THE EFFECT OF MODE OF OCCURRENCE OF GALENA AND SPHALERITE ON THE SELECTIVE FLOTATION OF ORE SAMPLES FROM THE ROSH PINAH MINE

Makunga Daudet Seke* and Petrus Christiaan Pistorius

Department of Materials Science and Metallurgical Engineering, University of Pretoria, Pretoria 0002, South Africa

ABSTRACT

The flotation response of a Pb-Zn sulphide ore from the Rosh Pinah Mine (Namibia) was studied in the presence of inorganic depressants such as sodium cyanide and zinc sulphate. Poor flotation selective was observed in the rougher concentrate of the galena circuit despite the use of excessive amount of sodium cyanide. Batch flotation tests have shown that the use of cyanide alone is not efficient for the depression of sphalerite from the Rosh Pinah ore when milling is carried out according to the current plant particle size distribution. The use of both cyanide and zinc sulphate improved the selectivity between galena and sphalerite much better than cyanide alone. Flotation selectivity is limited by the mineralogical texture of the Rosh Pinah ore sample.

Microscopic analysis has shown that the presence of sphalerite in the galena concentrate is also due to poor liberation between galena and sphalerite, especially in the middlings. Hence selectivity could be improved by regrinding the rougher concentrate prior to the cleaning stage.

Keywords- Sulphide ores, Flotation, Flotation depressant, Mineralogy.

1. INTRODUCTION

The Rosh Pinah zinc-lead sulphide deposit occurs in the Southwestern part of Namibia, close to the Orange River. The Rosh Pinah Mine treats a composite of copper-lead-zinc sulphide ores from various sites. Pyrite is the main sulphide gangue mineral in the Rosh Pinah composite sample. Traces of chalcopyrite, gold and silver are found in the ore sample (Figure 1).

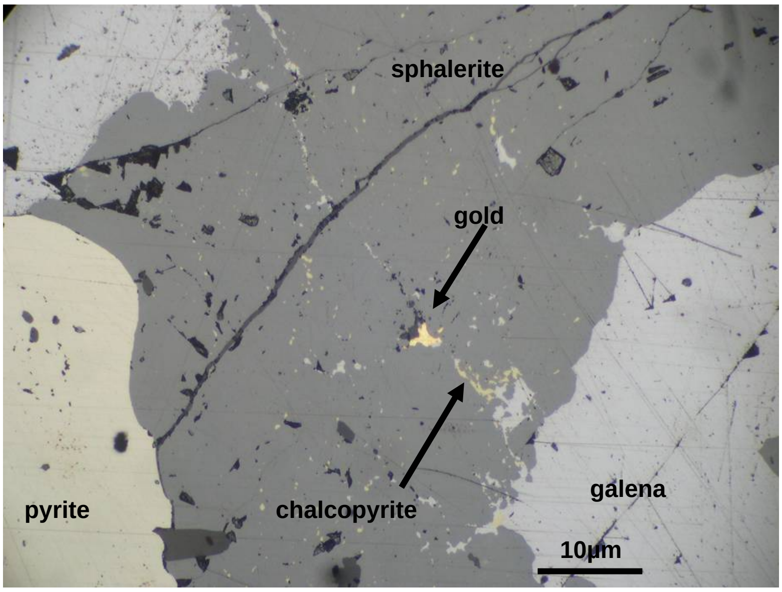

Figure 1. Photomicrograph showing sulphide minerals and gold in the Rosh Pinah ore sample.

The Rosh Pinah composite sample is processed by selective flotation, in which galena is floated first with sodium propyl xanthate (SNPX) as collector, while sphalerite and pyrite are depressed with cyanide. The sphalerite is floated further with xanthate in the zinc flotation circuit after activation with copper sulphate. Selectivity against sphalerite poses a difficult challenge in the lead flotation circuit at the Rosh Pinah Mine, where cyanide dosages as high as 150-180 g/t are being used to suppress the flotation of sphalerite and pyrite at the concentrator.

Although cyanide is an effective depressant in selective flotation of sulphide minerals, considerable amounts of zinc are still recovered together with lead, reflecting poor selectivity during the flotation of galena at Rosh Pinah. High dosages of cyanide are required to overcome this situation. Apart from the significant contribution to the loss of precious metals such as silver and gold by forming soluble metal complexes, the excessive use of cyanide is a cause for concern on environmental grounds. Furthermore, this necessitates the use of more copper sulphate to activate sphalerite for its subsequent flotation in the zinc circuit.

Despite the high dosage of cyanide used in the lead flotation circuit, it is assumed that approximately 1250 tons of zinc is lost every year in the lead concentrate (Katabua and Molelekoe, 2003). For a zinc price of approximately US-$1100 (Metal prices LME, March 2004) per ton of zinc, the annual income loss due to zinc deportment in the lead concentrate can be estimated to a total net smelter value of $1 168 750.
In most plants, sodium cyanide is usually used in conjunction with zinc sulphate for the effective depression of sphalerite from Cu-Pb-Zn sulphide ore at alkaline pH values. Examples are presented in Table 7.1 (Tveter and McQuiton, 1962). The metallurgical results of the Rosh Pinah plant are also given for comparison purposes.

Table 1. Selective flotation of complex lead-zinc sulphide minerals (Modified from Tveter and McQuiton, 1962).

Mine / Mineralogy	Depressants	Product	Metallurgical results			
	(g/t)		Assays (%)		Distribution (%)	
	Lead circuit		Pb	Zn	Pb	Zn
Bunker Hill Co., Kellogg, Idaho *(Galena, sphalerite, pyrite, quartz)*	NaCN: 46 $ZnSO_4$: 115	*Mill Feed*	*7.1*	*2.5*	*100*	*100*
		Pb Conc.	66.0	5.9	96.7	23.9
		Zn Conc.	1.8	54.1	0.8	65.2
		Tails	0.2	0.3	2.5	10.9
Société Algerienne du Zinc, Bou Beker, Morocco *(Galena, Sphalerite, pyrite, dolomite)*	NaCN: 130 $ZnSO_4$: 511	*Mill Feed*	*3.55*	*24.3*	*100*	*100*
		Pb Conc.	73.1	2.98	93	1
		Zn Conc.	0.39	62.4	4	98
		Tails	0.21	0.55	3	1
Rosh Pinah Mine *(Galena, sphalerite, pyrite, chalcopyrite, dolomite, quartz)*	NaCN: 150-180	*Mill Feed*	*1-3*	*6-9*	*100*	*100*
		Pb Conc.	55-60	5-7	70-75	2-3
		Zn Conc.	1-2	52-55		80-85

As seen in Table 1, the dosage ratio of $ZnSO_4$ to NaCN varied from approximately 2.5 to 4. The high dosage of depressant used at Société Algerienne du Zinc was probably due to the high content of zinc (24.3%) in the feed material as compared to 6-9% Zn at the Rosh Pinah plant. In addition, the mineralogy of the ore treated at both the Bunker Hill and Société Algerienne du Zinc concentrators is similar to the Rosh Pinah ore, despite the differences in their respective chemical compositions and metallurgical results (Table1).

A study on the deportment of sphalerite in the lead flotation circuit was carried out in the work reported here for a better understanding of the high dosage of cyanide required for the depression of sphalerite at the Rosh Pinah plant. Applied mineralogy has become a powerful tool to improve the understanding of the ore response to beneficiation practice in the mining industry. The main types of data required to provide an ore-dressing mineralogical assessment are generally as follows (Henley, 1983):

- Mineral identities;
- Mineral composition and proportion;
- Liberation and locking characteristics of the valuable and gangue minerals;
- Distribution of elements among various mineralogical sites throughout the particle size range being considered.

Of critical importance to assessing metallurgical performance during froth flotation are the liberation and locking characteristics of the minerals present in the ore. Optical and scanning electron microscopy usually supply detailed information on the textural properties of minerals and allow the comparison of these features between the various fractions (Seke, 2005; Hope et al., 2001; Lätti et al., 2001). Thus, it is believed that the persistent poor flotation selectivity observed between galena and sphalerite in the presence of cyanide can be explained by the mineralogical texture of the Rosh Pinah flotation products.

2. EXPERIMENTAL

2.1 Materials, reagents and solutions

The lead-zinc ore sample (-9 mm) used in this study was obtained from the crushing plant at the Rosh Pinah Mine in Namibia. The sample was removed from the actual feed to the milling circuit. The sample was screened at 1.7 mm and the oversize fraction crushed to -1.7 mm. A sub-sample was removed for head assays. The remainder of the sample was used for the flotation testwork. The chemical composition of the ore was determined using a sequential XRF spectrometer ARL 9400-241XP+ of which the results are shown in Table 2.

Table 2. The average chemical analysis of the lead-zinc ore sample used in this study, (weight %)

Pb	Zn	Cu	Fe	S	CaO	MgO	Al_2O_3	SiO_2
1.9	7.0	0.12	3.7	3.9	18.7	8.2	4.1	49.2

Sodium propyl xanthate (SNPX) and Senfroth 9325 (Polypropylene glycol) from Senmin (South Africa) were used as collector and frother, respectively. The xanthate was purified by dissolution in acetone and reprecipitation with petroleum ether as proposed by Rao (1971). Xanthate solutions were prepared daily. Sodium cyanide (NaCN) from Saarchem (South Africa) and zinc sulphate ($ZnSO_4.7H_2O$) from BDH Laboratory Supplies (England) were used for the depression of sphalerite. The cyanide solution was made up at pH 10.5 using NaOH to prevent the formation of HCN. Reagents were made up at 1% (w/w) with distilled water. However, Senfroth 9325 was used neat.

