Froth Flotation Techniques of Eshidiya Phosphate Mines, Jordan.

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ABSTRACT: The phosphate formations cover approximately 60% of Jordan and comprise about 1 billion tones of resources. Jordan with Al-Hassa Mine, Al-Abiad Mine and Eshidiya Mine produces 9.25 million tones of phosphate annually. The deposits at Eshidiya are comprised of overburden, four phosphate beds (A0, Al, A2 and A3), a coquina/marl waste bed, and two silicified phosphate/chert interwaste beds. At Eshidiya, the ore beds are treated separate through beneficiation and upgrading as it produces different grade products. They are classified into three classes, (1) Al Ore: requires crushing, scrubbing, screening and desliming to produce a 68-70% product, (2) A2 Ore: basically a direct shipping ore, which requires only two stages of dry screening to produce a 73-75% TCP product and (3) A3 Ore: must be washed, scrubbed and deslimed in a manner similar to Al and then floated to remove fine silica in order to make a 75-77% TCP product. A 65% TCP sub-commercial product is also produced.

1. INTRODUCTION

Phosphate bearing horizons in Jordan occur at varying depth and cover about 60% of the total area of Jordan (JPMC, 1991) and comprise about 1 billion tones of resources. Present marketing strategy in Jordan trends away from integration of the industry to finished fertilizer products (JPMC, 1999). With its good rock quality, long term reserves, low production costs, and good geographical position in the Asian market, Jordan is now the second leading exporter of phosphate rock in the world and exports to more than 25 counties.

Jordan with its Al-Hassa Mine (3.5 million tones), Al-Abiad Mine (2.5 million tones), and Eshidiya Mine (3.25 million tones) has the present design capacity to produce 9.25 million tones of phosphate on an annual basis (JPMC, 1999). In 1997, phosphate rock production in Jordan was about 5.8 million tones, which puts it in 6th place behind the United States, China, Morocco, the broken Soviet Union and Tunisia. The anticipated expansion of Eshidiya to 7.45 million tones should improve Jordan's production to 5th in the world.

The beneficiation process at Eshidiya is a little more complicated than that in the United States, since three separate ore types are treated at the same time:

1. Al Ore: this ore requires simple scrubbing, screening and desliming to produce an acceptable product when mined from under the coquina bed.
2. A2 Ore: this ore is basically a direct shipping high-grade bed that requires only dry screening and dedusting to produce an acceptable product.
3. A3 Ore: this ore must be scrubbed, screened, and deslimed in the same manner as for Al ore in addition to flotation for removal of fine silica in order to make an acceptable product.

2. GEOLOGY, GEOCHEMISTRY AND ORE CHARACTERISTICS

2.1 Geology

The phosphate deposits in central Jordan lie within the upper Cretaceous limestone plateau (Bender, 1974). It is estimated to be 65 million years old (Abed, 1985; Quannell, 1951). By comparison, the deposits of Florida in the United

States are much younger and range from 3-12 million years old (Moudgil and Chanchani, 1985; Hopper, 1976). However, deposits in both countries are sedimentary in nature and are thought to have been formed in similar sequences (Sheldon, 1964; Beall and Merritt, 1966; Gieseke, 1985).

The deposits at Eshidiya are comprised of overburden, four phosphate beds, a coquina/marl waste bed, and two silicified phosphate/chert interwaste beds. The lithology and stratigraphic column is given in Bender (1974). At the present time, A0 bed is considered to be waste. A1 bed requires crushing and beneficiation to make a saleable product, whereas A2 bed requires only crushing. On the other hand, A3 bed requires crushing, beneficiation and flotation to produce a saleable product.

2.2 Ore Characteristics

In sedimentary deposits, such as those found in Jordan and the U.S., the ore generally consists of phosphate particles range from 20 mm to 50 microns in size, sand ranging from 1 mm to 50 microns, and clay. The clay can be present in large lumps, but scrubbing and wetting with water will generally reduce it to its natural grain size of less than two microns.

The ore beds are generally rest on hard limestone and are overlain by overburden sand. In igneous deposits, such as those found in Canada and Brazil, the ore generally consists of phosphate particles ranging from 400 to 10 microns that are intergrown and rimmed with iron minerals and are associated with some clay. Grinding and scrubbing are required for liberation of the phosphate. The ore bed generally rests on fresh carbonate and is overlain by clay and silicates. The thickness of the ore, its depth below the surface, its richness, its association with minor detrimental elements and its pumpability and processability are all factors that determine its economic value. Some of the major economic ore characteristics for the United States, Canadian (Ranney, 1980; Zhang, 1993; Donald, 1994; Elliott, 1994; Will, 1997) and Eshidiya ore bodies are compared in Table 1.

