Chapter 7. Depression of sphalerite with cyanide and zinc sulphate

7.1. Introduction

Cyanide is the only depressant currently used at the Rosh Pinah Mine to depress sphalerite and pyrite in the lead flotation circuit. As explained in Chapter 2, cyanide dosages of 150-180 g/t NaCN are often used at the plant at the natural pH of about 8.5±0.3. 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. It is believed that this financial loss can be partly reduced if the reagent suite is optimised. In addition, decreasing the amount of cyanide in the lead circuit will also lead to a decrease in the dosage of copper sulphate that is needed to re-activate the sphalerite in the zinc flotation circuit.

Since chalcopyrite (0.3%) is also present in the Rosh Pinah Mine ore, it is believed that the dissolution and/or oxidation of chalcopyrite and galena can contribute to the presence of copper and lead ions in the flotation pulp during the beneficiation of the ore. The sphalerite can then be inadvertently activated by dissolved copper and lead ions during the flotation of galena. As discussed in Chapter 3, cyanide is known to depress the flotation of copper activated sphalerite by leaching out copper from the surface of sphalerite. However, the formation of stable lead cyanide complexes is thermodynamically unfavourable and hence cyanide cannot counteract activation by lead. 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. The expected effect of zinc sulphate will be discussed in the next section.

As seen in Table 7.1, 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 (Table 2.3), despite the differences in their respective chemical compositions and metallurgical results (Tables 2.4 and 7.1).

Table 7.1. 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

Based on the wide literature on sphalerite depression, it is necessary to study the flotation response of the Rosh Pinah ore in the presence of cyanide alone and in conjunction with zinc sulphate. The use of zinc sulphate alone has been ruled out since traces of chalcopyrite are present in the Rosh Pinah ore, and the deactivation of copper-activated sphalerite is not efficient at lower dosages of zinc sulphate alone. In addition, Trahar et al. (1997) have shown that the use of zinc salts at pH 9 decreased the recovery of galena due to the coating by hydrophilic zinc hydroxide. 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.

Since an overview on cyanide depression was presented in Chapter 3, only the effect of zinc sulphate alone and in conjunction with sodium cyanide will be discussed in the following sections.

7.2. Deactivation with zinc sulphate

At Rosh Pinah Mine, the selective flotation of the lead-zinc sulphide composite is carried out at mildly alkaline pH values. However, depending on the flotation conditions, sphalerite can be activated by products from the dissolution and/or oxidation of galena and chalcopyrite.

Fuerstenau and Metzger (1960) and El-shall et al. (2000) proposed that the deactivation lead-activated sphalerite by zinc sulphate would occur by the replacement of the lead ions out of the surface of sphalerite by zinc ions according to the following equation:

$$PbS_{(s)} + Zn^{2+} = ZnS_{(s)} + Pb^{2+} \quad [7.1]$$

They support the argument that zinc salts should be able to prevent Pb^{2+} activation of sphalerite only if the ratio of $[Zn^{2+}]/[Pb^{2+}]$ exceeds a value of 10^3 in solution. However, it is difficult to accept that lead ion, which has the ionic radius of approximately 1.2A would replace zinc ion which has a smaller ionic radius of 0.6A. It is likely that the adsorption of Zn^{2+} (at acidic pH values) onto the surface of lead-activated sphalerite will decrease its flotation because of the weakness of zinc-xanthate complexes. The solubility of zinc sulphate as a function of pH at 25°C is shown in Figure 7.1.

When flotation is conducted at alkaline pH values, Marsicano et al. (1975) assumed that the pH at which depression by zinc sulphate starts will coincide with the appearance of colloidal zinc compounds such as $Zn(OH)_2$. For a total concentration of 10^{-3}M $ZnSO_4$, which is usually used in plant practice, it can clearly be seen that the onset of $Zn(OH)_2$ precipitation is at pH 7.3. Thus, for mildly alkaline pH of about 8.5 used in the selective flotation of the lead-zinc sulphide composite at the Rosh Pinah Mine, it is clear that $Zn(OH)_2$ would be the depressing agent when zinc sulphate is used to depress the lead-activated sphalerite as shown in the following equation:

$$ZnS.PbS_{(s)} + Zn(OH)_2 = ZnS.PbS_{(s)}.Zn(OH)_2 \quad [7.2]$$

Therefore, the presence of hydrophilic zinc hydroxide at the surface of sphalerite will prevent the interaction between the lead-activated sphalerite and xanthate, and subsequently decrease its floatability in the lead flotation circuit.

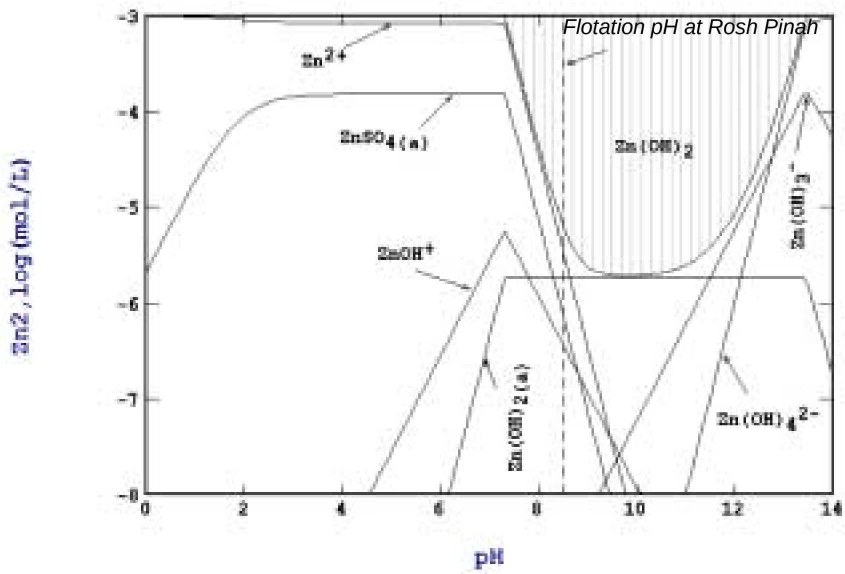

Figure 7.1. Speciation diagram for Zn(II) as a function of pH for [$ZnSO_4$] = 10^{-3}M at 25 °C. Stabcal software NBS database (Huang, 2003).

Overdosing of zinc sulphate will also decrease the recovery of galena due to the presence of zinc hydroxide on its surface. Since sphalerite from the Rosh Pinah composite is expected to be activated by copper ions, it is thus recommended that both sodium cyanide and zinc sulphate be used as depressants.

7.3. 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 7.2. As seen in Figure 7.2 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 7.3). In addition, a lower concentration of $Zn(CN)_4^{2-}$ is also expected to be present in the solution.