2.2 Flotation

A Denver D12 flotation machine, a 3 dm^3 flotation cell and tap water (Rand Water Board, Pretoria) were used for the batch flotation tests. All flotation experiments were carried out at about 33% (w/w) solids. The impeller speed was set at 1250 rpm and the air flow rate was 6 dm^3min^{-1}. Although no attempt was made to control the pulp potential and dissolved oxygen, they were monitored throughout the experiments.

1kg batch-sample was milled at 67% solids (w/w) in), in an unlined laboratory mild steel mill (Ø 200 x 250 mm) with mild steel rods (11kg) for 8 minutes to achieve the target grind of 80% passing 100 micron. The mill was not vented during the grinding stage. The particle size distributions of the ground products were determined using a Malvern Mastersizer 2000 instrument. After transferring the ore into the flotation cell, the collector (50g/t SNPX) was added and the pulp was conditioned for 3 minutes after which the frother (60g/t Senfroth 9325) was added and conditioned for a further 1 minute. For the depression of sphalerite with cyanide and zinc sulphate, the depressant was added simultaneously with the collector. After starting the air flow, the froth was removed by hand scraping every 15 seconds. Incremental rougher concentrates were collected after 1, 2, 4 and 8 minutes. The volume of the pulp in the flotation cell was kept constant by additions of tap water using a pulp level control device. Flotation tests (in duplicate unless stated otherwise) were carried out at the natural pH (8.5 ± 0.2) of the pulp and room temperature (22 ± 2 °C), which were measured with an Orion pH meter model 420.

Following the flotation tests, the concentrates and tailings were dried and analysed using XRF. Cumulative recoveries were calculated from the masses and chemical analyses of the concentrates and the tailings. The experimental data were fitted using the empirical flotation first order kinetics (Cullinan et al., 1999; Marin and Molina, 1988):

$$R = R_{max}[1-\exp(-kt)] \qquad [1]$$

where R is the recovery at a time t, k is the rate constant, and R_{max} is the recovery at infinite time. The SigmaPlot computer program was used for the fitting of the experimental data and calculations of the flotation rate constant and maximum recovery. Since the duplication of experimental data was within the acceptable statistical error, statistical analysis of the experimental results will not be discussed in this study.

2.3 Scanning electron microscopy (SEM)

A JEOL JSM-6300 scanning electron microscope with an attached Noran EDS was used for image analysis. Backscattered electron images were useful to distinguish the differences in mineral composition. The acceleration voltage was 30kV. The samples used for SEM examination were previously prepared for XRF.

3. RESULTS AND DISCUSSIONS

3.1 Effect of sodium cyanide on the flotation response of the Rosh Pinah composite

The recovery and grade of sphalerite at various dosages of sodium cyanide are presented in Figures 2 and 3, respectively. The recovery of sphalerite decreased from 37 to 32 and 28% with the additions of 50 and 100 g/t NaCN, respectively. There was only a slight decrease of approximately 1%, which is within experimental error, in the recovery of sphalerite upon increasing the amount of cyanide from 100 to 150 g/t.

The flotation results presented in Figure 3 indicate that both the recovery and grade of sphalerite decreased with the addition of sodium cyanide. In addition, maximal depression of sphalerite was obtained after the addition of 100 g/t NaCN.

The decrease in the recovery of sphalerite is likely to be due to the deactivation of copper-activated sphalerite by cyanide ions, because of the presence of chalcopyrite in the Rosh Pinah composite. The activation and deactivation of copper-activated sphalerite is discussed in the literature (Gerson et al., 1999; Finkelstein, 1997; Prestidge et al., 1997).

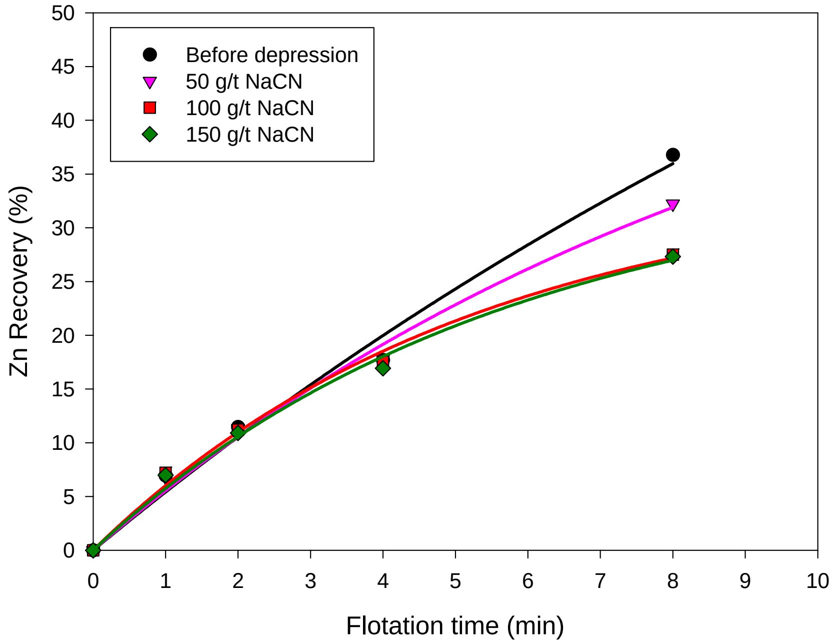

Figure 2. Flotation recovery of zinc from a galena-sphalerite composite from Rosh Pinah at various dosages of sodium cyanide, 50 g/t SNPX and pH 8.5.

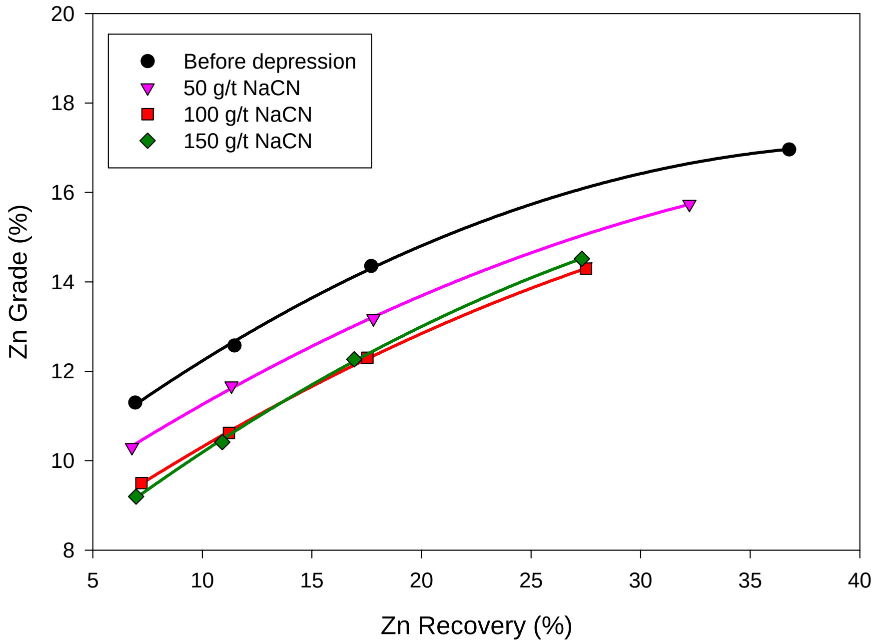

Figure 3. Recovery and grade of zinc from a galena-sphalerite composite from Rosh Pinah at various dosages of sodium cyanide, 50 g/t SNPX and pH 8.5.

The effects of sodium cyanide on the recovery and grade of galena are shown in Figure 4. As seen in Figure 4, the recovery of galena was not adversely affected by the presence of sodium cyanide. In addition, the grade of lead in the concentrate increased when cyanide was added in the flotation cell, as expected from the decreased sphalerite recovery.

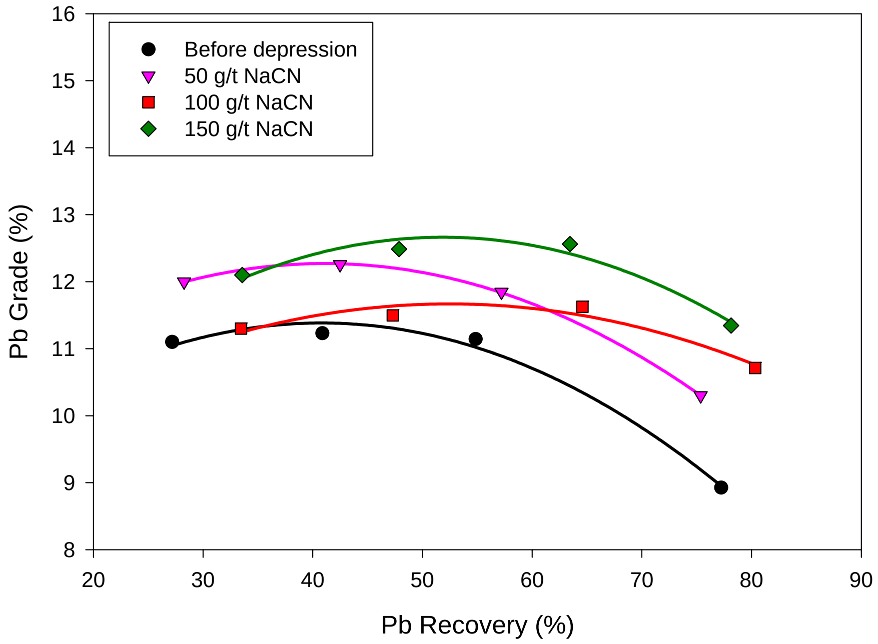

Figure 4. Recovery-grade of lead from a galena-sphalerite composite from Rosh Pinah at various dosages of sodium cyanide, 50 g/t SNPX and pH 8.5.

