

Influence of Temperature, Water Quality and Collector Type on Flotation Performance of a Peruvian Phosphate Ore

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Abstract: The sedimentary phosphate deposit of Bayovar is located in a very dry area of Peru (desert of Sechura) which is close to the Pacific coast. It consists of seven superposed layers (beds) which call for different strategy of concentration. The ore is composed predominantly by apatite (84% in weight basis) plus silicates (16%). To concentrate phosphate from beds 6-7, it is necessary to carry out further cationic reverse flotation of silicates, at neutral pH, to yield a concentrate which meets market specification. The new process was developed in laboratory scale by a collaborative program conducted between Vale S. A. and the University of Sao Paulo—Brazil. As water resources are very limited at Bayovar region, all the steps of concentration, including flotation, must be performed with seawater which must be continuously recycled. This work addresses some relevant topics related to the use of seawater in the reverse cationic flotation of silicates: influence of temperature, water quality (ageing and chemical composition) and collector type. The results indicate that amido amine works better than ether amine. If flotation is conducted with the former collector, the separation process is able to tolerate changes in temperature (25 °C-40 °C) and water quality caused by either evaporation or ageing.

Key words: Phosphate, flotation, seawater, temperature, ageing.

1. Introduction

Phosphates of sedimentary genesis are the most important deposits around the world not solely for the volume of its reserves, but also for the magnitude of production. Particularly in Peru, in the western Sechura desert, 280 million of tons of marine sediments of Miocene age assaying 18% of P₂O₅ belong to the ore body of Bayovar. It consists mostly of pellets of phosphorite (a fluor-hydroxy-carbonate apatite) disseminated in a matrix gangue composed of silicate minerals (quartz, feldspar, micas and diatomite), gypsum and organic matter [1].

The ore body of Bayovar occurs in seven superposed beds which call for different strategy of concentration. To treat beds 1-5, a standard mineral processing circuit started its operation in 2010, yielding 3.9 Mt/y of concentrate assaying 30% of P₂O₅. It is composed of scrubbing, screening (6 mm) and first desliming conducted by hydrocyclones. The underflow of the first desliming is submitted to attrition, followed by a second step desliming which yields the final concentrate. However, when beds 6-7 feed the plant, the basic set of unit operation fails to yield a final concentrate assaying P₂O₅ content greater than 30%. To meet this market specification, flotation must be conducted. These unit operations are depicted in the flow sheet presented in Fig. 1 and they may be

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regarded as the basic unit operations.

Cationic reverse flotation of silicates in natural pH (7.4-8.2) has been successfully developed to concentrate phosphate from beds 6-7 as the result from a collaborative research conducted by Vale S. A. and the Mineral Processing Research Group of the University of Sao Paulo—Brazil [2]. A pilot plant has currently been running at the mining site in order to reproduce the good results obtained in laboratory scale. In the future, after the fully accomplishment of the industrial flotation circuit, further 1.9 Mt of concentrate assaying P_2O_5 content greater than 30% will be yearly produced.

The lack of sweet water in the Bayovar area has compelled the concentration process to be conducted with seawater which must be collected in the Pacific Ocean, at a place located 35 km far from the mine site. The purpose of this paper is to present and discuss some relevant topics related to the use of sea water in the reverse cationic flotation of silicates from Bayovar phosphate ore [3].

2. Experiments

A sample of phosphate ore from beds 6-7 was taken directly from the underflow of the second desliming circuit, after it has been submitted to scrubbing,

screening, 1st desliming, attrition and 2nd desliming, as following the flow sheet depicted in Fig. 1. After sampling, the ore (top size ~ 0.8 mm) was submitted to desliming in a screen of 0.037 mm of aperture.

The ore sample bears 23.3% of P_2O_5 , 37.7% of CaO, 16.0% of SiO_2 , 0.43% of Fe_2O_3 , 0.67% of MgO, 3.58% of Al_2O_3 and 2.35% of sulphate. Regarding mineralogical composition (in weight basis), the size fraction + 0.044 mm is composed of apatite (84%), plagioclase (9%), quartz (4%), K-feldspar (3%) and also traces of mica, gypsum, calcite and dolomite. In terms of particle size distribution, the flotation feed presents $D_{50} \sim 0.09$ mm.

