Effect of particles size range on iron ore flotation

Efeito da faixa de tamanho de partículas na flotação de minério de ferro

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Resumo

A flotação é um dos principais processos de concentração, sendo empregada para diversas classes de minerais (sulfetos, óxidos, silicatos, fosfatos, etc.), em relativamente ampla faixa de tamanhos de partículas. Na indústria de minério de ferro, a flotação reversa de quartzo tem sido empregada com sucesso para partículas abaixo de 150µm, após a etapa de deslamagem. A elevada demanda por produtos de minérios de ferro torna a flotação o principal processo de concentração dessa indústria, sendo assim necessária uma melhor compreensão dos mecanismos do processo, assim como do efeito do tamanho das partículas nesse processo.

Foram realizados ensaios de flotação com três diferentes frações granulométricas de um minério de ferro itabirítico, obtidas por classificação em ciclones, após a etapa de deslamagem. Os resultados obtidos mostraram diferenças de comportamentos entre as três frações, com maior dosagem de eteramina para as frações grossa e fina flotadas separadamente. A flotação em separado apresentou maior sensibilidade às variações de processo, principalmente no que diz respeito à dosagem de eteramina e ao pH. As diferenças granulométricas e de área superficial específica podem justificar as diferenças de comportamento observadas nos ensaios de flotação.

A flotação em separado das frações grossa e fina indicou aumento de 3 pontos percentuais na recuperação metálica, com redução no teor de SiO_2 no concentrado, aumento de 30% na dosagem de eteramina e redução de 20% no consumo de amido de milho em comparação com a flotação em conjunto destas frações. Análise de viabilidade econômica indicou VPL positivo de 50 milhões de dólares com a separação entre os circuitos de flotação de grossos e finos para o minério estudado, considerando a produção de 10 milhões de toneladas por ano de pellet feed.

Palavras-chave: Flotação de minério de ferro, faixas de tamanho de partícula, reagentes de flotação.

Abstract

Flotation is one of the main concentration processes being employed for many classes of minerals (sulfides, oxides, silicates, phosphates, for example) at different particle sizes. In the iron ore industry, reverse quartz flotation has been successfully employed for particle sizes below 150µm after the desliming process. The high demand for iron ore products has made flotation the main process for concentration in this industry, thus a better understanding of its mechanisms and the effect of the particle sizes in the process has become imperative.

Flotation tests were carried out with three different size fractions of an itabirite *iron ore, obtained using cyclone classification after desliming. The results showed distinct behaviors of the different size ranges. Higher etheramine dosages are required when coarse and fine fractions are floated separately and also this procedure is more sensitive to variations in etheramine dosages and pH values. The differences in particle size distributions and the specific surface area may explain the different flotation behavior of the distinct size fractions.*

The split flotation circuits for coarse and fine particles indicated an increase of 3% points in the metallurgical recovery with reduction of SiO_2 content in final concentrate, increase of etheramine dosage and reduction of corn starch dosage. Economic feasibility analysis indicated a positive net present value of 50 million of dollars with split circuits for coarse and fine particles, considering a production of 10 million tons per year of pellet feed.

Keywords: *Iron ore flotation, particle size ranges, flotation reagents.*

1. Introduction

Flotation has been employed for over 100 years to a wide range of minerals: sulfides, oxides, phosphates, silicates, coal and soluble salts. The development of the mineral industry has been influenced substantially from the discovery and utilization of flotation. A large part of the world production of iron ore, necessary for the production of steel in the levels of current consumption, only became possible in the last decades with the utilization of the flotation process on a large scale (Oliveira, 2006).

The flotation processes for iron ore, either in mechanical cells or in columns, are fed with particles with sizes between 10 and 150μm, being the slimes removed as overflow in classification cyclones. This wide range of particle sizes can affect the selectivity of the process given the possible differences in hydrophobicity, specific surface area, weight, etc.).

Some authors (Tomlinson et al., 1963; Gonzales, 1978) described the flotation mechanism through probabilistic concepts using the expression:

$$Pf = Pc \cdot Pa \cdot Ps \quad (1)$$

where:
Pf = probability of flotation.
Pc = probability of collision between the particles.
Pa = probability of adhesion (thinning and rupture of the liquid film during the collision).
Ps = probability of forming a stable aggregate, capable of supporting the turbulences inside the flotation machines.