The influence of free cyanide on the flotation recovery of galena has been investigated in the literature (Prestidge et al. 1993; Grano et al., 1990). Prestidge et al. (1993) have studied the effect of cyanide on the adsorption of ethyl xanthate on galena at different pulp potentials. They have proposed an overall reaction, whereby cyanide ions enhance the dissolution of galena, as follows:

$$PbS + CN^- + 2X^- = PbX_2 + CNS^- + 2e \qquad [2]$$

Prestidge et al. (1993) and Ralston (1994) proposed that cyanide depleted the galena surface of sulphur, forming CNS^-, leaving a residual lead-rich surface, which is more receptive to ethyl xanthate interaction. Because lead hydroxide and lead xanthate species are less soluble and more stable than lead cyanide, it has been accepted that the depression of galena by cyanide is thermodynamically not favourable.

Figure 5 shows the effect of sodium cyanide on the flotation selectivity between galena and sphalerite. As expected, the flotation selectivity was improved by the addition of sodium cyanide. As stated above, increasing the cyanide dosage above 100 g/t NaCN gave no further improvement in flotation selectivity.

The results presented in this study have indicated that the depression of sphalerite from the Rosh Pinah ore can partly be achieved by using cyanide. However, the high dosage of cyanide used at the Rosh Pinah plant (up to 180g/t NaCN in the rougher flotation stage) could not be explained since there was no improvement in the flotation selectivity above 100 g/t NaCN as shown in Figure 5. The amount of zinc in the lead concentrate can be decreased further by upgrading the rougher concentrate and hence decreasing the mass pull.

Based on the chemical and mineralogical composition of the Rosh Pinah ore, it is possible that the sphalerite is activated by both copper and lead ions. It is not possible to depress the lead-activated sphalerite with cyanide ions, which is the proposed role of the second depressant, zinc sulphate. The combined effect of sodium cyanide and zinc sulphate on the flotation of sphalerite in the lead circuit is presented in the next section.

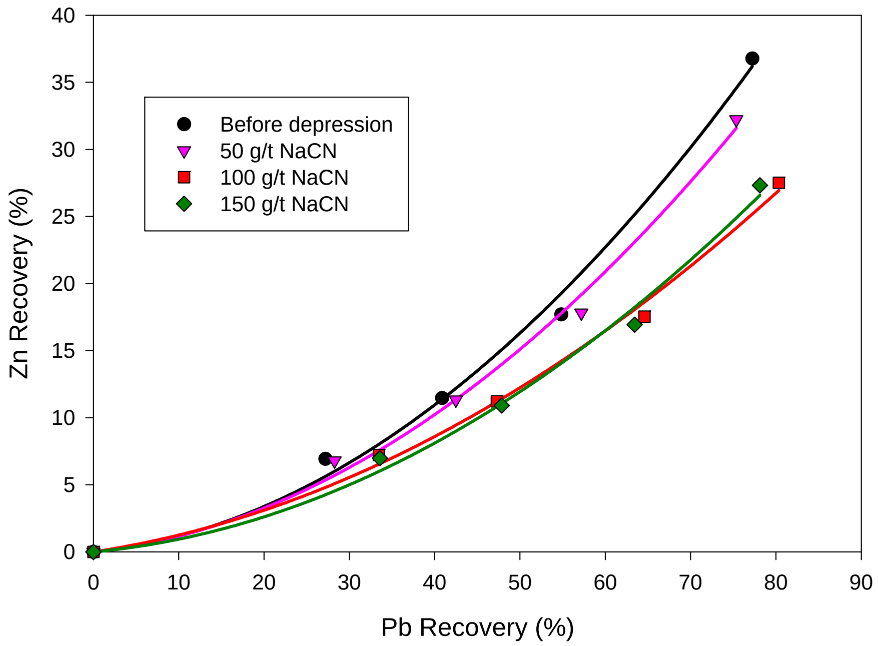

Figure 5. Recovery-grade of lead from a galena-sphalerite composite from Rosh Pinah at various dosages of sodium cyanide, 50 g/t SNPX and pH 8.5.

3.2 Effect of sodium cyanide and zinc sulphate on the flotation response of the Rosh Pinah composite

Flotation testwork was conducted at the natural pH (8.5±0.1) of the ore in the presence of various concentrations of sodium cyanide and zinc sulphate as explained in the previous section. Both sodium cyanide and zinc sulphate were added simultaneously with xanthate in the flotation cell. The cyanide dosage of 75 g/t was used based on the flotation results presented in Figure 5. In addition, the zinc sulphate dosages of 200 and 400 g/t were used to give $ZnSO_4$ to NaCN dosage ratios of approximately 3 and 5.

The recovery of sphalerite at various dosages of depressants is shown in Figure 6. The grade-recovery relationship for different depressant dosages is shown in Figure 7. The recovery of sphalerite decreased from approximately 37 to 22 and 19% in the presence of 200 and 400 g/t $ZnSO_4$ together with 75 g/t NaCN, respectively. The combination of zinc sulphate and sodium cyanide resulted in better depression of sphalerite when compared to the recoveries of 27% achieved in the presence of 100 and 150 g/t NaCN (Figure 2). Furthermore, the final grade of zinc in the lead concentrate decreased from 17.0 to 11.8 and 10.9%, respectively when 200 and 400 g/t of zinc sulphate were used in conjunction with 75 g/t NaCN.

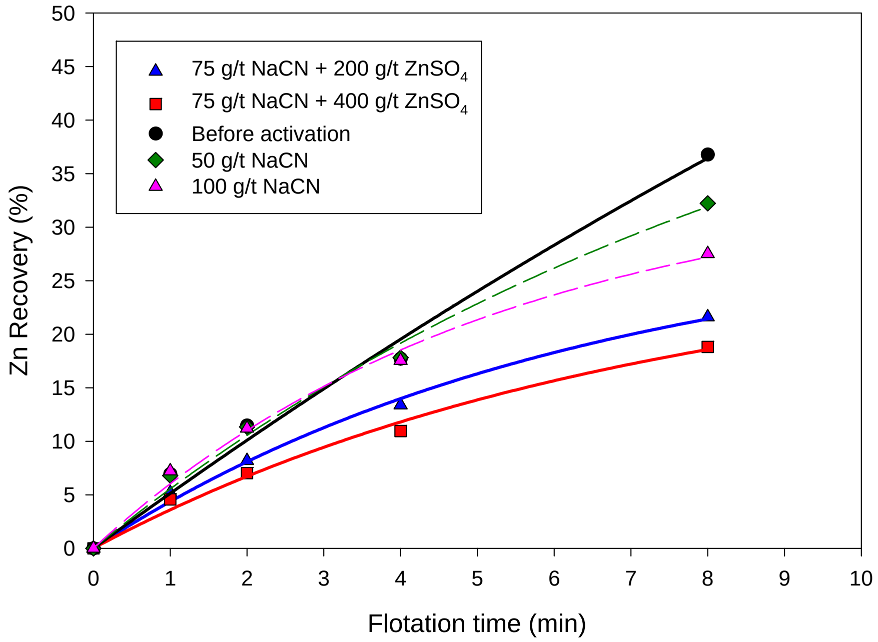

Figure 6. Flotation recovery of zinc from a Rosh Pinah composite sample at various dosages of sodium cyanide and zinc sulphate, 50 g/t SNPX and pH 8.5.

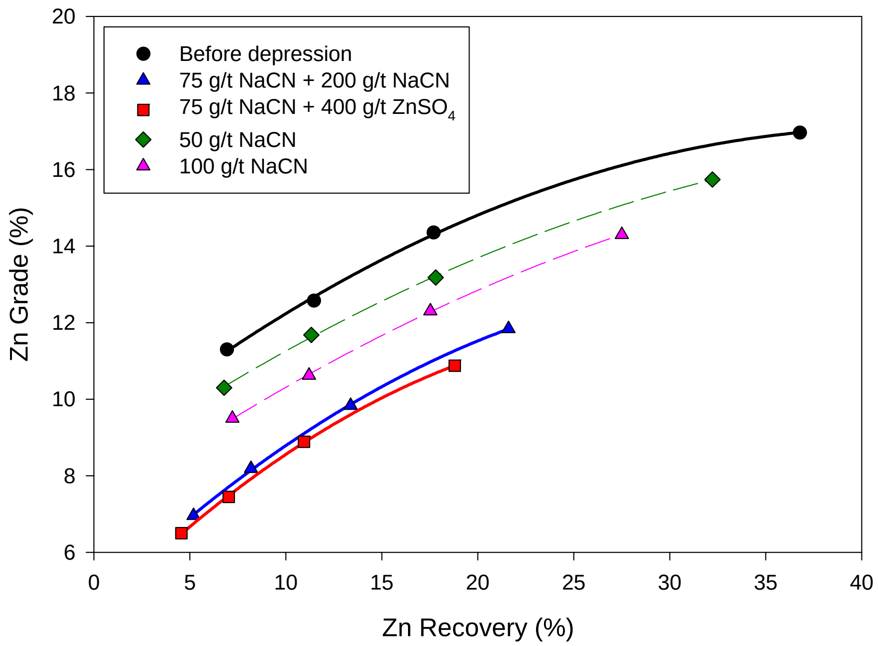

Figure 7. Recovery-grade relationship of zinc from a Rosh Pinah composite sample at various dosages of sodium cyanide and zinc sulphate, 50 g/t SNPX and pH 8.5.

