PRELIMINARY DESLIMING TESTS WITH NORTH CAROLINA PHOSPHATE USING A PILOT-SCALE LINATEX HYDROSIZER

by

Louis Schlesinger and Joel Hutwelker
Mineral Processing Engineers

November 25, 1992

Sample No. 5796 • Notebook No. 721 • Project LS #62-1

BACKGROUND

The Minerals Research Laboratory (MRL) has initiated an applied research project to study the effectiveness of using "hydraulic classifiers" as a means of improving the beneficiation of North Carolina minerals. Particular emphasis is to be given to closed-circuit grinding and desliming applications.

As defined here, hydraulic classifiers are devices that meet the following three criteria:

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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As defined here, hydraulic classifiers are devices that meet the following three criteria:

1) They do not use mechanical means, such as a screw or a rake, to remove the oversize product from the device. Instead, the discharge of the oversize depends upon its gravitational flow properties.

2) They are not fed under pressures high enough to induce the particles to separate primarily on the basis of differences in centrifugal force.

3) They operate by at least one, and sometimes both, of the following two mechanisms:

   Hindered Settling -- an oversize particle settles against an upward flowing fluid; the greater the density of the fluid, the larger the particle that will remain suspended ("teetered") in the fluid.

   Elutriation -- an undersize particle is lifted by an upward flowing stream of water; the greater the upflow velocity, the larger the particle that will be lifted.

This project is supported by funds from the North Carolina State University College of Engineering. In addition, various manufacturers of hydraulic classifiers are supporting the project by donating pilot-scale versions of their equipment to the MRL for evaluation of new applications.

OBJECTIVE

The purpose of this phase of the project was to test the feasibility of desliming North Carolina phosphate ore with a "Hydrosizer", the trade name of the hydraulic classifier manufactured by Linatex Corporation of Gallatin, Tennessee.

SAMPLES

Eight 55-gal. drums of -14 mesh screening plant undersize were received from Texasgulf, Incorporated's Aurora, N.C. operation. This 2,000 lb. sample was designated as MRL Laboratory No. 5796. Table 1 shows an analysis of the sample. Half of this material was tested with the Hydrosizer, while the remainder was used for the MRL's column flotation test program that is currently in progress.

TABLE 1. ANALYSIS OF HEAD FEED SAMPLE

Size Analysis

U.S. Series Sieve No.	Tyler Mesh	% Retained Individual	% Retained Cumulative	% Passing
12	10	0.7	0.7	99.3
16	14	0.4	1.1	98.9
20	20	0.6	1.7	98.3
30	28	1.0	2.7	97.3
40	35	3.0	5.7	94.3
50	48	11.1	16.8	83.2
70	65	43.1	59.9	41.1
100	100	24.1	84.0	16.0
140	150	5.0	89.0	11.0
200	200	0.7	89.7	10.3
PAN	PAN	10.3	100.0	---
Total		100.0	---	---

Chemical Analysis (Average of 6 Assays)

% P_2O_5	17.34
% CaO	29.75
% Acid Insol.	36.78
% P_2O_5/% CaO	1.72

PROCEDURES

Figure 1 shows a rendering of a commercial Linatex Hydrosizer. The pilot-scale version used by the MRL was 6-in. in diameter (Figure 2). It is similar to the commercial version in all ways

FIGURE 1. COMMERCIAL LINATEX HYDROSIZER

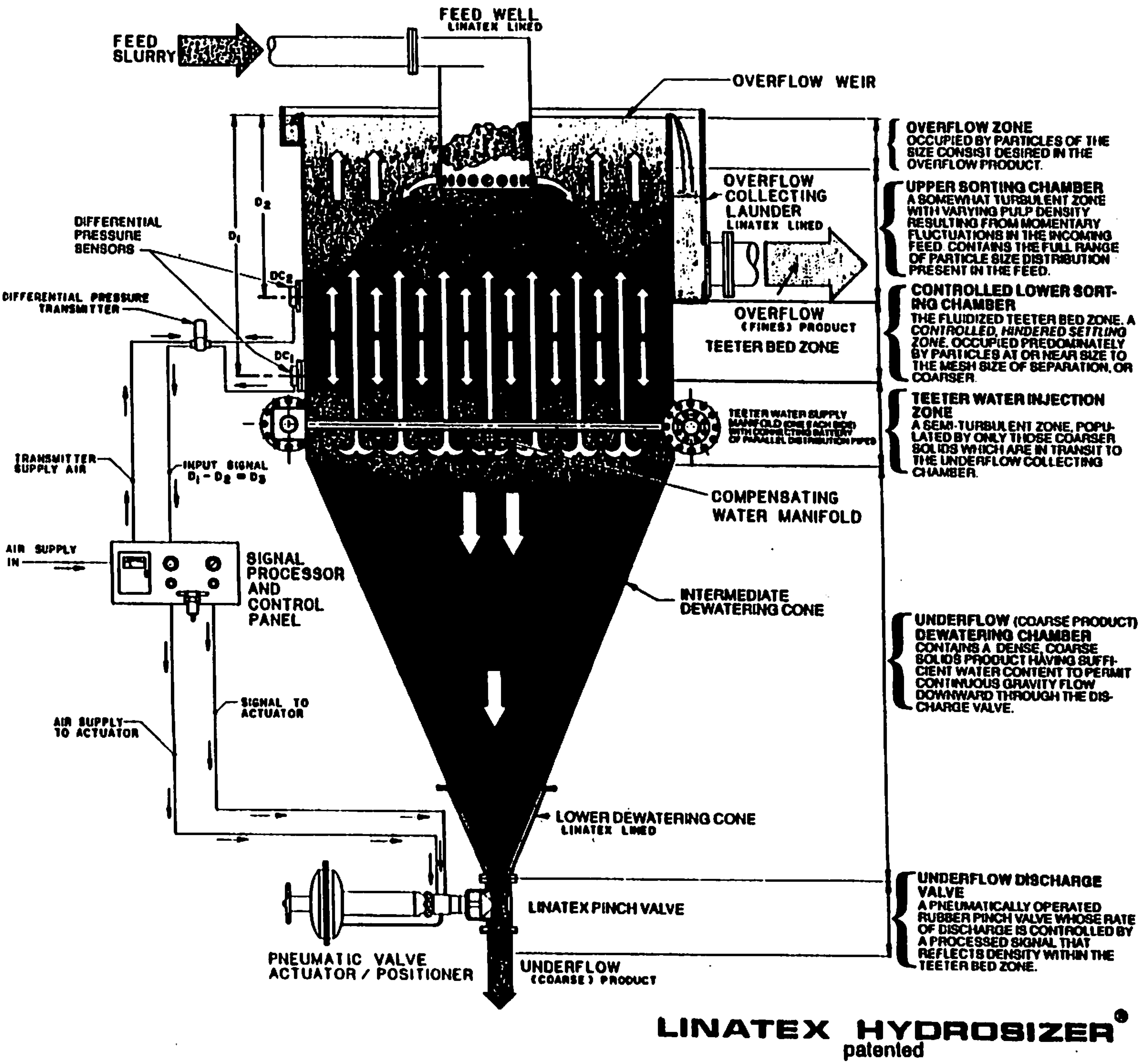
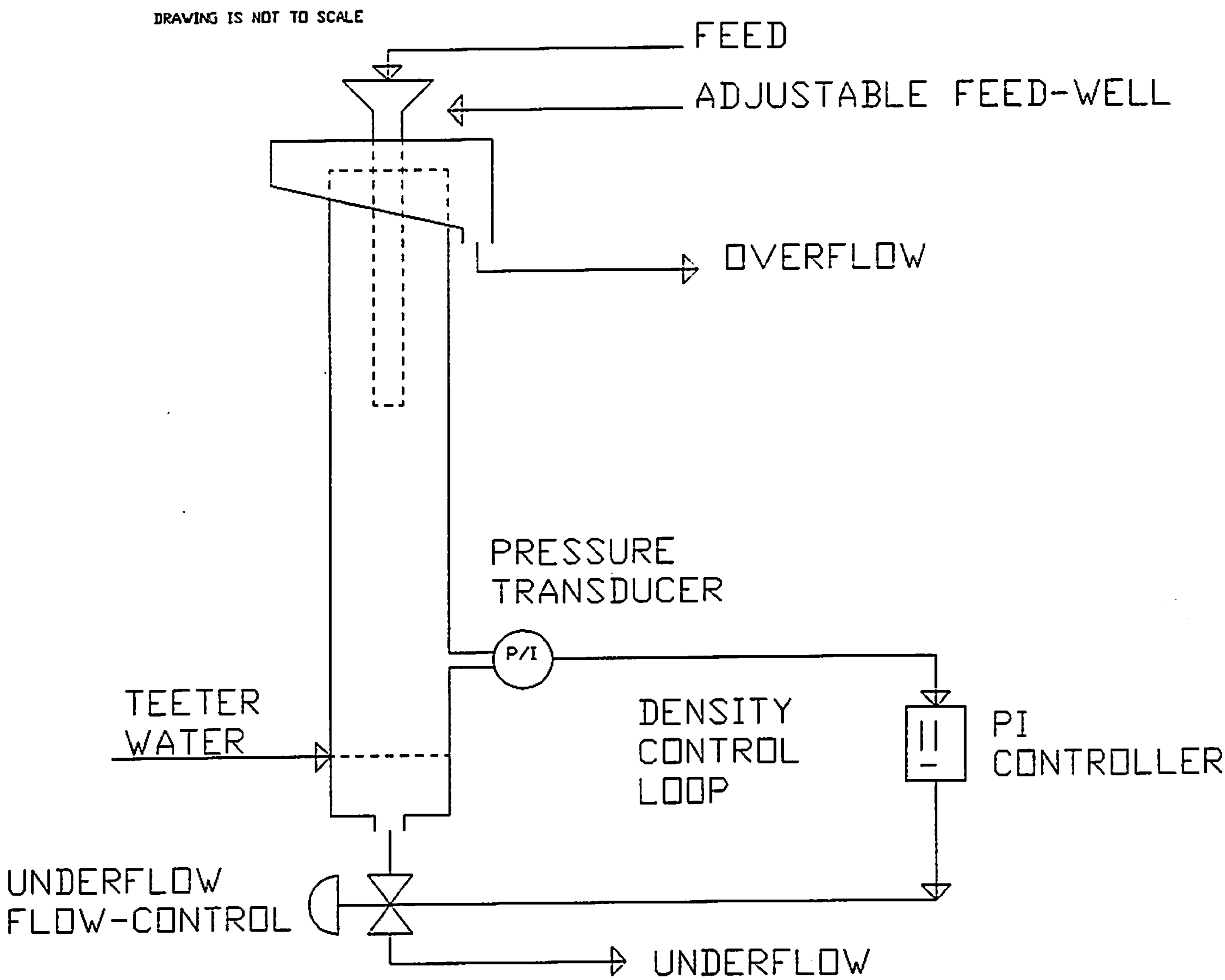


