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Characterization Studies of Florida Phosphate Slimes

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CHARACTERIZATION STUDIES OF FLORIDA PHOSPHATE SLIMES

by

W. E. Lamont,¹ J. T. McLendon,² L. W. Clements, Jr.,³ and I. L. Feld⁴

ABSTRACT

The Federal Bureau of Mines, in cooperation with phosphate companies in the Florida land-pebble area, made a comprehensive study of the waste clays, or "phosphate slimes," produced in the mining of phosphate rock in Florida. These slimes represent a significant ecological problem and a major deterrent to effective land recovery in the phosphate-mining areas.

Physical, chemical, and mineralogical studies were made of slime samples submitted by 15 of the 16 plants in Florida in an effort to identify factors that prevent successful consolidation of the slimes and subsequent recovery of the mined lands.

Results of these studies indicated that the clay mineral attapulgite, a hydrated magnesium silicate, was primarily responsible for the very poor settling characteristics of the slimes, and that the quantity of attapulgite in the slimes effectively controlled the settling rate, pulp density of terminal solids, viscosity, percent solids of filter cake, and flocculant requirements.

INTRODUCTION

Phosphate rock is mined and processed in Florida by 10 companies at 16 beneficiation plants. Except for one company located in northern Florida, all of the producers are located in the central Florida land-pebble area in the vicinity of Lakeland, Bartow, Bradley Junction, and Fort Meade.

The phosphate ore, locally called matrix, is an alluvial deposit of quartz sand, slime-size material, and phosphate rock. As a general rule, each of these components represents approximately one-third of the weight of the total matrix. The matrix is mined and processed by essentially the same method at each of the 16 operations. Figure 1 shows a generalized flowsheet of the process.

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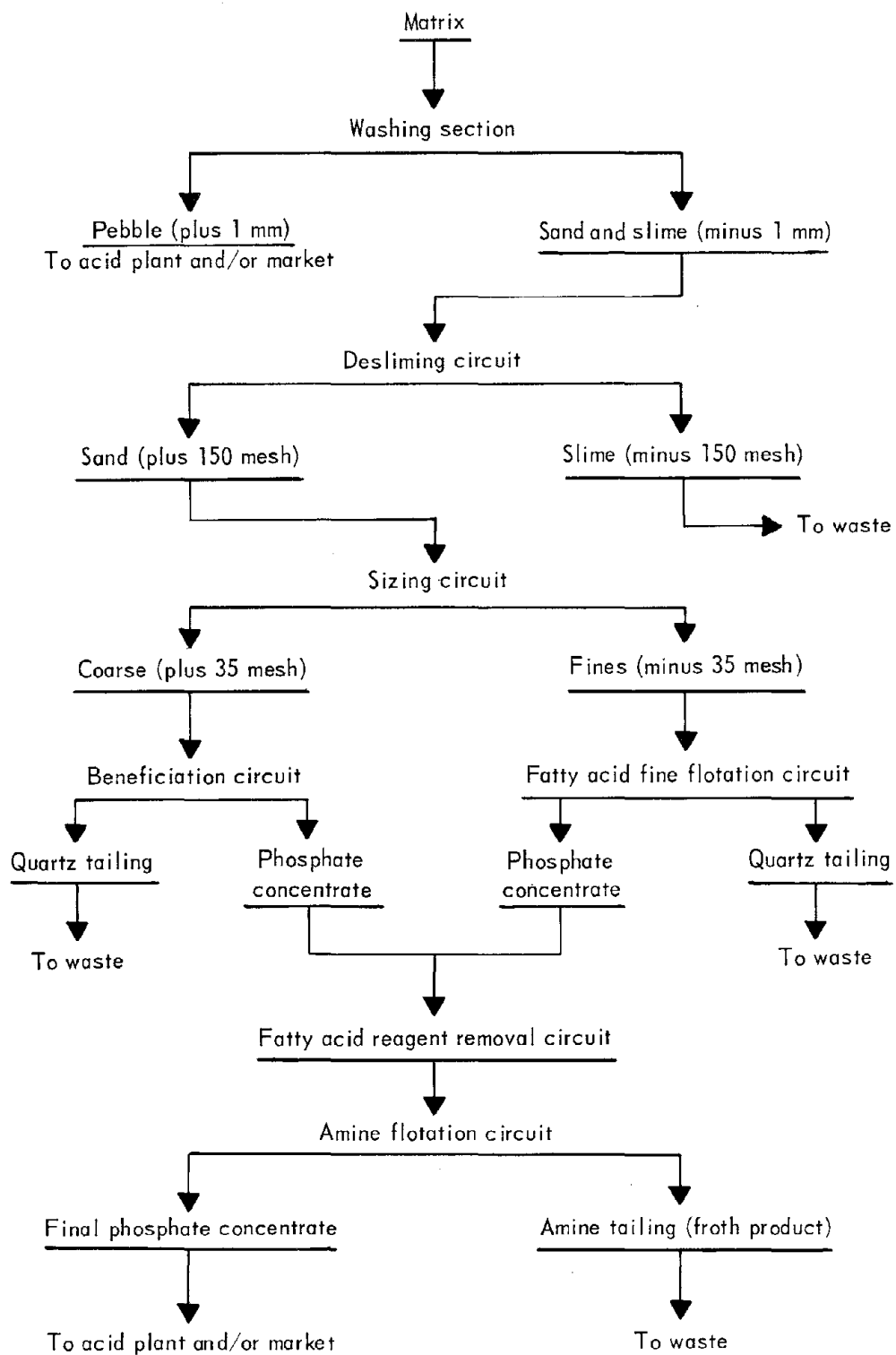


FIGURE 1. - Generalized flowsheet of Florida phosphate-processing plants.

As shown in figure 1, two waste products are produced from these mining operations--minus 1-millimeter plus 150-mesh flotation tailing sand and minus 150-mesh slimes. The tailing sand represents a normal materials-handling problem. It can be disposed of effectively by backfilling the mining cuts, and potentially useful land can be reclaimed.

The slimes represent a major materials-handling problem, as well as an ecological problem. The slime fraction is discharged from the plants at about 2 to 5 percent solids and is pumped to mined-out cuts. By constructing earthen dams 20 to 40 feet above ground level around these mined cuts, storage areas of several hundred acres⁵ are developed. These large impoundments are used to settle the slimes and recover water, which is then recirculated to the plants.

These slime-settling areas present a number of problems to the phosphate companies during and after filling. First, the dams surrounding the slime-settling areas are the responsibility of the individual company. In addition to the cost of constructing the dams, the companies must bear the cost of continuous monitoring and servicing to avert breaks in the dams and spillage of the slimes into nearby streams and rivers. Second, the loss of potentially valuable real estate, in the form of useless slime ponds, represents a land-use pattern unsatisfactory to the companies and local governing bodies. Third, the low-solids, high-water content of the slimes after years of settling represents a tremendous loss of water. It is estimated that about 20 billion gallons per year of water are lost at a slimes-production rate of 30 million tons of dry solids, which will settle to only about 25 percent solids.

Numerous studies have been made of phosphate slimes by the Bureau of Mines, private research organizations, universities, and the phosphate companies.⁶ To date, no economical method of treating the slimes to make them consolidate to more than 20 to 25 percent solids has been demonstrated, and no complete explanation has been advanced as to what causes the slimes to have such poor settling characteristics.

In September 1972, the Federal Bureau of Mines and the Florida Phosphatic Clays Research Project representing the phosphate-rock producers in Florida entered into a cooperative agreement to conduct a research and development program for solving the disposal problems of the phosphate slimes associated with the production of phosphate rock concentrates. Better and more complete determination of the physical, chemical, and mineralogical properties will help identify the factors preventing effective consolidation of the slimes and the subsequent poor utilization of the slimes and the areas used for their storage. This report is concerned only with that part of the research program dealing with these properties.

⁵Boyle, J. R. Waste Disposal Costs of a Florida Phosphate Operation. BuMines IC 8404, 1969, 24 pp.

