

# Chapter 36

## PRELIMINARY EVALUATION OF AIR-SPARGED HYDROCYCLONE TECHNOLOGY FOR SCAVENGER FLOTATION OF WESTERN PHOSPHATES

J. D. Miller and Q. Yu

Department of Metallurgical Engineering  
University of Utah  
Salt Lake City, Utah 84112

**Abstract.** The sedimentary western phosphate deposits of Idaho, Montana, Utah, and Wyoming tend to be calcareous and generally carry a significant amount of dolomite along with collophanite. In some cases, such as the Smokey Canyon Mine, Afton, Wyoming, the ore will also contain mudstone, and in this case the aluminosilicate minerals (clay, feldspar, etc.) together with some dolomite are floated from the collophanite in column flotation cells with an amine in order to meet product specifications (31%  $P_2O_5$ ) (Service et al.). In other cases, such as the SF Phosphates Limited Mine, Vernal, Utah, the ore is treated by traditional fatty acid flotation of the collophanite with mechanical flotation cells (Weber, 1986).

Preliminary tests have now been conducted to evaluate air-sparged hydrocyclone (ASH) technology for the flotation of western phosphate ore. For this preliminary study, samples were taken from the hydrosizer overflow stream (18–21%  $P_2O_5$ ) at the SF Phosphates Limited Plant in Vernal, Utah for scavenger flotation testing with the 2-inch ASH system in laboratories at the University of Utah. Selected design and operating variables are being studied, and the initial results show that satisfactory separations can be achieved by high-capacity ASH flotation at appropriate operating conditions. For example, with single-stage ASH flotation 80% recovery can be obtained with a scavenger concentrate grade of about 26%  $P_2O_5$ . These results are comparable to, or better than, those obtained at SF plant operations with conventional flotation cells and suggest that ASH flotation technology can be used to good advantage in the phosphate industry. Of course, research should be continued to consider other process streams, optimize the separation efficiency, and evaluate larger diameter ASH units.

### INTRODUCTION

Phosphate rock is an important commodity in the world agricultural industry. It was estimated that world production of phosphate in 1992 would reach 150 million tons. Froth flotation for the separation of phosphate minerals from other gangue minerals has been practiced by fatty acid flotation with pine oil as frother from as early as 1928. Many flotation strategies for the processing and concentration of phosphate ores have been developed since then (Gieseke, 1985; Houot, 1982; Houot et al., 1985; Miller et al., 1987; Rao et al., 1989; Sparks and Sirianni, 1974; Soto and Iwasaki, 1986; Snow et al., 1975). One of the commonly used phosphate flotation processes is the "double float" process, viz. anionic flotation of phosphate minerals at alkaline pH, followed by cationic "reverse" flotation of silica from the initial phosphate concentrate under acidic conditions. Most recently it has been realized that a suitable reagent schedule for both anionic and nonionic collectors can greatly improve phosphate flotation separations (Hassan, 1991).

Eighty percent of the world production of phosphate rock comes from the mining and concentration of sedimentary phosphate ores (Service et al.; Gieseke, 1985). Sedimentary deposits account for the majority of the phosphate reserves and resources. Most of the sedimentary phosphorites are associated with gangue minerals which may include appreciable amounts of dolomite, quartz, hematite, aluminosilicates and clay minerals. Although much research has been carried out to develop selective flotation technology for the recovery of phosphate, many problems regarding the effective separation of phosphate minerals from other gangue minerals still remain unsolved (Houot, 1982; Houot et al., 1985).

### Flotation of Western Phosphates at Vernal, Utah

The western phosphate deposits of the U.S. cover much of the area from northeastern Utah, through eastern Idaho, and southwestern Montana. Several phosphate plants are now in operation throughout this area (Service et al.; Weber, 1986). The Vernal phosphate operation which is currently owned by SF Phosphates Limited (SF) is located in Northeastern Utah, about 11 miles north of Vernal and about 175 miles east of Salt Lake City. The plant began initial operation in 1961, and later several expansions took place. Mine and plant ownership has changed hands several times. In the 1990's, the capacity of the plant was increased to about 1,500,000 tons of concentrate per year. A 94-mile slurry pipeline is used to transport the phosphate concentrate produced at the Vernal plant site to a chemical fertilizer plant near Rock Springs, Wyoming. The ore from the mine contains 18 to 21%  $P_2O_5$ , and it must be upgraded to 31%  $P_2O_5$  with 0.7 to 0.8% MgO before it can be accepted for the production of fertilizer. The Vernal plant consists of a two-stage grinding circuit, and the material from the primary grinding circuit is subject to size classification by both hydrocyclones and hydrosizers (Weber, 1986). The slimes from the hydrocyclone overflow (minus 200 mesh) are directly discharged into a tailings pond without recovery of  $P_2O_5$  values because of the poor separation efficiency by flotation. Although the slimes (minus 200 mesh) represent 30 to 35% of the feed, the  $P_2O_5$  content is low (about 10 to 11%). The coarse material from the hydrosizer underflow (70% solids by weight, 28×200 mesh) containing 25%  $P_2O_5$  is fed to conditioning tanks, and a mixture of fatty acid, diesel oil, petroleum sulfonate, and Dow frother is added for rougher flotation. Two-stage phosphate flotation is carried out, and the cleaner concentrate is reground as the final phosphate product (31%  $P_2O_5$ ). The hydrosizer overflow (20% solids by weight, minus 48 mesh) is sent directly to what is termed the scavenger flotation circuit. This can be considered scavenger flotation only in the sense that this is a lower grade of material containing 18%  $P_2O_5$ . At the SF plant a scavenger concentrate (~25%  $P_2O_5$ ) is recovered and returned to rougher flotation.

