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HIGH INTENSITY CONDITIONING TO IMPROVE FLOTATION OF FINE MINERAL PARTICLES

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ABSTRACT: This work studied the influence of the pre-conditioning stage on flotation parameters of gold and copper sulphides ore particles at laboratory and pilot plant scale. Best results for gold fines showed an increase in 24% recovery and 50% in concentrate grade, which depend on the intensity of conditioning and type of frother (Dowfroth 250>Pine oil>MIBC). Higher flotation rates (7 times faster) were found after applying this pre-treatment. As for copper sulphides, recoveries obtained in a pilot plant enhanced 3% at higher flotation rate. The very fines, because of their higher surface area and energy, adhere better to the surface of coarse particles at low turbulent flow (0.5-<2 kW7h/m3). This occurs similarly to the slime coating phenomenon. At moderate intensity conditioning (2-3 kW/h/m3), these fines dettach from the coarse particles due to the high shear forces operating at the contact surface. At high intensity conditioning (3-4kW/h/m3) however, ultrafines particles begin to form aggregates themselves yielding more floatable species. Finally at the highest turbulence degree (4kW/h/m3), interparticle detachment takes place again. Differences in response between the ores systems studied here are due to their different density values and hidrophobicity. These phenomena are demonstrated by the high flotation rate, high values of true flotation (flotation by actual particle-bubble adhesion), and by the low amount of entrained particles. Alternatives for this type of pulp conditioning and mechanisms involved are discussed.

1. INTRODUCTION

The problem of treating fine (6-50 micrometers) and ultrafines (< 6 micrometers) mineral particles is particularly relevant to mineral processing and continues to be a challenge for engineers working in this area.

Several works have been reported during the last years (Trahar and Warren, 1976; Trahar, 1981; Fuerstenau et alii, 1988 e 1978; Sivamohan, 1990 e Kitchener, 1978) focusing the difficulties caused by very fine particles during flotation and several alternative processes have been published, mainly based on particle aggregation: shear flocculation, carrier/autogeneous carrier flotation, oil agglomeration and selective flocculation (Kitchener, 1978, Guerra et alii, 1986; Warren, 19911 Subrahmanyan, 1989 and Rubio and Marabini, 1987)

The shear flocculation process is based on the selective aggregation of hydrophobic particles in a system under high turbulence. Warren has reported several studies on shear flocculation (Warren, 1977; Koh and Warren, .1979 and Warren, 1991) and concluded that formation of aggregates takes place in a short agitation range. Thus, at high stirring speed, the formed aggregates redispersed, due to attrition and/or high shear stress.

Autogeneous carrier flotation (Hu et alii, 1988) employes the same mineral species as carrier and it is believed that this process may include the effect of shear flocculation of particles, with the fine particles floating attached to the larger particles (Chia and Somasundaram, 1988). Studies on induced carrier flotation were carried out by Rubio and Hoberg (1993) to recover fine particles using hydrophobic polymeric spheres as carrier particles.

Dianzuo et alii. (1988) refer to shear flocculation, carrier flotation and emulsion flotation as main examples of hydrophobic aggregation enhancing particle capture by bubbles. This concept has been extended to the conditioning stage ahead to flotation

Bulatovic and Salter (1989), Stassen (1991, 1990) and Rnbio (1978, 1994), published data on better flotation (recoveries, grades and kinetics) after a high intensity conditioning.

They have found that the conditioning energy, often expressed as conditionmg time at constant impeller speed or as impeller speed at constant time, has a pronounced effect on the concentrate recovery and/or grade and flotation, rate without recognizing the carrier or the autogeneous carrier flotation phenomena.

Because the number of examples and data reported is still insufficient, the aim of this work is to study this shear conditioning by measuring its influence on the "true" flotation of gold and copper sulphides fine particles, concentrate grade and kinetics.

2. EXPERIMENTAL

2.1. Materials

Ore sample. A representative sample of a copper/gold ore from Atacama (46 kg) were sampled and crushed to less than 10 mesh. The mineralogjcal analysis showed that the mineral was constituted mainly by quartz, limonite, hematite, pyrite and chalcopyrite. Gold liberation in the 200 mesh fraction was about 82% (see Table I).

Table I. Chemical analysis of the gold ore sample.

Au	Ag (g/t)	CuT (%)	FeT (%)	SiO2 (%)
3.70	4.50	1.36	14.15	59.24

Grinding was carried out in a lab mill with 55 % solids by weight to yield a material which was about 64% under 400 mesh fraction. Also, more than 60% of the gold bearing particles were below this size.