FIGURE 2. PILOT-SCALE LINATEX HYDROSIZER



but one: the lack of a deep dewatering cone. The density of the teeter bed was controlled by means of a proportional-integral (PI) electronic control loop.

A simple pilot plant was constructed to attrition scrub and deslime the phosphate ore. Ore was fed dry with a Vibra-Screw Model SCR-20 volumetric feeder to a six-pot Wemco attrition scrubber. Water was added to create a slurry of 70% solids. For the approximate 100 lbs./hr. feed rate used, only the last two pots were used -- resulting in a retention time of about 5 minutes. (The remaining pots are available to provide additional capacity for higher throughput.) The scrubber discharged to a Denver vertical pump, where sufficient water was added to dilute the slurry to approximately 30% solids prior to delivery to the Hydrosizer. Table 2 summarizes the range of conditions tested.

TABLE 2. SUMMARY OF HYDROSIZER TEST CONDITIONS

	Test No.				
	4A	4B	4C	4D	4E
Feed Rate (lbs./hr.)	106	108	107	105	107
($stph/ft^2$)	0.27	0.27	0.27	0.26	0.27
Feed Percent Solids	30	27	30	29	31
Teeter Water (gpm)	0.25	0.50	0.75	0.95	0.95
(gpm/ft^2)	1.25	2.50	3.75	4.75	4.75
Hydrosizer Percent Solids	22	17	15	13	13
Upflow Velocity (cm/sec)	0.22	0.34	0.40	0.47	0.47
Actual Pressure (in. of H_2O)	47.8	47.3	48.0	48.0	44.5
Teeter Density (g/cm^3)	1.12	1.11	1.13	1.13	1.05

Tests 4A through 4D were conducted using the same hydrostatic pressure setpoint, 47.5 in. of water. This resulted in a reasonably constant teeter bed density for those four tests. However, the quantity of teeter water was increased approximately 0.25 gpm for each test, yielding a gradual increase in upflow velocity during each test. Test 4E utilized the same quantity of teeter water as Test 4D; however, the controller setpoint was reduced to 44.5 in. of water to give a lower teeter bed density.

Timed samples of the underflow and overflow streams were taken once the Hydrosizer reached steady-state. The total pulp in each sample was weighed and then oven-dried to drive off the liquid. The dried solids were then weighed and the weight of liquid calculated by difference. Representative samples of the solids were screen analyzed using the following U.S. Series Standard Sieves: 40, 50, 60, 70, 100, 140, 200 and 325. From those results, the data shown below were calculated:

- Product (underflow) yield
- Efficiencies (oversize, undersize, and total)
- Coefficient of Separation
- Partition Data (i.e., D_{25}, D_{50}, and D_{75})
- Sharpness Index
- Imperfection

Complete definitions and formulas for these terms are included in Appendix C.

In addition, samples of the screen fractions from the underflow and overflow samples from Test 4C were submitted for assay for P_2O_5, CaO, and acid insolubles. This data was used to calculate a complete metallurgical balance for that test.

RESULTS

Table 3 shows a summary of the test results. Plots of the partition curves are displayed in Figure 3. The curves for Tests 4A-4D are drawn with solid lines, while the curve for Test 4E is drawn with a dashed line.

