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RHEOLOGICAL EVALUATION AND CONTROL OF FLOW BEHAVIOR OF CONCENTRATED PHOSPHATE MINERAL SLURRIES

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RHEOLOGICAL EVALUATION AND CONTROL OF FLOW BEHAVIOR OF CONCENTRATED PHOSPHATE MINERAL SLURRIES

FINAL REPORT

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DISCLAIMER

PERSPECTIVE

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Over 100 million tons of phosphate matrix are transported from mining pits to beneficiation plants in Florida every year. The phosphate matrix is first slurried using high-pressure water guns and then pumped to the beneficiation plants using large-diameter pipelines. Assuming an average slurry density of 35%, the industry needs to pump approximately 300 million tons of matrix slurry annually. In many cases, the mining operations are several miles away from the processing plants. The energy costs for long-distance pumping of such a huge amount of slurry are incomprehensible. The industry also pumps millions of tons of products and tailings. During its peak production years, the Florida phosphate industry consumed about 4 billion kWh of electricity annually, equivalent to $200 million at a rate of five cents per kwh. Slurry pumping is believed to account for about one-third of the total energy consumption.

In order to save energy, the industry is constantly searching for ways to increase slurry density, thus reducing the amount of water to be pumped. However, this effort is often limited because of catastrophic clogging of the pipeline. One way of pumping high-solids material without plugging the pipeline is to increase the fluidity of the slurry by adding some viscosity-reducing chemicals.

This project focused on improving pumpability of sand tailings by adding amine-based surfactants, polymers or sodium silicate. Results indicate that the limit of pumpability can be pushed to higher solids loading (>50%) by adding sodium dodecyl sulfate (SDS) or polymeric additives. Economic analysis showed that addition of 0.02 lb SDS per ton of solids could achieve energy reduction of 14% for pumping at 76% solids. However, this analysis is based on 100% recycle of SDS, which is unlikely in practice for pumping sand tailings. The SDS loss would be significantly reduced if it were applied in pumping matrix, since the water is recycled.

For a full assessment of the overall benefits of this technology, extensive testing in a closed system is needed to answer the following questions: (1) how much of the water is recycled in the targeted application, (2) how much SDS is lost in the recycle process, and (3) whether an equilibrium concentration of SDS could be achieved without adding much fresh SDS after a certain number of cycles.

ABSTRACT

The overall goal of this project is to find economic and environmental friendly ways to reduce energy consumption in pumping particulate suspensions such as phosphate concentrate sand tailings. Pumping sand tailings slurries at high solids content is desirable from technological as well as economical point of view. In this study, the fluidity of the samples was studied in the presence of surfactants, polymeric additives, and sodium silicate. A significant improvement in the fluidity and pumpability of sand tailing slurries was observed with the addition of surfactants (anionic and cationic) and polymers to the system. Sodium silicate did not significantly affect the fluidity of sand tailing slurries due to the large size of the particles. It appears that increase in the level of fluidity of sand tailing slurries is significantly higher in the presence of surfactants than the polymer used. It was determined that the particle size distribution has also a very important role on the fluidity and the limit of pumpability of sand tailings.

Effect of residual anionic surfactant on flotation of phosphate ores was also studied. Results indicate that the surfactant used in this investigation did not significantly influence the flotation process at the recommended dosage levels.

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EXECUTIVE SUMMARY

The overall goal of this project is to find economic and environmental friendly ways to reduce energy consumption in pumping phosphate products including tailings. Pumping sand tailings slurries at high solids content is desirable from technological as well as economical point of view. In this work, fluidity of sand tailings was investigated as a function of solids content by measuring the power required to mix a standard sample size (500 cm^3) at different rotational speeds. The fluidity of the samples was studied in the presence of surfactants, polymeric additives, and sodium silicate. A significant improvement in the fluidity and pumpability of sand tailing slurries was observed through the addition of surfactants and polymers to the system. Sodium silicate did not significantly affect the fluidity of sand tailing slurries due to the large size of the particles.

The fluidity tests involved measuring the power exerted on an impeller rotating in a cylinder where the slurry is stirred by the impeller. The power is proportional to the fluids viscosity and is recorded in watts. Materials tested include sand tailings received from PCS Phosphate in Florida. In all experiments, volume of the slurry, impeller diameter, length of the shaft, shape and diameter of the testing chamber (cylinder), and the gap size between the impeller and the bottom as well as the wall of the cylinder were kept constant. In this part of the work, no attempt was made to convert the power to shear stress at the wall of the cylinder and the speed to shear rate. The readings are related to the fluidity of the samples and indicative of any changes in the fluidity rather than the absolute viscosity.

Results indicate that the limit of pumpability can be pushed to higher solids loading (>50% solids) by adding surfactants and polymeric additives to the system. In this work, sodium dodecyl sulfate (SDS), an amine-based surfactant, and Dispex N-40V (polymethacrylate acid derivative) polymer were used as flow modifiers. It appears that increase in the level of fluidity of sand tailing slurries is significantly higher in the presence of surfactants than the polymeric additives. Results indicate that at 76% solids, 0.02 lb/(ton solids) of SDS is needed to maximize the fluidity of sand tailing slurries. When amine-based surfactant is used as flow modifier, 0.2 lb/(ton solids) of this dispersant is needed to maximize the fluidity of the slurry. It is shown that the particle size distribution has also a very important role on the fluidity and the limit of pumpability of sand tailing slurries.

Effect of sodium dodecyl sulfate (SDS) on the flotation of phosphate ores was studied. The flotation performance of phosphate is affected by the presence of SDS in the system. Effects are not significant at SDS dosage levels as low as 0.02 lb/(ton solids). But higher levels of SDS dosage resulted in concentrates of slightly higher recovery due to floatation of sand particles in the presence of SDS and therefore an increase in the amount of acid insolubles in the system.

INTRODUCTION

Waste disposal at phosphate mining operation involves the handling of the by-products produced during the separation of the matrix at the beneficiation plant. In addition to phosphate rock, products of the beneficiation plant include phosphate clays and sand tailings.

Sand tailings are pumped to a disposal area leaving the plant as a slurry of less than 50% solids. The sands settle out rapidly and the water associated with the slurry can be recovered and recycled almost immediately. In addition, sand tailings can be used immediately for dam construction or reclamation. In dam construction, the sands are pumped to an established elevation in a pattern to impound an area for clay disposal. In reclamation, sand tailings can be used to fill mined out areas, as a cap for settling ponds, or to mix with clays.

The power required for pumping slurries through pipelines is directly related to the apparent viscosity of the mixture. Pumping at high solids contents is a key to pumping efficiency and is desirable from a technological as well as an economic point of view. Increasing the solids content will increase the viscosity of the system and can give rise to technological problems such as plugging and high energy consumption. In order to overcome these problems and to increase the efficiency of the transportation of the sand tailing slurries, methods for control and increase of fluidity should be developed. These methods will enable one to increase the solids loading while maintaining sufficient fluidity in the system for pumping and processing of these materials.

The pressure drop and energy consumed during pumping of these slurries is directly related to the fluidity of the material. Controlling the viscosity of these materials at high volume fraction of the particles is required from a technological as well as economical point of view due to energy savings by pumping these materials at high solids loading.

PURPOSE OF STUDY

The objective of the proposed research was to study the effect of different physical and chemical variables on the fluidity and stability of the mineral sand tailing slurries to identify optimal conditions for processing of these materials. Methods for controlling the fluidity and improving the processability of the slurries is being investigated.

In the first part of the project, effects of solids content on the fluidity of sand tailing slurries without and in the presence of surfactants and polymers are investigated. The results which are presented and discussed show that addition of surfactants and polymers can improve the fluidity and stability of sand tailing slurries and push the limit of pumpability to higher solids loadings. These show potential for further development of methods to control and minimize the fluidity of sand tailing slurries and to increase the stability of the slurry against sedimentation and hardening of the particles.

Also, the effect of particle size distribution (polydispersity) on the fluidity of sand tailings was investigated. The effect of surfactant additives on flotation behavior of the slurries was tested to make sure that there is no significant detrimental effect on flotation. The results are presented and discussed.

EXPERIMENTAL PROCEDURE

SAMPLE PREPARATIONS

Sand tailings used in this work were provided by PCS Phosphate in Florida. Two five gallon buckets full of sand tailings slurry were received. The slurries were mixed together in a large container. It was noticed that the settling rate for the particles was very fast. Over night settling made the solids to harden which will make the mixing and pumping of such material extremely difficult. Large sand tailing particles were separated by an 18-mesh. The amount of sands larger than this size was negligible. Sand tailings samples were dried at 120 °C by leaving several of batches of samples in aluminum pans in a convection oven for at least 24 hours. Pans were weighed several times during this period to make sure that all the water has been evaporated. Dried sand tailings were stored in closed containers at room temperatures. Dried samples were used to prepare slurries of known solids content.

The fluidity of the prepared slurry samples was tested using 500 cm^3 of sand tailing slurries of different solids content. Slurries were prepared by gradually adding a known amount of sand to water or water-additive solutions while mixing the sample using a rotational mixer. The power required to agitate the sample at different rotational speeds was recorded. The volume of water and the amount of sand used to prepare 500 cm^3 of sand tailing slurries of different solids loading are given in Table 1.

Table 1. Weight of the Sand and Volume of the Water Used to Prepare 500 cm^3 Sand Tailing Slurries of Different Solids Loadings (Density of Sand=2.65 gr/cm^3).