⁶Staff, Bureau of Mines. The Florida Phosphate Slimes Problem--A Review and A Bibliography. BuMines IC 8668, 1975, 41 pp.

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SAMPLING PROCEDURES

The samples of slime used in the study were provided by the cooperating companies. The samples were fresh slimes, taken from the plant outflows prior to deposition in settling areas. Samples were collected in one or more 55-gallon drums and allowed to settle for consolidation of solids. Information supplied by the companies indicated that the slimes were discharged at 2 to 5 percent solids. The arithmetical average solids content for all 15 as-discharged slimes was 3.7 percent.

The slime samples were delivered to the Tuscaloosa Laboratory and allowed to sit overnight to compensate for any disturbance during unloading. Two gallons of clear supernatant water were removed from each sample--one for supernatant water analysis, the other for dilution purposes.

In most cases, only one drum of settled slime was received from the field sampling program at each plant. However, when more than one drum was received from a single plant, the drums were individually mixed and buckets of slime were ladled from each drum successively to fill a single drum for future study. Any slime remaining after this operation was discarded.

In subsequent sampling of the slime from each drum, a heavy-duty mechanical mixer was first used to thoroughly mix and resuspend the slime. A head sample was then removed for determining solids content, and physical, chemical, and mineralogical composition. Several additional 4-liter samples were removed and stored in plastic jugs for studies of the as-received slimes.

CHARACTERIZATION

General Characteristics

A number of simple diagnostic tests such as percent solids, pH, specific conductance, color determination, specific gravity, and viscosity measurements (with both Fann⁷ and Brookfield viscometers) were made initially on each of the slimes. Percent solids, pH, specific conductance, color determination, and the viscosity measurements were made on each of the as-received slurries. When the weight of dried slime solids was required for calculating percent solids and specific gravity, the slimes were oven-dried at a temperature of 150° F (82° C) to prevent loss of water of hydration normally associated with clay minerals. Table 1 shows the results of these studies.

⁷Reference to specific trade names is made for identification only and does not imply endorsement by the Bureau of Mines.

TABLE 1. - General information regarding as-received phosphate slimes

Sample	Company	Plant	Solids content, pct	pH	Specific conductance, ¹ μ mhos/cm	Color ²	Specific gravity	Apparent viscosity, cp	
								Fann ³	Brookfield ⁴
2086B	IMC.....	Noralyn.....	4.7	6.94	657	Lead gray.....	2.584	9.5	174
2087B	...do.....	Kingsford.....	13.9	6.84	454	Gray.....	2.556	29.0	375
2088B	...do.....	Clear Springs	8.0	6.76	593	Sand.....	2.710	24.5	357
2089B	Agrico.....	Payne Creek..	9.7	6.69	519	Golden gray...	2.662	25.5	415
2090B	...do.....	Saddle Creek.	11.9	6.17	415	Putty.....	2.745	29.0	710
2091B	...do.....	Palmetto.....	8.1	6.66	479	Golden gray...	2.813	8.5	132
2092B	Grace.....	Bonny Lake...	12.5	6.76	693	Ivory.....	2.738	43.5	1,110
2093B	Brewster...	Haynesworth..	10.8	6.64	787	Cement.....	2.703	21.5	400
2096B	U.S.S. Agri-Chem.	Rockland.....	12.8	6.93	702	Ash blond.....	2.608	27.5	423
2097B	Borden.....	Tenoroc.....	10.5	6.15	327	Olive.....	2.687	25.0	306
2098B	Occidental..	White Springs	5.2	6.90	593	Putty.....	2.690	14.0	180
2099B	Cities Service.	Ft. Meade.....	16.9	5.98	552	Yellowish gray	2.661	30.0	437
2100B	Swift.....	Watson.....	6.0	6.59	462	Putty.....	2.785	24.0	195
2101B	...do.....	Silver City...	9.1	6.55	928	Khaki.....	2.714	14.0	210
2102B	Mobil.....	Ft. Meade.....	14.4	7.22	611	Lead gray.....	2.530	40.0	485

¹Beckman conductivity bridge, model RC 1682.

²Kornerup, A., and J. H. Wanscher. Reinhold Color Atlas. New York, 1961, 224 pp., Reinhold Pub. Corp., plates 3-4.

³Fann V-G meter, model 35; single reading.

⁴Brookfield Synchro-letric viscometer, multispeed model LVF; single reading.

The viscosity data shown in table 1 represent single readings only with each viscometer. Additional measurements were made using the Fann viscometer to develop data regarding Bingham plastic viscosity and yield point, and with the Brookfield instrument to study other rheological properties of the samples, such as thixotropy. Further discussion of these measurements will be found in the section on rheological properties.

Physical Properties

Sedimentation

Samples of the as-received slimes were placed in 1,000-milliliter glass soil-testing cylinders for long-term sedimentation studies. In addition, samples of the as-received slimes were diluted with their own supernatant water to 3.7 percent solids, which represented the arithmetical average solids content of the as-discharged slimes.

Data in table 2 show the results of settling tests conducted on the 3.7-percent-solids slimes for a period of 30 days. Long-term settling data, representing a settling period of about 8 months on 14 of the samples, is also included in table 2 for comparison.⁸ In this study, the terminal solids were taken as the percent solids of the settled fraction after this 8-month (240-day) settling period. The average solids content after 8 months was 12.9 percent solids, but the slime samples settled to an average of about 84 percent of terminal solids in 30 days. Thus, for the purposes of this report, the 30-day solids content is a good indication of the natural settling characteristics of the slimes, and is used as the basis of comparison throughout the report.

Settling-rate studies of the 15 samples, diluted to 3.7 percent solids, were made over a 3-day period. Results of these studies and the calculated cumulative water recovery, in acre-feet, are shown in table 3. Data in this table have been arranged in sequence to represent increasing solids content of the settled fraction after 30 days. The data indicate that settling rate is a function of terminal solids; the lower the terminal solids content of the slimes, the slower the settling rate.

⁸The samples used in the long-term settling tests developed apparent colonies of microorganisms ranging in color from light green to various shades of brown and black. The top few inches of some of the samples changed to a light cream color, indicating a possible oxidation reaction. Sample 2092B developed obvious voids or pockets throughout the column of slime, indicating the possibility of some type of gas-producing reaction.

TABLE 2. - Effect of settling time on solids content of as-received slimes diluted to 3.7 percent solids with supernatant water, percent

Sample	As received	After dilution							
		4 hr	1 day	2 days	5 days	10 days	20 days	30 days	240 ¹ days
2086B.....	4.7	3.9	4.5	4.9	5.4	5.6	5.7	5.7	6.3
2087B.....	13.9	7.3	10.2	11.8	13.5	14.3	15.2	15.5	15.5
2088B.....	8.0	4.4	6.1	7.0	7.7	7.8	7.8	7.9	9.4
2089B.....	9.7	4.2	6.1	7.4	8.7	9.2	9.2	9.3	11.1
2090B.....	11.9	6.8	9.7	11.5	13.8	15.0	15.5	15.9	19.7
2091B.....	8.1	5.1	7.5	8.4	9.9	10.9	11.5	11.5	12.8
2092B.....	12.5	4.1	6.2	8.2	10.1	10.2	10.5	10.5	14.2
2093B.....	10.8	3.9	4.8	5.8	8.2	10.0	10.8	10.9	13.1
2096B.....	12.8	6.2	8.7	10.2	11.8	12.4	12.6	13.1	15.0
2097B.....	10.5	3.8	4.3	4.8	6.0	7.5	8.4	8.5	11.9
2098B.....	5.2	3.8	4.3	4.7	5.4	5.6	5.7	5.7	6.0
2099B.....	16.9	7.2	9.9	11.5	13.5	14.5	14.9	15.2	19.9
2100B.....	6.0	4.0	4.7	5.1	5.8	6.1	6.1	6.1	7.2
2101B.....	9.1	5.7	8.7	10.5	12.4	12.8	13.3	13.8	13.7
2102B.....	14.4	6.5	8.7	9.8	10.9	11.6	12.2	12.6	² 17.8
Average.....	-	5.1	7.0	8.1	9.5	10.2	10.6	10.8	12.9
Percent of terminal solids ³	-	39.5	54.3	62.8	73.6	79.1	82.2	83.7	-

¹These data are based on sedimentation of as-received slimes rather than diluted slimes and are considered terminal solids.

