Publication No. 02-179-246

DEVELOPMENT OF REAGENT SCHEMES FOR REDUCING MgO CONTENT IN THE FLOTATION CONCENTRATE FOR PROCESSING FLORIDA'S HIGH-DOLOMITE PHOSPHATE DEPOSITS

FINAL REPORT

Prepared by

FLORIDA INDUSTRIAL AND PHOSPHATE RESEARCH INSTITUTE

with the collaboration of

CHINA BLUESTAR LEHIGH ENGINEERING CORPORATION

and

UNIVERSITY OF UTAH

under a grant sponsored by

FIPR
Florida Industrial and Phosphate Research Institute

September 2012

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FIPR Contract Number: 08-02-179

September 2012

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PERSPECTIVE

The rationale behind this project is a 1989 FIPR study of the future phosphate resources in Florida. Analytical results averaged on numerous core samples show that MgO will be a problem with both the pebble and concentrate as phosphate mining moves farther south in the Bone Valley deposit. Since the ratio of concentrate to pebble will become higher and higher in the future, reducing MgO content in the concentrate by a small margin would allow blending of a large portion of the high-dolomite pebble. A rough estimate based on the above data indicated that about 90% of the high-dolomite pebbles could be used, if the MgO content in the concentrate is reduced by 30%.

The current project was designed to develop techniques to reduce MgO content in the concentrate with minor modifications or no change to the current processing flowsheet. The ideal way of doing this is to depress dolomite while floating phosphate, but the following 6 approaches were tested under this project: (1) adding a dolomite depressant in the rougher flotation step; (2) dolomite flotation on the rougher concentrate with and without grinding; (3) dolomite flotation on the cleaner concentrate with and without grinding; (4) scrubbing the flotation feed; (5) scrubbing the rougher concentrate; and (6) scrubbing the cleaner concentrate.

Successful methods include adding a dolomite depressant in the rougher flotation, dolomite flotation on the cleaner concentrate with grinding, and scrubbing the cleaner concentrate in quartz sand. These techniques could reduce MgO content in the final concentrate by 20-40%. The flotation process could achieve a concentrate with the lowest MgO content, but it is the most expensive approach. Adding a dolomite depressant is inexpensive and easy, but the effect is limited. Overall, scrubbing may be the most promising technology for this purpose.

ACKNOWLEDGEMENTS

Co-funding from CF Industries and the Mosaic Company is highly appreciated. Both of these companies also made special effort to drill and wash core samples in order to obtain the high-dolomite samples for this project. Special thanks are due to the following individuals for their strong support and technical input: Bill Stewart, Chaucer Hwang and David Gossett of CF; and Paul Kucera, Charles Guan, Glen Oswald and Bruce Bodine of Mosaic. The technical guidance provided by the FIPR Beneficiation Technical Advisory Committee is particularly acknowledged.

ABSTRACT

A 1989 FIPR characterization study of the future phosphate resources in Florida showed that MgO would be a problem with both the pebble and concentrate as phosphate mining moves deeper. Since the ratio of concentrate to pebble will become higher and higher in the future, reducing MgO content in the concentrate by a small margin would allow blending of a large portion of the high-dolomite pebble. This research was conducted based on that logic.

The following six approaches were tested for reducing MgO content in the flotation concentrate: (1) Adding a dolomite depressant in the rougher flotation step; (2) Dolomite flotation on the rougher concentrate with and without grinding; (3) Dolomite flotation on the cleaner concentrate with and without grinding; (4) Scrubbing the flotation feed; (5) Scrubbing the rougher concentrate; (6) Scrubbing the cleaner concentrate. Successful methods include adding a dolomite depressant in the rougher flotation, dolomite flotation on the cleaner concentrate with grinding, and scrubbing the cleaner concentrate in quartz sand. These techniques could reduce MgO content in the final concentrate by 20-40%. The flotation process could achieve a concentrate with the lowest MgO content, but it is the most expensive approach. Adding a dolomite is inexpensive and easy, but the effect is limited. Overall, scrubbing may be the most promising technology for this purpose.

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EXECUTIVE SUMMARY

The objective of this project is to conduct laboratory flotation tests for developing reagent schemes to reduce MgO content in the flotation concentrate from processing high-dolomite phosphate deposits in Florida.

In 1989, FIPR conducted a characterization study of the future Florida phosphate resources. Detailed analyses of numerous core samples showed the following: (1) the MgO concentration in the upper zone would not pose a major problem for both the pebble and concentrate; (2) the pebble fraction in the lower zone is smaller but contains higher dolomite, averaging 6.19% MgO; and (3) the concentrate in the lower zone averages 1.2% MgO. These results suggest that MgO will be a problem with both the pebble and concentrate as phosphate mining moves into the lower-zone areas.

Since the ratio of concentrate to pebble will be higher in the future, reducing MgO content in the concentrate by a small margin would allow blending of a large portion of the high-dolomite pebble. FIPR proposes to develop techniques to reduce MgO content in the concentrate with little or no change to the current processing flowsheet. This objective may be achieved by focusing on the fatty acid flotation step. The ideal way of doing this is to depress dolomite while floating phosphate. This research program progressed with the close guidance of the FIPR Beneficiation Technical Advisory Committee and the two participating companies. As a result, the actual work deviated from the original proposal quite substantially in the following three aspects: (1) addition of scrubbing testing, (2) determination of Fe and Al distribution when a dolomite depressant is added, and (3) extensive testing of different dolomite flotation flowsheets.

SAMPLE COLLECTION AND CHARACTERIZATION

Both CF Industries and Mosaic made special efforts to drill core samples from their high-dolomite deposits. These cores were washed and sized using the standard lab procedures to produce the flotation samples for this project. CF produced one composite float feed of about 1000 dry pounds within the size range of 20 × 150 mesh, analyzing 7.72% P_2O_5, 0.48% MgO and 73.92% Insol. Mosaic provided two composite float samples each weighing about 500 pounds, with Sample #1 analyzing 6.53% P_2O_5, 0.59% MgO and 77.38% Insol, and Sample #2 analyzing 5.13% P_2O_5, 0.31% MgO and 82.78% Insol.

Mineral liberation analysis, particularly a dolomite liberation study, is critical to this project, because it determines the ultimate limit that any flotation reagent system could achieve in reducing the MgO content in the final concentrate. Mineral liberation studies were carried out in both the Lehigh lab in China and at the University of Utah. High-power microscopic pictures of both uncrushed and crushed particles showed impregnated dolomite and cementation of phosphate with gangue minerals. The samples were also examined by XRD for mineral identification and by high-resolution X-ray

micro CT (HRXMT) for liberation analysis. The liberation-limited grade/recovery curves constructed from 3D liberation spectra indicated that only about half of the dolomite could be separated by reverse flotation.

LABORATORY TESTS TO EVALUATE DOLOMITE DEPRESSANTS

These tests were for evaluating dolomite depressants while phosphate was floated using the corresponding fatty acid from each mine. Over 20 reagents were tested as a potential dolomite depressant. Some of these depressants actually increased MgO content in the rougher concentrate, some showed no effect, while the others lowered the MgO content to some degree. The most effective dolomite depressants were found to be carboxymethylcellulose, soluble starch, and polyacrylamide (PAM).

DOLOMITE FLOTATION WITH AND WITHOUT GRINDING

Dolomite depressant screening results indicate that adding a dolomite depressant alone in the fatty acid flotation step can lower the MgO content to some extent, but not to a degree of great success. This limitation may be attributed to non-liberated dolomite in the coarser fraction of the flotation feed. Under this task, several approaches were evaluated to float the dolomite.

Flotation without Grinding

Two dolomite collectors were evaluated for removing dolomite from both rougher concentrate and cleaner concentrate without grinding. Results showed that MgO reduction in the final concentrate was negligible when the rougher concentrate was subject to dolomite flotation. Flotation of the cleaner concentrate was more effective but not significant.

Grinding of Flotation Feed Followed by Flotation

Sizing analyses of the flotation feeds show that a majority of the dolomite is concentrated in the small amount of +0.5 mm fractions. For example, the +0.5 mm fraction accounts for 8.62% of the CF feed, and contains 1.46% MgO, or 28.28%, of the total MgO; the corresponding numbers for the Mosaic feed #1 are 7.55%, 2.14% and 31.33%. Grinding the flotation feed naturally makes some sense, but the results are not encouraging because of the significant loss of P_2O_5. This approach is therefore not recommended.

Grinding of Rougher Concentrate Followed by Flotation

This approach achieved a small reduction of MgO in the final concentrate, but with significant sacrifice of phosphate recovery.

Grinding of the Final Concentrate Followed by Flotation

The concentrate from the double float process was ground, followed by a dolomite flotation step to further reduce MgO content. This method obtained a final concentrate with the lowest MgO content, but phosphate loss was also appreciable.

SCRUBBING TESTS

Direct Scrubbing

After acid washing, the rougher concentrate was scrubbed and deslimed three times, which showed appreciable MgO reduction in the final concentrate. Dolomite in the slimes accounted for 28.32% of the total dolomite in the feed.

Scrubbing with Hard Media

Encouraged by the above scrubbing test, more scrubbing experiments were conducted to study the effect of scrubbing media, steel balls and quartz granules, on dolomite removal. The diameter of steel balls used was 0.8 mm. The scrubber was made of stainless steel with double stainless steel impellers. This type of scrubber can handle high-solids scrubbing, thus requiring a large sample load.

Scrubbing tests with steel balls on the original feed, rougher concentrate and final concentrate were conducted. Scrubbing of the final concentrate resulted in the highest MgO reduction and the lowest loss of phosphate.

Scrubbing tests were also carried out with quartz granules on the rougher concentrate and final concentrate. Again, the best results were achieved in scrubbing the final concentrate. Overall, quartz was a better scrubbing media than steel balls in this application.

DETERMINATION OF IRON AND ALUMINUM DISTRIBUTION

By request of a participating company in the project, the effects of dolomite depressants on distributions of Fe_2O_3 and Al_2O_3 were analyzed. Results indicated that most of the Fe and Al reported to the rougher concentrate or the final concentrate, regardless of what depressant was used.

SCREENING OF PHOSPHATE DEPRESSANTS

Numerous phosphate depressants were tested, including acidic, neutral and alkaline reagents. In these tests the cleaner concentrate was ground at 60% solids for 9 minutes to 45.22% passing 200 mesh, followed by dolomite flotation at 30% solids. The most effective phosphate depressant was found to be phosphoric acid, giving both high grade and recovery.

PRELIMINARY ECONOMIC ANALYSIS

Based on the extensive laboratory comparative tests, three approaches were selected as potential dolomite removal methods. Preliminary economic analyses of these methods are shown below.

Addition of Dolomite Depressant

In this process, the flotation feed slurry at about 70% solids was first conditioned with a pH modifier and phosphate collector, as is practiced currently in Florida. The dolomite depressant, a polyacrylamide, was added prior to dilution of the slurry to 30% solids followed by flotation. The dosage of the depressant was about one kilogram per ton of feed. This process could reduce MgO content in the concentrate to about 0.81%.

Reverse Flotation of Amine Concentrate

In this process, the final concentrate from the Crago process was dewatered to about 60% solids and ground to 45.22% passing 200 mesh. The ground feed was conditioned at 30% solids with sulfuric acid (2.75 kg/ton feed) and the dolomite collector USPA-31 (1 kg/ton feed). In this manner, MgO content in the final product can be reduced to about 0.7%.

Scrubbing in Quartz Sand Media

The amine concentrate from the Crago process was dewatered. The scrubbing media, quartz sand, was then added at a quartz-to-concentrate ratio of 1:2 by weight. The mixture was adjusted to about 60% solids and scrubbed for 40 minutes in a specially designed scrubber at a speed of 1500 RPM. After scrubbing, the final product contained 0.81% MgO.

Table 1 summarizes the performance parameters of the above-discussed three approaches.

Table 1. Performance Comparison of the Three MgO Removal Methods – CF.

Process	Product	Yield (%)	Grade (%)		Recovery (%)
			BPL	MgO	
Dolomite Depression	Concentrate	22.12	67.96	0.81	87.37
	Total Tails	77.88	2.78	0.36	
	Feed	100.00	17.20	0.46	
Dolomite Flotation	Concentrate	19.09	65.86	0.72	74.85
	Total Tails	80.91	5.21	0.45	
	Feed	100.00	16.79	0.50	
Scrubbing in Quartz Sand	Concentrate	21.58	67.11	0.81	86.30
	Total Tails	78.42	2.93	0.43	
	Feed	100.00	16.78	0.51	

Compared with the standard Crago process, the only extra cost for the dolomite depression process was the addition of one kilogram of polyacrylamide per ton of flotation feed.

Dolomite flotation of the Crago concentrate adds a grinding operation and associated costs, the dolomite flotation and scavenging steps, sulfuric acid (2.75 kilograms per ton of feed) for pH adjustment and phosphate depression, and the dolomite collector (USPA-31 at 1.0 kg/ton).

The scrubbing process includes two scrubbing steps and two desliming operations, plus the quartz sand scrubbing media.

A rough cost estimate for the three processes is shown in Table 2.

Table 2. Capital and Operating Cost Comparison of the Three Processes.

Process	Capital Cost ($/Ton)	Operating Cost ($/Ton)	Maintenance Fee ($/Ton)
Dolomite Depression	None	4.75-6.35	None
Dolomite Flotation	23.8-31.7	15.8	
Scrubbing	12.7-15.8	3.2-4.7	

The dolomite depression process is the simplest method, and only adds an extra cost for the depressant at 1.0 kg/ton, which translates to a cost of $5.4 per ton of product at a price of $1,190 per ton for the depressant.

The dolomite flotation approach involves capital investment for both grinding and flotation ($23.8-31.7 per ton of product) as well as operating and maintenance costs ($15.8 per ton of product).

Although the scrubbing process requires capital investment ($12.7-15.8 per ton), its operating cost is low ($1.6-3.2 per ton).

Among the three approaches, the dolomite flotation process gave the lowest MgO content in the final concentrate, but reduced phosphate recovery by over 10% with high capital and operating costs. Unless it is absolutely necessary to achieve a concentrate with 0.7% or less MgO, the dolomite flotation method is not recommended. The scrubbing process offers the following three major advantages: (1) it does not require any chemical; (2) the quartz sand used as scrubbing media is inexpensive and reusable; and (3) the operating cost is low. Therefore, the scrubbing technique is strongly recommended for further extensive testing.

INTRODUCTION

The United States is one of the major phosphate rock producers of the world, while Florida is the largest producer in America, accounting for roughly a quarter of the world's production.

With the depletion of the higher-grade, easy-to-process Bone Valley deposits, the central Florida phosphate industry has moved into the lower-grade, high-dolomite ore bodies from the Southern Extension. The phosphate deposits in the Southern Extension may be divided into two zones: an upper zone and a lower zone. The upper zone is readily processable using the current technology, but the lower zone is highly contaminated by dolomite. Geological and mineralogical statistics show that about 50% of the future phosphate resource would be wasted if the lower zone is bypassed in mining, and that about 13% of the resource would be wasted if the dolomitic pebbles in the lower zone are discarded.

In a study by El-Shall and Bogan (1994a), FIPR conducted a comparative evaluation on five seemingly promising flotation processes for separating dolomite from phosphate, utilizing the same flotation feed. Two of the processes failed to produce a concentrate of less than 1% MgO, and all the processes gave very poor overall phosphate recovery, ranging from 30-60%.

In 1989, FIPR conducted a comprehensive characterization study of the future phosphate resources in Florida (El-Shall and Bogan 1994b). Tables 3 and 4 show some analytical results on numerous core samples.

Table 3. Average Weight Distribution and Assay of Florida Future Phosphate Deposit.

Zone	Product	Wt. %	% P_2O_5	% MgO	% Insol
Upper Zone (33% of the total thickness)	Pebble	11	27.8	0.52	12.0
	Feed	69	7.0	0.12	75.9
	Clay	20	8.7	1.90	46.1
Lower Zone (67%)	Pebble	8	17.0	6.19	13.9
	Feed	58	7.0	0.67	29.1
	Clay	34	2.2	11.50	69.3

Table 4. Average Chemical Analyses (Wt. %) of Flotation Concentrates.

Zone	P_2O_5	CaO	MgO	Fe_2O_3	Al_2O_3	Na_2O	F	Insol
Upper	31.9	46.6	0.43	1.4	0.85	0.62	3.7	3.6
Lower	28.6	44.8	1.21	1.6	0.70	0.69	3.4	4.8

From these data, we can draw the following significant conclusions for developing processes for removing dolomite:

1. The MgO concentration in the upper zone would not pose a major problem for both the pebble and concentrate.
2. The pebble fraction in the lower zone is smaller but contains higher dolomite, averaging 6.19 % MgO.
3. The concentrate in the lower zone would average 1.2% MgO.

These results suggest that MgO will be a problem with both the pebble and concentrate as phosphate mining moves deeper. Since the ratio of concentrate to pebble will be higher in the future, reducing MgO content in the concentrate by a small margin would allow blending of a large portion of the high-dolomite pebble.

Therefore, FIPR initiated this in-house project to develop reagent systems to reduce MgO content in the concentrate with little or no change to the current processing flowsheet, thus allowing blending of low-grade, dolomitic pebbles.

The project includes seven tasks, which are described briefly below.

TASK 1. SAMPLE COLLECTION AND CHARACTERIZATION

Three high-dolomite flotation feeds, 500 lbs. each, were collected from two operating mines in central Florida. Detailed characterizations were conducted on these samples, including chemical analysis for MgO, CaO, P_2O_5, Fe_2O_3, Al_2O_3 and Insol, size distribution, mineralogical analysis, and dolomite liberation analysis.

TASK 2. LAB TESTS TO EVALUATE DOLOMITE DEPRESSANTS

Dolomite depressants were evaluated while phosphate was floated using the corresponding fatty acid from each mine. Dolomite depressants tested include sodium silicate, starch combined with carboxylic acids, carboxymethylcellulose, citric acid, naphthyl anthyl sulfonates, humic acid, nonylphenyltetraglycol ester, certain cations, etc.. After an initial screening, the most promising depressants were further tested to optimize major parameters, such as pH, conditioning solids and time, collector and depressant dosages, and flotation time.

TASK 3. LAB TESTS TO EVALUATE PHOSPHATE DEPRESSANTS

In this task, phosphate depressants were evaluated while dolomite was floated using the FIPR dolomite collector USPA-31 (Gao and others 2003). The following phosphate depressants were tested: hydrofluosilicic acid, orthophosphoric acid, phosphoric acid, diphosphonic acid, sulfuric acid, aluminum sulfate and tartaric acid, dipotassium hydrogen phosphate, sodium tripolyphosphate, alizarin red S (ARS), ethoxylated alkyl phenol, and starch (Zhang and others 2008).

TASK 4. EXPLORATORY FLOWSHEET DEVELOPMENT

Test results indicated that adding dolomite depressant alone in the fatty acid flotation step could lower the MgO content to some extent, but not to a degree of great success. This limitation may be attributed to non-liberated dolomite in the coarser fraction of the flotation feed. Therefore numerous approaches were evaluated to increase the odds of success. These approaches included the following:

1. Grinding the flotation feed followed by the Crago process.
2. Grinding the rougher concentrate in the Crago process.
3. Adding different reagents in the deoiling step.
4. Direct dolomite flotation of the feed.
5. Dolomite flotation of the final concentrate without grinding.
6. Dolomite flotation of the rougher concentrate followed by amine flotation.
7. Grinding the final concentrate followed by dolomite flotation.
8. Grinding the final concentrate followed by dolomite flotation with addition of a phosphate depressant.

Since the last approach proved to be the most effective, further parametric tests were conducted to optimize both the grinding and flotation parameters.

TASK 5. SCRUBBING TESTING

Extensive scrubbing testing was conducted since this method is inexpensive and some initial experiments achieved promising results. These tests included direct scrubbing of rougher concentrate, scrubbing of flotation feed with steel balls or quartz granules, scrubbing of rougher concentrate with steel balls or quartz granules, and scrubbing of the final concentrate with steel balls or quartz granules.

TASK 6. DETERMINATION OF IRON AND ALUMINUM DISTRIBUTION

By request of a participating company in the project, the effects of dolomite depressants on distributions of Fe_2O_3 and Al_2O_3 were analyzed.

TASK 7. PRELIMINARY ECONOMIC ANALYSIS

Based on the extensive laboratory comparative tests, three approaches were selected as potential dolomite removal methods. They included addition of a dolomite depressant in the fatty acid flotation step, dolomite flotation of the amine concentrate after grinding, and scrubbing of amine concentrate. Both capital and operating costs were estimated for the three selected systems.

SAMPLE PREPARATION AND CHARACTERIZATION

SAMPLE COLLECTION AND SHIPPING

Both CF Industries and Mosaic made special efforts to drill core samples from their high-dolomite deposits. These cores were washed and sized using the standard lab procedures to produce the flotation samples for this project.

A size analysis of the CF matrix is shown in Table 5.

Table 5. Size Distribution of the CF Phosphate Matrix.

Size (Mesh) Range	% Wt.
+½	0.03
½ × 3	0.24
3 × 16	6.97
16 × 20	1.70
20 × 50	56.65
-150	34.41

CF produced one composite float feed of about 1000 dry pounds within the size range of 20 × 150 mesh. This sample was shipped wet and received by Lehigh on May 7, 2007.

Mosaic provided two composite float samples each weighing about 500 pounds, generated by washing multiple cores from their Ona reserve. These samples arrived at the Lehigh lab on June 29, 2009.

The project was officially started on August 1, 2009.

SAMPLE PREPARATION

In the Lehigh mineral processing lab, each sample was well mixed again, a two-kilogram sample was taken for chemical and mineralogical analyses, and the remaining samples were split evenly, with one part used for lab tests and the other half stored for future use. The entire sample preparation flowsheet is shown in Figure 1.

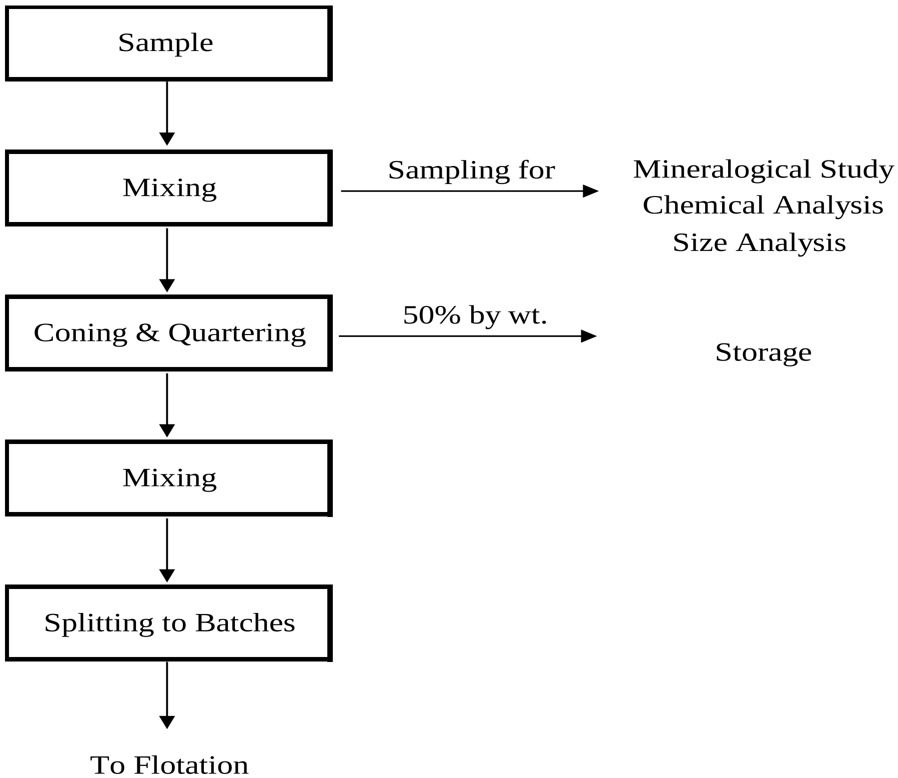


Figure 1. Sample Preparation Chart.

CHEMICAL AND SIZE ANALYSES

Tables 6 and 7 show chemical analyses of the three flotation feed samples, and corresponding sizing analysis results are listed in Tables 8-10.

Table 6. Chemical Analysis of the CF Feed.

Sample	Analysis, %			
	P_2O_5	BPL	MgO	Insol
CF Feed	7.72	16.87	0.48	73.92

Table 7. Chemical Analysis of the Mosaic Feed.

Sample	Analysis, %			
	P_2O_5	BPL	MgO	Insol
Mosaic #1	6.53	14.27	0.59	77.38
Mosaic #2	5.13	11.21	0.31	82.78

Table 8. Size Distribution of the CF Feed.

Sieve Fraction	Wt. (%)	Analysis (%)				Distribution (%)		
		P_2O_5	BPL	MgO	A.I.	BPL	MgO	A.I.
+0.5 mm	8.62	16.96	37.06	1.46	42.42	18.81	28.28	4.91
-0.5 + 0.3 mm	21.00	9.78	21.37	0.54	68.26	26.42	25.48	19.25
-0.3 + 0.16 mm	61.35	6.08	13.28	0.25	80.33	47.99	34.47	66.18
-0.16 mm	9.03	5.83	12.74	0.58	79.65	6.77	11.77	9.66
Total	100.00	7.77	16.98	0.45	74.47	100.00	100.00	100.00

Table 9. Size Distribution of the Mosaic #1 Feed.

Sieve Fraction	Wt. (%)	Analysis (%)				Distribution (%)		
		P_2O_5	BPL	MgO	A.I.	BPL	MgO	A.I.
+0.5 mm	7.55	13.75	30.04	2.14	47.43	15.87	31.33	4.62
-0.5 + 0.3 mm	23.94	7.48	16.34	0.53	74.16	27.38	24.60	22.90
-0.3 + 0.16 mm	58.15	5.24	11.45	0.30	82.71	46.59	33.83	62.03
-0.16 mm	10.36	6.41	14.01	0.51	78.25	10.15	10.24	10.46
Total	100.00	6.54	14.29	0.52	77.54	100.00	100.00	100.00

Table 10. Size Distribution of the Mosaic #2 Feed.

Sieve Fraction	Wt. (%)	Analysis (%)				Distribution (%)		
		P_2O_5	BPL	MgO	A.I.	BPL	MgO	A.I.
+0.5 mm	3.74	13.90	30.37	1.75	48.53	9.94	22.32	2.19
-0.5 + 0.3 mm	11.83	7.35	16.06	0.41	75.35	16.62	16.54	10.78
-0.3 + 0.16 mm	69.26	4.22	9.22	0.18	86.50	55.87	42.51	72.45
-0.16 mm	15.17	6.06	13.24	0.36	79.45	17.57	18.62	14.58
Total	100.00	5.23	11.43	0.29	82.69	100.00	100.00	100.00

MINERALOGICAL ANALYSIS

The deslimed flotation feeds contain particles of below 1 mm in size, showing the following colors: white, black, brown, and red. Polarizing microscopic analysis identified the major minerals quartz, francolite and dolomite, with minor amounts of feldspar and iron oxide. Detailed mineral compositions of the three samples are shown in Table 11.

Table 11. Mineralogical Compositions (Wt. %) of Test Samples.

Sample	Francolite	Dolomite	Quartz	Feldspar	Iron Oxide	Others
CF	18	3	75	1	1	1
Mosaic #1	15	3	78	1	1	1
Mosaic #2	12	2	82	1	1	1

Francolite Structures

The phosphate (francolite) in the test samples existed in the following five structures:

1. Siliceous rock, consisting of francolite cemented with fine quartz particles. In this structure, cemented particles accounted for 70-90% of the rock.
2. Siliceous pellet rock, composed of cemented phosphate rock with a brown color due to iron contamination, and granules of francolite, quartz and feldspar.
3. Granule rock: mainly oolitic-shape francolite granules ranging from 0.2-0.8 mm in size, cemented with quartz crumbs inside, impregnated with some -0.02 mm carbonate particles, and sometimes coated by carbonates.
4. Bulk rock: all francolite with three different colors, yellowish brown, black or opaque.
5. Bio-formation fragments: these were mainly apatite with bunchy or radial shapes, having some features of microorganism structure such as animal teeth.

With the exception of the bio-formation fragments, the above-discussed phosphate rock types all contained impregnated quartz particles of about 0.02 mm in size and carbonate particles of -0.02 mm. This type of carbonate impregnation will have a pronounced effect on MgO content in the final concentrate.

Carbonate Structures

There were three types of carbonate minerals in the samples, as discussed below.

1. Clayey dolomite: consisting of mainly dolomite in fine aggregates, colorless with some showing brownish yellow or gray due to iron or carbon

contaminations, sometimes associated with small amounts of fine silica or francolite.

2. Silica-cemented dolomite: composed of dolomite cemented with fine quartz particles and francolite granules, accounting for more than 70% of the dolomite in the test samples.
3. Sandy dolomite: fine dolomite particle aggregates cemented with various fine mineral particles such as quartz and francolite, with quartz being isometric particles ranging from 0.1 to 0.2 mm and francolite being homogeneous spherical particles of around 0.2 mm in size.

Quartz Structure

The quartz rock was composed of quartz granules inlayed in each other, while the sandy silica included crumbs of quartz.

MINERAL LIBERATION ANALYSIS

Mineral liberation analysis, particularly a dolomite liberation study, was critical to this project, because it determined the ultimate limit that any flotation reagent system could achieve in reducing the MgO content in the final concentrate. Mineral liberation studies were carried out in both the Lehigh lab and at the University of Utah.

THE LEHIGH INVESTIGATION

The flotation feed samples were screened into different size fractions, with each fraction measured for francolite liberation; the results are shown in Table 12.

Table 12. Monomer Liberation Measurements.

Size (mm)	Francolite Liberation Degree (%)		
	CF	Mosaic 1#	Mosaic 2#
+0.5	78	85	83
-0.5~+0.3	83	≥90	≥90
-0.3~+0.16	≥90	≥90	≥90
-0.16	≥90	≥90	≥90

These results show that liberation extent in the fine fractions did not vary much, since, in actual measurements, when phosphate content in a particle was over 80% this particle was considered to be francolite monomer. However, fine dolomite particles were impregnated in phosphate, which could be observed under the microscope after the phosphate particles were crushed. This type of dolomite was hard to liberate even with fine grinding.

Table 13 shows the chemical analysis of a phosphate particle.

Table 13. Chemical Analysis of a Phosphate Particle.

Component	Content (%)
P_2O_5	29.88
MgO	0.78
Insol	6.83

Figures 2-8 are microscopic photographs of selected samples. Normal petrographic microscope photos of the "pure" phosphate and dolomite particles indicated that they were basically monomers, as shown in Figures 3-5. However, high-power microscopic photos of both uncrushed and crushed particles (Figures 6-8) show impregnated dolomite and cementation of phosphate with gangue minerals.

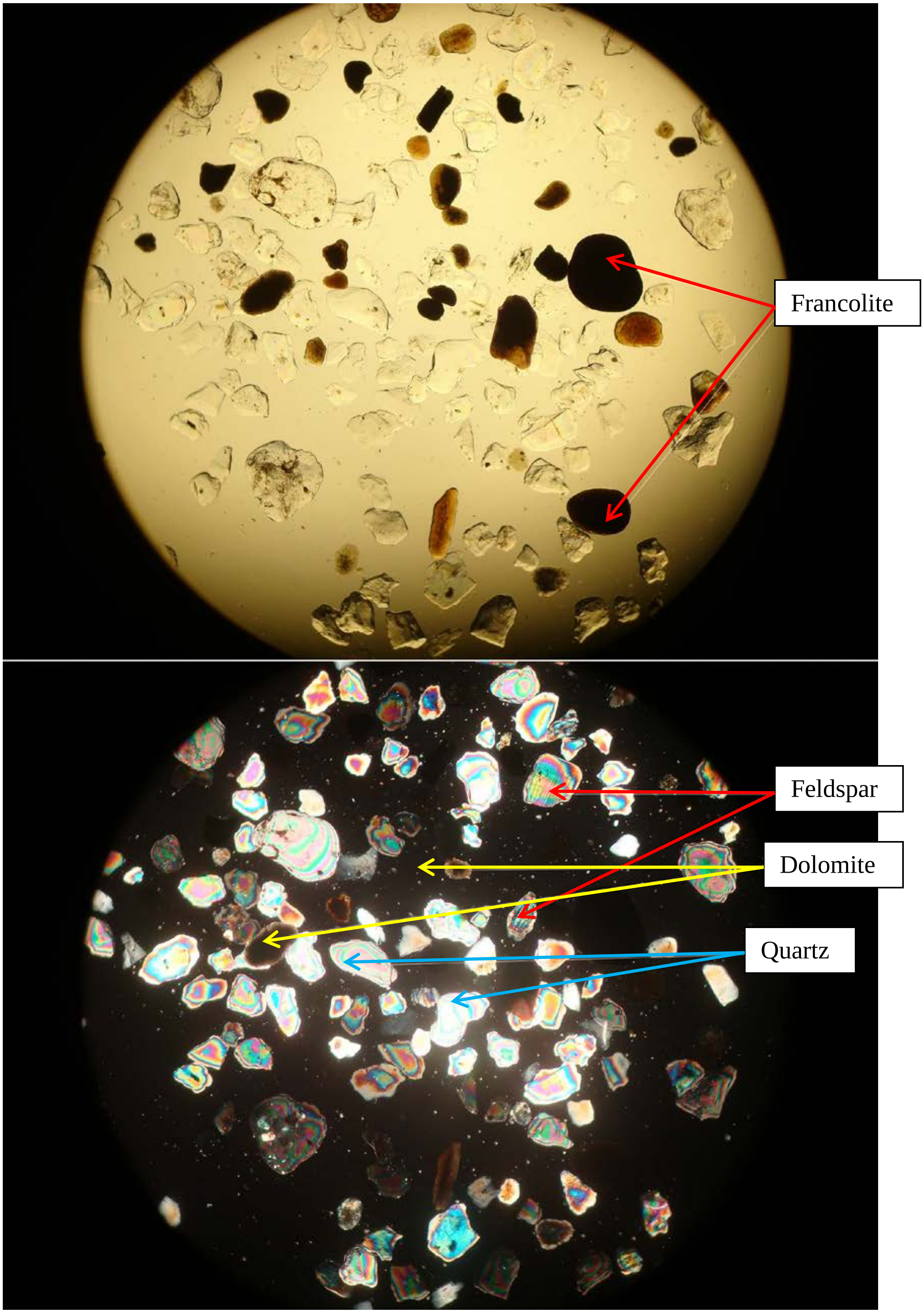


Figure 2. As-Received CF Sample, Single Polarizing and Orthogonal Photos, 40x.

