WATER IN MINERAL PROCESSING: BRAZILIAN CASE STUDIES

Antonio. E. C. Peres[1]; Joaquim D. Donda[2]; Mauro R. Carvalho[2]; Rogerio C. Guimarães[3]

[1] Universidade Federal de Minas Gerais, Belo Horizonte, Brazil
[2] Samarco Mineração SA, Mariana, Brazil
[3] Companhia Brasileira de Metalurgia e Mineração, Araxá, Brazil
aecperes@demet.ufrgs.br

ABSTRACT

The subject of water in mineral processing in Brazil is addressed and illustrated with three case studies, based on laboratory scale experiments. The development of a method, applied to iron ore concentrates, for predicting the specific energy consumption of industrial ball mills, based on tests in small laboratory mills, led to significant energy, so water, savings. The addition of hydrated lime to the concentrate thickners of an iron ore concentrator did not prevent the recycling of the thickners overflow as process water. A closed water circuit was achieved in a phosphate concentrator following the bench scale determination of concentration limits of interfering ions in the system.

Keywords: energy savings, calcium ions, interfering ions in flotation

1. INTRODUCCIÓN

The problems of the shortage of quality water in view of the increasing world population and the consequent increase of industrial and other activities affecting the environment and the difficulties in keeping mining operation environmentally and economically feasible in view of increasing environmental concern are global, from the point of view of water supply and mining area distribution around the world. Nevertheless, the mining sector is often more relevant to developing country's economy.

Water is an increasingly scarce asset, essential to life and a fundamental component to the sustainable development of nations. The Water and the Environment Summit (Dublin, 1992) alerted of the consequences of the water misuse and the resulting increased scarcity of water resources with regard to sustained development. Sustainability was defined by van Deventer [1] as "development meeting the needs of the present generation without undermining the capacity of future generations to meet their needs". Worse, still, is the impossibility of balancing the supply of potable water with the increasing world population estimated to be 20% greater in the coming 5 years.

The management of very large volumes of water resources is associated with all of the phases of mining activities: from the initial phase of mineral and excavation research, associated with water emergence, to the final phase of concentration, associated to consumption. The majority of operations are carried out by using water, thus meaning consumption in large scale.

The importance of mining to the Brazilian economy is headlined in the document prepared by the Center for Strategic Management in Science, Technology and Innovation of the Brazilian Ministry of Science and Technology (2001) in the following extract:

"According to DNPM (National Department of Mineral Production), the total Brazilian Mineral Production in 1999 was US$15.5 billion, of which US$8.0 billion from ore production and the remainder from petroleum and gas. For the same year, the total value for oil and gas imports, including derived products, was US$5.0 billion. The export of ores was US$6.3 billion in 1999. In recent decades, ore export (83% iron ores), besides covering the deficit caused by importing petroleum products, lead to a supersaver of the order of US$1 billion per year. The global value of manufactured products derived from Brazilian mineral products reached US$46 billion, corresponding to 8.3% of the GNP. In 1999, the whole value of exports by the Brazilian mineral sector, including raw materials, semi-manufactured, manufactured and chemicals was US$10 billion, representing 20.8% of all Brazilian exports. The IBGE (Brazilian Statistical Institute) estimates that 230.000 direct jobs are generated by the mineral sector and an order of 5 million of jobs are indirectly generated".

However, despite such an economical importance, mining activities worldwide will not survive without a strong commitment to the preservation of the environment. Therefore, it is of fundamental importance to the socio-economic development of Brazil and other mining areas that new strategies are created aimed at compromising the mining activities with conservation of natural resources, the economical growth and the protection of the environment.

Representatives from the most important mining corporations have indicated, in a recent survey, water-related topics as the most important issues challenging the mining sector.

Three case studies were selected: i. energy savings in iron ore grinding (electrical energy in Brazil derives from hydro sources, so energy savings = water savings); ii. water recycling in an iron ore concentrator; iii. water recycling in a phosphate concentrator.