2.3 Geochemistry

In general, the ore body at Eshidiya is richer than those in the United States but 2.5 to 3.5 times more overburden must be stripped off to reach the ore zone. Feed grades at Eshidiya are equal to those in Canada and about four times higher than the United States. Product quality at Eshidiya are similar to those in the United States, but much less than those in Canada, since the Canadian deposits are igneous in origin and the phosphate is present as pure apatite. Detrimental product impurities (Fe_2O_3, Al_2O_3, and MgO) at Eshidiya are some of the lowest in the world (Table-1).

Table 1: Ore Characteristics comparison of UnitedState, Canadian and Jordan (Eshidiya)

Characteristics	*Florida (Sed)*	*Canada (Ig)*	*Eshidiya (Sed)*
Tones Product/Hectare Mined	12,000 to 18,000	–	40,000
Overburden/Matrix	1.5 to 2.0	–	5.0
Ore m3/ Tone Product	2.5 to 5.0	1.5 to 3.0	2.5
Float feed % TCP	10 to 25	40 to 60	40 to 65
1 mm Sub com./Concentrate Tones	1.2 to 1.7	0	0.05
Product % TCP	62 to 74	83 to 88	65 to 78
Detrimental Impurities % (Fe_2O_3 + Al_2O_3 + MgO)	2.4 to 2.8	2.5 to 2.4	0.6 to 1.0

2.4 Mining of Phosphate

In Florida, the overburden is generally 10-15 meters thick consisting of fine sand, usually dug with a dragline and cast in spoil piles (Hopper, 1976). 1-4 meters thick and clayey in nature ore, is dug with a dragline and dropped into a pit where it is slurried with high-pressure water and pumped into the plant. The reserves at Eshidiya in Jordan consist of two ore bodies, eastern and western ore bodies. One of the pits is in the coquina area while the other is in the non-coquina area. At Eshidiya, the overburden is drilled and blasted and then removed with draglines. Overburden removal is down to the top of layer Al. The phosphate ore layers Al, A2, and A3 and the two inner waste layers are selectively removed with a system of shovels and trucks. It is important to note that the ore beds are kept separate through beneficiation since they upgrade in different manners and produce different grade products, they are classified as; (1) Al Ore: requires crushing, scrubbing, screening and desliming to produce a 68-70% product, (2) A2 Ore: basically a direct shipping ore, which requires only two stages of dry screening to produce a 73-75% TCP product and (3) A3 Ore: usually washed, scrubbed and deslimed in a manner similar to Al and then floated to remove fine silica in order to make a 75-77% TCP product . A 65% TCP sub-commercial product is also produced.

3. PHOSPHATE FLOTATION

In phosphate industry, a number of unit processes are generally required to produce a saleable product, since a number of gangue minerals are usually present (silica, clay, dolomite, hematite and others). Each of the basic unit processes required to beneficiate Al, A2, and A3 ore types, i.e., scrubbing, screening, cycloning, sizing, flotation and filtration. pH of slurry indicates the alkalinity or acidity of that stream and is measured on a scale of 0-14. It is critical that the pH is in the proper range for fatty acid conditioning (Florida: pH 8.5-9.5, Eshidiya: pH 10-11) and thickeners (pH 7-8). Eshidiya has on-line pH probes in the coarse rougher flotation cells of 0.01 pH.

3.1 Reagents

At Eshidiya, the fatty acid is made into soap by soaponifying it with caustic soda prior to conditioning. The diesel oil is also used to modify the resulting froth in the presence of slimes and to help float the coarser phosphate (Goldschmidt, 1954).

18 carbon chain fatty acids present in the tall oil act as a collector by forming a chemical bond with the phosphate mineral during conditioning. The fatty acid molecule has an uncharged body consisting of 18 carbon and hydrogen atoms and a negatively charged head consisting of one carbon, two oxygen and one hydrogen atom. The surface of the phosphate rock contains many calcium sites. When the pH is adjusted to 9.0, the fatty acid converts to soap by attaching to the positive calcium site on the phosphate and forming a calcium oleate. At Eshidiya, the fatty acid is premixed with caustic and partially converted to soap prior to use as a flotation collector (Glembotskii et al., 1972; Napier-Munn, 1991).

3.2 Conditioning

Conditioning fatty acid and fuel oil reagents onto the surface of the phosphate minerals is the single most important step in the overall flotation process (Hill, 1960). Well feed conditioned, will float well, but poor feed conditioned will never float well.