% Solids	Volume of Water, cm^3	Mass of Sand, Grams
50	363.0	363.0
55	342.2	418.2
60	319.0	479.0
65	294.0	546.0
70	266.0	620.4
75	235.0	703.5
76	227.8	721.3
77.5	217.0	748.9

PARTICLE SIZE DISTRIBUTION

The particle size distribution of sand tailings used in this study was measured using Coulter LS230 particle size analysis instrument. The instrument contains a fluid module, a sonicator that helps to disperse the particles, and a variable speed circulation pump that circulates the particles through sample cells. The particle size of the sand tailing slurry had a broad range of 0.04 micron to 2000 micron. The mean diameter of the studied particles was 403.6 μm. Detail information about the particle size distribution of sand tailings used in this work are provided in Tables 2 and 3. Figure 1 represents the particles size distribution of sand tailings.

Table 2. Volume-Based Average Particle Size of the Studied Sand Tailings.

	Volume (percent)	Mean (μm)	Median (μm)	95% Conf. Limit (μm)
Sample 1	100	408.3	335.5	0-872
Sample 2	100	413.5	341.4	0-878
Sample 3	100	397.0	330.4	0-841
Sample 4	100	395.4	321.6	0-871

Table 3. Volume-Based Average Particle Size Distribution of the Studied Sand Tailings.

% <	10	25	50	75	90
Sample 1	190.4 μm	246.9 μm	335.5 μm	504.5 μm	771.1 μm
Sample 2	194.5 μm	251.8 μm	341.4 μm	510.0 μm	777.5 μm
Sample 3	187.4 μm	234.6 μm	330.4 μm	486.1 μm	747.5 μm
Sample 4	184.7 μm	238.8 μm	321.6 μm	468.6 μm	750.9 μm

COULTER

LS Particle Size Analyzer

16 Nov 1998

File name:	sio2den1.$02	Group ID:	SiO2den1
Sample ID:	sandtail		
Operator:	patrick	Run number:	2
Comments:			
Optical model:	sio2.rfd PIDS included		
LS 230	Small Volume Module		
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Obscuration:	21%		
PIDS Obscur:	58%		
Fluid:	Water		
Software:	2.09	Firmware:	2.02 2.02

File name:	SIO2DEN4.$02	Group ID:	SiO2den4
Sample ID:	sandtail4		
Operator:	patrick	Run number:	2
Comments:			
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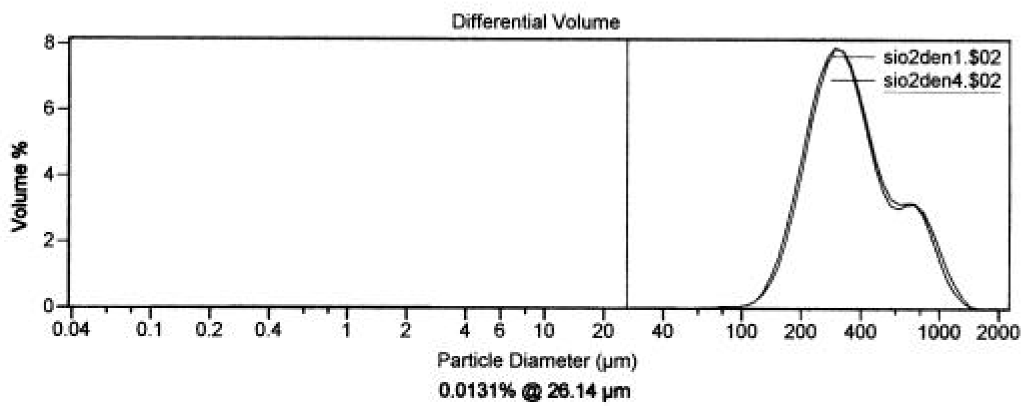

Figure 1. Volume-Based Particle Size Distribution of Sand Tailings Used in This Study.

DENSITY MEASUREMENT

An ultrapycnometer was used to measure the density of the samples. Density of the sample is required for the calculation of the amount of solids required to prepare a given volume of the slurry of desired solids loadings. Helium was used as a displaced gas which can penetrate the finest pores due to its small atomic dimensions, thereby assuring maximum accuracy. Its behavior as an ideal gas is also desirable. The average density of the dried sand particles was 2.65 gr/cm^3 based on 20 measurements.

FLUIDITY MEASUREMENT

The power required to mix a known volume of the slurry was measured using a Lightnin model L1U08F mixer. The mixing power required is measured based on the energy consumption of the mixer at a certain pumping capacity and can be interpreted as the degree of the fluidity of the sand tailing slurry. The standard slurry volume was chosen to be 500 cm^3. The pumping power for mixing was measured at different rotational speeds on samples of different solids loading. The results for blank sand tailing slurries (no additives) and for samples treated with polymers and surfactants are given and discussed in this section. The characteristics of the mixer, impeller, cylinder, reagents used are as follows:

Mixer model:	Lightnin L1U08F
Impeller diameter:	94 mm (3.7 in)
Cylinder diameter:	104 mm (4.1 in)
Cylinder height:	150 mm (5.9 in)
Rotational speed:	200, 250, 300, 350, 400, 450, 500, 550, 600, and 650 RPM
Pumping capacity:	92, 114, 138, 160, 184, 207, 230, 254, 277, and 299 L/min at above rotational speeds respectively
Reagent dosage:	as is given in this report as lb/(ton of solids)
Power (W):	is recorded at different rotational speeds and reagent levels as is given in this section
Volume of the slurry:	500 cm^3
Solids loadings:	as given in Table 1.

RESULTS

RESULTS FOR UNTREATED (BLANK) SAMPLES

The data for untreated samples at various solids loading are presented in Table 4. Figure 2 is a plot of mixing power as a function of the rotational speed at different solids content. It appears from the data that the plots (log-log) of mixing power versus rotational speed are linear for slurries of up to 70% solids. Therefore, the slurry has the characteristics of a Newtonian fluid for solids loadings of up to 70% solids. The power readings are plotted as a function of solids contents at different rotational speeds if Figure 3. Comparison of the data given in this figure indicate that at a fixed rotational speed, there is a significant increase in the amount of energy required to mix (pump) sand tailing slurries of concentrations larger than 65% solids loadings. While performing the experiments, it was observed that:

1. The settling rate for untreated slurries was very high. Particles settled down almost immediately after stopping the mixer.

2. Start up problem is more severe at higher solids loadings. It was very difficult to resuspend the particles at solids loadings larger than 65% solids. Over night settling caused the solids to harden making the slurry more difficult to mix and/or pump even at 50% solids.

3. Unusual flow behavior such as dilation was observed at solids contents larger than 70% solids. It was very difficult to homogenized the samples even at high rotational speeds. It will be very difficult to pump untreated samples at high solids contents. Untreated sand tailing slurries were not pumpable at all at solids contents larger than 76% solids.

4. Start-up tests were performed on all samples at 200 RPM after letting each sample to rest for twenty minutes by stopping the mixer after the tests for a period of 5 minutes. No start up problem was observed for samples of up to 65% solids. Over a solids contents range of 65% to 76% solids, it was difficult to start at 200 RPM. Increasing the rotational speed to 220 RPM helped to overcome this problem. At solids contents larger than 76% solids, dilation was observed at all rotational speeds and the slurry was non-uniform and not pumpable.

5. Performing start-up tests on blank sand tailings samples settled over a period of 24 hours indicated difficulties in mixing the settled particles. It was almost impossible to start up mixing on samples of solids contents above 50% even at high rotational speeds. Other methods had to be applied to loosen and brake the settled layers in order to mix and homogenize the system.

Table 4. Power Required to Mix 500 cm^3 of Blank Sand Tailing Slurries of Different Solids Loadings as a Function of Rotational Speed.

Speed RPM	Mixing power at 50% solids W	Mixing power at 55% solids W	Mixing power at 60% solids W	Mixing power at 65% solids W	Mixing power at 70% solids W	Mixing power at 75% solids W	Mixing power at 76% solids W	Mixing power at 77.5% solids W
200	0.15	0.2	0.2	0.3	0.6	3.9	5.9	8.8
250	0.25	0.4	0.5	0.6	1.1	5.5	8.6	11.5
300	0.55	0.7	0.8	1.1	1.9	7.8	11.9	--
350	0.1	1.3	1.5	1.8	2.9	10.9	15.1	--
400	0.15	1.9	2.1	2.6	3.9	13.7	17.7	--
450	2	2.4	2.9	3.4	4.9	15.5	19.7	--
500	2.7	3	3.6	4.1	6.2	16.4	21.4	--
550	3.2	3.8	4.3	5.1	7.6	17.6	23.2	--
600	3.7	4.3	5.1	6.2	8.9	18.7	25.7	--
650	4.4	5.1	6	7.1	10.3	20.6	28.6	--