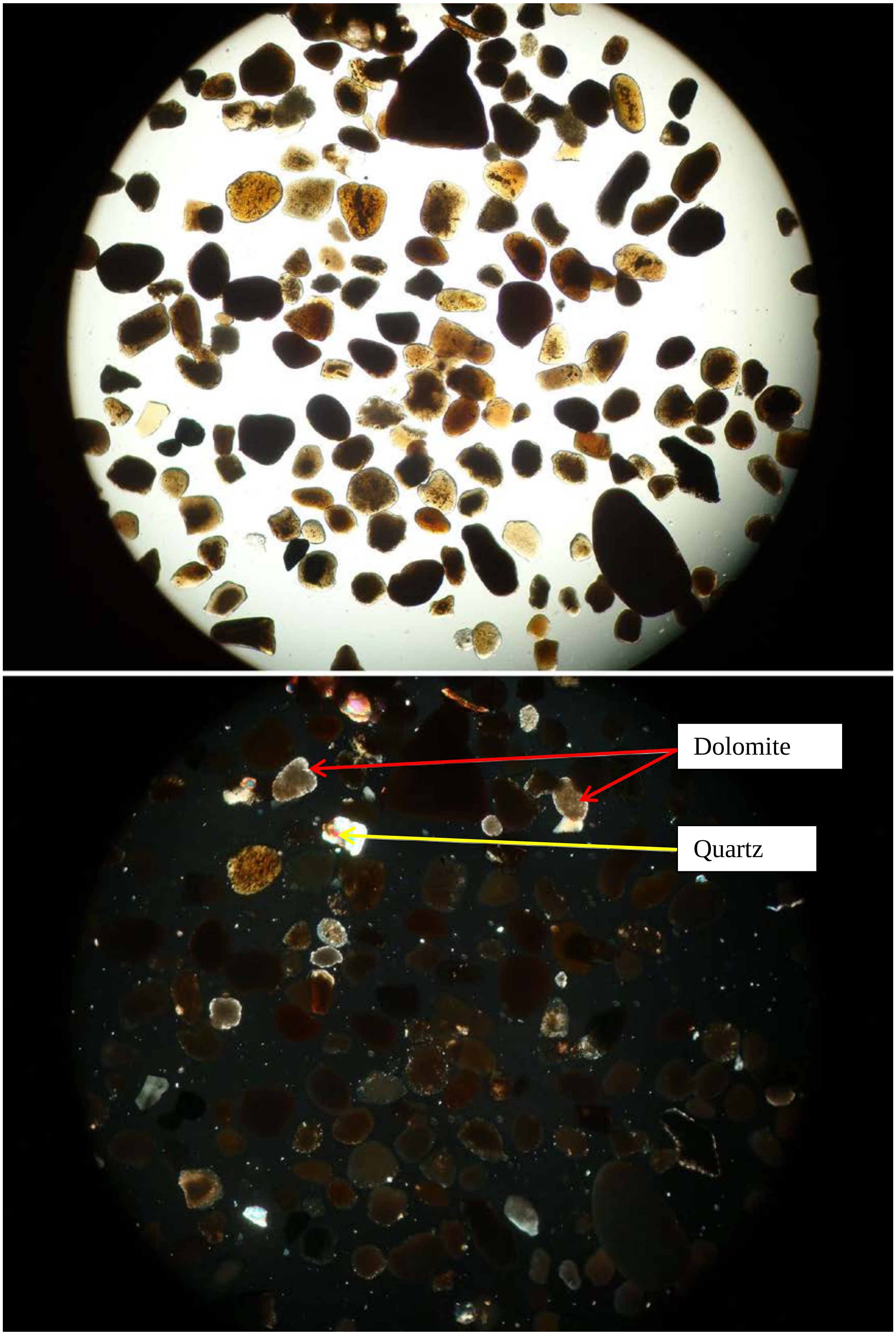


Figure 3. Concentrate, Single Polarizing and Orthogonal Photos, 40x.

Figure 4. Monomer (>80%) Phosphate and Dolomite Photos.

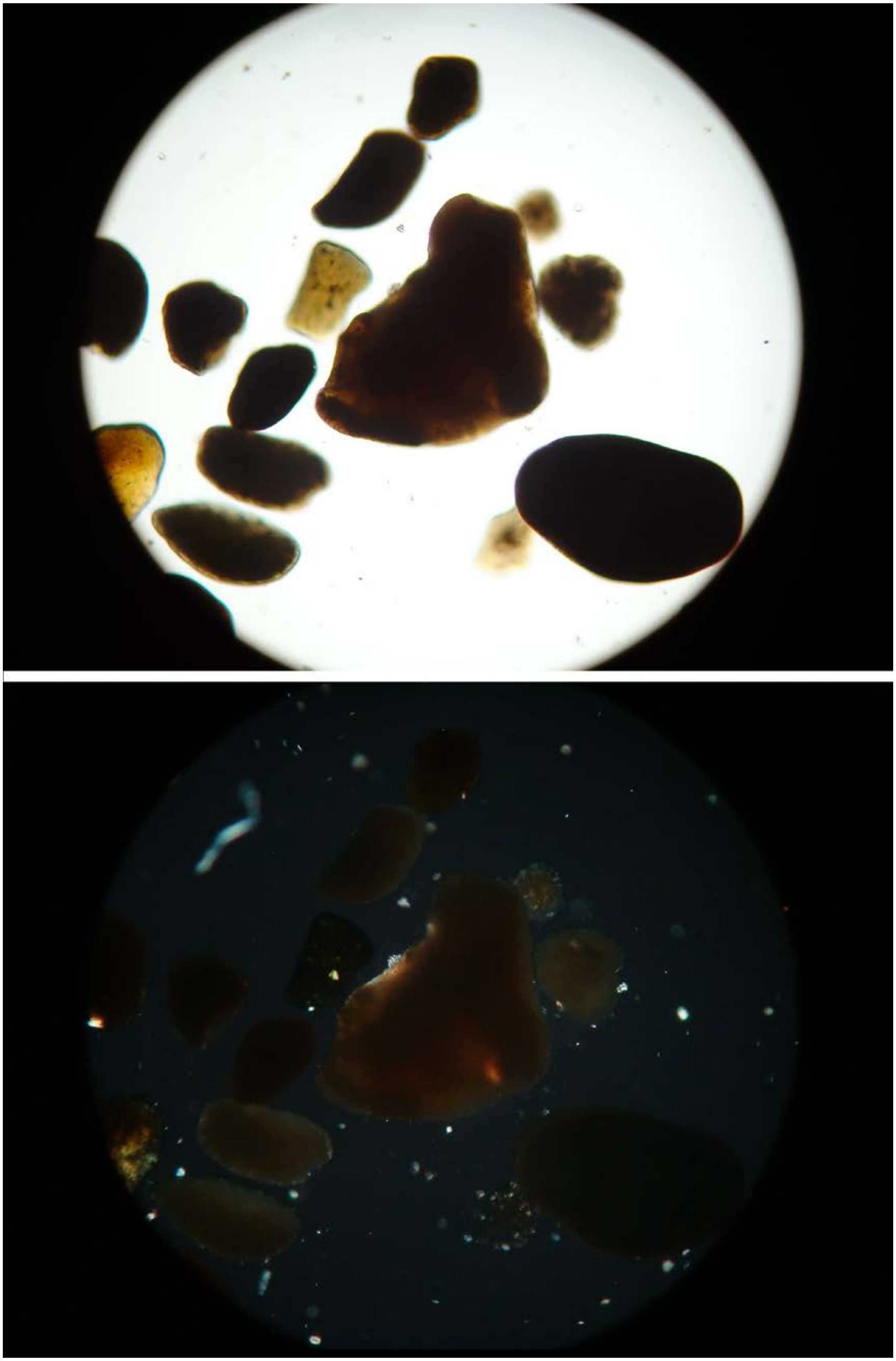


Figure 5. Phosphate Monomer, Single Polarizing and Orthogonal Photos, 100x.

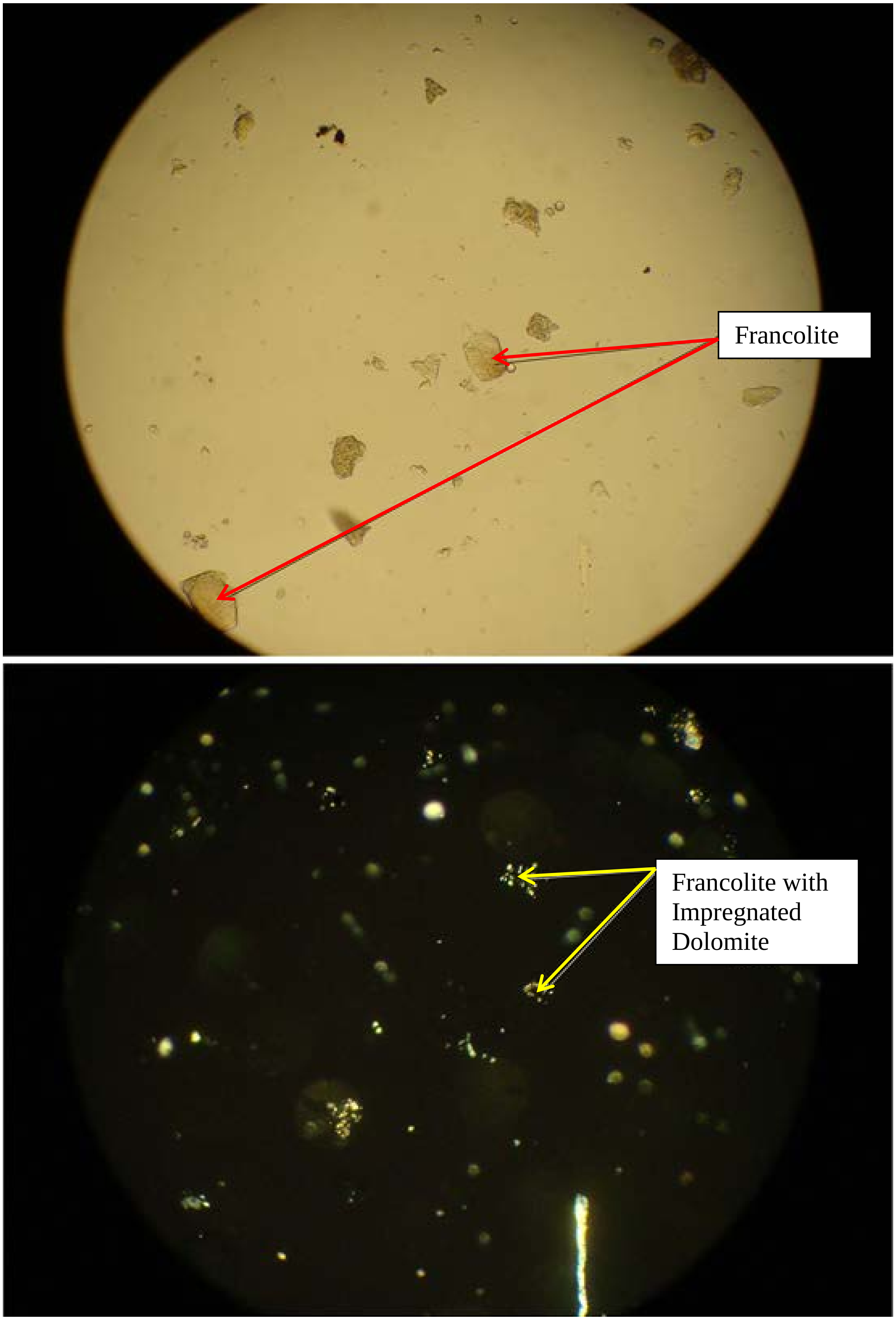


Figure 6. Crushed Phosphate Monomer, Single Polarizing and Orthogonal Photos, 200x.

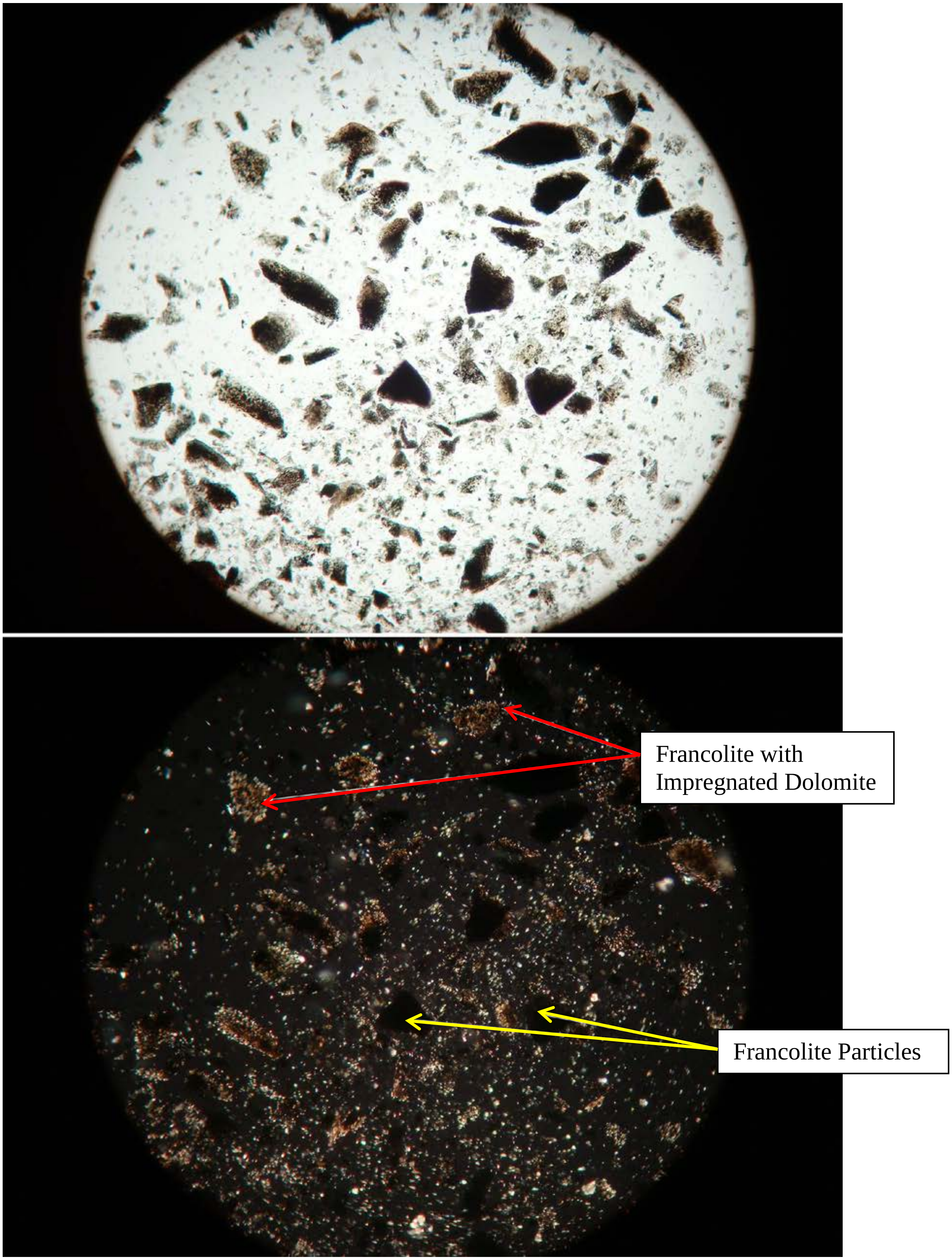


Figure 7. Crushed Phosphate Monomer, Single Polarizing and Orthogonal Photos, 100x.

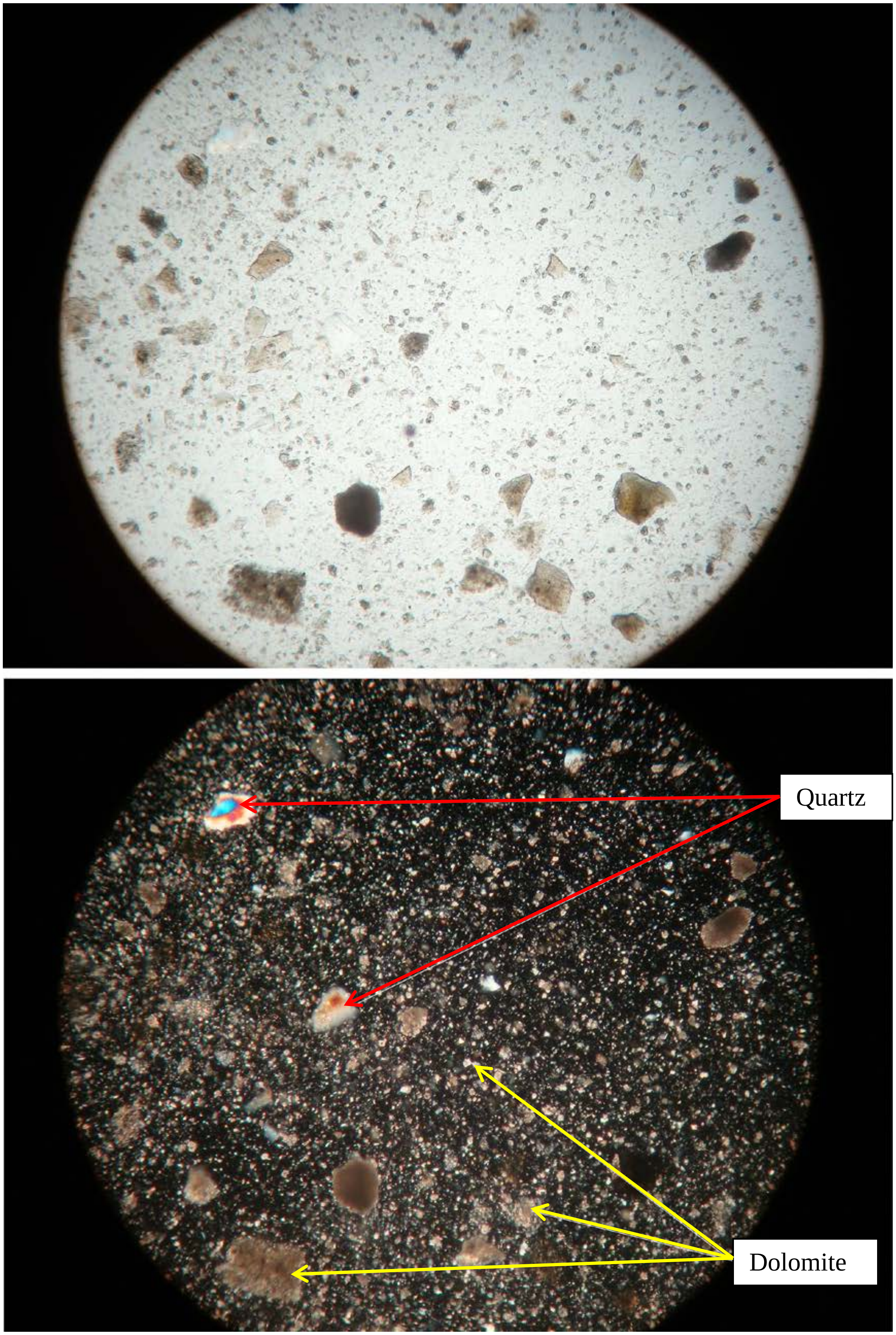


Figure 8. Crushed Dolomite Monomer, Single Polarizing and Orthogonal Photos, 100x.

THE UNIVERSITY OF UTAH STUDY

Phosphate flotation feed samples from two locations (CF and Mosaic #1) were delivered to the Utah lab for preliminary evaluation of dolomite liberation. The chemical analyses are presented in Table 14. The chemical composition reveals that the CF feed is slightly higher in P_2O_5 when compared with Mosaic feed. Conversely, the MgO content and insoluble residues are slightly higher in the Mosaic feed. The samples contain minor amounts of Fe_2O_3 and Al_2O_3.

Table 14. Chemical Analysis of Flotation Feed Samples.

Sample ID	P_2O_5 %	MgO %	Fe_2O_3 %	Al_2O_3 %	Insol
Mosaic Feed	6.75	0.58	0.61	0.33	76.10
CF Feed	8.05	0.55	0.38	0.43	72.80

Semi-quantitative mineralogical analyses are presented in Table 15. Both samples contain about 2.5% dolomite but the extent of liberation has not been established. Of particular concern is the issue of dolomite liberation. In this regard, the samples were examined by XRD for mineral identification and by high resolution X-ray micro CT (HRXMT) for liberation analysis.

Table 15. Mineralogical Analysis of Flotation Feed Samples.

Sample ID	Francolite %	Dolomite %	Quartz %
Mosaic Feed	18.30	2.65	76.10
CF Feed	21.80	2.50	72.80

XRD Analysis

The mineralogical compositions of CF feed and Mosaic feed samples were examined using X-ray diffraction (XRD) analysis of powdered samples. The X-ray diffraction analysis was carried out using a Siemens D5000 X-ray diffractometer. The powder samples were scanned at 2θ from 5-50°, with scan speed of -1.2°/min. Figure 9 shows the diffraction patterns for both samples. It is clear that the mineralogical composition is similar in both samples, being mainly composed of quartz, francolite, dolomite, calcite, and clays.

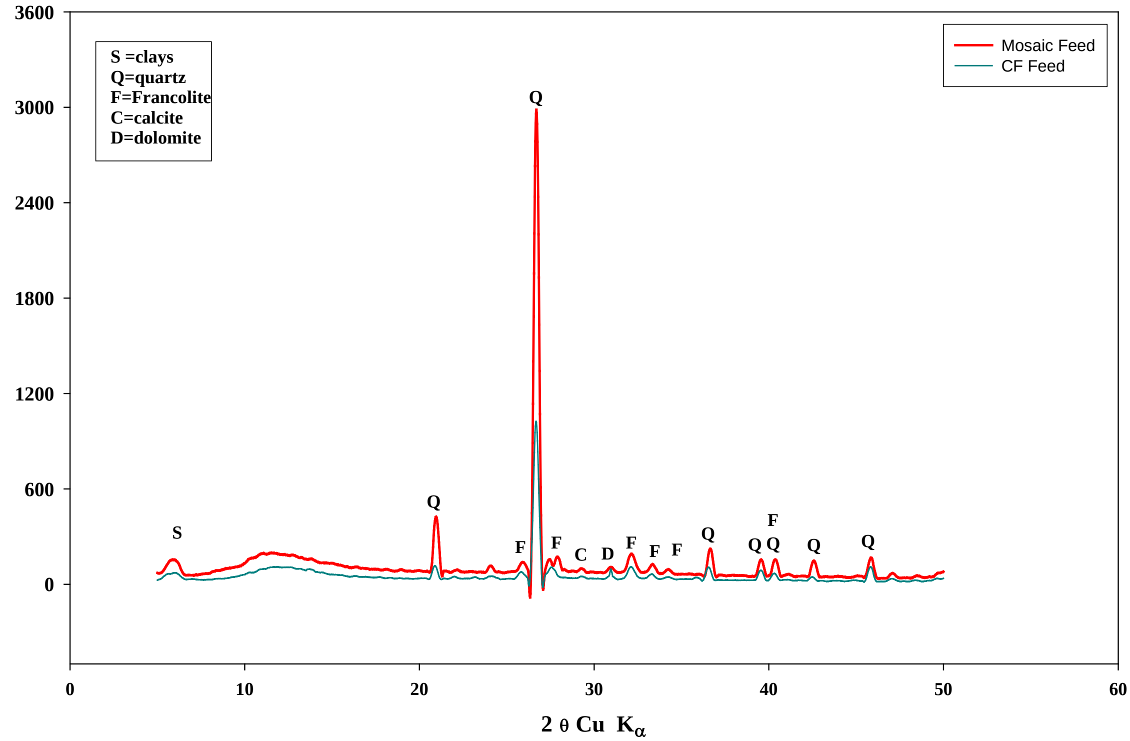


Figure 9. XRD Analyses of CF Feed and Mosaic Feed Samples from Florida Phosphate Rock.

High Resolution X-Ray Microtomography (HRXMT) Analysis

The 3D mineral liberation analyses were carried out using HRXMT data to classify particles in each of the samples into twelve grade classes based on both francolite and dolomite volume percent. These analyses were carried out for both feed samples (CF and Mosaic) from two different Florida phosphate locations. Based on the CT data, four types of minerals (gangue, dolomite, francolite and high-density gangue) were identified/classified and the results are presented in Table 16. The number of particles analyzed for CF and Mosaic samples were 4225 and 8010, respectively.

Table 16. Mineralogical Analyses by HRXMT.

Minerals	CF Sample		Mosaic #1 Sample	
	Volume %	No. of Particles	Volume %	No. of Particles
Silicate	81.84	4225	80.99	8010
Dolomite	2.11		2.80	
Francolite	15.85		16.11	
Others	0.19		0.09	

CF Feed

The HRXMT liberation spectra for francolite and dolomite are shown in Figures 10 and 11, respectively. The spectra show the amount of mineral component of interest in each grade class. Twelve grade classes: 0%, 5%, 15%, 25%, 35%, 45%, 55%, 65%, 75%, 85%, 95% and 100% by volume are used. It is evident that there are very few liberated francolite particles and very few liberated dolomite particles. The number of such particles is so small that they are not seen in the histogram.

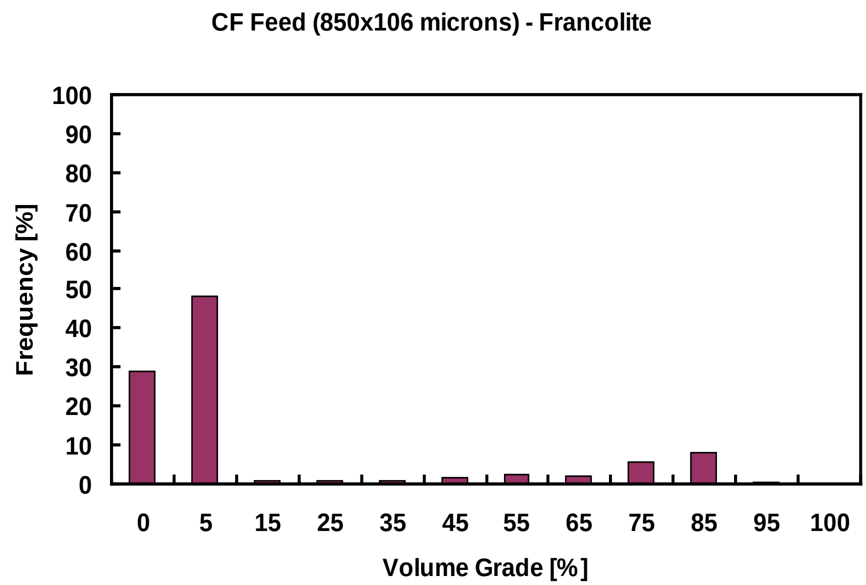


Figure 10. 3D Liberation Spectra of Francolite for the CF Flotation Feed Sample.

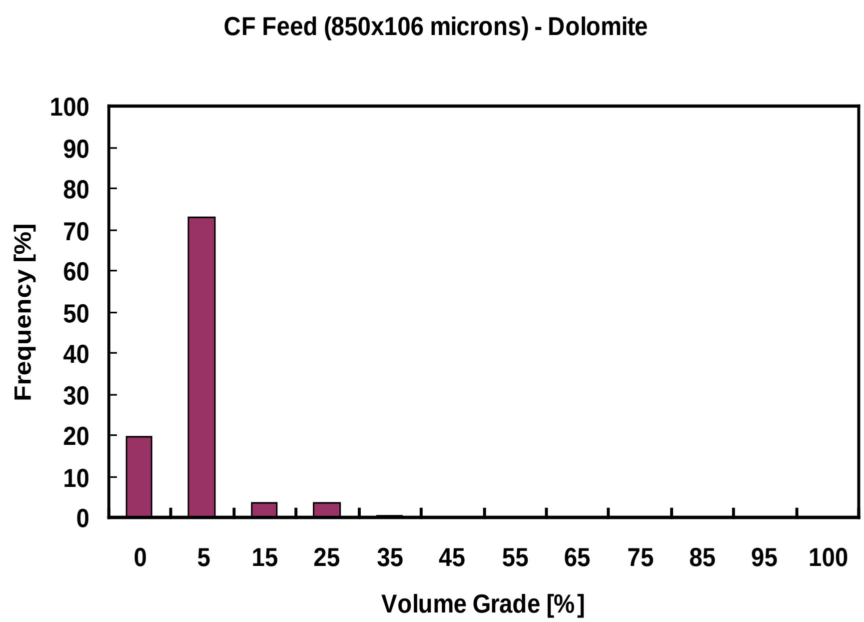


Figure 11. 3D Liberation Spectra of Dolomite for the CF Flotation Feed Sample.

The liberation-limited grade/recovery curve represents a boundary for separation efficiency. The grade and recovery for any actual separation cannot exceed the limit imposed by this curve. In the best case the actual grade and recovery would fall on the curve and under these circumstances improved separation could only be achieved with further liberation by size reduction. If the grade and recovery for an actual separation falls below the curve, then the separation efficiency is limited by other factors (mineral types, surface composition, slime coating, operating conditions, etc.) in addition to liberation limitations. Basically, the mineral content for all mineral-containing particles in each grade class is calculated and represented as a volume fraction of the total mineral in the feed. The mineral contribution from each grade class beginning with the richest grade class is then accumulated as more and more grade classes are considered until the final grade class, with the least amount of mineral, is considered. The liberation-limited grade/recovery curves constructed from 3D liberation spectra shown in Figures 10 and 11 for the 20 × 150 mesh (850 × 106 μm) CF flotation feed sample are presented in Figures 12 and 13 with respect to francolite and dolomite minerals. It is evident the volume percent dolomite in the feed is low, having a grade of about 2-3% by volume. Furthermore, the results show that half of the dolomite could be separated by reverse flotation, in the best case, into a dolomite concentrate containing ~17% by volume dolomite.

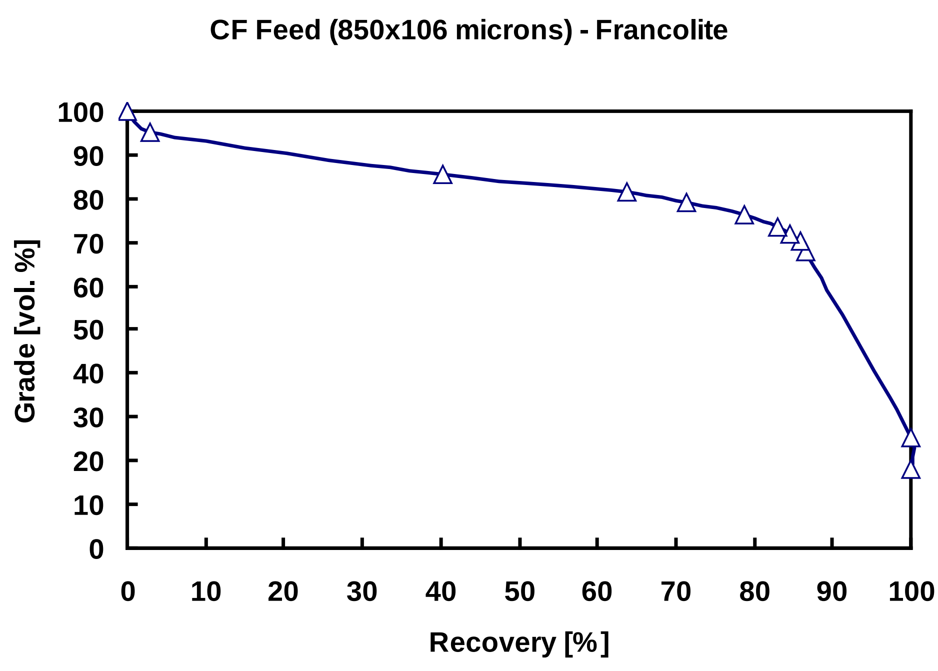


Figure 12. Liberation-Limited Grade/Recovery Curve of Francolite for the CF Flotation Feed Sample (20 × 150 Mesh).

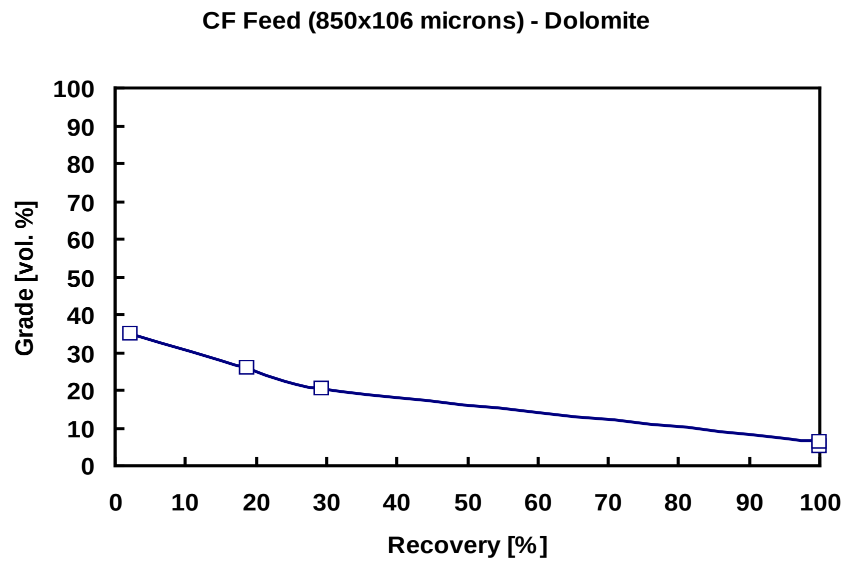


Figure 13. Liberation-Limited Grade/Recovery Curve of Dolomite for the CF Flotation Feed Sample (20 × 150 Mesh).

Mosaic Feed

The overall histograms for 3D liberation analysis of francolite and dolomite in Mosaic feed were constructed from HRXMT data and are presented in Figures 14 and 15, respectively. The spectra show the amount of mineral component of interest in each grade class. Twelve grade classes: 0%, 5%, 15%, 25%, 35%, 45%, 55%, 65%, 75%, 85%, 95% and 100% by volume are used. It is evident that there are very few liberated francolite particles and very few liberated dolomite particles. The number of such particles is so small that they are not seen in the histogram.

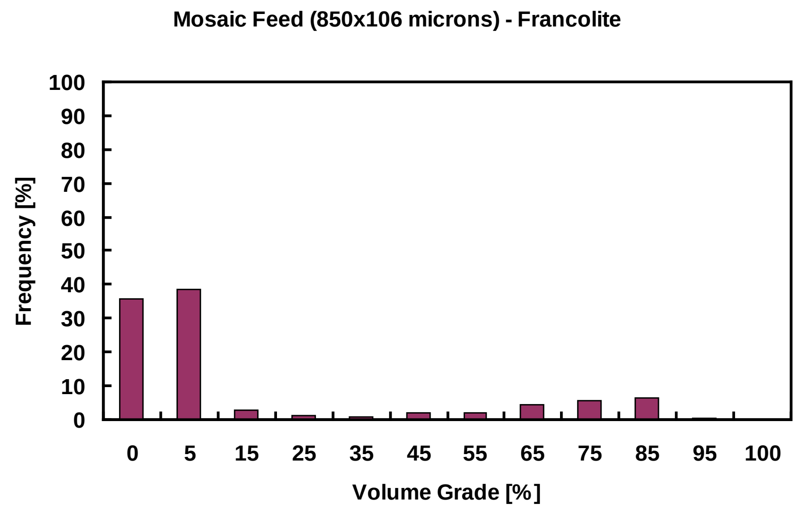


Figure 14. 3D Liberation Spectra of Francolite for the Mosaic Flotation Feed Sample.