Copper ore. A typical copper ore from North of Chile was used. Ore samples were quartered, crushed, grounded and classified accordingly to give a rougher flotation feed material sized at 78 % less than 210 microns. Samples analyzed, in average, 1,1-1,4% copper, 0,01-0,02% molybdenum, 1,0% iron, 1,1-1,4% sulphur (includying pyrite)and 90% of gangue material (basically quartz, silicates, carbonates and fluorides).

Reagents. Main reagents were lime to adjust pH 10,5, SF-113 (sodium isopropyl xanthate) 30-50 g/t and the frother (20 g/t) was a mixture (4: 2. 1) of DF 250, MIBC and pine oil.

2.2. Methods

2.2.1. Bench studies.

Gold ore. Conditioning of a gold flotation feed (22 % w/w) was conducted in a 3 1 Denver cell, endowed with four baffles to allow turbulent regime when required. Results expressed in kWh/m^3 pulp, were obtained by keeping the stirring constant at 1500 rpm, the pulp volume in 2 liters with conditionmg time varying in the range of 25-100 s to yield 0.5 to 4 kWh/m> pulp inputs. "Blank" experiments were standardized tests with pulps conditioned in the same 2 liters during 1.5 mm with no turbulence at 1000 rpm, pH 7.5 and 22 % solids content. Flotation tests were carried out maintaining pulp level constant by adding water and monitoring water content in each concentrate to calculate the true flotation values and entrainment following the method reported by Smith and Warren (1989).

Flotation was carried out with no baffles, with agitation at 1000 rpm and collecting aliquots every 6 s. Results reported are average of three different experiments. These concentrates were analyzed by the content of Au, gangue and water.

Copper ore. Bench flotation studies were performed in a 3 l lab Agitair LA 500 cell. The conditioning process was performed in the same cell which was endowed with baffles (7 altogether) allowing a turbulent hydrodynamic regime when required.

Other conditions and procedures were similar to those described above for the gold ore.

2.2.2. Pilot studies

The pilot plant used was an arrange of several Denver cells treating up to 50 Kg/h ore (only copper sulphide). To evaluate the conditioning stage, only the first 4 cells were considered. Conditioning was performed in a baffled (4 baffles) cylindrical reactor employing a Heidolph RZR 1 stirrer fixed in 1200 rpm, at a pulp rate of 2 1/min, to yield 0.12 kWh/m> pulp. Samples were collected every 0.5 min after circuit equilibration.

3. RESULTS AND DISCUSSION

3.1. Bench scale

Gold ore Figure 1 and Table II show that without turbulent conditioning, gold recovery was about 52.67% with 52.61 g/t Au. Best results were obtained with an energy transferred of 3.0 kWh/m^3

pulp, attaining 65.88% recovery and 79.68 g/t Au. The microscopic analysis of concentrates showed that the larger gold particles were the first to be collected; then the medium size and finally the very fine particles. Conversely, after intensive conditioning an assembly of big and small particles appeared in the first minutes.

Figure 1 shows two optimal values as a result of aggregation-disruption of small particles onto coarse or themselves. The first correspond to gold fines onto pyrite and medium size gold particles (revealed by microphotographs) and the second between gold fines themselves.

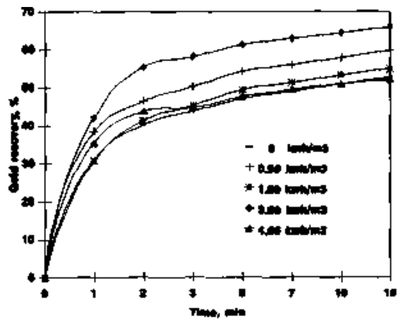


Figure 1 Flotation kinetics of gold particles as a function of the shear energy Pine oil, 72 g/t as frother and 120 g/t amyl xanthate as collector

Table II. Effect of frother and conditioning intensity on true flotation, enrichment ratio, degree of entrainment and concentrate gold grade.

Frother-kwh/m^3	True Recovery (%)	Entrainment	Er	Gold grade (g/t)
PO.O	35.38	1.12	14.22	52.61
P0.5	41.97	1.11	16.96	62.76
P1.0	36.68	1.19	16.86	62.33
P1.5	37.47	0.95	15.08	55.81
P2.0	36.32	0.93	16.84	62.29
P3.0	48.65	1.09	21.54	79.68
P4.0	38.54	0.82	17.19	63.59
M 0.5	37.04	0.92	18.21	67.37
M 2.0	34.14	0.82	19.02	70.39
M 4.0	40.66	0.95	19.06	70.52
D 0.5	49.20	0.77	17.71	65.53
D 2.0	58.64	0.82	21.45	79.37
D 4.0	50.11	0.69	21.10	78.07

Figures 1 and 2 show the effect of frother type on flotation kinetics and gold grade. Best values were found with Dowfroth (D) followed by Pine oil (P) and MIBC (M), even with a less intense conditioning, 2 kWh/m^ pulp. These results are due to the fact that with Dowfroth, the froth formed was more stable, smooth and well structured

Figure 3 and Table II summarize results of gold particle flotation with and without shear conditioning showing also the true flotation values, the degree of entrainment, enrichment ratios and concentrate grades for the three frothers studied. Results show that the true flotation recovery (particle-bubble interactions only) increased dramatically with the best frother, Dowfroth. These results are accompanied by a reduction of the entrainment high enrichment ratios (Er) and higher concentrate grades.

