



Dispersion effect on a lead–zinc sulphide ore flotation

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ABSTRACT

This investigation was performed with samples from a lead–zinc sulphide deposit aiming at studying the influence of the dispersion degree of the particles in the pulp on lead and zinc flotation. Samples of ore and also of the minerals sphalerite, galena, pyrite, and dolomite were selected for the experiments. Nine types of dispersing agents and six blends among them were employed.

A set of three dispersing agents was selected for the lead flotation and another set of three was chosen for zinc flotation. The criteria for the reagents selection were: high dispersion degree for galena and low for the other species, high dispersion degree for sphalerite and low for the other species, low dispersion degree for pyrite and high for the other species, and high dispersion degree for all species.

Lead flotation experiments were performed under three conditions aiming at verifying the influence of the dispersing agent, of the pH, and of sodium carbonate. The zinc flotation tests were carried out at pH 10.5, modulated with lime.

The use of dispersing agents in lead flotation did not improve the overall efficiency of the circuit for, despite improving the lead metallurgical recovery, they increase significantly the zinc losses in the lead concentrate.

Sodium carbonate presented a low dispersion degree and did not affect the lead flotation results when compared with those achieved at natural pH and at pH 9.8 modulated with lime.

Two dispersing agents were particularly effective in zinc flotation: dispersant 3223, a sodium polyacrylate, and sodium hexametaphosphate. Both reagents significantly enhanced zinc recovery without impairing the concentrate quality.

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1. Introduction

Votorantim Metais operates an underground mine in Paracatu, MG, Brazil, producing 1×10^6 tonnes of ROM at 4.3% zinc grade and 2.0% lead grade. Lead flotation consists of rougher and cleaner column flotation stages and scavenger stage performed in mechanical cells. The lead circuit tailings feed the zinc circuit consisting of rougher and cleaner column flotation and scavenger and recleaner stages in mechanical cells. The middlings from the flotation circuit (cleaner tailings and scavenger concentrate) are reground aiming at further sphalerite liberation. The production of lead concentrate in 2007 was 26,000 tonnes at 62% lead grade and 82.5% lead recovery. The production of zinc concentrate was 83,000 tonnes at 45.5% zinc grade and 89.0% zinc recovery.

The correlation between the dispersion degree of the particles in the pulp and flotation performance is well known in iron ores

cationic reverse flotation, where quartz particles must be disperse and selective flocculation of iron oxides is desirable and actually occurs. The system under investigation is much more complex regarding either mineralogy or flotation stages requirements. In the lead circuit, the dispersion of galena particles is essential. The aggregation of the other minerals (sphalerite, pyrite, and dolomite), that are expected to report to the tailings, may even improve the selectivity of the stage. The same approach applies to the zinc circuit: sphalerite particles must be disperse and aggregation of pyrite and dolomite might favour the rejection of these species to the tailings.

Many decades of investigation were necessary in order that some correlations between dispersion and flotation performance in iron ores reverse cationic flotation were established (Peres and Silva, 1994; Peres et al., 2003; Queiroz et al., 2005).

The flotation of silicate zinc minerals, willemite and hemimorphite, relies on adequate dispersion of the ore particles in the pulp. Highly disperse pulps eliminate the need for desliming, but no direct correlation between dispersion and flotation is observed. The most effective dispersants not always lead to the best flotation performances (Peres et al., 1994; Pereira and Peres, 2005).

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This study aims at addressing the dispersion degree of the particles in a lead–zinc sulphide ore pulp as a tool for better understanding the flotation behaviour.

2. Literature review

Desliming preceding flotation is an industrial practice established over 60 years ago, introduced in the USBM process for the iron ores cationic reverse flotation (Clemmer, 1947). A high dispersion degree of the particles in the pulp is essential for effective desliming, a requisite for the selectivity in most non-sulphide flotation systems. Desliming stages are not generally performed in sulphide minerals flotation systems. One exception is the Mt. Keith concentrator (Western Australia), where desliming is done on a nickel sulphide ore.

The theoretical aspects of ultrafine particles aggregation and dispersion are addressed by the DLVO theory, independently developed by the Russians Derjaguin and Landau and the Dutch Vervey and Overbeek, in the last century forties decade. After 50 years the classical DLVO theory was reviewed, incorporating structural forces suggested by Churaev and Derjaguin (1985), resulting

in the extended DLVO theory or X-DLVO (Israelachvili, 1991; Lins and Adamian, 2000).