²Settled at about 120 days rather than 240 days.

³Calculated from the values shown as averages and a terminal solids of 12.9 percent.

TABLE 3. - Settling rate and cumulative water recovery of as-received slimes diluted to 3.7 percent solids

Sample	Solids content at 30 days, pct	Settling rate, in/hr					Cumulative water recovery, acre-ft/3 days
		4 hr	6.5 hr	24 hr	48 hr	72 hr	
2086B.....	5.7	0.241	0.169	0.138	0.077	0.014	0.344
2098B.....	5.7	.155	.148	.092	.069	.055	.332
2100B.....	6.1	.344	.275	.138	.086	.064	.384
2088B.....	7.9	.619	.486	.238	.142	.099	.596
2097B.....	8.5	.155	.148	.094	.072	.061	.367
2089B.....	9.3	.516	.444	.241	.149	.109	.653
2092B.....	10.5	.412	.370	.246	.163	.117	.705
2093B.....	10.9	.275	.243	.146	.109	.090	.538
2091B.....	11.5	1.031	.867	.304	.168	.118	.710
2102B.....	12.6	1.547	1.047	.344	.185	.128	.768
2096B.....	13.1	1.478	1.015	.344	.189	.130	.779
2101B.....	13.8	1.289	.994	.344	.192	.135	.808
2099B.....	15.2	1.753	1.163	.372	.200	.139	.836
2087B.....	15.5	1.770	1.163	.315	.203	.140	.842
2090B.....	15.9	1.633	1.121	.367	.200	.138	.825
Average	10.8	.881	.644	.248	.147	.102	.632

Particle Size and Surface Area

The extreme fineness of phosphate slime particles has been reported many times in the literature as a factor influencing the settling behavior of the slimes. In this study, particle size distribution information was developed for the as-received slime samples to establish correlation with settling and other characteristics of the slimes. Each of the as-received slime samples was sized by three distinctly different methods to obtain comparative data: (1) sieving, sedimentation, and centrifuging; (2) the Andreason pipette method⁹; and (3) Coulter counter.

In the first method, each sample was diluted with distilled water to about 2.8 percent solids prior to dispersing the sample for treatment. Although problems were encountered in dispersing the samples, most of the slimes readily dispersed when the pH was adjusted to about 10 using sodium hydroxide. Other dispersants used included sodium silicate, sodium citrate, and quebracho in varying quantities.

The samples were sieve-sized at 150 and 325 mesh, sedimentation-sized at 20 and 10 micrometers, and centrifuged to isolate fractions finer than 10 micrometers. Stokes' law was used to determine the time required for making the desired size separation.

Table 4 shows the results of sizing by the sieving, sedimentation, and centrifuging method. The particle size distribution for each sample, as well as the high, low, and average size distribution for each sample in each size fraction is shown. Cumulative distribution of each size fraction is also shown. It is readily apparent from these data that the as-received slimes vary greatly in size composition.

Comparison of selected size ranges by the three sizing methods is summarized in table 5. These data show the significant variations in size indicated by the different sizing methods; however, differences were anticipated, since treatment to prepare the samples for sizing by the three methods varied considerably. The first two sizing methods shown in table 5 are based on sedimentation using Stokes' law. Since Stokes' law describes the settling behavior of spherical particles, and the particles in most mineral mixtures are rarely spherical, the calculated sizing results are expressed as equivalent spherical diameters. For this reason, significant differences in the values for size fractions result from sedimentation sizing methods based on Stokes' law and nonsedimentation sizing methods such as the Coulter counter, which measures the average particle diameter electronically.

⁹Herdan, G. Small Particle Statistics. Elsevier Publishing Company, New York, 1953, p. 470.

TABLE 4. - Particle size distribution of as-received slimes measured by sieving, sedimentation, and centrifuging, weight-percent

Sample.....	2086B	2087B	2088B	2089B	2090B	2091B	2092B	2093B	2096B	2097B	2098B	2099B	2100B	2101B	2102B	High	Low	Average
DISTRIBUTION																		
Plus 104 μm^1	7.0	4.4	2.8	0.9	0.1	0.8	0.4	0.9	3.1	3.9	0.4	6.8	3.1	1.6	14.4	14.4	0.1	3.4
Minus 104 plus 43 μm^2	8.0	10.0	7.5	3.5	4.1	2.6	5.8	5.2	13.4	14.5	5.4	16.2	7.0	9.0	14.1	16.2	2.6	8.4
Minus 43 plus 20 $\mu\text{m}..$	3.7	7.3	9.1	4.5	5.3	6.7	5.3	9.7	7.5	7.1	12.5	5.1	6.5	8.6	6.6	12.5	3.7	7.0
Minus 20 plus 10 $\mu\text{m}..$	4.6	7.1	5.8	4.2	4.4	8.8	3.8	9.0	9.7	7.2	6.9	5.3	4.1	7.0	3.6	9.7	3.6	6.1
Minus 10 plus 5 $\mu\text{m}..$	15.7	15.4	8.4	8.6	8.3	18.2	9.2	11.8	14.6	11.7	15.0	7.6	11.3	13.0	3.9	18.2	3.9	11.5
Minus 5 plus 1 $\mu\text{m}....$	11.5	13.8	14.1	7.9	7.0	10.1	11.2	10.8	11.0	9.8	13.1	10.4	9.0	19.8	11.2	19.8	7.0	11.4
Minus 1.0 plus 0.5 μm	3.8	10.3	7.4	4.9	9.5	10.2	9.2	7.4	5.5	5.5	4.4	11.4	8.7	6.8	7.3	11.4	3.8	7.5
Minus 0.5 plus 0.2 μm	9.5	13.1	17.6	14.2	15.3	15.7	13.9	9.9	8.1	9.1	9.5	12.5	16.3	16.5	13.4	17.6	8.1	13.0
Minus 0.2 $\mu\text{m}.....$	36.2	18.6	27.3	51.3	46.0	26.9	41.2	35.3	27.1	31.2	32.8	24.7	34.0	17.7	25.5	51.3	17.7	31.7
Composite total..	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	-	-
CUMULATIVE DISTRIBUTION																		
Plus 104 $\mu\text{m}.....$	7.0	4.4	2.8	0.9	0.1	0.8	0.4	0.9	3.1	3.9	0.4	6.8	3.1	1.6	14.4	14.4	0.1	3.4
Plus 43 $\mu\text{m}.....$	15.0	14.4	10.3	4.4	4.2	3.4	6.2	6.1	16.5	18.4	5.8	23.0	10.1	10.6	28.5	28.5	3.4	11.8
Plus 20 $\mu\text{m}.....$	18.7	21.7	19.4	8.9	9.5	10.1	11.5	15.8	24.0	25.5	18.3	28.1	16.6	19.2	35.1	35.1	10.1	18.8
Plus 10 $\mu\text{m}.....$	23.3	28.8	25.2	13.1	13.9	18.9	15.3	24.8	33.7	32.7	25.2	33.4	20.7	26.2	38.7	38.7	13.1	24.9
Plus 5 $\mu\text{m}.....$	39.0	44.2	33.6	21.7	22.2	37.1	24.5	36.6	48.3	44.4	40.2	41.0	32.0	39.2	42.6	48.3	21.7	36.4
Plus 1 $\mu\text{m}.....$	50.5	58.0	47.7	29.6	29.2	47.2	35.7	47.4	59.3	54.2	53.3	51.4	41.0	59.0	53.8	59.3	29.2	47.8
Plus 0.5 $\mu\text{m}.....$	54.3	68.3	55.1	34.5	38.7	57.4	44.9	54.8	64.8	59.7	57.7	62.8	49.7	65.8	61.1	68.3	34.5	55.3
Plus 0.2 $\mu\text{m}.....$	63.8	81.4	72.7	48.7	54.0	73.1	58.8	64.7	72.9	68.8	67.2	75.3	66.0	82.3	74.5	82.3	48.7	68.3

1150 mesh.
2325 mesh.