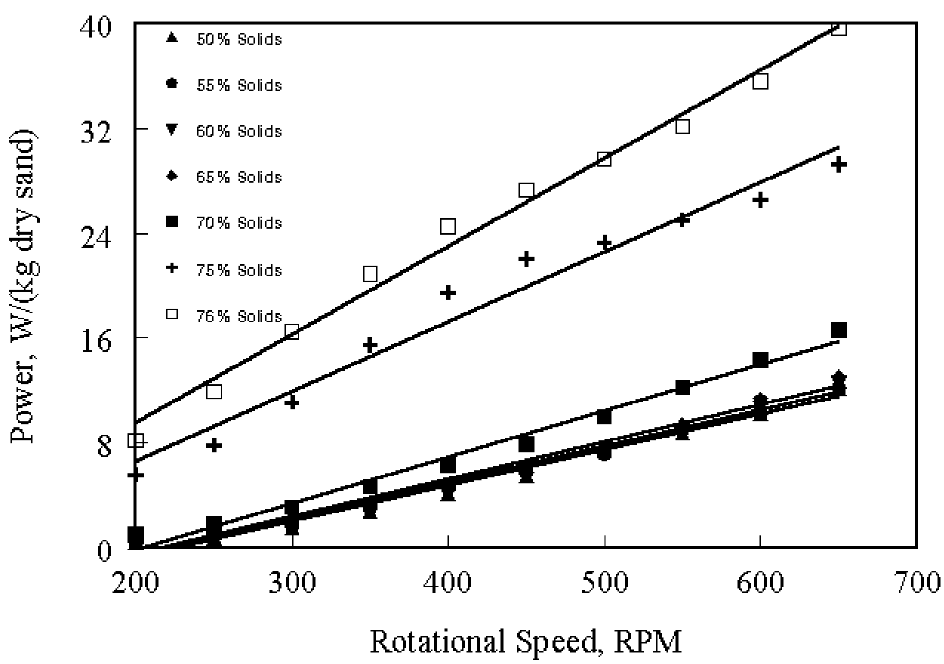

Figure 2. Power Readings as a Function of Rotational Speed for Blank Sand Tailings Slurries at Various Solids Loadings.

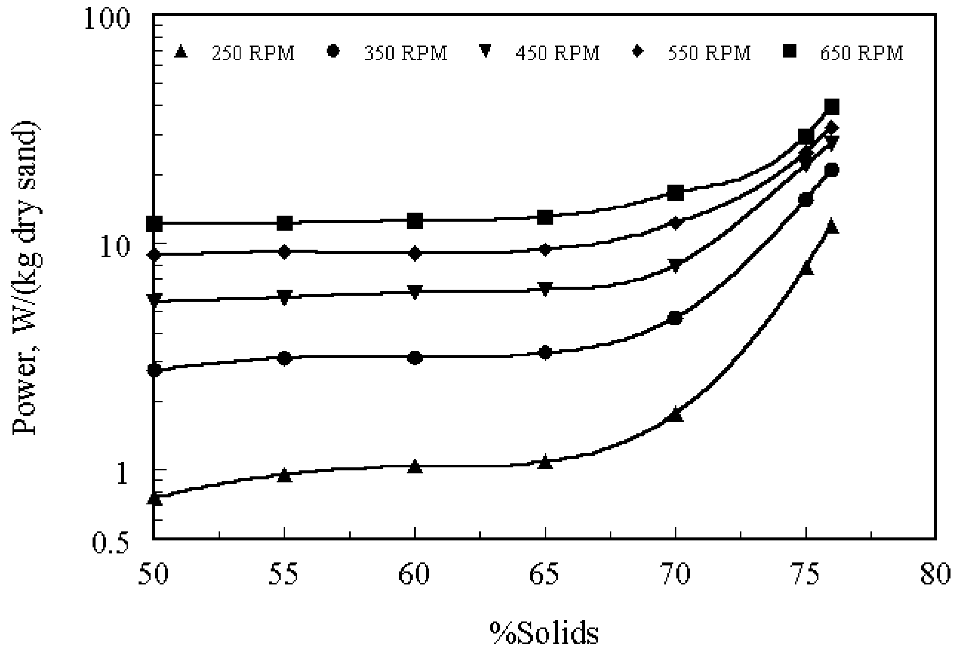

Figure 3. Power Readings as a Function of Solids Loadings for Blank Sand Tailings Slurries at Different Rotational Speeds.

RESULTS FOR TREATED SAMPLES WITH DISPEX N-40V (DERIVATIVE OF POLYMETHACRYLIC ACID POLYMER)

The data for the blank, and polymer-treated slurries at 76% solids are given in Table 5 which presents the mixing power as a function of rotational speed for untreated and treated samples with different Dispex N-40V dosage. Figure 4 also represents the power as a function of the rotational speed at different levels of polymer dosage. As can be observed, the polymer increases the flow ability of the slurry and there is a critical amount of polymer that must be added to the system to have maximum fluidity. As an example, at a rotational speed of 500 RPM, the power readings for the blank sample and the slurry treated with 1.6 lb/ton polymer are equal to 21.4 W and 15.1 W respectively which indicates about 25% drop in the mixing power due the higher fluidity of the second sample. It was noticed that the settling rate was slower in the presence of polymer and the start up problem was less severe for polymer-treated samples as compared with blank samples.

Table 5. Comparison Between Power Readings for Non-Treated and Polymer- (Dispex N-40V) Treated Slurries (500 cm^3) at 76% Solid.

	No polymer	0.4 lb/ton	1 lb/ton	1.6 lb/ton	2 lb/ton
RPM	Power, W	Power, W	Power, W	Power, W	Power, W
200	5.9	5.9	4.8	4.7	5.7
250	8.6	8.4	7.4	6.9	8.2
300	11.9	11.3	9.7	9.5	10.9
350	15.1	14.2	12.4	12.1	13
400	17.7	16.4	14.3	14.1	14.6
450	19.7	17.1	14.9	14.8	15.8
500	21.4	17.5	15.6	15.1	16.6
550	23.2	18.6	17.3	16.6	17
600	25.7	21.2	19.1	18.1	18.4
650	28.6	23.2	19.8	18.8	19.9

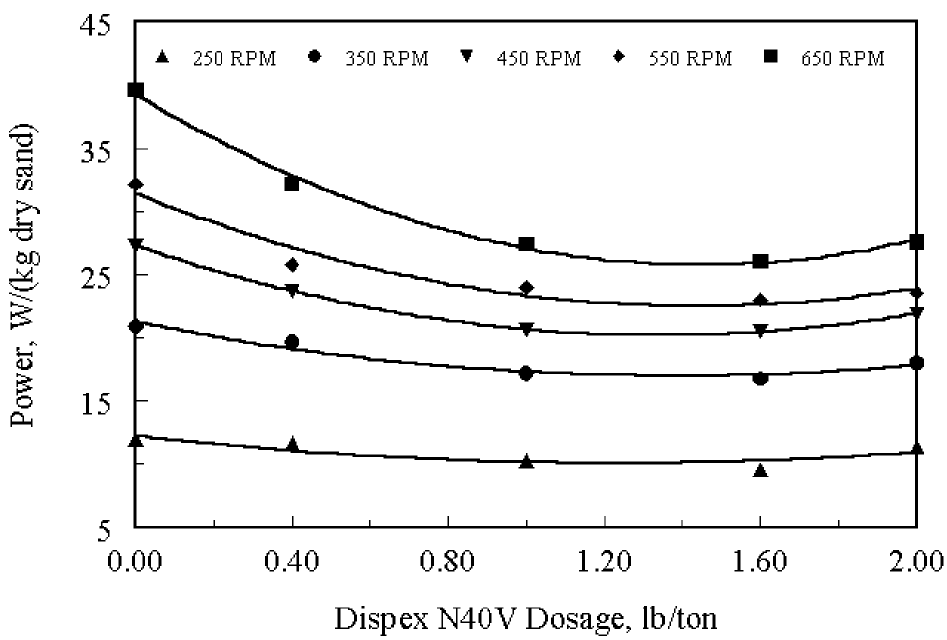

Figure 4. Power Readings as a Function of Rotational Speed for Sand Tailings Slurries of 76% Solids Treated with Different Amount of DISPEX N40V.

Increase in the fluidity of the samples in the presence of polymers is due to the lubrication forces induced by polymer molecules which reduces the frictional force among the particles and between the particles and the walls of the container or pipe which may reduce erosion. It should be considered that for suspensions of large particles, as is the case in this work, polymers become more effective at higher solids loading and may not be effective at lower solids content. This can be concluded from the data given in Table 6, which are the power readings as a function of rotational speed for slurries of sand tailings containing 2 lb/ton of polymer at different solids loadings. There is almost 20% decrease in the mixing power for 75% solids slurry which indicates a decrease in the effectiveness of the polymer as compared with the slurry of 76% solids. Also, it can be observed from the data given in this table that the addition of polymer to the system will push the limit of pumpability to higher solids loading. While blank sand tailing slurries of 77.5% solids were not pumpable at all, addition of polymer improved the fluidity of the sample significantly such that we were able to mix and homogenize the material much easier as compared with blank sample of the same solids loading. Performing start up tests after 24 hours of settling indicated that the polymer-treated sample at 75% solids can be mixed easily at 200 RPM. However, this was not the case for the sample of 77.5% solids and it was extremely difficult to start up to mix and homogenize the sample.

Table 6. Data for Sand Tailing Slurries of 75% Solids and 77.5% Solids (500 cm^3) Without and With 2 lb/ton of Polymer.