The concepts of the X-DLVO theory apply to the flotation process (Yoon, 1991). Flotation may be seen as the interaction between two “particles”: ore and bubble.

There is an interrelation between dispersion and depressant action in systems involving mineral pulps.

Among dispersing/depressant inorganic agents, polyphosphates play a special role, and among organic species low molecular weight acrylate polymers deserve special attention.

Rashchi and Finch (2000) investigated the chemistry and applications of polyphosphates, stressing that the metal ions-poliphosphate complexes formation may control the interfering ions action in the flotation process, preventing uncontrolled activation or depression effects.

Pereira and Peres (1988) investigated the flotation selectivity of a sulphide copper ore. The concentrate (chalcopyrite and bornite) was contaminated by magnesium present in hypersthene (an iron and magnesium silicate). Liberation studies, zeta potential determinations and microflotation experiments suggested that the hypersthene flotation with thiocollectors was activated by the presence of ferrous ions present in the mineral lattice and also released by grinding media and mill liners. After failure with the use of high molecular weight starch depressants, dispersion/depression was successfully achieved with the use of a low molecular weight dextrin. The MgO content in the industrial concentrate was brought down from 7.5% to 3.3%, well below the metallurgical specification 4.5%.

Bulatovic (1999) reviewed the use of organic polymers in the polymetallic ores flotation. Aspects of the chemistry of starches, dextrans, modified lignosulfonates, and quebracho were discussed.

Galena depression is achieved with dextrans (Bulatovic, 1999) and other organic polymers such as guar gum, corn starch, polysulphonated species (Pugh, 1989). Galena depression is a target in lead–copper systems, but is totally undesirable regarding the present investigation.

Lange et al. (1997) reported that the flotation of fine sphalerite (<20 µm), at pH 5, may be enhanced by aggregation with coarse particles (up to 100 µm) in the conditioning with xanthate. Even before the reagents addition, aggregation was observed. At pH 8.5 the surface hydroxides inhibit flotation.

Wightman et al. (2000) showed that the floatability of ultrafine galena (<5 µm) may be improved by selective aggregation onto coarse galena, precipitated in the laboratory, previously conditioned with a polymer.

Boulton et al. (2001a,b) investigated the iron sulphides depression in sphalerite flotation. Low molecular weight polyacrylamides,

Table 1
Lead flotation experiments planning.

Stage	Dispersant	Dosage (g/t)	pH	Sodium carbonate
Lead	Sodium silicate (Na ₂ SiO ₃)	1000	9.8	Yes
		1250		
		1500		
		1750		
		2000		
	Sodium silicate (Na ₂ SiO ₃)	1000	9.8	No, pH modified with lime
		1250		
		1500		
		1750		
		2000		
Lead	Sodium silicate (Na ₂ SiO ₃)	1000	Natural	No
		1250		
		1500		
		1750		
		2000		
	3223	100	9.8	Yes
		200		
		300		
		400		
		500		
Lead	3223	100	9.8	No, pH modified with lime
		200		
		300		
		400		
		500		
	3223	100	Natural	No
		200		
		300		
		400		
		500		
Lead	Sodium hexametaphosphate	250	9.8	Yes
		500		
		750		
		1000		
		1500		
	Sodium hexametaphosphate	250	9.8	No, pH modified with lime
		500		
		750		
		1000		
		1500		
Lead	Sodium hexametaphosphate	250	Natural	No
		500		
		750		
		1000		
		1500		

Table 2
Zinc flotation experiments planning.

Stage	Dispersant	Dosage (g/t)	pH
Zinc	Sodium silicate + metasilicate	500	10.5
		750	
		1000	
		1250	
		1500	
Zinc	3223	100	10.5
		200	
		300	
		400	
		500	
Zinc	Sodium hexametaphosphate	100	10.5
		200	
		300	
		400	
		500	

modified by the presence of carboxyl, sulphonate, hydroxyl, and thiourea, were efficient pyrite depressants. The depressant action was stronger on coarse particles and the polyacrylamides must be added prior to the collector addition.

Bandini et al. (2001) investigated the deleterious action of iron oxides slimes coating on galena flotation. Slimes may be removed by a shear conditioning and pH control combination, as well as the use of anionic reagents (carboxymethylcellulose and polyphosphates).