TABLE 5. - Summary of particle size distribution of as-received slimes¹ measured by three methods, weight-percent

Sizing method	Size fraction		
	Minus 10 plus 5 μm	Minus 5 plus 1 μm	Minus 1 plus 0.5 μm
Sieving, sedimentation, and centrifuging.....	11.5	11.4	7.5
Andreason pipette.....	8.3	23.2	11.2
Coulter counter.....	7.9	15.9	10.5

¹Average of all 15 samples.

The surface area of each of the slimes was measured using a Quantachrome Monosorb Surface Analyzer. Initial tests were attempted on slime samples dried at 100° C; however, it was found that some of the samples expelled too much moisture for efficient operation of the equipment. Hence, surface area measurements were made of each sample dried at 200° C. Although some clays lose significant water of hydration at 200° C, it was decided that, for comparative purposes, each slime sample should be tested after drying at the same temperature. The measurements were made with a standard gas mixture of 30 percent nitrogen and 70 percent helium. The samples were outgassed at a temperature slightly less than 200° C, and adsorption of nitrogen was made at the boiling point of liquid nitrogen, (-196° C). Results of these studies (table 6) showed that the surface area of the slimes ranged from 27.4 square meters per gram to 88.4 square meters per gram under these test conditions.

TABLE 6. - Surface area of as-received slimes, square meters per gram

Sample	Surface area ¹	Sample	Surface area ¹
2086B.....	88.4	2096B.....	59.0
2087B.....	34.9	2097B.....	64.0
2088B.....	44.2	2098B.....	69.4
2089B.....	31.5	2099B.....	46.2
2090B.....	35.4	2100B.....	45.5
2091B.....	27.4	2101B.....	48.5
2092B.....	42.1	2102B.....	31.6
2093B.....	28.7	Average..	46.5

¹BET method, Quantachrome Monosorb Surface Analyzer, model MS-4.

Flocculation

Screening studies made of anionic, nonionic, and cationic polyacrylamide-type flocculants on a single slime sample showed that Separan AP-30 was the most effective of numerous flocculants studied. This reagent is an anionic polyacrylamide with an estimated molecular weight of about 3 million. For comparative testing, each of the slime samples was diluted to 3.7 percent solids, and flocculation studies were made using the AP-30. One milliliter of a 0.1 percent solution of AP-30, representing 0.27 pound per ton of dry solids, was added to 200 milliliters of each of the 3.7-percent-solids slimes.

The graduated cylinders were inverted several times to assure mixing at the beginning of each settling test; flocculation characteristics were determined visually. It became immediately apparent that there were significant variations in the flocculation characteristics of the samples. Some of the samples yielded large, fast-settling floccules immediately; others showed signs of being partially flocculated, and still others showed no evidence of flocculation.

In order to establish a similar condition of flocculation in each of the samples, additional AP-30 in increments of 0.5 milliliter was added to those samples that failed to produce large, fast-settling floccules. Results of this test series are compared with the natural settling characteristics of the samples (table 7), and show two definite trends. First, those samples having the worst natural settling characteristics require the most flocculant to yield similar visual flocculation characteristics. Second, the solids content of the settled fraction after flocculation is a function of the solids content of the same slimes without the flocculant.

TABLE 7. - Flocculation studies of as-received slimes diluted to 3.7 percent solids

Sample	No reagent addition, solids content at 30 days, pct	AP-30 addition	
		Amount, ¹ lb/ton dry solids	Solids content at 9 days, pct
2086B	5.7	2.16	5.3
2098B	5.7	2.16	4.8
2100B	6.1	2.16	5.1
2088B	7.9	1.35	6.4
2097B	8.5	.54	7.2
2089B	9.3	1.35	8.0
2092B	10.5	.41	10.2
2093B	10.9	.41	11.0
2091B	11.5	.41	11.3
2102B	12.6	.41	11.9
2096B	13.1	.27	12.2
2101B	13.8	.27	12.5
2099B	15.2	.27	14.5
2087B	15.5	.27	15.0
2090B	15.9	.27	15.0

¹Amount required to produce large, fast-settling floccules.

Since water recovery from a slime is related to its solids content, flocculation characteristics of slime samples diluted to 2.0 percent solids were studied using four different concentration levels. Results of these studies are shown in table 8 and again illustrate the variable settling characteristics of the slimes using the same flocculating agent. The data shown represent the settling characteristics over a 2-hour period. Each of the tests was actually studied for a period of about 1 day or 3 days (over a weekend), depending upon the day of the week the tests were started. Of the samples studied for 1 day, 58 percent gave better water recoveries without any flocculant, whereas 67 percent of those samples settled for 3 days gave better

water recoveries without any flocculant. These data indicate that the majority, if not all, of the samples would have a higher terminal-solids content without flocculant than they would with flocculant. This observation has been confirmed by other research personnel studying Florida phosphate slimes.

TABLE 8. - Flocculation studies of as-received slimes, percent

Sample	No reagent addition ¹ ; solids content at 30 days	Water recovery ² after 2 hr with AP-30 addition of--				
		0 lb/ton dry solids	0.2 lb/ton dry solids	0.5 lb/ton dry solids	1.0 lb/ton dry solids	2.0 lb/ton dry solids
2086B	5.7	0.8	0.8	1.6	4.0	21.4
2098B	5.7	4.8	2.0	2.4	4.0	6.9
2100B	6.1	7.3	4.0	3.6	5.6	12.9
2088B	7.9	2.4	16.1	8.9	18.9	29.4
2097B	8.5	1.6	41.9	36.3	48.4	53.2
2089B	9.3	.8	8.5	19.4	35.9	58.9
2092B	10.5	12.1	29.0	53.2	64.9	64.9
2093B	10.9	28.2	29.8	44.3	62.9	64.5
2091B	11.5	25.8	44.3	51.2	60.4	66.1
2102B	12.6	58.9	58.9	62.9	65.3	68.6
2096B	13.1	38.7	48.4	59.3	67.7	67.3
2101B	13.8	57.2	49.2	59.7	67.7	70.1
2099B	15.2	³ 2.0	69.7	70.5	73.4	75.4
2087B	15.5	57.3	60.5	70.2	71.0	73.0
2090B	15.9	57.6	58.4	64.5	70.9	70.9

¹As-received slimes diluted to 3.7 percent solids.

²As-received slimes diluted to 2.0 percent solids.

³This sample was very slow settling under these conditions; however, after 3 days, 79 percent water recovery was obtained.

Filtration

Comparative pressure filtration studies at 5 pounds per square inch were made of each of the as-received slimes diluted to 3.7 percent solids. These tests were made with a Baroid Standard Filter Press using a specially hardened filter paper (Baroid Cat. No. 987) recommended for use with this filter. Filtration was considered complete when air bubbles, rather than water, were observed at the filtrate discharge orifice. The time required to produce the first air bubble was used to calculate filtration rates. No pressure drop was observed during these tests because of the density of the filter cake and the low pressure used. The filter cake was weighed, wet and dry, to develop solids content data.

The results of the studies (table 9) show no definitive relationship between solids content at 30 days settling and filtration rate; however, a trend was established between the settling characteristics and the solids content of the filter cake. Samples with the poorest settling characteristics yielded filter cakes with the lowest solids content.