The recoveries and grades of lead (galena) as a function of various dosages of cyanide and zinc sulphate are shown in Figure 8. The recovery of galena decreased slightly from 77 to 73 and 72% after the additions of 200 and 400 g/t $ZnSO_4$, respectively in conjunction with 75 g/t NaCN. The observed decrease in the recovery of galena can be caused by the presence of hydrophilic zinc hydroxide on the surface of galena, since zinc hydroxide is not expected to adsorb/precipitate selectively on galena and sphalerite.

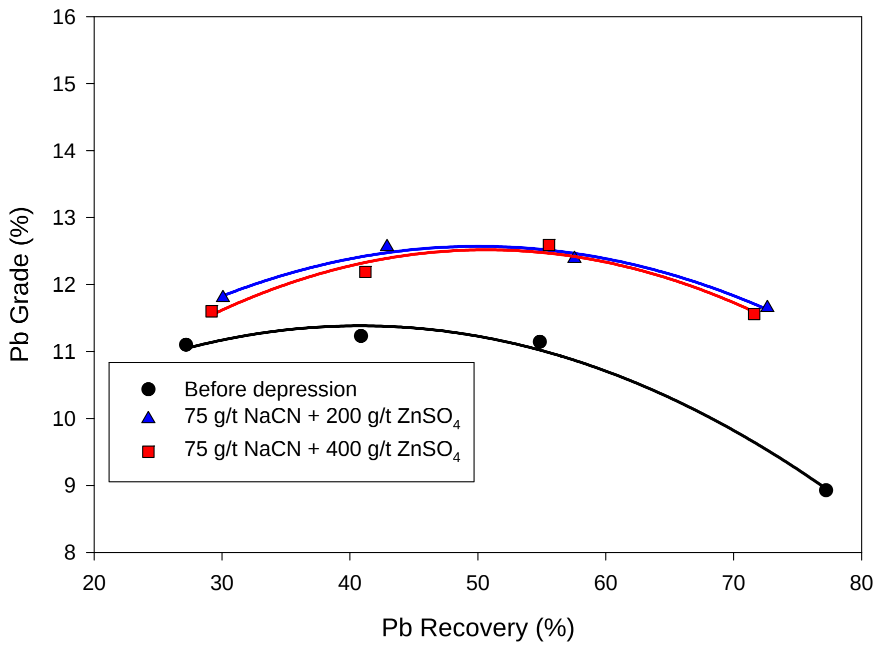

Figure 8. Recovery-grade of lead from a Rosh Pinah composite sample at various dosages of sodium cyanide and zinc sulphate, 50 g/t SNPX and pH 8.5.

As shown in Figure 8, the grade of lead in the concentrate increased after the additions of depressant. This was due to the decrease in the recovery of sphalerite in the lead concentrate. The grade of lead increased from 8.9 to 11.7 and 11.6% in the presence of respectively 200 and 400 g/t $ZnSO_4$, when used in conjunction with 75 g/t NaCN.

The flotation selectivity between galena and sphalerite for various dosages of depressants is shown in Figure 9. It can be seen that the selectivity improved with the addition of both cyanide and zinc sulphate. The additional effect of zinc sulphate on the flotation selectivity can be related to the depression of lead-activated sphalerite. Although the amount of lead that can activate sphalerite was not quantified, Greet and Smart (2002) proposed a method for the diagnostic leaching of galena and its oxidation products using ethylene diaminetetraacetic acid (EDTA). They demonstrated that all oxygen containing galena oxidation products such as sulphate, hydroxide, oxide, and carbonate are rapidly solubilised in EDTA. They also showed that EDTA does not extract lead from un-reacted galena.

It was interesting to observe that the selectivity achieved with 100 g/t NaCN alone was similar to that achieved with the combination of 75g/t NaCN and 200 g/t $ZnSO_4$. However, the recoveries of galena and sphalerite were lower when zinc sulphate was used in conjunction with sodium cyanide. Since the recovery of galena in the lead rougher concentrate has to be maximised in plant practice, it would be convenient to use 100 g/t NaCN for the depression of sphalerite followed by the optimisation of the depressant in the cleaning stage.

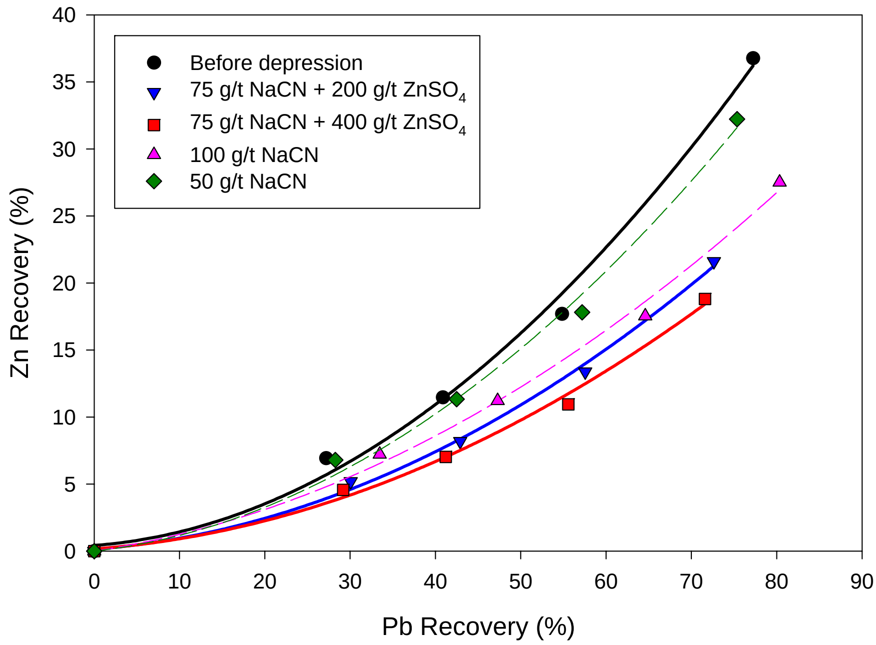

Figure 9. Lead and zinc recoveries from a Rosh Pinah composite sample at various dosages of sodium cyanide and zinc sulphate, 50 g/t SNPX and pH 8.5.

3.3 Deactivation with zinc sulphate and sodium cyanide

The solubility of zinc species as functions of pH in the presence of zinc sulphate and sodium cyanide is shown in Figure 10.

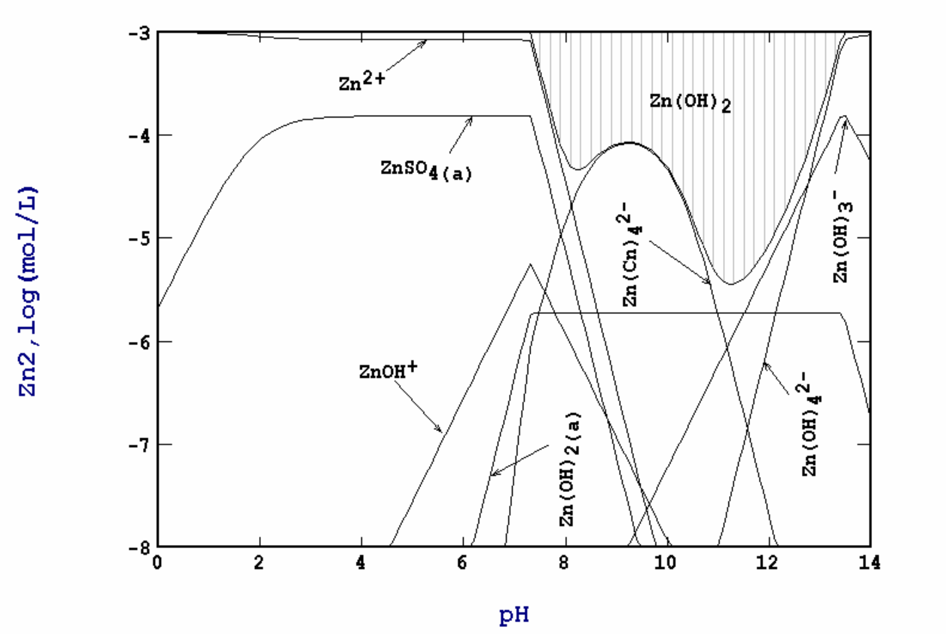

Figure 10. Speciation diagram for Zn(II) as a function of pH in the presence of 10^{-3}M NaCN and 10^{-3}M $ZnSO_4$ at 25 °C. Stabcal software. NBS database (Huang, 2003).

As seen in Figure 10 the precipitation of colloidal zinc hydroxide can occur at the range of alkaline pH values used at the Rosh Pinah plant during the selective flotation of galena and sphalerite if both zinc sulphate and sodium cyanide are used. However, it has been shown that sphalerite from the Rosh Pinah composite is primarily activated by copper ions present in the flotation pulp. Thus cyanide will react with the copper at the surface of sphalerite to form cuprous cyanide complexes. Thermodynamically, the cuprous cyanide complexes such as $Cu(CN)_3^{2-}$ and $Cu(CN)_2^{-}$ are predicted to be the most predominant cyanide species at alkaline pH values when sodium cyanide and zinc sulphate are used to depress sphalerite (Figure 11). In addition, a lower concentration of $Zn(CN)_4^{2-}$ is also expected to be present in the solution.