### Air Sparged Hydrocyclone Flotation Technology

Air-sparged hydrocyclone (ASH) technology combines advantages from both conventional hydrocyclones and froth flotation into a single piece of equipment. The ASH equipment provides a unique opportunity for the effective flotation of fine hydrophobic particles at a high rate, and many applications have been examined (Miller, 1981; Miller, 1983a; Miller, 1983b; Miller and Kinneberg, 1984; Miller and Kinneberg, 1988; Miller *et al.*, 1986; Miller and Van Camp, M. C., 1982; Miller and Ye, 1989a; Miller and Ye, 1989b; Miller *et al.*, 1988; Ye *et al.*, 1988). In all cases its specific capacity has been shown to be at least 100 times the specific capacity provided by conventional column and mechanical flotation machines.

Figure 1 is a schematic drawing of the air-sparged hydrocyclone which consists of a right-vertical tube having a jacketed porous wall, a conventional cyclone header with a vortex finder, and a froth pedestal/underflow structure which is centered on the cyclone axis at the bottom of the porous tube. The suspension is fed tangentially through the cyclone header to develop a swirl flow inside the porous tube. Air passes through the jacketed porous tube wall and is sheared into numerous small bubbles by the high-velocity swirl flow of the suspension. The fine hydrophobic mineral particles in the suspension collide with these bubbles, and, after bubble/particle attachment, are transported radially into a froth phase which forms on the cylindrical axis. The froth phase is supported and constrained by the froth pedestal and thus moves towards the vortex finder of the cyclone header, being discharged as an overflow froth product containing hydrophobic particles. The hydrophilic particles, generally unwanted gangue particles, are discharged as an underflow stream through the annulus created between the porous tube wall and the froth pedestal. The ASH capacity is at least 200–400 gallons per minute per cubic foot of cell volume. In other words, with one typical 6-inch diameter × 60-inch length ASH system, at least 300,000 gallons of suspension can be processed per day per unit. Large ASH diameter units are currently being evaluated, and the capacity is expected to vary with diameter to the 2.0–2.5 power. The specific capacities of various flotation machines are compared in Table 1.

During the past decade, both fundamental and applied research on air-sparged hydrocyclone technology has been carried out at the University of Utah (Miller and Kinneberg, 1984; Miller *et al.*, 1986; Miller and Van Camp, 1982; Miller and Ye, 1989a; Miller *et al.*, 1988; Ye *et al.*, 1988). As a result of these research efforts, six U.S. patents have been issued with a dozen foreign filings/patents (Miller, 1981; Miller, 1983a; Miller, 1983b; Miller and Kinneberg, 1988). The improved flotation recovery of fine particles and high processing capacities have been successfully demonstrated in pilot-plant testing for many mineral commodities. Recently, a plant-scale demonstration of the air-sparged hydrocyclone technology for fine coal flotation with a 15-inch ASH unit has been completed at Penelec's Homer City Coal Preparation Plant in Homer City, Pennsylvania by Advanced Processing Technologies, Inc. (Miller *et al.*, 1992). In addition, Ahlstrom-Kamyr, an international engineering and construction company, has also conducted extensive ASH research in the pulp and paper industry and has constructed the \$20 million Keiffer plant utilizing ASH technology for deinking flotation (4,000 gpm) in the recycle of fibers from wastepaper (the

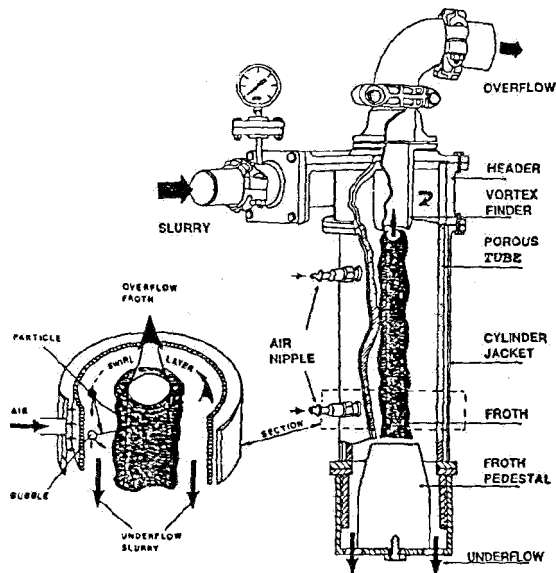


Figure 1. Schematic drawing of air-sparged hydrocyclone and flow characteristics.

Table 1. Comparison of Specific Capacities of Various Flotation Machines.

Machine Type	Capacity tpd/ft <sup>3</sup> (20% solids, s.g. 2.5 )
Mechanical Cell	1-5
Flotation Column	1-5
Air-Sparged Hydrocyclone	200-400

removal of ink particles from paper fiber). The cleaned cellulose fibers are then used for recycled paper (Chamblee and Greenwood, 1991; Yu *et al.*, 1992). The plant was commissioned in June 1992 and has been operating successfully since that time.