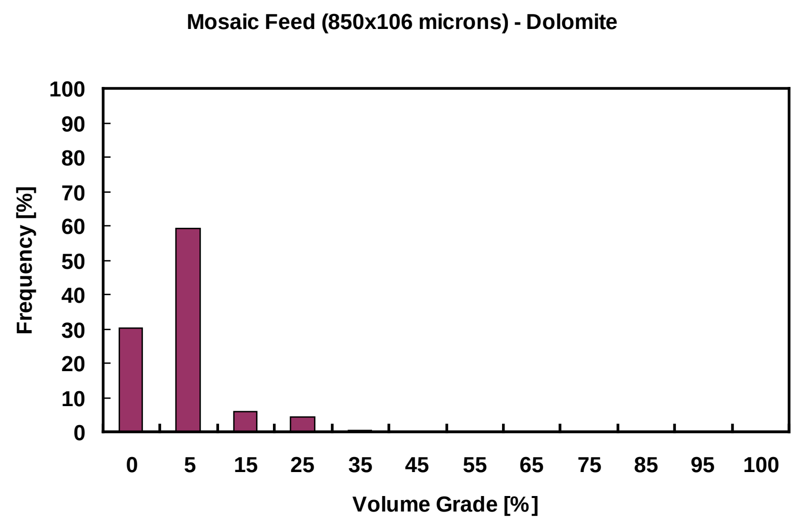


Figure 15. 3D Liberation Spectra of Dolomite for the Mosaic Flotation Feed Sample.

The liberation-limited grade/recovery curves constructed from the 3D liberation spectra shown in Figures 14 and 15 for the 20 × 150 mesh (850 × 106 μm) Mosaic flotation feed sample are presented in Figures 16 and 17 with respect to francolite and dolomite minerals. It is evident the volume percent of dolomite is low, having a grade of about 2-3% by volume.

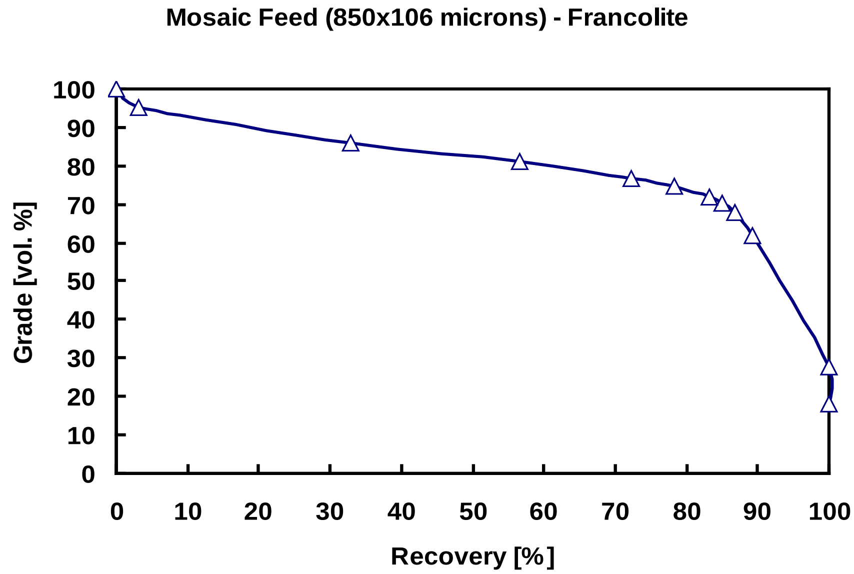


Figure 16. Liberation-Limited Grade/Recovery Curve of Francolite for the Mosaic Flotation Feed Sample (20 × 150 Mesh).

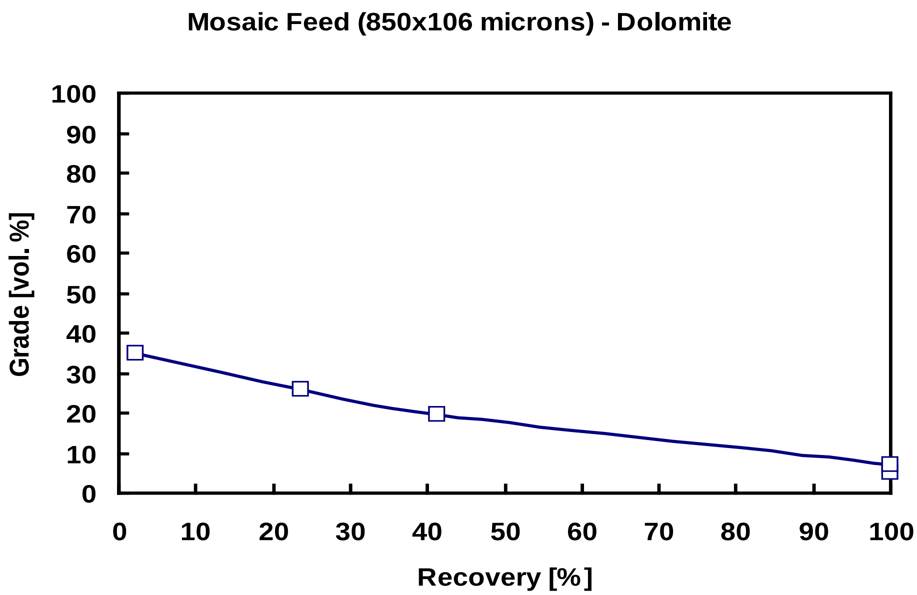


Figure 17. Liberation-Limited Grade/Recovery Curve of Dolomite for the Mosaic Flotation Feed Sample (20 × 150 Mesh).

Conclusions

The results show, for both CF and Mosaic feed material, that little of the dolomite is liberated and extensive separation/removal of dolomite will be difficult. Research funding should be established to further evaluate the texture of the locked dolomite (mineral phase association). For example, Figure 18 illustrates the texture of locked dolomite particles from a 2D slice of the 3D HRXMT data set for the CF feed sample. Further detailed analysis will establish mineral association in the locked particles as well as grain size information. In this way, the best possible phosphate recovery could be estimated for different levels of dolomite removal. In addition, the particle size required for improved liberation should be estimated. Subsequently, grinding experiments should be done to confirm the expected dependence of liberation on particle size and the corresponding expected improvement in the liberation-limited grade/recovery curves.

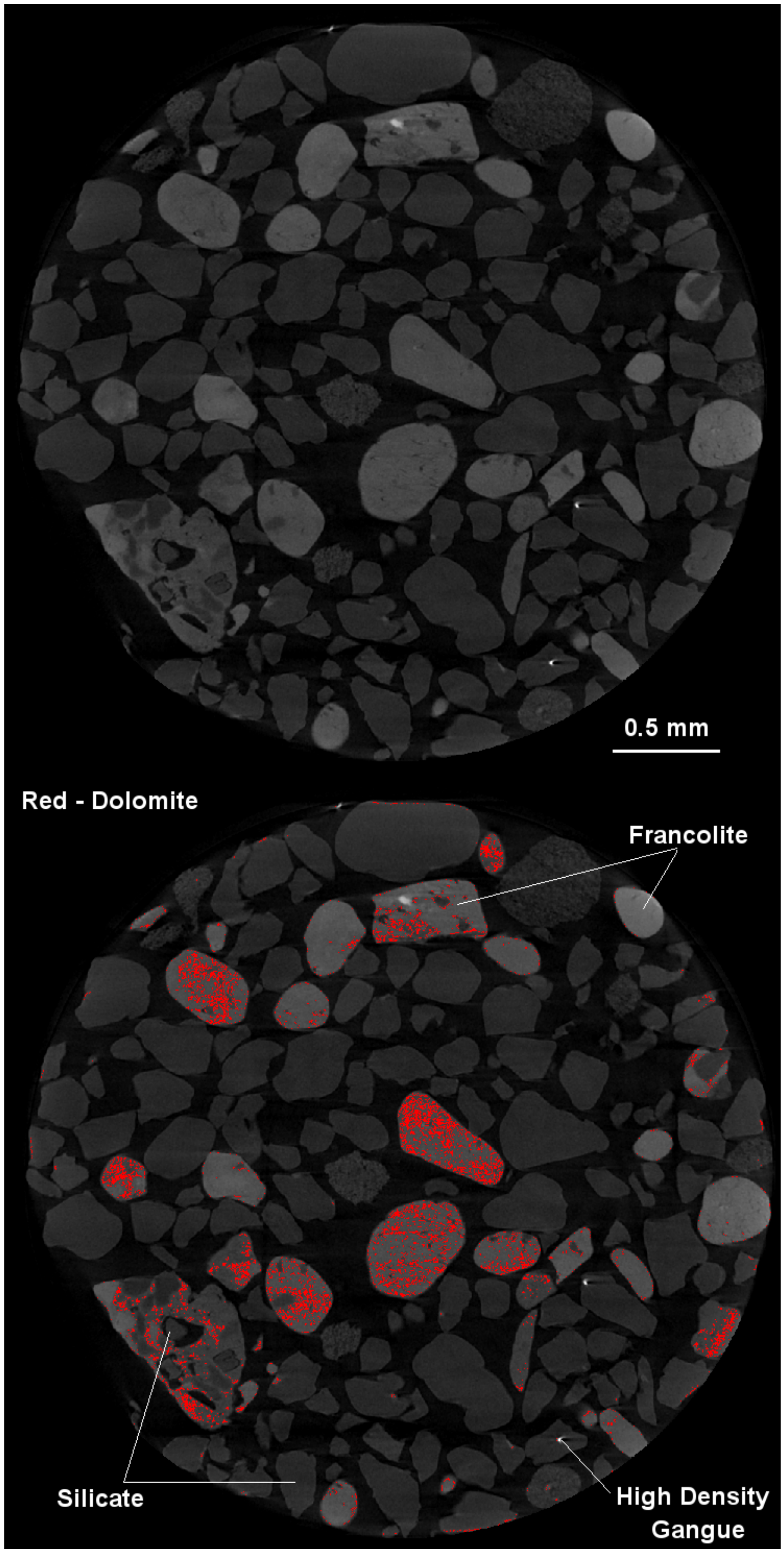


Figure 18. Texture of Locked Dolomite as Revealed from the 2D Sliced Image of 3D HRXMT Data Set for the CF Feed Sample.

SCREENING OF DOLOMITE DEPRESSANTS

TEST EQUIPMENT

A Denver D-12 flotation machine was used for all the laboratory flotation tests. The machine has a cell volume of 1.2 liters and a conditioner volume of 0.8 liter.

REAGENTS

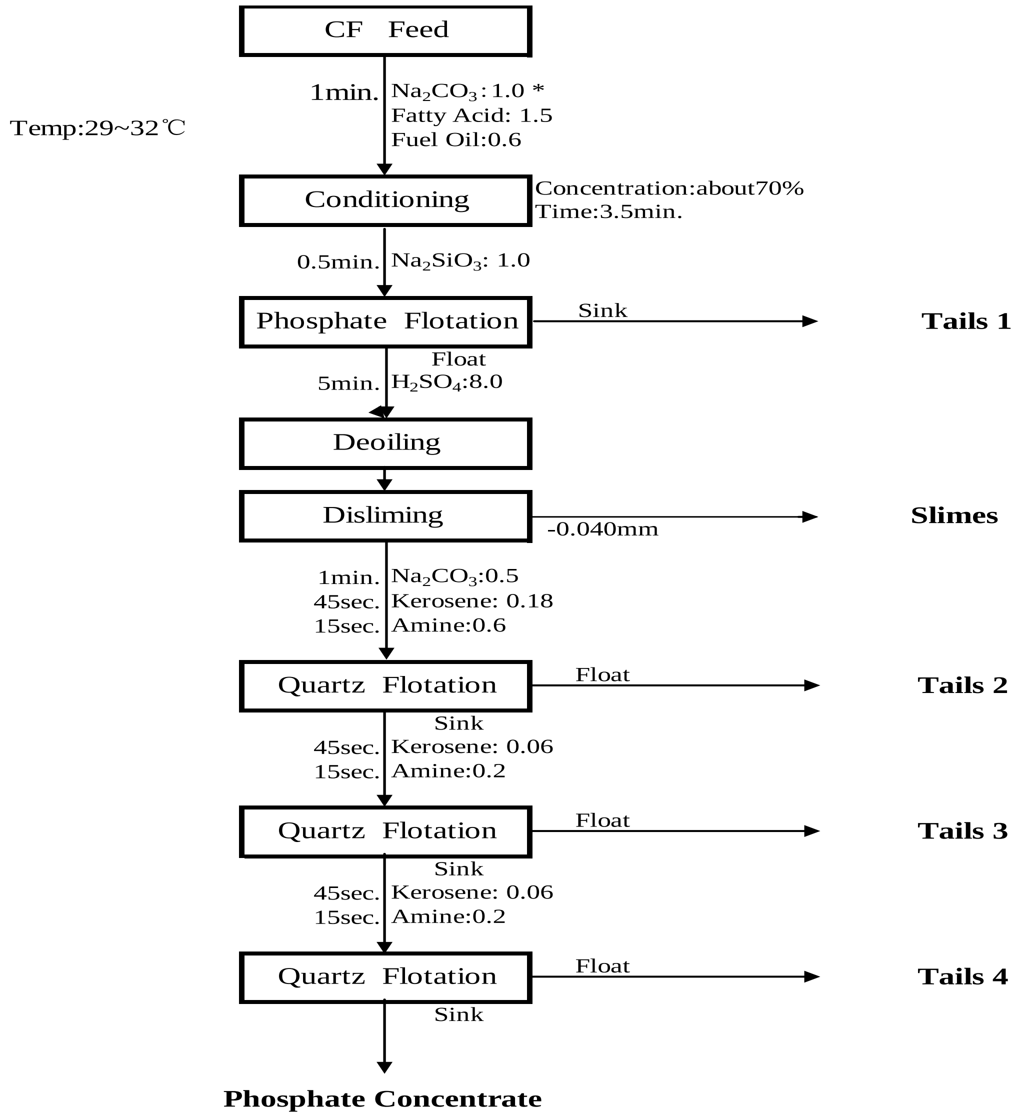
A 5% solution of sodium silicate (Na_2SiO_3) was prepared as a flotation modifier.

Mosaic provided all the flotation reagents used in their plant, including fatty acid, amine, fuel oil and diesel.

Lianyungang tap water was used in all tests.

BASELINE FLOTATION (DOUBLE FLOAT) TESTS

These tests try to mimic the double float (Crago) process currently practiced in Florida. The flotation feed is conditioned at about 70% solids under the desired pH level for about 5 minutes, and then water is added to achieve a flotation pulp density of about 30%, followed by flotation of phosphate to completion. The rougher flotation concentrate is acid-washed prior to amine flotation. Figure 19 shows the processing flowsheet, and Table 17 lists flotation conditions.



*All reagent dosages are measured by kg/t feed.

Figure 19. Direct-Reverse (Double Float) Flowsheet.

Table 18 shows flotation results using the double float, direct-reverse process. Since these results would be used to compare the effectiveness of different reagent systems, five parallel tests were conducted to obtain a reliable average value.

Table 17. Direct-Reverse Flotation Conditions.

Operation	Operating Conditions											
	Conditioning				Skimming	Reagent, kg/T, Feed						
	Impeller Rotation Speed	Aeration	Solids %	pH	Time (Min.)	Na_2CO_3	Fatty Acid	Fuel Oil	Na_2SiO_3	H_2SO_4	Kerosene	Amine
Phosphate Flotation			26.87	8.8~9.2	2.5	1.0	1.5	0.6	1.0			
Deoiling	1600 (rpm)	1.2 (L/min.)		3.4~4.1	5.0					8.0		
Quartz Flotation				7.4~7.5	4.0	0.5					0.3	1.0
Total Reagent Consumption, kg/T Feed						1.5	1.5	0.6	1.0	8.0	0.3	1.0

Table 18. Baseline "Double Float" Five Parallel Test Results and Their Average Values.

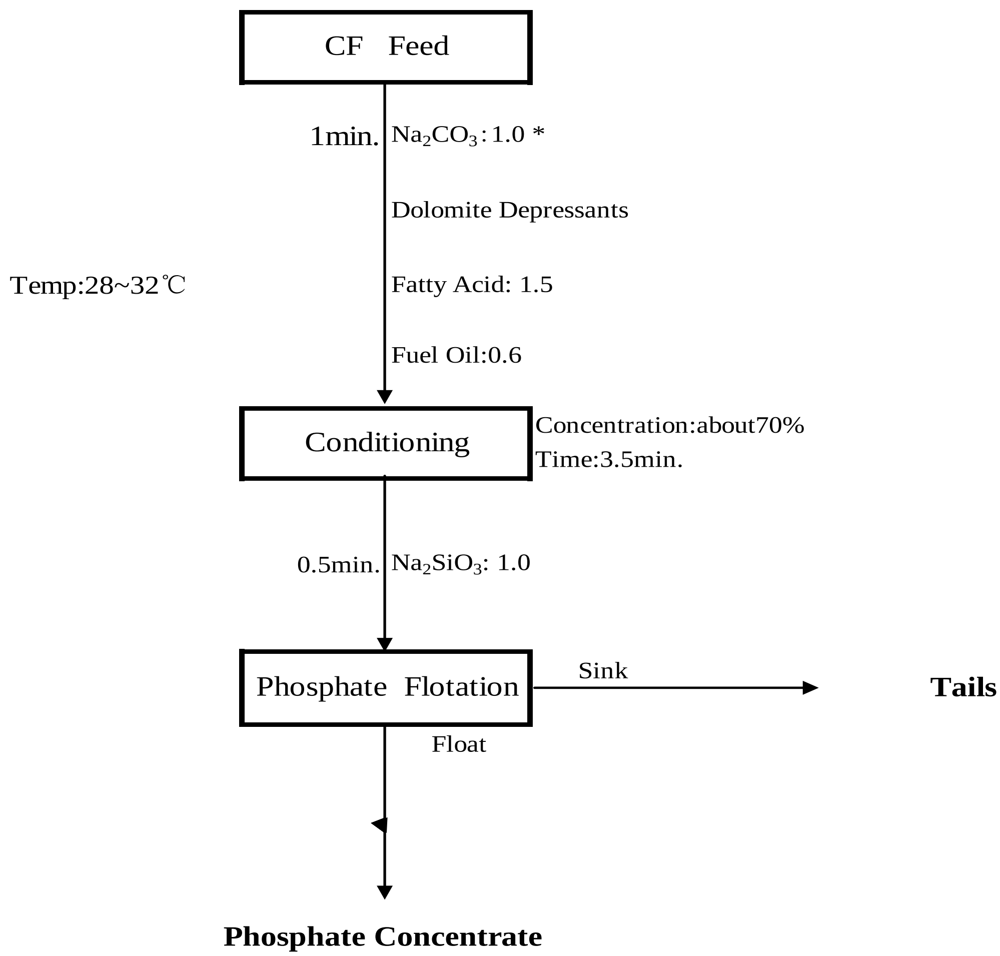
Test Number	Product	Weight (%)		Analysis (%)						Distribution (%)				
				BPL		MgO		A.I.		BPL		MgO	A.I.	
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.			
CF-2	Concentrate	24.58		64.06		1.00		10.40		92.83		47.85	3.41	
	Tails 4	0.62	25.20	9.09	62.72	0.22	0.98	86.37	12.26	0.33	93.16	0.26	0.71	4.13
	Tails 3	0.85	26.05	5.66	60.84	0.04	0.95	91.10	14.85	0.29	93.44	0.07	1.04	5.17
	Tails 2	3.66	29.71	4.06	53.85	0.15	0.85	93.71	24.56	0.88	94.32	1.07	4.58	9.74
	Slimes	1.40	31.11	18.27	52.25	9.26	1.23	21.56	24.42	1.51	95.83	25.26	0.40	10.15
	Tails 1	68.89	100.00	1.03	16.96	0.19	0.51	97.66	74.88	4.17	100.00	25.49	89.85	100.00
	Feed	100.00		16.96		0.51		74.88		100.00		100.00	100.00	
CF-64	Concentrate	24.95		64.87		0.96		9.77		93.32		52.70	3.27	
	Tails 4	0.50	25.45	4.02	63.67	0.10	0.94	93.46	11.43	0.12	93.43	0.11	0.63	3.90
	Tails 3	0.91	26.36	3.45	61.60	0.10	0.91	95.20	14.31	0.18	93.61	0.20	1.16	5.06
	Tails 2	5.37	31.73	2.14	51.54	0.11	0.78	96.55	28.22	0.66	94.28	1.30	6.95	12.00
	Slimes	0.88	32.61	17.41	50.61	9.03	1.00	26.00	28.16	0.89	95.16	17.52	0.31	12.31
	Tails 1	67.39	100.00	1.25	17.34	0.19	0.45	97.10	74.62	4.84	100.00	28.17	87.69	100.00
	Feed	100.00		17.34		0.45		74.62		100.00		100.00	100.00	
CF-91	Concentrate	24.70		64.81		1.01		7.83		94.18		52.24	2.59	
	Tails 4	0.81	25.50	5.88	62.95	0.24	0.99	90.06	10.43	0.28	94.46	0.41	0.97	3.57
	Tails 3	0.55	26.05	4.50	61.72	0.39	0.97	90.61	12.11	0.14	94.61	0.45	0.66	4.23
	Tails 2	4.36	30.41	2.99	53.30	0.14	0.85	94.98	23.99	0.77	95.37	1.28	5.55	9.78
	Slimes	1.07	31.48	21.76	52.23	7.58	1.08	26.16	24.07	1.37	96.74	16.93	0.37	10.16
	Tails 1	68.52	100.00	0.81	16.99	0.20	0.48	97.80	74.59	3.26	100.00	28.70	89.84	100.00
	Feed	100.00		16.99		0.48		74.59		100.00		100.00	100.00	

Table 18 (Cont.). Baseline "Double Float" Five Parallel Test Results and Their Average Values.

Test Number	Product	Weight (%)		Analysis (%)						Distribution (%)				
				BPL		MgO		A.I.		BPL		MgO	A.I.	
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.			
CF-92	Concentrate	23.80		66.05		1.09		6.19		93.57		47.90	1.98	
	Tails 4	0.26	24.06	39.55	65.76	1.08	1.09	41.63	6.58	0.62	94.18	0.52	0.15	2.12
	Tails 3	0.41	24.47	17.20	64.96	0.73	1.08	71.83	7.66	0.42	94.60	0.55	0.39	2.52
	Tails 2	5.59	30.05	2.77	53.40	0.09	0.90	95.37	23.96	0.92	95.52	0.93	7.15	9.66
	Slimes	1.34	31.39	13.68	51.71	11.06	1.33	21.23	23.84	1.09	96.61	27.30	0.38	10.05
	Tails 1	68.61	100.00	0.83	16.80	0.18	0.54	97.70	74.52	3.39	100.00	22.80	89.95	100.00
	Feed	100.00		16.80		0.54		74.52		100.00		100.00	100.00	
CF-93	Concentrate	24.10		66.12		1.00		6.22		94.30		46.68	2.02	
	Tails 4	0.38	24.48	19.36	65.39	0.54	0.99	69.23	7.20	0.43	94.73	0.40	0.35	2.37
	Tails 3	0.69	25.17	5.86	63.77	0.29	0.97	89.78	9.45	0.24	94.97	0.39	0.83	3.20
	Tails 2	5.18	30.35	2.77	53.35	0.14	0.83	94.84	24.04	0.85	95.82	1.41	6.62	9.82
	Slimes	1.30	31.65	15.23	51.78	9.78	1.20	25.44	24.09	1.17	97.00	24.66	0.45	10.27
	Tails 1	68.35	100.00	0.74	16.90	0.20	0.52	97.53	74.29	3.00	100.00	26.47	89.73	100.00
	Feed	100.00		16.90		0.52		74.29		100.00		100.00	100.00	
Average	Concentrate	24.42		65.18		1.01		8.08		93.42		49.40	2.65	
	Tails 4	0.51	24.93	15.58	64.16	0.44	1.00	76.15	9.47	0.47	93.89	0.45	0.52	3.17
	Tails 3	0.68	25.61	7.34	62.66	0.31	0.98	87.70	11.55	0.29	94.18	0.42	0.80	3.97
	Tails 2	4.82	30.43	2.95	53.20	0.13	0.85	95.09	24.78	0.83	95.01	1.26	6.15	10.12
	Slimes	1.20	31.63	17.26	51.83	9.34	1.17	24.08	24.76	1.22	96.23	22.45	0.39	10.51
	Tails 1	68.37	100.00	0.94	17.04	0.19	0.50	97.56	74.53	3.77	100.00	26.02	89.49	100.00
	Feed	100.00		17.04		0.50		74.53		100.00		100.00	100.00	

TESTING OF DOLOMITE DEPRESSANTS

In these tests, a dolomite depressant was added in the fatty acid conditioning stage after the pH modifier was added, as shown in Figure 20. Table 19 lists the flotation conditions. Various dolomite depressants were tested at varying points of addition and dosages, with the results shown in Table 20.



*All reagent dosage in kg/ton feed.

Figure 20. Flow Chart for Evaluating Dolomite Depressants.

Table 19. Test Conditions for Evaluating Dolomite Depressants.

Operation	Operating Conditions								
	Conditioning			Skimming Time (Min.)	Reagent, kg/T Feed				
	Impeller Rotation Speed (rpm)	Aeration (L/min.)	Solids %		Na_2CO_3	Dolomite Depressants	Fatty Acid	Fuel Oil	Na_2SiO_3
Conditioning	1000		70	5	1.0	Variable	1.5	0.6	
Phosphate Flotation	1600	1.2	30	2.5					1.0
Total Reagent Consumption, kg/T Feed					1.0		1.5	0.6	1.0

Table 20. Dolomite Depressants Evaluation Test Results.

Dolomite Depressants (kg/T, Feed)	Test Number	Product	Weight (%)	Analysis (%)			Distribution (%)		
				BPL	MgO	A.I.	BPL	MgO	A.I.
No Depressant		Concentrate	31.64	51.83	1.16	24.76	96.23	73.86	10.51
		Tails	68.36	0.94	0.19	97.56	3.77	26.14	89.49
		Feed	100.00	17.04	0.50	74.53	100.00	100.00	100.00
S711 0.5	CF-7	Concentrate	26.59	57.75	1.16	16.43	90.03	60.00	5.89
		Tails	73.41	2.32	0.28	94.99	9.97	40.00	94.11
		Feed	100.00	17.05	0.51	74.10	100.00	100.00	100.00
Lignin 5.0	CF-17	Concentrate	27.25	58.30	1.15	15.64	93.19	62.36	5.74
		Tails	72.75	1.60	0.26	96.22	6.81	37.64	94.26
		Feed	100.00	17.05	0.50	74.26	100.00	100.00	100.00
Alizarin Red 1.0	CF-20	Concentrate	31.34	52.57	1.17	22.36	95.23	73.76	9.53
		Tails	68.66	1.20	0.19	96.94	4.77	26.24	90.47
		Feed	100.00	17.30	0.50	73.57	100.00	100.00	100.00
Carboxymethylcellulose 1.0	CF-21	Concentrate	28.09	58.27	1.07	15.63	95.86	63.52	5.92
		Tails	71.91	0.98	0.24	96.95	4.14	36.48	94.08
		Feed	100.00	17.08	0.47	74.11	100.00	100.00	100.00
Alizarin Red 2.0	CF-23	Concentrate	23.51	56.50	1.44	15.95	76.07	67.82	5.10
		Tails	76.49	5.46	0.21	91.27	23.93	32.18	94.90
		Feed	100.00	17.46	0.50	73.56	100.00	100.00	100.00

Table 20 (Cont.). Dolomite Depressants Evaluation Test Results.

Dolomite Depressants (kg/T, Feed)	Test Number	Product	Weight (%)	Analysis (%)			Distribution (%)		
				BPL	MgO	A.I.	BPL	MgO	A.I.
Soluble Starch 1.0	CF-24	Concentrate	29.93	53.69	1.11	20.35	95.54	69.31	8.23
		Tails	70.07	1.07	0.21	96.88	4.46	30.69	91.77
		Feed	100.00	16.82	0.48	73.97	100.00	100.00	100.00
Sulfonated Humic Acid 1.0	CF-25	Concentrate	1.63	51.81	2.98	12.61	5.00	9.33	0.28
		Tails	98.37	16.30	0.48	75.14	95.00	90.67	99.72
		Feed	100.00	16.88	0.52	74.12	100.00	100.00	100.00
Sulfonated Humic Acid 0.3	CF-26	Concentrate	23.60	58.49	1.13	15.62	79.75	52.97	4.99
		Tails	76.40	4.59	0.31	91.88	20.25	47.03	95.01
		Feed	100.00	17.31	0.50	73.88	100.00	100.00	100.00
Dewatering Agent NF 1.5	CF-32	Concentrate	27.04	59.13	1.05	15.44	91.68	59.03	5.64
		Tails	72.96	1.99	0.27	95.78	8.32	40.97	94.36
		Feed	100.00	17.44	0.48	74.06	100.00	100.00	100.00
Tartaric Acid 1.0	CF-34	Concentrate	28.59	56.37	1.20	18.64	93.06	69.59	7.21
		Tails	71.41	1.68	0.21	96.04	6.94	30.41	92.79
		Feed	100.00	17.32	0.49	73.91	100.00	100.00	100.00
Citric Acid 1.0	CF-37	Concentrate	12.12	60.44	1.56	11.61	45.23	38.07	1.87
		Tails	87.88	10.09	0.35	84.10	54.77	61.93	98.13
		Feed	100.00	16.20	0.50	75.31	100.00	100.00	100.00

Table 20 (Cont.). Dolomite Depressants Evaluation Test Results.

Dolomite Depressants (kg/T, Feed)	Test Number	Product	Weight (%)	Analysis (%)			Distribution (%)		
				BPL	MgO	A.I.	BPL	MgO	A.I.
Polyacrylamide (PAM) 0.5	CF-38	Concentrate	27.41	59.83	1.05	14.82	95.04	53.83	5.52
		Tails	72.59	1.18	0.34	95.78	4.96	46.17	94.48
		Feed	100.00	17.25	0.53	73.59	100.00	100.00	100.00
PAM 0.8	CF-40	Concentrate	26.31	60.92	1.01	13.14	92.91	52.98	4.67
		Tails	73.69	1.66	0.32	95.68	7.09	47.02	95.33
		Feed	100.00	17.25	0.50	73.97	100.00	100.00	100.00
JD 0.1	CF-42	Concentrate	31.67	53.12	1.10	23.12	97.32	69.86	9.89
		Tails	68.33	0.68	0.22	97.60	2.68	30.14	90.11
		Feed	100.00	17.29	0.50	74.01	100.00	100.00	100.00
PAM 0.5 KCl 1.0	CF-43	Concentrate	26.37	60.48	0.90	15.54	92.62	51.79	5.51
		Tails	73.63	1.73	0.30	95.50	7.38	48.21	94.49
		Feed	100.00	17.22	0.46	74.42	100.00	100.00	100.00
PAM 0.5 S711 0.5	CF-44	Concentrate	24.62	61.31	0.90	12.52	88.94	46.37	4.16
		Tails	75.38	2.49	0.34	94.27	11.06	53.63	95.84
		Feed	100.00	16.97	0.48	74.14	100.00	100.00	100.00
PAM 0.5 $Al_2(SO_4)_3$ 1.0	CF-45	Concentrate	82.18	17.28	0.30	74.54	81.08	46.37	84.01
		Tails	17.82	18.59	1.60	65.40	18.92	53.63	15.99
		Feed	100.00	17.52	0.53	72.91	100.00	100.00	100.00

Table 20 (Cont.). Dolomite Depressants Evaluation Test Results.

Dolomite Depressants (kg/T, Feed)	Test Number	Product	Weight (%)	Analysis (%)			Distribution (%)		
				BPL	MgO	A.I.	BPL	MgO	A.I.
PAM 0.5 $Al_2(SO_4)_3$ 0.5	CF-46	Concentrate	29.76	55.19	1.06	19.84	95.20	59.16	8.02
		Tails	70.24	1.18	0.31	96.39	4.80	40.84	91.98
		Feed	100.00	17.25	0.53	73.61	100.00	100.00	100.00
PAM 0.5 Carboxymethylcellulose 1.0	CF-47	Concentrate	22.29	62.64	0.85	11.40	81.39	38.47	3.43
		Tails	77.71	4.11	0.39	92.01	18.61	61.53	96.57
		Feed	100.00	17.16	0.49	74.04	100.00	100.00	100.00
PAM 0.5 JD 0.1	CF-48	Concentrate	28.65	58.78	1.17	16.93	98.09	62.65	6.57
		Tails	71.35	0.46	0.28	96.69	1.91	37.35	93.43
		Feed	100.00	17.16	0.53	73.84	100.00	100.00	100.00
PAM 0.5 Alum 0.4	CF-50	Concentrate	27.89	58.84	1.02	15.89	95.42	56.80	6.00
		Tails	72.11	1.09	0.30	96.31	4.58	43.20	94.00
		Feed	100.00	17.20	0.50	73.88	100.00	100.00	100.00
PAM 0.3	CF-52	Concentrate	30.29	54.36	1.22	20.01	96.69	69.74	8.21
		Tails	69.71	0.81	0.23	97.16	3.31	30.26	91.79
		Feed	100.00	17.03	0.53	73.79	100.00	100.00	100.00
Alum 0.4	CF-53	Concentrate	31.81	52.35	1.20	23.49	97.22	73.68	10.11
		Tails	68.19	0.70	0.20	97.46	2.78	26.32	89.89
		Feed	100.00	17.13	0.52	73.93	100.00	100.00	100.00

Table 20 (Cont.). Dolomite Depressants Evaluation Test Results.

Dolomite Depressants (kg/T, Feed)	Test Number	Product	Weight (%)	Analysis (%)			Distribution (%)		
				BPL	MgO	A.I.	BPL	MgO	A.I.
PAM 0.5 Alum 0.8	CF-54	Concentrate	30.83	50.58	0.90	26.64	91.16	54.86	11.14
		Tails	69.17	2.19	0.33	94.74	8.84	45.14	88.86
		Feed	100.00	17.11	0.51	73.75	100.00	100.00	100.00
$KClO_3$ 1.0	CF-55	Concentrate	33.00	51.02	1.11	25.06	96.72	71.31	11.25
		Tails	67.00	0.85	0.22	97.38	3.28	28.69	88.75
		Feed	100.00	17.41	0.51	73.51	100.00	100.00	100.00
JD-02 1.5	CF-56	Concentrate	32.43	52.22	1.19	23.74	97.29	77.06	10.44
		Tails	67.57	0.70	0.17	97.67	2.71	22.94	89.56
		Feed	100.00	17.41	0.50	73.70	100.00	100.00	100.00
NH_4Cl 1.0	CF-57	Concentrate	32.65	51.61	1.07		97.36	73.19	10.90
		Tails	67.35	0.68	0.19		2.64	26.81	89.10
		Feed	100.00	17.31	0.48	0.00	100.00	100.00	100.00
PAM 0.5 Carboxymethylcellulose 1.0	CF-58	Concentrate	22.83	62.23	1.01		83.88	45.36	3.47
		Tails	77.17	3.54	0.36		16.12	54.64	96.53
		Feed	100.00	16.94	0.51	0.00	100.00	100.00	100.00
PAM 0.5 Carboxymethylcellulose 1.0	CF-59	Concentrate	25.47	61.97	1.02		90.99	49.90	4.59
		Tails	74.53	2.10	0.35		9.01	50.10	95.41
		Feed	100.00	17.35	0.52	0.00	100.00	100.00	100.00

Table 20 (Cont.). Dolomite Depressants Evaluation Test Results.