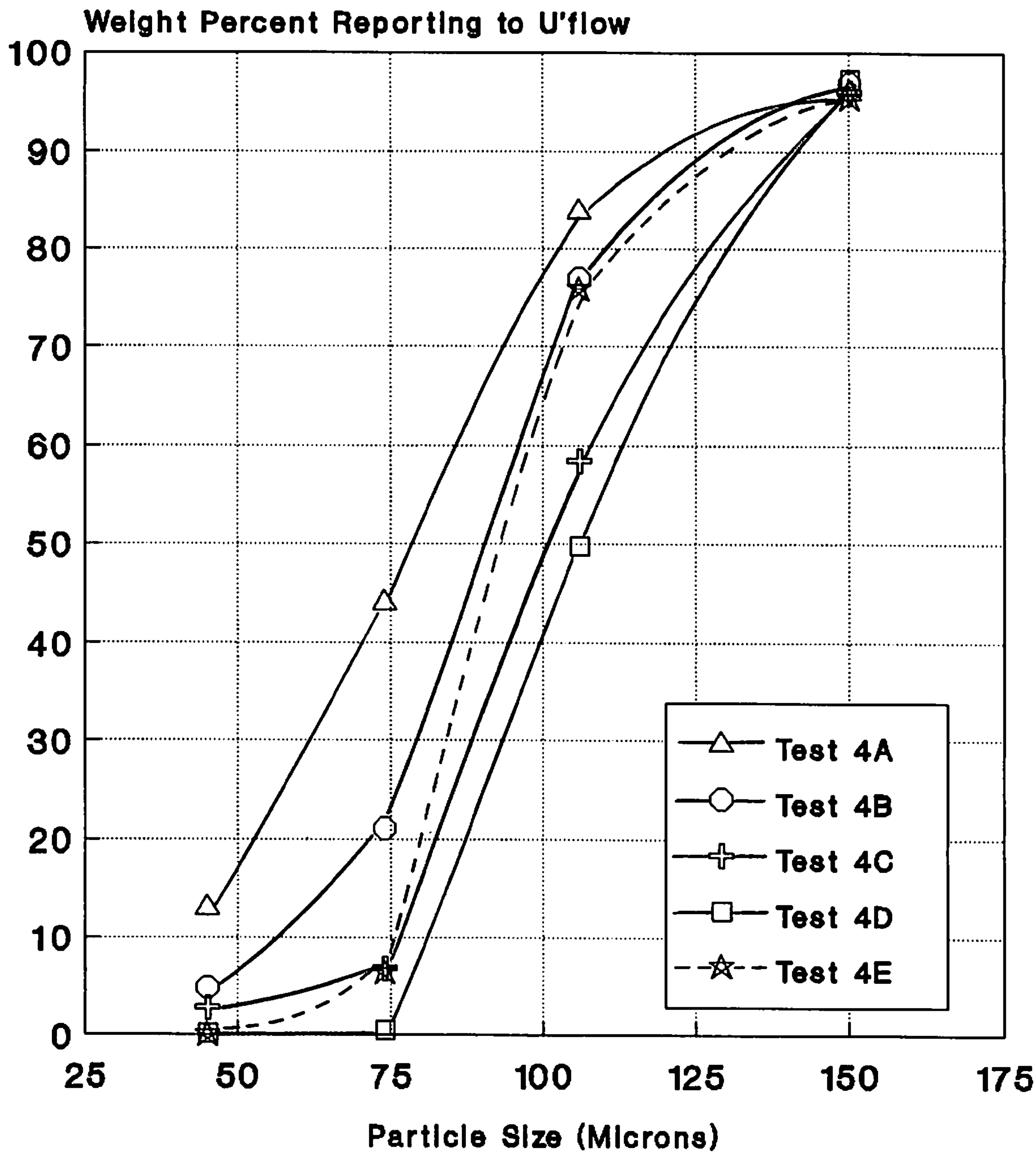
TABLE 3. SUMMARY OF HYDROSIZER TEST RESULTS

	Test No.				
	4A	4B	4C	4D	4E
Teeter Water (gpm)	0.25	0.50	0.75	0.95	0.95
(gpm/ft^2)	1.25	2.50	3.75	4.75	4.75
Upflow Velocity (cm/sec)	0.22	0.34	0.40	0.47	0.47
Teeter Density (g/cm^3)	1.12	1.11	1.13	1.13	1.05
Hydrosizer Percent Solids	22	17	15	13	13
U'Flow Percent Solids	65	66	64	63	65
O'Flow Percent Solids	3.0	2.4	2.0	1.9	1.8
D_{50} (microns)	77	91	103	107	93
D_{25} (microns)	57	77	90	94	82
D_{75} (microns)	91	105	115	121	107
Undersize Efficiency (%)	90.3	96.7	97.6	100.0	100.0
Oversize Efficiency (%)	96.4	96.3	96.1	95.8	95.1
Overall Efficiency (%)	96.0	96.3	96.2	96.1	95.4
Coefficient of Separation (0 - 1)	0.87	0.93	0.94	0.96	0.95
Sharpness Index (0 - 1)	0.63	0.73	0.78	0.78	0.77
Imperfection (1 - 0)	0.22	0.15	0.12	0.13	0.13

Note: The terminal settling velocity of a 74 micron particle of 2.7 g/cm^3 is 0.47 cm/sec.

All of the tests performed resulted in sharp classifications with excellent oversize efficiencies. Test 4C was the best overall in terms of sharpness index and imperfection. Tests 4D and 4E were best in terms of undersize efficiency and coefficient of separation. It is felt that the success of the tests was greatly helped by the sharp differential between the sizes of the clay slime particles and sand particles in the Texasgulf ore.

FIGURE 3. PARTITION CURVES FOR DESLIMING PHOSPHATE ORE (PILOT SCALE LINATEX HYDROSIZER)



Feed Rate = 0.27 stph/sq.ft.

When the density of the teeter bed was held fairly constant, as in Tests 4A-4D, the resulting oversize efficiency was also reasonably constant: approximately 95%-96%. This suggests that the hindered settling of the +200 oversize was not significantly altered by increasing the teeter water flow rate. However, increasing the teeter water improved the undersize efficiency from a low of about 90% at 1.25 gpm/ft^2 to a high of 100% at 4.75 gpm/ft^2. This suggests that this elutriation water supplemented the effect of hindered settling in the sizer. The water tended to wash slimes entrained with the descending particles in much the same way that wash water removes fine gangue particles in a flotation column. From Table 3, it can also be observed that increasing the teeter water gradually increased the cut point (D_{50}). When the teeter water supplemented the feed water to create an upflow velocity equal to 0.47 cm/sec (i.e., the terminal settling velocity predicted for a 2.7 g/cm^3 particle from the Stokes Equation), the cut point was 107 microns (about U.S. No. 140), and desliming was virtually perfect.

During Test 4E, the teeter bed density was reduced to 1.05 g/cm^3 but the teeter flow rate was maintained at 4.75 gpm/ft^2, as in Test 4D. The effect of this change was to lower the cut point to about 93 microns, about U.S. No. 170. However, desliming was still virtually perfect.

It is also important to note that, even with the lack of a sizeable dewatering cone, the Hydrosizer produced an underflow of about 65% solids -- regardless of the quantity of teeter water used.

A summary of the metallurgical balance from Test 4C is shown in Table 4. Recovery of P_2O_5 to the oversize was excellent, with less than 2% of the phosphatic value lost to the slimes. As was expected from the many ore evaluations conducted in the past, there was some preferential rejection of limestone and silica.

TABLE 4. METALLURGICAL SUMMARY OF TEST 4C

	UNDERFLOW	OVERFLOW	FEED
% Yield	89.2	10.8	100.0
% +200	99.8	33.1	92.6
% -200	0.2	66.9	7.4
% Distribution of +200	96.1	3.9	100.0
% Distribution of -200	2.4	97.6	100.0
% P_2O_5 (Calc. Assay)	19.48	3.00	17.70 (17.34)
% CaO (Calc. Assay)	30.93	19.96	29.75 (29.75)
% Insol. (Calc. Assay)	38.56	39.80	38.69 (36.78)
% CaO/% P_2O_5	1.59	6.65	1.68 (1.72)
% Distribution of P_2O_5	98.2	1.8	100.0
% Distribution of CaO	92.8	7.2	100.0
% Distribution of Insol.	88.9	11.1	100.0

Note: Actual feed assays are shown in parenthesis.