2. ENERGY SAVINGS IN IRON ORE GRINDING

Size distribution and specific surface area (measured by the Blaine method) are the major specifications for iron ore concentrates for the production of pellets. In order that the specified levels are reached the concentrates are submitted to regrinding stages, in general performed in ball mills. High costs and high energy consumption are characteristics of these stages which, added to the huge processed volumes, require very large mills. In most cases it is necessary to estimate the degree of difficulty for grinding a certain ore. There is no simple, standardized, and well-known laboratory method, equivalent to Bond's work index test, to predict the specific energy consumption of the regrinding operation in ball mills. The fact that the grinding stages for Bond's Wi determination are performed under dry condition prevent the utilization of this method whenever the target of grinding is the preparation for pelletizing, for the Blaine index for dry grinding differs significantly from that achieved in wet grinding. Most experiments for predicting specific energy consumption are performed either in pilot plant or laboratory mills with adapted torque meters, providing an indirect determination of the energy at the mill's trunnion. Pilot plant experiments present the disadvantages of requiring large amounts of material, being more expensive and requiring more time than laboratory tests. On the other hand, laboratory tests performed in mills calibrated from industrial mills reflect the plant development stage as it was during calibration.

The utilization of laboratory mills equipped with energy meters or torque meters requires sophisticated set ups and demands special care during the test.

Differences in performance between large industrial mills and laboratory or pilot mills have been stressed by Rowland [2] and Beraldo [3].

The objective of this investigation was, then, the development of a method [4], applied to iron ore concentrates, for predicting the specific energy consumption of industrial ball mills based on tests in small laboratory mills. The method is simple, standardizable, reproducible and utilizes small amounts of material.

The method is based on an equation similar to that proposed by Rowland [5] and Bond [6] for ball mills operating with overflow discharge and diameter > 2.44 m:

$$KWb = 6.3D^{0.3}\sin(51-22 (2.44 - D)/2.44)(3.2-V_p)Cs(1-0.1/2^{(9-10Cs)})$$

kWb = kW per ton of balls at the mill trunnion
D = mill internal diameterd inside liners (m)
V_p = volumetric fraction of the mill occupied by balls
C_s = fraction of critical velocity

The core of the method is an equation that was validated with data obtained during several years of operation of a large industrial plant, Germano's concentrator.

Two models were developed, for percent passing 0.044 mm and for specific surface area (Blaine method), respectively.

The variables that may interfere with the procedure are mill diameter, % filling, % critical velocity, and % solids.

The laboratory grinding tests were performed in a carefully homemade mill. No sophisticated pieces of equipment were required for energy measurements in the laboratory. The ball charge may be easily rebuilt.

Savings in electrical energy consumption of the order of 155 MkWh/year, representing US$4,65 million per year, were achieved. It is worthwhile stressing that almost all the energy consumed in Brazil comes from hydro sources, so saving energy represents not only financial benefits but it is equivalent to save the world's most important asset: *Water*.

3. WATER RECYCLING IN AN IRON ORE CONCENTRATOR

After an expansion of Samarco's concentrator, commissioned in 1997, the pumping capacity of the pipeline became, sometimes, the bottle neck of the production capacity. An analysis of the process and operation of the pipeline indicated the need of utilizing hydrated lime to minimize the risk of plugging, in the case of any unpredicted pumping interruption. A decision was made to add hydrated lime to the pipeline stocking tanks rather than to the concentrate thickeners feed point, to prevent the interference of Ca^{2+} cations, present in the recycled water, with the concentrator performance. Carvalho [7] investigated in laboratory scale the possibility of dosing hydrated lime to the concentrate thickeners and still using the thickeners overflow as process water. The benefits of this modification are increased pumping capacity, due to the fact that the stocked slurry will not be diluted by the lime solution addition, and also a reduction in starch consumption, replaced by lime in the thickening of the concentrate.

The ore sample utilized in the grinding and desliming and flotation tests was collected at the feed point of the concentrator, prior to any contact with the process water. This sample was collected during a CNS (normal silica concentrate, adequate for blast furnace pellets production) run operating with an ore presenting high grades of LOI (loss on ignition) and Al_2O_3, characteristic of ores containing large amounts of natural slimes.

The water sample preparation followed the steps described next. A sample was collected from the feed of the concentrate thickeners. Lime was added to this sample until pH 11.4 was reached. This dosage (1064 g/DMT (dry metric ton)) was considered ideal for the pipeline operation. Other water samples were prepared with positive and negative shifts of 25% with respect to the ideal dosage, in the range between 0% and 200%. After lime addition the samples were left under rest for sedimentation for 10 minutes and the water was then siphoned. A water sample collected from the thickener overflow was combined with the previously prepared water at a ratio 75% : 25% (overflow : previously prepared). This water was utilized in the grinding and desliming tests. The liquid phase for the flotation tests was prepared by combining 5% of the water generated as desliming cyclones overflow (recycled water) and 95% of water collected from the tailings pond (make up water utilized in industrial flotation, not containing Ca^{2+} cations from previous process stages). The 5% figure represents the by-pass of the desliming stage.