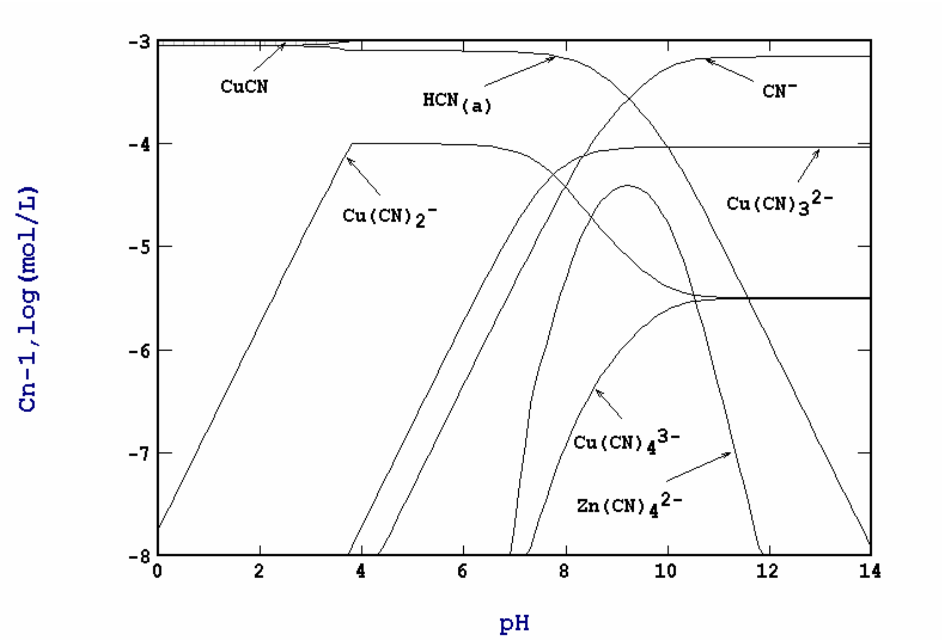

Figure 11. Speciation diagram for CN^- as a function of pH in the presence of 10^{-3}M NaCN, 10^{-3}M $ZnSO_4$, and 10^{-4}M Cu(I) at 25 °C. Stabcal software. NBS database (Huang, 2003).

As seen in Figure 11 the concentration of free cyanide in solution will decrease with decreasing pH. Thus, it is also important to monitor the pH of the flotation pulp for an efficient consumption of sodium cyanide during the depression of sphalerite to avoid the loss of free cyanide at pH values lower than 8.

Based on the thermodynamic information presented in Figures 10 and 11, it appears possible to depress sphalerite when it has been activated by both copper and lead ions by using sodium cyanide and zinc sulphate at alkaline pH values. The most plausible mechanisms of depression would be the complexation of surface copper with free cyanide and the precipitation of hydrophilic zinc hydroxide on the surface of sphalerite.

Although the recoveries and grades of sphalerite were decreased with the use of both cyanide and zinc sulphate, separation between galena and sphalerite remains rather poor, and it is important to understand the inefficiency of cyanide on the depression of zinc in the galena concentrate. Mineralogical analysis was carried out to further understand the poor flotation selectivity between galena and sphalerite which persists even in the presence of sodium cyanide.

3.4 Deportment of sphalerite through the flotation products

3.4.1 Deportment of sphalerite in the lead rougher concentrate

Qualitative mineralogy by image analysis on scanning electron microscopy (SEM) was performed on the flotation products after flotation of a composite ore from Rosh Pinah in the presence of 100 g/t NaCN and 50 g/t SNPX (Figure 12). These flotation results are similar to those presented in Figures 2-4.

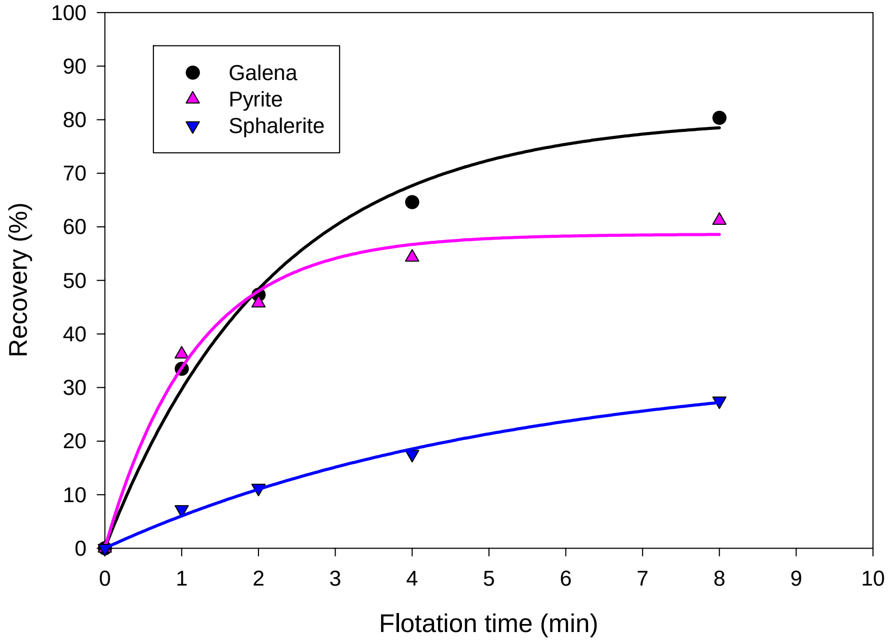

Figure 12. Recoveries of galena, pyrite and sphalerite after flotation of a composite from Rosh Pinah in the presence of 50 g/t SNPX and 100 g/t NaCN at pH 8.5.

The flotation results shown in Figure 12 indicate that galena and pyrite were the fast floating minerals, while sphalerite was the slow floating mineral. Figure 12 also indicates that approximately 36% of pyrite, 34% of galena and 7.2 % of sphalerite were recovered in the first minute of flotation. However, 16% of galena, 10% of sphalerite and 7% of pyrite were recovered in the last incremental concentrate (4-8 minutes).

The mineralogical textures of the concentrates obtained after one and 8 minutes of flotation are shown in Figures 13 and 14. As seen in Figures 13 and 14, the fractional amounts of galena and pyrite recovered in the concentrate decreased with the flotation time, while that of sphalerite and gangue increased. It was clear that the concentrate recovered in the first minute of flotation contained mainly liberated galena and pyrite. Figure 13 showed that liberated particles of galena were usually fine grained to about 25 micron, while pyrite particles seemed to be much coarser (more pictures are shown in the appendices). The mineralogical texture of the concentrate recovered after 8 minutes of flotation showed that the recovery and grade of gangue minerals (mainly silicate and dolomite) increased in the last concentrate when compared to the concentrate of the first minute. Figure 13 also showed that most of the slow floating materials were large sphalerite particles (+50µm). Their presence in the lead concentrate would be detrimental to flotation selectivity.

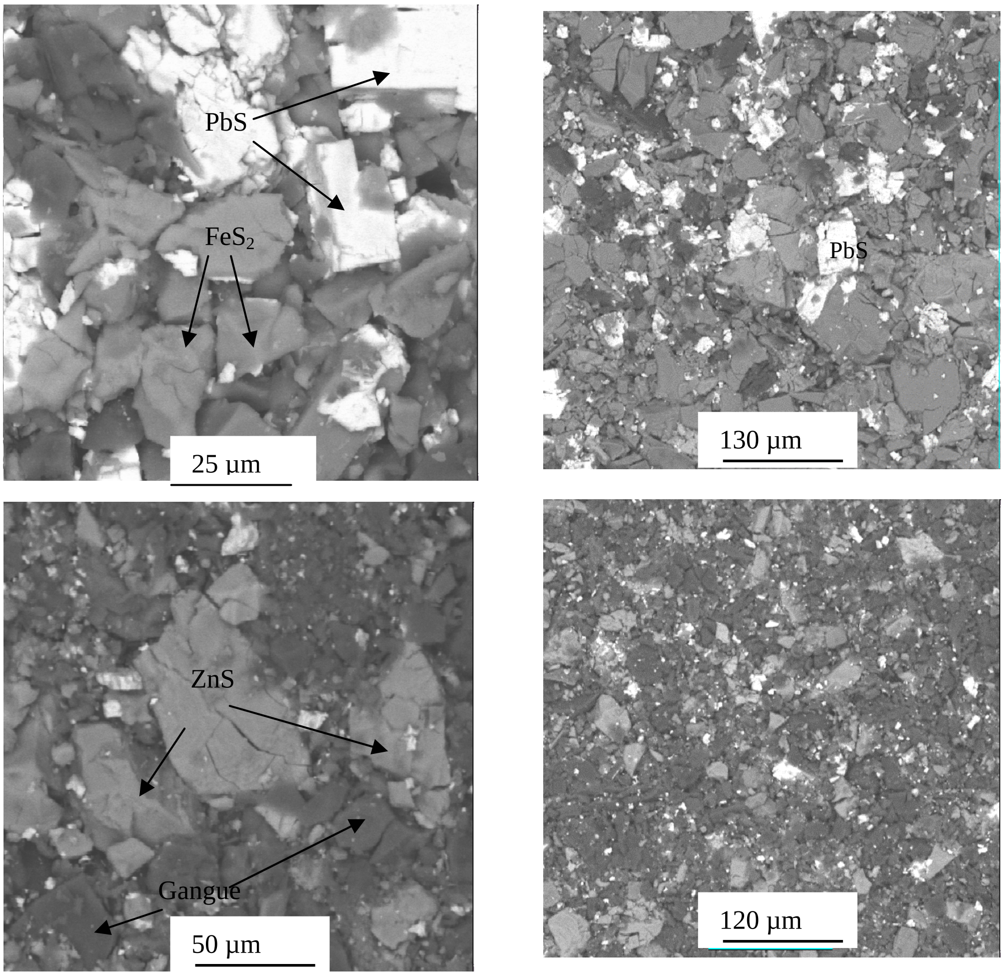

Figure 13. SEM- Backscattered images showing the general appearance of the rougher concentrates after 1 and 8 minutes. The flotation experiment was carried out in the presence of 100 g/t NaCN and 50 g/t SNPX.