#### Research Objective

A preliminary research program was undertaken to evaluate the effectiveness of ASH technology for scavenger flotation of hydrosizer overflow from the SF Phosphates plant to determine if a more detailed research program is warranted. In this preliminary study, the effect of selected operating variables on separation efficiency has been considered, and the experimental results are reported herein.

### EXPERIMENTAL

#### Phosphate Samples and Flotation Reagents

Two phosphate samples, the hydrosizer overflow (48×200 mesh material) and hydrocyclone overflow (−200 mesh slimes) were collected at the SF Phosphates Limited Plant near Vernal, Utah and used for all scavenger flotation tests and characterization studies. The hydrosizer overflow, which is the feed to scavenger flotation, contains about 18%

$P_2O_5$ , 2.5% MgO, and 0.4% soluble  $Fe_2O_3$  by weight, and the hydrocyclone overflow, the slimes which are discarded as tailings, contains about 10%  $P_2O_5$ , 4.0% MgO, and 0.7% soluble  $Fe_2O_3$  by weight. The major phosphate mineral in the samples is collophanite, and the gangue minerals are dolomite, quartz, hematite, and various aluminosilicates. Commercial grade flotation reagents (fatty acid, petroleum sulfonate, diesel oil, and Dow frother) were obtained from SF plant operations and were used for all scavenger flotation tests.

#### Bench-Scale Flotation

Single-stage scavenger flotation was carried out in a two-liter Denver flotation cell at ~20% solids by weight. The slurry was conditioned at 70% solid by weight for about 3 minutes at 1200 rpm. The flotation reagents were added at the desired level, and the slurry was again conditioned for another 10 minutes. The slurry was then diluted to about 20% by weight with the addition of fresh water. A scavenger flotation was accomplished at 900 rpm and an air flowrate of 3–4 liter/min for 5 minutes. The flotation pH was found to be about pH 8. Collophanite particles were floated and collected as a froth product while the gangue minerals such as dolomite, quartz, and aluminosilicate particles remained in the suspension as tailings. After flotation, both the concentrate and tailing products were filtered, dried and analyzed. Both  $P_2O_5$  and MgO content were determined by x-ray fluorescence.

For two-stage scavenger flotation, the first scavenger flotation concentrate was repulped with the addition of fresh water and flotation reagents. Again, following the same procedure as described above, second-stage scavenger flotation was carried out for about 4 minutes.

#### Air-Sparged Hydrocyclone Flotation

Of course, scavenger flotation was also carried out with the air-sparged hydrocyclone (ASH) in pilot plant facilities at the University of Utah. The sample was first conditioned for 10 minutes in a sump at 25–30% solids by weight with the desired addition of emulsified flotation reagents and then was further diluted to about 15–20% solids by weight with the addition of fresh water (facilities were not available to do high solids conditioning for the ASH tests). The slurry was again conditioned for another 10 minutes prior to ASH scavenger flotation with a 2-inch ASH-2C system. An exploratory series of tests was carried out with the ASH-2C to evaluate the scavenger flotation response. This pilot plant test series was conducted in order to establish appropriate ASH flotation conditions, and to determine the influence of various operating variables on the separation efficiency for scavenger flotation. Of course, the overflow froth product was the phosphate concentrate, and the underflow product was the tailings product which contains mostly the gangue minerals. Mass flow rates were established by taking full stream samples of both products for a specified time interval. After flotation, samples of both concentrate and tailings were collected, filtered, dried and analyzed.

In addition to scavenger flotation of the hydrosizer overflow (48×200 mesh) with the air-sparged hydrocyclone, one set of ASH experiments was done with the hydrocyclone overflow, the slimes (minus 200 mesh), which are currently discarded to the tailings pond.

#### Microscopic Analysis

In order to quickly evaluate the flotation results, the products were examined by optical microscopy. In this regard samples of the products were taken for microscopic analysis.

A stereomicroscope SV 8 (75×), manufactured by Carl Zeiss, West Germany, was employed for the analysis of ASH scavenger flotation products. The microscope is equipped with illumination lamp, filter, and beam splitter. Color photographs of the samples were taken using a Carl Zeiss Microscopic attachment (MC 100) system with a 35-mm camera and Kodak 100 film.

## RESULTS AND DISCUSSIONS

#### Bench-Scale Flotation

The results of bench-scale scavenger flotation (single-stage and two-stage) tests for the hydrosizer overflow (48×200 mesh) are presented in Tables 2 and 3. As seen from the single-stage flotation data presented in Table 2, for fatty acid collector only, at a suitable reagent addition (1.6 kg/ton), a phosphate concentrate with 21.5%  $P_2O_5$  was obtained at about 87%  $P_2O_5$  recovery from a feed which contained 16.3%  $P_2O_5$  by weight. Similar results were obtained for saponified fatty acid as collector. However, with emulsified reagents an improved phosphate concentrate

Table 2. The Results of Single-Stage Bench-Scale Scavenger Flotation for the Hydrosizer Overflow Feed Material (48×200 mesh, 16.3% P<sub>2</sub>O<sub>5</sub>)

Reagent Type (collectors)	Reagent Addition (kg/ton)	P <sub>2</sub> O <sub>5</sub> Grade in Scavenger Concentrate (%)	P <sub>2</sub> O <sub>5</sub> Recovery in Scavenger Concentrate (%)
Fatty Acid	1.6	21.5	87.0
Saponified Fatty Acid	1.8	21.7	82.5
Emulsified Reagents *	1.3	24.5	79.5

\* Emulsified reagents (1.6 kg/ton): fatty acid / petroleum sulfonate / kerosene / Dow frother 1012 = 2/0.5/1/0.3 by volume.