3. Methodology

The reagents used as dispersants were: sodium hexametaphosphate designated as HMP, commercial sodium silicate ($\text{SiO}_2/\text{Na}_2\text{O} = 3.27$) designated as Na_2SiO_3 , chemical grade sodium silicate designated as Na_2SiO_3 PA, sodium metasilicate designated as meta, Dispersol (commercial sodium polyacrylate, manufactured by

Nalco), Nalco 7220 (commercial sodium polyacrylate, manufactured by Nalco), NaOH, Cytec 3223 (commercial sodium polyacrylate, manufactured by Cytec), sodium carbonate Na_2CO_3 , and hydrated lime.

Blends of dispersants were also tested: 50% Na_2SiO_3 PA + 50% Dispersol; 50% Dispersol + 50% 3223; 50% Dispersol + 50% HMP; 50% Dispersol + 50% meta; 50% Na_2SiO_3 + 50% HMP; 50% Na_2SiO_3 + 50% meta.

Mineral samples as pure as possible were collected in the mine by the geology team: galena (Zn 0.75%, Pb 81.98%, Fe 0.33%), sphalerite (Zn 59.99%, Pb 1.70%, Fe 2.04%), pyrite (Zn 0.15%, Pb 0.21%, Fe 26.49%), and dolomite, the major gangue mineral (Zn 0.34%, Pb 0.13%, Fe 2.80%).

A sample of the ore was collected in the concentrator, at the feed point of the lead flotation circuit, to be used in the dispersion experiments. The metallic elements content of this sample was Zn 4.36%, Pb 1.82%, Fe 4.10%.

The dispersion degree determinations procedure is described next.

Each mineral sample (ground to $-150 \mu\text{m}$) weighing 5 g was added to the sedimentation tube in a pulp containing 13.5 mL water at pH 10, adjusted with Na_2CO_3 . The dispersant at a concentration of 0.5% was then added at three dosage levels, 500 g/tonnes, 1500 g/tonnes, and 3000 g/tonnes, and conditioned for 3 min. After the first conditioning stage, water at pH 10 was added to complete the tube volume to 200 mL and an extra 3 min conditioning time was provided. The system was brought to rest for five minutes and the underflow and overflow fractions were collected, dried, and weighed.

The dispersion degree was calculated as:

$$\text{DD} = [\text{overflow mass}/(\text{overflow mass} + \text{underflow mass})] \times 100$$

The sedimentation apparatus consists of a glass tube (4.5 cm diameter; 16.3 cm height) provided with an opening for the supernatant discharge (0.5 cm diameter) located at 1.5 cm from the bottom, sitting on a magnetic stirrer to keep the pulp under suspension.

A laboratory flotation machine supplied with an automatic froth removal system was used in the flotation tests. The sample for the laboratory flotation tests was collected at the industrial grinding circuit feed point, Fractions weighing 1400 g were wet ground in the laboratory (467 mL of water) and added to the tank of the

Table 3

Dispersion degree in the presence of the dispersants selected for flotation experiments.

Dispersant	Species	DD
3223	Ore	41.00
	galena	41.72
	sphalerite	45.33
	pyrite	8.23
	dolomite	40.12
HMP	Ore	36.10
	galena	41.64
	sphalerite	45.01
	pyrite	21.67
	dolomite	38.76
Na_2SiO_3	Ore	4.36
	galena	21.51
	sphalerite	3.48
	pyrite	6.40
	dolomite	21.29
Na_2SiO_3 + meta	Ore	4.80
	galena	4.35
	sphalerite	40.41
	pyrite	6.29
	dolomite	12.00