TABLE 9. - Pressure filtration of as-received slimes diluted to 3.7 percent solids

Sample	No filtration; solids content at 30 days, pct	Filtration, 5 psi	
		Filtration rate, lb/ft ² /hr	Filter cake solids, pct
2086B.....	5.7	0.234	29.7
2098B.....	5.7	.127	32.4
2100B.....	6.1	.110	35.0
2088B.....	7.9	.154	39.6
2097B.....	8.5	.083	37.9
2089B.....	9.3	.083	40.8
2092B.....	10.5	.142	43.3
2093B.....	10.9	.122	42.6
2091B.....	11.5	.124	42.6
2102B.....	12.6	.159	41.5
2096B.....	13.1	.112	38.9
2101B.....	13.8	.149	41.1
2099B.....	15.2	.110	41.0
2087B.....	15.5	.174	42.1
2090B.....	15.9	.089	43.3
Average..	10.8	.131	39.5

Other pressure filtration tests were made on the as-received slime samples and on slime samples diluted to 2.0 percent solids. Using the same filtration apparatus, pressures of 25 and 100 pounds per square inch were maintained for 30 minutes. Results of these tests revealed that at 2.0 percent solids, the water recovery averaged 83.6 percent and 91.8 percent at 25 and 100 pounds per square inch, respectively. At an average as-received solids content of 10.8 percent, the average water recovery was 42.4 percent and 51.4 percent at 25 and 100 pounds per square inch respectively. This decrease in water recovery per unit of time as the solids content increased was expected since there would be more weight of solids per unit area of filter media. The water recovery per unit of solids was not a straight-line function; this indicated the variability of filtration characteristics of the slimes at the higher solids content.

Rheology

Initial viscosity studies were made of each as-received slime sample using a Fann viscometer (table 10). Subsequent attempts to use the Fann viscometer on samples diluted to 3.7 percent solids gave results too closely grouped and showed no relationship to the original viscosity measurements of the as-received samples.

TABLE 10. - Viscosity and yield point measured with the Fann viscometer¹ compared with solids content of as-received slimes

Sample	Solids content, pct	Viscosity, cp		Yield point, lb/100 ft ²
		Apparent	Bingham plastic	
2086B	4.7	9.5	5.0	4.5
2087B	13.9	29.0	7.0	22.0
2088B	8.0	24.5	4.5	20.0
2089B	9.7	25.5	4.5	21.0
2090B	11.9	29.0	6.0	23.0
2091B	8.1	8.5	3.5	5.0
2092B	12.5	43.5	6.5	37.0
2093B	10.8	21.5	6.0	15.5
2096B	12.8	27.5	7.5	20.0
2097B	10.5	25.0	6.5	18.5
2098B	5.2	14.0	4.0	10.0
2099B	16.9	30.0	8.5	21.5
2100B	6.0	24.0	4.5	19.5
2101B	9.1	14.0	4.0	10.0
2102B	14.4	40.0	8.5	41.5

¹Fann V-G meter, model 35.

The Brookfield viscometer was used to analyze the viscosity of the 3.7-percent-solids slimes and the as-received slimes. In the latter case, six readings were taken on each sample at 2-minute intervals. Table 11 compares the solids content and viscosity of the slimes as received and after dilution.

TABLE 11. - Viscosity of slimes as received and after dilution to 3.7 percent solids as measured with the Brookfield viscometer¹

Sample	As received		After dilution		
	Solids content, pct	Viscosity, cp		Solids content at 30 days, pct	Viscosity, cp
		Initial	Final		
2086B	4.7	174	168	5.7	58.5
2098B	5.2	180	110	5.7	78.7
2100B	6.0	195	117	6.1	49.2
2088B	8.0	357	265	7.9	47.2
2097B	10.5	306	294	8.5	14.8
2089B	9.7	425	407	9.3	33.7
2092B	12.5	1,110	930	10.5	33.2
2093B	10.8	400	397	10.9	15.3
2091B	8.1	132	135	11.5	13.8
2102B	14.4	485	440	12.6	15.2
2096B	12.8	423	406	13.1	12.5
2101B	9.1	212	207	13.8	16.8
2099B	16.9	437	435	15.2	6.8
2087B	13.9	375	360	15.5	7.7
2090B	11.9	710	690	15.9	9.8

¹Brookfield Synchro-Lectric viscometer, multispeed model LVF.

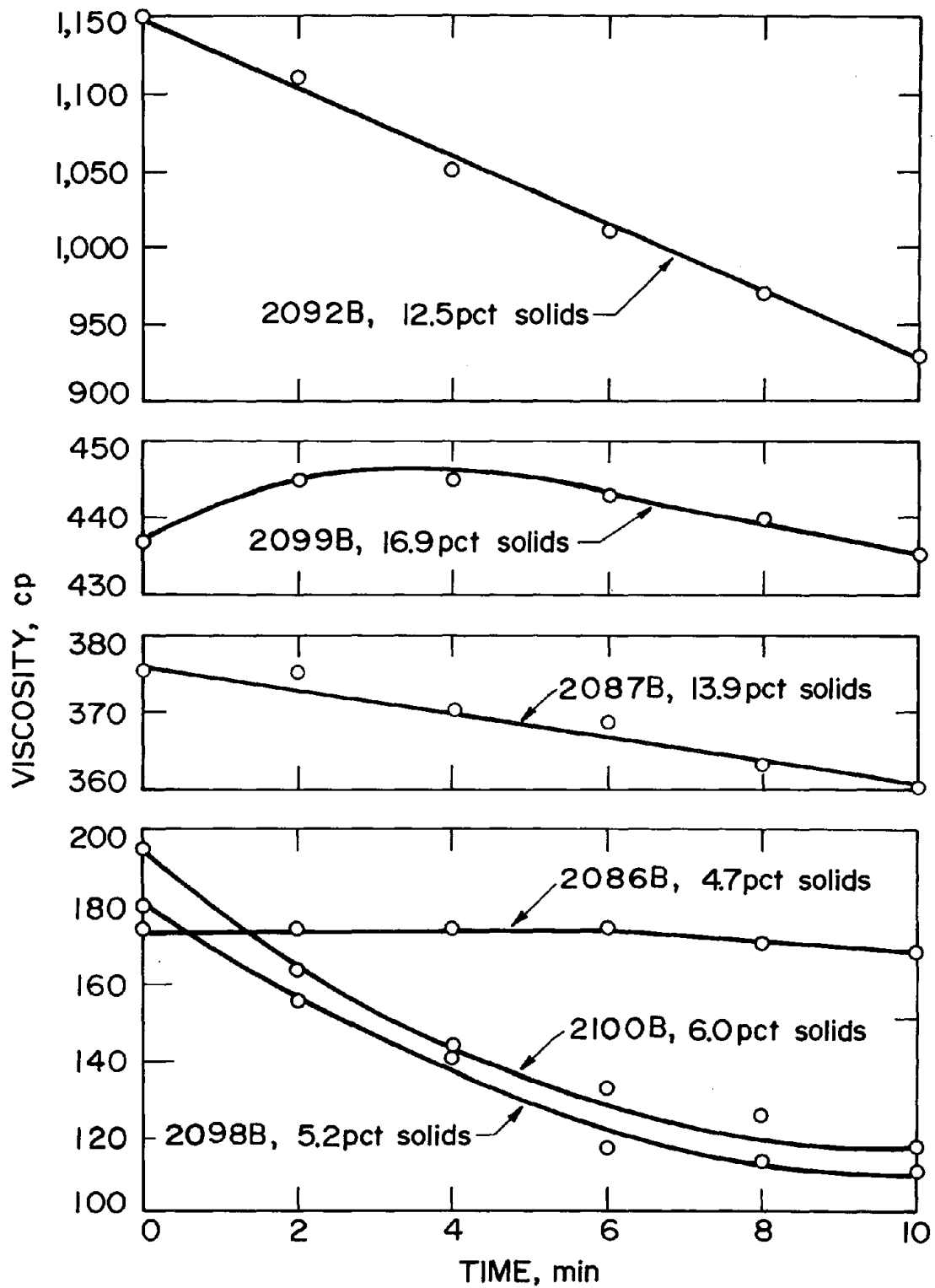


FIGURE 2. - Viscosity versus shearing time for as-received slime samples.