SUMMARY

The test results with the 6-in. diameter pilot-scale Linatex Hydrosizer show that North Carolina phosphate ore can be deslimed at 200 mesh quite efficiently through hydraulic classification. Overall efficiencies in excess of 95% were obtained at a throughput of 0.27 stph of feed per ft^2 of overflow area.

The tests utilized upflow velocities that were less than or equal to the terminal settling velocity of a 74 micron diameter particle having a density of 2.7 g/cm^3 (i.e., 0.47 cm/sec). The recovery of oversize (+200) material to the sizer underflow was consistently 95%-96% for these tests. However, the recovery of undersize (-200) material to the sizer overflow increased as the upflow velocity was increased. This was because the cut size (D_{50}) increased slightly with each increase. When the upflow velocity equaled 0.47 cm/sec, the recovery of undersize was 100% efficient.

A metallurgical balance was conducted for the test that utilized an upflow velocity of 0.40 cm/sec. Less than 2% of the P_2O_5 value was lost to the overflow; yet, over 96% of the -200 was removed.

The Linatex Hydrosizer is currently marketed for sizing applications ranging from U.S. No. 30 (28 mesh Tyler) to U.S. No. 100 (100 mesh Tyler). It sees limited service for finer size cuts or desliming, because the manufacturer itself does not aggressively encourage this practice. This is because the capacity of a hydraulic classifier decreases as the particle cut size is decreased. Conventional wisdom maintains that the capital costs favor hydrocycloning. Nonetheless, these preliminary results suggests that hydraulic classification has unique characteristics that offer several potential advantages (Table 5):

TABLE 5. POTENTIAL ADVANTAGES OF DESLIMING WITH A HYDRAULIC CLASSIFIER

CHARACTERISTIC	POTENTIAL ADVANTAGE
A high-solids, slime-free flotation feed can be produced.	Reduced reagent dosage.
Minimal losses of +200 material and phosphatic value.	Increased recovery.
Only a single stage of desliming is required due to minimal short circuiting of feed.	Reduced material handling and pumping.
High pressure pumping is not required.	Reduced energy consumption. Less abrasive wear. Potential for gravity feed.
Susceptible to automatic control.	Consistent performance. Amenable to fine tuning.
High capacitance.	Dampens feed surges.

RECOMMENDATIONS

The tests completed to date, although successful, are preliminary in nature. The following additional work is recommended in regards to desliming phosphate ore:

1) Conduct pilot tests to determine the capacity limitation of the Linatex Hydrosizer, in terms of stph/ft^2. Then, a commercial-scale unit can be accurately sized. (Note: capacity will probably be ultimately limited by the viscosity effect of the clay slimes and controlled by the percent solids within the sizer.)

2) Once capacity is determined, conduct a sidestream test at the mill site. The cyclone circuit can be sampled simultaneously. Mass, water, particle size, and metallurgical balances can be conducted to compare the performances of the two types of classifiers. Then, the gains that are made through hydraulic desliming can be realistically projected.

3) Following the sidestream tests, a cost analysis for implementing hydraulic desliming can be made. Since the gains can be projected, the payback period can be determined.

APPENDIX A: DETAILED HYDROSIZER TEST RESULTS

TABLE A1. PILOT-SCALE HYDRAULIIC SIZER TEST PERFORMANCE -- TEST 4A

Date:	09/15/92
Material:	Texasgulf -U.S. No. 16 Mill Feed
MRL Lab. No.:	5796
Test No.:	Linatex-4A
Application:	Deslime @ U.S. No. 200

SAMPLE DATA:

Specific Gravity of Solids:	2.7	Teeter Water (gpm):	0.25
Setpoint (in. of Water):	56.5	Actual in. of Water:	47.75

Stream	Sample Time (min.)	Pulp Weight (g.)	Dry Solids Weight (g.)	Liquid Weight (g.)	% Solids
U'flow	2.00	2231.0	1450.0	781	65.0
O'flow	2.00	4955.0	149.1	4805.9	3.0

ACTUAL MASS AND WATER BALANCE DATA:

					Percent by:		Percent of:	
Stream	lbs/hr	gph	gpm	S.G.	Weight	Volume	Feed	Total
Solids	105.8	4.70	0.08	2.7	30.2	13.8	100.0	100.0
Liquid	244.5	29.34	0.49	1.0	69.8	86.2	100.0	66.2
FEED:	350.3	34.04	0.57	1.235	100.0	100.0	100.0	73.7
Solids	9.9	0.44	0.01	2.7	3.0	1.1	9.3	9.3
Liquid	317.9	38.14	0.64	1.0	97.0	98.9	130.0	86.0
O'FLOW:	327.7	38.58	0.64	1.019	100.0	100.0	93.6	69.0
Solids	95.9	4.26	0.07	2.7	65.0	40.7	90.7	90.7
Liquid	51.7	6.20	0.10	1.0	35.0	59.3	21.1	14.0
U'FLOW:	147.6	10.46	0.17	1.693	100.0	100.0	42.1	31.0
TEETER: WATER	125.0	15.00	0.25	1.0	100.0	100.0	51.1	33.8
Solids	105.8	4.70	0.08	2.7	22.3	9.6	100.0	100.0
Liquid	369.5	44.34	0.74	1.0	77.7	90.4	151.1	100.0
TOTAL IN SIZER:	475.3	49.04	0.82	1.163	100.0	100.0	135.7	100.0

TABLE A1. PILOT-SCALE HYDRAULIIC SIZER TEST PERFORMANCE -- TEST 4A (Continued)

SIZE ANALYSIS OF PRODUCTS:

	U'flow			O'flow			Feed	
U.S. No.	% Ret.	% Cum.	% of Feed	% Ret.	% Cum.	% of Feed	% Ret.	% Cum.
40	6.8	6.8	6.2	0.0	0.0	0.0	6.2	6.2
50	8.9	15.7	8.1	0.6	0.6	0.1	8.1	14.3
70	60.2	75.9	54.6	14.0	14.6	1.3	55.9	70.2
100	19.3	95.2	17.5	7.9	22.5	0.7	18.2	88.4
140	3.5	98.7	3.2	6.6	29.1	0.6	3.8	92.2
200	0.6	99.3	0.5	7.4	36.5	0.7	1.2	93.4
325	0.4	99.7	0.4	26.1	62.6	2.4	2.8	96.2
-325	0.3	100.0	0.3	37.4	100.0	3.5	3.8	100.0
Total	100.0	---	90.7	100.0	---	9.3	100.0	---

DISTRIBUTION OF SIZE FRACTIONS TO PRODUCTS:

	% Distribution			% Recovery of +200		% Recovery of -200	
	to U'flow	to O'flow	to Feed	to U'flow	to O'flow	to U'flow	to O'flow
40	100.0	0.0	100.0	6.6	0.0	---	---
50	99.3	0.7	100.0	8.6	0.1	---	---
70	97.7	2.3	100.0	58.4	1.4	---	---
100	96.0	4.0	100.0	18.7	0.8	---	---
140	83.8	16.2	100.0	3.4	0.7	---	---
200	44.1	55.9	100.0	0.6	0.7	---	---
325	13.0	87.0	100.0	---	---	5.5	37.1
-325	7.2	92.8	100.0	---	---	4.1	53.2
Total	90.7	9.3	100.0	96.4	3.6	9.7	90.3

CALCULATION OF EFFICIENCIES:

Percent +200 in Feed:	93.4
Percent -200 in Feed:	6.6
Percent +200 in Oversize Product (U'flow):	99.3
Percent -200 in Undersize Product (O'flow):	63.5
Percent Yield to Undersize Product (O'flow):	9.3
Percent Yield to Oversize Product (U'flow):	90.7
Efficiency of Undersize (O'flow):	90.3
Efficiency of Oversize (U'flow):	96.4
Total Efficiency:	96.0
Coefficient of Separation	0.87

TABLE A2. PILOT-SCALE HYDRAULIIC SIZER TEST PERFORMANCE -- TEST 4B

Date:	09/15/92
Material:	Texasgulf -U.S. No. 16 Mill Feed
MRL Lab. No.:	5796
Test No.:	Linatex-4B
Application:	Deslime @ U.S. No. 200

SAMPLE DATA:

Specific Gravity of Solids:	2.7	Teeter Water (gpm):	0.5
Setpoint (in. of Water):	56.5	Actual in. of Water:	47.25

Stream	Sample Time (min.)	Pulp Weight (g.)	Dry Solids Weight (g.)	Liquid Weight (g.)	% Solids
U'flow	2.00	2206.0	1445.2	760.8	65.5
O'flow	2.00	7571.0	181.4	7389.6	2.4

ACTUAL MASS AND WATER BALANCE DATA:

					Percent by:		Percent of:	
Stream	lbs/hr	gph	gpm	S.G.	Weight	Volume	Feed	Total
Solids	107.6	4.78	0.08	2.7	27.1	12.1	100.0	100.0
Liquid	289.0	34.69	0.58	1.0	72.9	87.9	100.0	53.6
FEED:	396.6	39.47	0.66	1.206	100.0	100.0	100.0	61.3
Solids	12.0	0.53	0.01	2.7	2.4	0.9	11.2	11.2
Liquid	488.7	58.65	0.98	1.0	97.6	99.1	169.1	90.7
O'FLOW:	500.7	59.18	0.99	1.015	100.0	100.0	126.2	77.4
Solids	95.6	4.25	0.07	2.7	65.5	41.3	88.8	88.8
Liquid	50.3	6.04	0.10	1.0	34.5	58.7	17.4	9.3
U'FLOW:	145.9	10.29	0.17	1.702	100.0	100.0	36.8	22.6
TEETER: WATER	250.0	30.00	0.50	1.0	100.0	100.0	86.5	46.4
Solids	107.6	4.78	0.08	2.7	16.6	6.9	100.0	100.0
Liquid	539.0	64.69	1.08	1.0	83.4	93.1	186.5	100.0
TOTAL IN SIZER:	646.6	69.47	1.16	1.117	100.0	100.0	163.0	100.0

TABLE A2. PILOT-SCALE HYDRAULIIC SIZER TEST PERFORMANCE -- TEST 4B (Continued)

SIZE ANALYSIS OF PRODUCTS:

	U'flow			O'flow			Feed	
U.S. No.	% Ret.	% Cum.	% of Feed	% Ret.	% Cum.	% of Feed	% Ret.	% Cum.
40	6.2	6.2	5.5	0.0	0.0	0.0	5.5	5.5
50	9.1	15.3	8.1	0.6	0.6	0.1	8.2	13.7
70	58.5	73.8	52.0	3.2	3.8	0.4	52.3	66.0
100	21.7	95.5	19.3	5.8	9.6	0.6	19.9	85.9
140	3.8	99.3	3.4	9.1	18.7	1.0	4.4	90.3
200	0.4	99.7	0.4	12.0	30.7	1.3	1.7	92.0
325	0.2	99.9	0.2	31.6	62.3	3.5	3.7	95.7
-325	0.1	100.0	0.1	37.7	100.0	4.2	4.3	100.0
Total	100.0	---	88.8	100.0	---	11.2	100.0	---

DISTRIBUTION OF SIZE FRACTIONS TO PRODUCTS:

	% Distribution			% Recovery of +200		% Recovery of -200	
	to U'flow	to O'flow	to Feed	to U'flow	to O'flow	to U'flow	to O'flow
40	100.0	0.0	100.0	6.0	0.0	---	---
50	99.2	0.8	100.0	8.8	0.1	---	---
70	99.3	0.7	100.0	56.5	0.4	---	---
100	96.8	3.2	100.0	21.0	0.7	---	---
140	76.9	23.1	100.0	3.7	1.1	---	---
200	21.0	79.0	100.0	0.4	1.5	---	---
325	4.8	95.2	100.0	---	---	2.2	44.1
-325	2.1	97.9	100.0	---	---	1.1	52.6
Total	88.8	11.2	100.0	96.3	3.7	3.3	96.7

CALCULATION OF EFFICIENCIES:

Percent +200 in Feed:	92.0
Percent -200 in Feed:	8.0
Percent +200 in Oversize Product (U'flow):	99.7
Percent -200 in Undersize Product (O'flow):	69.3
Percent Yield to Undersize Product (O'flow):	11.2
Percent Yield to Oversize Product (U'flow):	88.8
Efficiency of Undersize (O'flow):	96.7
Efficiency of Oversize (U'flow):	96.3
Total Efficiency:	96.3
Coefficient of Separation	0.93

TABLE A3. PILOT-SCALE HYDRAULIIC SIZER TEST PERFORMANCE -- TEST 4C

Date:	09/15/92
Material:	Texasgulf -U.S. No. 16 Mill Feed
MRL Lab. No.:	5796
Test No.:	Linatex-4C
Application:	Deslime @ U.S. No. 200

SAMPLE DATA:

Specific Gravity of Solids:	2.7	Teeter Water (gpm):	0.75
Setpoint (in. of Water):	57	Actual in. of Water:	48

Stream	Sample Time (min.)	Pulp Weight (g.)	Dry Solids Weight (g.)	Liquid Weight (g.)	% Solids
U'flow	2.00	2269.0	1446.0	823.0	63.7
O'flow	2.00	8839.0	175.9	8663.1	2.0

ACTUAL MASS AND WATER BALANCE DATA:

					Percent by:		Percent of:	
Stream	lbs/hr	gph	gpm	S.G.	Weight	Volume	Feed	Total
Solids	107.3	4.77	0.08	2.7	29.8	13.6	100.0	100.0
Liquid	252.4	30.29	0.50	1.0	70.2	86.4	100.0	40.2
FEED:	359.7	35.05	0.58	1.231	100.0	100.0	100.0	49.0
Solids	11.6	0.52	0.01	2.7	2.0	0.7	10.8	10.8
Liquid	573.0	68.75	1.15	1.0	98.0	99.3	227.0	91.3
O'FLOW:	584.6	69.27	1.15	1.013	100.0	100.0	162.5	79.6
Solids	95.6	4.25	0.07	2.7	63.7	39.4	89.2	89.2
Liquid	54.4	6.53	0.11	1.0	36.3	60.6	21.6	8.7
U'FLOW:	150.1	10.78	0.18	1.670	100.0	100.0	41.7	20.4
TEETER: WATER	375.0	45.00	0.75	1.0	100.0	100.0	148.6	59.8
Solids	107.3	4.77	0.08	2.7	14.6	6.0	100.0	100.0
Liquid	627.4	75.29	1.25	1.0	85.4	94.0	248.6	100.0
TOTAL IN SIZER:	734.7	80.05	1.33	1.101	100.0	100.0	204.3	100.0

TABLE A3. PILOT-SCALE HYDRAULIIC SIZER TEST PERFORMANCE -- TEST 4C (Continued)

SIZE ANALYSIS OF PRODUCTS:

	U'flow			O'flow			Feed	
U.S. No.	% Ret.	% Cum.	% of Feed	% Ret.	% Cum.	% of Feed	% Ret.	% Cum.
40	6.6	6.6	5.9	0.0	0.0	0.0	5.9	5.9
50	8.2	14.8	7.3	0.0	0.0	0.0	7.3	13.2
70	63.5	78.3	56.6	5.0	5.0	0.5	57.2	70.4
100	19.7	98.0	17.6	6.9	11.9	0.7	18.3	88.7
140	1.7	99.7	1.5	10.0	21.9	1.1	2.6	91.3
200	0.1	99.8	0.1	11.2	33.1	1.2	1.3	92.6
325	0.1	99.9	0.1	29.5	62.6	3.2	3.3	95.9
-325	0.1	100.0	0.1	37.4	100.0	4.1	4.1	100.0
Total	100.0	---	89.2	100.0	---	10.8	100.0	---

DISTRIBUTION OF SIZE FRACTIONS TO PRODUCTS:

	% Distribution			% Recovery of +200		% Recovery of -200	
	to U'flow	to O'flow	to Feed	to U'flow	to O'flow	to U'flow	to O'flow
40	100.0	0.0	100.0	6.4	0.0	---	---
50	100.0	0.0	100.0	7.9	0.0	---	---
70	99.1	0.9	100.0	61.2	0.6	---	---
100	95.9	4.1	100.0	19.0	0.8	---	---
140	58.3	41.7	100.0	1.6	1.2	---	---
200	6.8	93.2	100.0	0.1	1.3	---	---
325	2.7	97.3	100.0	---	---	1.2	43.0
-325	2.2	97.8	100.0	---	---	1.2	54.6
Total	89.2	10.8	100.0	96.1	3.9	2.4	97.6

CALCULATION OF EFFICIENCIES:

Percent +200 in Feed:	92.6
Percent -200 in Feed:	7.4
Percent +200 in Oversize Product (U'flow):	99.8
Percent -200 in Undersize Product (O'flow):	66.9
Percent Yield to Undersize Product (O'flow):	10.8
Percent Yield to Oversize Product (U'flow):	89.2
Efficiency of Undersize (O'flow):	97.6
Efficiency of Oversize (U'flow):	96.1
Total Efficiency:	96.2
Coefficient of Separation	0.94

TABLE A4. PILOT-SCALE HYDRAULIIC SIZER TEST PERFORMANCE -- TEST 4D

Date:	09/15/92
Material:	Texasgulf -U.S. No. 16 Mill Feed
MRL Lab. No.:	5796
Test No.:	Linatex-4D
Application:	Deslime @ U.S. No. 200

SAMPLE DATA:

Specific Gravity of Solids:	2.7	Teeter Water (gpm):	0.95
Setpoint (in. of Water):	57	Actual in. of Water:	48

Stream	Sample Time (min.)	Pulp Weight (g.)	Dry Solids Weight (g.)	Liquid Weight (g.)	% Solids
U'flow	2.00	2194.0	1390.0	804.0	63.4
O'flow	2.00	10536.0	196.4	10339.6	1.9

ACTUAL MASS AND WATER BALANCE DATA:

					Percent by:		Percent of:	
Stream	lbs/hr	gph	gpm	S.G.	Weight	Volume	Feed	Total
Solids	104.9	4.66	0.08	2.7	28.6	12.9	100.0	100.0
Liquid	262.0	31.44	0.52	1.0	71.4	87.1	100.0	35.6
FEED:	366.9	36.10	0.60	1.220	100.0	100.0	100.0	43.6
Solids	13.0	0.58	0.01	2.7	1.9	0.7	12.4	12.4
Liquid	683.8	82.06	1.37	1.0	98.1	99.3	261.0	92.8
O'FLOW:	696.8	82.64	1.38	1.012	100.0	100.0	189.9	82.8
Solids	91.9	4.09	0.07	2.7	63.4	39.0	87.6	87.6
Liquid	53.2	6.38	0.11	1.0	36.6	61.0	20.3	7.2
U'FLOW:	145.1	10.47	0.17	1.664	100.0	100.0	39.5	17.2
TEETER: WATER	475.0	57.00	0.95	1.0	100.0	100.0	181.3	64.4
Solids	104.9	4.66	0.08	2.7	12.5	5.0	100.0	100.0
Liquid	737.0	88.44	1.47	1.0	87.5	95.0	281.3	100.0
TOTAL IN SIZER:	841.9	93.10	1.55	1.085	100.0	100.0	229.5	100.0

TABLE A4. PILOT-SCALE HYDRAULIIC SIZER TEST PERFORMANCE -- TEST 4D (Continued)

SIZE ANALYSIS OF PRODUCTS:

U.S. No.	U'flow % Ret.	U'flow % Cum.	U'flow % of Feed	O'flow % Ret.	O'flow % Cum.	O'flow % of Feed	Feed % Ret.	Feed % Cum.
40	5.2	5.2	4.6	0.0	0.0	0.0	4.6	4.6
50	9.1	14.3	8.0	0.0	0.0	0.0	8.0	12.5
70	62.3	76.6	54.6	1.6	1.6	0.2	54.8	67.3
100	21.4	98.0	18.8	4.4	6.0	0.5	19.3	86.6
140	2.0	100.0	1.8	14.4	20.4	1.8	3.5	90.1
200	0.0	100.0	0.0	10.8	31.2	1.3	1.3	91.5
325	0.0	100.0	0.0	29.4	60.6	3.6	3.6	95.1
-325	0.0	100.0	0.0	39.4	100.0	4.9	4.9	100.0
Total	100.0	---	87.6	100.0	---	12.4	100.0	---

DISTRIBUTION OF SIZE FRACTIONS TO PRODUCTS:

	% Distribution to U'flow	% Distribution to O'flow	% Distribution to Feed	% Recovery of +200 to U'flow	% Recovery of +200 to O'flow	% Recovery of -200 to U'flow	% Recovery of -200 to O'flow
40	100.0	0.0	100.0	5.0	0.0	---	---
50	100.0	0.0	100.0	8.7	0.0	---	---
70	99.6	0.4	100.0	59.7	0.2	---	---
100	97.2	2.8	100.0	20.5	0.6	---	---
140	49.6	50.4	100.0	1.9	1.9	---	---
200	0.0	100.0	100.0	0.0	1.5	---	---
325	0.0	100.0	100.0	---	---	0.0	42.7
-325	0.0	100.0	100.0	---	---	0.0	57.3
Total	87.6	12.4	100.0	95.8	4.2	0.0	100.0

CALCULATION OF EFFICIENCIES:

Percent +200 in Feed:	91.5
Percent -200 in Feed:	8.5
Percent +200 in Oversize Product (U'flow):	100.0
Percent -200 in Undersize Product (O'flow):	68.8
Percent Yield to Undersize Product (O'flow):	12.4
Percent Yield to Oversize Product (U'flow):	87.6
Efficiency of Undersize (O'flow):	100.0
Efficiency of Oversize (U'flow):	95.8
Total Efficiency:	96.1
Coefficient of Separation	0.96

TABLE A5. PILOT-SCALE HYDRAULIIC SIZER TEST PERFORMANCE -- TEST 4E

Date: 09/15/92
Material: Texasgulf -U.S. No. 16 Mill Feed
MRL Lab. No.: 5796
Test No.: Linatex-4E
Application: Deslime @ U.S. No. 200

SAMPLE DATA:

Specific Gravity of Solids: 2.7 Teeter Water (gpm): 0.95
Setpoint (in. of Water): 53.5 Actual in. of Water: 44.5

Stream	Sample Time (min.)	Pulp Weight (g.)	Dry Solids Weight (g.)	Liquid Weight (g.)	% Solids
U'flow	2.00	2231.0	1439.7	791.3	64.5
O'flow	2.00	10242.0	183.9	10058.1	1.8

ACTUAL MASS AND WATER BALANCE DATA:

					Percent by:		Percent of:	
Stream	lbs/hr	gph	gpm	S.G.	Weight	Volume	Feed	Total
Solids	107.4	4.77	0.08	2.7	30.7	14.1	100.0	100.0
Liquid	242.6	29.11	0.49	1.0	69.3	85.9	100.0	33.8
FEED:	349.9	33.88	0.56	1.239	100.0	100.0	100.0	42.4
Solids	12.2	0.54	0.01	2.7	1.8	0.7	11.3	11.3
Liquid	665.2	79.83	1.33	1.0	98.2	99.3	274.3	92.7
O'FLOW:	677.4	80.37	1.34	1.011	100.0	100.0	193.6	82.1
Solids	95.2	4.23	0.07	2.7	64.5	40.3	88.7	88.7
Liquid	52.3	6.28	0.10	1.0	35.5	59.7	21.6	7.3
U'FLOW:	147.6	10.51	0.18	1.684	100.0	100.0	42.2	17.9
TEETER: WATER	475.0	57.00	0.95	1.0	100.0	100.0	195.8	66.2
Solids	107.4	4.77	0.08	2.7	13.0	5.3	100.0	100.0
Liquid	717.6	86.11	1.44	1.0	87.0	94.7	295.8	100.0
TOTAL IN SIZER:	824.9	90.88	1.51	1.089	100.0	100.0	235.7	100.0

TABLE A5. PILOT-SCALE HYDRAULIIC SIZER TEST PERFORMANCE -- TEST 4E (Continued)

SIZE ANALYSIS OF PRODUCTS:

	U'flow			O'flow			Feed	
U.S. No.	% Ret.	% Cum.	% of Feed	% Ret.	% Cum.	% of Feed	% Ret.	% Cum.
40	9.9	9.9	8.8	0.0	0.0	0.0	8.8	8.8
50	8.5	18.4	7.5	0.0	0.0	0.0	7.5	16.3
70	55.4	73.8	49.1	10.4	10.4	1.2	50.3	66.6
100	22.1	95.9	19.6	8.4	18.8	1.0	20.5	87.2
140	4.0	99.9	3.5	10.0	28.8	1.1	4.7	91.8
200	0.1	100.0	0.1	11.4	40.2	1.3	1.4	93.2
325	0.0	100.0	0.0	27.8	68.0	3.1	3.1	96.4
-325	0.0	100.0	0.0	32.0	100.0	3.6	3.6	100.0
Total	100.0	---	88.7	100.0	---	11.3	100.0	---

DISTRIBUTION OF SIZE FRACTIONS TO PRODUCTS:

	% Distribution			% Recovery of +200		% Recovery of -200	
	to U'flow	to O'flow	to Feed	to U'flow	to O'flow	to U'flow	to O'flow
40	100.0	0.0	100.0	9.4	0.0	---	---
50	100.0	0.0	100.0	8.1	0.0	---	---
70	97.7	2.3	100.0	52.7	1.3	---	---
100	95.4	4.6	100.0	21.0	1.0	---	---
140	75.8	24.2	100.0	3.8	1.2	---	---
200	6.4	93.6	100.0	0.1	1.4	---	---
325	0.0	100.0	100.0	---	---	0.0	46.5
-325	0.0	100.0	100.0	---	---	0.0	53.5
Total	88.7	11.3	100.0	95.1	4.9	0.0	100.0

CALCULATION OF EFFICIENCIES:

Percent +200 in Feed:	93.2
Percent -200 in Feed:	6.8
Percent +200 in Oversize Product (U'flow):	100.0
Percent -200 in Undersize Product (O'flow):	59.8
Percent Yield to Undersize Product (O'flow):	11.3
Percent Yield to Oversize Product (U'flow):	88.7
Efficiency of Undersize (O'flow):	100.0
Efficiency of Oversize (U'flow):	95.1
Total Efficiency:	95.4
Coefficient of Separation	0.95

APPENDIX B: DETAILED METALLURGICAL BALANCE (TEST 4C)

TABLE B1. CHEMICAL ANALYSIS OF INDIVIDUAL SIZE FRACTIONS (TEST 4C)

UNDERFLOW

U.S.No.	% Wt.	% of Feed	% P_2O_5	% CaO	% Insol	% CaO÷ % P_2O_5
40	6.6	5.9	14.78	24.20	51.82	1.64
50	8.2	7.3	16.78	26.80	46.58	1.60
70	63.5	56.6	18.56	29.30	42.00	1.58
100	19.7	17.6	24.51	39.10	21.78	1.60
140	1.7	1.5	26.46	42.60	14.92	1.61
200	0.1	0.1	19.38	31.87	32.33	1.64
-200	0.2	0.2	21.09	36.83	15.92	1.75
Total	100.0	89.2	19.48	30.93	38.56	1.59

OVERFLOW

U.S.No.	% Wt.	% of Feed	% P_2O_5	% CaO	% Insol	% CaO÷ % P_2O_5
70	5.0	0.5	3.21	14.50	45.34	4.52
100	6.9	0.7	3.95	20.30	45.14	5.14
190	10.0	1.1	4.93	17.20	45.61	3.49
200	11.2	1.2	4.81	20.20	44.62	4.20
-200	66.9	7.2	2.29	20.70	37.16	9.04
Total	100.0	10.8	3.00	19.96	39.80	6.65

CALC. FEED

U.S.No.	% Wt.	% of Feed	% P_2O_5	% CaO	% Insol	% CaO÷ % P_2O_5
40	5.9	5.9	14.78	24.20	51.82	1.64
50	7.3	7.3	16.78	26.80	46.58	1.60
70	57.2	57.2	18.42	29.16	42.09	1.58
100	18.3	18.3	23.67	38.34	22.73	1.62
140	2.6	2.6	17.50	32.03	27.69	1.83
200	1.3	1.3	5.81	21.00	43.78	3.61
-200	7.4	7.4	2.74	21.09	26.65	7.70
Total	100.0	100.0	17.70	29.75	38.69	1.68

TABLE B2. CHEMICAL ANALYSIS OF CUMULATIVE SIZE FRACTIONS (TEST 4C)

UNDERFLOW

U.S.No.	% Wt.	% of Feed	% P_2O_5	% CaO	% Insol	% CaO÷ % P_2O_5
40	6.6	5.9	14.78	24.20	51.82	1.64
50	14.8	13.2	15.89	25.64	48.92	1.62
70	78.3	69.8	18.05	28.61	43.36	1.59
100	98.0	87.4	19.35	30.72	39.02	1.59
140	99.7	88.9	19.47	30.92	38.61	1.59
200	99.8	89.0	19.47	30.92	38.60	1.59
-200	100.0	89.2	19.48	30.93	38.56	1.59

OVERFLOW

U.S.No.	% Wt.	% of Feed	% P_2O_5	% CaO	% Insol	% CaO÷ % P_2O_5
70	5.0	0.5	3.21	14.50	45.34	4.52
100	11.9	1.3	3.64	17.86	45.22	4.91
190	21.9	2.4	4.23	17.56	45.40	4.15
200	33.1	3.6	4.43	18.45	45.14	4.16
-200	100.0	10.8	3.00	19.96	39.80	6.65