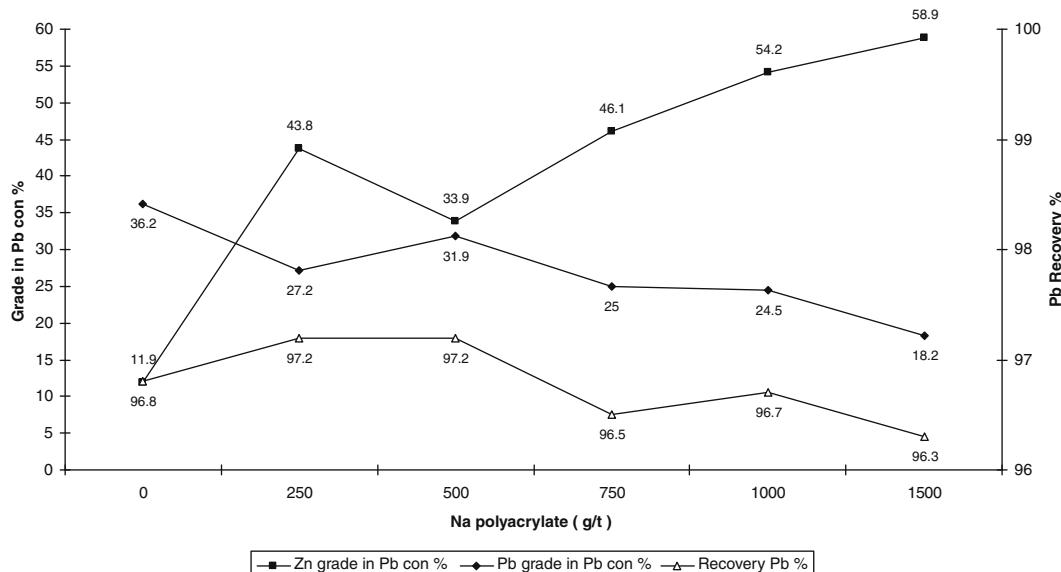


Fig. 1. Lead flotation in the presence of sodium polyacrylate 3223.

flotation machine. Tap water was added to complete the volume (3500 mL).

Reagents for galena flotation (Na_2CO_3 dosed to raise the pulp pH to 9.8; dispersant, potassium isopropyl xanthate 70 g/t ROM and frother) were conditioned at 1500 rpm. The rotor speed was then reduced to 1100 rpm, the air flow rate was adjusted at 8 NL/min, and flotation proceeded for 20 min.

The tailings from the galena flotation were conditioned with copper sulphate (300 g/t ROM) for 5 min, at 1500 rpm, after pH modulation to 10.5 with lime. Potassium isobutyl xanthate was dosed at 150 g/t ROM and conditioned for 5 min. The rotor speed was brought down to 1100 rpm and sphalerite was floated for 20 min.

In the flotation experiments results, dispersant dosage zero g/t refers to the standard test in the absence of dispersant.

Table 1 illustrates the lead flotation experiments planning. One of the targets was checking the sodium carbonate role in the system.

Table 2 illustrates the zinc flotation experiments planning. The pH was modified with lime.

4. Results

4.1. Sedimentation tests

Duplicated sedimentation experiments were performed with five mineral fractions, using nine individual or blended dispersing agents, at three addition levels, yielding a total of 450 tests. Dispersion degrees (DD) below 15% were considered as low, between 15% and 30% medium, and figures above 30% were treated as a high dispersion degree.

For each mineral fraction sets of four dispersing agents (individual or combination) were selected as representative of reagents yielding higher and lower dispersion degrees, respectively.

Considering the 1500 g/t dosage, the reagents are listed in a sequence of high to low dispersing effectiveness.

- Ore high DD: 3223 > HMP = Dispersol > Dispersol + HMP
- Ore low DD: Na_2CO_3 > Na_2SiO_3 + meta > Na_2SiO_3 > NaOH
- Sphalerite high DD: Dispersol = 3223 = HMP > Na_2SiO_3 + meta
- Sphalerite low DD: Na_2CO_3 > NaOH > Na_2SiO_3 PA > Na_2SiO_3

- Galena high DD: 3223 = HMP = Dispersol + HMP > Na_2SiO_3
- Galena low DD: Na_2SiO_3 + meta > Na_2CO_3 > Na_2SiO_3 PA = NaOH
- Pyrite high DD: Dispersol + HMP = HMP > Dispersol > Na_2SiO_3 PA + Dispersol
- Pyrite low DD: 3223 > Na_2SiO_3 PA > NaOH = 7220
- Dolomite high DD: Dispersol = 3223 = HMP = 7220
- Dolomite low DD: Na_2SiO_3 PA = meta = NaOH = Na_2CO_3

Dispersion degrees in the presence of the reagents selected for the flotation experiments, at 1500 g/t dosage, are presented in **Table 3**.

Based on information on the dispersion behaviour of the ore and its components, provided by the sedimentation experiments, four criteria were established for the selection of reagents to be used in the laboratory flotation experiments:

- (i) Lead flotation: reagent yielding high dispersion degree for galena and low dispersion degree for the other minerals and ore; sodium silicate was selected, even being just a medium dispersant for pyrite.
- (ii) Zinc flotation: reagent yielding high dispersion degree for sphalerite and low dispersion degree for the other minerals and ore; a blend of sodium silicate and sodium metasilicate was selected for meeting all the required conditions.
- (iii) Lead and zinc flotation: reagent yielding low dispersion degree for pyrite and high dispersion degree for the other minerals and ore; dispersant 3223 was selected for sharply meeting the required conditions.
- (iv) Lead and zinc flotation: reagent yielding high dispersion degree for all the minerals and ore; sodium hexametaphosphate was selected for sharply meeting the required conditions.