The results indicate a potential relationship between settling characteristics and viscosity of the slime samples. Those samples having the lowest viscosity at 3.7 percent solids have the best settling characteristics, whereas those slimes having the highest viscosity at 3.7 percent solids have the poorest settling characteristics.

Figure 2 illustrates the effect of shearing time on viscosity. The graph indicates that the rheological properties of the slimes are highly variable. However, most of the samples do indicate thixotropy, the reversible softening of a fluid by continual shearing at a constant shearing stress.

Chemical Properties

Slime Solids

Chemical analyses were made of the solids content of the as-received slime samples (table 12) and the size fractions isolated in the sizing studies. The range of chemical content found in the size fractions is summarized for all 15 samples in table 13. The results illustrate the extreme variations in the chemical composition of the slime samples. On the basis of these data and the information presented in the sections on settling characteristics and particle size, it is appropriate to point out that there is probably no such thing as a "typical" phosphate slime. However, the average data for particle size and chemical composition shown in table 14 are possibly indicative of the characteristics of a typical slime generated from composited data.

Supernatant Water

Samples of supernatant water removed from the as-received slimes were sent to the U.S. Geological Survey District Laboratory, Ocala, Fla., for water analyses.¹⁰ The results of these analyses (table 15) show no definite trends and no apparent correlation with settling characteristics.

¹⁰Brown, E., M. W. Skougstad, and M. J. Fishman. Methods for Collection and Analysis of Water Samples for Dissolved Minerals and Gases. Techniques of Water Resources Investigations of the U.S. Geological Survey. Book 5, Chapter A-1, 1970, pp. 1-160.

TABLE 12. - Chemical analyses and loss on ignition of as-received slimes solids, pct

Sample	Chemical analyses											Loss on ignition						
	CaO	P ₂ O ₅	Equiv. BPL	CaO P ₂ O ₅	MgO	Al ₂ O ₃	Fe ₂ O ₃	SiO ₂	Na ₂ O	K ₂ O	F	C	CO ₂	S	105° C	250° C	500° C	1,000° C
2086B....	8.3	5.1	11.1	1.63	6.7	10.3	4.6	47.6	0.3	0.5	1.1	1.1	2.2	0.22	6.2	10.1	14.7	18.2
2087B....	12.8	8.2	17.9	1.56	2.3	13.7	4.3	46.1	.3	1.4	1.2	.8	1.3	.17	4.5	6.9	10.1	13.0
2088B....	18.5	13.7	29.9	1.35	4.0	12.2	2.5	30.4	.2	.6	2.3	1.7	5.0	.21	2.6	6.3	10.9	16.8
2089B....	18.6	13.7	29.9	1.36	1.5	13.5	1.9	33.4	.3	.8	1.6	1.0	1.5	.31	3.2	5.7	9.7	13.8
2090B....	18.4	16.2	35.4	1.14	.8	16.8	1.7	28.2	.1	.6	1.6	.5	1.0	.11	2.1	4.9	9.9	12.8
2091B....	26.9	19.7	43.0	1.37	2.0	10.4	1.6	23.1	.2	.6	2.2	1.5	3.4	.36	2.1	5.0	9.0	13.9
2092B....	21.6	17.3	37.8	1.25	1.4	12.9	3.2	27.5	.3	.8	1.8	.5	1.3	.12	2.8	5.2	9.2	12.5
2093B....	16.4	11.6	25.3	1.41	3.2	12.6	2.3	33.5	.2	.2	1.6	1.9	4.6	.22	3.1	6.9	11.2	16.9
2096B....	9.1	5.9	12.9	1.54	3.6	12.5	5.5	45.8	.3	1.3	.7	1.0	2.9	.10	4.4	7.4	10.7	15.0
2097B....	18.7	13.5	29.5	1.39	2.7	10.7	5.4	34.5	.2	.5	1.4	.6	1.2	.14	3.9	7.2	10.6	14.1
2098B....	18.7	11.0	24.0	1.70	6.2	7.6	2.1	34.0	.3	.5	1.4	1.8	5.3	.18	3.7	7.3	10.9	17.6
2099B....	9.6	8.3	18.1	1.16	1.6	12.5	3.3	49.1	.3	1.5	1.0	.4	.7	.12	3.7	6.9	9.3	12.1
2100B....	24.6	17.2	37.6	1.43	3.0	8.2	1.6	28.6	.5	.4	1.8	1.0	2.2	.31	2.9	5.8	9.0	13.7
2101B....	11.2	8.7	19.0	1.29	2.2	13.0	8.3	39.5	.4	1.1	1.0	.6	1.1	.21	3.7	7.0	10.3	13.9
2102B....	10.1	9.7	21.2	1.04	1.6	12.1	2.8	46.6	1.2	.8	1.2	.7	1.0	.17	4.0	6.5	9.6	12.5
Average	16.2	12.0	26.2	1.35	2.9	11.9	3.4	36.5	.3	.8	1.5	1.0	2.3	.20	3.5	6.0	10.3	14.5
High....	26.9	19.7	43.0	1.70	6.7	16.8	8.3	49.1	1.2	1.5	2.3	1.9	5.3	.36	6.2	10.1	14.7	18.2
Low.....	8.3	5.1	11.1	1.04	.8	7.6	1.6	23.1	.1	.2	.7	.4	.7	.10	2.1	4.9	9.0	12.1

TABLE 13. - Range of chemical content in size fractions of as-received slimes solids, pct

Size, μm	CaO	P ₂ O ₅	MgO	Al ₂ O ₃	Fe ₂ O ₃	SiO ₂	CO ₂
Plus 104.....	5.4-29.3	4.0-19.4	0.3-6.8	2.2-10.1	0.6-3.8	36.1-74.2	0.4-2.6
Minus 104 plus 43.....	8.8-25.9	5.4-20.2	.3-5.8	5.7-11.0	.5-10.2	30.1-67.4	.5-7.0
Minus 43 plus 20.....	13.6-32.3	7.3-21.5	.2-9.2	3.4-11.4	.5-21.8	17.6-53.1	1.0-18.1
Minus 20 plus 10.....	11.6-35.2	5.4-23.1	.4-7.9	4.4-13.6	.3-7.4	12.3-42.3	1.1-15.3
Minus 10 plus 5.....	9.7-34.7	5.1-24.9	.5-7.4	4.9-17.1	.6-6.3	15.0-46.3	1.2-17.7
Minus 5 plus 1.0.....	6.6-31.2	4.5-21.5	.6-5.6	7.6-18.8	.6-6.0	20.3-48.4	.8-5.6
Minus 1.0 plus 0.5.....	7.5-42.6	5.8-27.9	.7-2.9	5.8-22.3	.4-6.2	7.9-47.0	.3-3.2
Minus 0.5 plus 0.2.....	8.2-39.1	6.2-26.2	.8-4.3	7.4-22.4	1.4-6.7	10.9-44.5	.7-3.0
Minus 0.2.....	0.7-14.6	0.8-13.4	1.1-8.6	12.1-22.8	2.1-6.4	31.3-56.9	.1-1.2