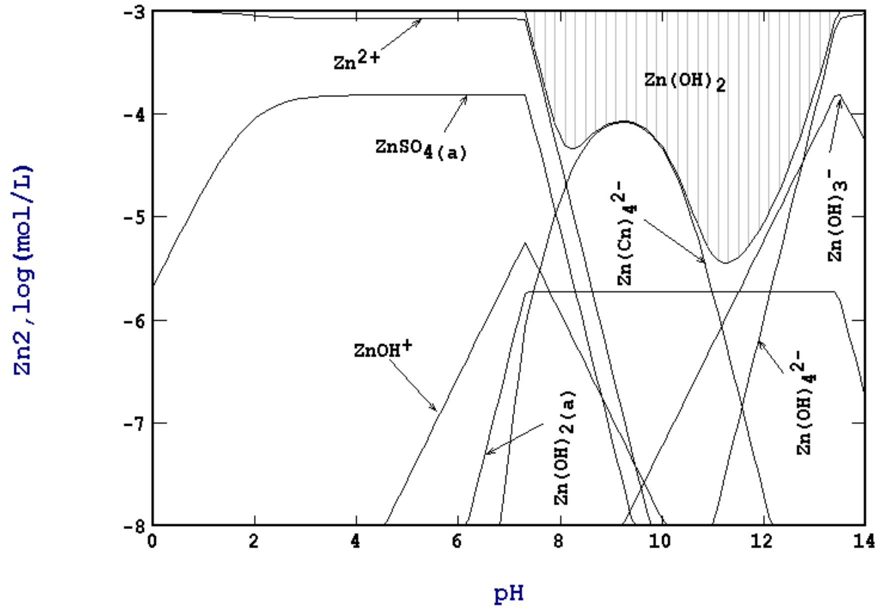

Figure 7.2. Speciation diagram for Zn(II) as a function of pH in the presence of 10^{-3}M NaCN and 10^{-3}M $ZnSO_4$ at 25 °C. Stabcal software. NBS database (Huang, 2003).

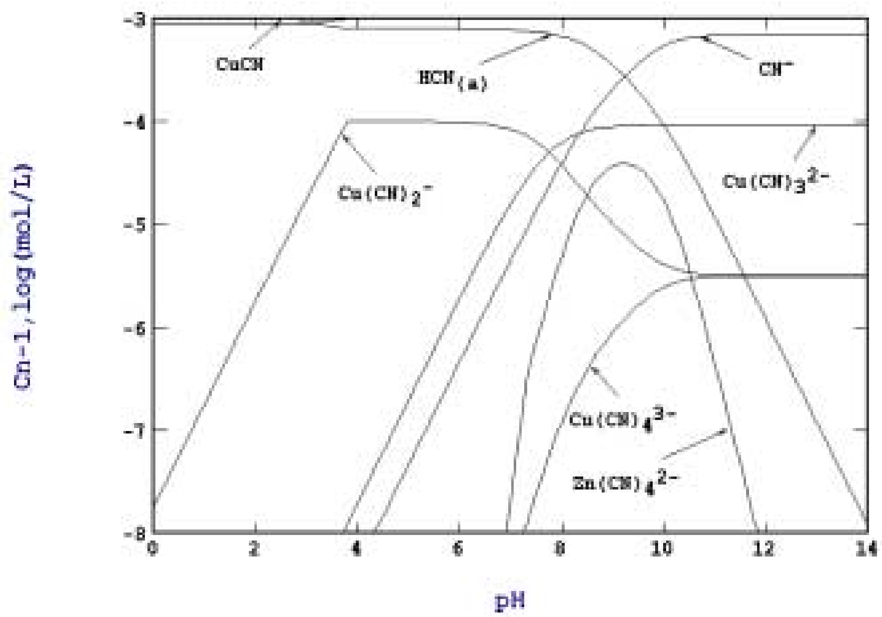

Figure 7.3. Speciation diagram for CN^- as a function of pH in the presence of 10^{-3}M NaCN, 10^{-3}M $ZnSO_4$, and 10^{-4}M Cu(I) at 25 °C. Stabcal software. NBS database (Huang, 2003).

As seen in Figure 7.3 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 7.2 and 7.3, 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.

The experimentally determined effects of sodium cyanide and zinc sulphate dosages on the flotation of sphalerite from the Rosh Pinah composite ore are presented in the following sections.

7.4. Effect of sodium cyanide on the flotation response of the Rosh Pinah composite

The composite sample was milled at approximately 67% (w/w) solids in an unlined mild steel mill with mild steel rods. The target grind was 80% passing 100 micron as used previously in Chapter 6. After milling, the pulp was transferred into the flotation cell and then diluted to 33% (w/w) solids. The desired amounts of depressant and 50g/t SNPX were added simultaneously and the pulp was conditioned for 3 minutes. Senfroth 9325 was added and the pulp conditioned for a further 1 minute. Rougher rate tests were carried out at the natural pH of 8.5 without copper cyanide in order to study the effect of depressant in the presence of potential activating species from the composite itself. This testwork differs from that carried out in Chapter 5 (Figures 5.10-5.14) in the sense that in that case the composite sample was dry milled to 80% passing 75 micron (the effect of milling environment on flotation selectivity was discussed in detail in Chapter 6).

The effect of sodium cyanide dosage on the concentrate mass pull is presented in Figure 7.4. As seen in Figure 7.4, the concentrate mass pull decreased from 15.0 to

14.4% when 50 g/t NaCN was added into the flotation cell. The mass pull decreased from 15.0 to 12.8 and 12.9% when 100 and 150g/t NaCN were added, respectively.

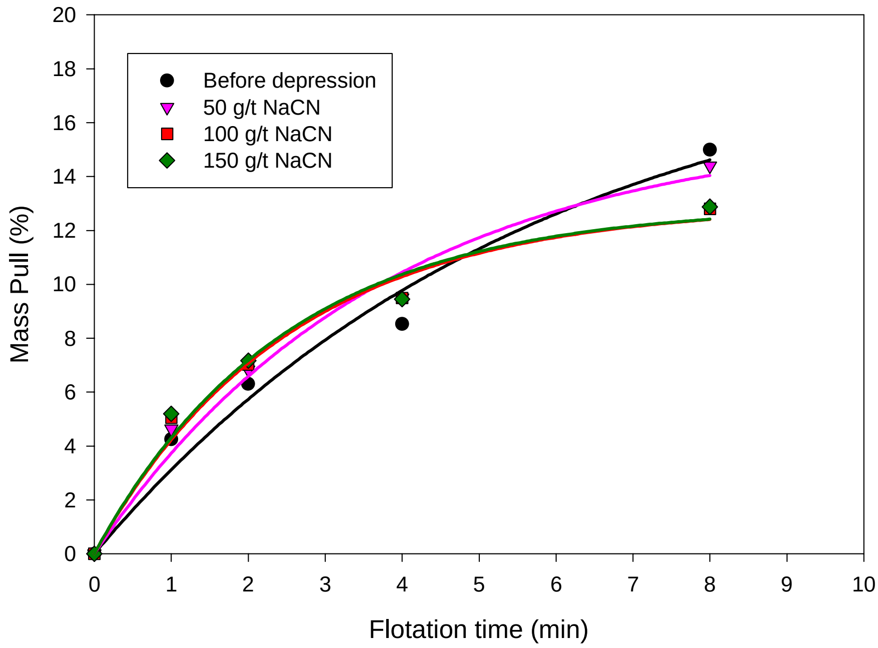

Figure 7.4. Effect of sodium cyanide dosages on the concentrate mass pull of the Rosh Pinah composite after flotation with 50g/t SNPX.

The recovery and grade of sphalerite at various dosages of sodium cyanide are presented in Figures 7.5 and 7.6, respectively.