Seawater from the Pacific Ocean (Piura) was used in this investigation. It was collected in three different occasions: November 2010 (Piura-I-A), April 2011 (Piura-II) and August 2011 (Piura-III). They were used to probe the influence of water ageing on flotation performance. Water named Piura-I-A was submitted to increasing evaporation, yielding two other samples which exhibited higher concentration of electrolytes. Chemical composition of water from Piura is shown in Table 1. It may be compared with tap sweet water from Bayovar mine site and also with the distilled water yielded in laboratory of USP.

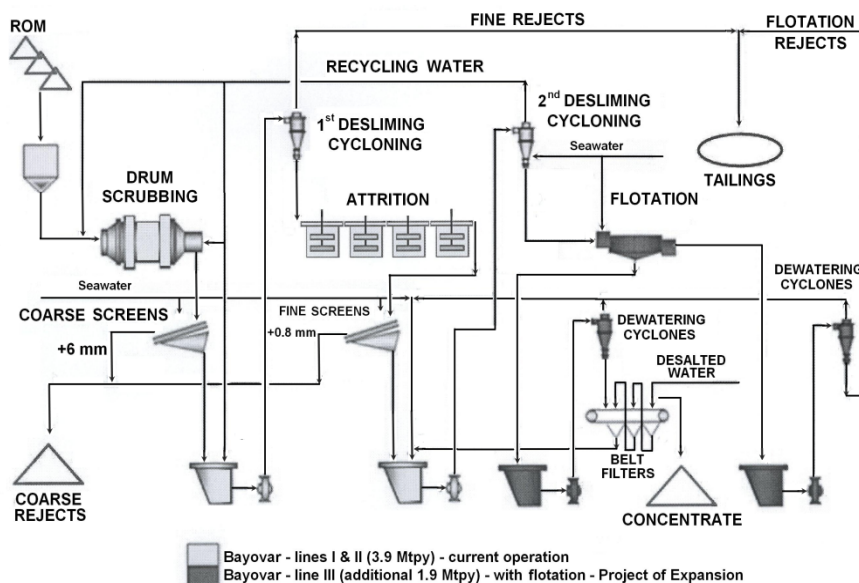


Fig. 1 General flow sheet of Bayovar.

Table 1 Chemical composition of water used in flotation experiments.

| Elements | Concentration (g/L) | | | | | |
|------------------|---------------------|----------------------|----------------------|--------------------|-------------------|------------------|
| | Piura I-A | Piura I-B | Piura I-C | Piura-II | Piura-III | “Tap” |
| Sodium | 10.4 | 16.52 | 22.29 | 9.8 | 9.8 | 0.247 |
| Potassium | 0.48 | 0.77 | 1.15 | 0.48 | 0.51 | 0.007 |
| Calcium | 0.45 (p Ca = 1.9) | 0.52 (p Ca = 1.9) | 0.68 (p Ca = 1.8) | 0.43 (p Ca = 2.0) | 0.41 (p Ca = 2.0) | 0.073 (p Ca=2.7) |
| Magnesium | 1.28 (p Mg = 1.3) | 1.93 (p Mg = 1.1) | 2.79 (p Mg = 0.9) | 1.20 (p Mg=1.3) | 1.16 (p Mg=1.3) | 0.018(pMg=3.1) |
| Manganese | < L. D. | < L. D. | < L. D. | < L. D. | < L. D. | < L. D. |
| Iron | < L. D. | 0.02 | 0.01 | < L. D. | < L. D. | < L. D. |
| Aluminium | < L. D. | < L. D. | < L. D. | < L. D. | < L. D. | < L. D. |
| Chloride | 21.57 | 28.43 | 36.8 | 19.05 | 17.55 | 0.386 |
| Sulphate | 1.24 | 5.48 | 5.42 | 2.51 | 3.44 | 0.1 |
| Phosphate | < L. D. | 2.3×10^{-4} | 2.0×10^{-4} | < L. D. | < L. D. | < L. D. |
| Nitrate | 8×10^{-5} | 4×10^{-5} | 6×10^{-5} | 3×10^{-5} | < L. D. | < L. D. |
| Suspended solids | < L. D. | 0.73 | 3.91 | < L. D. | < L. D. | < L. D. |
| Dissolved solids | 32.2 | 65.5 | 84.2 | 41.0 | 36.3 | 1.3 |

< L. D.= Below detection limit of chemical analysis method limit of detection.