Table 3. The Results of Two-Stage Bench-Scale Scavenger Phosphate Flotation for the Hydrosizer Overflow Feed Material (48×200 mesh, 20.5% P<sub>2</sub>O<sub>5</sub>) with Emulsified Reagent\*

Flotation Product	Weight Percent (%)	Analysis (%)			Recovery (%)		
		P <sub>2</sub> O <sub>5</sub>	MgO	Fe <sub>2</sub> O <sub>3</sub>	P <sub>2</sub> O <sub>5</sub>	MgO	Fe <sub>2</sub> O <sub>3</sub>
2nd-Stage Scavenger Concentrate	54.8	26.8	2.0	0.19	71.7	45.7	35.1
2nd-Stage Scavenger Tailing	26.9	15.7	2.6	0.28	20.6	29.2	25.4
1st-Stage Scavenger Tailing	18.3	8.6	3.3	0.64	7.7	25.1	39.5
Feed	100.0	20.5	2.4	0.30	100.0	100.0	100.0

\* Emulsified reagents (1.6 kg/ton): fatty acid / petroleum sulfonate / kerosene / Dow frother 1012 = 2/0.5/1/0.3 by volume.

product was obtained from the same feed material with a concentrate grade of 24.5% P<sub>2</sub>O<sub>5</sub>, at a recovery of 79.5% P<sub>2</sub>O<sub>5</sub>.

In order to produce higher grade phosphate concentrates a two-stage scavenger flotation test for another sample of hydrosizer overflow (48×200 mesh) containing 20.5% P<sub>2</sub>O<sub>5</sub>, was conducted with the 2-liter Denver flotation cell. Table 3 lists the flotation results as obtained from the two-stage bench test. It is evident from Table 3 that a cleaner phosphate concentrate containing about 26.8% P<sub>2</sub>O<sub>5</sub> at a recovery of 71.7% was obtained for two-stage scavenger flotation. A higher P<sub>2</sub>O<sub>5</sub> recovery can be realized if the tailings from the second stage of scavenger flotation is recycled back to the first-stage scavenger flotation in a continuous two-stage process. In fact, such results have been demonstrated on a continuous basis for 2-inch ASH-2C flotation as is discussed in the next section.

In both single- and two-stage scavenger flotation experiments the suspension pH remained constant at a pH value from pH 8.0 to 8.5, and the flotation time was held constant at about 5 minutes. The flotation rate of collophanite particles with the addition of emulsified reagents was found to be faster than that obtained with fatty acid collector only.

#### Air-Sparged Hydrocyclone Flotation

The details of the ASH flotation technology have been described previously. As shown in Figure 1, the fine particle suspension containing the desired flotation chemicals is introduced through the hydrocyclone header to generate a swirl flow. Pressurized air, is sparged through the porous tube into the suspension, and fine air bubbles are created which facilitates intimate bubble/mineral particle contact. Hydrophobic particles, promoted by adsorption of the flotation reagents, attach to these bubbles and are transported through the suspension in the centrifugal field, forming a froth phase located at the center of the ASH unit. This froth stream, which in this case contains collophanite particles and air bubbles, flows as a froth product upward and exits through the vortex finder where it is recovered as a phosphate concentrate product. Hydrophilic gangue particles are discharged through a specially designed annular opening at the bottom.

Preliminary scavenger flotation experiments were conducted for the hydrosizer overflow material (48×200 mesh) with the 2-inch air sparged hydrocyclone, the ASH-2C, and the results from single-stage scavenger flotation are presented in Figures 2-4. The effect of reagent addition (emulsified reagent) on scavenger flotation is shown in Figure 2. It is seen from Figure 2 that, under certain operating conditions (1 pedestal rotation and 8 psi slurry feed pressure) the  $P_2O_5$  recovery in the phosphate concentrate increases significantly with an increase in reagent addition while the  $P_2O_5$  grade in the concentrate decreases slightly. At low reagent additions (1.3 kg/ton) a phosphate

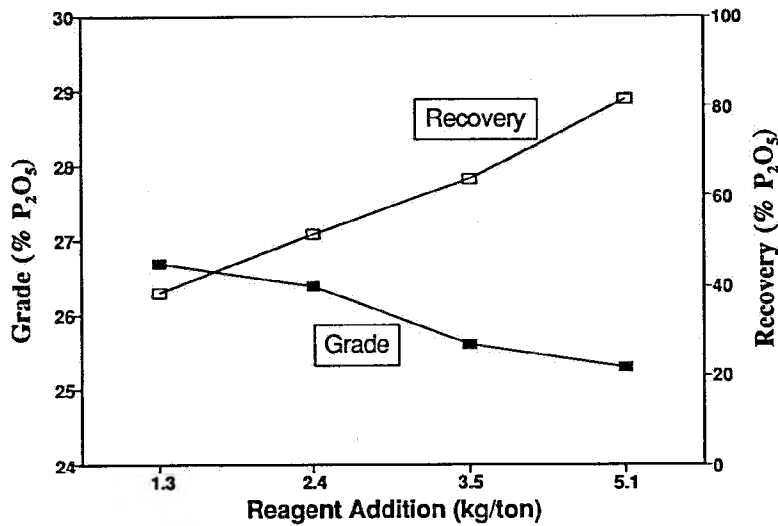


Figure 2. Effect of emulsified reagent addition on scavenger flotation response of hydrosizer overflow material with the ASH-2C (1 pedestal rotation and 8 psi feed pressure).

