Influence of attrition variables on iron ore flotation

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Abstract

The presence of slimes is harmful to the flotation process: the performance and consumption of reagents are negatively affected. Traditionally, the desliming stage has been responsible for removing slimes. However, depending on the porosity of the mineral particles, desliming may not be sufficient to maximize the concentration results. An attrition process before the desliming operation can improve the removal of slime, especially when slimes cover the surface and/or are confined to the cavities/pores of the mineral particles. Attrition is present in the flowcharts of the beneficiation process of phosphate and industrial sand (silica sand). Research has been undertaken for its application to produce pre-concentrates of zircon and iron ore. However, there is still little knowledge of the influence of the attrition variables on the beneficiation process of iron ore. This study presents a factorial design and analysis of the effects of these variables on the reverse flotation of iron ore. The standard of the experimental procedures for all tests included the attrition of pulp, under the conditions of dispersion, desliming and flotation. The parameter analysed (variable response) was the metallurgical recovery in reverse flotation tests. The planning and analysis of the full factorial experiment indicated that with 95% reliability, the rotation speed of the attrition cell impeller was the main variable in the attrition process of the iron ore. The percentage of solid variables in the pulp and the time of the attrition, as well as their interactions, were not indicated to be significant.

Keywords: iron ore, slime and attrition.

1. Introduction

In order to improve the beneficiation process of lower grade and very fine (<300 microns) ores, the flotation process was developed in the early twentieth century. As the ore reserves are shifting from high grade to lower grade, the flotation process is currently the main method of concentration in mining engineering (Araujo *et al,* 2009). In the flotation process, the differentiation between the mineral species is given by the hydrophobicity of the surfaces, most often induced by reagents. However, the performance of flotation can be affected by the presence of slime (Bulatović, 2007), which may result in higher consumption of the reagents because of the higher specific surface. Slime coating, greater rigidity of the foam, difficulty of the bubble-particle contact and low rate of sedimentation, can also be listed as harmful aspects for flotation due to the presence of slimes.

As affirmed by Bulatović (2007), "the future of development of an effective separation system lies not in the correct understanding of surface chemistry but in the correct understanding of the phenomena interaction of much more complex systems such as slimes and surface interaction in more complex environments". The removal of slimes depends on how they are present in minerals. The slime may be found adsorbed on the surface of the mineral due to electrostatic forces in a phenomenon known as slime coating (Bulatović, 2007). In this case, the dispersants act to promote the increase of electrostatic repulsion or the steric stabilization of the particles, making slime removal easier. Another phenomenon is the presence of slime in the wells, especially related to the porosity of the mineral. The removal of such slimes would be aided by a physical process named by Taggart (1954) as scrubbing or scuffing. By definition, this is the attrition of larger and harder grains against each other in order to discard unconsolidated pellets or remove scale clays in the mineral particles (Taggart, 1954).

Fine particles, once removed from the mineral pores by a physical scrubbing process, tend to return to their stable state, adsorbing on the surface of minerals or forming aggregates with each other. As discussed in previous research (Sabedot and Sampaio, 2002; Queiroz, 2003), the dispersion of the pulp is essential for the removal of slime in the process of scrubbing followed by desliming.

In order to increase the efficiency of the scrubbing process, it is necessary to take care of the process variables. Sabedot and Sampaio (2002) tested attrition on a semi-pilot scale by which they concluded that the time and dosage of NaOH influenced on the removal of fouling in the pre-zircon concentrate. In addition, they affirm that the lowest percentage of solids evaluated could be the most adequate, resulting in minerals with clay adhered only in deep cavities. Queiroz (2003), found in their bench-scale tests that under a high dispersion condition, regardless of the hematite and goethitic ore characteristics, the release degree of slimes increases with the time of attrition. The conclusions presented by Queiroz (2003) were based on experiments considering the percentage of solids and agitator rotation constants. These studies point to attrition as a possibility for increasing the efficiency of the concentration process. However, there is a knowledge gap of the attrition variables.

Iron ore is inherently porous. Schneider *et al.* (2005) argue that, regardless of mineralogy, porosity is usually present in most of the iron ore reserves. Fernandes (2008) mentioned that 63.7% of hematite from Tamanduá (Minas Gerais/Brazil) is porous and 41.8% of hematite from Capitão do Mato (Minas Gerais/Brazil) is porous. In addition to the porosity, the presence of goethite (which is the most responsible for generating slime) with a variety of micro structural features and associations, forms an array of micro pores in Tamanduá's ore (Fernandes, 2008).

The aim of this paper was to investigate the influence of attrition conditions on the reverse flotation of iron ore using a factorial design tool. The evaluation of results was based on the metallurgical recovery of each experiment. The combination of the high percentage of porous particles and the high generation of slimes in the Capitão do Mato and Tamanduá ores justify research on attrition.