	75% solids	75% solids	77.5% solids	77.5% solids
RPM	No polymer	2 lb/ton	No polymer	2 lb/ton
200	3.9	3.2	8.8	5
250	5.5	4.4	11.8	8.3
300	7.8	6.2	Not pumpable	1.4
350	10.9	7.7	Not pumpable	13.9
400	13.8	9.2	Not pumpable	15.3
450	15.5	10.6	Not pumpable	16.2
500	16.4	11.6	Not pumpable	16.3
550	17.6	12.6	Not pumpable	17.2
600	18.7	13.3	Not pumpable	17.9
650	20.6	14.9	Not pumpable	--

RESULTS FOR TREATED SAMPLES WITH AMINE-BASED SURFACTANT USED IN THE FLOATION PLANT OF PCS PHOSPHATE

The amine-based surfactant used in this study to investigate its effect on the fluidity of sand tailing slurries was provided by PCS Phosphate at Florida. This surfactant is currently used in the flotation plant of PCS Phosphate. Data for the blank, and surfactant-treated sand tailing slurries at 76% solids are given in Table 7, which presents the power readings as a function of rotational speed for untreated and treated samples with different amount of surfactant. Figure 5 represents the power readings as a function of the amine-based surfactant dosage at different rotational speeds. It is observed that even small amount of surfactant increases the fluidity of the slurry significantly and there is an optimal dosage of surfactant that should be used to have maximum fluidity. Considering the data at 500 RPM given in Table 7, the power readings for the blank sample and samples containing 0.04; 0.10; and 0.20; lb/ton of surfactant, are 21.4; 10.3; 9.5; and 8.1 W respectively. These indicate that there is 53%; 56%; and 62%; reduction in the mixing power for samples containing 0.04; 0.10; and 0.20 lb/ton of amine-based surfactant. It was noticed that the settling rate was very slow for amine-based surfactant-treated samples as compared with polymer-treated samples. Also, there was no start up problem even after overnight settling. In general, surfactants have the advantage of bubble generation in addition to their lubricating property which causes flotation of the particles and prevents hardening of the settled phase during the resting period.

Table 7. Power Required to Mix 500 cm^3 of Blank and Amine-Based Treated Sand Tailing Slurries of 76% Solids as a Function of Rotational Speed.

	No Surfactant	0.04 lb/ton Amine-based Surfactant	0.10 lb/ton Amine-based Surfactant	0.20 lb/ton Amine-based Surfactant	0.30 lb/ton Amine-based Surfactant	0.40 lb/ton Amine-based Surfactant	1.0 lb/ton Amine-based Surfactant
RPM	Mixing power, W	Mixing power, W	Mixing power, W	Mixing power, W	Mixing power, W	Mixing power, W	Mixing power, W
200	5.9	1.9	1.6	1.3	3	3.2	3.5
250	8.6	2.8	2.5	2.1	4.1	4.5	5.1
300	11.9	4	3.5	3	5.2	5.8	6.9
350	15.1	5.4	4.8	4.2	7	8.4	9.4
400	17.7	7.3	6.4	5.5	9.3	9.8	11
450	19.7	8.5	7.7	6.7	10.9	11.7	12.5
500	21.4	10.3	9.5	8.1	11.8	12.5	13.3
550	23.2	10.9	10.9	9.6	13.9	14.4	14.9
600	25.7	12.8	12.6	11.3	14.9	15.2	15.5
650	28.6	14.3	14.0	12.4	16	16.5	17

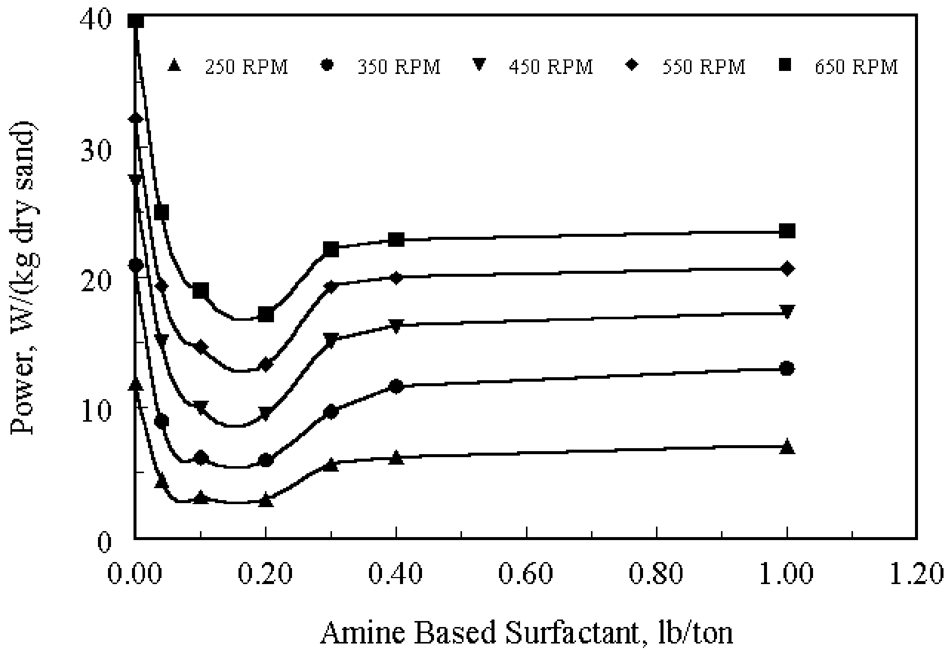

Figure 5. Power Readings as a Function of Amine-Based Surfactant Dosage for Sand Tailings Slurries of 76% Solids at Various Rotational Speeds.

Table 8 is a comparison between the power required to mix sand tailing slurries treated with 1.0 lb/ton of Dispex N-40V and 0.04 lb/ton of amine-based surfactant. The results indicate that amine-based surfactant is more effective than the polymer in term of increasing the fluidity of the system. At 500 RPM the power required to mix the amine treated slurry is almost 12% lower than the power required to mix the polymer-treated slurry. Increase in the fluidity of the samples in the presence of surfactant is due to the lubrication forces induced by surfactant molecules and also the air bubbles generated during the mixing of the slurry. Air bubbles will help the particles to stay suspended in water over a longer period of time. Since most of the generated bubbles will not collapse after stopping the mixer, this will keep some of the particles separated from each other which will make the start up (even after a very long stopping period) much easier as was observed experimentally in this work.

Table 8. Comparison Between Power Reading for Polymer- (Dispex N-40V) and Surfactant-Treated Sand Tailing Slurries (500 cm^3) at 76% Solid.

RPM	1.0 lb/ton Polymer Power, W	0.04 lb/ton Amine-Based Surfactant Power, W
200	4.8	1.9
250	7.4	2.8
300	9.7	4
350	12.4	5.4
400	14.3	7.3
450	14.9	8.5
500	15.6	10.3
550	16.6	10.9
600	17.1	12.8
650	19.8	14.3

Similar to polymers, surfactants also become more effective at higher solids loading and may not be effective in term of fluidity at lower solids content. This can be concluded from the data given in Tables 9 and 10, which are the power readings as a function of amine-based surfactant dosage and rotational speed for slurries of sand tailings at 50% and 70% solids. There is almost no change in the power readings as the surfactant dosage is increased. Also, in Table 10, the data is given for sand tailing slurries at 77.5% solids. While the blank sample at 77.5% solids was not pumpable at all, addition of amine-based surfactant improved the fluidity of the sample significantly such that we were able to mix and homogenize the material easily. Performing start up tests after 24 hours of settling indicated that the surfactant-treated sample at 76% solids can be mixed easily at 200 RPM. However, this was not the case for polymer-treated sample at the same solids loadings as it was extremely difficult to start up to mix and homogenize the sample.

Table 9. Effect of Amine-Based Surfactant Dosage on the Power Required to Mix Sand Tailing Slurries of 50% Solids (500 cm^3).

RPM	0.10 lb/ton Amine-based Surfactant	0.20 lb/ton Amine-based Surfactant	0.40 lb/ton Amine-based Surfactant
200	1.8	1.8	1.8
250	0.4	0.4	0.4
300	0.6	0.5	0.5
350	1.1	1.2	1.2
400	1.6	1.7	1.7
450	2.3	2.3	2.3
500	2.9	2.9	2.9
550	3.6	3.6	3.6
600	4.3	4.3	4.3
650	4.9	4.7	4.7

Table 10. Effect of Amine-Based Surfactant Dosage on the Power Required to Mix Sand Tailing Slurries of 70% and 77.5% Solids (500 cm^3).

	70% Solids	70% Solids	77.5% Solids	77.5% Solids
RPM	0.10 lb/ton Amine-based Surfactant	0.20 lb/ton Amine-based Surfactant	No Additive	0.10 lb/ton Amine-based Surfactant
200	0.5	0.5	8.8	2.2
250	0.9	0.9	11.8	3.4
300	1.6	1.6	Not pumpable	4.6
350	2.4	2.3	Not pumpable	6.6
400	3.2	3	Not pumpable	8.5
450	4.3	4.1	Not pumpable	10.3
500	5.4	5.2	Not pumpable	11.6
550	6.4	6.3	Not pumpable	13.2
600	8	7.6	Not pumpable	13.1
650	9.1	8.7	Not pumpable	15.2

RESULTS FOR TREATED SAMPLES WITH LAURYL SULFATE (SDS) SURFACTANT (ANIONIC)

The effect of sodium dodecyl sulfate surfactant (SDS) on the fluidity of sand tailing slurries was investigated in this work. The data for sand tailing slurries of 76% solids treated with different amount of SDS is presented in Table 11. Comparison of these data with the data given in Table 7 indicate that SDS is more effective than the amine-based surfactant in term of the fluidity of sand tailing slurries. Considering the data at 500 RPM, the power readings for the blank sample and samples containing 0.002; 0.010; 0.015; 0.02; 0.04; and 0.06 lb/ton of SDS, are 21.4; 17.3; 13.7; 11.3; 10.8; 8.5; and 7.4 W respectively. These indicate that there is 19%; 36%; 47%; 49%; 60%; and 65% reduction in the mixing power for samples containing 0.002; 0.010; 0.015; 0.02; 0.04; and 0.06 lb/ton of SDS surfactant. It was noticed that the settling rate was very slow for SDS as well as amine-based surfactant-treated samples as compared with polymer-treated samples. Also, there was no start up problem even after overnight settling.