The grinding time required to reproduce the concentrator operation condition (10% retained in 100#) was determined. Each individual portion of the standard sample was wet ground in the presence of the water previously prepared. The product of grinding was then sent to the desliming tests. The optimum pH range for dispersion of the standard sample was determined (9.6 to 10.0). Desliming tests were performed with the slurry at pH 10.0, adjusted with NaOH whenever necessary. This pH adjustment was necessary for lime dosages lower than 1064g/DMT. For higher lime dosages the pH of the slurry was already higher than 10.

The plot of dispersion degree as a function of pH, determined in the presence of water containing lime dosage of 1064 g/DMT is presented in Figure 1. When the pH reaches values higher than 10.0, for lime dosage of 1064 g/DMT, the dispersion degree decreases, a fact that did not happen in the presence of de-ionized water. Lime dosages that raise the slurry pH above 10.0 hinder the desliming efficiency.

The metallurgical performance of desliming as a function of the hydrated lime content in the recovered water is illustrated in Figure 2. Weight and metallurgical recoveries increase for higher hydrated lime dosages.

The kinetic behavior of the standard sample was determined, with the utilization of a sample consisting of the products of grinding and desliming performed with distilled water.

The results, presented in Figure 3, show that the ore presents a fast quartz flotation

kinetics, the SiO_2 content in the concentrate being stabilized after 1 to 2 min.

The flotation weight and metallic recoveries and the silica content in the concentrate are illustrated in Figures 4 and 5, respectively, both plots presented as a function of the hydrated lime content in the recycled dosage range from 50% to 175%, with a slight increase for the addition level 200%.
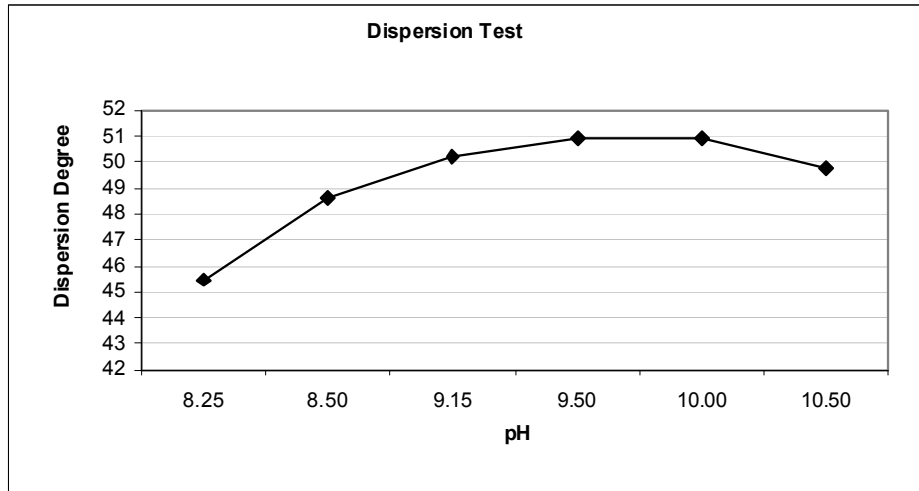

Figure 1 – Dispersion degree with water containing Ca^{2+} cations (1064 g/DMT).
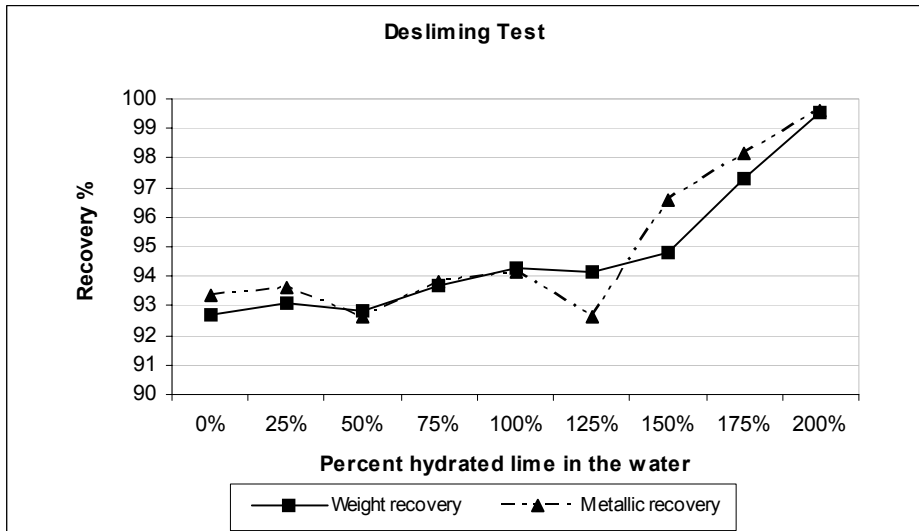