2. Materials and methods

The tests were conducted with a blend of hematite iron ore, provided by Vale S.A., from the Capitão do Mato and Tamanduá Mines. The Mossbauer spectrum showed that the sample is composed by 80% of hematite and 5% of goethite, considering that the total iron content is 59.56%. The sample was prepared over a period of 43 days using an industrial cross belt sampler located in the crusher product with size distribution below 31.5 mm and the total mass collected was 433 kg. The sample was wet screened in a 0.15 mm sieve at the laboratory. As in the industrial process, the size range + 0.15 mm was separated, comprising the final sinter feed product. The size range – 0.15 mm was manually homogenized, quartered and reserved for laboratory tests. The iron content of the quartered aliquots presented a normal distribution and no outlier, considering three sigma, validating the equality of the sample units. Equality of samples can be understood as stability of values around the mean. The instability criteria are based on the probability of occurrence of Normal curve values.

The planning of experiments was divided into two stages: pre-selection of the variables based on Plackett-Burman and investigation of the significant variables in the attrition process through Complete Factorial Experiment 2^3. The experiments were conducted as stipulated in the factorial design 2^k. The tests were undertaken in duplicate and with a random order of realization. Only replication with errors of less than 5% was accepted. Three variables were selected in the attrition: the percentage of solids (wt%), time and the rotation speed (RS) of the attrition cell impeller. The variables and their levels (maximum and minimum values) are shown in Table 1. The matrix of planning for the tests is shown in Table 2. The parameter analysed (variable response) was the metallurgical recovery in the reverse flotation cell. The analysis was performed with the aid of the module DOE (Design of Experiments) of Minitab software version 16, considering 95% reliability.

The attrition tests were carried out in a 1.5 liter Equipron attrition cell, a steel vat with a transparent viewing window, one shaft and two impellers with blades that promote flows in opposite directions. The attrition cell has a motor with an inverter, allowing frequency adjustment within the range 0–60 Hz, which corresponds to a velocity within the range 0–1750 rpm. The percentage of solids in the pulp was adjusted as described in Experiment Planning (30% or 70% solids).

The standard procedure for all tests was attrition of the pulp in a condition of dispersion, desliming and flotation. The pH of the pulp was adjusted to 9.8 (value of the maximum dispersion of the ore) for the desliming tests and 10.5 for the flotation tests. The pH was adjusted with solutions of NaOH and HCl. The slaking was conducted with pulp containing 25% solids by weight. The pulp was stirred for 5 minutes with the aid of an electromechanical stirrer, followed by settling for 3 minutes, and finally the suspended solid was siphoned from the interface separating the sedimented solid. The sunken material was dried and weighed to feed the bench flotation tests. Bench-scale flotation tests were undertaken in a CDC cell (Engender) model CFB-1000 EEP NBA. The volumetric capacity of the cube used was 1 L, the velocity of the rotor was 1.200 rpm and aeration was set at 8 mL/min. The solids percentage of the pulp was 50% for all experiments. Amine was used as a collector at a dosage of 45 g/t and starch was used as the depressant at a dosage of 1000 g/t of feed. The starch was conditioned for 3 minutes and the amine for 1 minute. The chemical analyses of the floated and sunk products were undertaken by X-ray fluorescence.

Variables		Level	
		+	-
Percentage of solids	%	70	30
Time	Min	20	5
Rotation speed (RS)	Rpm	1000	100

Table 1
Levels of variables
in the attrition of the iron ore.

Test	Variables		
	% Solids	Time (min)	RS
R1j*	30	5	100
R2j	70	5	100
R3j	30	20	100
R4j	70	20	100
R5j	30	5	1000
R6j	70	5	1000
R7j	30	20	1000
R8j	70	20	1000

* j = 1, means first test; j = 2, means duplicate test.

Table 2
Matrix of the full factorial design 2^3 for attrition of iron ore.

3. Results and discussion

The results of the metallurgical recovery of the flotation tests, according to factorial design 2^3, are presented in Table 3.

Tests	Variables			Metallurgical Recovery
	% Solids	Time (min)	RS	
R11	30	5	100	84.2
R12	30	5	100	92.3
R21	70	5	100	79.2
R22	70	5	100	82.2
R31	30	20	100	84.2
R32	30	20	100	92.1
R41	70	20	100	88.4
R42	70	20	100	91.3
R51	30	5	1000	94.4
R52	30	5	1000	92.2
R61	70	5	1000	91.6
R62	70	5	1000	93.4
R71	30	20	1000	92.8
R72	30	20	1000	92.9
R81	70	20	1000	92.6
R82	70	20	1000	90.8

Table 3
Results of metallurgical recovery of flotation tests according to conditions established in factorial design.

Every pair of duplicate experiments presented a relative error below the acceptable value, 5%. Table 4 shows the output of the Minitab DOE module for metallurgical recovery.

Term	Effect	Coefficient	T
Constant		89.663	114.58
% Solids	-1.950	-0.975	-1.25
Time	1.950	0.975	1.25
Rotation Speed (RS)	5.850	2.925	3.74
% Solids * Time	2.225	1.112	1.42
% Solids * RS	0.975	0.487	0.62
Time* RS	-2.575	-1.288	-1.65
% Solids * Time * RS	-2.400	-1.200	-1.53

Table 4
Estimated effects and coefficients for the metallurgical recovery of flotation of the full factorial experiment of attrition of iron ore.