4.2. Flotation

Galena flotation results, designated as lead flotation, in the presence of sodium polyacrylate (reagent 3223) are presented in **Fig. 1**.

Unacceptable losses of zinc in the lead concentrate were observed, with consequent drop in lead grade. Lead recovery was

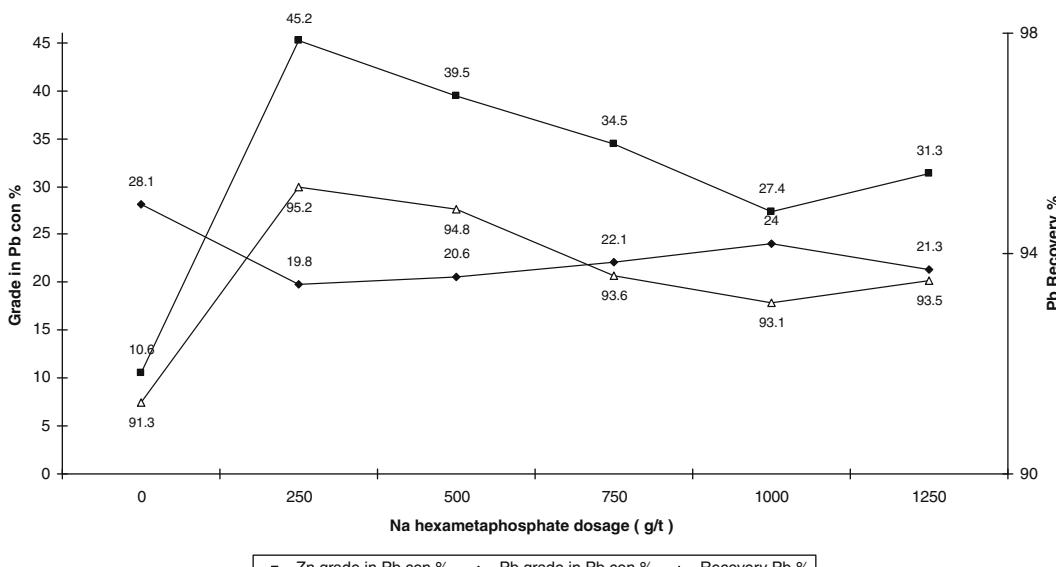


Fig. 2. Lead flotation in the presence of sodium hexametaphosphate.

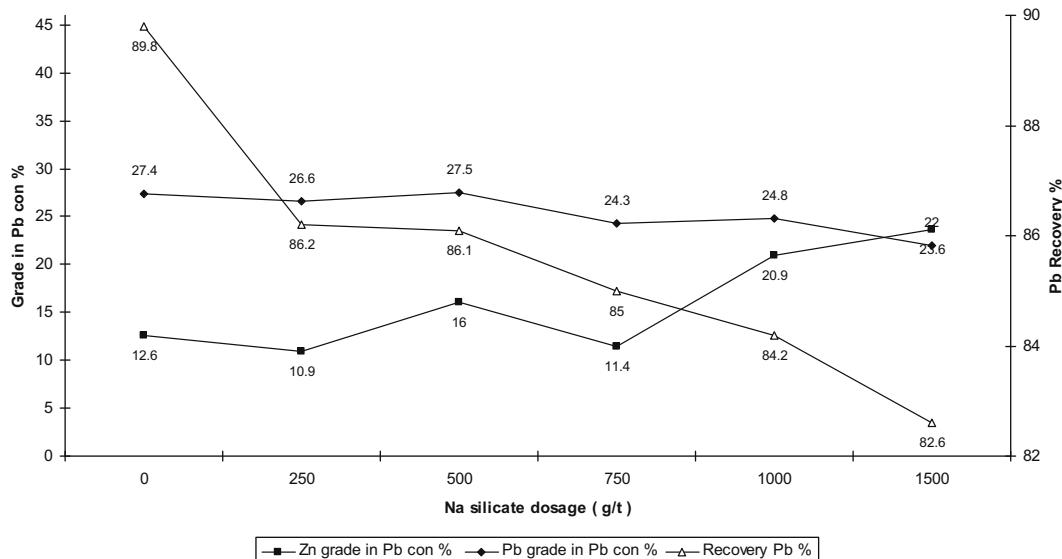


Fig. 3. Lead flotation in the presence of sodium silicate.

not affected. The reagent seems to activate sphalerite flotation even in copper sulphate absence.