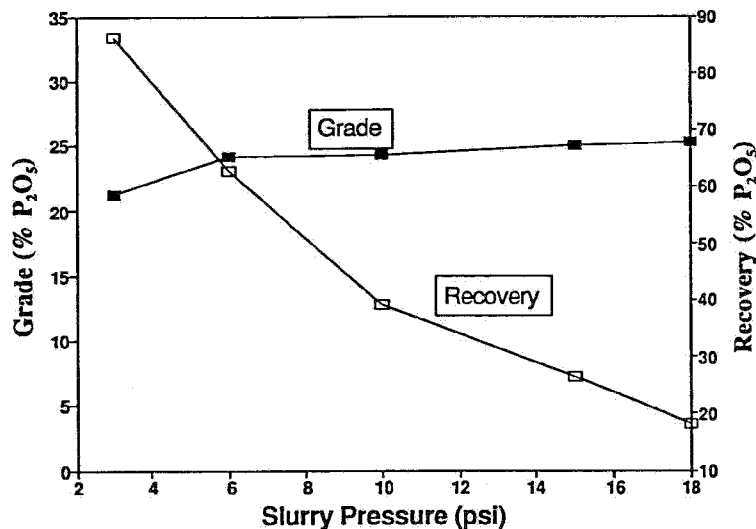


Figure 3. Effect of slurry feed pressure on scavenger flotation response of hydrosizer overflow material with the ASH-2C (1 pedestal rotation and 2.4 kg/ton reagent addition).

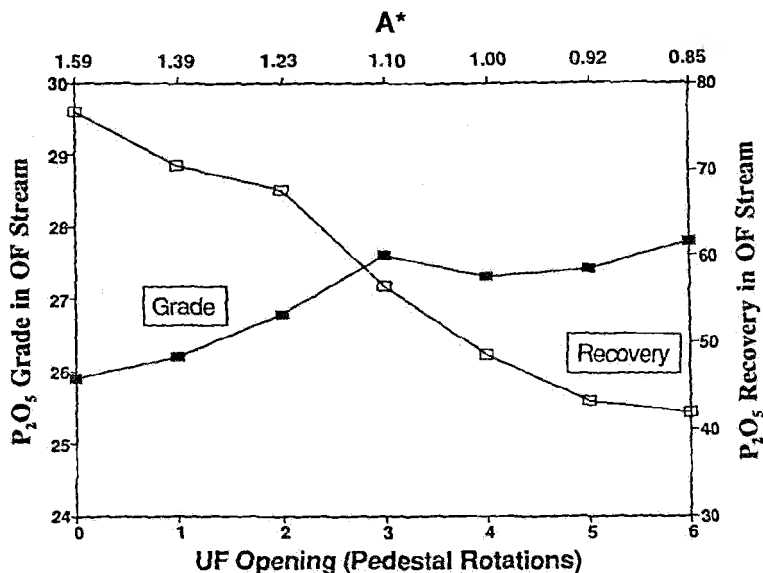


Figure 4. Effect of underflow opening (pedestal rotations) on scavenger phosphate flotation response of coarse material with ASH-2C (6 psi feed pressure and 2.6 kg/ton reagent addition).

concentrate containing 26.7%  $P_2O_5$  was obtained at a  $P_2O_5$  recovery of only 38%. With a high reagent addition (5.1 kg/ton) the  $P_2O_5$  recovery in the overflow product reaches 81% with a concentrate containing 25.6%  $P_2O_5$ . It should be noted that these ASH results compare favorably with typical plant results in which a scavenger concentrate containing 25%  $P_2O_5$  is obtained at a recovery of 75%.

In general, for most flotation testing with the ASH-2C unit, a relatively high reagent addition is required in order to achieve the same recovery as that achieved in bench-scale flotation. This high reagent demand in ASH-2C flotation arises because of the high centrifugal force generated by swirl flow during ASH flotation. Higher reagent addition is required to stabilize the bubble/particle attachment in the relatively high centrifugal field. When a larger diameter ASH unit (the six- or fifteen-inch ASH unit) is used, the centrifugal force is smaller, and therefore the reagent addition will be reduced significantly, as has been observed in other ASH flotation applications (coal, copper, quartz, deinking, etc.). Such an understanding is evident from the effect of slurry feed pressure on the scavenger flotation response, as shown in Figure 3. It should be noted that, if high percent solids conditioning (say 70% by weight) were used, the reagent consumption would be reduced even more, and it is expected that under appropriate conditions the reagent demand for scavenger flotation with the ASH system will be similar to that for conventional scavenger flotation.