3.3 Effect of % Solids

The % solid of the slurry is the most important variable that an operator has to work with during the conditioning step. However, this variable is controllable through adjustments in feed cyclones or classifier overflows (Gieseke, 1985). High % solids leads to the following six positive effects during conditioning: increases the reaction rate of the collector/mineral attachment since there is less dilution with water; increases retention time in the units because there is less dilution with water; increases the ability of the reagents to be smeared on the surface of the phosphate; requires less reagents to be used; increases the speed of float in the flotation cells and negates, to some extent, the influence of slimy feeds.

3.4. Effect of pH

The pH during conditioning is very critical since it must be in the proper range for absorption of fatty acid to take place on the phosphate mineral (Wills, 1997; Robinson, 1972). Different pH levels are sometimes required for different feeds. Slimy feeds may require a lower pH while good clean feeds may require a higher pH for optimum results. Coarse feeds at Eshidiya seem to require a high pH for good flotation, while fine feeds require no pH adjustment at all. The caustic soda is also a froth modifier to some extent, which depends upon the character of the froth on the flotation cells and the amounts of other reagents being used.

3.5. Effect of Feed Loads

Poor mixing efficiency can result from higher tonnages because the flow patterns within the conditioner change and mixing slow down. The result is a loss in recovery sometimes coupled with increased flotation of gangue minerals. The lower % solids result from light loads, which require higher reagent consumption to offset a potential loss in recovery. Light loads can also cause problems with the softer feeds encountered at Eshidiya, which tend to break down with longer conditioning times. Cyclones are perhaps one of the best tools to deal with problems associated with slimy feed, soft feed and slimy water. In each case, slimes associated with the feed or slimes generated from softer feeds would preferentially be sent to the cyclone overflow and thus, flotation performance would be improved.

Froth paddles operated properly can enhance recovery by 1-2% for fatty acid flotation. Paddles set too deep tend to dip into the gangue zone and rake unwanted minerals into the froth. Deep-set paddles also tend to block a free flowing froth and slow down its travel to the lip of the cell. A properly controlled froth is one that flows faster as it approaches the lip of the cell and does not lose velocity as it passes over the lip. Cell levels adjusted to carry over little of the gangue zone in the slurry or froth paddles set to the proper height are good tools to optimize froth removal and enhance recovery. Some types of phosphate particles come to the surface only one time and these must be raked off as quickly as possible. The characteristics of a given froth are primarily feed and reagent related. Every feed has a reagent setting that is right for its characteristics. This is an area where distributive control and on-line sampling take a back seat to operator experience.

Water clarity is critical for plants that use recycled water for both fatty acid and amine flotation. Turbid water for fatty acid flotation is best handled with extra fuel oil or diesel oil. At times, recycled water can contain dissolved P_2O_5, which tends to depress phosphate during fatty acid flotation. This situation will probably not occur at Eshidiya. The effect of dissolved P_2O_5 is best mitigated by using more fatty acid collector. Sized feeds are treated at Eshidiya as in many other areas of the world. Overall, the plant at Eshidiya is capable of producing an additional 294,983 tones of Al and A3 product per year by simply treating 10 tph more ore for each circuit, operating each circuit 1 hour more each day and recovering 4.8% more phosphate during A3 flotation.

6. CONCLUSIONS

During the process of phosphate flotation at Eshidiya mines, the followings should be considered in order to enhance the productivity:

1. Clean Feed: the presence of clay and other fine minerals during conditioning and can consume excessive amount of reagents and hinder recovery and product grade.
2. Condition at Proper % Solids: this means high % solids prior to rougher flotation; 70-75% using neat tall oil and 60% and above using soap.
3. Good Sizing: size feed well in both fractions. Properly sized feed generally results in higher recovery of the coarser fractions in the feed and more selective concentrates from the finer fractions at reduced reagent usage.
4. Clean Water: water used prior to flotation can be somewhat dirtier than that used directly in flotation but should be relatively free of solids. Water used directly in flotation should be as clean as possible.
5. Steady and Appropriate Feed Rates: the feed rates should be stable and matched with the grade of feed being treated. Overload feed rates whenever possible should be avoided.
6. Proper Reagent Dosages: this item may be modified somewhat at Eshidiya since additional reagent is sometimes needed to aid downstream operations such as filtering and to avoid scaling.
7. Adequate Conditioning and Flotation Times: keep all conditioners and cells open even at reduced tonnages to compensate for variations in feed.

8. Maintenance: good mechanical condition of the operating equipment should be followed.

The above requirements for phosphate flotation are obvious and make sense. However, nearly all everyday occurring problems in a plant can be traced back to not adhering to these requirements.

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