Galena flotation results in the presence of sodium hexametaphosphate are presented in Fig. 2.

Comparing with the standard test (0 g/t), a drop in the lead content in the concentrate was observed as a consequence of zinc loss. Again, undesirable activation of sphalerite was observed.

Galena flotation results in the presence of sodium silicate are presented in Fig. 3.

The reagent not only decreases lead grade and recovery in the concentrate, but also increases sharply zinc losses.

The activation of sphalerite by dispersants may be explained by the fact that disperse fine galena particles are prone to surface oxidation and, thus releasing Pb^{2+} ions in solution. Lead cations are well-known sphalerite activators (Basilio et al., 1996).

It is worthwhile stressing that the lead feed grades in the three sets of experiments were different due to fluctuations in the ROM, resulting in different results for the standard test (absence of dispersant). The experiments with sodium hexametaphosphate were

performed with lead feed grade 2.1%, a figure similar to that of the sequence in the presence of sodium silicate (2.2% Pb). Both sequences yielded similar results for the standard test. The standard test in the presence of polyacrylate was carried out with a richer sample (3.6% Pb), producing higher concentrate lead grade and recovery.

A final comment on dispersants effect on lead flotation is that none of them enhanced this stage performance. Nevertheless, the dispersion studies provided a relevant technological information. Sodium carbonate does not have any dispersing effect towards either individual minerals or the ore. Bench scale experiments were performed with the less expensive reagent hydrated lime substituting for soda ash as pH modulator in the lead circuit. Laboratory experiments indicated also that lead flotation is possible at natural pH. A successful plant trial conducted to the incorporation of lime to the concentrator plant practice.

Sphalerite flotation results, designated as zinc flotation, in the presence of sodium polyacrylate (reagent 3223) are presented in Fig. 4. This reagent presence in concentrations up to 300 g/t caused

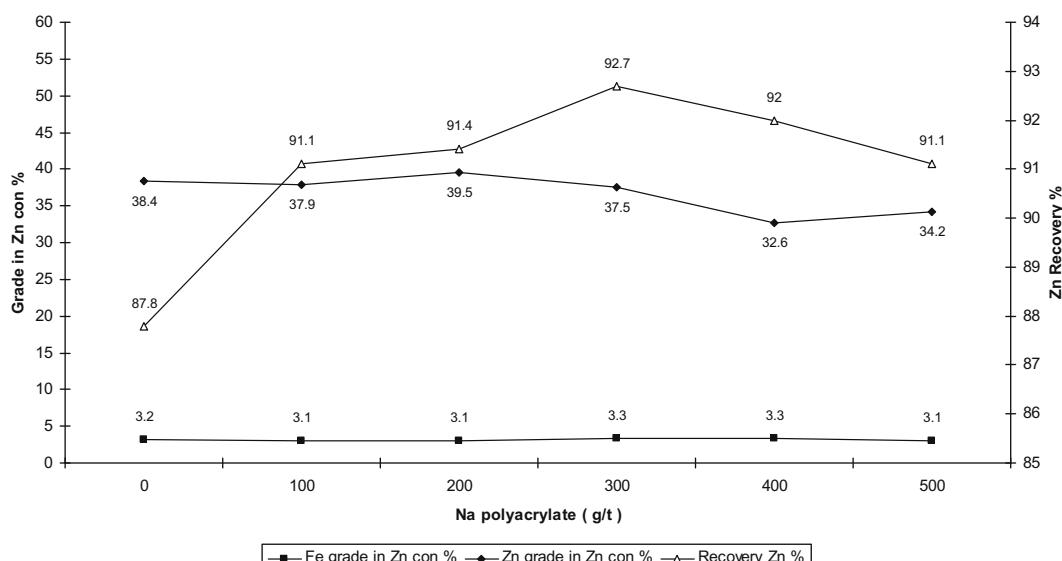


Fig. 4. Zinc flotation in the presence of sodium polyacrylate 3223.