The probability of collision has deserved the attention of various researchers (Flint & Howarth, 1971; Reay & Ratcliff, 1975; Anfruns & Kitchener, 1977; Collins & Jameson, 1978), who showed that Pc is directly related to physical variables such as: density, pulp viscosity, relative speed of the bubble-particle and, more specifically, the diameter of the particle and of the bubble. An expression firstly deduced by Collins & Jameson (1978) shows that, for a given gas flow, the efficiency of the collision (Ec) would be expressed by:

$$Ec \approx (dp / db)^2 \quad (2)$$

where:
dp = particle diameter
db = bubble diameter

This expression is in agreement with experimental results obtained by Ray and Ratcliff (1975), who found the correlation:

$$Ec \approx dp^{1,5} \quad (3)$$

Figure 1 illustrates the collision efficiencies calculated and obtained experimentally for the different sizes of particles, according to the general model of collision proposed by Sutherland (1948).

The results from Figure 1 indicate a considerable increase in the collision efficiency with the increase in the particle size.

The adhesion efficiency for the different sizes of the particles was obtained experimentally by Dai (1999), presenting a good adherence to the calculated values.

According to Oliveira (2006), the concept that the quicker and disproportional consumption of the collector by fine particles, due to their greater specific surface area, causes a lower hydrophobic coverage of the coarse particles, which therefore are less floatable, is quite well known throughout the technical literature. This concept was initially supported by the experimental work of Robinson (1975), referring to the quartz-dodecylamine system and by Glembotsky (1968) referring to the pyrite-xanthate system. These authors have observed that a greater dosage of reagents is necessary to float larger particles.

In the iron ore industry reverse quartz flotation is carried out with the addition of etheramine as collector and corn starch as iron oxides depressant. According to the work carried out by Brandão (2005), the explanation for the selectivity observed in the industry and in the laboratory is not related to the qualitative aspects of the adsorption of the collectors (primary ammonium salts) and depressants (starch), but to the quantitative aspects. Thus the starch is adsorbed extensively onto hematite and with lesser intensity onto quartz; in the following stage the cationic alkyletheramine collector could only be adsorbed in small quantities on hematite, yet achieves a much greater

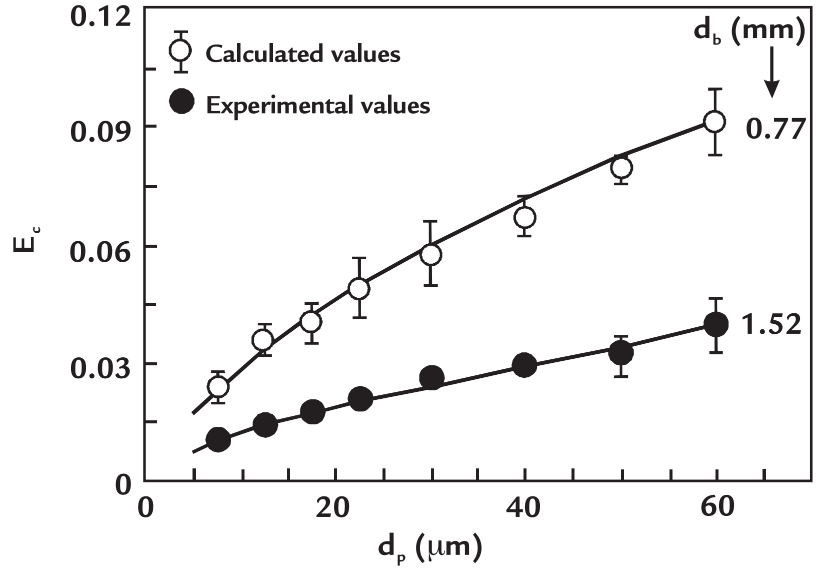

Figure 1
Calculated and experimental collision efficiencies using the general model of collision. Adapted from Sutherland (1948).

adsorption on quartz. In this way, after sequential conditioning with two reagents, hematite remains clearly hydrophilic and quartz, on the other hand, changes its hydrophilic character to predominantly hydrophobic.

Work carried out by Lima (2001) demonstrates the effect of the presence of ultrafine particles (<10μm) in the flotation of different iron ore samples. Figure 2 shows the SiO_2 contents in the concentrate for the different ultrafine percentages.