Figure 2 – Desliming metallurgical performance as a function of hydrated lime dosage in the water (100% = 1064 g/DMT).

water. Figure 4 shows a trend to stabilization of metallic recovery in the hydrated lime
It may be observed from Figure 4 that the SiO_2 grade in the concentrate is stable for lime dosages in the water up to 150%, with a significant increase for higher levels. These findings suggest that the increased iron

recoveries and SiO_2 grades in the flotation concentrate may be due to a low dispersion degree of the particles in the pulp and not to the depressant effect of calcium hydroxo-complexes that might have been formed in solution.
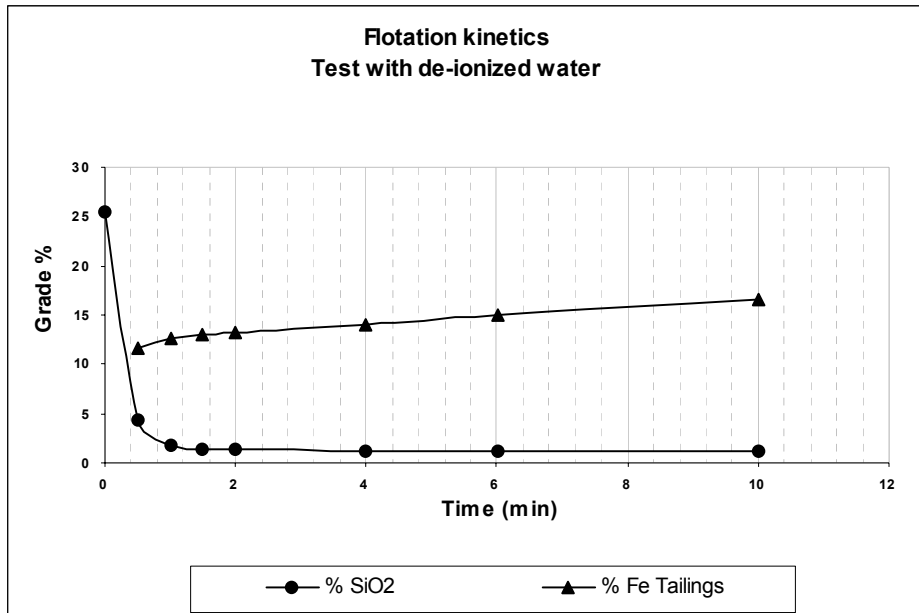

Flotation kinetics
Test with de-ionized water

Figure 3 – Flotation kinetics curve for the standard sample in the presence of distilled water
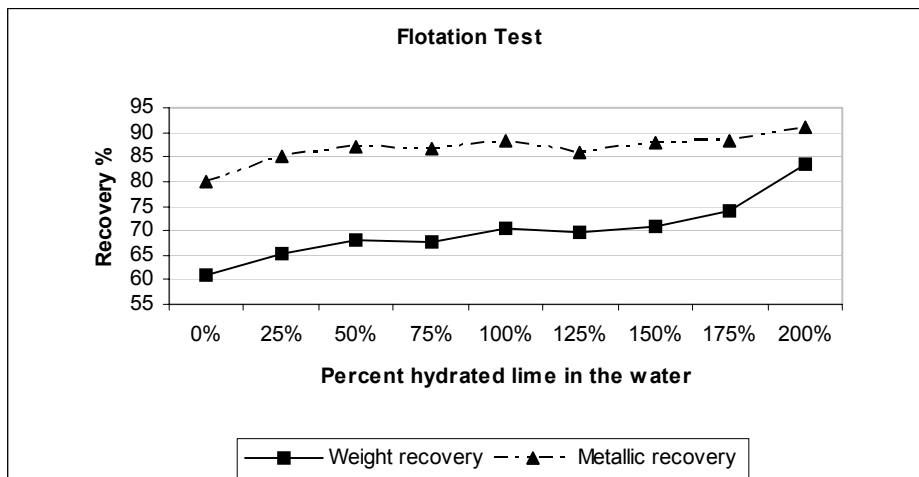