Figure 6 is a plot of power readings as a function of SDS dosage at various rotational speeds. These data indicate that the amount of SDS used to increase the fluidity of sand tailing slurries is smaller than amount of amine-based surfactant required to maximize the fluidity of the system. This is probably due to the adsorption of the amine-based surfactant on quartz particles which is not the case for SDS.

Table 11. Power Required to Mix 500 cm^3 of SDS-Treated Sand Tailing Slurries of 76% Solids as a Function of Rotational Speed.

	0.004 lb/ton SDS	0.010 lb/ton SDS	0.015 lb/ton SDS	0.02 lb/ton SDS	0.04 lb/ton SDS	0.06 lb/ton SDS
RPM	Power, W	Power, W	Power, W	Power, W	Power, W	Power, W
200	3.9	3.4	2.6	2.1	1.0	1.0
250	6.2	5.5	4.1	3.3	2.1	1.9
300	8.9	8.3	6	4.5	3.0	3.0
350	12	10.3	7.1	6.2	4.3	4.0
400	16.2	12.3	9.2	8.3	5.8	5.4
450	16.3	13	10.2	9.6	7.7	7.1
500	17.3	13.7	11.3	10.8	8.5	7.4
550	18	15.3	11.9	11.4	8.7	8.4
600	19.5	16.6	12.6	11.9	10.7	9.9
650	22.5	19	14.9	14.2	11.7	10.8

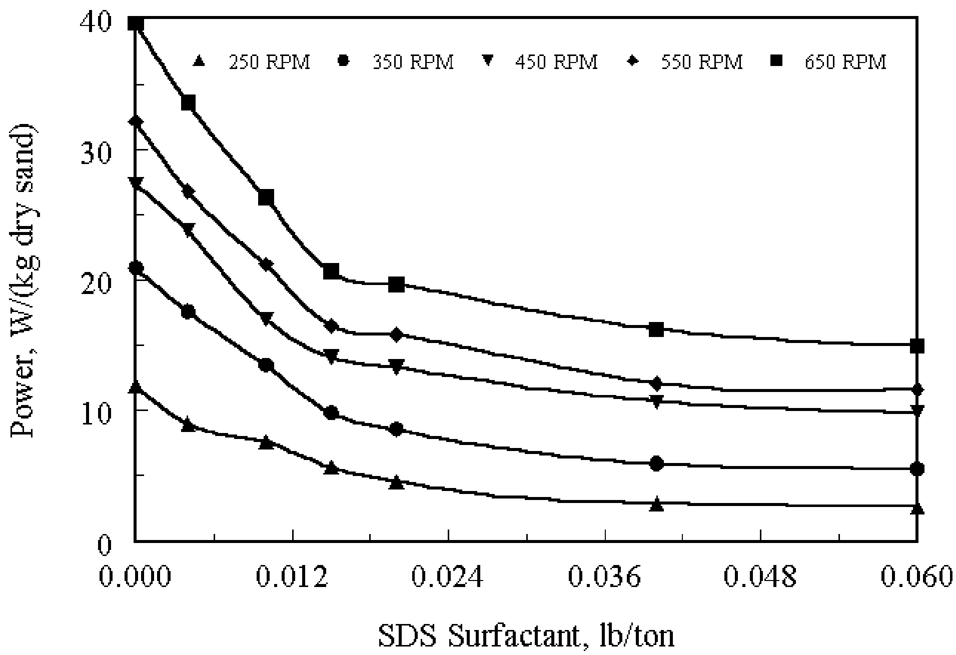

Figure 6. Power Readings as a Function of SDS Dosage for Sand Tailings Slurries of 76% Solids at Various Rotational Speeds.

EFFECT OF PARTICLE SIZE DISTRIBUTION (PSD) ON THE FLUIDITY OF SAND TAILING SLURRIES

To study the effect of polydispersity (PSD) on the fluidity of sand tailing slurries, conventional sieving was employed to separate the particles in two different portions. Sieves that were used were of Nos. 45 (of an opening 355 μm), 60 (of an opening 250 μm), and 70 (of an opening 212 μm), to separate the sand tailing particles into the coarse and fine portions of two different particle size distributions. For a given sieve, the coarse portion contains particles that are larger than the size of the openings of the sieve and the fine portion contains particles that are equal or smaller than the openings of the sieve used. The feed samples that were separated to coarse and fine portions were of the same origin in all cases. Three sets of experiments were performed to study the effect of polydispersity (PSD) on the fluidity of sand tailing slurries. In each set, only the fine and coarse portions obtained from a given sieve were mixed together at different volume (weight) ratios while the total volume (weight) fraction of the particles was kept constant.

Before sieving, the feed was weighed and then loaded into the sieve that was then placed on a sieve shaker. Enough time was provided for all samples to be separated into fine and coarse portions. After the sieving, the two portions were weighed to determine weight fraction of the samples passed through the sieve (or remained on the sieve). Analysis of the data indicates that 69% of the feed passed through the sieve No. 45, 55% passed through sieve No. 60, and 21% of the feed passed through the sieve No. 70. Sieving on all samples was performed in the dry state. Analysis of the data is as follows:

Sieve No.:	Coarse:	Fine:
45	31% >355 μm	69% <355 μm
60	45% >250 μm	55% <250 μm
70	79% >212 μm	21% <212 μm

In order to study the mixtures of fine and coarse portions (obtained from each sieve), the sand tailing slurries were prepared by varying the volume (weight) ratio of small particles to large particles at a fixed total solids content of 75% solids and the power required for mixing was measured at different rotational speeds. The composition of the mixtures is given in terms of the volume (weight) percent of the small particles. The results indicate that the power required for mixing the two portions obtained from sieve No. 45 did not change significantly as the weight ratio of the fine and coarse portions were varied. But these changes were quiet significant as the weight ratio of the two portions obtained from sieves No. 60 and No. 70 were varied. These results are presented and discussed here.

RESULTS FOR SAMPLES OBTAINED USING SIEVE NO. 60

Sieve No. 60 has openings of 250 μm in diameter, therefore; the coarse portion obtained from this sieve contains sand particles of diameters larger then 250 μm (assuming that the particles are nearly spherical in shape) and the fine portion consists of particles that are smaller than 250 μm. Predetermined amounts of the two portions (of different weight ratios) were mixed together to obtain sand tailing slurries of 75% solids. The power of mixing data for sand tailing slurries of 75% solids (of different fine-to-coarse volume (weight) rations as well as that for sand tailing slurry prepared using the original sample), at different rotational speeds, is presented in Table 12.

Figure 7 is a plot of power readings as a function of the vol % of the fine particles in the system at rotational speeds of 250, 450, and 650 RPM. In all cases, a minimum in the power required for mixing is observed as the volume ratio of the small particles in the suspension is increased indicating that the resistance to flow can be decreased significantly by using bimodal particle size distribution. This is the result of more efficient packing of polydisperse spheres. In these systems, small particles can fit into the spaces between the larger particles and if they are small enough, along with the suspending fluid act like a larger sea for the big particles. From the data given in Figure 7, it is evident that the lowest level of power required for mixing is obtained when the volume ratio of small to large particles is equal to 40/60. There is about 16% decrease in the power of mixing (at 650 RPM) for the sample containing 40% of the fine and 60% of the coarse particles as compared with the original sand tailing sample (before sieving).

RESULTS FOR SAMPLES OBTAINED USING SIEVE NO. 70

Sieve No. 70 has openings of 212 μm in diameter, therefore; the coarse portion obtained from this sieve contains sand particles of diameters larger then 212 μm and the fine portion consists of particles that are smaller than 212 μm. Certain amounts of the two portions (of different weight ratios) were mixed together to obtain sand tailing slurries of 75 %solids. The power of mixing data for sand tailing slurries of 75% solids at different rotational speeds is presented in Table 13.

As indicated in Figure 8 which shows plots of power readings as a function of vol % of the fine particles in the system, at rotational speeds of 250, 450, and 650 RPM, in all cases, the power required for mixing decreases as the volume ratio of the small particles in the suspension is increased, reaches a minimum at a volume ratio of 40/60 (fine/coarse), and then starts to increase with further increase of fines in the system. There is about 30% decrease in the power of mixing (at 650 RPM) for the sample consist of 40% fine and 60% coarse particles as compared with the original sand tailing sample.

Table 12. Power Required to Mix 500 cm^3 of Sand Tailing Slurries of 75% Total Solids Loading at Different Rotational Speeds as a Function of the Weight Ratio of Fine and Coarse Portions (F/C) Obtained Using Sieve No. 60.