Dolomite Depressants (kg/T, Feed)	Test Number	Product	Weight (%)	Analysis (%)			Distribution (%)		
				BPL	MgO	A.I.	BPL	MgO	A.I.
PAM 0.50 Carboxymethylcellulose 0.5	CF-60	Concentrate	26.72	58.69	1.07	15.52	90.15	55.73	5.63
		Tails	73.28	2.34	0.31	94.81	9.85	44.27	94.37
		Feed	100.00	17.40	0.51	73.62	100.00	100.00	100.00
PAM Anomic 0.1	CF-65	Concentrate	32.33	51.78	1.18	24.23	96.75	72.86	10.64
		Tails	67.67	0.83	0.21	97.28	3.25	27.14	89.36
		Feed	100.00	17.31	0.52	73.66	100.00	100.00	100.00
PAM Anomic 0.1	CF-66	Concentrate	18.11	64.81	0.95	8.17	67.91	30.89	2.02
		Tails	81.89	6.77	0.47	87.74	32.09	69.11	97.98
		Feed	100.00	17.28	0.56	73.33	100.00	100.00	100.00
PAM Anomic 0.05	CF-67	Concentrate	30.76	54.52	1.13	20.74	97.11	66.76	8.66
		Tails	69.24	0.72	0.25	97.20	2.89	33.24	91.34
		Feed	100.00	17.27	0.52	73.68	100.00	100.00	100.00
Hengju #1 Polymer 0.1	CF-68	Concentrate	32.24	51.43	1.14	24.49	97.31	73.06	10.67
		Tails	67.76	0.68	0.20	97.55	2.69	26.94	89.33
		Feed	100.00	17.04	0.50	74.00	100.00	100.00	100.00
Hengju #2 Polymer 0.05	CF-69	Concentrate	30.72	53.71	1.04	21.13	96.72	66.73	8.77
		Tails	69.28	0.81	0.23	97.44	3.28	33.27	91.23
		Feed	100.00	17.06	0.48	74.00	100.00	100.00	100.00

Table 20 (Cont.). Dolomite Depressants Evaluation Test Results.

Dolomite Depressants (kg/T, Feed)	Test Number	Product	Weight (%)	Analysis (%)			Distribution (%)		
				BPL	MgO	A.I.	BPL	MgO	A.I.
Hengju #3 0.05	CF-70	Concentrate	30.11	55.39	1.13	19.92	97.15	66.98	8.12
		Tails	69.89	0.70	0.24	97.14	2.85	33.02	91.88
		Feed	100.00	17.17	0.51	73.89	100.00	100.00	100.00
Hengju #4 0.05	CF-71	Concentrate	32.50	50.84	1.21	24.73	96.64	76.39	10.86
		Tails	67.50	0.85	0.18	97.67	3.36	23.61	89.14
		Feed	100.00	17.10	0.51	73.97	100.00	100.00	100.00
Hengju #5 0.05	CF-72	Concentrate	33.03	50.12	1.19	26.40	96.67	74.58	11.77
		Tails	66.97	0.85	0.20	97.55	3.33	25.42	88.23
		Feed	100.00	17.12	0.53	74.05	100.00	100.00	100.00
Hengju #6 0.05	CF-73	Concentrate	34.05	50.32	1.17	27.38	97.70	80.10	12.62
		Tails	65.95	0.61	0.15	97.88	2.30	19.90	87.38
		Feed	100.00	17.54	0.50	73.88	100.00	100.00	100.00
Hengju #7 0.05	CF-74	Concentrate	32.62	50.91	1.19	24.38	96.08	75.20	10.79
		Tails	67.38	1.01	0.19	97.61	3.92	24.80	89.21
		Feed	100.00	17.28	0.52	73.72	100.00	100.00	100.00
Hengju #8 0.05	CF-75	Concentrate	33.15	51.81	1.13	26.08	97.43	72.74	11.74
		Tails	66.85	0.68	0.21	97.25	2.57	27.26	88.26
		Feed	100.00	17.63	0.51	73.66	100.00	100.00	100.00

Table 20 (Cont.). Dolomite Depressants Evaluation Test Results.

Dolomite Depressants (kg/T, Feed)	Test Number	Product	Weight (%)	Analysis (%)			Distribution (%)		
				BPL	MgO	A.I.	BPL	MgO	A.I.
Hengju #9 0.05	CF-76	Concentrate	32.04	51.92	1.09	25.18	97.14	69.08	10.85
		Tails	67.96	0.72	0.23	97.49	2.86	30.92	89.15
		Feed	100.00	17.12	0.51	74.32	100.00	100.00	100.00
Hengju #10 0.05	CF-77	Concentrate	31.44	53.45	1.15	21.95	97.40	72.50	9.34
		Tails	68.56	0.66	0.20	97.76	2.60	27.50	90.66
		Feed	100.00	17.25	0.50	73.93	100.00	100.00	100.00
Hengju #11 0.05	CF-78	Concentrate	31.18	54.30	1.18	21.04	96.99	69.92	8.92
		Tails	68.82	0.76	0.23	97.38	3.01	30.08	91.08
		Feed	100.00	17.46	0.53	73.57	100.00	100.00	100.00
Hengju #12 0.05	CF-79	Concentrate	32.01	52.88	1.20	22.77	97.52	73.85	9.89
		Tails	67.99	0.63	0.20	97.70	2.48	26.15	90.11
		Feed	100.00	17.35	0.52	73.72	100.00	100.00	100.00
Hengju #13 0.05	CF-80	Concentrate	32.93	50.67	1.12	26.25	96.52	69.62	11.70
		Tails	67.07	0.90	0.24	97.25	3.48	30.38	88.30
		Feed	100.00	17.29	0.53	73.87	100.00	100.00	100.00
Hengju #14 0.05	CF-81	Concentrate	33.91	50.12	1.15	27.40	98.33	77.63	12.61
		Tails	66.09	0.44	0.17	97.46	1.67	22.37	87.39
		Feed	100.00	17.29	0.50	73.70	100.00	100.00	100.00

Table 20 (Cont.). Dolomite Depressants Evaluation Test Results.

Dolomite Depressants (kg/T, Feed)	Test Number	Product	Weight (%)	Analysis (%)			Distribution (%)		
				BPL	MgO	A.I.	BPL	MgO	A.I.
Hengju #9 0.05	CF-82	Concentrate	33.98	50.45	1.26	25.62	97.86	78.28	11.87
		Tails	66.02	0.57	0.18	97.88	2.14	21.72	88.13
		Feed	100.00	17.52	0.55	73.32	100.00	100.00	100.00
Hengju #10 0.05	CF-83	Concentrate	33.02	51.52	1.22	25.04	97.16	76.97	11.20
		Tails	66.98	0.74	0.18	97.88	2.84	23.03	88.80
		Feed	100.00	17.51	0.52	73.83	100.00	100.00	100.00
Hengju #11 0.05	CF-84	Concentrate	31.56	52.90	1.20	21.83	97.47	71.55	9.36
		Tails	68.44	0.63	0.22	97.49	2.53	28.45	90.64
		Feed	100.00	17.13	0.53	73.61	100.00	100.00	100.00
Hengju #12 0.05	CF-85	Concentrate	31.52	53.40	1.18	21.83	97.07	73.09	9.36
		Tails	68.48	0.74	0.20	97.32	2.93	26.91	90.64
		Feed	100.00	17.34	0.51	73.52	100.00	100.00	100.00
Hengju #13 0.05	CF-86	Concentrate	32.16	52.57	1.22	22.36	97.77	77.29	9.80
		Tails	67.84	0.57	0.17	97.61	2.23	22.71	90.20
		Feed	100.00	17.29	0.51	73.41	100.00	100.00	100.00
Hengju #14 0.05	CF-87	Concentrate	32.52	52.00	1.18	23.68	97.62	75.96	10.43
		Tails	67.48	0.61	0.18	98.05	2.38	24.04	89.57
		Feed	100.00	17.32	0.51	73.86	100.00	100.00	100.00

Table 20 (Cont.). Dolomite Depressants Evaluation Test Results.

Dolomite Depressants (kg/T, Feed)	Test Number	Product	Weight (%)	Analysis (%)			Distribution (%)		
				BPL	MgO	A.I.	BPL	MgO	A.I.
Hengju #21 0.05	CF-88	Concentrate	33.10	51.57	1.15	24.70	97.82	78.05	11.06
		Tails	66.90	0.57	0.16	98.26	2.18	21.95	88.94
		Feed	100.00	17.45	0.49	73.91	100.00	100.00	100.00
Hengju #22 0.05	CF-89	Concentrate	31.62	52.68	1.20	23.62	96.70	73.51	10.07
		Tails	68.38	0.83	0.20	97.52	3.30	26.49	89.93
		Feed	100.00	17.23	0.52	74.15	100.00	100.00	100.00

Table 20 presents results from lab-scale evaluation of various dolomite depressants, including inorganic reagents, organic reagents, and organic/inorganic mixtures. Some of these depressants actually increased MgO content in the rougher concentrate, some showed no effect, while the others lowered the MgO content to some degree. The most effective dolomite depressants were found to be carboxymethylcellulose, soluble starch, and polyacrylamide (PAM). In order to determine the effect of the relatively more efficient dolomite depressants on MgO content in the final concentrate, some laboratory tests were conducted with the complete Crago process, fatty acid rougher flotation, acid scrubbing (deoiling) and amine flotation. The results in Table 21 show limited reduction in MgO from the addition of the dolomite depressants.

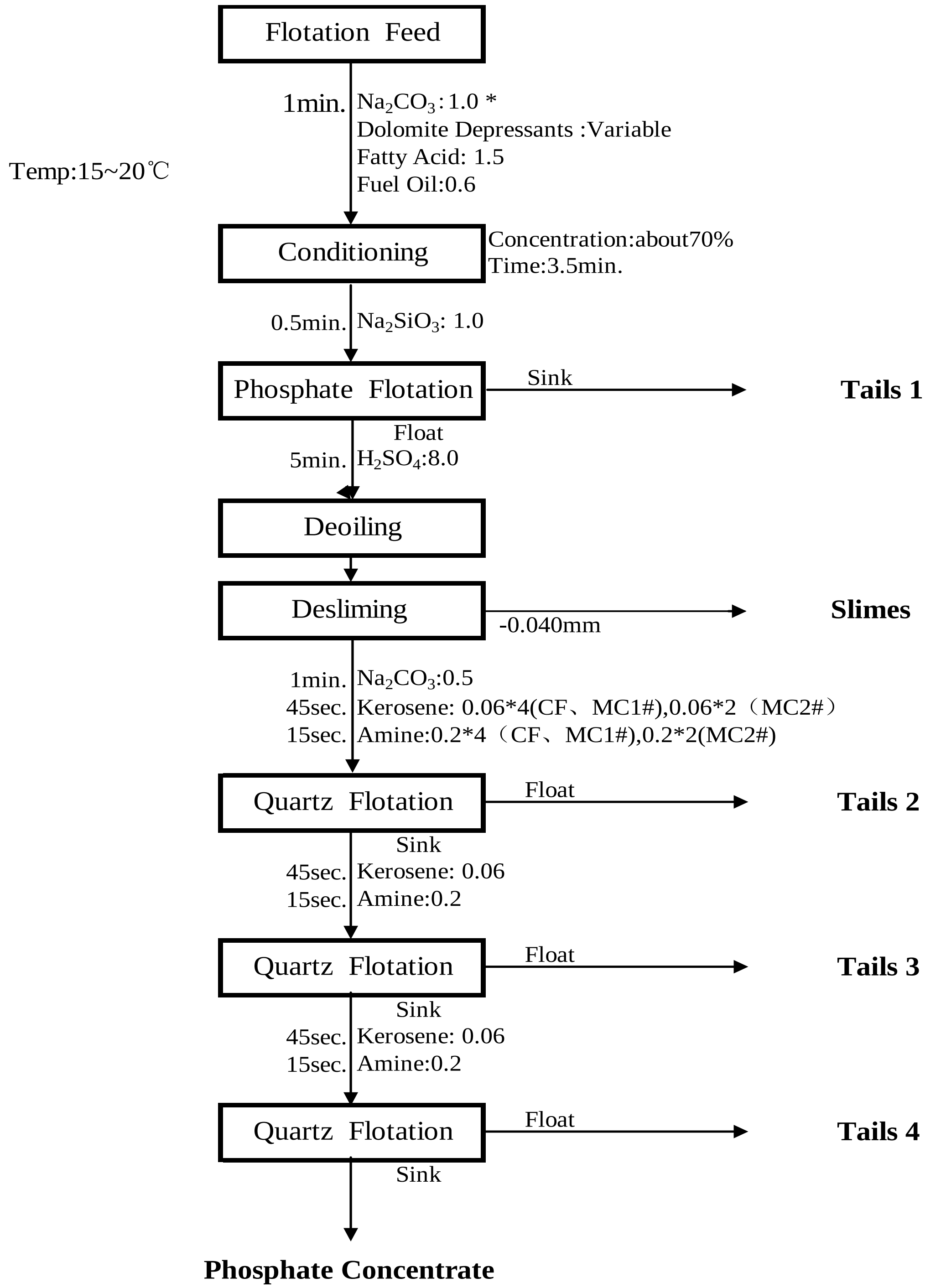
Table 21. Test Results Using the Complete Crago Flowsheet.

Reagent	Product	Weight (%)		Analysis (%)						Distribution (%)			
				BPL		MgO		A.I.		BPL		MgO	A.I.
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		
Control	Concentrate	24.42		65.18		1.00		8.08		93.42		49.14	2.65
	Tails 4	0.50	24.92	15.58	64.17	0.44	0.99	76.15	9.46	0.46	93.88	0.45	0.52
	Tails 3	0.67	25.59	7.34	62.68	0.31	0.97	87.70	11.52	0.29	94.17	0.42	0.79
	Tails 2	4.83	30.43	2.95	53.20	0.13	0.84	95.09	24.78	0.84	95.01	1.26	6.16
	Slimes	1.20	31.63	17.26	51.83	9.34	1.16	24.08	24.76	1.22	96.23	22.59	0.39
	Tails 1	68.37	100.00	0.94	17.04	0.19	0.50	97.56	74.53	3.77	100.00	26.14	89.49
	Feed	100.00		17.04		0.50		74.53		100.00		100.00	100.00
PAM 0.50	Concentrate	22.90		65.55		0.92		7.18		90.31		40.67	2.21
	Tails 2	3.00	25.90	14.29	59.61	2.09	1.06	65.86	13.98	2.58	92.89	12.11	2.66
	Tails 1	74.10	100.00	1.60	16.62	0.33	0.52	95.54	74.42	7.11	100.00	47.21	95.13
	Feed	100.00		16.62		0.52		74.42		100.00		100.00	100.00
PAM 0.50 Alum 0.4	Concentrate	24.07		65.53		0.99		7.69		96.56		45.42	2.49
	Tails 2	3.32	27.39	6.49	58.37	0.19	0.89	89.24	17.58	1.32	97.88	1.20	2.66
	Slimes	0.26	27.65	11.82	57.94	7.59	0.96	25.64	17.65	0.19	98.06	3.73	2.66
	Tails 1	72.35	100.00	0.44	16.33	0.36	0.52	96.16	74.45	1.94	100.00	49.65	93.44
	Feed	100.00		16.33		0.52		74.45		100.00		100.00	101.25

DETAILED EVALUATION OF FOUR PROMISING DOLOMITE DEPRESSANTS

The dolomite depressant screening results presented above indicate that four of the depressants have the potential to substantially lower MgO content in the final concentrate. They include carboxymethylcellulose (CMC), soluble starch, polyacrylamide (PAM), and Hengju #9. Further flotation tests were conducted to optimize the dosage and flotation parameters for these depressants. In these tests, dolomite depressants were added in the fatty acid flotation step of the double float process. Test samples included Mosaic #1 and #2, and the CF feed. The flotation flowsheet is shown in Figure 21. The flotation feed was first conditioned with fatty acid at 70% solids for five minutes. The conditioned feed was then diluted to 30% solids and floated. The rougher concentrate was acid-scrubbed and washed prior to amine flotation. The major flotation parameters are listed in Table 21.

The effects of different dolomite depressants on flotation of the three test feeds are shown in Tables 22-24.



*Reagent dosage in kg/ton of feed.

Figure 21. Flowsheet for Evaluating Promising Dolomite Depressants.

Table 22. Flotation Operating Conditions.

Operation	Operating Conditions												
	Conditioning					Reagent, kg/T Feed							
	Impeller Rotation Speed (rpm)	Aeration (L/min.)	Solids %	pH	Time (Min.)	Na_2CO_3	Dolomite Depressants	Fatty Acid	Fuel Oil	Na_2SiO_3	H_2SO_4	Kerosene	Amine
Phosphate Flotation			26.87	8.8~9.2	2.5	1.0		1.5	0.6	1.0			
Deoiling	1600	1.2		3.4~4.1	5.0		Variable				8.0		
Quartz Flotation				7.4~7.5	4.0	0.5							
Total Reagent Consumption, kg/T Feed						1.5		1.5	0.6	1.0	8.0		

Table 23. Complete Flowsheet Test Results Using CF Feed.

Depressant (kg/T, Feed)	Product	Weight (%)		Analysis (%)						Distribution (%)			
				BPL		MgO		A.I.		BPL		MgO	A.I.
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		
None	Concentrate	24.42		65.18		1.00		8.08		93.42		49.14	2.65
	Tails 4	0.50	24.92	15.58	64.17	0.44	0.99	76.15	9.46	0.46	93.88	0.45	0.52
	Tails 3	0.67	25.59	7.34	62.68	0.31	0.97	87.70	11.52	0.29	94.17	0.42	0.79
	Tails 2	4.83	30.43	2.95	53.20	0.13	0.84	95.09	24.78	0.84	95.01	1.26	6.16
	Slimes	1.20	31.63	17.26	51.83	9.34	1.16	24.08	24.76	1.22	96.23	22.59	0.39
	Tails 1	68.37	100.00	0.94	17.04	0.19	0.50	97.56	74.53	3.77	100.00	26.14	89.49
	Feed	100.00		17.04		0.50		74.53		100.00		100.00	100.00
PAM 0.50	Concentrate	22.90		65.55		0.92		7.18		90.31		40.67	2.21
	Tails 2	3.00	25.90	14.29	59.61	2.09	1.06	65.86	13.98	2.58	92.89	12.11	2.66
	Tails 1	74.10	100.00	1.60	16.62	0.33	0.52	95.54	74.42	7.11	100.00	47.21	95.13
	Feed	100.00		16.62		0.52		74.42		100.00		100.00	100.00
Starch 1.0	Concentrate	23.65		66.62		0.89		6.69		90.42		39.74	2.15
	Tails 4	0.51	24.17	18.55	65.60	0.50	0.88	71.41	8.07	0.55	90.97	0.49	0.50
	Tails 3	0.54	24.71	8.57	64.35	0.28	0.87	86.22	9.77	0.27	91.23	0.29	0.63
	Tails 2	4.24	28.95	3.21	55.40	0.14	0.76	94.73	22.22	0.78	92.01	1.12	5.45
	Slimes	1.08	30.02	25.54	54.32	7.26	1.00	25.40	22.33	1.58	93.60	14.78	0.37
	Tails 1	69.98	100.00	1.60	17.43	0.33	0.53	95.71	73.68	6.40	100.00	43.59	90.90
	Feed	100.00		17.43		0.53		73.68		100.00		100.00	100.00

Table 23 (Cont.). Complete Flowsheet Test Results Using CF Feed.

Reagent (kg/T, Feed)	Product	Weight (%)		Analysis (%)						Distribution (%)			
				BPL		MgO		A.I.		BPL		MgO	A.I.
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		
CMC 1.0	Concentrate	22.37		66.93		1.04		6.09		88.27		44.85	1.83
	Tails 3	0.93	23.30	45.47	66.07	0.88	1.92	34.56	40.65	2.49	90.76	1.58	0.43
	Tails 2	3.35	26.66	8.17	58.79	0.09	0.91	91.23	17.79	1.62	92.38	0.58	4.11
	Slimes	0.93	27.59	19.97	57.48	9.32	1.20	17.36	17.78	1.10	93.47	16.71	0.22
	Tails 1	72.41	100.00	1.53	16.96	0.26	0.52	96.06	74.46	6.53	100.00	36.28	93.41
	Feed	100.00		16.96		0.52		74.46		100.00		100.00	100.00
Hengju #9 0.05	Concentrate	24.78		63.74		1.01		11.03		94.21		46.99	3.67
	Tails 4	0.87	25.65	4.50	61.72	0.27	0.98	91.76	13.77	0.23	94.44	0.44	1.07
	Tails 3	0.73	26.37	3.47	60.12	0.20	0.96	93.65	15.97	0.15	94.59	0.27	0.91
	Tails 2	3.39	29.76	3.04	53.62	0.23	0.88	94.58	24.92	0.61	95.21	1.46	4.30
	Slimes	0.87	30.63	17.41	52.59	9.57	1.13	22.08	24.84	0.90	96.11	15.65	0.26
	Tails 1	69.37	100.00	0.94	16.76	0.27	0.53	96.37	74.46	3.89	100.00	35.17	89.78
	Feed	100.00		16.76		0.53		74.46		100.00		100.00	100.00

Table 24. Complete Flowsheet Test Results Using Mosaic #1 Feed.

Depressant (kg/T, Feed)	Product	Weight (%)		Analysis (%)						Distribution (%)			
				BPL		MgO		A.I.		BPL		MgO	A.I.
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		
None	Concentrate	20.58		60.81		1.27		9.45		92.98		52.41	2.49
	Tails 4	0.70	21.29	13.83	59.25	0.52	1.25	78.14	11.72	0.72	93.70	0.73	0.70
	Tails 3	1.93	23.22	3.61	54.63	0.21	1.16	92.80	18.47	0.52	94.22	0.81	2.29
	Tails 2	5.52	28.74	1.03	44.33	0.02	0.94	97.06	33.56	0.42	94.64	0.22	6.85
	Slimes	0.61	29.35	14.38	43.70	9.61	1.12	20.64	33.29	0.66	95.30	11.82	0.16
	Tails 1	70.65	100.00	0.90	13.46	0.24	0.50	96.86	78.20	4.70	100.00	34.00	87.50
	Feed	100.00		13.46		0.50		78.20		100.00		100.00	100.00
PAM 0.50	Concentrate	18.98		60.68		1.07		7.87		86.33		39.74	1.92
	Tails 3	1.10	20.08	21.59	58.54	0.51	1.04	66.45	11.08	1.78	88.11	1.10	0.94
	Tails 2	3.02	23.11	3.06	51.28	0.04	0.91	94.11	21.94	0.69	88.80	0.24	3.65
	Slimes	0.71	23.81	11.19	50.09	8.08	1.12	26.32	22.07	0.60	89.40	11.22	0.24
	Tails 1	76.19	100.00	1.86	13.34	0.32	0.51	95.44	77.97	10.60	100.00	47.70	93.26
	Feed	100.00		13.34		0.51		77.97		100.00		100.00	100.00
Starch 1.0	Concentrate	17.46		64.63		1.20		5.71		81.95		42.41	1.27
	Tails 4	0.44	17.90	41.93	64.08	0.99	1.19	36.48	6.46	1.33	83.28	0.87	0.20
	Tails 3	0.71	18.61	8.32	61.95	0.45	1.17	85.04	9.46	0.43	83.71	0.65	0.77
	Tails 2	3.69	22.30	2.43	52.09	0.08	0.99	96.08	23.81	0.65	84.36	0.60	4.53
	Slimes	0.71	23.02	12.02	50.85	10.39	1.28	21.04	23.72	0.62	84.98	14.96	0.19
	Tails 1	76.98	100.00	2.69	13.77	0.26	0.49	94.68	78.35	15.02	100.00	40.51	93.03
	Feed	100.00		13.77		0.49		78.35		100.00		100.00	100.00

Table 24 (Cont.). Complete Flowsheet Test Results Using Mosaic #1 Feed.

Reagent (kg/T, Feed)	Product	Weight (%)		Analysis (%)						Distribution (%)			
				BPL		MgO		A.I.		BPL		MgO	A.I.
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		
CMC 1.0	Concentrate	15.01		64.83		1.17		6.82		73.66		35.93	1.30
	Tails 4	1.01	16.02	39.22	63.21	0.74	1.14	42.36	9.06	3.00	76.67	1.53	0.54
	Tails 3	0.80	16.82	3.98	60.38	0.34	1.10	90.96	12.98	0.24	76.91	0.56	0.93
	Tails 2	1.42	18.25	2.08	55.83	0.09	1.03	96.08	19.47	0.22	77.13	0.26	1.73
	Slimes	0.48	18.73	18.70	54.87	10.30	1.26	13.14	19.31	0.68	77.82	10.17	0.08
	Tails 1	81.27	100.00	3.61	13.21	0.31	0.49	92.76	79.00	22.18	100.00	51.55	95.42
	Feed	100.00		13.21		0.49		79.00		100.00		100.00	100.00
Hengju #9 0.05	Concentrate	17.71		64.76		1.01		5.84		83.94		35.13	1.32
	Tails 4	0.64	18.35	48.64	64.20	0.99	1.01	28.55	6.63	2.27	86.21	1.24	0.23
	Tails 3	0.68	19.03	11.82	62.32	0.70	1.00	78.40	9.21	0.59	86.80	0.94	0.69
	Tails 2	2.88	21.91	2.67	54.48	0.20	0.89	94.70	20.45	0.56	87.36	1.13	3.49
	Slimes	0.47	22.38	17.28	53.69	8.83	1.06	21.96	20.48	0.60	87.96	8.19	0.13
	Tails 1	77.62	100.00	2.12	13.66	0.35	0.51	94.80	78.16	12.04	100.00	53.36	94.13
	Feed	100.00		13.66		0.51		78.16		100.00		100.00	100.00

Table 25. Complete Flowsheet Test Results Using Mosaic #2 Feed.

Depressant (kg/T, Feed)	Product	Weight (%)		P_2O_5	Analysis (%)						Distribution (%)			
					BPL		MgO		A.I.		BPL		MgO	A.I.
		Indiv.	Cum.		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		
None	Concentrate	14.63		29.70	64.89		1.11		6.99		87.63		58.20	1.23
	Tails 4	0.82	15.45	21.53	47.04	63.94	0.68	1.09	33.18	8.39	3.57	91.20	2.01	0.33
	Tails 3	1.01	16.46	8.56	18.70	61.16	0.36	1.04	72.64	12.33	1.75	92.95	1.30	0.88
	Tails 2	6.30	22.77	1.30	2.84	45.02	0.09	0.78	95.05	35.23	1.65	94.60	2.03	7.18
	Slimes	0.52	23.28	7.24	15.82	44.37	6.31	0.90	33.24	35.19	0.76	95.36	11.70	0.21
	Tails 1	76.72	100.00	0.30	0.66	10.83	0.09	0.28	98.10	83.45	4.64	100.00	24.75	90.18
	Feed	100.00		4.96	10.83		0.28		83.45		100.00		100.00	100.00
PAM 0.5	Concentrate	13.23		29.55	64.57		0.97		7.31		81.29		38.53	1.16
	Tails 4	1.51	14.74	19.23	42.02	62.26	0.56	0.93	40.61	10.71	6.02	87.30	2.53	0.73
	Tails 3	0.66	15.39	5.50	12.02	60.12	0.33	0.90	81.14	13.71	0.75	88.05	0.65	0.64
	Tails 2	2.82	18.21	1.31	2.86	51.27	0.14	0.78	94.82	26.26	0.77	88.82	1.18	3.19
	Slimes	0.36	18.57	6.81	14.88	50.55	5.29	0.87	35.53	26.44	0.52	89.33	5.78	0.15
	Tails 1	81.43	100.00	0.63	1.38	10.51	0.21	0.33	96.73	83.67	10.67	100.00	51.33	94.13
	Feed	100.00		4.81	10.51		0.33		83.67		100.00		100.00	100.00
Starch 1.0	Concentrate	13.16		29.75	65.00		0.94		6.01		79.86		45.13	0.95
	Tails 4	1.49	14.65	28.19	61.60	64.66	0.78	0.92	12.09	6.63	8.55	88.41	4.23	0.22
	Tails 3	0.58	15.22	13.37	29.21	63.32	0.46	0.91	55.82	8.49	1.57	89.98	0.97	0.38
	Tails 2	5.54	20.76	1.29	2.82	47.18	0.06	0.68	95.30	31.64	1.46	91.44	1.21	6.32
	Slimes	0.55	21.31	9.05	19.77	46.47	5.54	0.81	33.32	31.69	1.02	92.45	11.14	0.22
	Tails 1	78.69	100.00	0.47	1.03	10.71	0.13	0.27	97.45	83.44	7.55	100.00	37.32	91.91
	Feed	100.00		4.90	10.71		0.27		83.44		100.00		100.00	100.00

Table 25 (Cont.). Complete Flowsheet Test Results Using Mosaic #2 Feed.

Reagent (kg/T, Feed)	Product	Weight (%)		Analysis (%)						Distribution (%)			
				BPL		MgO		A.I.		BPL		MgO	A.I.
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		
CMC 1.0	Concentrate	12.63		65.35		0.79		6.60		74.32		39.99	1.00
	Tails 3	1.23	13.86	49.84	63.98	0.55	0.77	28.40	8.54	5.52	79.85	2.71	0.42
	Tails 2	2.78	16.65	4.68	54.06	0.11	0.66	92.22	22.52	1.17	81.02	1.23	3.07
	Slimes	0.37	17.02	21.02	53.35	6.43	0.78	20.55	22.48	0.70	81.72	9.52	0.09
	Tails 1	82.98	100.00	2.45	11.11	0.14	0.25	96.01	83.50	18.28	100.00	46.55	95.42
	Feed	100.00		11.11		0.25		83.50		100.00		100.00	100.00
Hengju #9 0.05	Concentrate	14.41		65.33		0.85		6.83		87.90		44.19	1.18
	Tails 4	0.62	15.02	42.96	64.41	0.58	0.84	37.34	8.08	2.48	90.38	1.29	0.28
	Tails 3	0.67	15.69	13.18	62.23	0.27	0.81	79.18	11.11	0.82	91.20	0.65	0.63
	Tails 2	3.21	18.90	3.19	52.20	0.08	0.69	93.88	25.17	0.96	92.16	0.93	3.61
	Slimes	0.44	19.35	18.33	51.42	5.78	0.81	32.53	25.34	0.76	92.92	9.28	0.17
	Tails 1	80.65	100.00	0.94	10.71	0.15	0.28	97.56	83.59	7.08	100.00	43.66	94.13
	Feed	100.00		10.71		0.28		83.59		100.00		100.00	100.00

EXPLORATORY FLOWSHEET DEVELOPMENT

The test results discussed above indicate that adding dolomite depressant alone in the fatty acid flotation step can lower the MgO content to some extent, but cannot meet the goal of the proposed research program. This limitation is mainly attributed to non-liberated dolomite in the coarser fraction of the flotation feed. Therefore, eight different approaches were tested to increase the chance of success.

FLOTATION FEED GRINDING FOLLOWED BY FLOTATION

Sizing analyses of the flotation feeds (Tables 8-10) show that a majority of the dolomite is concentrated in the small amount of +0.5 mm fraction. For example, the +0.5 mm fraction accounts for 8.62% of the CF feed and contains 1.46% MgO, or 28.28% of the total MgO; the corresponding numbers for the Mosaic feed #1 are 7.55%, 2.14% and 31.33%. Grinding the flotation feed naturally makes some sense. Figure 22 shows the processing flowsheet. The test results are shown in Table 26. These results are somewhat surprising because the finer the grinding, the higher the MgO content was in the final concentrate. Besides, phosphate loss was significant. This approach therefore did not prove to be viable.

ROUGHER CONCENTRATE GRINDING FOLLOWED BY FLOTATION

Figure 23 is a flowchart for this approach. The test results shown in Table 26 indicate a small reduction of MgO in the final concentrate, but with significant sacrifice of phosphate recovery.

CONCENTRATE GRINDING FOLLOWED BY FLOTATION

The concentrate from the double float process was ground, followed by a dolomite flotation step to further reduce MgO content using a 0.5 liter XFD-0.5 flotation machine. The flowsheet is shown in Figure 24. Results (Table 27) indicate that MgO was reduced substantially with appreciable loss of phosphate.

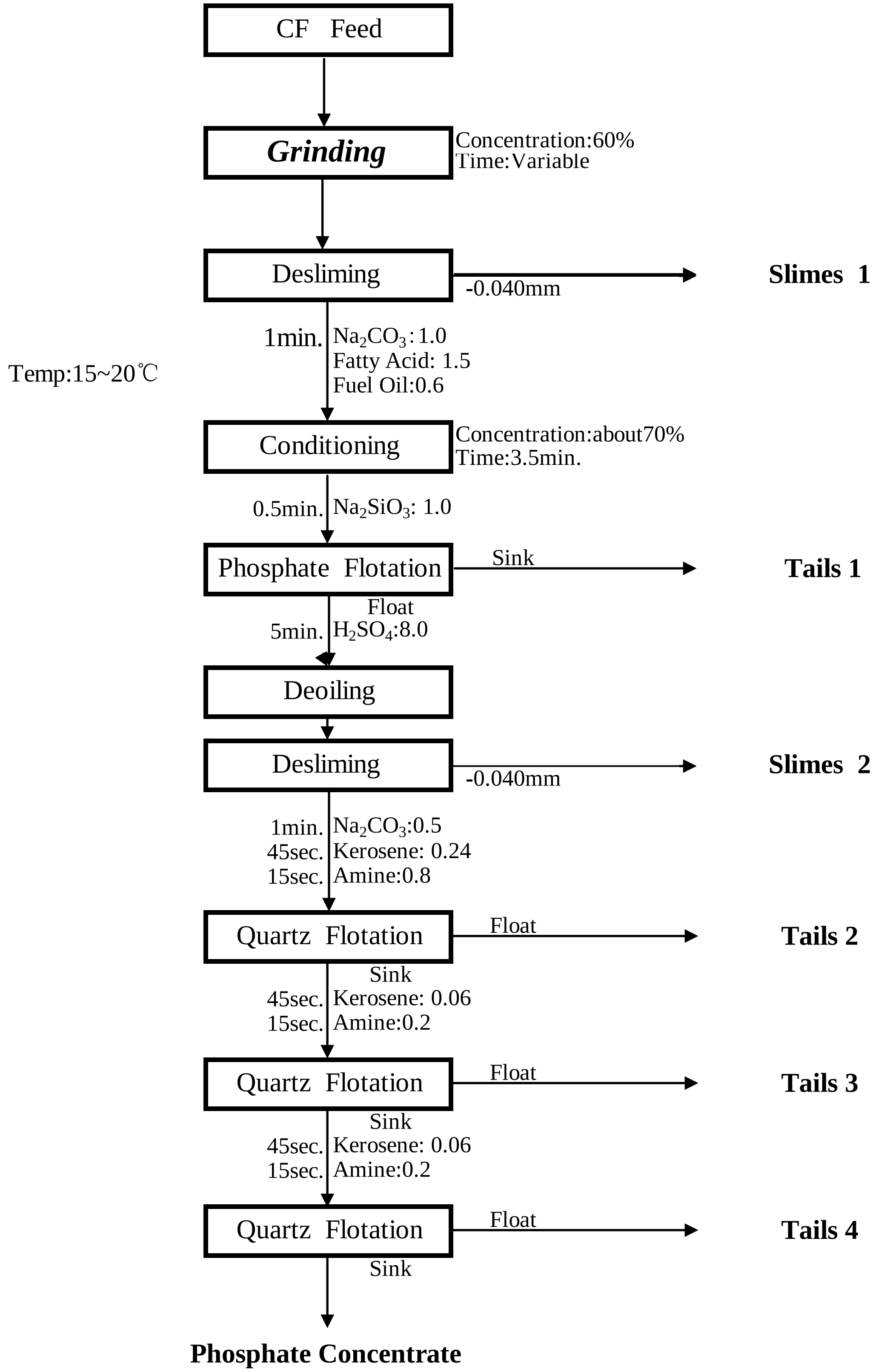


Figure 22. Flowsheet with Feed Grinding.