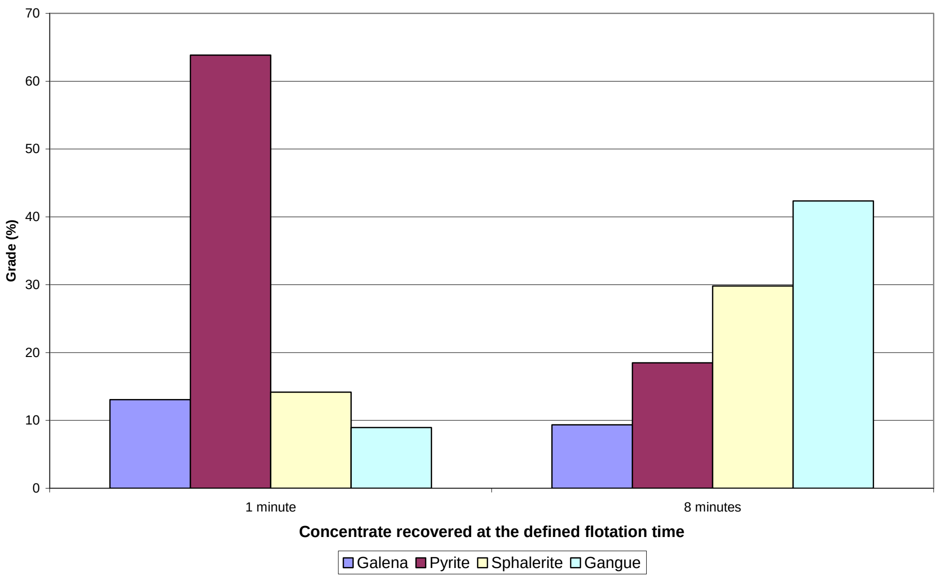

Figure 14. Mineralogical composition of the first and last concentrates after flotation in the presence of 50 g/t SNPX and 100 g/t NaCN at pH 8.5.

The striking feature of the texture of the concentrates was the large quantity of binary locked galena and sphalerite (Figure 15).

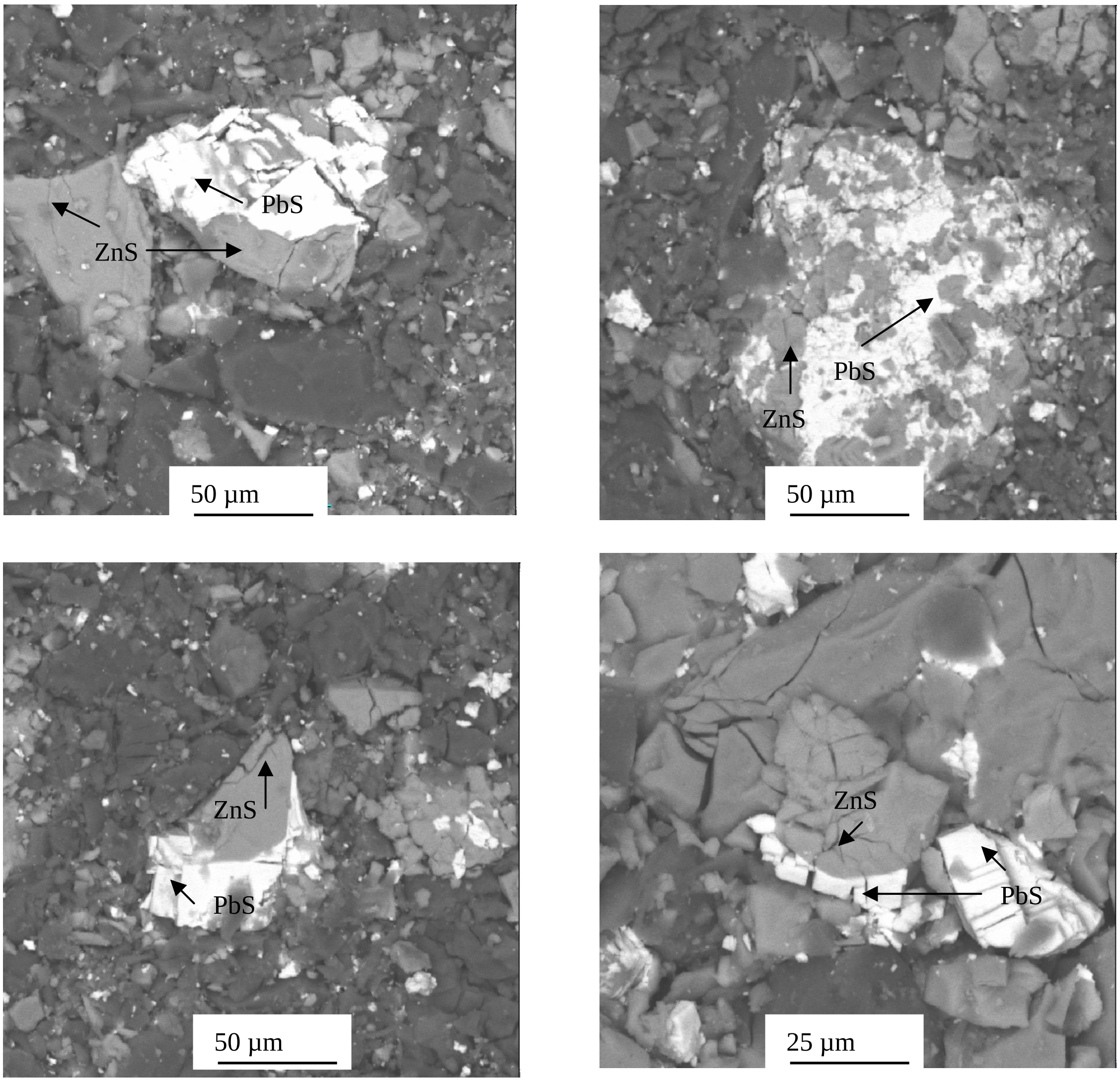

Figure 15. SEM- Backscattered images of concentrate showing the association between galena (white) and sphalerite (grey) in the galena concentrate.

It was observed that the occurrence of galena locked and/or attached to sphalerite increases with increasing particle size, especially above the 50 micron size. Thus, the poorly liberated sphalerite particles from the middlings would contribute to the problem of zinc deportment into the lead concentrate at the Rosh Pinah Mine. Hence, increasing the dosage of depressant would not solve the problem without affecting the recovery of galena. However, with severe depression of sphalerite, galena particles which are occluded in sphalerite may also be lost in the rougher tailings as shown in Figure 16. In addition, the loss of galena in the rougher tailings can be increased due to the presence of slow floating particles when the retention time is not long enough to account for their flotation. As seen in Figure 17, the rougher tailings mostly contained liberated sphalerite and gangue, which are sent to the zinc flotation circuit. The sphalerite is then intentionally activated with copper sulphate followed by its flotation with xanthate at high pH values to depress the flotation of pyrite.

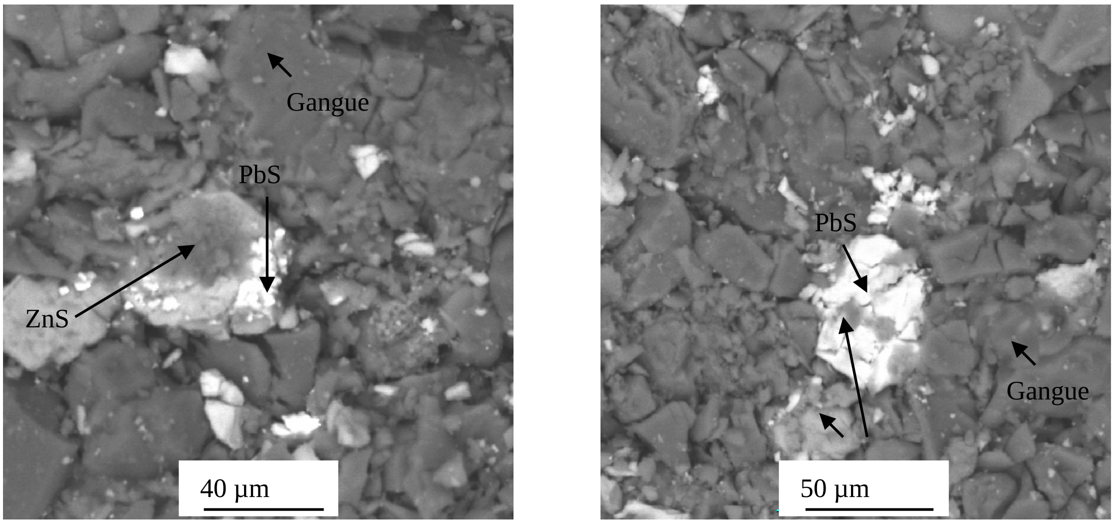

Figure 16. SEM- Backscattered images showing the association between galena and sphalerite in the lead rougher tailings.