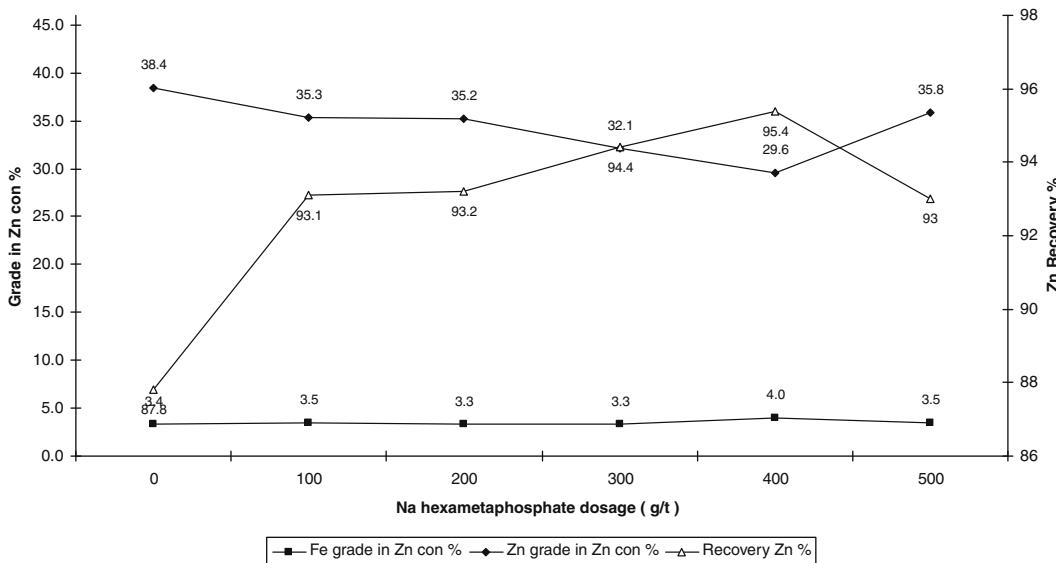


Fig. 5. Zinc flotation in the presence of sodium hexametaphosphate.

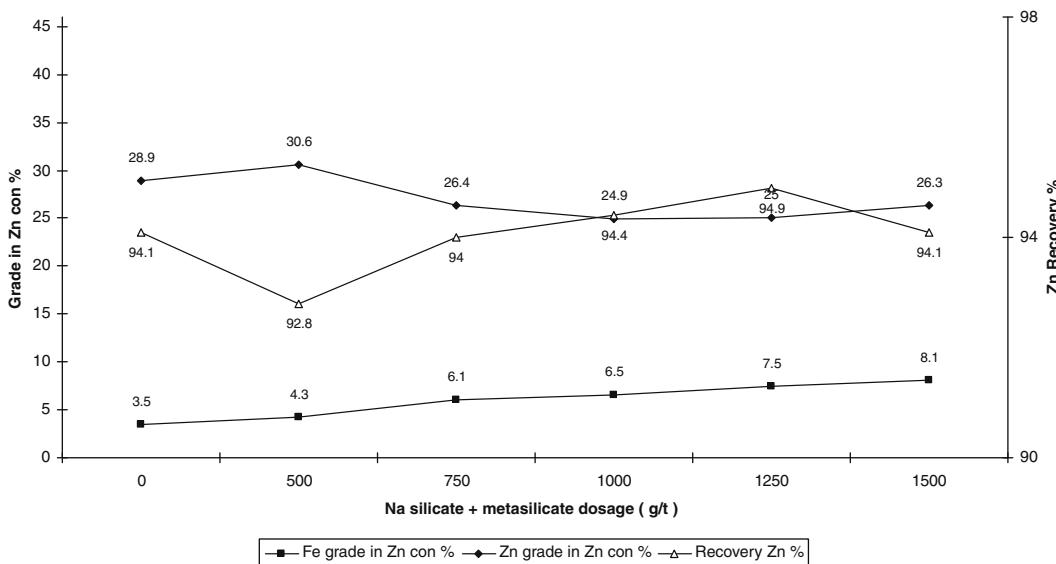


Fig. 6. Zinc flotation in the presence of sodium silicate and metasilicate blend.

a sharp increase in zinc recovery, without significant drop in zinc grade and no lead contamination in the concentrate.

Sphalerite flotation results in sodium hexametaphosphate presence are presented in Fig. 5. The reagent was effective in increasing zinc recovery and keeping the lead content in the concentrate low. A decrease in the zinc grade in the concentrate was observed.

Sphalerite flotation results in the presence of a sodium silicate and metasilicate blend are illustrated in Fig. 6. No significant effect was observed regarding both zinc grade and grade.

Zinc feed grade in the sequence with the sodium silicate and metasilicate blend was different from that of the tests in the presence of sodium polyacrylate and sodium hexametaphosphate.