The results in Figure 2 illustrate the effect of the presence of ultrafine particles in iron ore flotation, therefore justifying the necessity for desliming. The high levels of SiO_2 in concentrate in the case of the high ultrafine contents can be justified by the high consumption of collector by the ultrafine particles, caused by their high specific surface area.

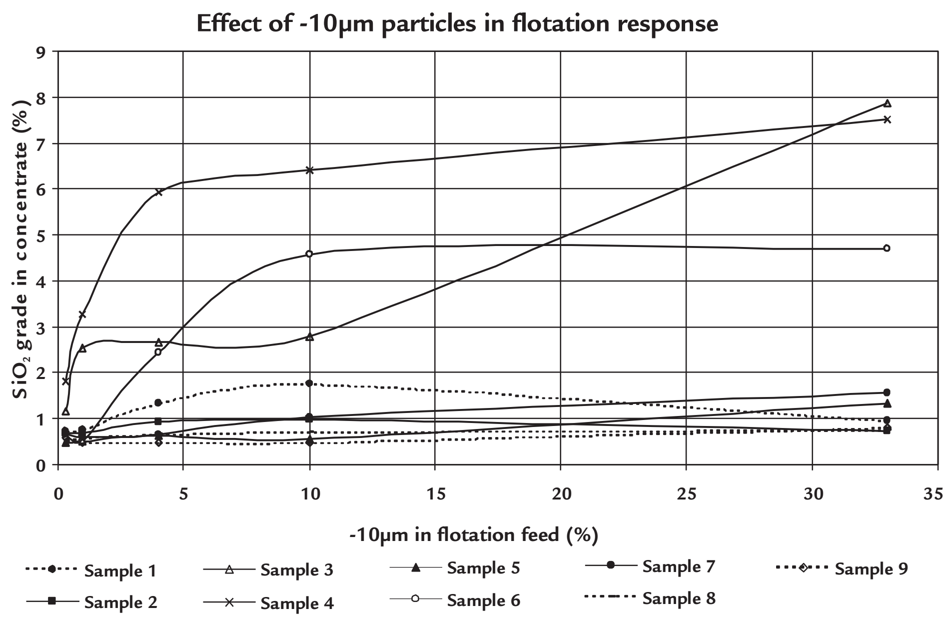

Figure 2
Effect of the presence of ultrafine particles in flotation for different samples of iron ore. Adapted from Lima (2001).

2. Materials and methods

The sample used in this work represents an itabirite iron ore from the Iron Quadrangle. The characterization was performed through chemical analyses (global and by size range) and size distribution. After desliming, the sample was classified in order to obtain two size distribution fractions (-150 +45μm and -45μm), to be used in laboratory scale flotation tests with different reagent dosages (corn starch and etheramine) and pH values. The flotation tests were carried out with coarse fraction (-150+45μm) and fine fraction (-45μm) and compared with the performance of the global fraction (-150 μm, pellet feed product).

The tests aimed at evaluating the effect of different reagent dosages and pH values for the three size distribution fractions.

The flotation tests were carried out under the following conditions:

- Collector: etheramine with 30% neutralization degree, prepared at 2% concentration by weight.
- Depressant: corn starch, prepared at 2% concentration by weight.
- Sodium hydroxide: utilized to adjust the flotation pH, prepared at 5% concentration by weight.
- Percentage of solids in mass: 50%.

Table 1 shows the levels of variables practiced during the flotation tests for each size fraction.

Conditions	Size fraction (μm)		
	-150 (global)	-150+45 (coarse)	-45 (fine)
pH	9.5 and 10.7	9.5 and 10.7	9.5 and 10.7
Etheramine (g/tSiO_2)	180 and 300	150 and 250	120 and 200
Corn starch (g/t_{feed})	500 and 1000	500 and 1000	500 and 1000

Table 1
Levels of variables practiced in the flotation tests.

3. Results and discussion

Table 2 shows the results of chemical analyses and the partition of the three size fractions obtained by laboratory screening scale after desliming.

The mineralogical analysis indicated that the main mineral species present in all size fractions are hematite and quartz.

The particle size distribution of the coarse and global fractions is shown in Figure 3. The fine fraction presented 100% of particles passing 45μm.