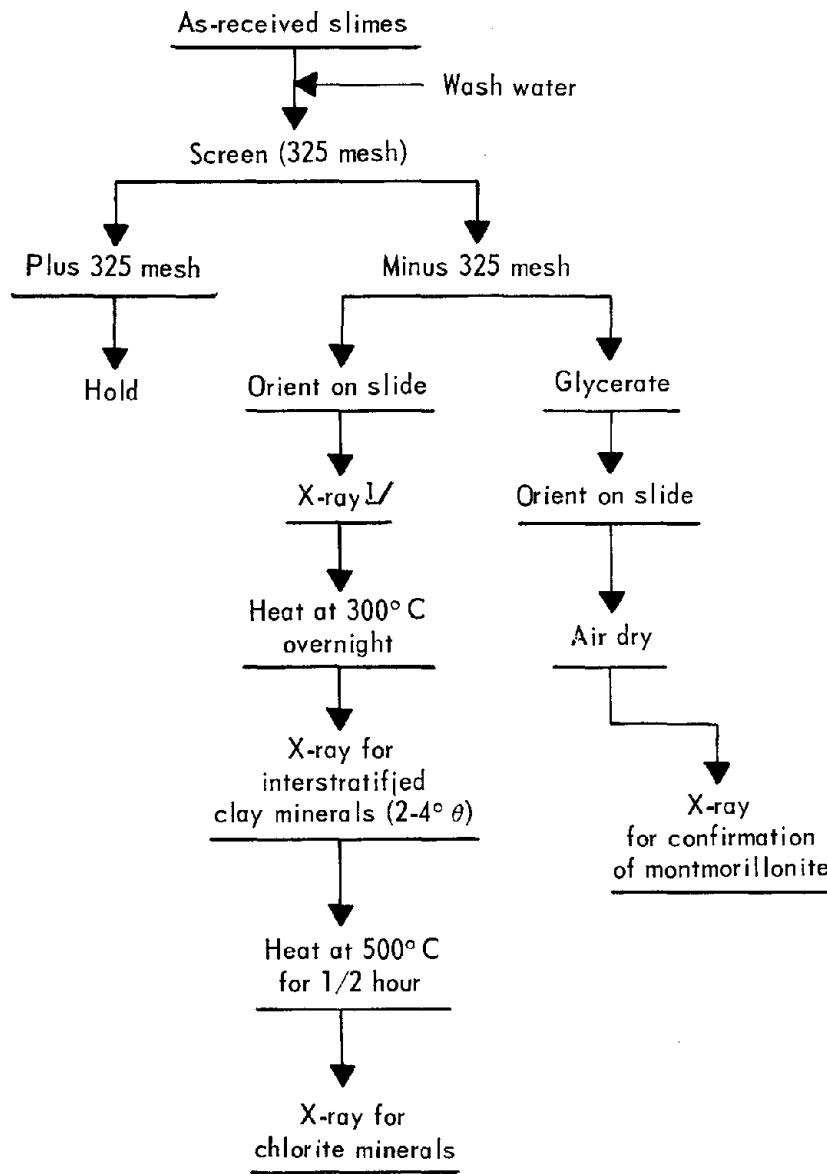
TABLE 15. - Analyses of supernatant water from as-received slimes

Sample.....	2086B	2087B	2088B	2089B	2090B	2091B	2092B	2093B	2096B	2097B	2098B	2099B	2100B	2101B	2102B	Average	High	Low
Chemical analyses, mg/l:																		
Calcium.....	68	45	56	55	50	46	52	80	67	29	58	50	54	95	56	57	95	29
Magnesium.....	31	17	28	21	10	17	26	34	25	11	26	17	17	36	16	22	36	10
Sodium.....	32	15	23	14	15	14	35	12	12	10	18	16	15	35	11	18	35	10
Potassium.....	3.2	1.1	1.2	1.5	0.9	0.9	0.9	1.6	1.4	0.8	1.6	1.5	0.8	1.5	0.6	1.3	3.2	0.6
Iron, total recoverable.....	0.070	0.230	0.170	0.050	0.070	0.050	0.050	0.060	0.040	0.280	0.230	0.100	0.240	0.130	0.010	0.119	0,280	0.010
Manganese, total recoverable.....	0.020	0.020	0.010	0.010	0.020	0.020	0.050	0.050	0.020	0.020	0.010	0.040	0.050	0.070	0.040	0.030	0.070	0.010
Aluminum, total recoverable.....	0.090	0.490	0.500	0.080	0.150	0.220	0.100	0.090	0.030	0.270	0.230	0.050	0.420	0.050	0.010	0.185	0.500	0.010
Bicarbonate.....	180	198	162	88	52	105	140	124	172	78	144	26	75	75	56	112	198	26
Carbonate.....	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfate.....	180	29	137	150	130	100	160	220	120	50	120	190	140	300	140	144	300	27
Chloride.....	20	10	18	14	12	12	12	12	14	14	12	10	20	50	10	17	50	10
Fluoride.....	2.4	1.9	2.6	1.5	1.4	2.3	1.0	1.3	2.6	1.3	2.7	1.3	1.6	3.6	2.3	2.0	3.6	1.0
Nitrite, total as N.....	0.003	0.003	0.003	0.002	0.001	0.002	0.003	0.051	0.001	0.006	0.001	0.002	0.002	0.002	0.000	0.005	0.051	0.000
Nitrate, total as N.....	0.20	0.73	0.60	0.21	0.80	0.23	2.30	3.70	1.90	0.40	3.50	0.00	0.00	1.40	0.00	1.06	3.70	0.00
Phosphate as HPO ₄	-	-	-	-	0.5	1.3	-	0.4	0.6	-	-	-	1.6	1.7	-	(¹)	-	-
Phosphate as H ₂ PO ₄	-	-	-	-	0.2	0.3	-	0.1	0.1	-	-	-	0.7	1.1	-	(¹)	-	-
Phosphorus, total as P.....	0.055	0.050	0.130	0.270	0.280	0.640	0.065	0.180	0.240	0.065	0.095	0.040	0.800	1.100	0.085	0.273	1.100	0.040
Phosphorus, total as ortho P.....	0.028	0.027	0.077	0.240	0.240	0.520	0.063	0.180	0.240	0.093	0.070	0.023	0.730	0.900	0.050	0.229	0.900	0.023
Silica as SiO ₂	5.9	5.8	1.5	1.7	9.0	1.2	7.2	1.7	4.3	2.7	5.7	8.7	8.4	15.0	2.4	5.4	15.0	1.2
Dissolved solids as residue.....	446	226	366	333	241	263	390	467	363	189	359	308	312	644	306	348	644	189
Total hardness as CaCO ₃	300	180	250	220	170	180	240	340	270	120	250	200	200	380	210	234	380	120
Noncarbonate hard- ness as CaCO ₃	150	20	120	150	120	100	120	240	130	56	130	180	140	320	160	142	320	20
Alkalinity as CaCO ₃ pH.....	148	162	133	72	43	87	115	102	141	64	118	21	62	62	46	92	162	21
Specific conductance umhos/cm at 25° C..	7.9	8.0	8.0	≈1.7	7.6	7.9	8.0	7.7	8.0	7.9	8.0	7.0	7.6	7.4	7.5	7.8	8.0	7.0
Turbidity.....JTU ³ ..	670	390	595	500	400	410	610	670	560	270	550	430	460	890	440	523	890	270
	4	9	10	2	6	10	3	3	1	100	8	3	10	1	3	12	100	1

¹Insufficient data for averaging.

²Excluded from average.

³Jackson Turbidity Units.



✓ Stopped at this point in studies of minus 0.2- μ m fractions.

FIGURE 3. - Schematic diagram of X-ray diffraction technique used in mineralogical studies of phosphate slimes.

Mineralogical Properties

Mineralogical studies using X-ray diffraction techniques were made of the minus 325-mesh fractions of each of the as-received slimes after removal of the plus 325-mesh fractions by wet screening. A schematic diagram of the treatment sequence used in the study is shown in figure 3. Table 16 shows the results of these studies. Neither interstratified clay minerals nor chlorites were detected.