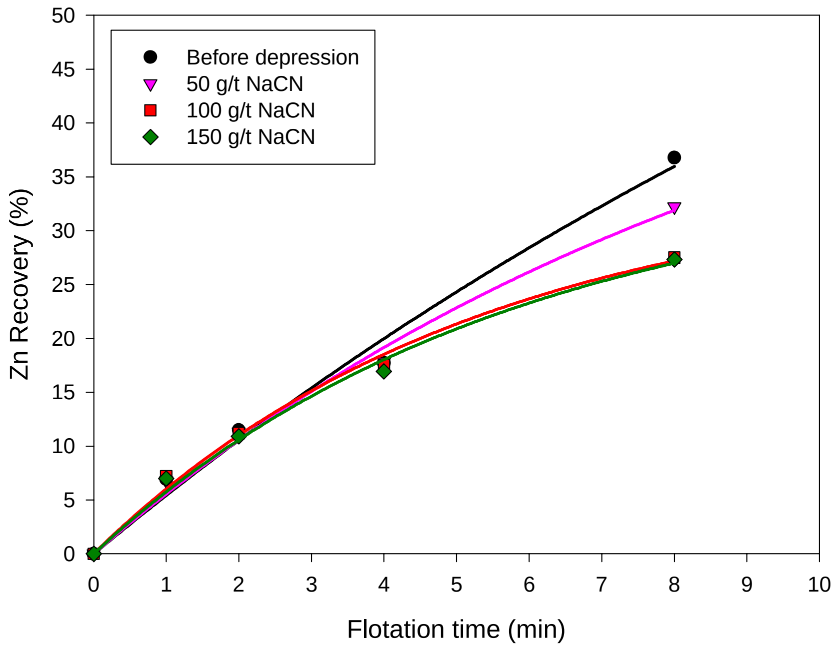

Figure 7.5. Flotation recovery of zinc from a galena-sphalerite composite from Rosh Pinah at various dosages of sodium cyanide, 50 g/t SNPX and pH 8.5.

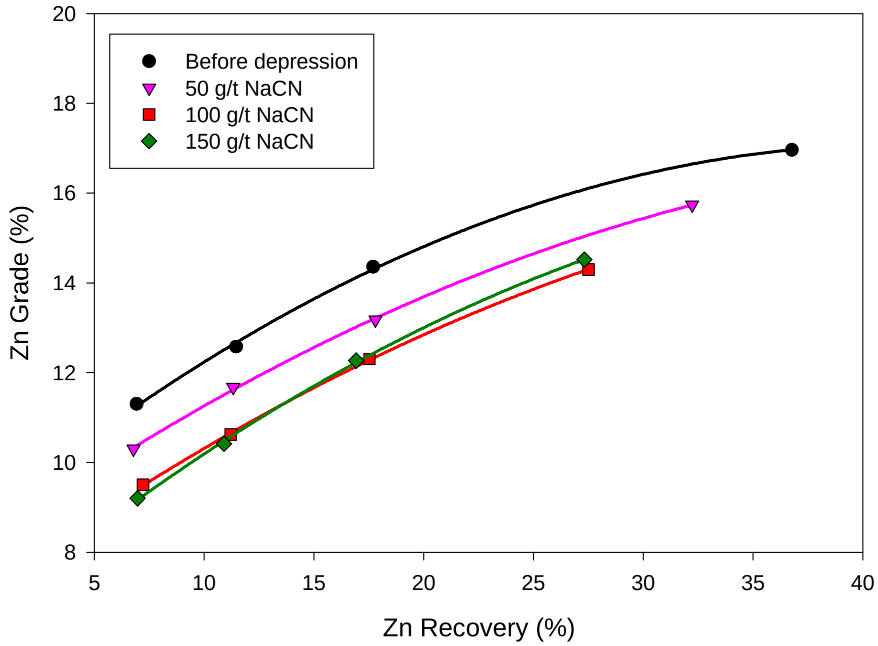

Figure 7.6. Recovery and grade of zinc from a galena-sphalerite composite from Rosh Pinah at various dosages of sodium cyanide, 50 g/t SNPX and pH 8.5.

The 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 7.6 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 (Prestidge et al., 1997).

The effects of sodium cyanide on the recovery and grade of galena are shown in Figures 7.7 and 7.8, respectively. As seen in Figure 7.7, 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 (Figure 7.8), as expected from the decreased sphalerite recovery.

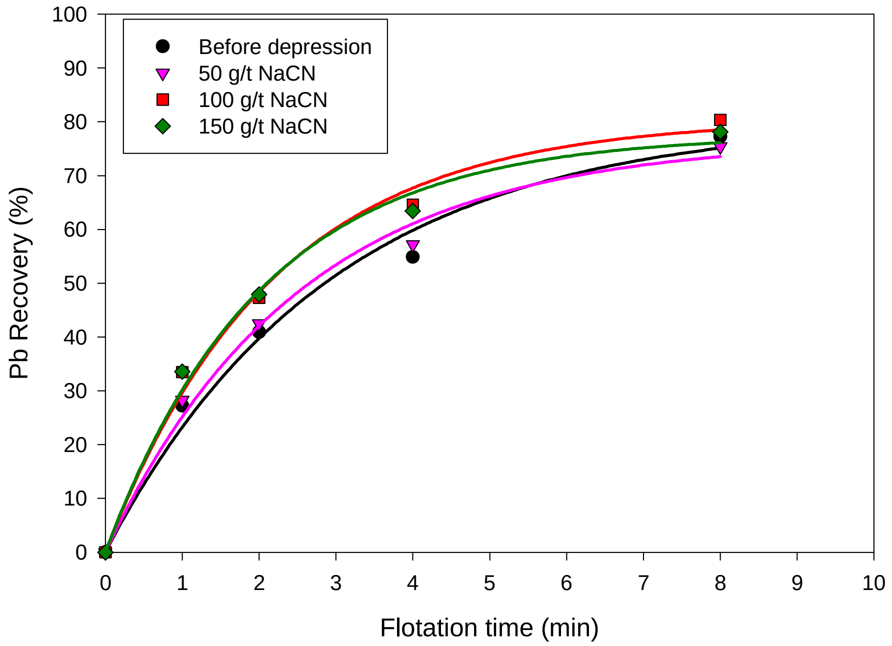

Figure 7.7. Flotation recovery of lead from a galena-sphalerite composite from Rosh Pinah at various dosages of sodium cyanide, 50 g/t SNPX and pH 8.5.

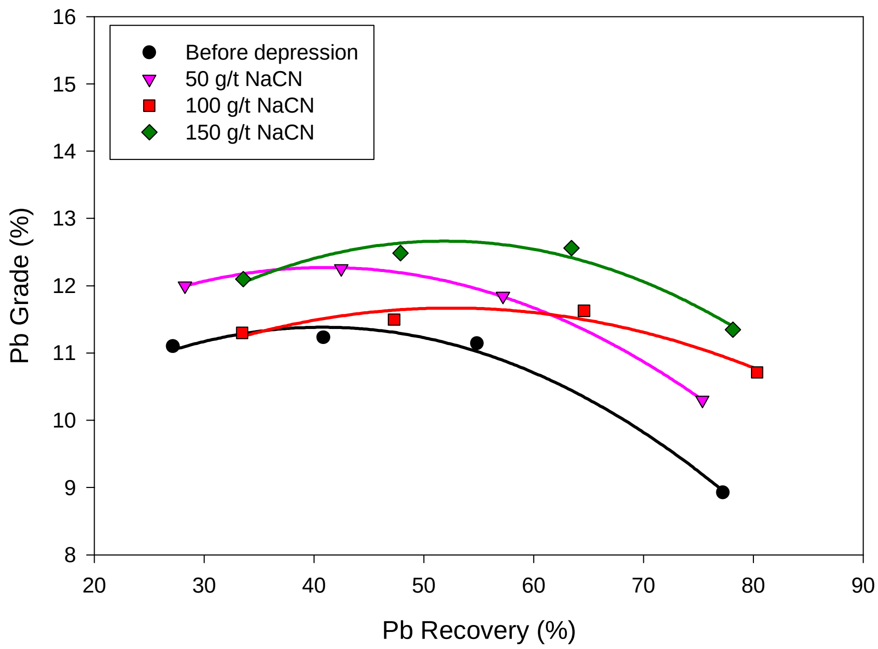

Figure 7.8. Recovery-grade of lead from a galena-sphalerite composite from Rosh Pinah at various dosages of sodium cyanide, 50 g/t SNPX and pH 8.5.

