails	24.2	20.76		.707	11.5	51.4						
	Slime	9.3	24.60		.535	5.2	15.0	2.0*	2.0*	0.5			
	Composite	100.0	43.78		.333	100.0	100.0						
7[2/]	Concentrate	46.6	56.53	15.22	.095	60.8	13.4		2.5	1.0	1.0	1.5	1.0
	Middling 1	13.9	50.98		.231	16.4	9.7		1.0				
	Middling 2	8.2	40.49		.463	7.7	11.5		1.5				
	Tails	23.6	21.38		.737	11.6	52.9						
	Slime	7.7	19.94		.529	3.5	12.5	2.0*	2.0*	0.5			
	Composite	100.0	43.34		.329	100.0	100.0						
8[2/]	Concentrate	36.6	56.53	15.38	.106	47.9	11.6		2.5	1.0	1.0	1.5	2.0
	Middling 1	15.1	55.09		.169	19.3	7.8		1.0				
	Middling 2	10.7	49.33		.309	12.2	9.9		1.5				
	Tails	30.2	24.66		.660	17.2	59.6						
	Slime	7.4	19.53		.502	3.4	11.1	2.0*	2.0*	0.5			
	Composite	100.0	43.19		.334	100.0	100.0						
9[2/]	Concentrate	27.0	58.99	13.36	.097	36.8	7.8		2.5	0.5	1.0	1.5	0.75
	Middling 1	17.2	55.91		.173	22.2	9.1		1.0				
	Middling 2	9.4	51.39		.290	11.2	8.2		1.5				
	Middling 3	6.3	42.75		.430	6.2	8.2		1.5				
	Tails	27.5	25.69		.585	16.3	48.6						
	Slime	12.6	25.08		.477	7.3	18.1	2.0*	2.0*	0.5			
	Composite	100.0	43.29		.331	100.0	100.0						
10[2/]	Concentrate	30.1	58.79	11.87	.114	40.6	10.3		2.5	.75	1.0	1.5	0.75
	Middling 1	19.5	54.68		.182	24.4	10.6		1.0				
	Middling 2	10.7	48.71		.307	11.9	10.0		1.5				
	Middling 3	6.0	41.49		.515	5.7	9.4		1.5				
	Tails	28.6	23.33		.609	15.3	52.7						
	Slime	5.1	18.29		.450	2.1	7.0	2.0*	2.0*	0.5			
	Composite	100.0	43.66		.330	100.0	100.0						

See footnotes at end of table

TABLE 3A - Crest crude ore-9662, Summary of flotation results[1] (Continued)

Test No.	Product	Weight, percent	Analysis, percent			Dist., percent		Reagents, lbs/S. ton feed					
			Fe	SiO_2	P	Fe	P	Na_2SiO_3	NaOH	Tapioca	Na_2CO_3	FA-2	Aero Promoter 825
11[5]	Concentrate	32.2	58.58	13.28	.093	43.5	9.0		2.5	1.0	1.0	2.0	0.75
	Middling 1	19.9	56.11		.151	25.8	9.0		1.0				
	Middling 2	8.8	49.13		.326	10.0	8.6		1.5				
	Middling 3	4.8	38.23		.498	4.2	7.2		1.5				
	Tails	28.1	21.79		.677	14.1	56.9						
	Slime	6.2	17.06		.493	2.4	9.3	2.0*	2.0*	0.5			
	Composite	100.0	43.37		.334	100.0	100.0						
12[5]	Concentrate	47.5	56.94	14.68	.091	62.4	12.9		2.5	1.0	1.0	2.0	
	Middling 1	13.0	52.83		.146	15.8	5.7		1.0				
	Middling 2	6.4	44.19		.583	6.5	11.1		1.5				
	Tails	26.4	20.14		.752	12.3	59.8						
	Slime	6.7	19.22		.529	3.0	10.5	2.0*	2.0*	0.5			
	Composite	100.0	43.36		.333	100.0	100.0						

1/ Ore given a 20 minute grind for each test.
2/ $CaCl_2 \cdot 2H_2O$
3/ Tetrasodium salt of ethylenediamine tetraacetic acid.
4/ Na_2CO_3
5/ Subsequent to desliming, the pulp conditioned at 50 to 60 percent solids.

* Reagents added to grind.