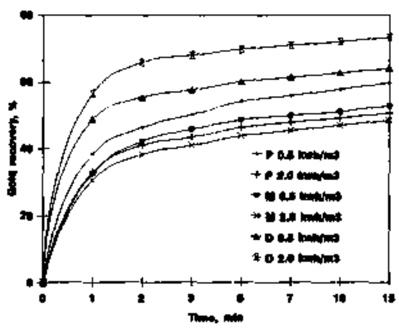


Figure 2 Effect of frother type on flotation kinetics of gold **particles As a function of shear energy** in **the** conditioning **stage 120 g/t amyl xanthate as collector**

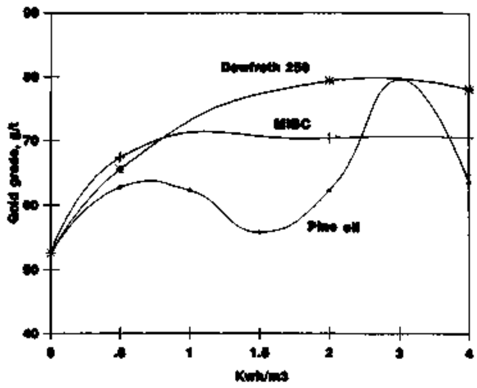


Figure 3 Effect of shear energy on gold concentrate grade for different frothers 120 g/t amylxanthate as collector

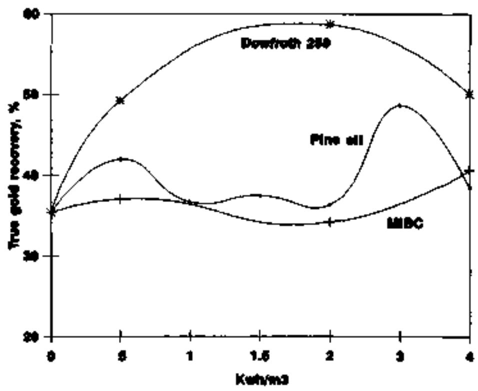


Figure 4 Effect of shear conditioning energy on gold true flotation recovery (Rt) for three different frothers 120 g/t amylxanthate as collector

Copper ore Conventional, blank tests without intensive conditioning, yielded averaged recoveries of the order of 90% copper (15 3 % Cu) and 67% molybdenum (0,24% Mo) Figure 5 present results of copper for three collector concentrations as a function of shear energy This figure shows that a minimum input energy of 1-2 kWh/m3 pulp is required to enhance copper recoveries Concentrate grades, however, remain similar to the blank tests with a slight decrease at lower collector concentrations (Table DI) Best results were obtained with 30 g/t collector concentration and energies greater than 2 kWh/m3 pulp, yielding copper recoveries of the order of 93% with 16% copper grade This concentration is approximately 25 % less than that utilized in industrial scale

Table ID Separation parameters data for the froth flotation of copper sulphides at 30 g/t collector concentration

Shear Energy kWh/m^3	R°o	Grade, %Cu
Blank	92 4	53
1	92,7	16 5
2	94 9	14 6
3	95 2	13 4
4	95 2	14 3

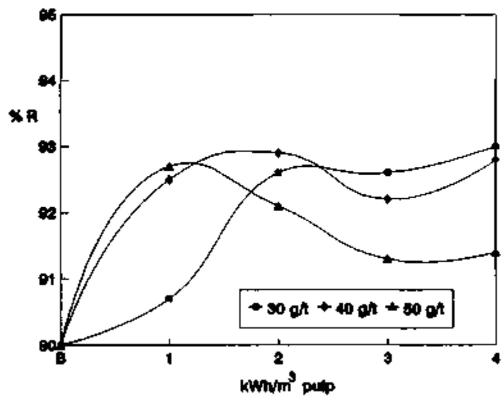
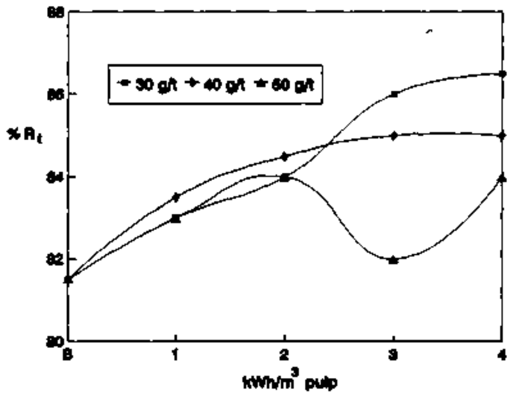