Assuming 95% reliability and 8 degrees of freedom, t-Student's statistic, $t_{0.05,\,8}$, is equal to 2.306. Comparing this value with those of the statistic T shown in Table 4, it can be stated that only the variable RS (T= 3.74 > 2.306) is significant. In this case, the regression model to estimate the metallurgical recovery is presented by Equation 1.

$$\text{Metallurgical Recovery Estimated} = 89.663 + (2.925 / 2) * RS \quad (1)$$

where, RS is the rotation speed of the impeller in the attrition cell in revolutions per minute (rpm) where, RS is the rotation speed of the impeller in the attrition cell in revolutions per minute (rpm).

All flotation variables were kept constant and taking into account the three attrition variables under study, only the rotation of the impeller in the attrition cell influences the metallurgical recovery of the flotation.

Attrition is a known step in the enrichment process of phosphate and silica sand. However, its effects on iron ore are an unknown process. For situations where there is reduced bibliographic information and practical experience, statistical methods are important. The planning and analysis factorial of the experiments enable the investigation of the possible effects with the variables, as well as the interactions of the second and third orders. In order to have reliable conclusions, it becomes necessary to examine the residues and the non-violation of the basic assumption so that the results follow a normal distribution. Residue (eij) is the difference between the value estimated in the regression model and the value of metallurgical recovery found in each test. The graph of normal probability of the residue is shown in Figure 1.

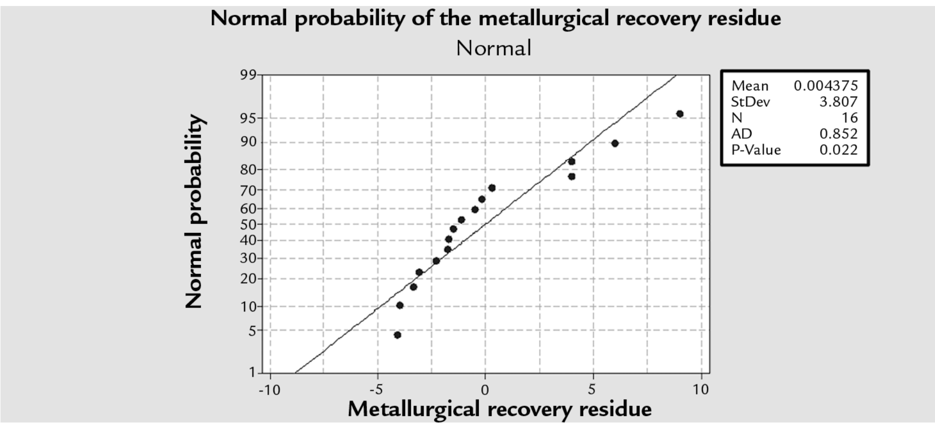

Figure 1
Graph of the normal probability of the factorial experiment residuals.

Upon analysing the P-value (<0.05) and with the distribution of the points being roughly along a straight line, indicates that there is no problem with the normality of the data. Thus, the regression model relating the rotation velocity of the attrition cell impeller and the metallurgical recovery in bench flotation tests is statistically valid.

The granulometric analysis of the attrition feed and of the flotation feed (test with lower metallurgical recovery, R21), shown in Figure 2, indicates that the passing percentage of 0.038 mm is higher in the flotation feed (71%). It suggests that scrubbing caused fragmentation of the ore, mainly of the finer fraction, which corroborates the plant's observation of the high generation of fines in processing this ore.

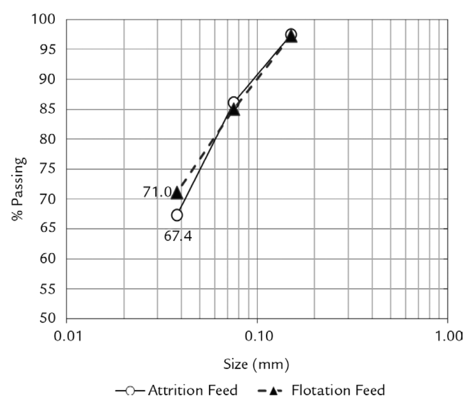

Figure 2
Particle size distribution of attrition and flotation feeds.

4. Conclusion

The planning and analysis of the full factorial experiment indicated that, with 95% reliability, the rotation speed of the attrition cell impeller was the main variable in the attrition of the iron ore composed of ores from Capitão do Mato and Tamanduá Mines. The variables, percentage of solids in the pulp and the time of attrition, as well as their interactions, were not statistically significant. It is possible to conclude that there was an increase in the metallurgical recovery of the reverse flotation of porous hematitic iron ore with the attrition of feed pulp followed by desliming of the dispersed ore. The attrition also presented side-effects. There was evidence of finer fraction degradation ore after the attrition. The higher speed of agitation in the flotation cell is directly proportional to the metallurgical recovery.

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