Influence of agitation intensity on flotation rate of apatite particles

http://dx.doi.org/10.1590/0370-44672017700010

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Abstract

The agitation intensity has a directly influence on flotation performance, lifting the particles and promoting the contact of bubbles and particles. In this paper, the energy input by the agitation on apatite flotation was investigated. The influence of pulp agitation in the flotation rate of particles with different sizes and two dosage levels was evaluated by batch testing. The flotation tests were conducted in an oscillating grid flotation cell (OGC), developed to promote a near isotropic turbulence environment. The cell is able to control the intensity of agitation and measure the energy transferred to the pulp phase. A sample of pure apatite was crushed (P_{80}=310μm), characterized and floated with sodium oleate as collector. Four levels of energy dissipation, from 0.1 to 2 kWm^{-3}, and two levels of collector dosage are used during the tests. The flotation kinetics by particle size were determined in function of the energy transferred. The results show a strong influence of the agitation intensity on the apatite flotation rate with both low and high dosage. For fine particles, when increasing the energy input, the flotation rate increase too, and this fact can be attributed to elevation of bubble-particle collisions. The kinetic result for the coarse particles demonstrated a reduction of the flotation rate whenever the energy input for this particle size was increased, whereby the turbulence caused by the agitation promotes the detachment of bubble-particle.

Keywords: flotation kinetics; apatite; agitation.

1. Introduction

The agitation in a conventional flotation machine is promoted by the rotor-stator system with the turbulence suspending the particles and drawing the pulp through the stator to disperse the bubbles, promoting the contact of bubbles and particles (Schubert, 1999). The typical industrial range of energy input using mechanically agitated flotation cells is 1.0-2.0kW/m^3 (Deglon, 2005). Frequently in flotation plants the agitation intensity of the flotation cells is the same for coarse and fine particles.

Experimental studies investigated the effect of particle size on flotation kinetics showing there is a favorable particle size range to float (Bartlett and Mular, 1974). The flotation performance of fine and ultrafine particles is low due to the low collision probability with bubbles due to their low momentum (Ahmed and Jameson, 2007 and Miettinen *et al.*, 2010).

Coarse particles require enough energy in the agitation to be lifted in the flotation cell (Lima *et al.*, 2009), and under this condition, the detachment effects become important (Ahmed and Jameson, 1989). Near the impeller, there occurs a dissipation of energy 300 times greater than the average system (Schulze, 1977), and the detachment in this region is much more expressive. The consequence is coarse particles that do not float efficiently because the turbulence created by the impeller to accomplish particle suspension, bubble dispersion and further collision between bubbles and particles may be sufficiently high to destroy particle-bubbles aggregates and cause the recovery to fail (Leal Filho *et al.*, 2002). Massey (2011) observed that when using high levels of power dissipation of energy in the agitated cells, the high occurrence of detachment near the rotor becomes dominant.

To avoid the effect of anisotropy caused by impeller in mechanical cells and investigate the effect of energy, Changunda *et al*. (2008) developed a flotation cell with oscillating grid. In this cell, the agitation is promoted by the oscillatory motion of parallel grids positioned inside the machine. Posteriorly, based on the cell by Changunda *et al*. (2008), Massey (2011) developed a cell flotation with the same dimensions, but which can operate at higher energies, reaching 5 kW/m³, similar to the conventional cells.

The concept of agitation (energy input) by oscillating plates or grids to promote an environment with homogeneous turbulent agitation in flotation cells has been used in several studies, the Table 1 shows the papers and the minerals investigated.

Title	Mineral	Authors and year
Investigating the effect of energy input on flotation kinetics in an oscillating grid flotation cell	Quartz	Changunda *et al.*, 2008
Flotation in a novel oscillatory baffled column	Quartz	Anderson *et al.*, 2009
Investigating the effect of energy dissipation on flotation kinetics in an oscillating grid flotation cell	Quartz	Massey, 2011
The effect of energy input on the flotation of quartz in an oscillating grid flotation cell	Quartz	Massey *et al.*, 2012
The effect of energy input on the flotation kinetics of galena in an oscillating grid flotation cell	Galena	Safari *et al.*, 2014
The effect of energy input on flotation kinetics	Quartz, Galena, Pyrite, Apatite, Pentlandite and Hematite	Safari *et al.*, 2016

Table 1
Published studies of mineral flotation using agitation by a grid oscillation.