Speed, RPM	Mixing Power, W	Mixing Power, W	Mixing Power, W	Mixing Power, W	Mixing Power, W	Mixing Power, W	Mixing Power, W	Mixing Power, W
	Before Sieving	F/C 0/100	F/C 20/80	F/C 30/70	F/C 40/60	F/C 60/40	F/C 80/20	F/C 100/0
200	5.6	6	5.9	5.5	5.8	6.6	7.4	9
250	7.2	9.2	8.9	8.6	8	9.6	10.1	13.5
300	9.8	14.6	11.5	11.3	11.1	12.3	14.5	18
350	12.7	16.3	14.8	14.3	13	15	18.4	23.3
400	15.3	19.6	16.7	16.4	15	17.7	19.7	22.8
450	17.6	21.7	18.4	17.8	16	19.4	21.7	23.6
500	19.8	23.5	19.8	19.4	17.6	21.1	23.3	24.9
550	22.6	25.3	21.7	20.9	20	23.1	24.5	26.6
600	24.4	28.1	23.9	22	21.5	25.1	26.5	28.6
650	29.1	32.3	27.6	25.8	25	28.4	31.6	33.5

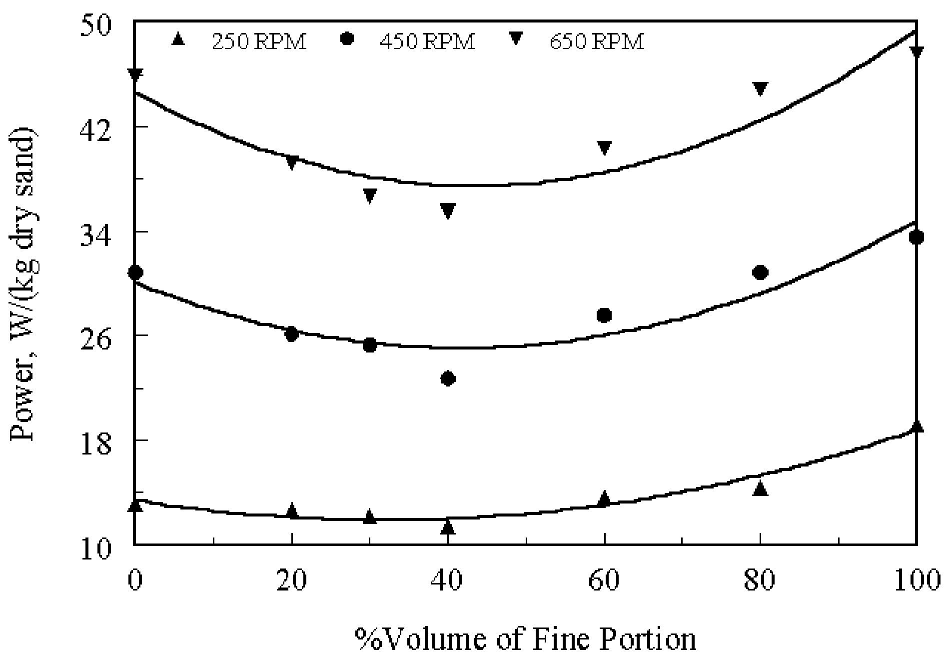

Figure 7. Power Readings as a Function of %Volume of Fine Portion (Sieve No. 60) for Sand Tailings Slurries of 75% Solids at Various Rotational Speeds.

Table 13. Power Required to Mix 500 cm^3 of Sand Tailing Slurries of 75% Total Solids Loading at Different Rotational Speeds as a Function of the Weight Ratio of Fine and Coarse Portions (F/C) Obtained Using Sieve No. 70.

Speed, RPM	Mixing Power, W	Mixing Power, W	Mixing Power, W	Mixing Power, W	Mixing Power, W	Mixing Power, W	Mixing Power, W	Mixing Power, W
	Before Sieving	F/C 0/100	F/C 20/80	F/C 30/70	F/C 40/60	F/C 60/40	F/C 80/20	F/C 100/0
250	7.2	5.5	5.3	4.8	4.8	5.1	5.3	5.6
300	9.8	7.4	7.6	7.0	6.5	7.5	7.6	8.3
350	12.7	9.4	10	9.3	8.7	10.2	10.3	11.4
400	15.3	12.3	12.5	12.0	11.2	13.0	13.5	15.1
450	17.6	16.6	14.6	13.8	13.3	15.6	15.7	18.1
500	19.8	18.5	16.1	15.8	15.2	17.0	17.9	20.9
550	22.6	20.8	17.8	17.5	17.3	18.8	16.5	21.3
600	24.4	23.6	18.4	18.2	18.0	19.0	22.3	23.9
650	29.1	24.5	21.3	20.6	19.7	20.4	22.9	26.5

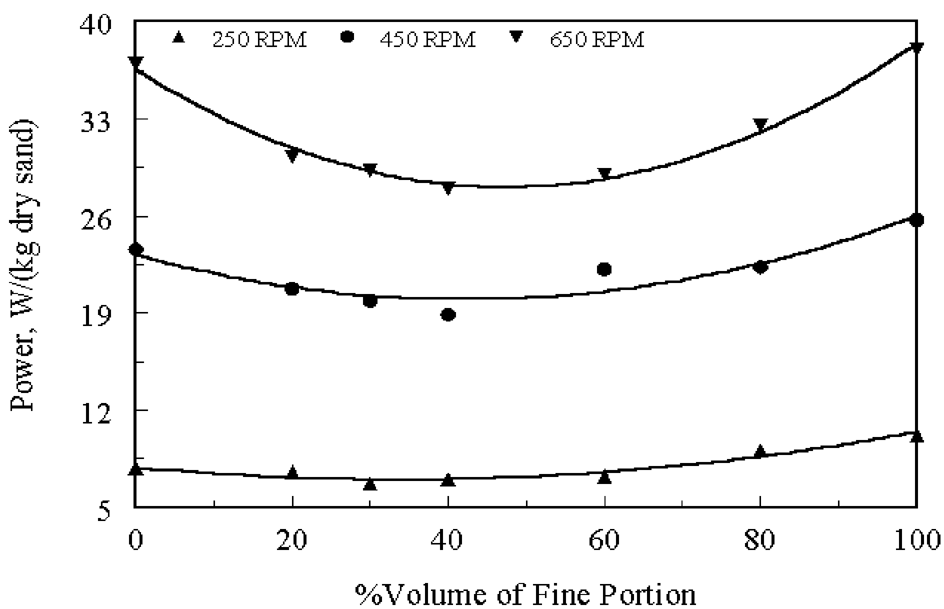

Figure 8. Power Readings as a Function of %Volume of Fine Portion (Sieve No. 70) for Sand Tailing Slurries of 75% Solids at Various Rotational Speeds.

COMPARISON OF THE RESULTS OBTAINED USING SIEVES NO. 60 AND 70

Figure 9 is a comparison between power readings at 650 RPM as a function of vol % of the fines for sand tailing slurries of 75% solids prepared by mixing the two portions obtained from sieve No. 60 and sieve No. 70. These data indicate that the mixtures obtained using the two portions of the sieve No. 70 are of higher fluidity levels than the mixtures of the two portions obtained using sieve No. 60. Since the coarse portion obtained using sieve No. 70 has a broader particle size distribution than the coarse portion obtained using sieve No. 60, therefore; it is expected that the sand tailing slurries prepared using the coarse portion of the sieve No. 70 show a lower resistance against flow than the sand tailing slurries prepared using the coarse portion of the sieve No. 60. The data presented in Figure 9 indicate that this is the case over the entire range of vol % of fines in both mixtures. Although one may expect that there may be a cross over in the data as the amount of fines in the system is increased and sand tailing slurries prepared using the fine portion of the sieve No. 70 should show higher resistance against flow than the slurries prepared using the fine portion of the sieve No. 60, but this can be true only under certain conditions (e.g., if all the particles are spherical in shape and the surface is smooth). Even though the fine portion obtained using sieve No. 60 has a broader size distribution than the fine portion obtained using sieve No. 70, but the results indicate that the fine sand tailing slurry prepared using the fine portion of sieve No. 70 shows higher fluidity than the sand tailing slurry prepared using the fine portion of sieve No. 60. This can be attributed to the shape and surface roughness of the particles. It is quite possible for the sand particles of smaller sizes to have shapes closer to spherical geometry and also have a smoother surface which will cause an increase in the fluidity of the system.

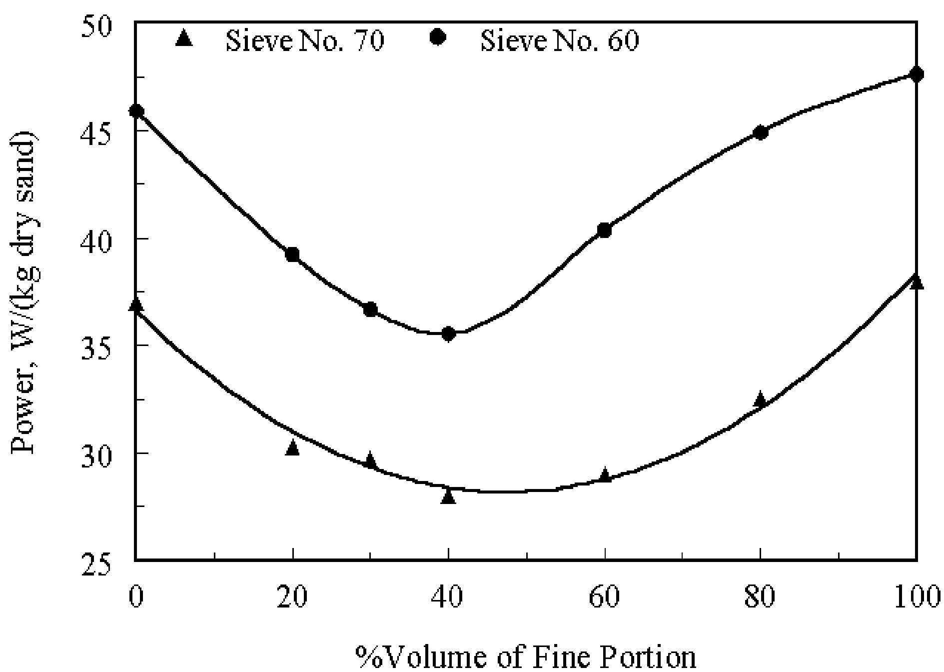

Figure 9. Power Readings as a Function of %Volume of Fine Portion (Sieves No. 60 and 70) for Sand Tailings Slurries of 75% Solids at 600 RPM.