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:

$$PbS + CN^- + 2X^- = PbX_2 + CNS^- + 2e \quad [7.3]$$

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 7.9 shows the effect of sodium cyanide on the flotation selectivity between galena and sphalerite.

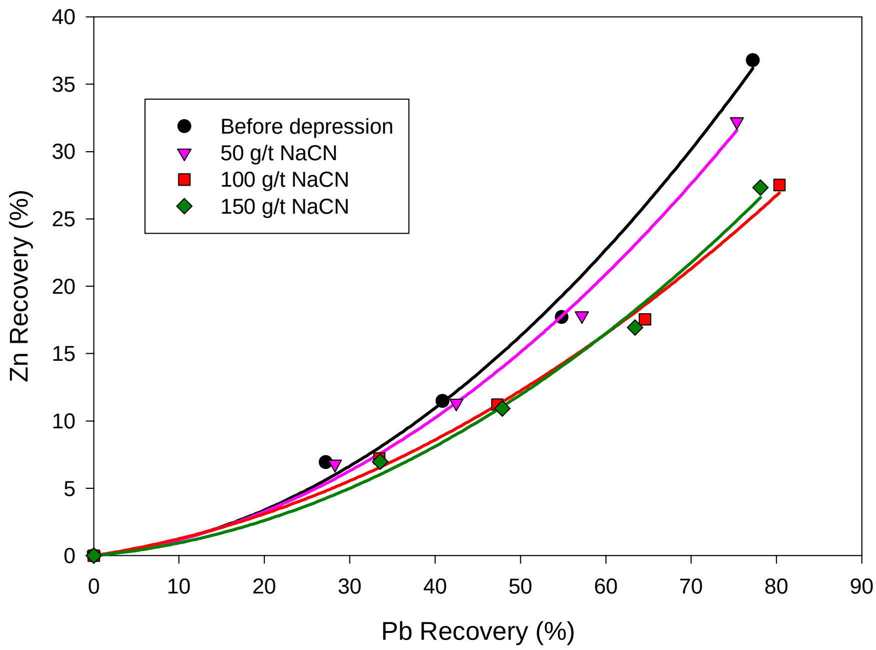

Figure 7.9. Recovery-grade of lead from a galena-sphalerite composite from Rosh Pinah at various dosages of sodium cyanide, 50 g/t SNPX and pH 8.5.

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. These results are in agreement with those reported by Bredenhann and Coetzer (2002). They conducted flotation testwork on the same ore bodies and they failed to decrease substantially the recovery of sphalerite in the lead concentrate even at higher dosages such as 400 g/t NaCN (Figure 7.10). However, their sphalerite recoveries were much higher than that obtained in this study probably due to their higher concentrate mass pull (approximately 30%) as compared to lower values obtained in this study (Table 7.2).

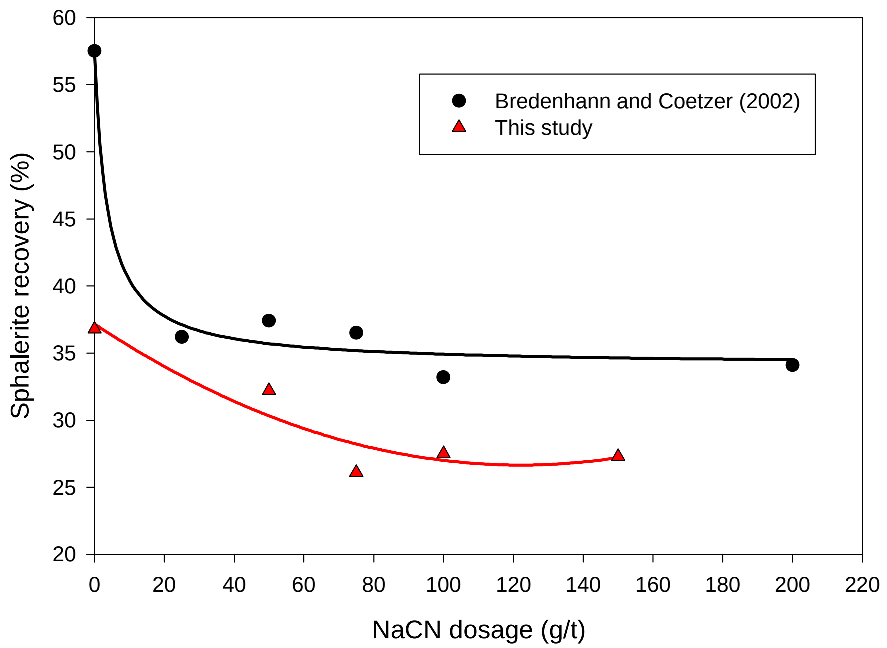

Figure 7.10. Effect of sodium cyanide on the recovery of sphalerite during the flotation of galena from a composite from Rosh Pinah.

Table 7.2. Metallurgical results of the Rosh Pinah composite after 8 minutes of flotation time in the presence of 50 g/t PNBX and various concentrations of sodium cyanide at pH 8.5

Depressant	Mass Pull	Recovery (%)		Grade (%)	
NaCN (g/t)	(%)	Pb	Zn	Pb	Zn
0	15.0	77.4	36.8	8.9	17.0
50	14.4	75.0	32.2	10.3	15.7
75	11.8	71.7	26.2	10.4	15.3
100	12.8	80.1	27.5	10.7	14.3
150	12.9	78.2	27.4	11.4	14.5

The results presented in this section 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) could not be explained since there was no improvement in the flotation selectivity above 100 g/t NaCN as shown in Figure 7.9. The recovery of sphalerite 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.

7.5. 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 7.9. 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. Figure 7.11 shows the effect of depressant dosages on the concentrate mass pull.

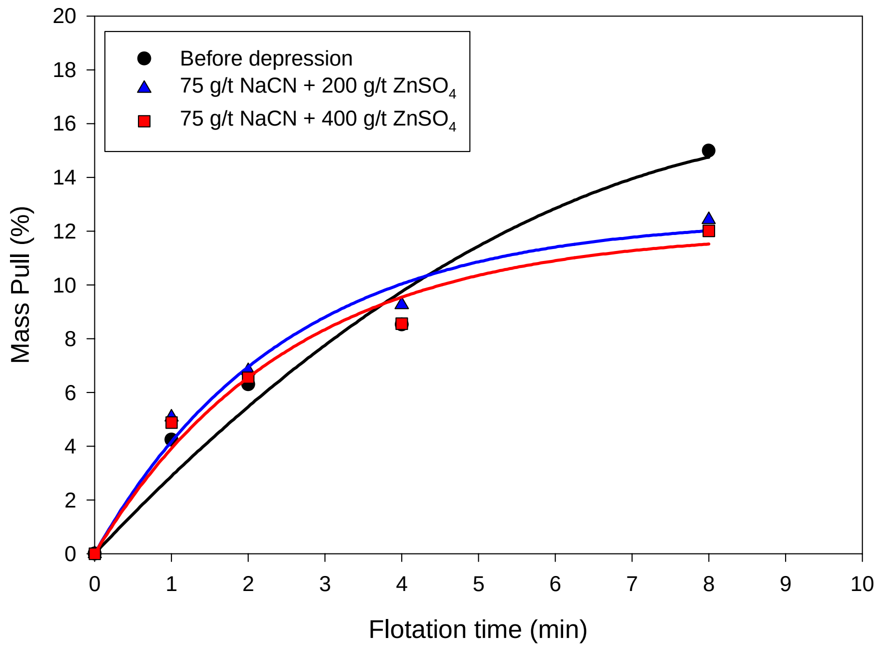

Figure 7.11. Effect of sodium cyanide and zinc sulphate dosages on the concentrate mass pull of a composite sample from Rosh Pinah in the presence of 50g/t SNPX.