The data presented in Figure 3 show that, at 2.4 kg/ton reagent addition and a fixed underflow opening, the  $P_2O_5$  recovery in the phosphate concentrate decreases dramatically with an increase in slurry feed pressure (psi) from 86%  $P_2O_5$  recovery at 3 psi down to 18%  $P_2O_5$  recovery at 18 psi while the grade of the concentrate increases slightly from 22%  $P_2O_5$  at 3 psi to about 26%  $P_2O_5$  at 18 psi. It is clear that in the case of the 2-inch ASH-2C unit, the feed pressure should be maintained at less than 10 psi in order to obtain a good  $P_2O_5$  recovery. As mentioned previously higher feed pressures result in higher tangential velocities and a greater centrifugal force field. Consequently, the stability of the bubble/particle aggregate is reduced, particularly for larger particle sizes, and the recovery decreases accordingly. The absolute values will be dependent on the reagent schedule and the ASH diameter.

The effect of underflow opening (number of pedestal rotations) on scavenger phosphate flotation is given in Figure 4. It can be seen from Figure 4 that, at 6 psi slurry feed pressure and 2.6 kg/ton reagent addition, the  $P_2O_5$  recovery in the phosphate concentrate (overflow product) is found to decrease dramatically while the grade of the concentrate (% $P_2O_5$ ) increases slightly with an increase in the underflow opening. The underflow opening is frequently described as a percent of the ASH radius and/or as the dimensionless area,  $A^*$ , which is the ratio of the overflow area determined by the internal diameter of the vortex finder pipe to the underflow area corresponding to the annular opening created by the froth pedestal. The larger the underflow opening for constant vortex finder diameter (1 inch

in this case) the greater the amount of material which will be discharged as a tailings product. Thus, the recovery of  $P_2O_5$  in the overflow froth product decreases. As shown in Figure 4 a concentrate containing 26%  $P_2O_5$  was obtained at 76%  $P_2O_5$  recovery at zero pedestal rotation (annular opening equal to 6% of the ASH radius and  $A^* = 1.59$ ) while a concentrate containing 27.8%  $P_2O_5$  was obtained at only 42%  $P_2O_5$  recovery when the annular opening was increased to 12% of the ASH radius ( $A^* = 0.85$ ), all other conditions remained the same. It is evident that the underflow opening should be maintained at 6–8% of the ASH radius (0–2 rotations) in order to obtain a high phosphate recovery by ASH flotation.

Based on the previous results from single-stage scavenger flotation a 3-stage scavenger flotation process was evaluated in order to improve the phosphate separation efficiency. The three-stage ASH–2C scavenger flotation tests were conducted for both hydrosizer overflow material (48×200 mesh) and slimes (minus 200 mesh). In each case, in these three-stage experiments, the overflow product (froth concentrate) from the 1st stage was subjected to a 2nd stage of scavenger ASH flotation, and the underflow product (tailing) from the 1st stage was also subjected to a 2nd stage of ASH flotation. The results obtained from the three-stage ASH–2C flotation tests are presented in Tables 4 and 5. As seen from the data presented in Tables 4 and 5, it is evident that the ASH flotation technology provides for satisfactory separation efficiency at a high specific capacity because of its unique design. With three-stage scavenger flotation, the overall  $P_2O_5$  recovery can reach 82.1% from hydrosizer overflow feed material (48×200 mesh and 18.3%  $P_2O_5$ ) with a concentrate grade of about 29%  $P_2O_5$ . These results were found to be comparable to, or better than, those obtained at the SF plant.

In the case of the slimes (–200 mesh and 10.9%  $P_2O_5$ ) a  $P_2O_5$  recovery of 75.3% was possible with a cleaner concentrate containing only 14.5%  $P_2O_5$  as indicated in Table 5. It is expected that an improved concentrate grade should be possible if the slimes are further deslimed and the ASH is operated at higher feed pressures with a modified reagent schedule. In any event, it is clear that the ASH flotation technology has great potential to provide for excellent phosphate flotation separations at a high specific capacity, and further research efforts in this area should be sustained.

Table 4. The Results of Three-Stage ASH Flotation for Hydrosizer Overflow Material (48×200 mesh) (Slurry Pressure = 8 psi; Pedestal Rotation = 0; Reagent Addition = 2.3 kg/ton)

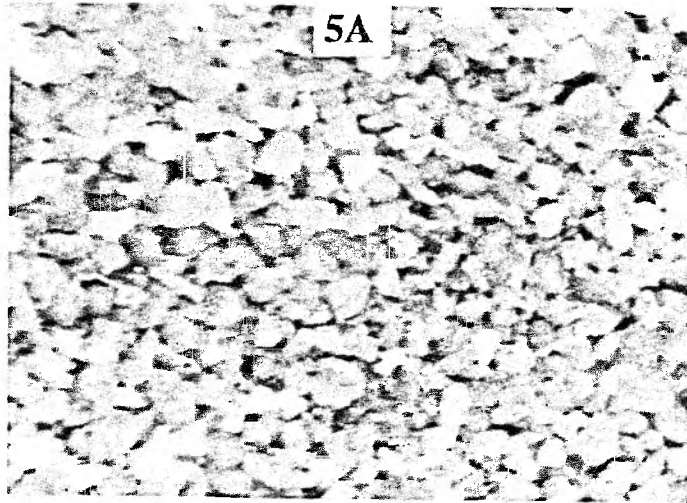
	$P_2O_5$ Grade (%)	MgO Grade (%)	Soluble $Fe_2O_3$ (%)	$P_2O_5$ Recovery (%)
Scavenger Conc.	25.6	1.1	0.3	79.7
Conc. from Reflotation of Scavenger Conc.	28.8	0.8	0.2	87.7
Conc. from Reflotation of Scavenger Tails	20.7	1.6	0.4	68.4
Feed	18.3	2.3	0.4	

Table 5. The Results of Three-Stage ASH Flotation for Slimes (–200 mesh) (Slurry Pressure = 10 psi; Pedestal Rotation = 1; Reagent Addition = 2.4 kg/ton).