The results of Massey (2011) using Oscillating Grid Cell (OGC) show concordance with the literature of stirred flotation cells using low energy input. This makes it possible to compare the results obtained in these two cell types wherein the studies with oscillatory grid cell can be considered a more accurate representation.

Safari *et al*. (2014) studied the effect of energy inserted into the cell of the flotation kinetics of galena using the OGC, which is the first work for sulfide with that cell type. The results show that for fine particles, the increased energy stepped up the flotation rate, while for coarse particles, the effect of the inserted energy in flotation is the opposite, reducing the rate of flotation.

2. Experimental

Materials

The sample used in the tests was a pure apatite sample from the Ipiá mine in Brazil. The preparation of the sample consisted in comminuted apatite fragments in a jaw crusher followed by ball mill pursuing a similar particle size of an industrial apatite ore.

A laser diffraction equipment Malvern Mastersize™ M2000 measured the particle size of the sample. The Figure 1 shows the particle size distribution of the sample used in the flotation tests, with high quantities of coarse particles.

The chemical assay has been determined using XRF, the results presented in Table 2 show high P_2O_5 and CaO grades proving the predominance of apatite in the sample.

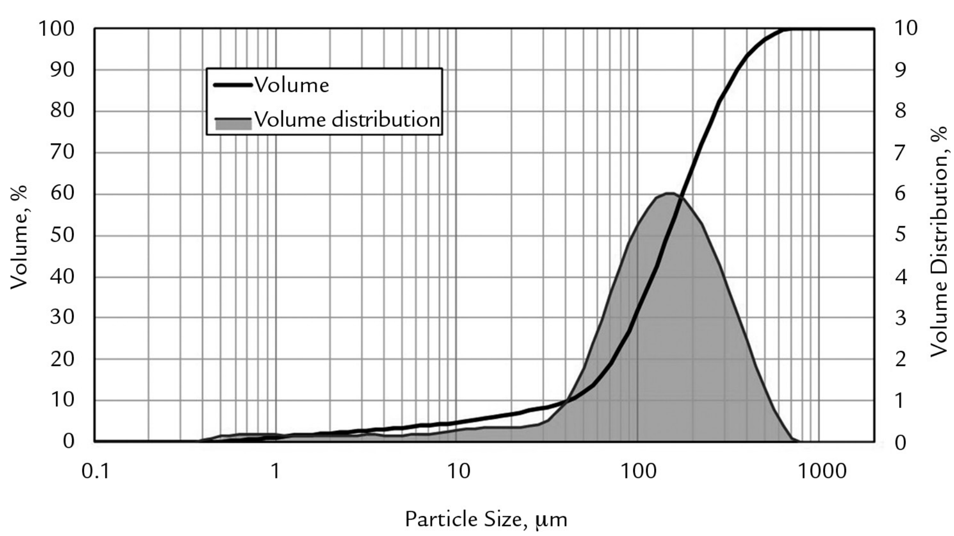

Figure 1
Particle size distribution of the apatite sample.

Table 2
Apatite sample chemical assay results.

Grade (%)

P_2O_5	CaO	Fe_2O_3	SiO_2	Al_2O_3	TiO_2	MgO	Na_2O	K_2O	PF
37.5	51.9	0.22	7.6	<0.1	0.01	<0.1	<0.1	<0.01	0.63

Saponified oleic acid was used as the apatite collector in the tests with the preparation consisting of adding NaOH to the oleic acid under agitation, after which deionized water was added to dilute until 2%. An MIBC frother is used in all tests in a concentration of 100ppm to ensure stable bubble size during the flotation.