As expected, the concentrate mass pull decreased from 15.0 to 12.4% after the addition of 75 g/t NaCN and 200 g/t $ZnSO_4$. However, the concentrate mass pull remained almost unchanged (12.0%) after increasing the dosage of zinc sulphate further to 400 g/t. These results indicated that the mass pull was decreased slightly further by the combination of 75 g/t NaCN and 200 g/t $ZnSO_4$ when compared to the use of 100 g/t NaCN alone (mass pull of 12.8% -see section 7.4).

The recovery of sphalerite at various dosages of depressants is shown in Figure 7.12 and summarised in Table 7.3. The grade-recovery relationship for different depressant dosages is shown in Figure 7.13.

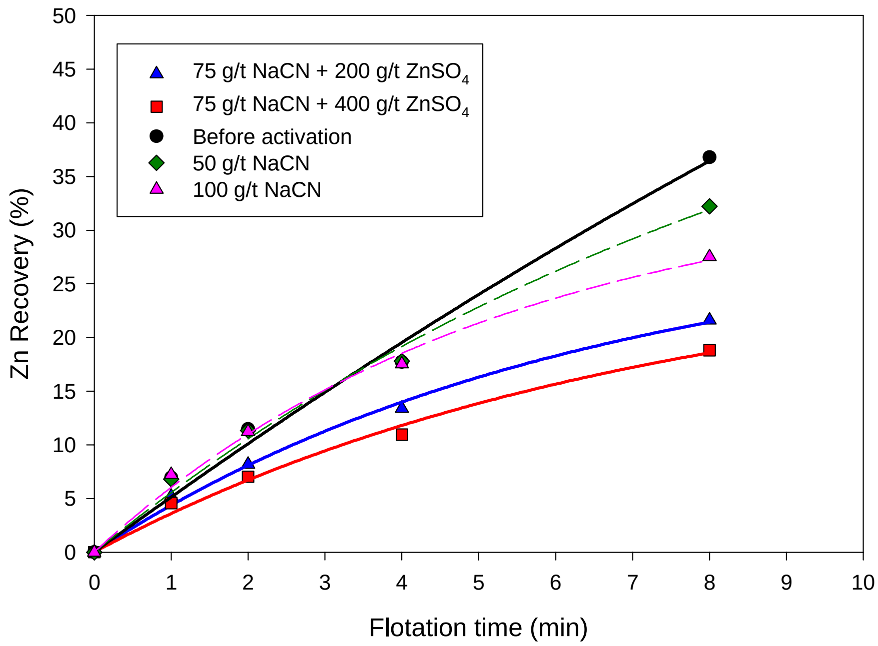

Figure 7.12. Flotation recovery of zinc from a Rosh Pinah composite sample at various dosages of sodium cyanide and zinc sulphate, 50 g/t SNPX and pH 8.5.

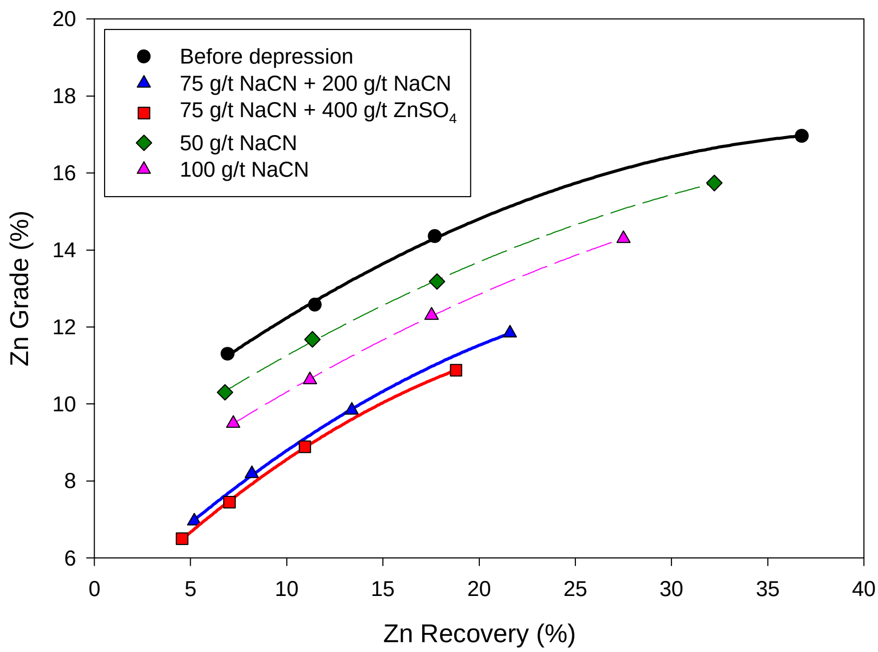

Figure 7.13. Recovery-grade relationship of zinc from a Rosh Pinah composite sample at various dosages of sodium cyanide and zinc sulphate, 50 g/t SNPX and pH 8.5.

Table 7.3. Metallurgical results of the Rosh Pinah composite after 8 minutes of flotation time in the presence of 50 g/t PNBX and various concentrations of sodium cyanide at pH 8.5

Depressants (g/t)		Mass Pull	Recovery (%)		Grade (%)	
NaCN	$ZnSO_4$	(%)	Pb	Zn	Pb	Zn
0	0	15.0	77.4	36.8	8.9	17.0
75	100	10.3	71.9	21.8	11.3	13.3
75	200	12.4	72.7	21.6	11.7	11.8
75	400	12.0	71.5	18.8	11.6	10.9
50	0	14.4	75.0	32.2	10.3	15.7
100	0	12.8	80.1	27.5	10.7	14.3

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 7.5). 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.

The recoveries of galena as a function of various dosages of cyanide and zinc sulphate are shown in Figure 7.14.

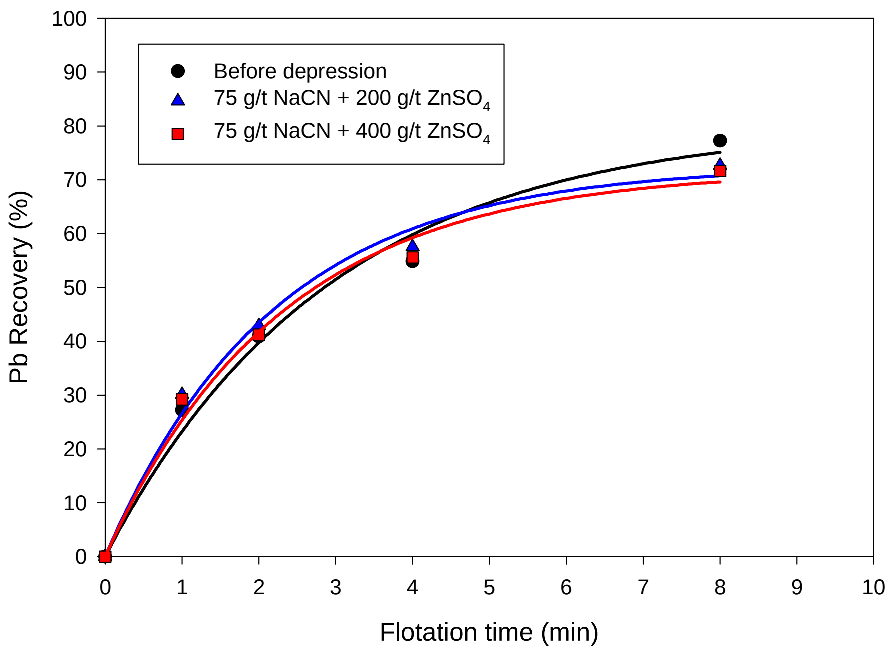

Figure 7.14. Flotation recovery of lead from a Rosh Pinah composite sample at various dosages of sodium cyanide and zinc sulphate,50 g/t SNPX and pH 8.5.