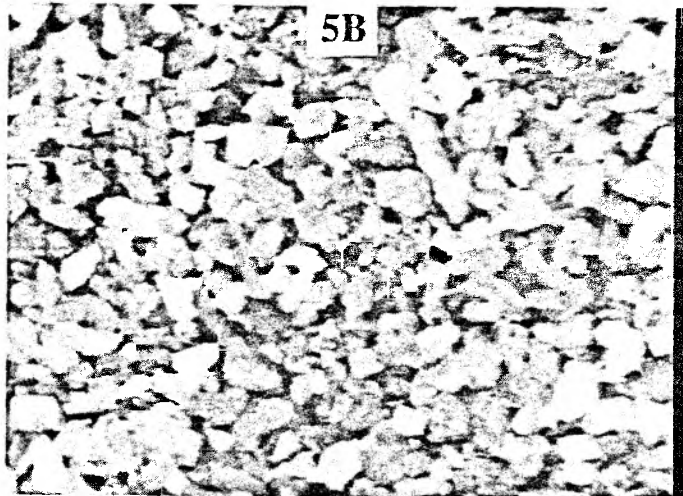
	$P_2O_5$ Grade (%)	MgO Grade (%)	Soluble $Fe_2O_3$ (%)	$P_2O_5$ Recovery (%)
Scavenger Conc.	12.9	5.6	0.6	71.3
Conc. from Reflotation of Scavenger Conc.	14.5	5.7	0.6	75.4
Conc. from Reflotation of Scavenger Tails	9.8	4.9	0.7	58.9
Feed	10.9	4.1	0.7	

### Microscopic Examination

Optical microscopy was used to examine the products obtained from scavenger flotation experiments with the ASH-2C system. Microphotographs presented in Figure 5 show light-brown collophanite particles in the concentrate (Figure 5A) which tend to be rather smooth while most of the gangue mineral particles (dolomite, quartz, and aluminosilicate) observed in the tailings product (Figure 5B) are colorless and angular in shape. Other gangue minerals are hematite (red-brownish) and magnesium-bearing minerals (dark-grayish). It is evident that the concentrate from scavenger flotation (ASH overflow product) consists mainly of smooth collophanite particles which have a light-brown color. However, a few gangue mineral particles, which dilute the product, are still found in the phosphate concentrate. The tailings from scavenger flotation (ASH underflow product) consist mostly of dolomite, quartz, and aluminosilicates which have a lighter color. Most of the gangue minerals are found to report to the tailings or the ASH underflow product. A number of locked particles containing collophanite and gangue minerals were occasionally found both in the concentrate and in the underflow tailings product, but in general the feed material was well liberated. Only a few hematite and magnesium-bearing mineral particles were found in the concentrate.



**ASH Overflow (Phosphate Concentrate)**



**ASH Underflow (Tailings)**

Figure 5. Microscopic analysis of products obtained from scavenger flotation with the ASH-2C for hydrosizer overflow feed material (48×200 mesh).

## SUMMARY AND CONCLUSIONS

Preliminary tests have been conducted at the University of Utah to evaluate the air-sparged hydrocyclone (ASH) technology for scavenger flotation of western phosphate ore from SF Phosphates Limited plant operations near Vernal, Utah. Experimental results with the hydrosizer overflow stream (48×200 mesh, 18–20% P<sub>2</sub>O<sub>5</sub>) indicate that 80% P<sub>2</sub>O<sub>5</sub> recovery can be obtained in single-stage scavenger flotation at a concentrate grade of about 26% P<sub>2</sub>O<sub>5</sub>. It should be noted that these ASH results compare favorably with typical plant results in which a scavenger concentrate containing 25% P<sub>2</sub>O<sub>5</sub> is obtained at a recovery of 75%. It appears that satisfactory separations can be obtained by high-capacity ASH flotation under appropriate operating conditions.

On the basis of these results the potential of ASH technology for scavenger phosphate flotation is evident. Of course, research should be continued to consider other process streams, optimize the separation efficiency, and evaluate larger diameter ASH units. In this regard, further research and development is warranted, and efforts are being made to initiate a dedicated R&D program.

## ACKNOWLEDGEMENT

The authors wish to acknowledge Mr. Merrill Allen, senior metallurgist, of SF Phosphates Limited for arranging for plant samples and the analysis of some phosphate samples. Fundamental X-ray CT studies which have contributed to the development of the ASH technology have been supported by NSF grant, CTS 9000406 and DOE contract, DE FG22 90PC90311.