Flotation Test

Figure 4 - Flotation metallurgical performance as a function of hydrated lime dosage in the water (100% = 1064 g/DMT).
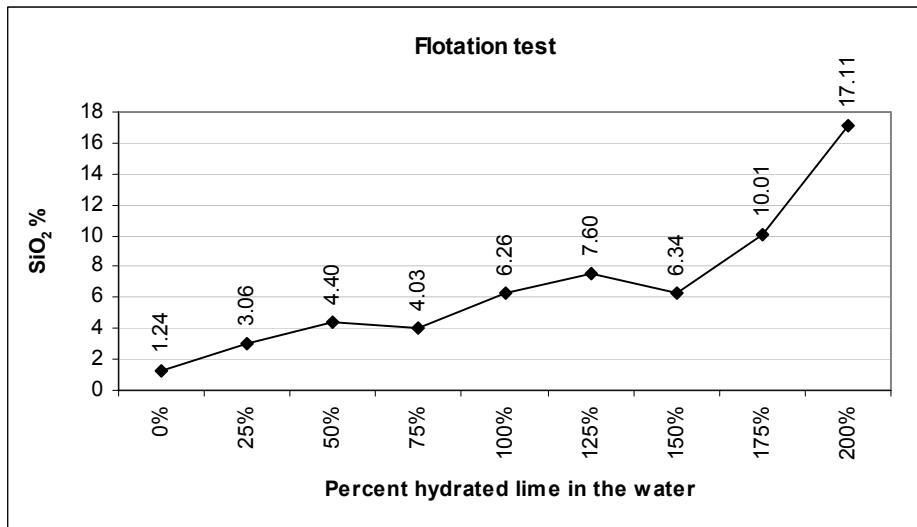
Figure 5 – SiO_2 content in the concentrate as a function of hydrated lime dosage in the water (100% = 1064 g/DMT).

The bench scale results suggested that it is possible to change the point of addition of hydrated lime from the stocking tanks of the pipeline to the feed of the concentrate thickeners. This alteration may impair the desliming performance due to the excess of Ca^{2+} cations, that might act as coagulants for pH values above 10, yielding concentrates with silica content higher than the specifications.

Due to the small proportion of recycled water in the flotation, approximately 5%, this stage is not affected by the calcium ions dosages in the recycled water.

Thus, the addition of hydrated lime, replacing starch, to the thickeners is feasible, since the desliming process is adjusted, either by adjustments of the cyclones parameters (apex, vortex, etc.) or adjustments of the process parameters (% solids, pH control, etc). The use of hydrated lime enhances the clarification of the overflow water and will provide an expected reduction of 2250t/year in starch consumption, besides increasing the pipeline pumping capacity, due to the lack of dilution of the slurry stocked in the tanks.

Since July 2003, the thickeners are being operated with hydrated lime addition. No detrimental effects on the desliming and flotation performances have been observed so far.

4. WATER RECYCLING IN A PHOSPHATE CONCENTRATOR

Bunge Fertilizantes (former Arafertil) mines the "Barreiro" carbonatite complex, located in Araxá, MG, Brazil, producing apatite concentrate since 1978, and the current production capacity is 850,000 metric tons per year. The following unit operations are performed in the concentrator: grinding, classification, low field magnetic separation, desliming, apatite and barite flotation, high field magnetic separation, filtration and drying. Barite and apatite flotations were performed in 300 ft^3 (8.5 m^3) mechanical cells until 1992. The replacement of the mechanical cells by flotation columns occurred in two stages: fine fraction flotation circuit in 1993 and coarse fraction flotation circuit in 1994. All the 64 mechanical cells were replaced by 6 flotation columns (3.0 x 4.5 x 14.5 m), resulting in improved selectivity and P_2O_5 recovery and significant reductions in the consumption of the collectors for barite and, mainly, for apatite. The flotation process control monitoring in laboratory bench scale

mechanical cells was then inadequate due to the discrepancy with the industrial practice. A specific methodology was developed for batch column flotation [8]. The technique was checked by means of comparison with the industrial plant practice of apatite and barite flotation showing its reproducibility and reliability for process development testwork. A batch flotation column was utilized to evaluate the effect of ions (dosed in the conditioning stage) on the flotation of barite and apatite. These experiments aimed at establishing flotation tolerance limits for the ions calcium, magnesium, phosphate, fluoride and rice bran oil soaps.