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.

As shown in Figure 7.15, 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.

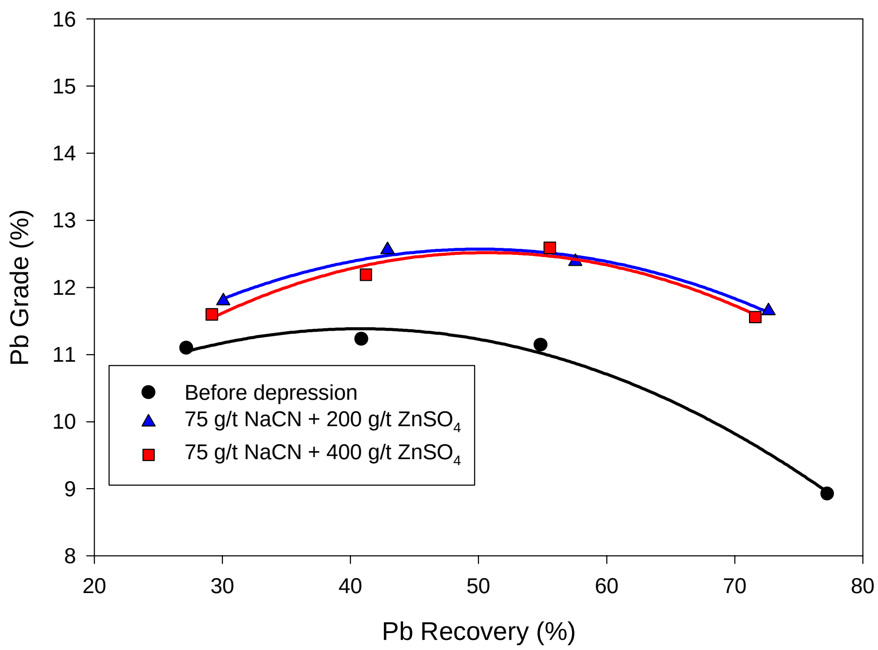

Figure 7.15. Recovery-grade of lead from a Rosh Pinah composite sample at various dosages of sodium cyanide and zinc sulphate,50 g/t SNPX and pH 8.5.

The flotation selectivity between galena and sphalerite for various dosages of depressants is shown in Figure 7.16. 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 as discussed earlier (section 7.2). 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.

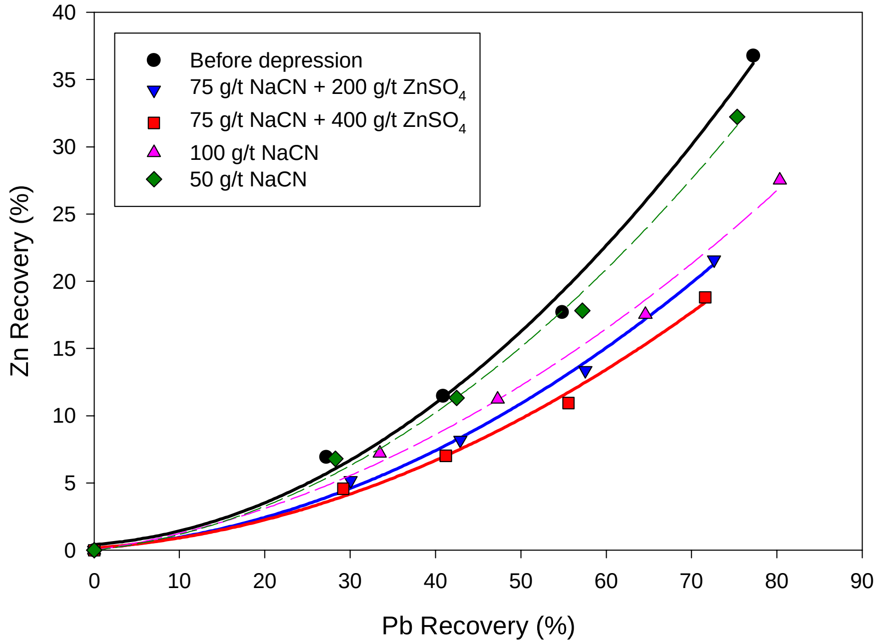

Figure 7.16. Lead and zinc recoveries from a Rosh Pinah composite sample at various dosages of sodium cyanide and zinc sulphate, 50 g/t SNPX and pH 8.5.

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 in spite of the similarities in their respective concentrate mass pull (Figures 7.2 and 7.9). 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.

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.

7.6. Deportment of sphalerite through the flotation products

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 et al., 2003b; 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.

7.6.1. Deportment of sphalerite in the lead concentrate from the Rosh Pinah Mine

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 Table 7.4 with selected data being plotted in Figure 7.17.

As seen in Figure 7.17, 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 (Figure 3.3), the concentrate mass pull in the +106μm fraction size will be negligible.

Table 7.4. Particle-counting results (% of 500 particles counted)-Lead concentrate from Rosh Pinah Mine (Reyneke, 2000)

FRACTION	+106 μM	+75 μM	-75 μM
Liberated galena	0.6	4.4	68.8
Liberated sphalerite	2.2	14.8	5.2
Liberated pyrite	1.6	10.0	9.6
Gangue (quartz, dolomite)	92.0	47.4	2.0
Unliberated sphalerite & gangue	1.8	4.4	-
Galena + attached sphalerite (<10μm)	-	-	0.8
Galena + attached gangue (<10μm)	-	0.6	0.4
Galena + attached sphalerite (10-50μm)	0.4	10.6	8.4
Galena + attached gangue (10-50μm)	0.2	2.6	0.4
Galena + attached gangue (>50μm)	1.0	4.0	1.4
Galena + attached sphalerite (>50μm)	0.2	0.8	0.4
Galena + sphalerite inclusions (<10μm)	-	-	0.2
Galena + gangue inclusions (<10μm)	-	0.2	0.4
Galena + sphalerite inclusions (10-50μm)	-	0.2	1.6
Galena + gangue inclusions (10-50μm)	-	-	0.4

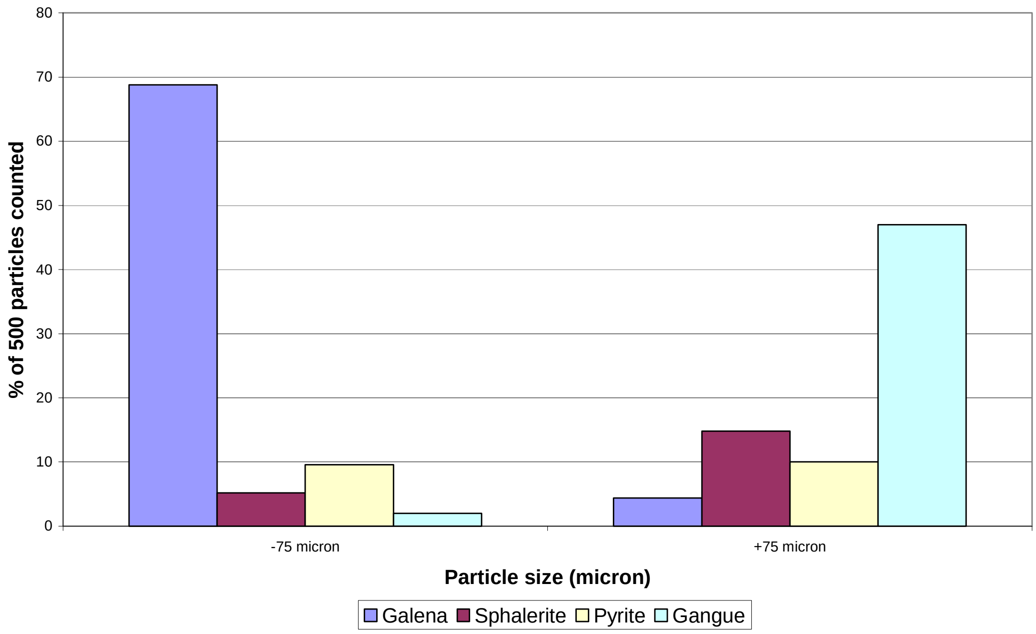

Figure 7.17. Minerals distribution in the lead concentrate from the Rosh Pinah Mine as a function of particle size (After Reyneke, 2000). (Fully liberated minerals only)