Table 26. Double Float Testing Results with Feed Grinding.

Grinding Time	Product	Weight (%)		Analysis (%)						Distribution (%)			
				BPL		MgO		A.I.		BPL		MgO	A.I.
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		
3 min.	Concentrate	22.28		66.53		1.03		5.74		86.84		53.93	1.73
	Tails 4	0.92	23.20	31.49	65.14	0.59	1.01	54.71	7.69	1.70	88.55	1.28	0.68
	Tails 3	1.07	24.27	12.04	62.80	0.33	0.98	81.59	10.95	0.75	89.30	0.83	1.18
	Tails 2	7.47	31.74	2.67	48.65	0.14	0.78	95.40	30.82	1.17	90.47	2.46	9.62
	Slimes 2	2.12	33.85	31.81	47.60	5.61	1.09	26.26	30.53	3.94	94.41	27.90	0.75
	Tails 1	64.28	98.13	0.63	16.84	0.09	0.43	98.17	74.84	2.39	96.80	13.60	85.24
	Slimes 1	1.87	100.00	29.19	17.07	5.28	0.52	31.48	74.02	3.20	100.00	23.24	0.80
	Feed	100.00		17.07		0.52		74.02		100.00		100.00	100.00
9 min.	Concentrate	19.58		66.42		1.15		5.10		76.03		41.77	1.35
	Tails 3	1.95	21.52	43.79	64.38	0.70	1.11	39.20	8.18	4.98	81.02	2.53	1.03
	Tails 2	3.31	24.84	3.04	56.19	0.03	0.97	95.34	19.81	0.59	81.61	0.18	4.27
	Slimes 2	3.41	28.25	40.71	54.32	2.83	1.19	30.74	21.13	8.12	89.72	17.91	1.42
	Tails 1	68.10	96.35	1.01	16.64	0.11	0.43	97.84	75.35	4.00	93.73	13.90	90.00
	Slimes 1	3.65	100.00	29.39	17.10	3.50	0.54	39.30	74.03	6.27	100.00	23.71	1.94
	Feed	100.00		17.10		0.54		74.03		100.00		100.00	100.00

Operating Conditions

Operation	Conditioning				Times (Min.)	Reagents, kg/T Feed						
	Impeller Rotation Speed (rpm)	Aeration (L/Min.)	Solids %	pH		Na_2CO_3	Fatty Acid	Fuel Oil	Na_2SiO_3	H_2SO_4	Kerosene	Amine
Grinding			60									
Phosphate Flotation	1600	1.2	30	8.8~9.2	2.5	1.0	1.5	0.6	1.0			
Deoiling	1600				5.0					8.0		
Quartz Flotation	1600	1.2		7.4~7.5	4.0	0.5					0.3	1.0
Total Reagent Consumption, kg/T Feed						1.5	1.5	0.6	1.0	8.0	0.3	1.0

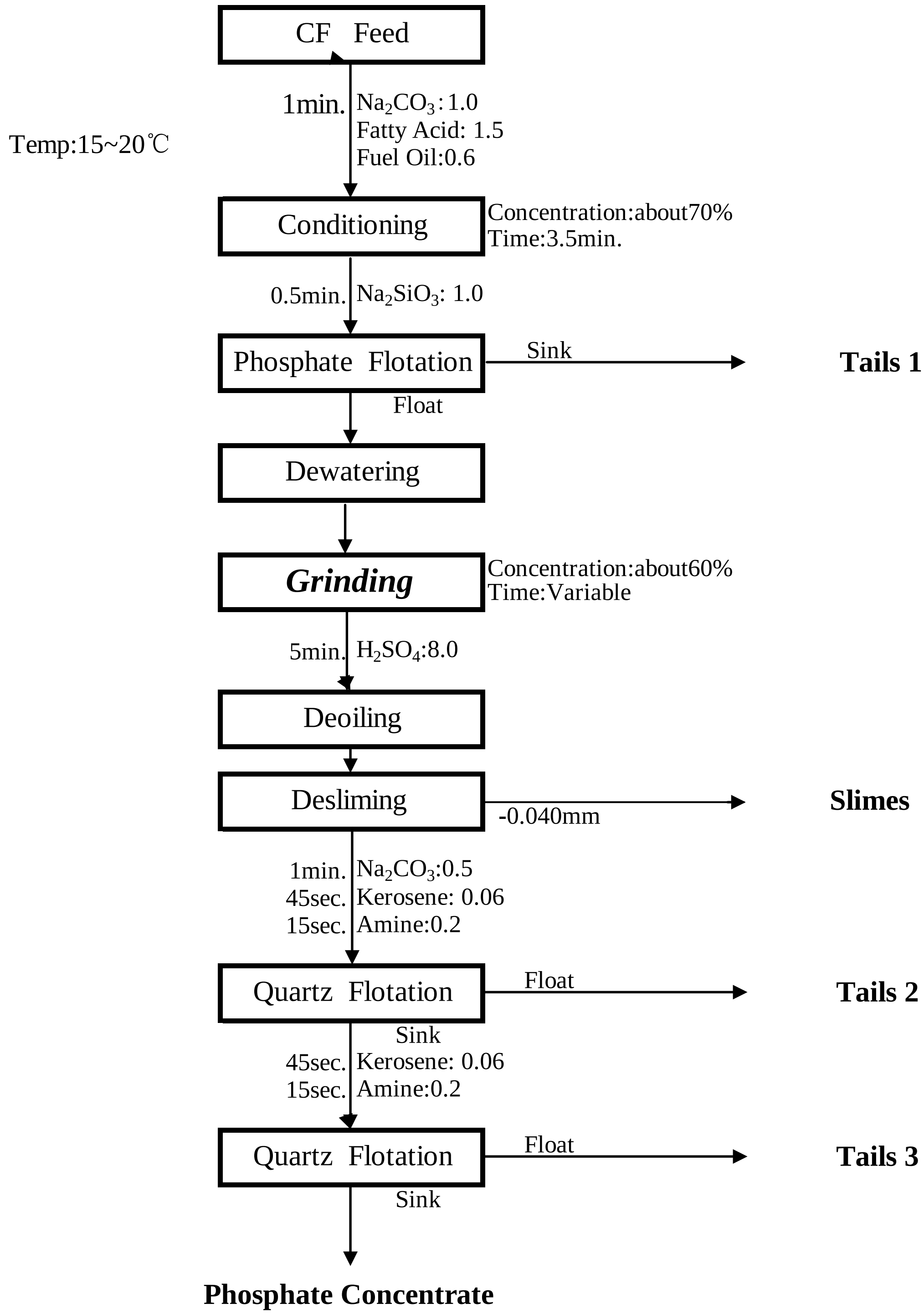


Figure 23. Flowsheet for Rougher Concentrate Grinding.

Table 27. Flotation Results with Rougher Concentrate Grinding.

Grinding Time	Product	Weight (%)		Analysis (%)						Distribution (%)			
				BPL		MgO		A.I.		BPL		MgO	A.I.
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		
3 min.	Concentrate	20.69		65.72		0.99				81.09		41.26	0.00
	Tails 3	2.21	22.90	20.98	86.70	0.27	1.26	6.75	6.75	2.76	83.85	1.20	0.78
	Tails 2	5.58	28.48	2.05	49.78	0.02	0.74	69.66	14.18	0.68	84.53	0.22	20.37
	Slimes	4.09	32.57	47.17	49.45	3.82	1.13	96.81	24.56	11.51	96.05	31.50	20.76
	Tails 1	67.43	100.00	0.98	16.77	0.19	0.50	16.45	19.09	3.95	100.00	25.81	58.10
	Feed	100.00		16.77		0.50		97.21		100.00		100.00	100.00
5 min.	Concentrate	17.22		66.18		0.97		5.78		68.28		33.76	1.33
	Tails 3	3.01	20.23	44.44	110.63	0.52	1.49	37.93	43.71	8.02	76.30	3.17	1.53
	Tails 2	6.12	26.35	2.47	48.89	0.02	0.70	96.16	30.45	0.91	77.21	0.25	7.88
	Slimes	6.51	32.87	50.28	49.17	2.71	1.10	18.05	28.00	19.63	96.84	35.69	1.57
	Tails 1	67.13	100.00	0.79	16.69	0.20	0.49	97.62	74.74	3.16	100.00	27.14	87.69
	Feed	100.00		16.69		0.49		74.74		100.00		100.00	100.00

Operating Conditions

Operation	Conditioning				Times (Min.)	Reagents, kg/T Feed						
	Impeller Rotation Speed (rpm)	Aeration (L/Min.)	Solids %	pH		Na_2CO_3	Fatty Acid	Fuel Oil	Na_2SiO_3	H_2SO_4	Kerosene	Amine
Phosphate Flotation	1600	1.2	27	8.8~9.2	2.5	1.0	1.5	0.6	1.0			
Grinding			~ 60		Variable							
Deoiling	1600				5.0					8.0		
Quartz Flotation	1600	1.2		7.4~7.5	4.0	0.5					0.3	1.0
Total Reagent Consumption, kg/T Feed						1.5	1.5	0.6	1.0	8.0	0.3	1.0

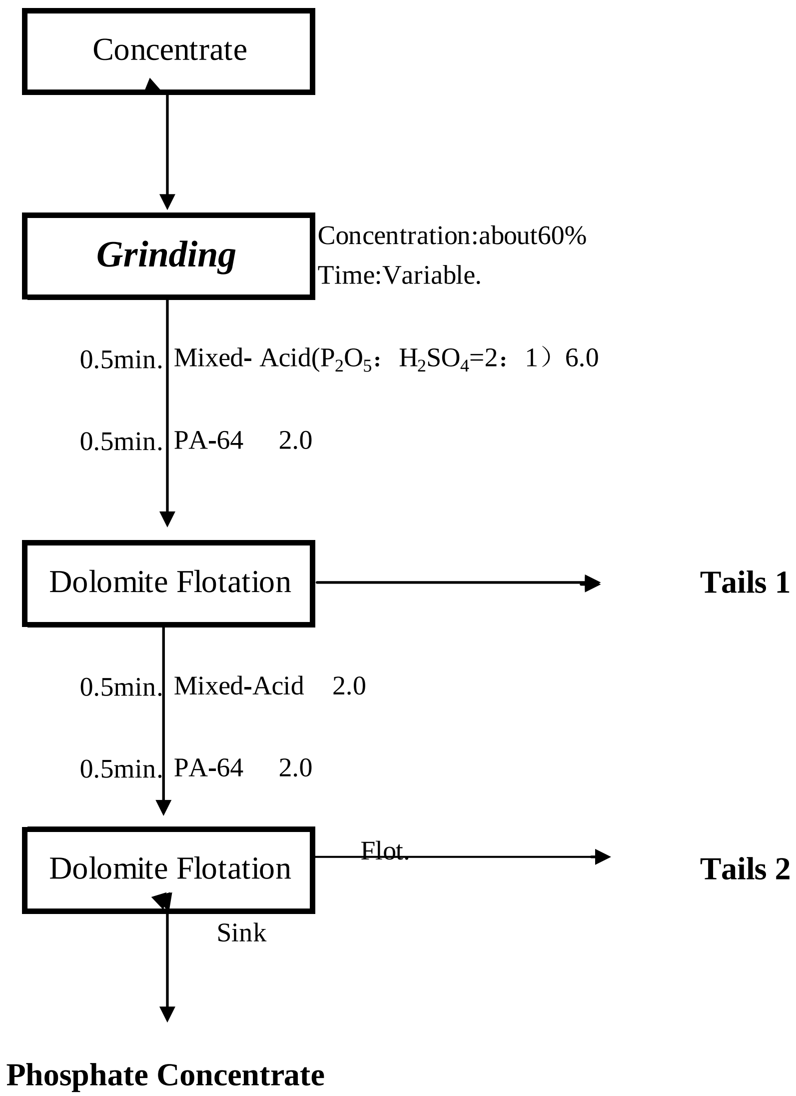


Figure 24. Flowsheet for Concentrate Grinding Followed by Dolomite Flotation.

Table 28. Test Results with Concentrate Grinding.

Grinding Time	Product	Weight (%)	Analysis (%)			Distribution (%)		
			BPL	MgO	A.I.	BPL	MgO	A.I.
5 min.	Concentrate	91.81	66.73	0.78	7.15	92.58	76.76	92.93
	Tails 2	3.18	65.40	1.33	5.86	3.14	4.53	2.64
	Tails 1	5.02	56.42	3.48	6.25	4.28	18.71	4.44
	Feed	100.00	66.17	0.93	7.06	100.00	100.00	100.00

Operating Conditions

Operation	Conditioning			Reagents, kg/T Feed	
	Impeller Rotation Speed (rpm)	Aeration (L/Min.)	pH	Mixed Acid*	PA-64
Dolomite Flotation I	2000	0.3	4.3~5.0	6.0	2.0
Dolomite Flotation II	2000	0.3	4.1~4.7	2.0	2.0
Total Reagent Consumption, kg/T Feed				8.0	4.0

REAGENT ADDITION IN THE DEOILING STEP

In these tests the standard double float process was followed, but different reagents were added in the deoiling step, as is shown in Figure 25. Test results are shown in Table 29. It can be seen from Table 29 that addition of NaOH, Na_2CO_3, and HCl did not have a significant effect, while H_3PO_4 lowered MgO by a small amount. Increased use of H_2SO_4 had a more dramatic impact on MgO reduction, but phosphate loss was equally higher.

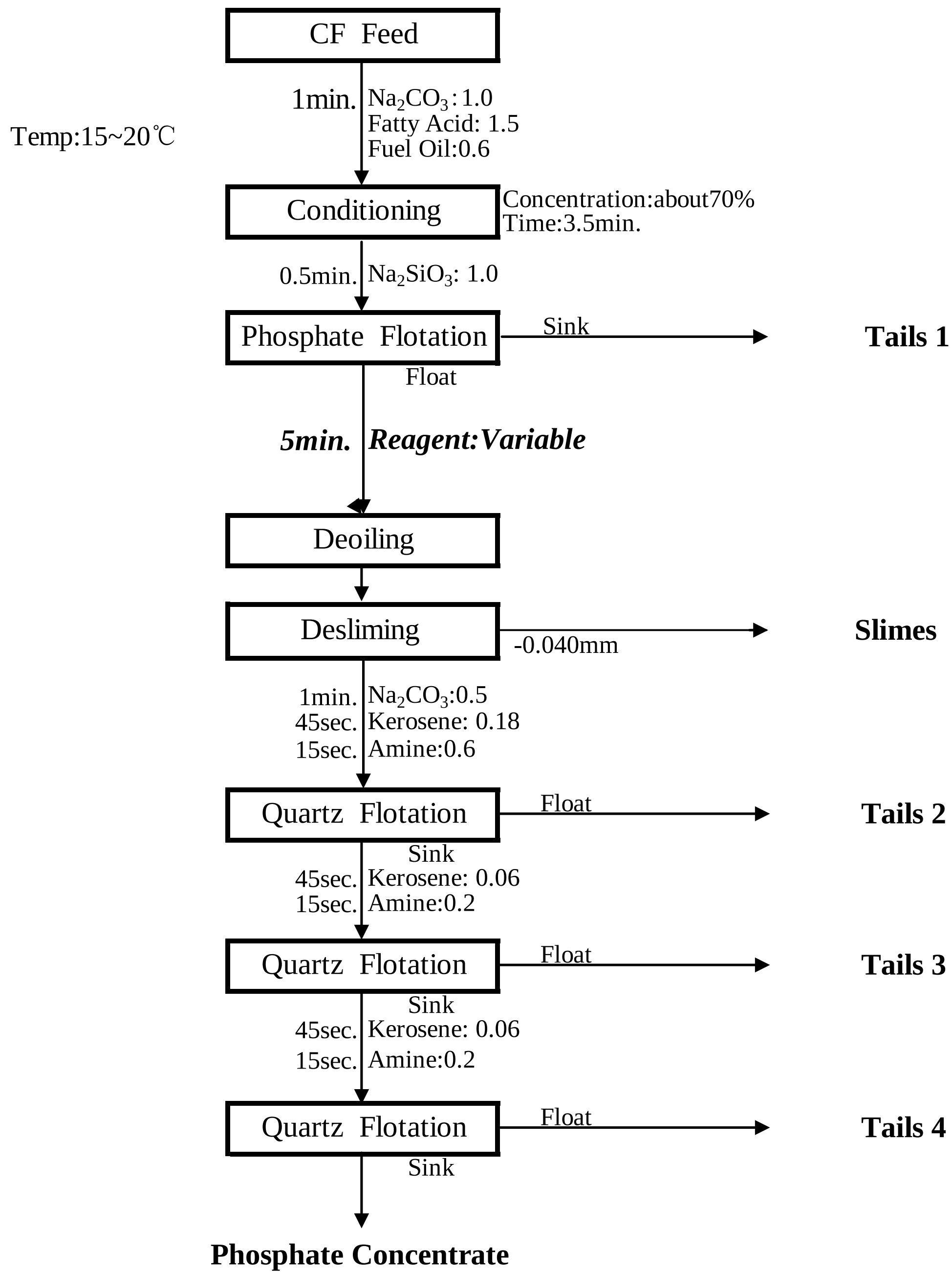


Figure 25. Flowsheet for Testing Different Reagents in the Deoiling Step.

Table 29. Effect of Deoiling Agents on MgO Content in the Concentrate.

Reagent (kg/T, Feed)	Product	Weight (%)		Analysis (%)						Distribution (%)				
				BPL		MgO		A.I.		BPL		MgO	A.I.	
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		Indiv.	Cum.
NaOH 5.0	Concentrate	24.03		60.09		1.13		14.93		81.90		49.80	4.86	
	Tails 3	5.97	29.99	21.57	81.65	0.35	1.48	69.77	84.70	7.30	89.20	3.83	5.64	10.51
	Tails 2	2.27	32.26	46.21	51.99	0.59	0.95	36.23	26.57	5.94	95.14	2.45	1.11	11.62
	Slimes	0.81	33.07	4.65	50.83	11.36	1.20	25.39	26.54	0.21	95.35	16.90	0.28	11.90
	Tails 1	66.93	100.00	1.22	17.63	0.22	0.55	97.10	73.76	4.65	100.00	27.01	88.10	100.00
	Feed	100.00		17.63		0.55		73.76		100.00		100.00	100.00	
Na_2CO_3 5.0	Concentrate	19.58		65.05		1.30		7.18		73.56		47.81	1.91	
	Tails 4	1.21	20.79	43.07	63.76	0.65	1.26	38.94	9.03	3.02	76.58	1.48	0.64	2.55
	Tails 3	4.85	25.64	25.52	56.53	0.37	1.09	63.84	19.40	7.15	83.73	3.37	4.21	6.76
	Tails 2	6.90	32.54	29.98	50.90	0.42	0.95	58.41	27.67	11.95	95.68	5.44	5.47	12.24
	Slimes	0.95	33.49	5.35	49.61	10.16	1.21	27.92	27.68	0.29	95.97	18.16	0.36	12.60
	Tails 1	66.51	100.00	1.05	17.31	0.19	0.53	96.72	73.60	4.03	100.00	23.74	87.40	100.00
	Feed	100.00		17.31		0.53		73.60		100.00		100.00	100.00	
HCl 8.0	Concentrate	24.13		65.70		1.13		6.60		93.83		55.35	2.13	
	Tails 4	0.53	24.66	13.98	64.59	0.43	1.11	78.76	8.15	0.44	94.27	0.46	0.56	2.69
	Tails 3	2.25	26.91	5.55	59.66	0.16	1.04	91.68	15.13	0.74	95.00	0.73	2.76	5.45
	Tails 2	4.76	31.67	4.57	51.38	0.11	0.90	93.05	26.84	1.29	96.29	1.06	5.93	11.38
	Slimes	0.92	32.58	8.94	50.19	11.00	1.18	26.72	26.83	0.49	96.77	20.50	0.33	11.71
	Tails 1	67.42	100.00	0.81	16.90	0.16	0.49	97.76	74.65	3.23	100.00	21.90	88.29	100.00
	Feed	100.00		16.90		0.49		74.65		100.00		100.00	100.00	

Table 29 (Cont.). Effect of Deoiling Agents on MgO Content in the Concentrate.

Reagent (kg/T, Feed)	Product	Weight (%)		Analysis (%)						Distribution (%)				
				BPL		MgO		A.I.		BPL		MgO	A.I.	
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		Indiv.	Cum.
$H_3PO_4(P_2O_5)$ 8.0	Concentrate	23.28		67.76		1.02		5.45		90.71		48.26	1.71	
	Tails 4	0.89	24.17	59.43	67.45	0.83	1.01	17.07	5.88	3.04	93.76	1.50	0.20	1.92
	Tails 3	0.84	25.01	15.91	65.71	0.51	1.00	76.22	8.25	0.77	94.53	0.87	0.87	2.78
	Tails 2	6.69	31.70	3.36	52.55	0.13	0.81	94.85	26.53	1.30	95.82	1.77	8.56	11.34
	Slimes	0.99	32.69	10.97	51.30	10.77	1.11	25.56	26.50	0.62	96.45	21.60	0.34	11.68
	Tails 1	67.31	100.00	0.92	17.39	0.19	0.49	97.35	74.19	3.55	100.00	25.99	88.32	100.00
	Feed	100.00		17.39		0.49		74.19		100.00		100.00	100.00	
H_2SO_4 16.0 Times: 30'	Concentrate	20.54		66.86		0.79		6.07		83.35		37.62	1.67	
	Tails 2	8.15	28.69	2.95	48.70	0.12	0.60	95.37	31.44	1.46	84.81	2.27	10.44	12.11
	Slimes	4.16	32.85	41.45	47.78	2.84	0.88	12.56	29.05	10.47	95.28	27.41	0.70	12.81
	Tails 1	67.15	100.00	1.16	16.48	0.21	0.43	96.72	74.49	4.72	100.00	32.70	87.19	100.00
	Feed	100.00		16.48		0.43		74.49		100.00		100.00	100.00	

Operating Conditions

Operation	Conditioning				Times (Min.)	Reagents, kg/T Feed							
	Impeller Rotation Speed (rpm)	Aeration (L/Min.)	Solids %	pH		Na_2CO_3	Fatty Acid	Fuel Oil	Na_2SiO_3	H_2SO_4	Kerosene	Amine	Deoiling Reagent
Phosphate Flotation	1600	1.2	27	8.8~9.2	2.5	1.0	1.5	0.6	1.0				
Deoiling	1600				5.0								Variable
Quartz Flotation	1600	1.2		7.4~7.5	4.0	0.5					0.3	1.0	
Total Reagent Consumption, kg/T Feed						1.5	1.5	0.6	1.0		0.3	1.0	

DOLOMITE FLOTATION WITHOUT GRINDING

Both the rougher and cleaner concentrates generated using the Crago flowsheet were subject to dolomite flotation to compare performance of dolomite collectors USPA-31 and PA-64. Collector USPA-31 is a proprietary reagent produced in the FIPR lab, while PA-64 is a product made in China (Gruber and others 2001; Gu and others 1999).

A flowsheet for floating rougher concentrate is shown in Figure 26, with the results listed in Table 30. The corresponding flowsheet and test results for cleaner concentrate are shown in Figure 27 and Table 31.

As shown in Tables 30 and 31, in the flotation of the rougher concentrate dolomite removal was insignificant using either collector, while dolomite was reduced by a small margin by flotation of the cleaner concentrate.

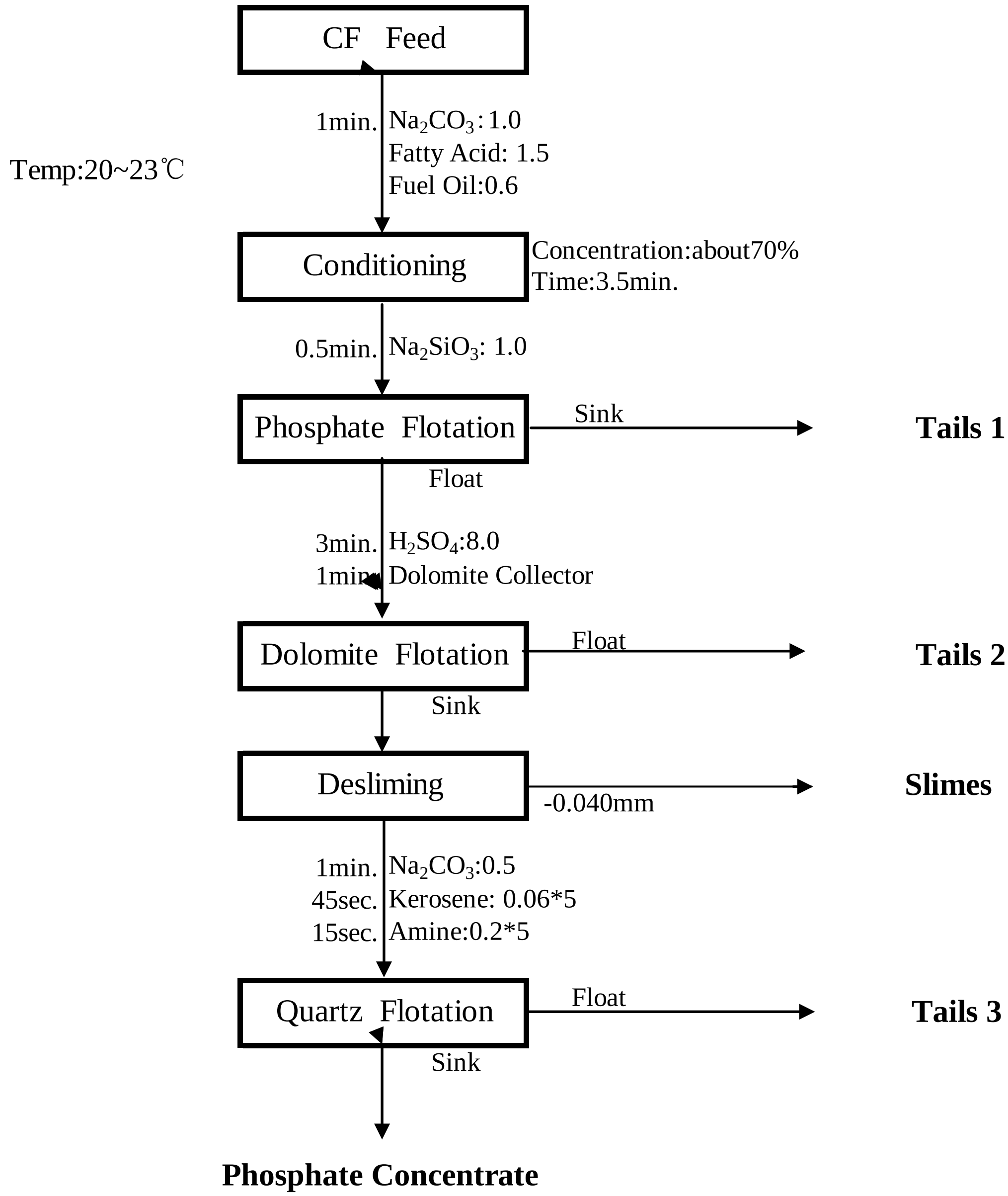


Figure 26. Flowsheet for Direct Flotation of the Rougher Concentrate.

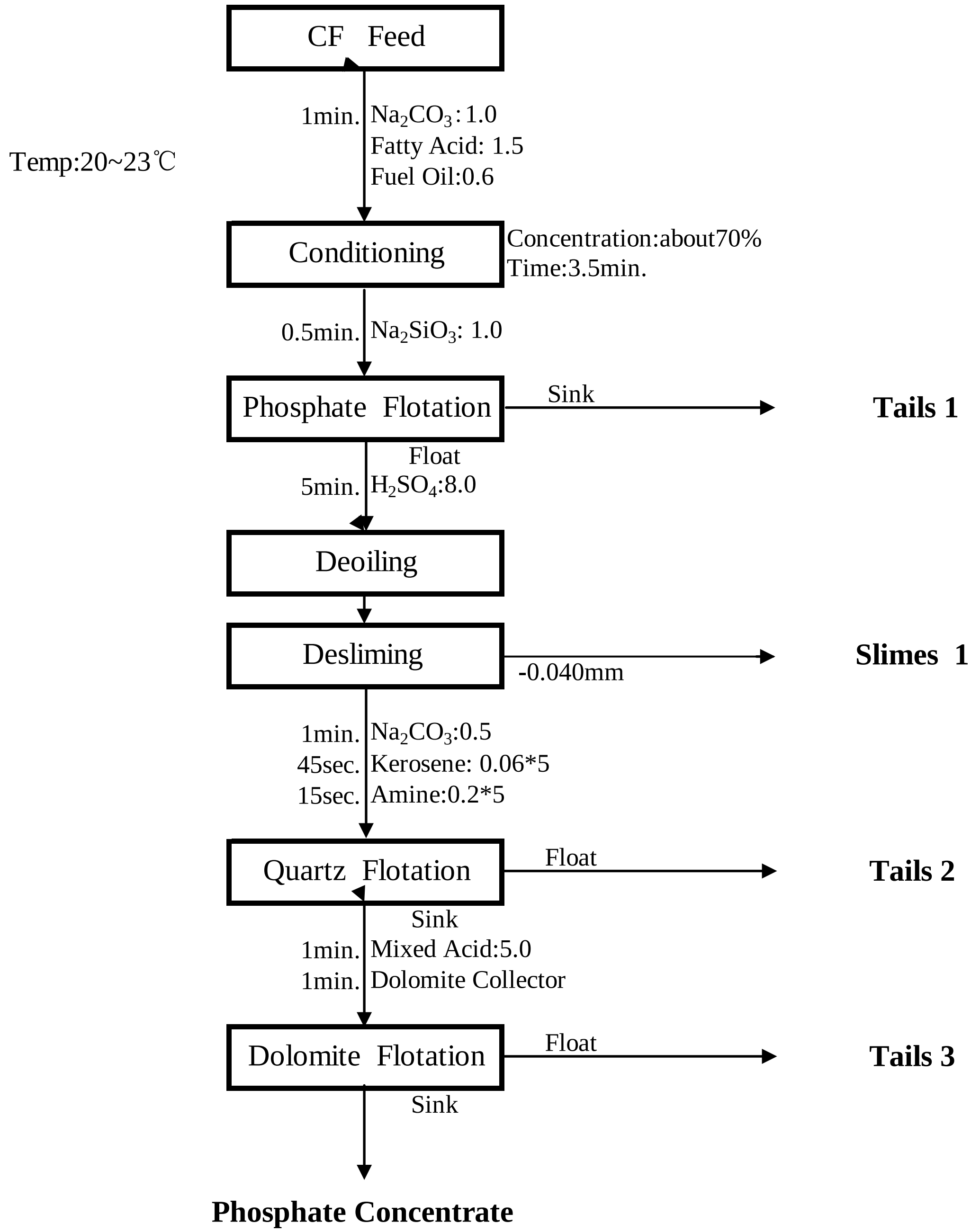


Figure 27. Flowsheet for Direct Flotation of the Cleaner Concentrate.

Table 30. Results from Direct Flotation of the Rougher Concentrate.

Dolomite Collector	Product	Weight (%)		Analysis (%)						Distribution (%)			
				BPL		MgO		A.I.		BPL		MgO	A.I.
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		
PA-64 2.0 kg/t	Concentrate	23.54		66.66		1.10		6.53		92.60		46.69	2.09
	Tails 3	9.35	32.89	3.30	48.65	0.20	1.30	94.14	100.67	1.82	94.43	3.37	11.97
	Slimes	0.50	33.38	19.03	48.21	7.77	0.95	27.09	31.37	0.56	94.98	6.95	0.18
	Tails 2	1.02	34.40	17.35	47.30	7.96	1.15	31.41	31.38	1.04	96.02	14.60	0.43
	Tails 1	65.60	100.00	1.03	16.94	0.24	0.55	95.62	73.52	3.98	100.00	28.39	85.32
	Feed	100.00		16.94		0.55		73.52		100.00		100.00	100.00
H_2SO_4 16.0 Times: 30’	Concentrate	23.79		65.75		1.03		6.98		92.81		46.09	2.23
	Tails 3	8.98	32.77	2.75	48.48	0.15	1.18	95.13	102.11	1.47	94.27	2.53	11.47
	Slimes	0.57	33.34	18.07	47.96	7.46	0.90	27.06	31.07	0.61	94.88	7.97	0.21
	Tails 2	0.84	34.18	18.79	47.25	7.89	1.07	27.54	30.99	0.94	95.82	12.45	0.31
	Tails 1	65.82	100.00	1.07	16.85	0.25	0.53	97.14	74.53	4.18	100.00	30.95	85.79
	Feed	100.00		16.85		0.53		74.53		100.00		100.00	100.00

Operating Conditions

Operation	Conditioning			Times (Min.)	Reagents, kg/T Feed						
	Impeller Rotation Speed (rpm)	Aeration (L/Min.)	pH		Na_2CO_3	Fatty Acid	Fuel Oil	Na_2SiO_3	H_2SO_4	Kerosene	Amine
Phosphate Flotation	1600	1.2	8.8~9.2	2.5	1.0	1.5	0.6	1.0			
Dolomite Flotation	1600		4.5~5.0	3.0					8.0		
Desliming	1600										
Quartz Flotation	1600	1.2	7.4~7.5	4.0	0.5					0.3	1.0
Total Reagent Consumption, kg/T Feed					1.5	1.5	0.6	1.0	8.0	0.3	1.0

Table 31. Results from Direct Flotation of the Cleaner Concentrate.

Dolomite Collector	Product	Weight (%)		Analysis (%)						Distribution (%)			
				BPL		MgO		A.I.		BPL		MgO	A.I.
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		
PA-64 2.0 kg/t	Concentrate	24.00		65.31		0.99		7.72		94.56		47.22	2.47
	Tails 3	0.00	24.00	0.00	65.31	0.00	0.99	0.00	7.72	0.00	94.56	0.00	0.00
	Tails 2	8.90	32.90	2.84	48.41	0.21	0.78	94.64	31.23	1.52	96.08	3.71	11.24
	Slimes	1.05	33.95	13.81	47.35	9.71	1.05	25.02	31.04	0.87	96.95	20.20	0.35
	Tails 1	66.05	100.00	0.76	16.58	0.22	0.50	97.44	74.90	3.05	100.00	28.87	85.93
	Feed	100.00		16.58		0.50		74.90		100.00		100.00	100.00
USPA-31 2.5 kg/t	Concentrate	23.68		66.05		1.02		7.09		93.62		48.87	2.23
	Tails 3	0.00	23.68	0.00	66.05	0.00	1.02	0.00	7.09	0.00	93.62	0.00	0.00
	Tails 2	9.18	32.86	2.91	48.42	0.20	0.79	94.77	31.58	1.60	95.22	3.71	11.54
	Slimes	1.08	33.93	13.90	47.32	9.51	1.07	26.46	31.42	0.89	96.11	20.69	0.38
	Tails 1	66.07	100.00	0.98	16.71	0.20	0.49	97.95	75.37	3.89	100.00	26.73	85.86
	Feed	100.00		16.71		0.49		75.37		100.00		100.00	100.00

Operating Conditions

Operation	Conditioning			Times (Min.)	Reagents, kg/T Feed							
	Impeller Rotation Speed (rpm)	Aeration (L/Min.)	pH		Na_2CO_3	Fatty Acid	Fuel Oil	Na_2SiO_3	H_2SO_4	Kerosene	Amine	Mixed Acid
Phosphate Flotation	1600	1.2	8.8~9.2	2.5	1.0	1.5	0.6	1.0				
Desliming	1600								8.0			
Quartz Flotation	1600	1.2	7.4~7.5	4.0	0.5					0.3	1.0	
Dolomite Flotation	1600		4.5~5.0	3.0								5.0
Total Reagent Consumption, kg/T Feed					1.5	1.5	0.6	1.0	8.0	0.3	1.0	5.0

DOLOMITE FLOTATION WITH GRINDING

Since dolomite flotation without grinding did not produce satisfactory results, further experiments were conducted with the rougher concentrate and cleaner concentrate ground to a degree. Again, comparative flotation tests were conducted with dolomite collectors USPA-31 and PA-64. In these experiments, the effects of grinding time and fineness were evaluated. The test flowsheet is shown in Figure 28. Comparison results for the two dolomite collectors are shown in Table 32, and the effect of grinding time is reported in Table 33.