## REFERENCES

- Chamblee, J. W., and Greenwood, B. F., 1991, "Evaluation of High Throughput, High Consistency Deinking Technology," Proceedings of 1991 TAPPI Pulping Conference, Orlando, Florida, Nov. 4–7, 1991.
- Gieseke, E. W., 1985, "Phosphate Rock," Section 21, Mineral Processing Handbook, Volume 2, SME, AIME, New York.
- Hassan, El-Shall, 1991, Phosphate Research Proposal Announcement, Florida Institute of Phosphate Research.
- Houot, R., 1982, "Beneficiation of Phosphatic Ores through Flotation: Review of Industrial Applications and Potential Developments," International Journal of Mineral Processing, 9, p. 353.
- Houot, R., Joussemet, R., Tracez, J., and Brouard, R., 1985, "Selective Flotation of Phosphatic Ores Having a Siliceous and/or a Carbonated Gangue," International Journal of Mineral Processing, 14, p. 245.
- Miller, J. D., 1981, "Air-Sparged Hydrocyclone and Method," U.S. Patent No. 4,279,743.
- Miller, J. D., 1983a, "Flotation Apparatus and Method for Achieving Flotation in a Centrifugal Field," U.S. Patent No. 4,399,027.
- Miller, J. D., 1983b, "Flotation Apparatus and Method for Separating Particles from a Fluid Suspension," U.S. Patent No. 4,397,741.
- Miller, J. D., and Kinneberg, D. J., 1984, "Fast Flotation in an Air-Sparged Hydrocyclone," Proceedings of MINTEK 50, South Africa, Vol. 1, 1984, p. 353.
- Miller, J. D., and Kinneberg, D. J., 1988, "Flotation Apparatus and Method," U.S. Patent 4,744,890.
- Miller, J. D., Misra, M., and Gopalakrishnan, S., 1986, "Gold Flotation from Colorado River Sand with the Air-Sparged Hydrocyclone," Minerals & Metallurgical Processing, SME/AIME, 1986, p. 145.
- Miller, J. D., Misra, M., and Hu, J. S., 1987, "Fluoride Activation in Oleate Flotation of Collophanite," Minerals and Metallurgical Processing, August, 1987, p. 133.
- Miller, J. D., and Van Camp, M. C., 1982, "Fine Coal Flotation in a Centrifugal Field with an Air-Sparged Hydrocyclone," Technical Papers, Mining Engineering, SME/AIME, 1982, p. 1575.

- Miller, J. D., and Ye Yi, 1989a, "Air-Sparged Hydrocyclone Flotation Apparatus and Methods for Separating Particles from a Particulate Suspension," U.S. Patent No. 4,834,434.
- Miller, J. D., and Ye, Y., 1989b, "Froth Characteristics in Air-Sparged Hydrocyclone Flotation," *Mineral Processing and Technology Review*, Vol. 5, 1989, p. 307.
- Miller, J. D., Ye, Y., Baker, M. W., and Gopalakrishnan, S., 1988, "Design and Operating Variables in Flotation Separation with the Air-Sparged Hydrocyclone," *Proceedings of the 16th International Mineral Processing Congress*, 1988, p. 499.
- Miller, J. D., Ye, Y., and Gopalakrishnan, S., 1992, "Testing of Large Diameter Air-Sparged Hydrocyclones for Fine Coal Flotation at the Homer City Coal Preparation Plant," *Proceedings of Coal Preparation 92*, p. 349, May 5-7, 1992.
- Rao, K. Hanumantha, Antti, Britt-Marie, and Forssberg, Eric, 1989, "Flotation of Phosphatic Material Containing Carbonatic Gangue Using Sodium Oleate as Collector and Sodium Silicate as Modifier," *International Journal of Mineral Processing*, 26, p. 123.
- Service, H. L. *et al.*, "The Western Phosphate Industry and Its Resources in Five Parts"; Pt. 1 "Introductory Review," RI 6485; Pt. 2, "Montana," RI 6611; Pt. 3, "Idaho," RI 6801; Pt. 4, "Wyoming and Utah," RI 6934; Pt. 5, "Trends and Outlook," U.S. Bureau of Mines.
- Snow, R. E., Parcell, V. I., and Sun, S. C., 1975, "Flotation Characteristics of a Florida Leached Zone Phosphate Ore with Fatty Acids," *Trans. AIME*, vol. 208, p. 70.
- Sparks, B. D., and Sirianni, A. F., 1974, "Beneficiation of a Phosphoriferous Iron Ore by Agglomeration Methods," *International Journal of Mineral Processing*, 1, p. 231.
- Soto, H., and Iwasaki, I., 1986, "Selective Flotation of Phosphates from Dolomite Using Cationic Collectors," *International Journal of Mineral Processing*, 16, p. 3.
- Weber, I. R., 1986, "General Overview of the Vernal Phosphate Operations," Presented at the AMC International Mining Show, Las Vegas, Nevada, October 5-9, 1986.
- Ye, Y., Gopalakrishnan, S., Pacquet, E., and Miller, J. D., 1988, "Development of the Air-Sparged Hydrocyclone - A Swirl Flotation Column," *Column Flotation 1988*, AIME/SME, p. 305.
- Yu, Q., Ye, Y., and Miller, J. D., 1992, "Dispersion and Aggregation of Newspaper Pulps for Fiber Recovery by Deinking Flotation," *Proceedings of the Engineering Foundation Conference*, Palm Coast, Florida, 15-20 March, 1992, to be published in 1993.