Thus, the results of particle counting of the +106μm size fraction were omitted in Figure 7.17. The distribution of liberated sphalerite and sphalerite attached to galena is shown in Figure 7.18.

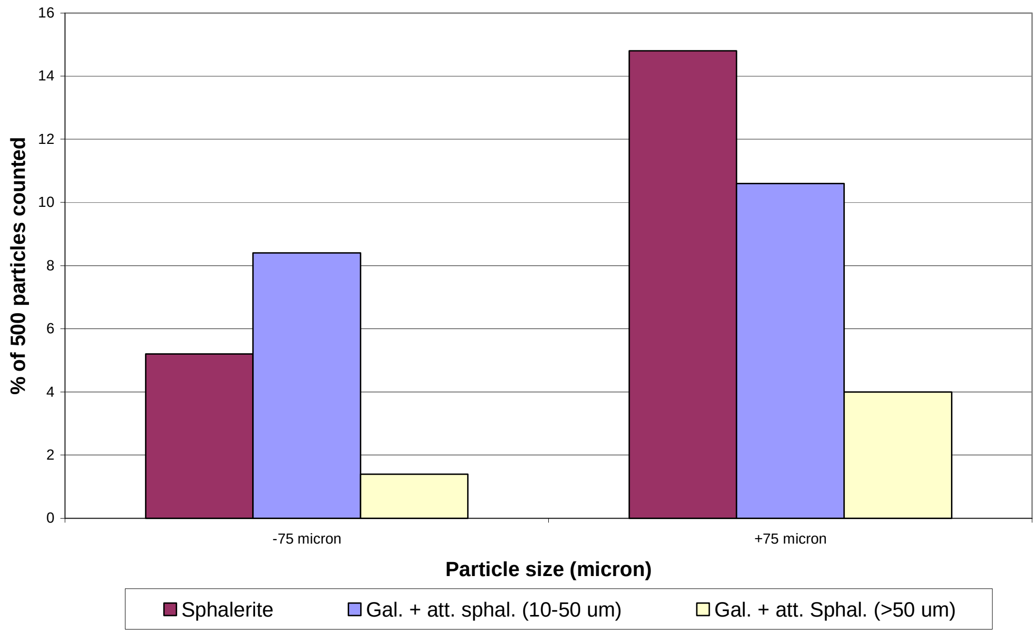

Figure 7.18. Sphalerite distribution in the lead concentrate from the Rosh Pinah Mine as a function of particle size (After Reyneke, 2000).

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 Table 7.5 and Figure 7.19. As seen in Figure 7.19, 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.

Table.7.5. Particle-counting results (% of 500 particles counted)-Feed sample from Rosh Pinah Mine (Reyneke, 2000)

FRACTION	+106 µM	+75 µM	-75 µM
Liberated galena	0.6	2.0	5.4
Liberated sphalerite	5.2	10.4	18.4
Liberated pyrite	2.8	12.0	21.0
Gangue (quartz, dolomite)	82.8	63.0	49.4
Unliberated sphalerite & gangue	0.6	0.2	-
Sphalerite + attached galena / gangue (<10µm)	0.2	0.4	-
Sphalerite + attached galena / gangue (10-50µm)	4.2	2.8	0.6
Sphalerite + attached galena / gangue (>50µm)	1.2	1.0	-
Galena + attached sphalerite / gangue (<10µm)	-	-	-
Galena + attached sphalerite / gangue (1-50µm)	0.4	0.6	-
Galena + attached sphalerite / gangue (>50µm)	-	0.2	-
Sphalerite + galena / gangue inclusions (<10µm)	1.6	6.2	5.0
Sphalerite + galena / gangue inclusions (10-50µm)	0.2	1.2	-
Sphalerite + galena / gangue inclusions (>50µm)	0.2	-	-
Galena + sphalerite / gangue inclusions (>50µm)	-	-	0.2

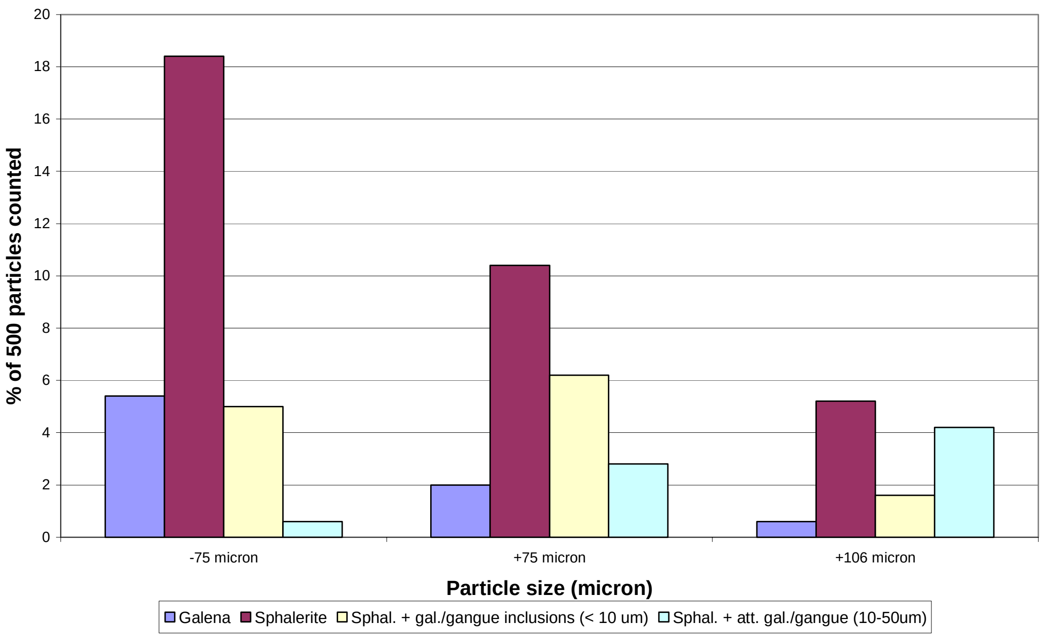

Figure 7.19. Galena and sphalerite distribution of the feed sample from the Rosh Pinah Mine as a function of particle size.

The rougher concentrates and tailings from the present laboratory study will be examined in the next section to ascertain the liberation characteristics of the sulphides and to establish whether other mineralogical factors could be responsible for the poor selectivity during flotation.

7.6.2. 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 7.20). These flotation results are similar to those presented in Figures 7.5 and 7.7.