5. Conclusions

The dispersants used in the lead flotation stage did not improve the overall circuit efficiency. Despite enhancing the lead recovery, the reagents caused unacceptable zinc losses in the lead concentrate.

Lead flotation either at natural pH or pH 9.8 modified with sodium carbonate or lime presented similar results.

A technological consequence of the low sodium carbonate dispersing ability was the use of lime substituting for the more expensive sodium carbonate as pH modifier in the industrial circuit.

The use of both, the sodium polyacrylate 3223 and the inorganic dispersant sodium hexametaphosphate, increased significantly the zinc recovery, keeping low the lead content in the zinc concentrate and not interfering with the iron content in this product.

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References

- Bandini, P., Prestidge, C.A., Ralston, J., 2001. Colloidal iron oxide slime coatings and galena particle flotation. Minerals Engineering 14 (5), 487–497.

- Basilio, C.I., Kartio, I.J., Yoon, R.H., 1996. Lead activation of sphalerite during galena flotation. *Minerals Engineering* 9 (8), 869–879.
- Boulton, A., Fornasiero, D., Ralston, J., 2001a. Selective depression of pyrite with polyacrylamide polymers. *International Journal of Mineral Processing* 61, 13–22.
- Boulton, A., Fornasiero, D., Ralston, J., 2001b. Depression of iron sulphide flotation in zinc roughers. *Minerals Engineering* 14 (9), 1067–1079.
- Bulatovic, S.M., 1999. Use of organic polymers in flotation of polymetallic ores. *Minerals Engineering* 12 (4), 341–354.
- Churaev, N.V., Derjaguin, B.V., 1985. Inclusion of structural forces in the theory of stability of colloids and films. *Journal of Colloid and Interface Science* 103, 542–553.
- Clemmer, J.B. 1947. Flotation of iron ore. In: 8th Ann. Min. Symposium, January.
- Israelachvili, J. 1991. *Journal of Intermolecular and Surface Forces*. second ed. Chapter 13.
- Lange, A.G., Skinner, W.M., Smart, R.St.C., 1997. Fine: coarse particle interactions and aggregation in sphalerite flotation. *Minerals Engineering* 10 (7), 681–693.
- Lins, F.A.F., Adamian, R. 2000. Colloidal minerals, extended DLVO theory and structural forces. *Tecnologia Mineral*, 78. Rio de Janeiro: CETEM/MCT, 29p (in Portuguese).
- Pereira, C.E., Peres, A.E.C., 1988. Reduction of Magnesium Content in Copper Concentrates. *Developments in Mineral Processing* 9 Froth Flotation. Elsevier. pp. 317–328.
- Pereira, C.A., Peres, A.E.C., 2005. Reagents in calamine zinc ores flotation. *Minerals Engineering* 18, 275–277.
- Peres, A.E.C., Silva, G.M.A. 1994. Dispersion degree of iron ore suspensions. In: *Proceedings III Congresso Italo Brasiliense di Ingegneria Mineraria*, Verona, pp. 169–172.
- Peres, A.E.C., Borges, A.A.M., Galery, R., 1994. The effect of the dispersion degree on the floatability of an oxidized zinc ore. *Minerals Engineering* 7, 1435–1439.
- Peres, A.E.C., Lima, N.P., Araújo, A.C. 2003. How different iron ore types behave in desliming in hydrocyclones and flotation. In: *Hydrocyclones 03*, Cape Town, pp. 6.1–6.19.
- Pugh, R.J., 1989. Macromolecular organic depressants in sulphide flotation – a review. 1. Principles, types and application. *International Journal of Mineral Processing* 25, 101–130.
- Queiroz, L.A., Padovezi, A.D., Ferreira, A.D., Peres, A.E.C. 2005. The effect of mineralogy on desliming and flotation of itabirite iron ores. In: *Proceedings Iron ore 2005*, Fremantle, pp. 385–388.
- Rashchi, F., Finch, J.A., 2000. Polyphosphates: a review their chemistry and application with particular reference to mineral processing. *Minerals Engineering* 13 (10–11), 1019–1035.
- Wightman, E.M., Grano, S.R., Ralston, J., 2000. Selectivity in the polymer assisted separation of galena from quartz by flotation. *Minerals Engineering* 13 (8–9), 843–956.
- Yoon, R.H. 1991. Hydrodynamic and surface forces in bubble-particle interactions. In: *International Mineral Processing Congress*, vol. 2, Dresden, pp. 17–31.