Oscillating Grid Cell

The flotation cell used in the study (Figure 2) is the same as that of the quartz study conducted by Massey (2011) and Massey *et al.* (2012) and the study of Safari *et al.* (2014) to float galena.

Figure 2
Oscillating grid flotation cell (OGC) developed by Massey (2011).

A tank, an agitation system, an aeration system, a recycle pump, and collector system compose the OGC. The tank is made of transparent acrylic, and has a height of 380mm, width of 180mm and a volume of 10L.

The OGC has 19 horizontal parallel grids fixed on the drive shaft, spaced 18mm between each other; the grids promote the agitation inside the vessel. The grids are made of stainless steel and cut by laser forming a square hole with 6.8mm side and grid solid size of 1.6mm. Grid oscillation frequencies are varied by a frequency inverter of a motor connected to the crank.

The force on the driving shaft is measured by an S-type load cell mounted in line, and the force transmitted to the slurry is the difference between the force with slurry in the cell and without slurry. An optical sensor on the drive shaft measured the frequency of oscillations. The average power input is calculated using the measured force, the velocity of grid stack and oscillation frequency.

The OGC is equipped with a recycle system, required to keep the particles adequately dispersed. A peristaltic pump suctions the pulp from the bottom of cell and discharges it on the top. Three spargers on the bottom of the cell generate bubbles by the injection of air through sintered glass frits. A flowmeter measured the gas flow controlled by a pinch valve; the superficial gas velocity was 0.0065cm/s. The low airflow rate and low quantity of sample are used to minimize the influence on turbulence of the system.

The procedure of the tests consisted in disposing 60g of the apatite sample into the OGC vessel, without the injection of air, full of tap water with a pH of 10.5, regulated by addition of NaOH. After one minute under agitation, the collector and frother were added while under agitation for one more minute. Then, conditioning the agitation intensity was set according the test, and the air valve was opened. Two dosages of collector were used: low dosage corresponds to a concentration of 30 ppm and high dosage corresponds to 60ppm.

If the system has no froth phase, the concentrate was collected by suction in different flasks over the minutes 1, 2, 3, 6 and 9, to calculate the flotation rate. The concentrates and the tailings are filtered using a lab vacuum filter, and dried in a lab oven. The dried samples were weighed on an analytical scale, and the mass losses could not exceed 1%. The particle size distribution of each concentrate and the tailings were determined using Malvern Mastersize™ 2000. These data were used to determine the flotation rate by particle size.

3. Results and discussion

The results are expressed in three particle size fractions, *Fines* for the particles less than 45µm, *Intermediate* for the particles between 45 and 160 µm, and *Coarse* for the particles larger than 160 µm. These fractions are selected based on the flotation behavior when submitted to different levels of agitation.

The Figure 3 shows the results obtained in the tests in the OGC using low collector dosage. The results are expressed by size fractions: fines correspond to particles with diameters less than 44 µm, and intermediate fraction corresponds to the particles between 44 µm and 150µm. The coarse fraction represents the particle larger than 150 µm.

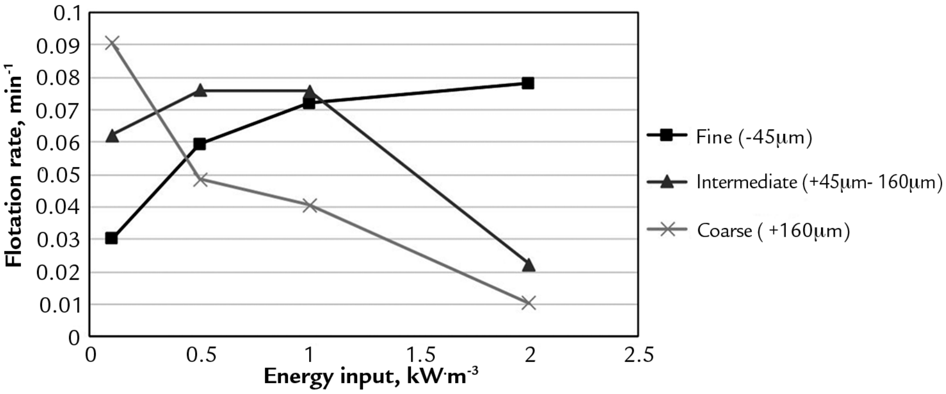

Figure 3
Effect of energy input on the flotation rate using low collector dosage.