The results shown in Table 32 show that for the 7-minute grinding feed, both collectors were somewhat effective in removing dolomite, with PA-64 being a little better. Grinding-flotation tests (Table 33) indicated that the finer the flotation feed, the lower the dolomite in the final concentrate, with the lowest achievable MgO content being around 0.7%.

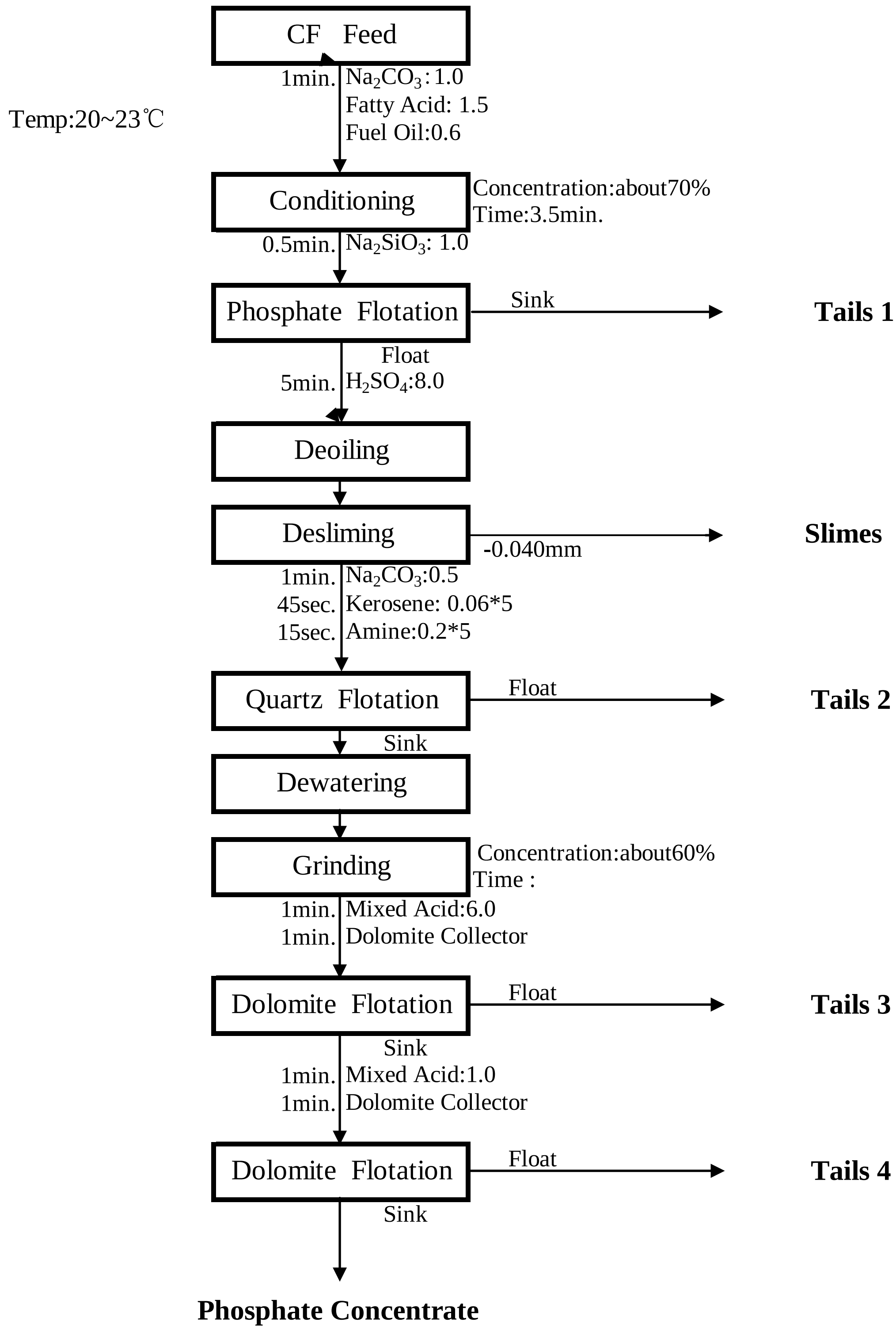


Figure 28. Flowsheet for Dolomite Flotation with Grinding.

Table 32. Dolomite Collector Comparison with Concentrate Grinding.

Dolomite Collector	Product	Weight (%)		Analysis (%)						Distribution (%)			
				BPL		MgO		A.I.		BPL		MgO	A.I.
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		
PA-64 2.0 + 2.0	Concentrate	18.85		67.91		0.77		6.17		75.38		27.76	1.56
	Tails 4	1.27	20.12	63.32	67.62	1.69	0.83	6.08	6.16	4.74	80.12	4.11	0.10
	Tails 3	3.65	23.77	62.99	66.91	1.98	1.01	6.18	6.17	13.55	93.67	13.84	0.30
	Tails 2	8.48	32.26	3.80	50.32	0.29	0.82	92.57	28.88	1.90	95.57	4.70	10.54
	Slimes	0.98	33.23	14.25	49.26	10.83	1.11	25.12	28.77	0.82	96.39	20.20	0.33
	Tails 1	66.77	100.00	0.92	16.98	0.23	0.52	97.22	74.47	3.61	100.00	29.38	87.16
	Feed	100.00		16.98		0.52		74.47		100.00		100.00	100.00
USPA-31 2.0 + 2.0	Concentrate	20.15		67.04		0.89		7.06		80.48		34.20	1.90
	Tails 4	1.27	21.42	61.38	66.70	2.23	0.97	6.25	7.01	4.64	85.12	5.40	0.11
	Tails 3	2.63	24.05	61.55	66.14	2.04	1.09	6.76	6.98	9.63	94.76	10.22	0.24
	Tails 2	8.31	32.36	2.88	49.89	0.24	0.87	94.40	29.44	1.43	96.18	3.80	10.49
	Slimes	0.94	33.30	13.90	48.88	10.29	1.13	24.28	29.29	0.78	96.96	18.39	0.30
	Tails 1	66.70	100.00	0.76	16.78	0.22	0.52	97.54	74.82	3.04	100.00	27.98	86.96
	Feed	100.00		16.78		0.52		74.82		100.00		100.00	100.00

Operating Conditions

Operation	Conditioning				Times (Min.)	Reagents, kg/T Feed							
	Impeller Rotation Speed (rpm)	Aeration (L/Min.)	Solids %	pH		Na_2CO_3	Fatty Acid	Fuel Oil	Na_2SiO_3	H_2SO_4	Kerosene	Amine	Mixed Acid
Phosphate Flotation	1600	1.2	27	8.8~9.2	2.5	1.0	1.5	0.6	1.0				
Desliming	1600									8.0			
Quartz Flotation	1600	1.2		7.4~7.5	4.0	0.5					0.3	1.0	
Grinding	1600				7.0								
Dolomite Flotation	2000			4.5~5.0	7.0+6.0								6.0+2.0
Total Reagent Consumption, kg/T Feed						1.5	1.5	0.6	1.0	8.0	0.3	1.0	8.0

Table 33. Concentrate Flotation Results with Varying Grinding Time (Fineness).

Grinding Time	Product	Weight (%)		Analysis (%)						Distribution (%)			
				BPL		MgO		A.I.		BPL		MgO	A.I.
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		
5 min. -200 mesh 19.69%	Concentrate	20.00		66.62		0.88		6.96		79.29		36.11	1.86
	Tails 4	1.08	21.08	62.32	66.40	2.00	0.94	6.68	6.95	4.00	83.29	4.43	0.10
	Tails 3	2.93	24.01	61.31	65.78	2.12	1.08	7.24	6.98	10.68	93.97	12.73	0.28
	Tails 2	7.86	31.87	5.05	50.80	0.25	0.88	93.54	28.33	2.36	96.33	4.03	9.83
	Slimes	1.00	32.88	13.26	49.65	9.36	1.14	24.98	28.23	0.79	97.12	19.29	0.34
	Tails 1	67.12	100.00	0.72	16.81	0.17	0.49	97.67	74.84	2.88	100.00	23.41	87.60
	Feed	100.00		16.81		0.49		74.84		100.00		100.00	100.00
7 min. -200 mesh 30.91%	Concentrate	18.85		67.91		0.77		6.17		75.38		27.76	1.56
	Tails 4	1.27	20.12	63.32	67.62	1.69	0.83	6.08	6.16	4.74	80.12	4.11	0.10
	Tails 3	3.65	23.77	62.99	66.91	1.98	1.01	6.18	6.17	13.55	93.67	13.84	0.30
	Tails 2	8.48	32.26	3.80	50.32	0.29	0.82	92.57	28.88	1.90	95.57	4.70	10.54
	Slimes	0.98	33.23	14.25	49.26	10.83	1.11	25.12	28.77	0.82	96.39	20.20	0.33
	Tails 1	66.77	100.00	0.92	16.98	0.23	0.52	97.22	74.47	3.61	100.00	29.38	87.16
	Feed	100.00		16.98		0.52		74.47		100.00		100.00	100.00

Table 33 (Cont.). Concentrate Flotation Results with Varying Grinding Time (Fineness).

Grinding Time	Product	Weight (%)		Analysis (%)						Distribution (%)			
				BPL		MgO		A.I.		BPL		MgO	A.I.
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		
9 min. -200 mesh 45.22%	Concentrate	16.06		68.26		0.72		5.56		65.18		24.32	1.20
	Tails 4	1.77	17.83	65.51	67.99	1.22	0.77	5.99	5.60	6.89	72.07	4.54	0.14
	Tails 3	5.65	23.49	63.32	66.86	1.73	1.00	5.75	5.64	21.28	93.35	20.56	0.44
	Tails 2	8.41	31.89	3.69	50.21	0.21	0.79	93.32	28.75	1.85	95.19	3.71	10.52
	Slimes	1.02	32.91	14.62	49.11	8.70	1.04	22.99	28.57	0.89	96.08	18.66	0.31
	Tails 1	67.09	100.00	0.98	16.82	0.20	0.48	97.09	74.54	3.92	100.00	28.21	87.38
	Feed	100.00		16.82		0.48		74.54		100.00		100.00	100.00
11 min. -200 mesh 58.88%	Concentrate	14.84		67.65		0.71		6.24		59.24		20.53	1.25
	Tails 4	1.91	16.75	66.73	67.54	1.06	0.75	6.19	6.23	7.54	66.79	3.96	0.16
	Tails 3	7.19	23.94	64.15	66.52	1.66	1.02	5.99	6.16	27.23	94.02	23.27	0.58
	Tails 2	8.09	32.03	3.43	50.59	0.23	0.82	93.64	28.25	1.64	95.65	3.63	10.19
	Slimes	0.97	33.00	14.03	49.52	9.84	1.09	24.28	28.13	0.80	96.46	18.59	0.32
	Tails 1	67.00	100.00	0.90	16.94	0.23	0.51	97.10	74.34	3.54	100.00	30.03	87.51
	Feed	100.00		16.94		0.51		74.34		100.00		100.00	100.00

Operating Conditions													
Operation	Conditioning				Times (Min.)	Reagents, kg/T Feed							
	Impeller Rotation Speed (rpm)	Aeration (L/Min.)	Solids %	pH		Na_2CO_3	Fatty Acid	Fuel Oil	Na_2SiO_3	H_2SO_4	Kerosene	Amine	Mixed Acid
Phosphate Flotation	1600	1.2	27	8.8~9.2	2.5	1.0	1.5	0.6	1.0				
Desliming	1600									8.0			
Quartz Flotation	1600	1.2		7.4~7.5	4.0	0.5					0.3	1.0	
Dolomite Flotation	2000			4.5~5.0	7.0+6.0								6.0+2.0
Total Reagent Consumption, kg/T Feed						1.5	1.5	0.6	1.0	8.0	0.3	1.0	8.0

DOLOMITE FLOTATION WITH PHOSPHATE DEPRESSANTS

In these experiments, the cleaner concentrate from the Crago flowsheet was ground at 60% solids for 9 minutes to achieve a feed of 45.22% passing 200 mesh. Flotation was conducted at 30% solids with two stages of collector addition and two stages of flotation. The flotation flowsheet is shown in Figure 29, and test conditions and results reported in Tables 34 and 35.

Phosphate depressants evaluated included acidic, neutral and alkaline reagents (Zhang and others 2002). Table 35 shows the neutral and alkaline depressants had little effect, while the strongly acidic depressants performed better. Phosphoric acid gave the highest BPL concentrate and recovery.

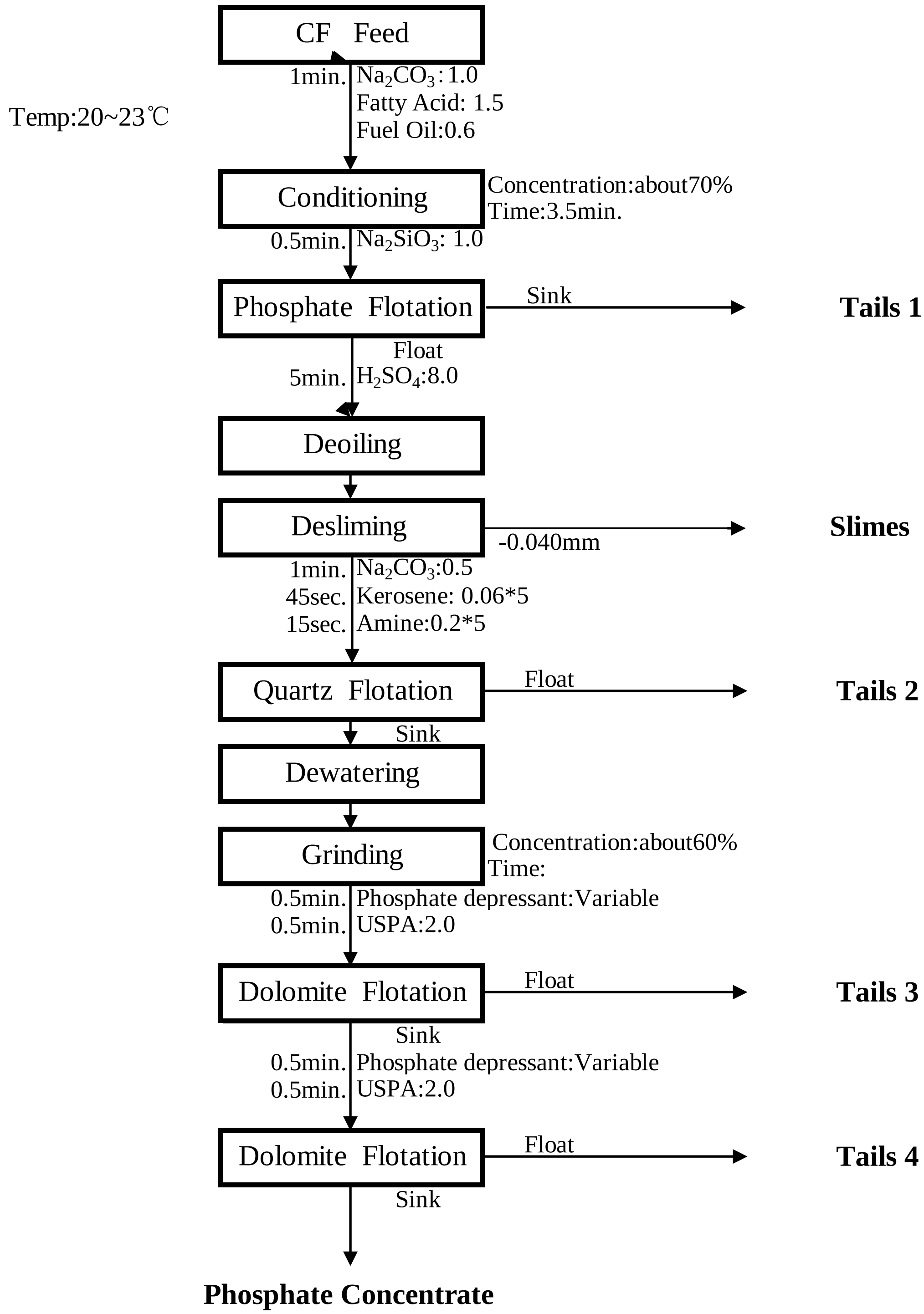


Figure 29. Flowsheet for Dolomite Flotation with Phosphate Depressants.

Table 34. Experimental Conditions for Dolomite Flotation with Phosphate Depressants.

Operating Conditions														
Operation	Conditioning				Times (Min.)	Reagents, kg/T Feed								
	Impeller Rotation Speed (rpm)	Aeration (L/Min.)	Solids %	pH		Na_2CO_3	Fatty Acid	Fuel Oil	Na_2SiO_3	H_2SO_4	Kero -sene	Amine	Phosphate Depressant	USPA-31
Phosphate Flotation	1600	1.2	26.87	8.8~9.2	2.5	1.0	1.5	0.6	1.0					
Deoiling	1600			3.4~4.1	5.0					8.0				
Quartz Flotation	1600	1.2		7.4~7.5	4.0	0.5					0.3	1.0		
Dolomite Flotation	2000	0.3	~30		7.0+6.0								Variable	2.0+2.0
Total Reagent Consumption, kg/T Feed						1.5	1.5	0.6	1.0	8.0	0.3	1.0		4.0

Table 35. Dolomite Flotation Results with Phosphate Depressants.

Depressant (kg/T, Feed)	Product	Weight (%)		Analysis (%)						Distribution (%)			
				BPL		MgO		A.I.		BPL		MgO	A.I.
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		
Blank	Concentrate	12.20		65.20		0.73		8.68		47.45		16.51	1.43
	Tails 4	4.07	16.27	65.51	65.28	0.91	0.78	6.04	8.02	15.92	63.37	6.87	0.33
	Tails 3	7.91	24.18	63.65	64.74	1.38	0.97	6.53	7.53	30.04	93.40	20.24	0.70
	Tails 2	7.77	31.94	4.24	50.03	0.18	0.78	92.78	28.26	1.96	95.37	2.59	9.73
	Slimes	1.81	33.75	14.16	48.12	9.09	1.22	26.67	28.17	1.52	96.89	30.43	0.65
	Tails 1	66.25	100.00	0.79	16.76	0.19	0.54	97.42	74.05	3.11	100.00	23.35	87.16
	Feed	100.00		16.76		0.54		74.05		100.00		100.00	100.00
I NaOH 2.0 II NaOH 0.5	Concentrate	10.08		64.54		0.73		9.31		38.89		14.03	1.27
	Tails 4	5.57	15.66	59.00	62.57	0.82	0.76	15.43	11.49	19.64	58.53	8.71	1.17
	Tails 3	9.52	25.17	62.43	62.52	1.37	0.99	7.38	9.93	35.51	94.04	24.86	0.95
	Tails 2	7.44	32.61	3.63	49.09	0.22	0.82	93.60	29.01	1.61	95.65	3.12	9.45
	Slimes	1.23	33.84	14.53	47.83	8.67	1.10	24.14	28.84	1.07	96.72	20.28	0.40
	Tails 1	66.16	100.00	0.83	16.74	0.23	0.52	96.64	73.70	3.28	100.00	29.00	86.76
	Feed	100.00		16.74		0.52		73.70		100.00		100.00	100.00
I Starch 2.0 II Starch 2.0	Concentrate	12.56		64.50		0.70		9.16		48.17		16.99	1.55
	Tails 4	4.58	17.14	66.12	64.93	0.92	0.76	5.52	8.19	18.00	66.17	8.14	0.34
	Tails 3	7.35	24.48	62.38	64.17	1.48	0.98	6.54	7.69	27.25	93.42	21.01	0.65
	Tails 2	8.18	32.66	3.95	49.09	0.20	0.78	92.96	29.04	1.92	95.34	3.16	10.27
	Slimes	1.10	33.77	14.57	47.96	9.37	1.06	23.67	28.87	0.96	96.30	20.00	0.35
	Tails 1	66.23	100.00	0.94	16.82	0.24	0.52	97.07	74.04	3.70	100.00	30.71	86.83
	Feed	100.00		16.82		0.52		74.04		100.00		100.00	100.00

Table 35 (Cont.). Dolomite Flotation Results with Phosphate Depressants.

Depressant (kg/T, Feed)	Product	Weight (%)		Analysis (%)						Distribution (%)			
				BPL		MgO		A.I.		BPL		MgO	A.I.
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		
I Triethyl phosphate 2.0 II Triethyl phosphate 0.5	Concentrate	8.50		64.20		0.69		10.31		33.02		11.57	1.18
	Tails 4	5.70	14.21	66.36	65.06	0.93	0.79	5.36	8.32	22.90	55.92	10.47	0.41
	Tails 3	10.00	24.21	62.60	64.05	1.30	1.00	6.60	7.61	37.89	93.82	25.66	0.89
	Tails 2	8.03	32.24	3.91	49.07	0.20	0.80	93.06	28.89	1.90	95.72	3.17	10.05
	Slimes	1.09	33.33	15.45	47.97	9.36	1.08	23.60	28.72	1.02	96.74	20.20	0.35
	Tails 1	66.67	100.00	0.81	16.53	0.22	0.51	97.21	74.38	3.26	100.00	28.94	87.13
	Feed	100.00		16.53		0.51		74.38		100.00		100.00	100.00
I Sodium fluosilicate 2.0 II Sodium fluosilicate 0.5	Concentrate	13.82		65.00		0.70		8.14		54.12		18.52	1.51
	Tails 4	3.66	17.47	64.52	64.90	1.08	0.78	5.98	7.69	14.21	68.33	7.56	0.29
	Tails 3	6.61	24.08	62.95	64.37	1.55	0.99	6.28	7.30	25.05	93.38	19.60	0.56
	Tails 2	7.98	32.06	4.59	49.49	0.25	0.81	92.33	28.47	2.21	95.59	3.82	9.90
	Slimes	1.15	33.21	15.45	48.31	8.98	1.09	24.35	28.33	1.07	96.66	19.81	0.38
	Tails 1	66.79	100.00	0.83	16.60	0.24	0.52	97.34	74.42	3.34	100.00	30.69	87.36
	Feed	100.00		16.60		0.52		74.42		100.00		100.00	100.00
I Boric acid 2.0 II Boric acid 0.5	Concentrate	11.67		65.77		0.68		6.82		45.65		15.28	1.08
	Tails 4	3.99	15.66	65.64	65.74	0.97	0.75	4.61	6.26	15.59	61.24	7.46	0.25
	Tails 3	8.49	24.15	63.50	64.95	1.45	1.00	5.32	5.93	32.06	93.30	23.70	0.61
	Tails 2	8.45	32.60	3.91	49.13	0.26	0.81	92.50	28.37	1.97	95.27	4.23	10.61
	Slimes	1.05	33.65	14.99	48.06	9.22	1.07	22.59	28.19	0.94	96.21	18.67	0.32
	Tails 1	66.35	100.00	0.96	16.81	0.24	0.52	96.75	73.68	3.79	100.00	30.66	87.13
	Feed	100.00		16.81		0.52		73.68		100.00		100.00	100.00

Table 35 (Cont.). Dolomite Flotation Results with Phosphate Depressants.

Depressant (kg/T, Feed)	Product	Weight (%)		Analysis (%)						Distribution (%)			
				BPL		MgO		A.I.		BPL		MgO	A.I.
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		
I Tartaric acid 2.0 II Tartaric acid 0.5	Concentrate	13.89		65.22		0.67		6.79		54.79		18.93	1.28
	Tails 4	3.02	16.91	64.33	65.06	1.19	0.76	4.45	6.37	11.75	66.54	7.31	0.18
	Tails 3	7.20	24.11	62.88	64.41	1.44	0.97	5.44	6.09	27.37	93.91	21.08	0.53
	Tails 2	9.07	33.18	3.89	47.86	0.22	0.76	92.88	29.82	2.13	96.04	4.06	11.45
	Slimes	1.01	34.18	15.03	46.90	8.70	1.00	23.04	29.62	0.92	96.96	17.82	0.32
	Tails 1	65.82	100.00	0.76	16.54	0.23	0.49	96.40	73.57	3.04	100.00	30.80	86.24
	Feed	100.00		16.54		0.49		73.57		100.00		100.00	100.00
I HCl 6.0 II HCl 2.0	Concentrate	16.02		64.63		0.72		8.26		62.48		21.92	1.79
	Tails 4	2.34	18.36	63.23	64.45	1.60	0.83	5.25	7.88	8.93	71.42	7.12	0.17
	Tails 3	5.91	24.28	63.41	64.20	1.53	1.00	5.85	7.38	22.63	94.04	17.19	0.47
	Tails 2	8.74	33.02	4.02	48.27	0.28	0.81	91.90	29.76	2.12	96.16	4.65	10.87
	Slimes	1.24	34.26	14.16	47.03	9.16	1.11	22.40	29.49	1.06	97.23	21.65	0.38
	Tails 1	65.74	100.00	0.70	16.57	0.22	0.53	97.05	73.90	2.77	100.00	27.48	86.33
	Feed	100.00		16.57		0.53		73.90		100.00		100.00	100.00
I Na polyphosphate 2.0 II Na polyphosphate 0.5	Concentrate	17.90		67.52		0.71		5.27		71.82		25.25	1.27
	Tails 4	2.96	20.86	62.93	66.86	1.39	0.81	6.07	5.38	11.08	82.91	8.18	0.24
	Tails 3	2.30	23.16	60.28	66.21	1.99	0.92	6.30	5.47	8.23	91.14	9.09	0.20
	Tails 2	8.19	31.35	5.13	50.26	0.23	0.74	91.14	27.85	2.50	93.64	3.74	10.07
	Slimes	1.25	32.60	14.99	48.91	9.27	1.07	23.43	27.68	1.11	94.75	22.94	0.39
	Tails 1	67.40	100.00	1.31	16.83	0.23	0.50	96.51	74.07	5.25	100.00	30.80	87.82
	Feed	100.00		16.83		0.50		74.07		100.00		100.00	100.00

Table 35 (Cont.). Dolomite Flotation Results with Phosphate Depressants.

Depressant (kg/T, Feed)	Product	Weight (%)		Analysis (%)						Distribution (%)			
				BPL		MgO		A.I.		BPL		MgO	A.I.
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		
I KH_2PO_4 2.0 II KH_2PO_4 0.5	Concentrate	13.68		66.36		0.67		7.03		54.21		18.76	1.29
	Tails 4	3.18	16.87	64.89	66.08	1.21	0.77	5.66	6.77	12.34	66.55	7.88	0.24
	Tails 3	7.14	24.01	64.06	65.48	1.41	0.96	6.24	6.61	27.31	93.86	20.60	0.60
	Tails 2	8.68	32.69	4.11	49.18	0.24	0.77	92.53	29.43	0.98	95.99	4.26	10.78
	Slimes	1.06	33.75	15.60	48.13	9.26	1.04	24.36	29.27	0.98	96.97	20.03	0.35
	Tails 1	66.25	100.00	0.76	16.75	0.21	0.49	97.63	74.56	3.03	100.00	28.47	86.75
	Feed	100.00		16.75		0.49		74.56		100.00		100.00	100.00
I Phos. Acid 8.0 II Phos. Acid 3.0	Concentrate	18.86		67.69		0.77		6.52		74.45		28.30	1.66
	Tails 4	1.44	20.30	63.32	67.38	1.83	0.85	6.26	6.50	5.31	79.76	5.13	0.12
	Tails 3	3.87	24.17	62.16	66.55	2.15	1.05	5.87	6.40	14.02	93.78	16.20	0.31
	Tails 2	8.75	32.92	4.20	49.97	0.26	0.84	92.44	29.27	2.14	95.92	4.43	10.90
	Slimes	1.10	34.02	15.10	48.85	8.82	1.10	25.08	29.13	0.97	96.89	18.93	0.37
	Tails 1	65.98	100.00	0.81	17.15	0.21	0.51	97.44	74.20	3.11	100.00	27.00	86.64
	Feed	100.00		17.15		0.51		74.20		100.00		100.00	100.00
I Sulfuric acid 8.0 II Sulfuric acid 3.0	Concentrate	19.04		65.35		0.72		7.47		74.53		27.78	1.93
	Tails 4	1.50	20.54	61.62	65.08	1.77	0.80	6.32	7.39	5.52	80.06	5.37	0.13
	Tails 3	3.72	24.26	61.68	64.56	1.61	0.92	5.83	7.15	13.75	93.81	12.14	0.29
	Tails 2	8.11	32.37	3.19	49.18	0.20	0.74	93.75	28.85	1.55	95.36	3.29	10.31
	Slimes	1.17	33.54	14.09	47.96	8.64	1.02	25.74	28.75	0.99	96.35	20.45	0.41
	Tails 1	66.46	100.00	0.92	16.69	0.23	0.49	96.56	73.82	3.65	100.00	30.97	86.94
	Feed	100.00		16.69		0.49		73.82		100.00		100.00	100.00

REDUCING MgO CONTENT BY SCRUBBING

Tables 36 and 37 show sizing analysis of a rougher concentrate and a final concentrate from floating the CF feed. In the rougher concentrate, the MgO content in the -0.16 mm fraction is 2.1%, about two times the content in the other size fractions. In the final concentrate, the variation in the MgO content in the different size fractions is less dramatic. Therefore, it was first decided to conduct scrubbing and desliming tests on the rougher concentrate to determine how much dolomite could be removed by this simple technique.

DIRECT SCRUBBING OF ROUGHER CONCENTRATE

The processing flowsheet is shown in Figure 30, and the test results are shown in Table 38. After acid scrubbing, the rougher concentrate was scrubbed and deslimed three times, which resulted in appreciable MgO reduction in the final concentrate. Dolomite in the slimes accounts for 28.32% of the total dolomite in the feed.

Table 36. Sizing Analysis of the Rougher Concentrate from CF Feed.

Sieve Fraction	Wt. (%)	Analysis (%)				Distribution (%)		
		P_2O_5	BPL	MgO	A.I.	BPL	MgO	A.I.
+0.5 mm	13.50	28.79	62.91	1.19	8.25	17.40	13.60	3.96
-0.5 + 0.3 mm	22.08	26.94	58.86	1.19	14.18	26.63	22.25	11.13
-0.3 + 0.16 mm	50.00	21.50	46.98	0.91	32.88	48.13	38.52	58.44
-0.16 mm	14.42	12.13	26.50	2.10	51.64	7.83	25.63	26.47
Total	100.00	22.33	48.80	1.18	28.13	100.00	100.00	100.00

Table 37. Sizing Analyses of the Final Concentrate from CF Feed.

Sieve Fraction	Wt. (%)	Analysis (%)				Distribution (%)		
		P_2O_5	BPL	MgO	A.I.	BPL	MgO	A.I.
+0.5 mm	17.62	29.31	64.04	1.00	7.79	17.76	19.17	13.66
-0.5 + 0.3 mm	26.42	28.92	63.19	0.91	9.98	26.29	26.16	26.25
-0.3 + 0.16 mm	47.15	29.23	63.87	0.86	10.38	47.42	44.13	48.72
-0.16 mm	8.81	28.13	61.46	1.10	12.96	8.52	10.54	11.36
Total	100.00	29.07	63.51	0.92	10.05	100.00	100.00	100.00

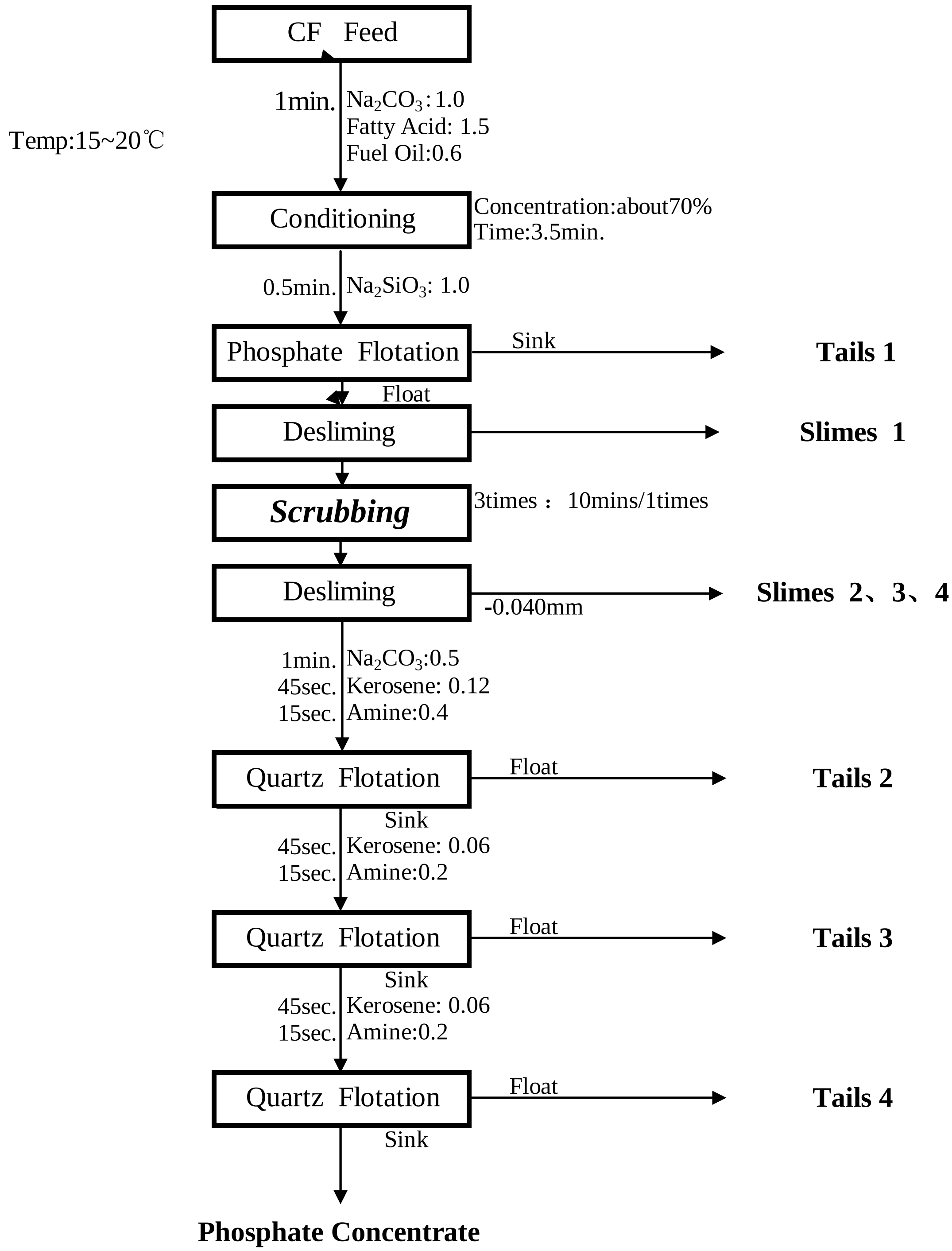


Figure 30. Scrubbing Flowsheet for the Rougher Concentrate of CF Feed.