Size fraction (μm)	%	Chemical assay (%)	
		Fe	SiO_2
-150 (global)	100.00	46.00	32.90
-150+45 (coarse)	42.20	30.03	55.52
-45 (fine)	57.80	57.67	16.38

Table 2
Chemical analyses and partition of the global, coarse and fine fractions.

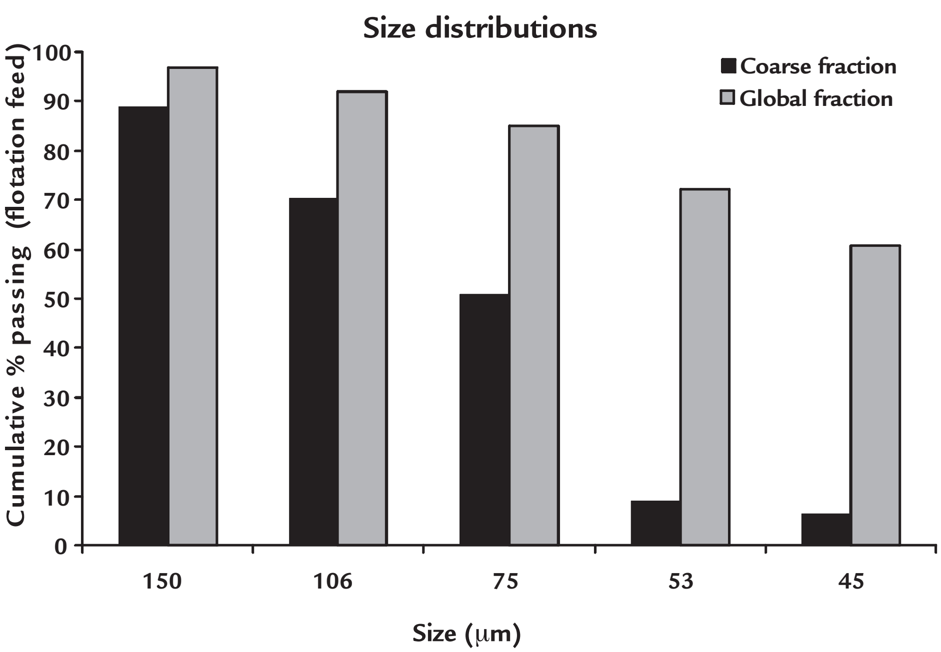

Figure 3
Size distributions in the flotation feed of the global and coarse fractions.

The global fraction presented high percentage of fine particles, approximately 60% passing 45μm, whereas the coarse fraction presented only 6% of fine particles and 15% of particles retained in 150μm.

Table 3 shows the specific surface area of the three size fractions.

Tables 4 and 5 show the results of iron recovery in concentrate, SiO_2 content in concentrate and iron content in tailings for the three particle size fractions obtained for the different dosages of etheramine and corn starch and pH values.

The results on Tables 4 and 5 indicate that the three particle size fractions presented different flotation behaviors for the different dosages of reagents and pH used. The global fraction -150μm yielded the best results regarding recovery and SiO_2 content in concentrate for 1000g/t of corn starch, 180g/tSiO_2 of etheramine and pH equal to 9.5. The best results for the coarse fraction were obtained with 500g/t of corn starch, 250g/tSiO_2 of etheramine and pH equal to 9.5. The fine fraction presented the best results with 1000g/t of corn starch, 200g/tSiO_2 of etheramine and pH equal to 10.7. The results on Tables 4 and 5 also show that the SiO_2 content in concentrate presents a greater sensitivity to the variations in dosage of etheramine and pH for the coarse and fine fractions, lower sensitivity being observed for the global fraction -150μm. The differences

Size fraction (μm)	Specific surface area (cm^2/g)
-150 (global)	550
-150+45 (coarse)	450
-45 (fine)	750

Table 3
Specific surface area of three size fractions.

in size, density and specific surface area can justify the differences in behavior observed in Tables 4 and 5.

The best results achieved for each particle size fraction are summarized on Table 6.

The results presented on Table 6 indicate that the best etheramine dosage is different for each size fraction. The coarse fraction requires higher etheramine dosage, lower corn starch dosage and yields higher iron recovery in concentrate. The fine fraction yields a concentrate presenting the lowest silica content.