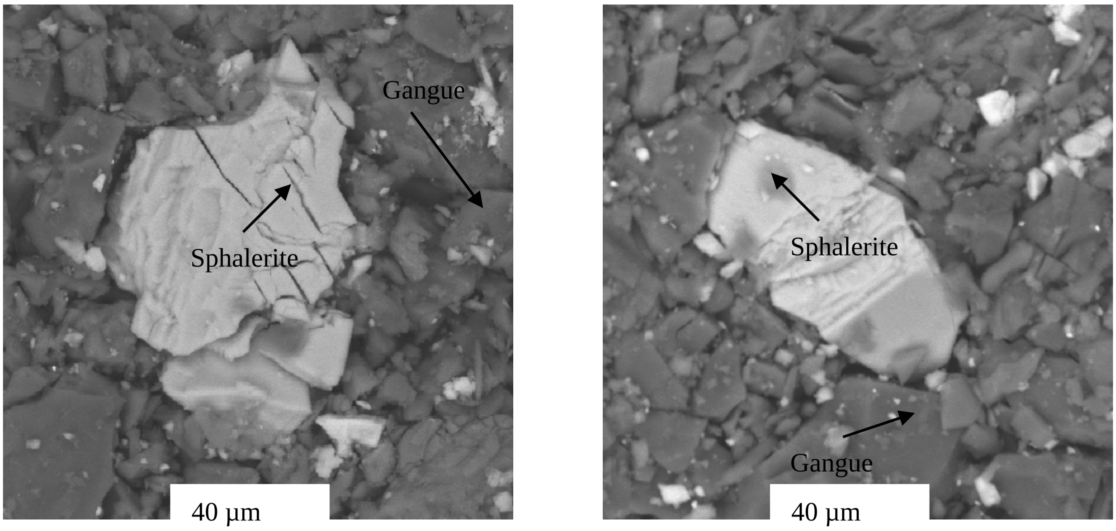

Figure 17. SEM- Backscattered images showing the general appearance of the rougher tailings. The flotation experiment was carried out in the presence of 100 g/t NaCN and 50 g/t SNPX.

The results obtained in this study were compared with those obtained when using the flotation products from the Rosh Pinah plant (Reyneke, 2000). The results of Reyneke (2000) are discussed in the next section.

3.4.2 Deportment of sphalerite in the flotation products from the Rosh Pinah plant

Mineralogical examination of flotation products from the Rosh Pinah plant was conducted at Kumba Resources R&D (Pretoria) to study the presence of zinc in the galena concentrate in spite of the high dosage of cyanide used to decrease the recovery of sphalerite. The textural properties of the Rosh Pinah final lead concentrate were semi-quantitatively determined by optical particle counting and the results are presented in Figure 18.

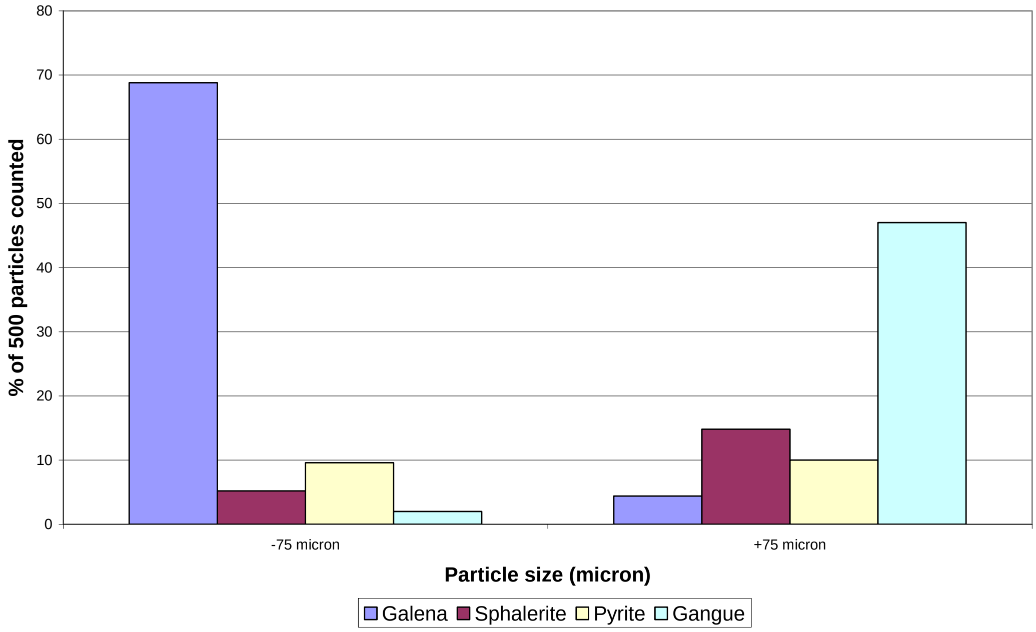

Figure 18. Minerals distribution in the lead concentrate from the Rosh Pinah Mine as a function of particle size (After Reyneke, 2000). (Fully liberated minerals only)

As seen in Figure 18, most of liberated galena particles were recovered in the -75µm size fraction, while the amounts of liberated sphalerite and gangue particles increased in the +75µm size fraction. Since flotation in the lead circuit is carried out at a primary grind of 80% passing 100µm, the concentrate mass pull in the +106µm fraction size will be negligible. Thus, the results of particle counting of the +106µm size fraction were omitted in Figure 18. The distribution of liberated sphalerite and sphalerite attached to galena is shown in Figure 19.

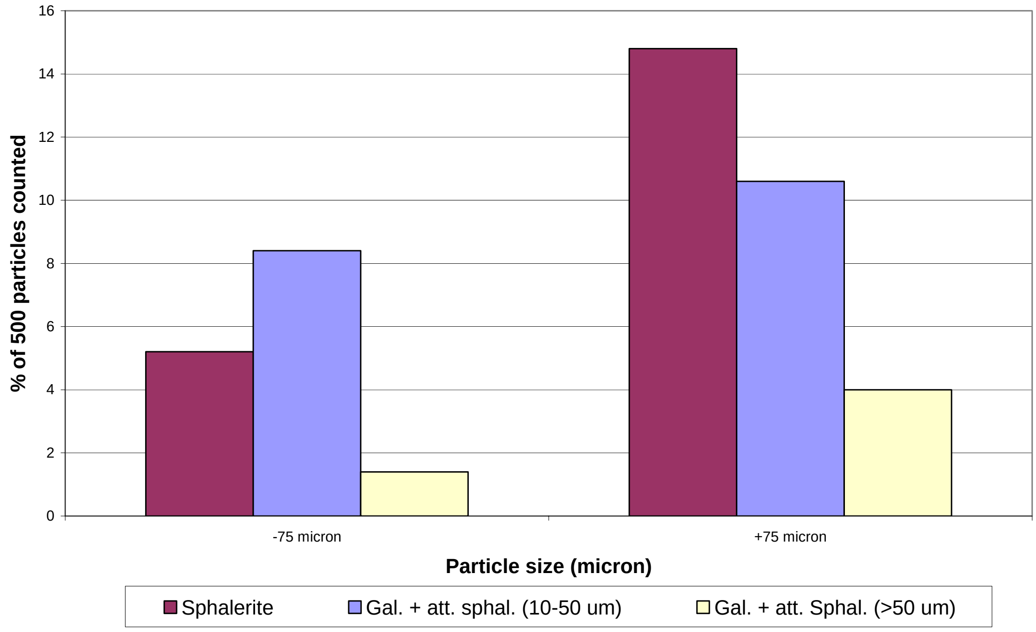

Figure 19. Sphalerite distribution in the lead concentrate from the Rosh Pinah Mine as a function of particle size (After Reyneke, 2000).

It was interesting to observe that the fraction of both liberated sphalerite and sphalerite particles attached to galena increased with increasing particle size. However, the fraction of binary locked particles of galena and sphalerite was higher than that of liberated sphalerite in the -75µm size. The fraction of sphalerite particles (size of sphalerite particle: 10-50µm) attached to galena increased in the +75µm size. Based on the primary grind of 80% passing 100µm used at the Rosh Pinah Mine, it was assumed that the concentrate mass pull would be higher in the -75 micron. Hence, it is believed that the fraction of sphalerite particles (10-50µm) attached to galena would adversely affect the flotation selectivity in the lead circuit. Therefore, it is clear that the liberation of sphalerite and galena particles has to be optimised instead of only increasing the depressant dosage during the flotation of galena.

Since the flotation response of ores is usually a function of the primary grind, the mode of occurrence of the Rosh Pinah feed sample was also semi-quantitatively determined by optical particle counting and the results are presented in Figure 20.

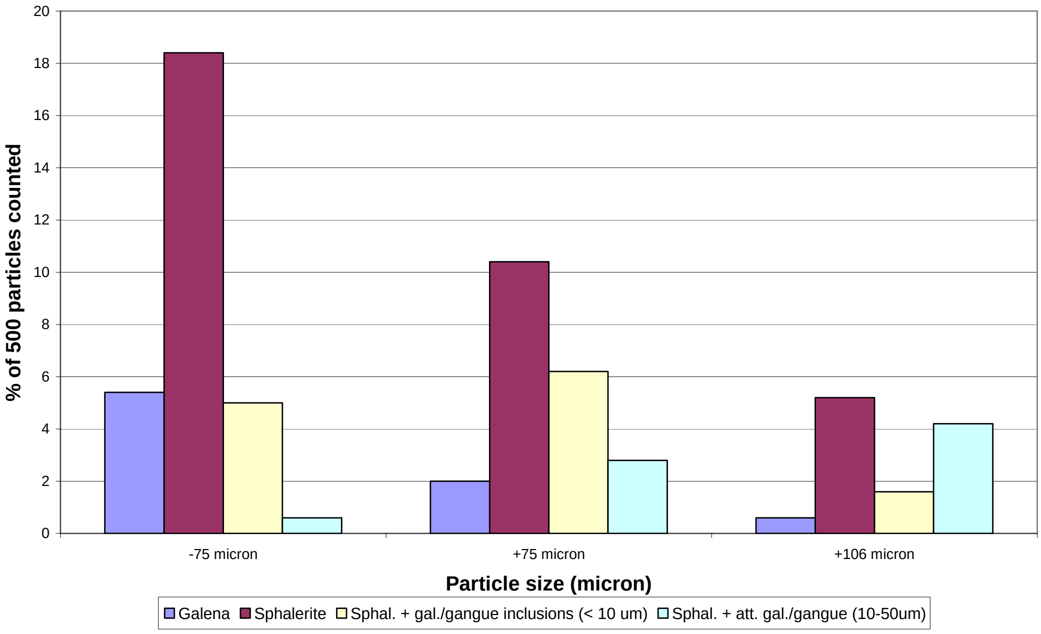

Figure 20. Galena and sphalerite distribution of the feed sample from the Rosh Pinah Mine as a function of particle size (After Reyneke, 2000).