RESULTS FOR SAMPLES (OF 40/60 VOL. RATIO, SIEVE NO. 70) TREATED WITH SDS

The effect of sodium dodecyl sulfate surfactant (SDS) on the fluidity of sand tailing slurries was reported in section 2.4.4. For cost-benefit analysis, it was necessary to generate the data for samples of 40/60 volume ratio of fine-to-coarse particles (sieve No. 70) that showed to have the lowest resistance against flow. The sample (at 75% solids) was treated with 0.02 lb/(ton solids) of SDS and the power of mixing at different rotational speeds was recorded. These data are summarized in Table 14. Comparison of these data with the data given in Table 12 (before sieving) indicate that there is approximately 40% - 50% drop in the power required for mixing at different rotational speeds.

Table 14. Power Readings for SDS- (0.02 lb/ton) Treated Sand Tailing Slurry of 75% Solids (500 cm^3) Containing 40% Fine and 60% Coarse (Sieve No. 70).

Speed	250	300	350	400	450	500	550	600	650
Power, W	1.8	2.8	4.0	5.6	7.2	8.7	10.4	12.0	13.8

EFFECT OF SDS SURFACTANT ON FLOTATION EFFICIENCY

In this part of the work, the effect of SDS (sodium dodecyl sulfate, that was used to improve flowability of phosphate sand tailing slurries) on the flotation of phosphate ores is studied.

A sample of Florida phosphate was used as feed for flotation experiments at 76% solid (similar to that was used to study the fluidity of sand tailing slurries). The conventional mixture of fatty acid-fuel oil of a 1:1 ratio was used as a collector for phosphate particles and sodium silicate as a depressant for sand. SDS was added during conditioning of samples with reagents. The results indicated a small change in grade or recovery of concentrates while adding SDS within the range 0.02-0.06 lb/(ton solids). A concentrate of higher recovery (89.70% in the presence of surfactant as compared with 82.34% in the absence of surfactant) but of lower grade (63.58% BPL in the presence of surfactant as compared with 70.60% BPL in the absence of surfactant) was obtained at a SDS dosage of 0.08 lb/(ton of solids) due to flotation of sand particles as a result of adding SDS to the system. This is reflected by an increase in A.I.% from 9.98% in the absence of SDS to 15.53% in the presence of SDS in the system. The results indicate that SDS can either be added to the solids and then mixed with the water and other chemicals or to the water and chemicals and then mixed with solids.

EXPERIMENTS

Materials

The effect of SDS on flotation was studied using samples of Florida phosphate (10-35 mesh), which contains approximately 18.36% BPL, and 76.24% A.I (acid insoluble). Flotation tests were performed using a mixture of fatty acid and fuel oil of a ratio of 1/1 (supplied by Westvaco Co., USA) as a collector for phosphate. NaOH and HCl were used as pH regulators. A solution of 10% sodium silicate (supplied by SEGMA Co., USA) was prepared and predetermined amount of it used as a depressant for sand particles (2 lb/ton solids). A stock solution of 0.1% (by weight) SDS was prepared and then diluted to the required concentrations to study the effect of the surfactant dosage (lb/ton dry solids) on flotation of Florida phosphate.

Methods

In flotation experiments, a phosphate feed sample of 250 g (dry basis) was conditioned with the required amounts of collector, depressant, and SDS at 76% solids. The pH of the medium was adjusted to 9.2 - 9.3 using Fisher brand, NaOH. Experiments were performed using 6.0 lb/ton of collector mixture and 2.0 lb/ton of sodium silicate. The conditioning process was performed in a 1.0 L (4.1 inch diameter) stainless steel container using a stirrer of 3.7 inch in diameter. A LIGHTNIN L1U08 mixer was employed for conditioning samples with reagents at a fixed rotational speed of 465 RPM. The reagentized pulp, after its conditioning for 3 min, was transferred to the flotation cell.

A Denver D12 flotation machine with a 1.5 L stainless steel container was employed to perform flotation tests at a constant speed of 1200 RPM. Both froth (concentrate) and tail samples were collected, dried, weighed, ground, and chemically analyzed for P_2O_5 (using ICP) and acid insoluble (A.I.) content.

Residual Concentration of SDS After Removal of Sand Particles From Water

To determine the amount of surfactant left in water that could be recycled in the plant, it was required to determine the amount of SDS that remains in supernatant after separation of sand particles from water. Due to the anionic nature of SDS and surface charge of the sand particles being negative, adsorption of SDS onto the surface of sand particles is not expected. However, part of the SDS used will be trapped between the particles and disposed with solids. To determine the amount of SDS in the recycled water, several samples of 76% solids containing 0.02 lb/(ton solids) of SDS were prepared. After equilibration, the samples were centrifuged for 10 minutes at 15,000 RPM and the supernatant was carefully withdrawn. Supernatant was left in the refrigerator over night to assure sedimentation of the remained particles in the solution. The residual of concentration of carbon in supernatant was then determined using a Tekmar-Dorhmann Phoenix 8000 Total Organic Carbon (TOC) analyzer. Results indicated that the concentration of the carbon in supernatant was considerably higher than the concentration of the carbon in the suspending fluid before addition of the sand particles. This is due to contamination of sand particles with fatty acids used for flotation of phosphate in PCS plant. To account for the amount of carbon that is released due to the presence of fatty acids, several blank samples (without surfactant) were prepared and centrifuged for TOC analysis. The corrected results indicate that about 80% of the amount of SDS used will remain in water which will be recycled back and reused in the plant.

Results and Discussion

The effect of adding SDS on flotation of phosphate is presented in Table 15. A concentrate of about 70.6 % BPL, and 10% A.I. with a recovery of about 82.3 % was obtained in the absence of SDS. The results as summarized in Table 15 indicate that addition of SDS in the range of 0.02 – 0.06 lb/(ton solids) to the system has a small effect on the recovery of phosphate. However a concentrate of higher recovery (89.7 %) but of lower grade (63.58% BPL) was obtained in the presence of 0.08 lb/(ton solids) of SDS. This is due to the flotation of sand particles together with phosphate in the presence of SDS which causes an increase in the amount of AI. in the concentrate from 10% (in the absence of SDS) to approximately 15.5 % (in the presence of SDS at a dosage of 0.08 lb/ton of solids).

Table 15. Effect of SDS (Added to Feed Samples) on Flotation of Phosphate.

Conditions	Conditions Lb/ton SDS	Weight %	A.I.%	P2O5%	BPL%	BPL% Recovery
Froth 2	0.0	21.7	9.98	32.31	70.60	82.34
Tailing 2		78.3	94.41	1.92	4.20	17.66
Froth 4	0.02	23.7	10.87	31.16	68.08	84.61
Tailing 4		76.3	95.25	1.76	3.85	15.39
Froth 5	0.04	19.3	9.85	31.39	68.59	81.01
Tailing 5		80.7	95.59	1.76	3.85	18.99
Froth 6	0.06	17.7	9.55	32.77	71.60	81.59
Tailing 6		82.3	93.31	1.59	3.47	18.41
Froth 7	0.08	24.1	15.53	29.10	63.58	89.71
Tailing 7		75.9	96.97	1.06	2.32	10.29

A second series of flotation experiments was performed while adding SDS and other chemicals to the mixture of water and solids. Comparisons of these results, which are summarized in Table 16, with the results given in Table 15, indicate more or less, a similar trend. A slight improvement in BPL recovery is observed in the presence of SDS, there is an increase in acid insoluble (A.I.) due to flotation of sand particles, and there is a decrease in %BPL.

Table 16. Effect of SDS on Flotation of Phosphate (SDS Is Added as Residual Concentration in Water).