Table 38. Flotation Results with Rougher Concentrate Scrubbed.

Product	Weight (%)		Analysis (%)						Distribution (%)			
			BPL		MgO		A.I.		BPL		MgO	A.I.
	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		
Concentrate	22.69		65.42		0.94		7.11		86.69		41.14	2.19
Tails 4	0.90	23.59	58.95	65.17	0.76	0.93	15.82	7.44	3.10	89.79	1.32	0.19
Tails 3	1.00	24.59	44.38	64.33	0.61	0.92	35.72	8.59	2.59	92.38	1.18	0.48
Tails 2	7.21	31.80	3.26	50.48	0.08	0.73	94.52	28.07	1.37	93.75	1.11	9.24
Slimes 4	0.13	31.93	38.74	50.43	5.80	0.75	12.29	28.01	0.29	94.04	1.45	0.02
Slimes 3	0.19	32.12	31.94	50.32	7.25	0.79	14.84	27.93	0.35	94.40	2.66	0.04
Slimes 2	0.87	32.99	19.03	49.50	9.52	1.02	19.18	27.70	0.97	95.37	15.98	0.23
Slimes 1	0.52	33.51	4.50	48.80	8.21	1.13	34.14	27.80	0.14	95.50	8.23	0.24
Tails 1	66.49	100.00	1.16	17.12	0.21	0.52	96.92	73.76	4.50	100.00	26.93	87.37
Feed	100.00		17.12		0.52		73.76		100.00		100.00	100.00

Operating Conditions

Operation	Conditioning				Times (Min.)	Reagents, kg/T Feed						
	Impeller Rotation Speed (rpm)	Aeration (L/Min.)	Solids %	pH		Na_2CO_3	Fatty Acid	Fuel Oil	Na_2SiO_3	H_2SO_4	Kero-sene	Amine
Phosphate Flotation	1600	1.2	27	8.8~9.2	2.5	1.0	1.5	0.6	1.0			
Deoiling	1600				5.0					8.0		
Scrubbing	1600		~60		10*3							
Quartz Flotation	1600	1.2		7.4~7.5	4.0	0.5					0.3	1.0
Total Reagent Consumption, kg/T Feed						1.5	1.5	0.6	1.0	8.0	0.3	1.0

SCRUBBING WITH HARD MEDIA

Encouraged by the above scrubbing test, we designed more scrubbing experiments to study the effect of scrubbing media (steel balls and quartz granules) on dolomite removal. The diameter of the steel balls used was 0.8 mm. The scrubber was made of stainless steel with double stainless steel impellers, as is shown in Photo 1. This type of scrubber can handle high-solids scrubbing, thus requiring a large sample load of 800 grams. When quartz granules (ranging from 1.25 to 2 mm) were used as grinding media, a single-impeller glass scrubber was used, as is shown in Photo 2. A smaller sample, 200 grams, was used in this case.

Flowsheets for scrubbing tests with steel balls on the original feed, rougher concentrate and final concentrate are shown in Figures 31, 32 and 33, respectively, with the corresponding test results summarized in Tables 39-41. Scrubbing the final concentrate resulted in the highest MgO reduction and the lowest loss of phosphate.

Flowsheets for scrubbing tests with quartz granules on the rougher concentrate and final concentrate are shown in Figures 34 and 35, respectively, with the corresponding test results summarized in Tables 42 and 43. Again, the best results were achieved by scrubbing the final concentrate.

Photo 1. Steel Scrubber with Steel Balls and Double Impellers.

Photo 2. Glass Scrubber with Quartz Granules and Single Impeller.

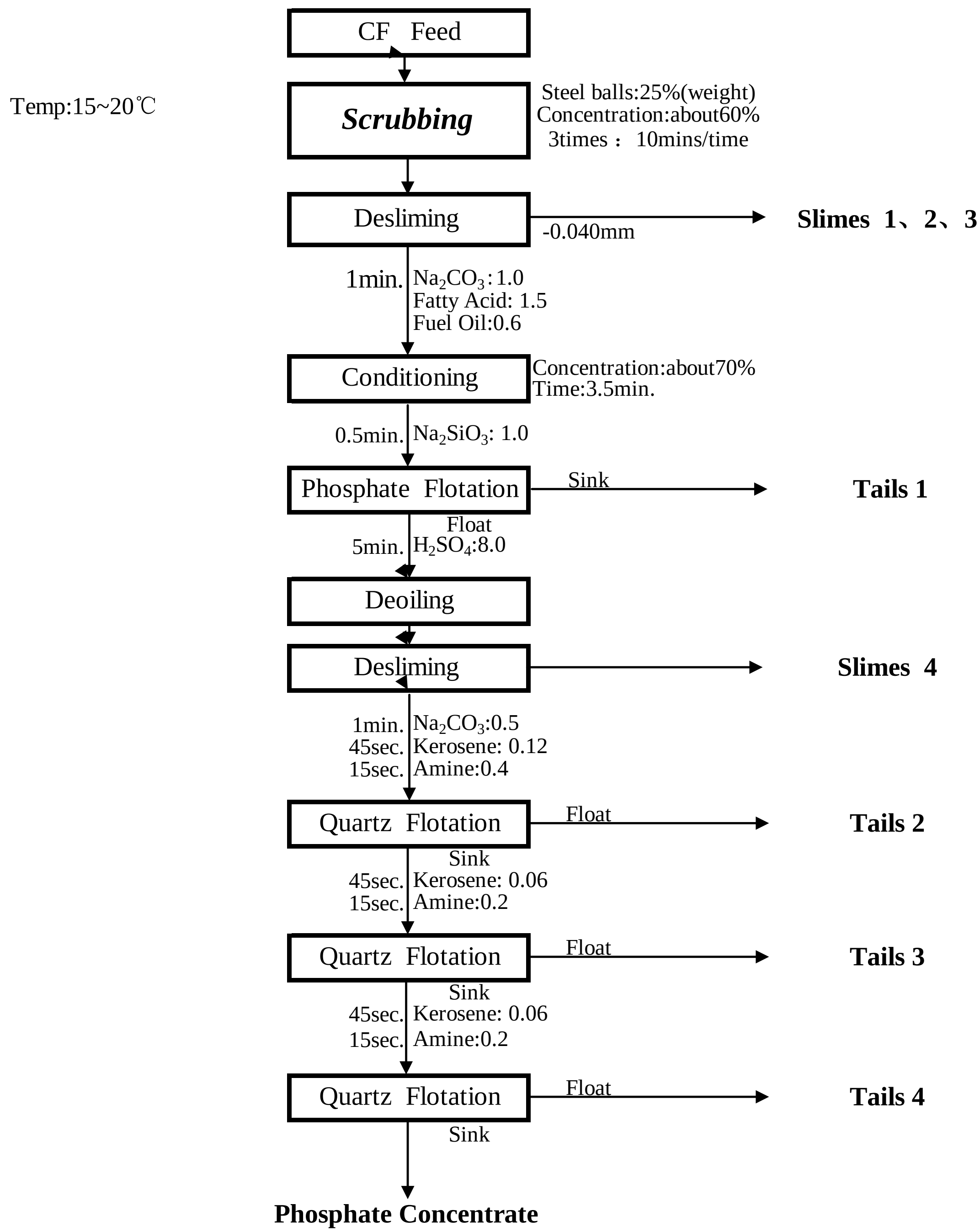
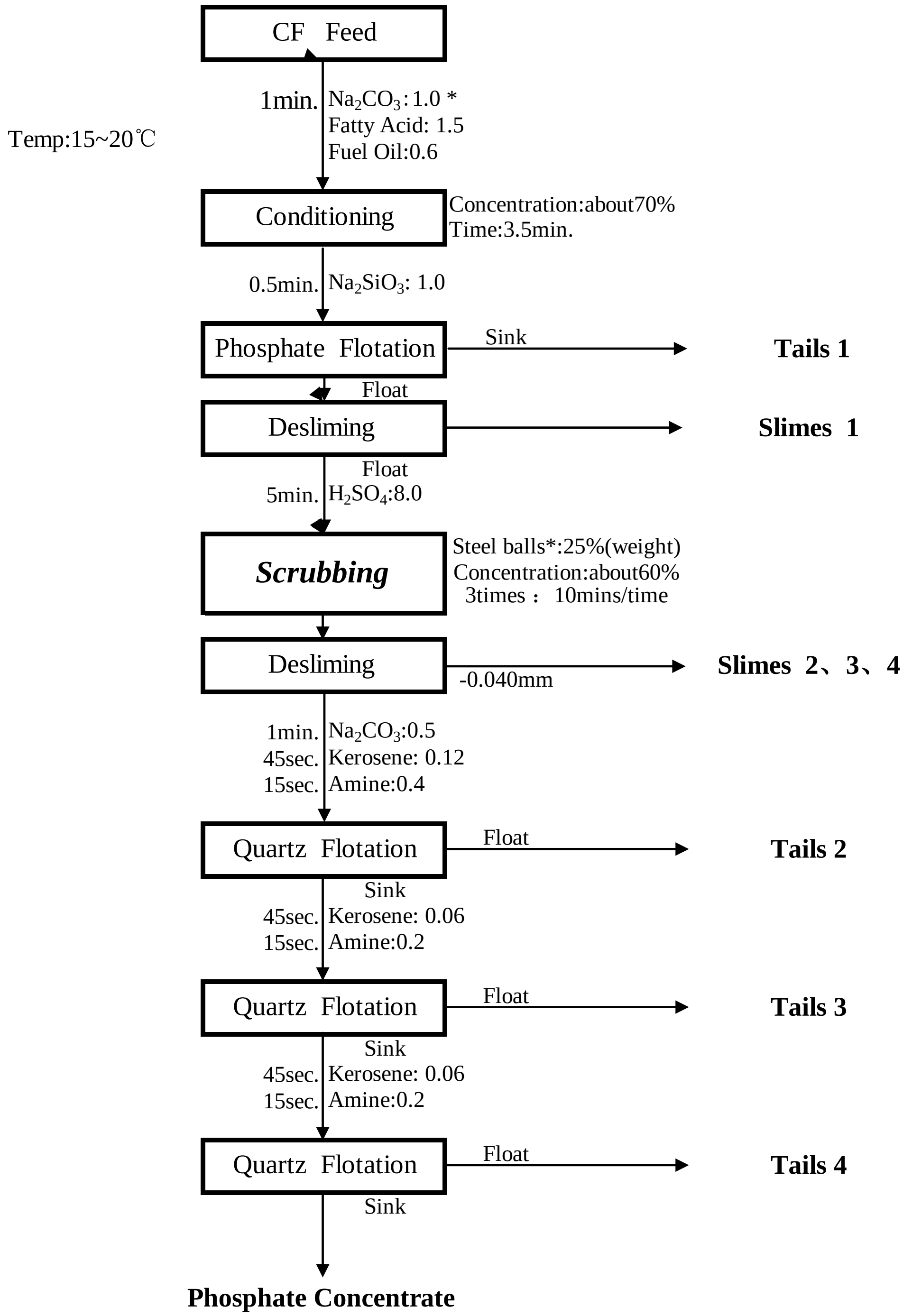


Figure 31. Feed Scrubbing Using the Steel Scrubber.



＊ Diameter of steel balls is 0.8mm.

Figure 32. Rougher Concentrate Scrubbing using the Steel Scrubber.

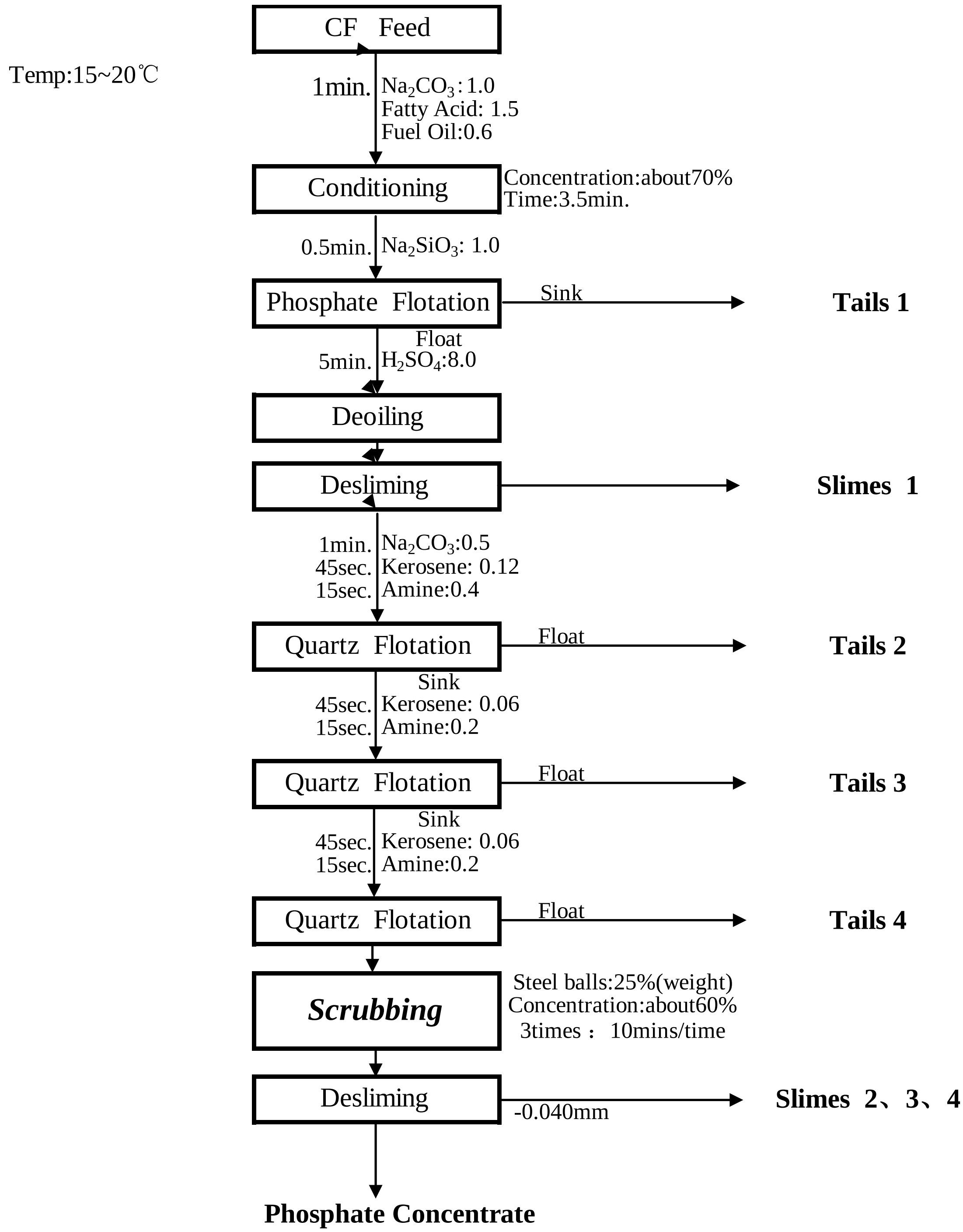


Figure 33. Final Concentrate Scrubbing using the Steel Scrubber.

Table 39. Scrubbing Test Results on Flotation Feed in Steel Balls Media.

Process	Product	Weight (%)		Analysis (%)						Distribution (%)				
				BPL		MgO		A.I.		BPL		MgO	A.I.	
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		Indiv.	Cum.
Feed Scrubbing	Concentrate	19.37		68.59		0.86		2.90		78.15		34.07	0.76	
	Tails 4	0.58	19.95	56.42	68.23	0.95	0.86	17.37	3.32	1.92	80.07	1.13	0.14	0.90
	Tails 3	1.00	20.95	25.76	66.21	0.42	0.84	62.55	6.15	1.52	81.59	0.86	0.85	1.75
	Tails 2	13.93	34.88	1.53	40.38	0.01	0.51	97.23	42.52	1.25	82.84	0.28	18.38	20.12
	Slimes 4	0.60	35.48	55.72	40.64	1.24	0.52	18.36	42.11	1.97	84.81	1.52	0.15	20.27
	Tails 1	57.00	92.48	0.46	15.87	0.02	0.21	98.67	76.97	1.54	86.35	2.33	76.31	96.58
	Slimes 3	1.78	94.26	41.60	16.36	1.45	0.24	34.20	76.16	4.36	90.70	5.28	0.83	97.41
	Slimes 2	1.98	96.24	39.64	16.84	2.26	0.28	32.09	75.26	4.62	95.32	9.15	0.86	98.27
	Slimes 1	3.76	100.00	21.17	17.00	5.90	0.49	33.91	73.70	4.68	100.00	45.37	1.73	100.00
	Feed	100.00		17.00		0.49		73.70		100.00		100.00	100.00	

Operating Conditions

Operation	Conditioning				Times (Min.)	Reagents, kg/T Feed							
	Impeller Rotation Speed (rpm)	Aeration (L/Min.)	Solids %	pH		Na_2CO_3	Fatty Acid	Fuel Oil	Na_2SiO_3	H_2SO_4	Kerosene	Amine	Deoiling Reagent
Scrubbing	1000		~60		10*3								
Phosphate Flotation		1.2	27	8.8~9.2	2.5	1.0	1.5	0.6	1.0				
Deoiling	1600				5.0					8.0			Variable
Quartz Flotation		1.2		7.4~7.5	4.0	0.5					0.3	1.0	
Total Reagent Consumption, kg/T Feed						1.5	1.5	0.6	1.0	8.0	0.3	1.0	

Table 40. Scrubbing Test Results on Rougher Concentrate in Steel Balls Media.

Process	Product	Weight (%)		Analysis (%)						Distribution (%)				
				BPL		MgO		A.I.		BPL		MgO	A.I.	
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		Indiv.	Cum.
Coarse Concentrate Scrubbing	Concentrate	19.86		69.18		0.88		4.46		78.42		32.62	1.21	
	Tails 4	0.80	20.66	60.83	68.85	0.73	0.87	15.12	4.87	2.78	81.20	1.09	0.17	1.38
	Tails 3	0.76	21.42	33.52	67.60	0.41	0.86	53.80	6.61	1.45	82.65	0.58	0.56	1.94
	Tails 2	6.80	28.22	3.54	52.16	0.12	0.68	94.27	27.73	1.37	84.03	1.52	8.77	10.71
	Slimes 4	1.02	29.24	61.88	52.50	1.67	0.71	9.11	27.08	3.60	87.63	3.18	0.13	10.83
	Slimes 3	1.17	30.41	56.53	52.66	2.60	0.79	9.71	26.41	3.78	91.41	5.68	0.16	10.99
	Slimes 2	1.65	32.06	41.43	52.08	5.28	1.02	15.03	25.83	3.90	95.31	16.26	0.34	11.33
	Slimes 1	0.54	32.60	4.94	51.30	10.04	1.17	29.89	25.90	0.15	95.46	10.12	0.22	11.55
	Tails 1	67.40	100.00	1.18	17.52	0.23	0.54	95.94	73.11	4.54	100.00	28.94	88.45	100.00
	Feed	100.00		17.52		0.54		73.11		100.00		100.00	100.00	

Operating Conditions

Operation	Conditioning				Times (Min.)	Reagents, kg/T Feed							
	Impeller Rotation Speed (rpm)	Aeration (L/Min.)	Solids %	pH		Na_2CO_3	Fatty Acid	Fuel Oil	Na_2SiO_3	H_2SO_4	Kerosene	Amine	Deoiling Reagent
Phosphate Flotation	1600	1.2	27	8.8~9.2	2.5	1.0	1.5	0.6	1.0				
Scrubbing	1000	1.2	~60		5.0					8.0			Variable
Quartz Flotation	1600	1.2		7.4~7.5	4.0	0.5					0.3	1.0	
Total Reagent Consumption, kg/T Feed						1.5	1.5	0.6	1.0	8.0	0.3	1.0	

Table 41. Scrubbing Test Results on Final Concentrate in Steel Balls Media.

Process	Product	Weight (%)		Analysis (%)						Distribution (%)				
				BPL		MgO		A.I.		BPL		MgO	A.I.	
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		Indiv.	Cum.
Concentrate Scrubbing	Concentrate	20.48		67.56		0.75		4.20		81.64		30.94	1.16	
	Slimes 3	1.05	21.53	66.29	67.50	1.29	0.78	2.94	4.14	4.11	85.75	2.73	0.04	1.20
	Slimes 2	1.04	22.58	63.87	67.33	1.72	0.82	3.95	4.13	3.93	89.68	3.62	0.06	1.26
	Slimes 1	1.22	23.80	52.46	66.57	3.25	0.94	8.93	4.38	3.77	93.45	7.97	0.15	1.41
	Tails 4	0.34	24.14	17.11	65.87	0.61	0.94	72.61	5.34	0.34	93.80	0.42	0.33	1.74
	Tails 3	0.75	24.89	8.06	64.12	0.29	0.92	86.71	7.80	0.36	94.16	0.44	0.88	2.62
	Tails 2	6.97	31.86	2.58	50.66	0.11	0.74	95.60	27.01	1.06	95.22	1.54	9.00	11.62
	Slimes	1.01	32.87	17.79	49.64	9.08	1.00	25.86	26.98	1.06	96.28	18.53	0.35	11.97
	Tails 1	67.13	100.00	0.94	16.95	0.25	0.50	97.15	74.08	3.72	100.00	33.80	88.03	100.00
	Feed	100.00		16.95		0.50		74.08		100.00		100.00	100.00	

Operating Conditions

Operation	Conditioning				Times (Min.)	Reagents, kg/T Feed							
	Impeller Rotation Speed (rpm)	Aeration (L/Min.)	Solids %	pH		Na_2CO_3	Fatty Acid	Fuel Oil	Na_2SiO_3	H_2SO_4	Kerosene	Amine	Deoiling Reagent
Phosphate Flotation	1600	1.2	27	9.2~8.8	2.5	1.0	1.5	0.6	1.0				
Deoiling	1600				5.0					8.0			Variable
Quartz Flotation	1600	1.2		7.4~7.5	4.0	0.5					0.3	1.0	
Scrubbing	1000		~60		10*3								
Total Reagent Consumption, kg/T Feed						1.5	1.5	0.6	1.0	8.0	0.3	1.0	

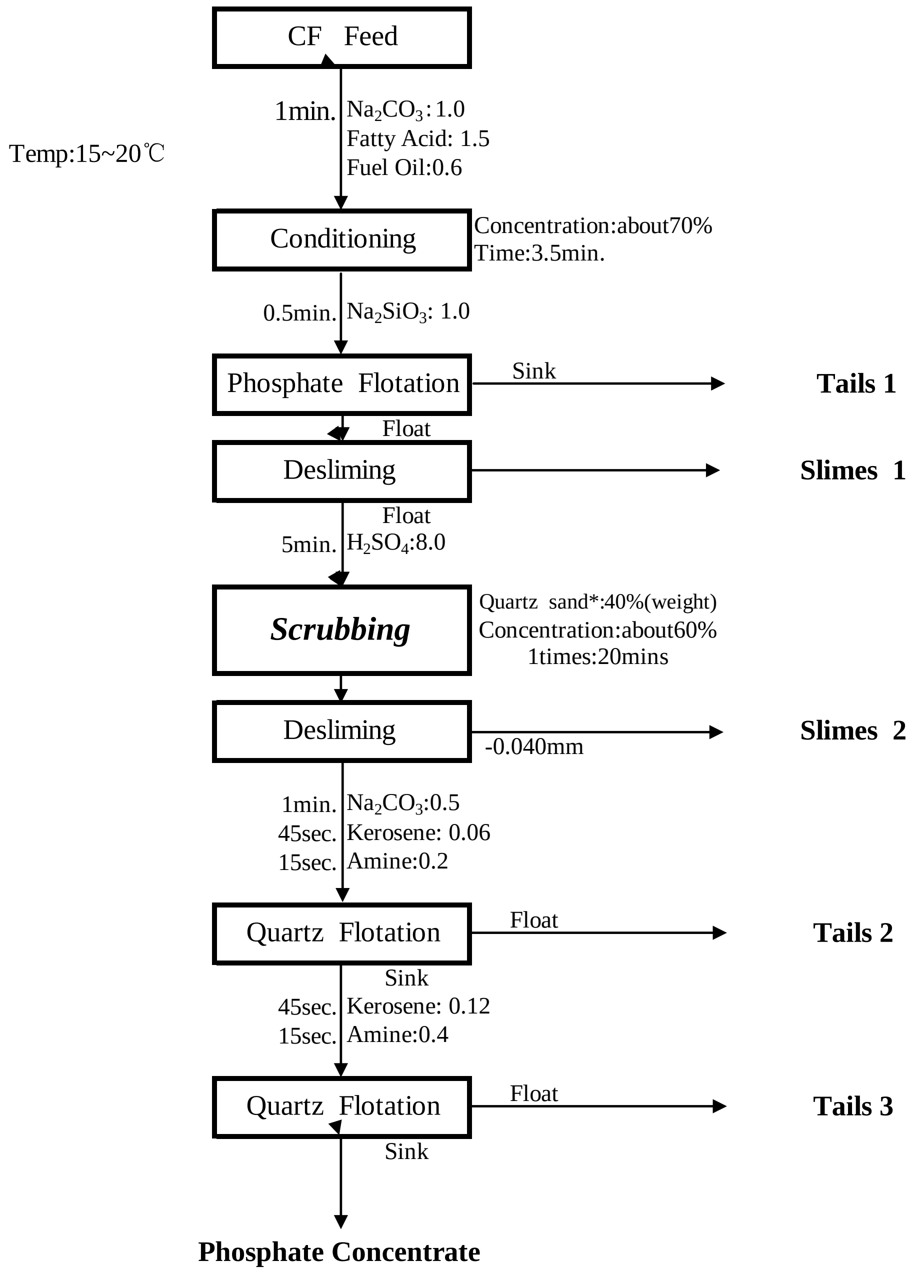


Figure 34. Rougher Concentrate Scrubbing in Quartz Media.

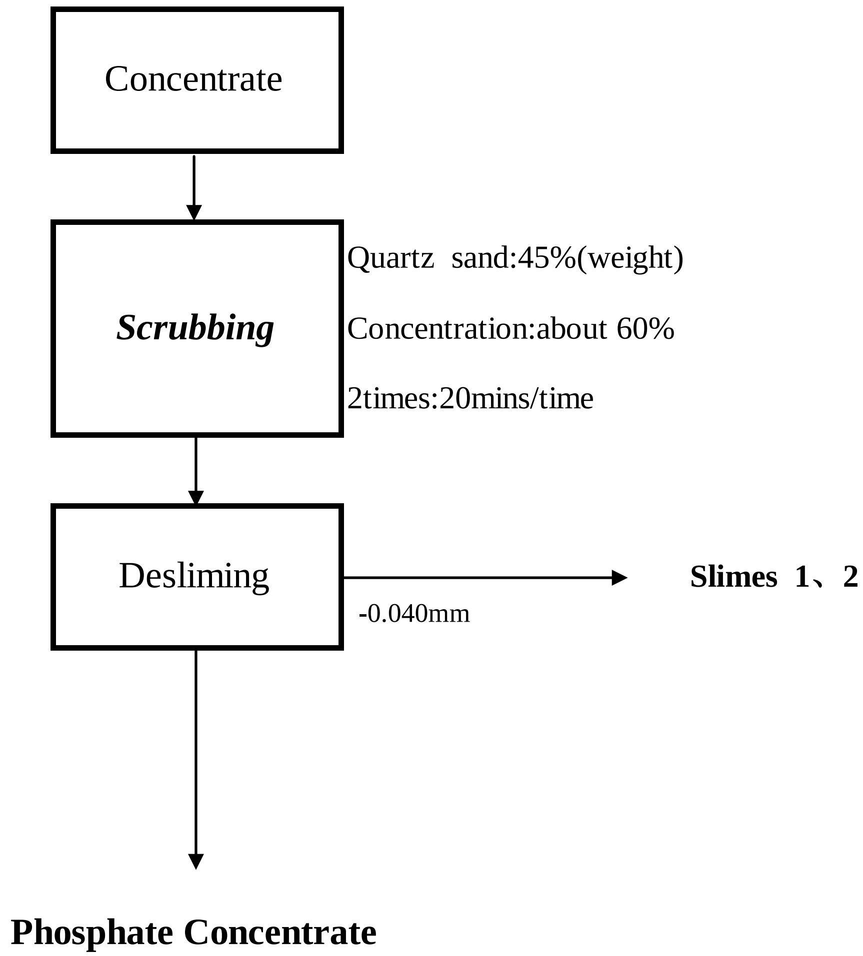


Figure 35. Final Concentrate Scrubbing in Quartz Media.

Table 42. Scrubbing Test Results on Rougher Concentrate in Quartz Media.

Process	Product	Weight (%)		Analysis (%)						Distribution (%)				
				BPL		MgO		A.I.		BPL		MgO	A.I.	
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		Indiv.	Cum.
Coarse Concentrate Scrubbing	Concentrate	23.50		66.45		0.93		7.20		90.66		40.12	2.29	
	Tails 3	0.75	24.25	28.14	65.26	0.50	0.92	59.26	8.81	1.23	91.89	0.69	0.60	2.89
	Tails 2	7.05	31.31	4.09	51.48	0.29	0.78	93.29	27.84	1.67	93.56	3.75	8.91	11.81
	Slimes 2	1.26	32.56	27.95	50.57	7.18	1.02	16.94	27.42	2.04	95.60	16.55	0.29	12.09
	Slimes 1	0.65	33.21	6.77	49.72	10.06	1.20	33.05	27.53	0.25	95.85	11.92	0.29	12.38
	Tails 1	66.79	100.00	1.07	17.23	0.22	0.54	96.85	73.83	4.15	100.00	26.97	87.62	100.00
	Feed	100.00		17.23		0.54		73.83		100.00		100.00	100.00	

Operating Conditions

Operation	Conditioning				Times (Min.)	Reagents, kg/T Feed						
	Impeller Rotation Speed (rpm)	Aeration (L/Min.)	Solids %	pH		Na_2CO_3	Fatty Acid	Fuel Oil	Na_2SiO_3	H_2SO_4	Kerosene	Amine
Phosphate Flotation	1600	1.2	27	9.2~8.8	2.5	1.0	1.5	0.6	1.0			
Scrubbing	1000		~60		20.0					8.0		
Quartz Flotation	1600	1.2		7.4~7.5	4.0	0.5					0.18	0.6
Total Reagent Consumption, kg/T Feed						1.5	1.5	0.6	1.0	8.0	0.18	0.6

Table 43. Scrubbing Test Results on Final Concentrate in Quartz Media.

Process	Product	Weight (%)		Analysis (%)						Distribution (%)				
				BPL		MgO		A.I.		BPL		MgO	A.I.	
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		Indiv.	Cum.
Concentrate Scrubbing	Concentrate	96.66		67.34		0.94		6.45		97.85		82.38	93.82	
	Slimes 2	0.98	97.64	53.16	67.20	4.06	0.97	7.54	6.46	0.79	98.64	3.62	1.11	94.93
	Slimes 1	2.36	100.00	38.48	66.52	6.55	1.10	14.29	6.65	1.36	100.00	14.00	5.07	100.00
	Feed	100.00		66.52		1.10		6.65		100.00		100.00	100.00	

Operating Conditions

Operation	Conditioning				Times (Min.)	Reagents, kg/T Feed						
	Impeller Rotation Speed (rpm)	Aeration (L/Min.)	Solids %	pH		Na_2CO_3	Fatty Acid	Fuel Oil	Na_2SiO_3	H_2SO_4	Kerosene	Amine
Scrubbing	1000		~60		20.0							
Total Reagent Consumption, kg/T Feed												

PARAMETRIC TESTING OF SCRUBBING WITH MEDIA

In order to study the effect of scrubbing in quartz sand media on dolomite removal, many scrubbing parameters were tested, including media ratio, slurry concentration, scrubbing time, and scrubbing intensity. Different types of scrubbing media were also compared.

Since scrubbing was done on the amine concentrate, enough Crago floats had to be done to accumulate enough concentrate. The flotation flowsheet for generating feed for the scrubbing test is shown in Figure 36, and the flotation parameters are shown in Table 44.

Figure 37 shows a detailed flowchart of the scrubbing process. Scrubbing results at varying additions of quartz sand media are presented in Table 45. In scrubbing, slurry concentration was based on concentrate feed weight percent without including the scrubbing media. Trial tests indicated that the optimal slurry concentration was about 60%, as shown in Table 46 at different slurry concentrations. The effect of scrubbing time is demonstrated in Table 47, while the effect of impeller speed is shown in Table 48. Table 49 shows a comparison of different grinding media. A sizing analysis of the scrubbed product is given in Table 50.

The following conclusions may be made based on the parametric test results:

1. The higher the addition of scrubbing media, the better the scrubbing performance. However, beyond 50% addition of quartz sand, scrubbing results got worse. Therefore, 50% addition of scrubbing media was considered to be the optimal dosage.
2. When other conditions were kept constant, higher slurry concentration gave better scrubbing results with lower MgO content in the final product.
3. Scrubbing time testing showed that the first ten minutes of scrubbing were the most efficient, removing 70.36% of the total MgO removed during the entire 40 minutes of scrubbing.
4. Dolomite removal was improved by increasing scrubbing intensity.
5. Under the same scrubbing conditions and at the same weight of scrubbing media, scrubbing with steel balls removed most of the dolomite but with a significant loss of phosphate.
6. Screening analysis of the scrubbed products showed that MgO content in the finer particles was lower, indicating that scrubbing was more effective on the fine fraction. This was due to the fact that the dolomite on the surface of fine phosphate particles was easy to scrub, while the dolomite enclosed in large particles was difficult to remove by this method.