As seen in Figure 20, it was clear that the fraction of liberated galena and liberated sphalerite increased with decreasing particle size. In addition, it was observed that the fraction of sphalerite and attached galena/gangue (10-50µm) particles decreased with decreasing particle size of the feed sample. However, a considerable amount of sphalerite particles with galena inclusions of less than 10µm in size was observed in all size fractions. These binary sphalerite-galena particles would be difficult to depress.

Selectivity can be improved by better liberation of galena from sphalerite in the milling circuit, or alternatively by regrinding the rougher concentrate before the cleaning stage. However, practical implementation of this would need to take into account the softness of galena. In practice, it would be recommended to install a classifying cyclone before the regrind mill in order to avoid the over-grinding of fine particles from the rougher concentrate.

Based on the flotation and mineralogical results presented in this chapter, it is believed that the flotation selectivity between galena and sphalerite can be improved by changing the current flowsheet by including a cyclone and re-grind mill after the rougher flotation stage as shown in Figure 21.

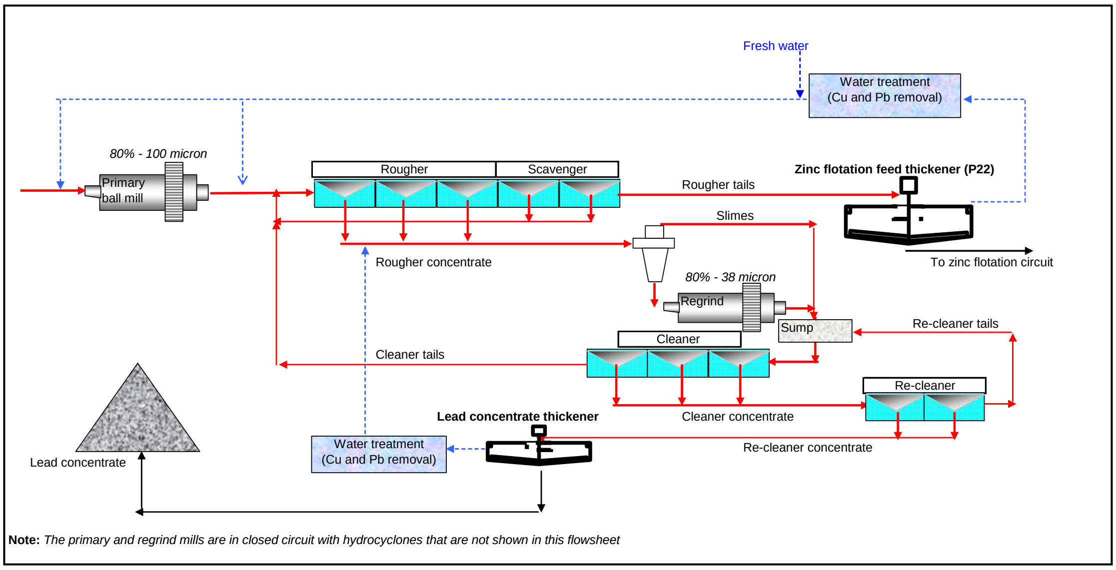

Figure 21. Proposed flowsheet diagram of the lead flotation circuit at the Rosh Pinah Mine.

The modified flowsheet can be summarised as follow:

- Using a primary grind of 80% passing 100 micron to avoid the over-grinding of galena;
- Using up to 100 g/t NaCN to depress mainly copper-activated sphalerite in the lead rougher-scavenger flotation circuit and to maximise the recovery of galena;
- Using a cyclone to split the fine fraction (-38 micron) from the middlings to avoid the over-grinding of fine galena particles (Figure 21);
- Regrinding of the middlings from the rougher concentrate to improve the liberation of galena and sphalerite particles prior to the cleaning stages (Figure 21);
- Cleaning of the rougher concentrate to achieve the required smelter grade (Figure 21). Figure 14 shows that pyrite and sphalerite were the major impurity sulphides in the lead rougher concentrate. Thus, it is recommended to increase the pH during the cleaning stage for an effective depression of pyrite (pyrite can be depressed at pH values higher than 9).
- Using sodium cyanide and zinc sulphate in the cleaning stages to depress sphalerite and pyrite.

4. CONCLUSION

Batch flotation tests have shown that the use of cyanide alone is not efficient for the depression of sphalerite from the Rosh Pinah ore when milling is carried out according to the current plant particle size distribution. The use of both cyanide and zinc sulphate improved the depression of sphalerite much better than cyanide alone. In addition, an increase in the recovery and grade of galena was observed when cyanide or both cyanide and zinc sulphate were used.

Flotation selectivity is limited by the mineralogical texture of the Rosh Pinah ore sample. Microscopic analysis has shown that the presence of sphalerite in the galena concentrate is also due to poor liberation between galena and sphalerite, especially in the middlings. Hence selectivity could be improved by regrinding the rougher concentrate prior to the cleaning stage.

It is recommended that the flotation products such as rougher, scavenger and cleaner concentrates be analysed statistically using the QEM-SCAN to determine the correct fraction of locked and associated sphalerite particles in the lead concentrate.

It is also recommended that variability testwork be conducted on the Rosh Pinah Eastern and Western ore field samples using the proposed flowsheet. In addition, locked cycle test, which is a series of repetitive batch tests conducted in the laboratory, is required to simulate plant conditions before implementing the proposed reagent suite and flowsheet at the Rosh Pinah Mine.

5. AKNOWLEDGEMENT

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6. REFERENCES

Cullinan, V.J., Grano, S.R., Greet, C.J., Johnson, N.W. and Ralston, J. 1999. Investigating fine galena recovery problems in the lead circuit of Mount Isa Mines lead/zinc concentrator. Part1: Grinding effects. *Minerals Engineering*, 12(2): 147-163.

Finkelstein, N.P., 1997. The activation of sulphide minerals for flotation: a review. *Int. J. Min. Process*. 52:81-120.

Gerson, A.R., Lange, A.G., Prince, K.E., Smart, R.St.C., 1999. The mechanism of copper activation of sphalerite. *Applied Surface Science*, 137: 207-223.

Grano, S.R., Ralston, J. and Smart, R.S.C., 1990. Influence of electrochemical environment on the flotation behaviour of Mt. Isa copper and lead-zinc ore. *Int. J. Miner. Process.* 30:69-97.

Greet, C. and Smart, R.St.C., 2002. Diagnostic leaching of galena and its oxidation products with EDTA. *Minerals Engineering*, 15:515-522

Henley, K.J., 1983. Ore-dressing mineralogy- A review of the techniques, applications and recent developments. *Spec. Pub. Geo. Soc. S. Afr.*, 7: 175-200.

Hope, G.A., Woods, R. and Munce, C.G., 2001. Raman microprobe identification. *Minerals Engineering*, 14(12): 1565-1577.

Huang, H.H., 2003. *Stabcal Software: Stability Calculation for Aqueous Systems*. Metallurgical Engineering, Montana Tech. (USA).

Katabua, J. and Molelekoe, R., 2003. Rosh Pinah Water Project. *Report: Doc. No. RD-AP-015*. Kumba Technology, R&D. Kumba Resources. Pretoria (South Africa). p. 12

Lätti, D., Doyle, J. and Adair, B.J.I., 2001. A QEM*SEM study of a suite of pressure leach products from a gold circuit. *Minerals Engineering*, 14(12): 1671-1678.

Marin, G. and Molina, E., 1988. Characterisation of collectors through flotation rate data. In: S.C. Flores and Moisan J.A. (Eds.), *Froth Flotation*, Developments in Minerals Processing, vol. 9. Elsevier. pp. 329-340.

Prestidge, C.A., Skinner, W.M., Ralston, J., and Smart, R.C., 1997. Copper (II) activation and cyanide deactivation of zinc sulphide under mildly alkaline conditions. *App. Surf. Sci.*, 108: 333-344.

Prestidge, C.A., Ralston, J., and Smart, R.C., 1993. Role of cyanide in the interaction of ethyl xanthate with galena. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 81: 103-119.

Ralston, J. 1994. The chemistry of galena flotation: Principles and practice. *Minerals Engineering*, 7(5/6): 715-735.

Rao, S.R., 1971. *Xanthates and related coumponds*. Marcel Dekker, New York (USA), p 504.

Reyneke, L., 2000. Mineralogical composition and particle-counting of zinc, lead, feed and waste samples from Rosh Pinah, Namibia. *Report No. M2000/33*. Kumba Resources R&D (Pretoria, South Africa). p. 9.

Seke, M.D, 2005. Optimisation of the selective flotation of galena and sphalerite at Rosh Pinah mine. PhD Thesis. University of Pretoria, Pretoria (South Africa).

Tveter, E.C. and McQuiston, F.W., 1962. Plant practice in sulphide mineral flotation. In D.W. Fuerstenau (Editor), *Froth Flotation. 50th Anniversary Volume*. AIME, New York, USA, pp. 382-426.