<table>
<tr><th>Dosage of SDS as mg/L</th><th>Sample</th><th>Weight %</th><th>A.I.%</th><th>P2O5%</th><th>BPL%</th><th>BPL% Recovery</th></tr>
<tr><td rowspan="2">0.0</td><td>Froth 2</td><td>21.7</td><td>9.98</td><td>32.31</td><td>70.60</td><td>82.34</td></tr>
<tr><td>Tailing 2</td><td>78.3</td><td>94.41</td><td>1.92</td><td>4.20</td><td>17.66</td></tr>
<tr><td rowspan="2">16.7
or
0.17 (lb/ton)</td><td>Froth 8</td><td>26.1</td><td>19.35</td><td>28.87</td><td>63.08</td><td>87.40</td></tr>
<tr><td>Tailing 8</td><td>73.9</td><td>95.19</td><td>1.47</td><td>3.21</td><td>12.60</td></tr>
<tr><td rowspan="2">30.0
or
0.31 (lb/ton)</td><td>Froth 9</td><td>22.2</td><td>13.33</td><td>30.93</td><td>67.58</td><td>83.45</td></tr>
<tr><td>Tailing 9</td><td>77.8</td><td>95.7</td><td>1.75</td><td>3.82</td><td>16.55</td></tr>
<tr><td rowspan="2">33.3
or
0.34 lb/(ton)</td><td>Froth 10</td><td>24.8</td><td>18.16</td><td>28.64</td><td>62.58</td><td>86.06</td></tr>
<tr><td>Tailing 10</td><td>75.2</td><td>95.13</td><td>1.53</td><td>3.34</td><td>13.94</td></tr>
</table>

It is clear from these flotation experiments that the presence of SDS affects the flotation performance of phosphate. Higher dosage of SDS gives concentrates of slightly higher recovery at the expense of grade. It is well known that SDS has both frothing power in addition to its collecting action and in turn it can increase the hydrophobicity of sand particles. Meanwhile, it was noticed during these flotation experiments that the presence of high dosage of SDS forms intense foams. This might, also, increase flotation of sand particles by entrainment in the water lamella as indicated by the larger amount of water recovered with concentrates. However, this was not a problem at a SDS dosage level which is recommended to be used to improve the fluidity of sand tailing slurries (0.02 lb/ton solids).

COST BENEFIT ANALYSIS

Assuming % solids in the slurry being pumped in the plants is	**50%**
Dry tons	1000.0
Specific gravity	1.45
Mass of slurry	2000.0
Volume of slurry, Gallon	363859.5
Inside diameter of pipe, in	19.25”
Pumping distance, ft	5280 (1 mile)
Pumping rate, GPM	13000.0
Operating hours	0.466
Slurry viscosity, cp	105.0
Calculated frictional loss at 50% solids	246.8 ft/mile
Head loss due to pump suction at plant	13.0 ft
Elevation change, plant to disposal area	8.0 ft
Assume pumping efficiency	76%
Energy consumption to pump 50% solid slurry, KWH/mile	584.32
Calculated frictional loss for water	107.2 ft/mile
Energy consumption to pump water back, KWH/mile	117.13
Total energy consumption, KWH/mile	701.5

Assuming % solids in the slurry being pumped in the plants is	**76%**
Dry tons	1000.0
Specific gravity	1.90
Mass of slurry	1315.8
Volume of slurry, Gallon	183110.2
Inside diameter of pipe, in	19.25”
Pumping distance, ft	5280 (1 mile)
Pumping rate, GPM	13000.0
Operating hours	0.235
Slurry viscosity, cp	682.30
Calculated frictional loss at 76% solids	358.86 ft/mile
Head loss due to pump suction at plant	13.0 ft
Elevation change, plant to disposal area	8.0 ft
Assume pumping efficiency	76%
Energy consumption to pump 50% solid slurry, KWH/mile	546.55
Calculated frictional loss for water	107.2 ft/mile
Energy consumption to pump water back, KWH/mile	36.99
Total energy consumption, KWH/mile	583.54

Percent decrease in energy with respect to pumping at 50% solids	16.8%

Use of 0.04 lb/ton amine

Assuming % solids in the slurry being pumped in the plants is	**76%**
Dry tons	1000.0
Specific gravity	1.90
Mass of slurry	1315.8
Volume of slurry, Gallon	183110.2
Inside diameter of pipe, in	19.25”
Pumping distance, ft	5280 (1 mile)
Pumping rate, GPM	13000.0
Operating hours	0.235
Slurry viscosity, cp	341.20
Calculated frictional loss at 76% solids	312.4 ft/mile
Head loss due to pump suction at plant	13.0 ft
Elevation change, plant to disposal area	8.0 ft
Assume pumping efficiency	76%
Energy consumption to pump 76% solid slurry, KWH/mile	479.71
Calculated frictional loss for water	107.2 ft/mile
Energy consumption to pump water back, KWH/mile	36.99
Total energy consumption, KWH/mile	516.7
Mass of amine for 1000 ton solids	40
Amine price, $/lb	0.25
Cost of amine, $	10.0
Assuming 50% of amine is recycled back to the process, $	-5.0
Equivalent KWH for amine (50% recycled)	100
Equivalent KWH for amine (assuming amine will be disposed with sand)	200

Percent decrease in energy with respect to pumping at 50% solids assuming amine is recycled back to the process 12%

Percent decrease in energy with respect to pumping at 50% solids assuming amine is recycled back to the process -2.2%

Use of 0.02 lb/ton SDS

Assuming % solids in the slurry being pumped in the plants is	**76%**
Dry tons	1000.0
Specific gravity	1.90
Mass of slurry	1315.8
Volume of slurry, Gallon	183110.2
Inside diameter of pipe, in	19.25”
Pumping distance, ft	5280 (1 mile)
Pumping rate, GPM	13000.0
Operating hours	0.235
Slurry viscosity, cp	341.20
Calculated frictional loss at 76% solids	312.4 ft/mile

Head loss due to pump suction at plant	13.0	ft
Elevation change, plant to disposal area	8.0	ft
Assume pumping efficiency	76%	
Energy consumption to pump 76% solid slurry, KWH/mile	479.71	
Calculated frictional loss for water	107.2 ft/mile	
Energy consumption to pump water back, KWH/mile	36.99	
Total energy consumption, KWH/mile	516.7	
Mass of SDS for 1000 ton solids	20	
SDS price, $/lb	1.0	
Cost of SDS, $	20.0	
Assuming 80% of SDS is recycled back to the process, $	-16.0	
Equivalent KWH for SDS (80% recycled)	80.0	
Equivalent KWH for SDS (not recycled)	400.0	

Percent decrease in energy with respect to pumping at 50% solids assuming SDS is recycled back to the process 14%

Percent decrease in energy with respect to pumping at 50% solids assuming SDS is disposed with sand -31%

CONCLUSION FOR COST BENEFIT

It is more economical to pump sand tailing slurries at higher solids loading. With the assumption that chemicals added to the slurry will be recycled back to the process, amine-based and SDS surfactants reduce the power consumption in transporting slurry at 76% solids as compared to that at 50% solids without using surfactants. However, this is not the case if all the chemicals used will be disposed with sand particles and there will be an increase in the cost of slurry transportation. One needs to take into account that at high solids loading such as 76% solids, in the absence of surfactants; high settling rate, hardening of solids, and non-uniformity of the slurry during mixing are problems that creates difficulties in pumping of high solids slurries.

CONCLUDING REMARKS

1. Untreated sand tailing slurries settle down almost immediately after stopping the mixer and/or pumping. It was very difficult to resuspend the particles at solids loadings larger than 65% solids. Over night settling caused the solids to harden making the slurry more difficult to mix and/or pump even at 50% solids.

2. Untreated sand tailing slurries show unusual flow behavior such as dilation at high solids contents. It is extremely difficult to mix and homogenized the sample at this condition. Results indicate that untreated sand tailing slurries used in this work were not pumpable at all at solids contents larger than 76% solids.

3. The limit of pumpability of the slurry is determined by the particle size distribution as well as other physical and chemical characteristics of the system. This limit can vary from plant-to-plant depending upon the size distribution of the particles and impurities (e.g., chemicals, non-similar particles, etc.) in the system.

4. Polymers and surfactants significantly increase the fluidity of highly concentrated sand tailing slurries. These materials can push the limit of pumpability to higher solids loadings. Polymer and surfactant treated sand tailings slurries showed to be more stable against sedimentation and hardening of the particles.

5. Surfactant additives used in this work shown to be more effective in term of increasing the fluidity and stability of sand tailing slurries.

6. The results indicate at 76% solids, less amount of SDS (0.02 lb/ton solids) is needed to increase the fluidity of sand tailing slurries as compared with the dosage of amine-based surfactant (0.2 lb/ton solids) that has to be added to maximize the fluidity of the system.

7. The effect of polydispersity on the fluidity of sand tailing slurries was studied by separating the particles in two portions using sieve Nos. 45, 60, and 70. Three sets of experiments were performed to study the effect of polydispersity on the fluidity of sand tailing slurries. In each set, only the fine and coarse portions obtained from a given sieve were mixed together at different volume (weight) ratios while the total weight (volume) fraction of the particles was kept constant at 76% solids. No significant change was observed in the power of mixing when the two portions of sieve No. 45 were mixed together at different volume ratio of the two portions. Changes were significant when the portions of sieve No. 60 and sieve No. 70 were mixed together. The lowest level of power required for mixing was obtained when the volume ratio of small to large particles was equal to 40/60. It was observed that there is about 20% and 30% decrease in the power of mixing (at 650 RPM) for the samples containing 40% of the fine and 60% of the coarse particles (as compared with the original sand tailing sample) when the two portions of sieves No. 60 and No. 70 are mixed respectively.

8. Effect of SDS on the flotation of phosphate ores was studied. The flotation performance of phosphate is affected by the presence of SDS in the system. Effects are not significant at low SDS levels. But higher levels of SDS dosage resulted in concentrates of slightly higher recovery at the expense of grade. Although there is an increase in concentrate yield, the majority of these particles are, however, sand (as A.I.). Therefore, SDS increases the flotation of sand particles.