TABLE 16. - Approximate net peak intensities of clay minerals in minus 325-mesh fractions of as-received slimes, counts per second¹

Sample	Montmorillonite	Kaolinite	Attapulgite	Illite	Apatite	Quartz	Dolomite	Wavellite	Crandallite
2086B	2,330	ND	² 1,270	ND	² 205	² 350	180	ND	ND
2087B	1,750	(20-30)	ND	110	280	730	45	ND	ND
2088B	480	145	² 290	ND	² 370	² 770	600	² 190	90
2089B	640	130	² 100	² 110	460	410	ND	ND	ND
2090B	120	680	ND	115	550	² 660	ND	130	180
2091B	370	125	² 60	² 80	560	360	190	² 95	(20-30)
2092B	660	90	90	(20-30)	630	270	ND	ND	110
2093B	900	120	(20-30)	² 90	² 350	740	480	² 120	(20-30)
2096B	2,250	50	(40-50)	² 70	² 180	830	345	² 80	ND
2097B	1,850	310	² 130	ND	480	160	ND	ND	(20-30)
2098B	270	ND	860	ND	² 380	350	² 390	ND	ND
2099B	3,200	60	ND	210	310	560	ND	250	ND
2100B	250	ND	510	ND	490	270	ND	80	ND
2101B	1,280	210	(30-40)	² 80	260	680	(30-40)	75	(20-30)
2102B	1,320	280	² 150	(30-40)	330	730	60	² 320	ND

ND Not detected.

¹Values were obtained from the scan of the oriented glycerated sample except for wavellite, for which the oriented sample was used. The lines measured were as follows: montmorillonite (montmorillonite-glycerol), about 18 angstroms; kaolinite, about 7 angstroms; attapulgite, about 10.6 angstroms; illite, about 10 angstroms; apatite (second strongest line), about 2.70 angstroms; quartz, about 3.34 angstroms; dolomite, about 2.89 angstroms; wavellite, about 8.7 angstroms; and crandallite, about 2.94 angstroms. Values in parentheses indicate the probable maximum intensities for those minerals present in low concentrations.

²The diffraction line was either not completely resolved from a nearby line or was in a high background region, resulting in some inexactness of the value.

Diffraction studies were also made of the minus 0.2-micrometer fractions from the sizing studies. Table 17 compares the natural settling characteristics of the slimes at 30 days with the clay mineralogy of both the minus 0.2-micrometer and the minus 325-mesh size fractions. Although the X-ray diffraction data are not directly comparable from a size standpoint, the relationship of the clay mineralogy from one size to another represents a reasonable expectation in clay-mineral sizing studies. The results shown in table 17 are significant, indicating that the attapulgite very probably controls the terminal solids of settled fraction from phosphate slimes. This premise, that the attapulgite content influences slime behavior, is also supported by the data in table 18, which shows a summary of other characterization results in conjunction with attapulgite content.

TABLE 17. - Settling characteristics of as-received phosphate slimes compared with clay mineralogy determined by X-ray diffractations

Sample	Solids content at 30 days, ¹ pct	Minus 0.2 μ m, wt-pct	Approximate net peak intensities, counts/sec ²											
			Attapulgite		Montmorillonite		Kaolinite		Illite					
			Minus 0.2 μ m	Minus 325 mesh	Minus 0.2 μ m	Minus 325 mesh	Minus 0.2 μ m	Minus 325 mesh	Minus 0.2 μ m	Minus 325 mesh				
2086B	5.7	36.2	4,200	³ 1,270	4,900	2,330	80	ND	ND	ND	ND	ND	ND	
2098B	5.7	32.8	4,800	860	2,350	270	50	ND	ND	ND	ND	ND	ND	
2100B	6.1	34.0	2,650	510	1,500	250	100	ND	ND	ND	ND	ND	ND	
2088B	7.9	27.3	1,500	³ 290	1,100	480	410	145	ND	ND	ND	ND	ND	
2097B	8.5	31.2	250	³ 130	3,500	1,850	800	310	ND	ND	ND	ND	ND	
2089B	9.3	51.3	200	³ 100	1,300	640	250	130	175	³ 110	ND	ND	ND	
2092B	10.5	41.2	140	90	1,450	600	280	90	ND	ND	ND	ND	ND	
2093B	10.9	35.3	200	(20-30)	2,825	900	300	120	150	³ 90	ND	ND	ND	
2091B	11.5	26.9	350	³ 60	1,775	370	250	125	125	³ 80	ND	ND	ND	
2102B	12.6	25.5	713	³ 150	2,500	1,320	688	280	ND	ND	ND	ND	ND	
2096B	13.1	27.1	200	(40-50)	3,750	2,250	100	50	150	³ 70	ND	ND	ND	
2101B	13.8	17.7	190	(30-40)	3,075	1,280	700	210	80	³ 80	ND	ND	ND	
2099B	15.2	24.7	ND	ND	6,150	3,200	65	60	<50	210	ND	ND	ND	
2087B	15.5	27.3	<50	ND	3,550	1,750	40	(20-30)	<50	110	ND	ND	ND	
2090B	15.9	46.0	ND	ND	425	120	1,450	680	120	115	ND	ND	ND	

ND Not detected.

¹As-received slimes diluted to 3.7 percent solids.

²Values were obtained from the scan of the oriented glycerated sample except for wavelite, for which the oriented sample was used. The lines measured were as follows: attapulgite, about 10.6 angstroms; montmorillonite (montmorillonite-glycerol), about 18 angstroms; kaolinite, about 7 angstroms; and illite, about 10 angstroms. Values in parentheses indicate the probable maximum intensities for those minerals present in low concentrations.

³The diffraction line was either not completely resolved from a nearby line or was in a high-background region, resulting in some inexactness of the value.

SUMMARY AND CONCLUSIONS

Characterization studies of 15 samples of Florida phosphate slimes indicated that, although the physical, chemical, and mineralogical composition of phosphate slimes are highly variable, the clay mineral attapulgite was determined as a common factor controlling several of the physical characteristics of the slimes, including the settling rate, terminal solids, viscosity, percent solids of filter cake, and flocculant requirements. No other parameter studied, including size analyses, surface area, chemical analyses of the solids, chemical analyses of the supernatant water or other mineral species, showed such a strong correlation with the settling characteristics of any of the samples. Table 18 presents a summary of the various parameters affecting land recovery in the phosphate mining areas of Florida.

Additional research should emphasize dewatering studies of relatively pure attapulgite collected from the phosphate district, and high attapulgite-content slimes. These types of plant slimes presumably would represent the clay mineral mixtures most difficult to dewater.

TABLE 18. - Summary of characterization studies of Florida phosphate slimes

Sample	Company	Plant	Net peak intensities of attapulgite, counts/sec	Solids content at 30 days, pct	Settling rate, in/hr		Viscosity, cp	Filter-cake solids, pct	Flocculant requirements, lb/ton of dry solids
					4 hr	72 hr			
2086B	IMC.....	Noralyn.....	1,270	5.7	0.241	0.014	58.5	29.7	2.16
2098B	Occidental.....	White Springs	860	5.7	.155	.055	78.7	32.4	2.16
2100B	Swift.....	Watson.....	510	6.1	.344	.064	49.2	35.0	2.16
2088B	IMC.....	Clear Springs	290	7.9	.619	.099	47.2	39.6	1.35
2097B	Borden.....	Tenoroc.....	130	8.5	.155	.061	14.8	37.9	.54
2089B	Agrico.....	Payne Creek..	100	9.3	.516	.191	33.7	40.8	1.35
2092B	Grace.....	Bonny Lake....	90	10.5	.412	.117	33.2	43.3	.41
2093B	Brewster.....	Haynesworth..	20-30	10.9	.275	.090	15.3	42.6	.41
2091B	Agrico.....	Palmetto.....	60	11.5	1.031	.118	13.8	42.6	.41
2102B	Mobil.....	Ft. Meade.....	150	12.6	1.547	.128	15.2	41.5	.41
2096B	U.S.S. Agri. Chem.	Rockland.....	40-50	13.1	1.478	.130	12.5	38.9	.27
2101B	Swift.....	Silver City..	30-40	13.8	1.289	.135	16.8	41.1	.27
2099B	Cities Service.	Ft. Meade.....	ND	15.2	1.753	.139	6.8	41.0	.27
2087B	IMC.....	Kingsford.....	ND	15.5	1.770	.140	7.7	42.1	.27
2090B	Agrico.....	Saddle Creek..	ND	15.9	1.633	.138	9.8	43.3	.27

ND Not detected.