The environmental benefits were a consequence of the full knowledge and control of the mineral processing plant practice, including its fundamentals, in the company. The batch column was then used to investigate the effect of interfering ions in the barite and apatite flotation circuits.

Apatite and the major gangue minerals, barite, calcite, dolomite, micas, and altered silicates are classified as sparingly soluble minerals. Ions introduced in the pulp by these species, and also the collectors for barite and apatite, build up in the circuit when process water is recirculated. The challenge was: is a closed water circuit feasible? The answer based on the previous experience was: there is no flotation selectivity in the presence of interfering ions.

The batch flotation column is built in acrylic, presents internal diameter of 2" (51 mm) and total height 3,748 mm, consisting of four sections: (i) top section: height 1,030 mm, contains the weir for collecting the floated fraction; (ii) second section: height 1,030 mm, contains the pulp feed opening; (iii) third section: height 1,030 mm; (iv) bottom section; height 680 mm, contains the air sparger and the discharge end for the non floated fraction.

The air sparger utilized is a polyethylene tube with 30% porosity and the following dimensions: external diameter 40 mm; internal diameter 24 mm; height 75 mm. Air and wash water flow rates are measured by

means of flowmeters. A pump, peristaltic to the feed, positioned in the second section, recycles the pulp. The pulp is previously conditioned and then diluted to feed the batch flotation column from the top, after adjusting the air flow rate and connecting the recycling device. The wash water is turned on and the floated material is collected until the froth is barren. The fraction that did not float is then drained from the equipment. The effect of the following variables was evaluated: air flow rate, wash water flow rate, non floated recycled pulp flow rate, mass of solids and fed pulp volume. The reagents types and dosages utilized in the industrial plant were reproduced in the batch column. Sodium cetyl-stearyl sulphate and rice bran oil soap were employed, respectively, as barite and apatite collector.

The influence of ions was checked individually for the flotation of barite and apatite: (i) barite flotation: the effect of cations (sodium, calcium, and magnesium) and anions (chloride, phosphate, fluoride and fatty) dosed one at a time and together was assessed; (ii) apatite flotation: the effect of cations (sodium, calcium, and magnesium) and anions (chloride, phosphate, fluoride, and fatty) dosed one at a time and together was assessed.

Apatite loss in barite flotation was lower than 2% in all tests. The addition of sodium chloride, even at high dosages, did not affect barite flotation (the reason for checking this effect is the fact that cations were added as chlorides and anions as sodium salts). Barite flotation was performed at pH 9.5. The ions calcium and magnesium react with the apatite collector, forming insoluble rice bran oil soaps, reducing the collector level in the system. Phosphate and fluoride ions are common to the apatite lattice, and consequently act as apatite depressants. The addition of sodium chloride, even at high dosages, did not affect apatite flotation. Apatite flotation was performed at pH 11.5.
An evaluation of the interference of ions on the flotation of barite and apatite provided the suggestion of tolerance limits for these ions expressed in Table I.

The definition of the tolerance limits rendered feasible the development of a water recycling project for Bunge's concentrator, resulting in a closed water circuit. A system for monitoring and controlling the quality of recycled water in terms of ions content was established. From 1996 to 2003 the ions content in the recycled water was kept below 5.0 mg/L for magnesium and calcium and below 8.5 mg/L for phosphate and fluoride. Water recycling reduced the phosphorus content concentration in the receiving body of Bunge's wastewater to values lower than the background legal limit of 0.22 mg/L.

Table I.   Limit concentrations of interfering ions in batch column flotation of apatite and barite

Interfering ion	Limit concentration (mg/L)	
	Barite	Apatite
fluoride	50	10
phosphate (expressed as P)	40	10
calcium	30	20
magnesium	30	30
rice bran oil soap	5	-

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