Figure 5 Effect of shear energy and collector concentration on copper sulphide flotation recovery B = Blank test, without conditioning

True flotation and entrainment Figure 6 show, for all tests with feed pre-treatment, an increase in the true flotation of copper bearing particles with respect to the blank

This increase can only be due to the increase in fines recovery yielding concentrates with less water content and with more hydrophobic mineral particles However, gangue particles presented true flotation values of the order of 1- 2 % showing that middlings were either floating or entrapped among valuable particle-bubble units The latter would happens because of the physical oclusion of fine gangue particles inside the "new" aggregates bemg formed



,# Figure 6. Effect of shear energy on copper sulphide "true" flotation recovery. B = Blank test.

Pilot studies

Results of copper sulphide flotation obtained at pilot scale (Figure 7) confirmed bench results at even lower intensity conditioning. This may be due to the design of the conditioner, cylindrical with deep baffles in it. The energy value amounted to 0,12 kWh/m^3 pulp which converted to kWh/t of dried mineral gave similar values to those suggested by Stassen (23), that is 0,3 a 2,0 kWh/t copper sulphide and 0,15 a 0,6 kWh/t mob/.

Therefore, the important fact here, is to provide sufficient flow fluid velocity in a suitable manner, to increase particle-particle interactions and formation of aggregates. The magnitude of the effect of this intensive conditioning will always depend on particle size distribution and hydrophobicity of the mineral system.

The same Figure 7 show an increase in flotation rate for the high intensity conditioning, especially in the first two cells. Recoveries under shear conditioning were about 3 % higher, but because of the increase in the flotation of middlings, or entrapment of gangue particles, concentrate grades were kept constant.

Despite the lower feed copper grade of samples studied here, compared to those reported by Bulatovic, results obtained, at pilot plant scale, are very similar.

This work shows that a suitable shear conditioning of pulp ahead of flotation. This shear is required to collide particles with sufficient energy to allow the action of the hydrophobic effect (Warren 1991; Dianzuo, 1988).

Flotation results can only be explained by the formation of readily floatable species which enhance the true flotation values and decrease the degree of entrainment. The very fines, because of their higher surface area and energy, adhere better to the surface of coarse particles at low turbulent flow. This occurs similarly to the slime coating phenomenon. At high intensity conditioning, fines attached to coarse particles begin to detach due to the high shear forces operating at the contact surface. Here, however, ultrafines particles begin to form aggregates yielding more floatable species. Finally at the highest turbulence degree (4kW/h/m^3), interparticle detachment takes place again.

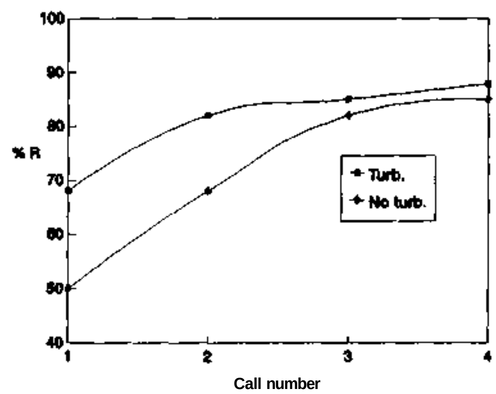


Figure 7. Effect of conditioning on copper sulfide flotation recovery and kinetics at pilot plant.

Thus, alternatives to provide the shearing needed, at low costs, have to be found from mineral system to mineral system, either by changing the degree of turbulence in the pulp transport system, modifying the design of present conditioners or simply by changing drastically the concept of pulp conditioning for froth flotation. The use, for example, of static mixers or the recycling of a fraction of particles already floated, which may serve as "seeds" for aggregates formation, should be explored. By making any decision, economical considerations based on energy costs versus production gains will be unavoidable.

CONCLUSIONS

Results found in this work allow the following conclusions:

1. Shear conditioning as a pulp pre-treatmenl enhanced flotation concentrate recoveries of metal sulphides rougher feeds in about 3%. No effect was found on concentrates grades but higher flotation

rates were found. As for the gold ore kinetic enhanced 7 times, the recovery 24% and 50% the grade.

2. Results obtained are explained by the increase in the concentration of hydrophobic particles as a result of an aggregation process followed by carrier or by an autogeneous carrier flotation phenomenon. This was demonstrated by the enhancement in the true flotation values.

3. Alternatives for practical shear conditioning have to be found and the need for new conditioners appears to be the key to improve fines particle recovery by froth flotation.

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