Fine particles (−45 µm) are furthered by increasing the energy; the flotation rate increases by around 160% (0.0301 to 0.0782min^{-1}) with an increase in energy input from 0.1 to 2 kWm^{-3}. However, the flotation rate constant for the very coarse particles (+150 µm) over the same energy input range decreases by over 770% (0.0908 to 0.0104min^{-1}), suggesting a strong detachment of the particle-bubble aggregate.

Results show that different conditions are required to float the particles of different sizes. The flotation rate of coarse particles decreases with the energy increasing, however to fine particles high energy increase the flotation rate. In addition, the where to the contrary, intermediate particles have a maximum flotation rate in an intermediary energy input. Due to the low momentum of the fine particles, high levels of energy are required to promote the collisions between the bubbles and rupture of the intervening film.

The Figure 4 shows the results of the tests using a high dosage of collector. The flotation rate behavior in function of the energy input was similar to that of the low dosage, with an increase of the flotation rate caused by the increase of collector rather than an increase of the contact angle.

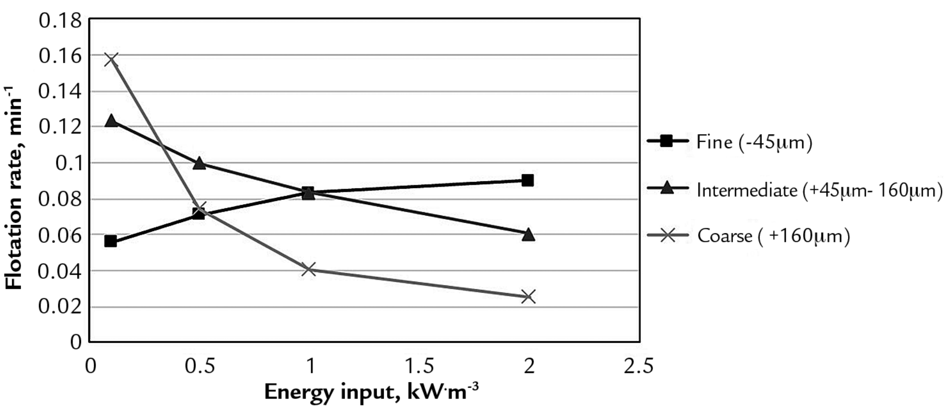

Figure 4
Effect of energy input in the flotation rate using high collector dosage.

The flotation rate was higher using high collector dosage, especially in the lowest energy input level (0.1kWm^{-3}). This behavior was attributed to the agglomeration of the particles caused by a high dosage of fatty acid, and by increasing the energy, this effect is attenuated because the turbulence breaks the aggregates.

These results clearly demonstrate that optimal energy inputs for the flotation of fine and coarse apatite differ significantly, due to the wide particle size range found in most industrial flotation applications.

4. Conclusions

This study investigated the effect of energy/agitation input on the flotation of apatite in an oscillating grid flotation cell (OGC). From this study, one may conclude that the effect of energy/power input on the flotation rate is strongly dependent on the particle size and collector dosage. Flotation rates generally increase with increasing particle size and increasing collector dosage, as is commonly found in literature. The results show that the operational conditions to float fine and coarse particles are different. Increasing energy input generally leads to an increase in the flotation rate for finer particles, an optimum flotation rate for moderate particles and a decrease in the flotation rate for coarser particles. The fine particles require high energy in flotation to promote the collisions between the bubbles and particles, whilst coarse particles are strongly influenced by the detachment. The increases/decreases in the flotation rate with increasing energy/power input are very large, indicating that this is an important parameter in flotation. It is suggested to use different conditions to float fine and coarse particles, where special cells developed for a specific particle size could improve the flotation performance.

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Received: 6 March 2017 - Accepted: 18 May 2017.