CALC. FEED

U.S.No.	% Wt.	% of Feed	% P_2O_5	% CaO	% Insol	% CaO÷ % P_2O_5
40	5.9	5.9	14.78	24.20	51.82	1.64
50	13.2	13.2	15.89	25.64	48.92	1.61
70	70.4	70.4	17.94	28.50	43.37	1.59
100	88.7	88.7	19.12	30.53	39.11	1.60
140	91.3	91.3	19.08	30.57	38.78	1.60
200	92.6	92.6	18.89	30.44	38.85	1.61
-200	100.0	100.0	17.70	29.75	38.69	1.68

TABLE B3. DISTRIBUTION OF CHEMICAL CONSTITUENTS BY INDIVIDUAL SIZE FRACTION (TEST 4C)

UNDERFLOW

U.S.No.	% Wt.	% of Feed	P_2O_5	CaO	Insol
40	6.6	5.9	4.9	4.8	7.9
50	8.2	7.3	6.9	6.6	8.8
70	63.5	56.6	59.4	55.8	61.6
100	19.7	17.6	24.3	23.1	9.9
140	1.7	1.5	2.3	2.2	0.6
200	0.1	0.1	0.1	0.1	0.1
-200	0.2	0.2	0.2	0.2	0.1
Total	100.0	89.2	98.2	92.8	88.9

OVERFLOW

U.S.No.	% Wt.	% of Feed	P_2O_5	CaO	Insol
70	5.0	0.5	0.1	0.3	0.6
100	6.9	0.7	0.2	0.5	0.9
140	10.0	1.1	0.3	0.6	1.3
200	11.2	1.2	0.3	0.8	1.4
-200	66.9	7.2	0.9	5.0	6.9
Total	100.0	10.8	1.8	7.2	11.1

CALC. FEED

U.S.No.	% Wt.	% of Feed	P_2O_5	CaO	Insol
40	5.9	5.9	4.9	4.8	7.9
50	7.3	7.3	6.9	6.6	8.8
70	57.2	57.2	59.5	56.1	62.2
100	18.3	18.3	24.5	23.6	10.8
140	2.6	2.6	2.6	2.8	1.9
200	1.3	1.3	0.4	0.9	1.5
-200	7.4	7.4	1.1	5.2	7.0
Total	100.0	100.0	100.0	100.0	100.0

TABLE B4. DISTRIBUTION OF CHEMICAL CONSTITUENTS BY CUMULATIVE SIZE FRACTION (TEST 4C)

UNDERFLOW

U.S.No.	% Wt.	% of Feed	P_2O_5	CaO	Insol
40	6.6	5.9	4.9	4.8	7.9
50	14.8	13.2	11.9	11.4	16.7
70	78.3	69.8	71.3	67.2	78.3
100	98.0	87.4	95.6	90.3	88.2
140	99.7	88.9	97.9	92.4	88.7
200	99.8	89.0	98.0	92.5	88.8
-200	100.0	89.2	98.2	92.8	88.9

OVERFLOW

U.S.No.	% Wt.	% of Feed	P_2O_5	CaO	Insol
70	5.0	0.5	0.1	0.3	0.6
100	11.9	1.3	0.3	0.8	1.5
140	21.9	2.4	0.6	1.4	2.8
200	33.1	3.6	0.9	2.2	4.2
-200	100.0	10.8	1.8	7.2	11.1

CALC. FEED

U.S.No.	% Wt.	% of Feed	P_2O_5	CaO	Insol
40	5.9	5.9	4.9	4.8	7.9
50	13.2	13.2	11.9	11.4	16.7
70	70.4	70.4	71.4	67.4	78.9
100	88.7	88.7	95.9	91.0	89.7
140	91.3	91.3	98.4	93.8	91.5
200	92.6	92.6	98.9	94.8	93.0
-200	100.0	100.0	100.0	100.0	100.0

APPENDIX C: DEFINITIONS AND FORMULAS

DEFINITIONS AND FORMULAS

The following terms, definitions, and formulas were used for evaluating the tests:

YIELD -- The weight percentage of sizer feed reporting to a sizer product. Yield (Y) is expressed as:

- % Weight to Oversize (U'flow) Product, Y_o
- % Weight to Undersize (O'flow) Product, Y_u

IDEAL YIELD -- The weight percentage of sizer feed that would report to a sizer product with perfect classification. The ideal yields (I.Y.) are:

- % Weight of oversize material in feed, $I.Y._o$
- % Weight of undersize material in feed, $I.Y._u$

COMPOSITION -- The weight percentage of a given size range within a sizer product. Composition (C) is expressed as:

- % Weight of Oversize in U'flow Product, C_o
- % Weight of Undersize in O'flow Product, C_u

EFFICIENCY -- The percentage recovery of a given size range of material to a given sizer product.

$$\text{Efficiency, } E = \frac{\text{Composition X Yield}}{\text{Ideal Yield}}$$

Efficiency was calculated on the basis of oversize, undersize, and total (combined) recovery.

- Oversize Efficiency, $E_o = \dfrac{C_o \text{ X } Y_o}{I.Y._o}$
- Undersize Efficiency, $E_u = \dfrac{C_u \text{ X } Y_u}{I.Y._u}$
- Total Efficiency, $E_T = \dfrac{(C_o \text{ X } Y_o) + (C_u \text{ X } Y_u)}{100}$

COEFFICIENT OF SEPARATION -- A means of representing the efficiency of a classification with a single number between 0 (no separation) and 1 (perfect separation). Mathematically:

$$C.S. \quad = \quad (E_o/100 + E_u/100) - 1$$

Unlike E_T, which accounts for the proportion of material reporting to each product, the coefficient of separation depends only on the undersize and oversize efficiencies. It is possible to have a high E_o and a low E_μ and still have a high E_T, if the feed is predominantly oversize. However, this would not be a good result if the recovery of undersize material were desirable. Appropriately, that classification would have a mediocre C.S.. Thus, C.S. is a measure of how "on target" a classification's cut point is.

PARTITION CURVE -- A plot which indicates the weight percent of material in each size interval which reports to the coarse material stream (U'flow). The steeper the slope of partition curve, the sharper the classification. Several important points are obtained from the curve:

D_{50} -- The particle size (in microns) on the partition curve which reported to the U'flow and O'flow streams in equal amounts. This is generally referred to as the "cut point". The cut point differs from the designated mesh of separation. Example: For a +35 mesh product, it may require a D_{50} cut point of 250 microns (60 mesh) to ensure that an acceptable quantity of +35 mesh material is recovered.

D_{25} -- The particle size (in microns) on the partition curve which had 1/4 of its original material report to the U'flow.

D_{75} -- The particle size (in microns) on the partition curve which had 3/4 of its original material report to the U'flow.

SHARPNESS INDEX -- A single number measurement of the steepness of the partition curve. Mathematically defined as:

$$S_I \quad = \quad \frac{D_{25}}{D_{75}}$$

S_I must be a number between 0 (no classification) and 1 (ideal classification. It indicates the sharpness of a cut only and does not consider whether the cut point is on target. Thus, a classification could have a good S_I but a poor C.S. However, that could be remedied by adjusting the D_{50} ~~apply~~

appropriately

IMPERFECTION -- A single number measurement of the sharpness of a classification, which indicates the fraction of misplaced material. Mathematically defined as:

$$I = \frac{D_{75} - D_{25}}{2D_{50}}$$

Imperfection will vary from 0 (ideal classification) to 1 (no classification.