Flotation experiments were conducted in a laboratory Denver cell, at neutral pH (7.4-8.2), using 1,000 grams of ore. A slurry containing 50% of solids (weight basis) was conditioned with 500 g/t of collector agent for 1 min. Two collectors were used in the experiments: ether amine and amido amine. After collector conditioning, fresh water was added to the pulp in order to achieve 30% of solids. Rougher flotation was carried out until achieving the total exhaustion of the mineralized froth. The rougher concentrate (sunk product) was mixed with further amount of water in order to prepare a slurry containing 40% of solids. After addition of 250 g/t of collector followed by one minute of conditioning time, further water was added to the pulp in order to achieve 25% of solids and carry out cleaner flotation stage until the exhaustion of mineralized froth. The tailings (floated products) and the concentrate (sunk product yielded by the cleaner stage) were dried, weighed and sent to chemical analysis.

3. Results and Discussion

3.1 Influence of Reagent Type: Ether Versus Amido Amine

Ether amines have been successfully used in Brazil

to remove quartz from itabirites during the last 30 years [4]. Such a large experience motivated the choice of this sort of collector to start exploratory flotation tests to conduct reverse cationic flotation of silicates from the phosphate of Bayovar. However, that kind of collector was unable to yield apatite concentrates with P₂O₅ content in the range of 29%-31%. After an extensive screening with many other cationic surfactants, amido amines proved to be able to produce a flotation concentrate which met the desired target for P₂O₅ content, as depicted in Table 2. Amido amine also yielded very much lower recovery of SiO₂ in the apatite concentrate if compared with ether amine (Table 2). The mechanisms which make amido amines to behave better than ether amines (and other cationic surfactants) in the seawater environment are the subject of current research at the University of Sao Paulo.

Table 2 Flotation performance of ether amine versus amido amine with water Piura-I-A (*).

| Collector | Final concentrate Grade (%) | | Final concentrate-recovery (%) | | |
|-------------|-------------------------------|------------------|--------------------------------|-------------------------------|------------------|
| | P ₂ O ₅ | SiO ₂ | Mass | P ₂ O ₅ | SiO ₂ |
| Ether amine | 24.9 | 14.8 | 91.1 | 94.0 | 82.8 |
| Amido Amine | 29.9 | 4.4 | 74.0 | 89.9 | 20.5 |

(*) Collector dosage at rougher and cleaner stage is 500 g/t and 250 g/t, respectively.

3.2 Influence of Temperature

Because significant changes in the temperature of process water are expected to occur along a single day in very dry areas as the Sechura desert, it was necessary to probe the influence of water temperature on flotation performance of Bayovar phosphate ore. This way, flotation experiments were conducted with Piura seawater (Sample 1-A) at 25 °C, 30 °C and 40 °C. According to results depicted in Table 3, regardless the value of the temperature, it was possible to yield phosphate concentrates exhibiting P₂O₅ content greater than 30%, accompanied by apatite recovery in the range of 87%-89%. Unlike flotation performance of sylvite with long chain primary amines in brines, which is strongly influenced by water temperature [5], the flotation of silicates from the phosphate of Bayovar with amido amine in seawater is rather tolerant to changes in water temperature.

3.3 Influence of Seawater Ageing

Because seawater is a natural electrolyte solution containing not solely organic plus inorganic species, but also microorganisms, its chemical composition may vary upon time as the result of changes in complex equilibria involving those species [6]. To probe the influence of water ageing on flotation response with amido amine, water samples collected in the Pacific Ocean (Piura-Peru) at different dates were used to conduct flotation experiments. The sample identified as Piura-I was collected in November of 2010, whereas the samples named Piura-II and Piura-III were collected in April and August of 2011, respectively. Because comparative

Table 3 Influence of temperature on flotation performance with amido amine with water Piura-I-A.

| Temp. (°C) | Final concentrate Grade (%) | | Final concentrate-recovery (%) | | |
|------------|-------------------------------|------------------|--------------------------------|-------------------------------|------------------|
| | P ₂ O ₅ | SiO ₂ | Mass | P ₂ O ₅ | SiO ₂ |
| 25 | 30.4 | 2.8 | 71.1 | 89.1 | 12.5 |
| 30 | 30.4 | 3.0 | 70.3 | 87.2 | 13.6 |
| 40 | 30.7 | 2.9 | 71.6 | 89.3 | 13.4 |

flotation experiments were conducted in October of 2011, it was possible to study the influence of water ageing after 60, 180 and 400 days, respectively. According to information depicted in Table 1, the chemical composition of the three sorts of seawater is roughly similar. Results from flotation experiments are displayed in Table 4, where it is possible to see that flotation performance was not strongly influenced by water ageing, because all the yielded concentrates assayed 30.2%-30.7% of P₂O₅, whereas apatite recovery lay in a narrow range (92%-94%).