Table 7 shows a comparison between the results considering the flotation of split and global size fractions.

Splitting the flotation feed in coarse and fine fractions allowed 3% gain in the metallurgical recovery, with reduction in the SiO_2 content in final concentrate, with a greater consumption of etheramine and lower consumption of corn starch. These results indicate the possibility of increasing flotation efficiency when fed by narrow ranges of particle size distribution, due to the differences in behavior between them. Moreover, due to the greater specific surface area of the fine fraction particles, insufficient collector coverage on the coarse particles may occur when these fractions are floated together.

Table 4
Effect of etheramine dosage and pH (using 500g/t of corn starch).

Size fraction (μm)	Etheramine ($g/tSiO_2$)	pH	Recovery of Fe in concentrate (%)	SiO_2 in concentrate (%)	Fe in tailings (%)
-150 (global)	180	9.5	70.72	1.04	25.83
	300		60.99	0.70	30.55
	180	10.7	75.79	1.62	23.07
	300		60.74	0.92	30.88
-150+45 (coarse)	150	9.5	78.65	1.18	9.89
	250		83.76	3.81	7.54
	150	10.7	75.70	0.77	11.08
	250		84.70	1.16	7.33
-45 (fine)	120	9.5	81.46	5.73	38.20
	200		63.06	1.33	45.72
	120	10.7	82.69	2.30	32.28
	200		73.47	0.87	40.52

Table 5
Effect of etheramine dosage and pH (using 1000g/t of corn starch).

Size fraction (μm)	Etheramine ($g/tSiO_2$)	pH	Recovery of Fe in concentrate (%)	SiO_2 in concentrate (%)	Fe in tailings (%)
-150 (global)	180	9.5	74.95	1.17	23.37
	300		65.77	0.67	28.77
	180	10.7	76.76	1.35	22.50
	300		64.63	1.00	29.08
-150+45 (coarse)	150	9.5	79.06	1.17	9.68
	250		83.63	4.70	8.34
	150	10.7	80.86	0.64	9.04
	250		82.73	1.90	8.10
-45 (fine)	120	9.5	86.05	4.95	33.19
	200		75.01	0.86	39.19
	120	10.7	89.25	2.39	26.25
	200		79.52	0.63	35.78

Table 6
Summary of the best flotation tests results.

Size fraction (μm)	Etheramine ($g/tSiO_2$)	Corn starch (g/t_{feed})	pH	Recovery of Fe in concentrate (%)	SiO_2 in concentrate (%)	Fe in tailings (%)
-150 (global)	180	1000	9.5	74.95	1.17	23.37
-150+45 (coarse)	250	500	10.7	84.70	1.16	7.33
-45 (fine)	200	1000	9.5	75.01	0.86	39.19

Table 7
Comparison between flotation of global and split particle size fractions.

Conditions of flotation	Etheramine ($g/tSiO_2$)	Corn starch (g/t_{feed})	pH	Recovery of Fe in concentrate (%)	SiO_2 in concentrate (%)	Fe in tailings (%)
Coarse and fine together	180	1000	9.5	74.95	1.17	23.37
Coarse and fine separated	236	789	10.0	77.67	0.95	21.53

4. Conclusions

Flotation tests carried out in bench scale with three different particle size fractions of itabirite iron ore indicated distinct behaviors, as well as differences in the required dosages of etheramine and corn starch and in the pH values. Flotation in separate circuits for the coarse and fine fractions yielded an increase of 3% points in the metallurgical recovery with a reduction in the SiO_2 content in the final concentrate, an increase of 30% in the consumption of etheramine, a reduction of 20% in the consumption of corn starch and a slightly higher pH level. In addition the results indicated that the separate flotation circuit presents a greater sensitivity to SiO_2 content in concentrate with respect to variations in the etheramine dosage and pH value.

Economic feasibility analyses carried out on splitting the flotation circuits indicated a positive NPV (net present value) of 50 million of dollars, taking into consideration an increase of 3% in the metallurgical recovery, the increase in the cost of etheramine and the cost of acquiring the equipments (tanks, pumps, conditioners, etc) for the separation of the circuit. The analysis was done considering the production of 10 million tons per year of pellet feed.

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