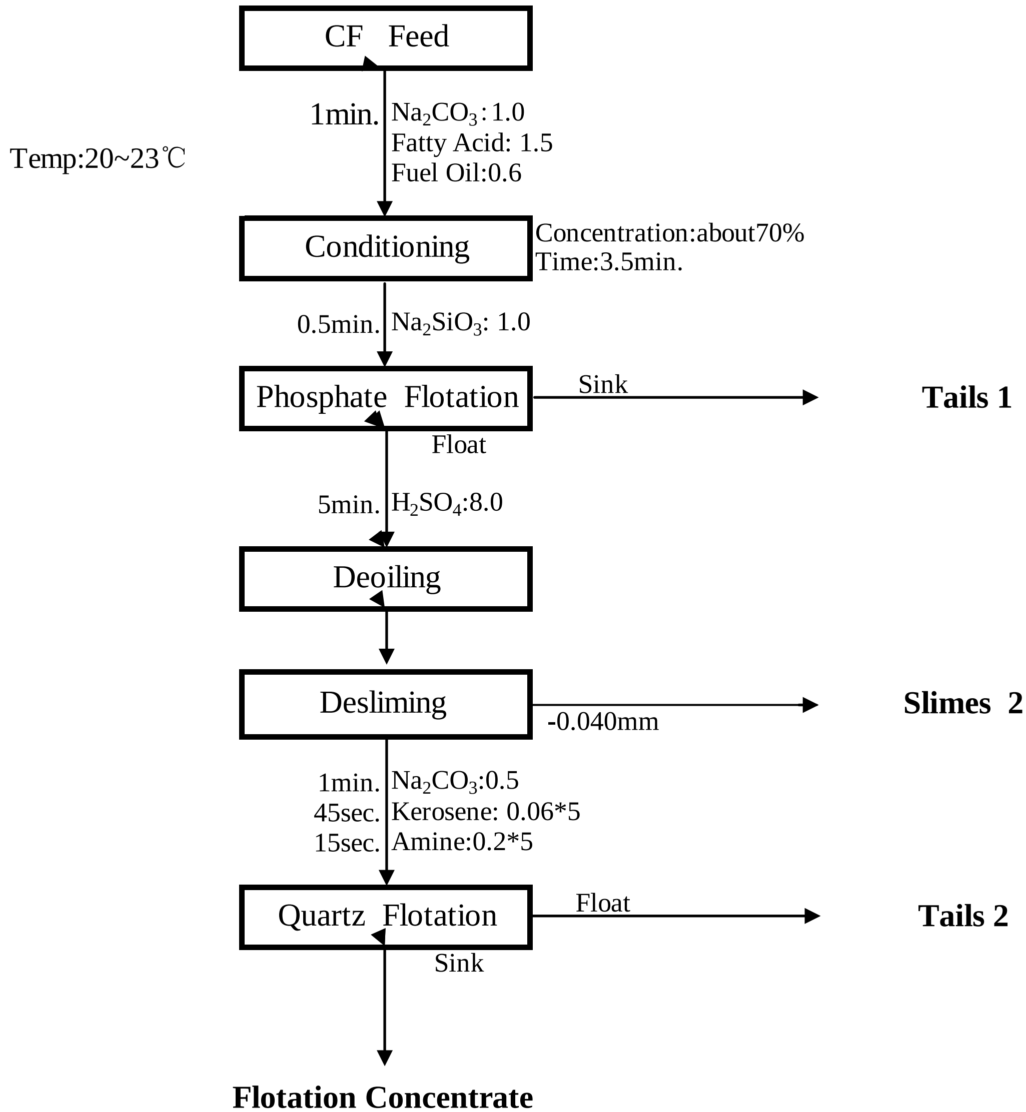


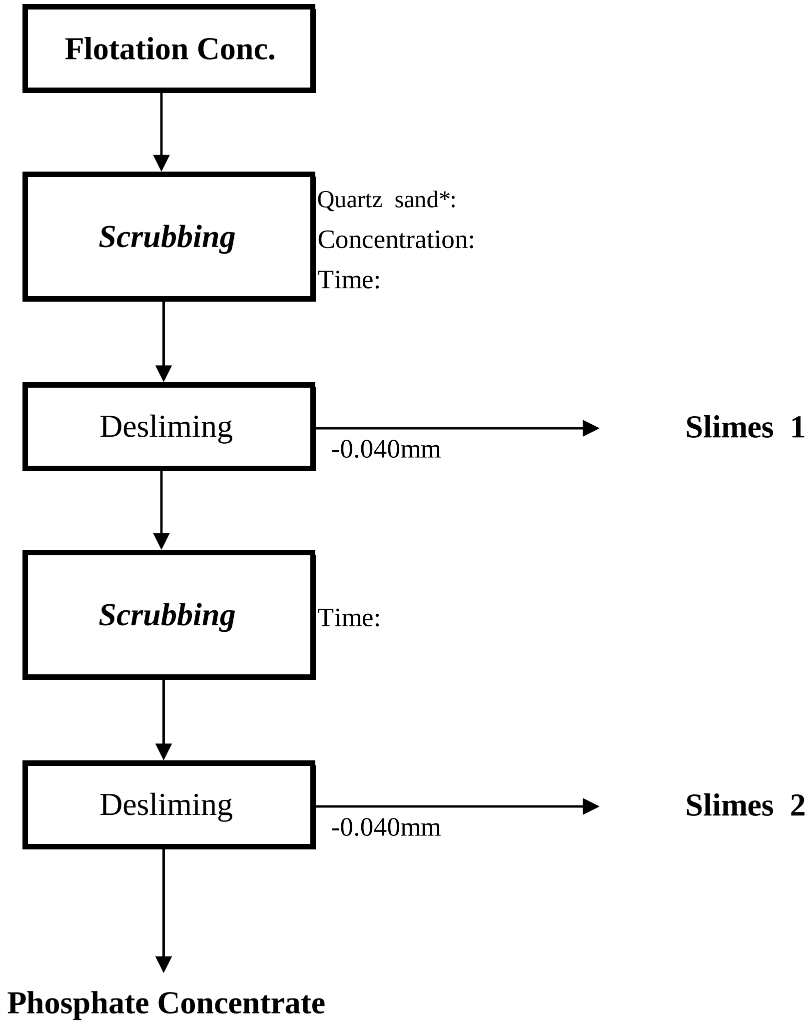
Figure 36. Flowsheet for Scrubbing Feed Preparation.

Table 44. Operating Conditions for Scrubbing Feed Preparation.

Product	Weight (%)		Analysis (%)						Distribution (%)			
			BPL		MgO		A.I.		BPL		MgO	A.I.
	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		
Concentrate	23.74		65.70		1.08		6.54		93.28		49.57	2.07
Tails 2	8.49	32.23	4.26	49.52	0.32	0.88	92.36	29.15	2.16	95.45	5.25	10.48
Slimes	1.08	33.30	16.56	48.45	9.31	1.15	22.40	28.93	1.07	96.51	19.39	0.32
Tails 1	66.70	100.00	0.87	16.72	0.20	0.52	97.74	74.82	3.49	100.00	25.79	87.12
Feed	100.00		16.72		0.52		74.82		100.00		100.00	100.00

Operating Conditions

Operation	Conditioning				Times (Min.)	Reagents, kg/T Feed						
	Impeller Rotation Speed (rpm)	Aeration (L/Min.)	Solids %	pH		Na_2CO_3	Fatty Acid	Fuel Oil	Na_2SiO_3	H_2SO_4	Kero-sene	Amine
Phosphate Flotation	1600	1.2	27	8.8~9.2	2.5	1.0	1.5	0.6	1.0			
Deoiling	1600				5.0					8.0		
Quartz Flotation	1600	1.2		7.4~7.5	5.0	0.5					0.3	1.0
Total Reagent Consumption, kg/T Feed						1.5	1.5	0.6	1.0	8.0	0.3	1.0



*quartz sand size:-2.0+1.25mm.

Figure 37. Flowsheet for Parametric Scrubbing Testing.

Table 45. Scrubbing Results at Different Ratios of Quartz Sand.

Medium (Weight %)	Product	Weight (%)		Analysis (%)						Distribution (%)			
				BPL		MgO		A.I.		BPL		MgO	A.I.
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		
0	Concentrate	23.01		67.23		0.95		5.92		91.52		42.23	1.82
	Slimes 2	0.21	23.22	51.68	67.09	4.13	0.98	8.71	5.95	0.64	92.16	1.68	0.02
	Slimes 1	0.51	23.73	39.48	66.50	5.74	1.08	15.93	6.16	1.19	93.35	5.66	0.11
	Tails 2	8.49	32.22	4.26	50.10	0.32	0.88	92.36	28.87	2.14	95.49	5.25	10.49
	Slimes	1.08	33.30	16.56	49.01	9.31	1.15	22.40	28.66	1.06	96.55	19.42	0.32
	Tails 1	66.70	100.00	0.87	16.90	0.20	0.52	97.74	74.74	3.45	100.00	25.77	87.23
	Feed	100.00		16.90		0.52		74.74		100.00		100.00	100.00
25	Concentrate	22.72		66.73		0.92		6.59		90.56		39.96	2.00
	Slimes 2	0.26	22.98	55.72	66.60	3.43	0.95	5.66	6.58	0.88	91.44	1.73	0.02
	Slimes 1	0.75	23.73	41.38	65.81	5.87	1.10	13.40	6.79	1.85	93.29	8.39	0.13
	Tails 2	8.49	32.22	4.26	49.59	0.32	0.90	92.36	29.34	2.16	95.45	5.19	10.47
	Slimes	1.08	33.30	16.56	48.52	9.31	1.17	22.40	29.11	1.07	96.52	19.22	0.32
	Tails 1	66.70	100.00	0.87	16.74	0.20	0.52	97.74	74.89	3.48	100.00	25.50	87.05
	Feed	100.00		16.74		0.52		74.89		100.00		100.00	100.00

Table 45 (Cont.). Scrubbing Results at Different Ratios of Quartz Sand.

Medium (Weight %)	Product	Weight (%)		Analysis (%)						Distribution (%)			
				BPL		MgO		A.I.		BPL		MgO	A.I.
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		
50	Concentrate	22.43		66.97		0.86		6.31		89.57		37.41	1.89
	Slimes 2	0.34	22.77	60.52	66.87	2.85	0.89	5.35	6.30	1.22	90.78	1.86	0.02
	Slimes 1	0.96	23.73	43.92	65.94	5.41	1.07	12.23	6.54	2.52	93.30	10.09	0.16
	Tails 2	8.49	32.22	4.26	49.69	0.32	0.87	92.36	29.15	2.16	95.46	5.27	10.48
	Slimes	1.08	33.30	16.56	48.62	9.31	1.15	22.40	28.93	1.07	96.52	19.50	0.32
	Tails 1	66.70	100.00	0.87	16.77	0.20	0.52	97.74	74.83	3.48	100.00	25.87	87.12
	Feed	100.00		16.77		0.52		74.83		100.00		100.00	100.00
75	Concentrate	22.21		67.47		0.87		5.88		88.82		37.08	1.75
	Slimes 2	0.39	22.60	62.34	67.38	2.22	0.89	4.45	5.86	1.45	90.27	1.67	0.02
	Slimes 1	1.13	23.73	45.97	66.37	5.15	1.10	10.91	6.10	3.07	93.34	11.14	0.16
	Tails 2	8.49	32.22	4.26	50.00	0.32	0.89	92.36	28.83	2.14	95.48	5.21	10.49
	Slimes	1.08	33.30	16.56	48.92	9.31	1.16	22.40	28.62	1.06	96.54	19.29	0.32
	Tails 1	66.70	100.00	0.87	16.87	0.20	0.52	97.74	74.72	3.46	100.00	25.60	87.25
	Feed	100.00		16.87		0.52		74.72		100.00		100.00	100.00

Operating Conditions

Operation	Medium	Impeller Rotation Speed (rpm)	Medium (Weight %)	Solids (%)	Time (Min.)
Scrubbing	Quartz	1000	Variable	60	20*2

Table 46. Scrubbing Results at Different Solids Concentrations.

Solids (%)	Product	Weight (%)		Analysis (%)						Distribution (%)			
				BPL		MgO		A.I.		BPL		MgO	A.I.
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		
60	Concentrate	22.46		66.31		0.86		6.33		89.61		37.61	1.90
	Slimes 4	0.14	22.60	61.33	66.28	2.49	0.87	4.68	6.32	0.53	90.14	0.70	0.01
	Slimes 3	0.19	22.79	59.61	66.23	2.84	0.89	5.12	6.31	0.67	90.81	1.04	0.01
	Slimes 2	0.24	23.03	55.63	66.12	3.56	0.91	6.27	6.31	0.81	91.62	1.68	0.02
	Slimes 1	0.69	23.73	38.87	65.32	6.05	1.06	14.08	6.54	1.62	93.24	8.14	0.13
	Tails 2	8.49	32.22	4.26	49.23	0.32	0.87	92.36	29.15	2.18	95.42	5.29	10.48
	Slimes	1.08	33.30	16.56	48.17	9.31	1.14	22.40	28.93	1.08	96.49	19.58	0.32
	Tails 1	66.70	100.00	0.87	16.62	0.20	0.51	97.74	74.83	3.51	100.00	25.97	87.13
	Feed	100.00		16.62		0.51		74.83		100.00		100.00	100.00
50	Concentrate	22.65		65.86		0.91		6.23		90.29		39.31	1.89
	Slimes 4	0.13	22.78	57.44	65.81	3.05	0.92	5.54	6.23	0.44	90.72	0.73	0.01
	Slimes 3	0.19	22.96	54.87	65.72	3.67	0.94	6.26	6.23	0.62	91.35	1.31	0.02
	Slimes 2	0.27	23.23	48.44	65.52	4.95	0.99	9.03	6.26	0.79	92.14	2.55	0.03
	Slimes 1	0.49	23.73	35.42	64.89	6.69	1.11	15.28	6.45	1.06	93.20	6.30	0.10
	Tails 2	8.49	32.22	4.26	48.91	0.32	0.90	92.36	29.09	2.19	95.39	5.18	10.48
	Slimes	1.08	33.30	16.56	47.87	9.31	1.17	22.40	28.87	1.08	96.47	19.17	0.32
	Tails 1	66.70	100.00	0.87	16.52	0.20	0.52	97.74	74.81	3.53	100.00	25.44	87.15
	Feed	100.00		16.52		0.52		74.81		100.00		100.00	100.00

Operating Conditions					
Operation	Medium	Impeller Rotation Speed (rpm)	Medium (Weight %)	Solids (%)	Time (Min.)
Scrubbing	Quartz	1000	50	60	10*4

Table 47. Scrubbing Results at Different Scrubbing Times.

Product	Weight (%)		Analysis (%)						Distribution (%)			
			BPL		MgO		A.I.		BPL		MgO	A.I.
	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		
Concentrate	22.46		66.31		0.86		6.33		89.61		37.61	1.90
Slimes 4	0.14	22.60	61.33	66.28	2.49	0.87	4.68	6.32	0.53	90.14	0.70	0.01
Slimes 3	0.19	22.79	59.61	66.23	2.84	0.89	5.12	6.31	0.67	90.81	1.04	0.01
Slimes 2	0.24	23.03	55.63	66.12	3.56	0.91	6.27	6.31	0.81	91.62	1.68	0.02
Slimes 1	0.69	23.73	38.87	65.32	6.05	1.06	14.08	6.54	1.62	93.24	8.14	0.13
Tails 2	8.49	32.22	4.26	49.23	0.32	0.87	92.36	29.15	2.18	95.42	5.29	10.48
Slimes	1.08	33.30	16.56	48.17	9.31	1.14	22.40	28.93	1.08	96.49	19.58	0.32
Tails 1	66.70	100.00	0.87	16.62	0.20	0.51	97.74	74.83	3.51	100.00	25.97	87.13
Feed	100.00		16.62		0.51		74.83		100.00		100.00	100.00

Operating Conditions					
Operation	Medium	Impeller Rotation Speed (rpm)	Medium (Weight %)	Solids (%)	Time (Min.)
Scrubbing	Quartz	1000	50	60	10*4

Table 48. Scrubbing Results at Different Impeller Speeds.

Impeller Rotation Speed	Product	Weight (%)		Analysis (%)						Distribution (%)			
				BPL		MgO		A.I.		BPL		MgO	A.I.
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		
1000	Concentrate	22.46		66.31		0.86		6.33		89.61		37.61	1.90
	Slimes 4	0.14	22.60	61.33	66.28	2.49	0.87	4.68	6.32	0.53	90.14	0.70	0.01
	Slimes 3	0.19	22.79	59.61	66.23	2.84	0.89	5.12	6.31	0.67	90.81	1.04	0.01
	Slimes 2	0.24	23.03	55.63	66.12	3.56	0.91	6.27	6.31	0.81	91.62	1.68	0.02
	Slimes 1	0.69	23.73	38.87	65.32	6.05	1.06	14.08	6.54	1.62	93.24	8.14	0.13
	Tails 2	8.49	32.22	4.26	49.23	0.32	0.87	92.36	29.15	2.18	95.42	5.29	10.48
	Slimes	1.08	33.30	16.56	48.17	9.31	1.14	22.40	28.93	1.08	96.49	19.58	0.32
	Tails 1	66.70	100.00	0.87	16.62	0.20	0.51	97.74	74.83	3.51	100.00	25.97	87.13
	Feed	100.00		16.62		0.51		74.83		100.00		100.00	100.00
1500	Concentrate	21.57		67.10		0.81		6.27		86.29		34.08	1.81
	Slimes 4	0.26	21.83	64.50	67.07	1.53	0.82	4.46	6.25	1.00	87.30	0.78	0.02
	Slimes 3	0.33	22.16	63.71	67.02	1.70	0.83	3.99	6.21	1.25	88.55	1.09	0.02
	Slimes 2	0.44	22.60	62.01	66.92	2.12	0.86	4.76	6.19	1.62	90.18	1.82	0.03
	Slimes 1	1.13	23.73	46.47	65.95	5.14	1.06	10.51	6.39	3.12	93.30	11.30	0.16
	Tails 2	8.49	32.22	4.26	49.69	0.32	0.87	92.36	29.05	2.16	95.46	5.30	10.48
	Slimes	1.08	33.30	16.56	48.62	9.31	1.14	22.40	28.83	1.07	96.52	19.61	0.32
	Tails 1	66.70	100.00	0.87	16.77	0.20	0.51	97.74	74.79	3.48	100.00	26.02	87.16
	Feed	100.00		16.77		0.51		74.79		100.00		100.00	100.00

Operating Conditions

Operation	Medium	Impeller Rotation Speed (rpm)	Medium (Weight %)	Solids (%)	Time (Min.)
Scrubbing	Quartz	Variable	50	60	10*4

Table 49. Scrubbing Results Using Different Scrubbing Media.

Medium	Product	Weight (%)		Analysis (%)						Distribution (%)			
				BPL		MgO		A.I.		BPL		MgO	A.I.
		Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.	Indiv.	Cum.		
Quartz	Concentrate	22.61		66.29		0.87		6.32		90.15		38.30	1.91
	Slimes 3	0.19	22.80	59.61	66.24	2.84	0.89	5.12	6.31	0.67	90.82	1.04	0.01
	Slimes 2	0.24	23.04	55.63	66.13	3.56	0.91	6.27	6.31	0.81	91.63	1.68	0.02
	Slimes 1	0.69	23.73	38.87	65.33	6.05	1.06	14.08	6.54	1.62	93.24	8.14	0.13
	Tails 2	8.49	32.22	4.26	49.24	0.32	0.87	92.36	29.15	2.18	95.42	5.29	10.48
	Slimes	1.08	33.30	16.56	48.18	9.31	1.14	22.40	28.93	1.08	96.49	19.58	0.32
	Tails 1	66.70	100.00	0.87	16.63	0.20	0.51	97.74	74.83	3.51	100.00	25.98	87.12
	Feed	100.00		16.63		0.51		74.83		100.00		100.00	100.00
Steel Balls	Concentrate	18.10		67.12		0.81		6.26		72.41		28.18	1.52
	Slimes 3	1.93	20.03	65.90	67.01	1.22	0.85	5.28	6.17	7.58	80.00	4.53	0.14
	Slimes 2	1.66	21.69	63.87	66.76	1.69	0.91	5.70	6.13	6.33	86.32	5.40	0.13
	Slimes 1	2.05	23.74	57.07	65.93	2.97	1.09	7.80	6.27	6.98	93.30	11.71	0.21
	Tails 2	8.49	32.23	4.26	49.68	0.32	0.89	92.36	28.95	2.16	95.46	5.22	10.49
	Slimes	1.08	33.31	16.56	48.61	9.31	1.16	22.40	28.74	1.07	96.52	19.33	0.32
	Tails 1	66.70	100.01	0.87	16.77	0.20	0.52	97.74	74.76	3.48	100.00	25.64	87.20
	Feed	100.00		16.77		0.52		74.77		100.00		100.00	100.00

Operating Conditions					
Operation	Medium	Impeller Rotation Speed (rpm)	Medium (Weight %)	Solids (%)	Time (Min.)
Scrubbing	Variable	1000	50	60	10*3

Table 50. Screen Analysis of the Final Scrubbed Concentrate.

Sieve Fraction	Wt. (%)	Analysis (%)				Distribution (%)		
		P_2O_5	BPL	MgO	A.I.	BPL	MgO	A.I.
+0.5 mm	20.15	29.48	64.41	0.90	8.46	19.36	20.60	26.82
-0.5 + 0.3 mm	27.80	30.62	66.90	0.95	6.63	27.75	30.00	28.99
-0.3 + 0.16 mm	44.73	31.27	68.32	0.84	5.12	45.59	42.67	36.03
-0.16 mm	7.32	30.60	66.86	0.81	7.09	7.30	6.73	8.16
Total	100.00	30.68	67.03	0.88	6.36	100.00	100.00	100.00

IRON AND ALUMINUM DISTRIBUTION ANALYSIS

By request of a participating company in the project, the effect of dolomite depressants on distributions of Fe_2O_3 and Al_2O_3 were analyzed. Figure 38 shows the processing flowsheet for rougher flotation. Results in Table 51 indicate that most of the Fe and Al reported to the rougher concentrate or the final concentrate, regardless of what depressant was used.

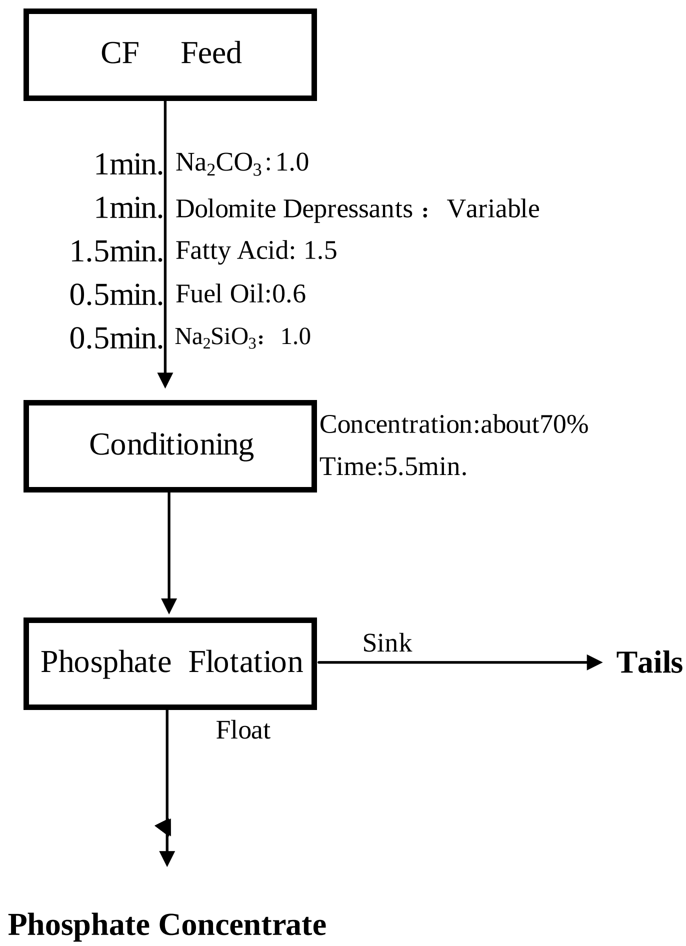


Figure 38. Flotation Flowsheet for Testing Fe and Al Distribution.

Table 51. Analyses of Fe_2O_3 and Al_2O_3 Under Different Test Conditions.

Number*	Dolomite Depressants	Product	Weight (%)	Analysis (%)						Distribution (%)				
				P_2O_5	BPL	MgO	A.I.	Fe_2O_3	Al_2O_3*	BPL	MgO	A.I.	Fe_2O_3	Al_2O_3
1	None	Conc.	31.53	23.74	51.87	1.10	24.17	0.76	0.81	93.58	77.15	10.35	79.54	74.15
		Tails	68.47	0.75	1.64	0.15	96.44	0.09	0.13	6.42	22.85	89.65	20.46	25.85
		Feed	100.00	8.00	17.48	0.45	73.65	0.30	0.34	100.00	100.00	100.00	100.00	100.00
2	None	Conc.	31.74	23.99	52.42	1.24	22.70	0.72	0.77	96.71	76.21	9.75	77.00	67.81
		Tails	68.26	0.38	0.83	0.18	97.72	0.10	0.17	3.29	23.79	90.25	23.00	32.19
		Feed	100.00	7.87	17.21	0.52	73.91	0.30	0.36	100.00	100.00	100.00	100.00	100.00
3	Alizarin Red	Conc.	31.34	24.06	52.57	1.17	22.36	0.67	0.82	95.23	73.76	9.53	70.17	78.92
		Tails	68.66	0.55	1.20	0.19	96.94	0.13	0.10	4.77	26.24	90.47	29.83	21.08
		Feed	100.00	7.92	17.30	0.50	73.57	0.30	0.33	100.00	100.00	100.00	100.00	100.00
4	Starch 1.0 kg/T, Feed	Conc.	29.93	24.57	53.69	1.11	20.35	0.74	0.91	95.54	69.31	8.23	74.19	69.57
		Tails	70.07	0.49	1.07	0.21	96.88	0.11	0.17	4.46	30.69	91.77	25.81	30.43
		Feed	100.00	7.70	16.82	0.48	73.97	0.30	0.39	100.00	100.00	100.00	100.00	100.00
5	PAM 0.75 kg/T, Feed	Conc.	23.90	29.12	63.63	0.90	10.42	0.79	0.77	88.23	41.40	3.37	65.62	53.52
		Tails	76.10	1.22	2.67	0.40	93.70	0.13	0.21	11.77	58.60	96.63	34.38	46.48
		Feed	100.00	7.89	17.23	0.52	73.80	0.29	0.34	100.00	100.00	100.00	100.00	100.00
6	Hengju #9 0.05 kg/T, Feed	Conc.	32.04	23.45	51.24	1.09	25.18	0.70	0.77	97.10	69.08	10.85	76.74	66.85
		Tails	67.96	0.33	0.72	0.23	97.49	0.10	0.18	2.90	30.92	89.15	23.26	33.15
		Feed	100.00	7.74	16.91	0.51	74.32	0.29	0.37	100.00	100.00	100.00	100.00	100.00

Table 51 (Cont.). Analyses of Fe_2O_3 and Al_2O_3 Under Different Test Conditions.

Number	Process	Product	Weight (%)		Analysis (%)							Distribution (%)					
			Indiv.	Cum.	BPL	MgO	A.I.	Fe_2O_3 Indiv.	Fe_2O_3 Cum.	Al_2O_3* Indiv.	Al_2O_3* Cum.	BPL	MgO	A.I. Indiv.	A.I. Cum.	Fe_2O_3	Al_2O_3
7	Final Conc. Scrub.	Conc.	20.48		67.56	0.75	4.20	0.87		0.73		81.64	30.94	1.16		55.71	41.69
		Slimes 3*	1.05	21.53	66.29	1.29	2.94	0.91	0.87	1.60	0.77	4.11	2.73	0.04	1.20	2.99	4.69
		Slimes 2*	1.04	22.58	63.87	1.72	3.95	1.31	0.89	1.61	0.81	3.93	3.62	0.06	1.26	4.28	4.69
		Slimes 1*	1.22	23.80	52.46	3.25	8.93	1.36	0.92	3.55	0.95	3.77	7.97	0.15	1.41	5.18	12.05
		Tails 4	0.34	24.14	17.11	0.61	72.61	0.53	0.91	0.43	0.94	0.34	0.42	0.33	1.74	0.56	0.41
		Tails 3	0.75	24.89	8.06	0.29	86.71	0.23	0.89	0.26	0.92	0.36	0.44	0.88	2.62	0.54	0.55
		Tails 2	6.97	31.86	2.58	0.11	95.60	0.10	0.72	0.11	0.75	1.06	1.54	9.00	11.62	2.18	2.14
		Slimes*	1.01	32.87	17.79	9.08	25.86	2.39	0.77	4.01	0.85	1.06	18.53	0.35	11.97	7.57	11.33
		Tails 1*	67.13	100.00	0.94	0.25	97.15	0.10	0.32	0.12	0.36	3.72	33.80	88.03	100.00	20.99	22.46
		Feed	100.00		16.95	0.50	74.08	0.32		0.36		100.00	100.00	100.00		100.00	100.00
8	Rougher Conc. Scrub.	Conc.	19.86		69.18	0.88	4.46	0.84		0.81		78.42	32.62	1.21		51.67	36.92
		Tails 4	0.80	20.66	60.83	0.73	15.12	0.84	0.84	0.81	0.81	2.78	1.09	0.17	1.38	2.08	1.49
		Tails 3	0.76	21.42	33.52	0.41	53.80	0.50	0.83	0.51	0.80	1.45	0.58	0.56	1.94	1.18	0.89
		Tails 2	6.80	28.22	3.54	0.12	94.27	0.10	0.65	0.15	0.64	1.37	1.52	8.77	10.71	2.11	2.34
		Slimes 4*	1.02	29.24	61.88	1.67	9.11	1.07	0.67	1.47	0.67	3.60	3.18	0.13	10.83	3.38	3.44
		Slimes 3*	1.17	30.41	56.53	2.60	9.71	1.17	0.69	2.15	0.73	3.78	5.68	0.16	10.99	4.24	5.77
		Slimes 2*	1.65	32.06	41.43	5.28	15.03	1.63	0.74	2.97	0.84	3.90	16.26	0.34	11.33	8.33	11.25
		Slimes 1*	0.54	32.60	4.94	10.04	29.89	2.42	0.76	4.38	0.90	0.15	10.12	0.22	11.55	4.05	5.43
		Tails 1*	67.40	100.00	1.18	0.23	95.94	0.11	0.32	0.21	0.44	4.54	28.94	88.45	100.00	22.96	32.48
		Feed	100.00		17.52	0.54	73.11	0.32		0.44		100.00	100.00	100.00		100.00	100.00

Table 51 (Cont.). Analyses of Fe_2O_3 and Al_2O_3 Under Different Test Conditions.

Number	Process	Product	Weight (%)		Analysis (%)							Distribution (%)					
					BPL	MgO	A.I.	Fe_2O_3		Al_2O_3*		BPL	MgO	A.I.		Fe_2O_3	Al_2O_3
			Indiv.	Cum.				Indiv.	Cum.	Indiv.	Cum.			Indiv.	Cum.		
9	Feed Scrub.	Conc.	19.37		68.59	0.86	2.90	0.83		0.81		78.15	34.07	0.76		44.43	38.42
		Tails 4	0.58	19.95	56.42	0.95	17.37	0.94	0.83	0.77	0.81	1.92	1.13	0.14	0.90	1.51	1.09
		Tails 3	1.00	20.95	25.76	0.42	62.55	0.44	0.81	0.43	0.79	1.52	0.86	0.85	1.75	1.22	1.05
		Tails 2	13.93	34.88	1.53	0.01	97.23	0.06	0.51	0.09	0.51	1.25	0.28	18.38	20.12	2.31	3.07
		Slimes 4*	0.60	35.48	55.72	1.24	18.36	2.07	0.54	2.31	0.54	1.97	1.52	0.15	20.27	3.43	3.39
		Tails 1	57.00	92.48	0.46	0.02	98.67	0.04	0.23	0.11	0.28	1.54	2.33	76.31	96.58	6.30	15.35
		Slimes 3*	1.78	94.26	41.60	1.45	34.20	1.17	0.25	1.61	0.30	4.36	5.28	0.83	97.41	5.76	7.02
		Slimes 2*	1.98	96.24	39.64	2.26	32.09	1.62	0.28	1.83	0.33	4.62	9.15	0.86	98.27	8.86	8.87
		Slimes 1*	3.76	100.00	21.17	5.90	33.91	2.52	0.36	2.36	0.41	4.68	45.37	1.73	100.00	26.19	21.73
		Feed	100.00		17.00	0.49	73.70	0.36		0.41		100.00	100.00	100.00		100.00	100.00

*The flowsheet for test numbers 1-6 is shown in Figure 38, the flowsheet for test number 7 in Figure 33, the flowsheet for test number 8 in Figure 32, and the flowsheet for test number 9 in Figure 31.

OVERALL CONCLUSIONS AND ECONOMIC ANALYSIS

Based on the extensive laboratory comparative tests, three approaches were selected as potential dolomite removal methods. Preliminary economic analyses of these methods are shown below.

ADDITION OF DOLOMITE DEPRESSANT

In this process, the flotation feed slurry at about 70% solids is first conditioned with a pH modifier and phosphate collector, as is practiced currently in Florida. The dolomite depressant, a polyacrylamide, is added prior to dilution of the slurry to 30% solids followed by flotation. The dosage of the depressant is about one kilogram per ton of feed. This process could reduce MgO content in the concentrate to about 0.81%.

REVERSE FLOTATION OF AMINE CONCENTRATE

In this process, the final concentrate from the Crago process is dewatered to about 60% solids and ground to 45.22% passing 200 mesh. The ground feed is conditioned at 30% solids with sulfuric acid (2.75 kg/ton feed) and the dolomite collector USPA-31 (1 kg/ton feed). In this manner, MgO content in the final product can be reduced to about 0.7%.

SCRUBBING IN QUARTZ SAND MEDIA

The amine concentrate from the Crago process is dewatered. The scrubbing media quartz sand is then added at a quartz-to-concentrate ratio of 1:2 by weight. The mixture is adjusted to about 60% solids and scrubbed for 40 minutes in a specially designed scrubber at a speed of 1500 RPM. After scrubbing, the final product contains 0.81% MgO.

Table 52 summarizes the performance parameters of the three approaches discussed above.

Table 52. Performance Comparison of the Three MgO Removal Methods – CF.

Process	Product	Yield (%)	Grade (%)		Recovery (%)
			BPL	MgO	
Dolomite Depression	Concentrate	22.12	67.96	0.81	87.37
	Total Tails	77.88	2.78	0.36	
	Feed	100.00	17.20	0.46	
Dolomite Flotation	Concentrate	19.09	65.86	0.72	74.85
	Total Tails	80.91	5.21	0.45	
	Feed	100.00	16.79	0.50	
Scrubbing in Quartz Sand	Concentrate	21.58	67.11	0.81	86.30
	Total Tails	78.42	2.93	0.43	
	Feed	100.00	16.78	0.51	

Compared with the standard Crago process, the only extra cost for the dolomite depression process is the addition of one kilogram of polyacrylamide per ton of feed.

Dolomite flotation of the Crago concentrate adds a grinding operation and associated costs, the dolomite flotation and scavenging steps, sulfuric acid (2.75 kilograms per ton of feed) for pH adjustment and phosphate depression, and the dolomite collector (USPA-31 at 1.0 kg/ton).

The scrubbing process includes two scrubbing steps and two desliming operations, plus the quartz sand scrubbing media.

A rough cost estimate for the three processes is shown in Table 52.

Table 53. Capital and Operating Costs Comparison of the Three Processes.

Process	Capital Cost ($/Ton)	Operating Cost ($/Ton)	Maintenance Fee ($/Ton)
Dolomite Depression	None	4.75-6.35	None
Dolomite Flotation	23.8-31.7	15.8	
Scrubbing	12.7-15.8	3.2-4.7	

The dolomite depression process is the simplest method, and only adds an extra cost for the depressant at 1.0 kg/ton, which translates to a cost of $5.4 per ton of product at a price of $1,190 per ton for the depressant.

The dolomite flotation approach involves capital investment for both grinding and flotation ($23.8-31.7 per ton of product) as well as operating and maintenance costs ($15.8 per ton of product).

Although the scrubbing process requires capital investment ($12.7-15.8 per ton), its operating cost is low ($1.6-3.2 per ton).

Among the three approaches, the dolomite flotation process gives the lowest MgO content in the final concentrate, but reduces phosphate recovery by over 10% with high capital and operating costs. Unless it is absolutely necessary to achieve a concentrate with 0.7% or less MgO, dolomite flotation is not recommended. The scrubbing process offers the following three major advantages: (1) it does not require any chemicals; (2) the quartz sand used as scrubbing media is inexpensive and reusable; and (3) the operating cost is low. Therefore, the scrubbing technique is strongly recommended for further extensive testing.

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