3.4 Influence of the Composition of Piura Seawater

Because Sechura desert is a very dry area, evaporation of water (seawater) stored in a dam for the purpose of recycling is likely to happen. In this case, considerable change in its chemical composition is expected to occur. Attempting to simulate this hypothetical situation, sample Piura-1A (22 g/L of chloride) was submitted to evaporation in laboratory, yielding Piura-1B (28 g/L of chloride) and Piura-1C (37 g/L of chloride), as depicted in Table 1. Flotation experiments conducted with these three sorts of seawater yielded the results depicted in Table 5, where it is possible to see that flotation performance was not affected by the change in chemical composition provoked by evaporation.

Table 4 Influence of seawater ageing on flotation performance with amido amine.

| Sea Water type | Agein g time (days) | Grade-concentrate (%) | | Concentrate-recovery (%) | | |
|----------------|---------------------|-------------------------------|------------------|--------------------------|-------------------------------|------------------|
| | | P ₂ O ₅ | SiO ₂ | Mass | P ₂ O ₅ | SiO ₂ |
| Piura-IA | 400 | 30.3 | 3.0 | 75.4 | 94.1 | 14.2 |
| Piura-II | 180 | 30.2 | 3.1 | 75.8 | 94.0 | 15.0 |
| Piura-III | 60 | 30.7 | 3.1 | 74.4 | 92.1 | 14.9 |

Table 5 Influence of the composition of seawater on flotation performance with amido amine.

| Water type | Chloride (g/L) | Grade-concentrate (%) | | Concentrate-recovery (%) | | |
|------------|----------------|-------------------------------|------------------|--------------------------|-------------------------------|------------------|
| | | P ₂ O ₅ | SiO ₂ | Mass | P ₂ O ₅ | SiO ₂ |
| Piura-IA | 22 | 30.4 | 2.8 | 71.1 | 89.1 | 12.5 |
| Piura-IB | 28 | 29.7 | 5.0 | 73.6 | 91.7 | 21.1 |
| Piura-IC | 37 | 30.7 | 3.1 | 73.8 | 92.0 | 14.2 |

Table 6 Influence of the composition of water on flotation performance with amido amine.

| Water type | Grade-concentrate (%) | | Concentrate-recovery (%) | | |
|----------------------|-------------------------------|------------------|--------------------------|-------------------------------|------------------|
| | P ₂ O ₅ | SiO ₂ | Mass | P ₂ O ₅ | SiO ₂ |
| Piura-III (seawater) | 30.7 | 3.1 | 74.4 | 92.1 | 14.9 |
| Distilled | 29.8 | 3.5 | 68.9 | 86.5 | 14.4 |
| Tap | 29.7 | 4.5 | 77.7 | 95.8 | 21.2 |

3.5 Influence of the Composition of Water

Some further flotation experiments were conducted with other water sources. The following types of water were used: distilled water and tap sweet water (from Illescas River near Bayovar deposit) and Bayovar seawater Piura-III. The compositions of each type of sample are depicted in Table 1. Results from flotation experiments are displayed in Table 6, where it is possible to see that flotation performance was not strongly influenced by these sources of water.

4. Conclusions

The phosphate ore from Bayovar (Peru) is composed predominantly of apatite (84%) and silicates (16%). Because the ore body is located in a very dry area (Sechura desert), it is mandatory to use seawater instead of sweet water in the process of beneficiation. To concentrate that ore via reverse cationic flotation of silicates at natural pH (7.4-8.2), unlike ether amine, amido amine was able to yield a concentrate which met the target for P₂O₅ content (29%-31%), accompanied by high P₂O₅ recovery

(89.9%). The developed flotation process was proved to be tolerant to changes in temperature, water ageing and changes in chemical composition provoked by evaporation.

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