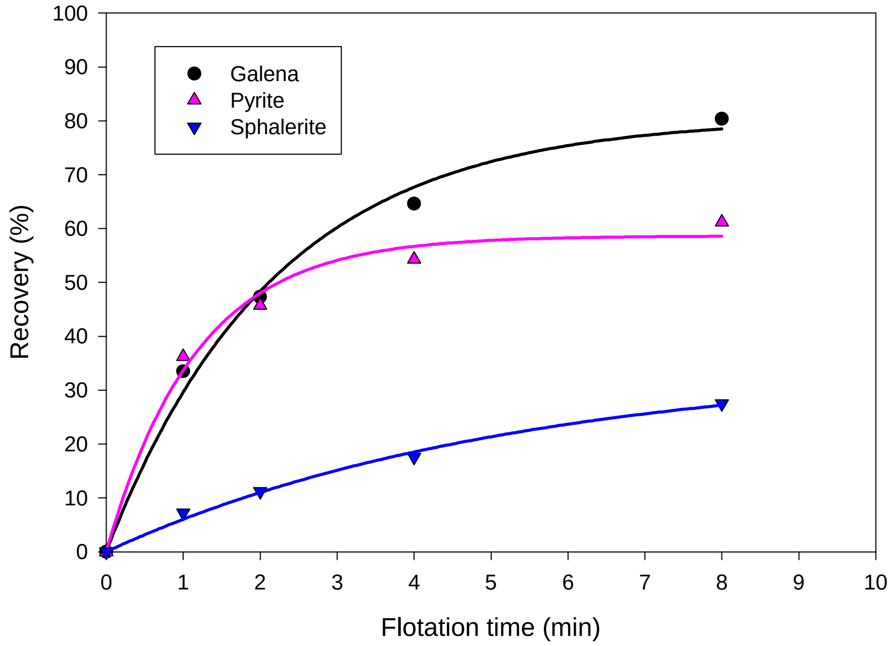

Figure 7.20. Recoveries of galena, pyrite and sphalerite after flotation of a composite from Rosh Pinah in the presence of 50 g/t SNPX and 100 g/t NaCN at pH 8.5.

The flotation results shown in Figure 7.20 indicate that galena and pyrite were the fast floating minerals, while sphalerite was the slow floating mineral. Figure 7.20 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 7.21 and 7.22. As seen in Figures 7.21 and 7.22, 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.

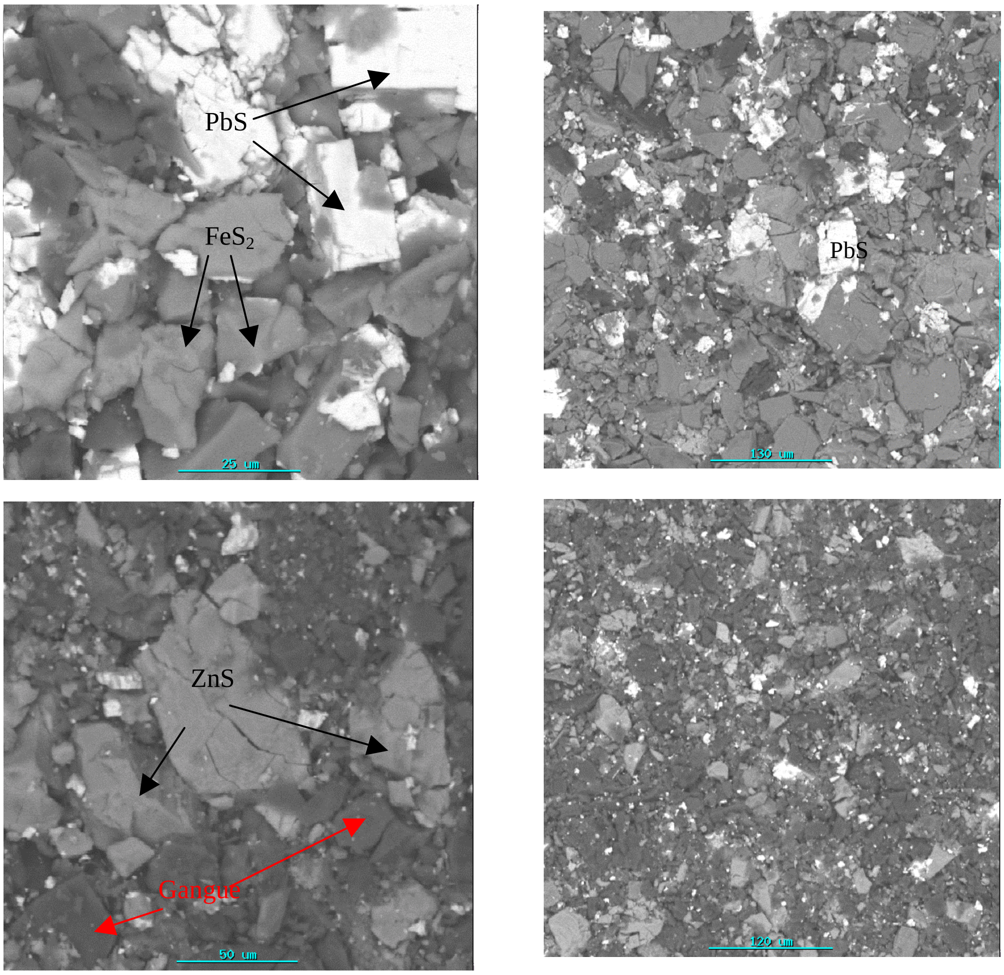

Figure 7.21. SEM- Backscattered images showing the general appearance of the rougher concentrates after 1 and 8 minutes. The flotation experiment was carried out in the presence of 100 g/t NaCN and 50 g/t SNPX.

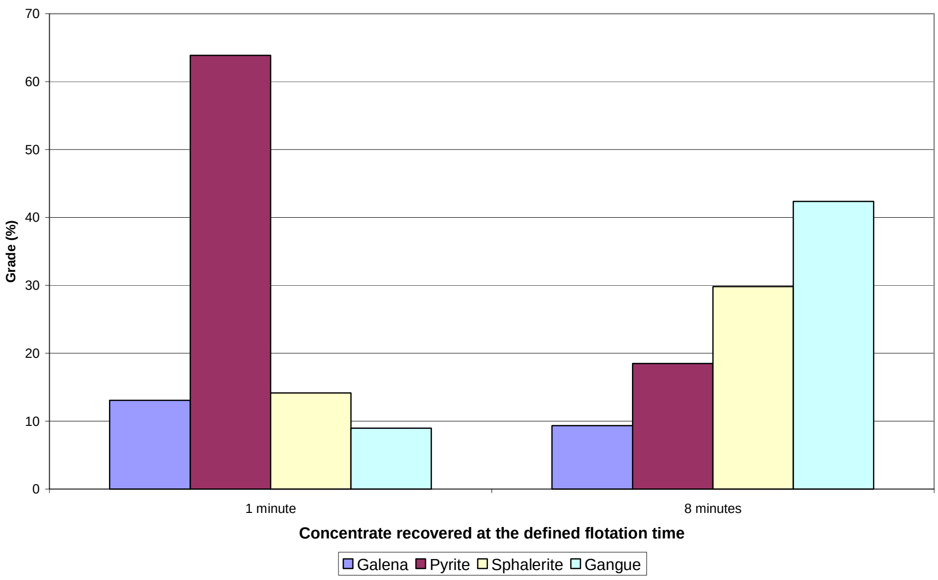

Figure 7.22. Mineralogical composition of the first and last concentrates after flotation in the presence of 50 g/t SNPX and 100 g/t NaCN at pH 8.5.(See appendices for details).

Figure 7.21 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 7.21 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.

The striking feature of the texture of the concentrates was the large quantity of binary locked galena and sphalerite (Figure 7.23).

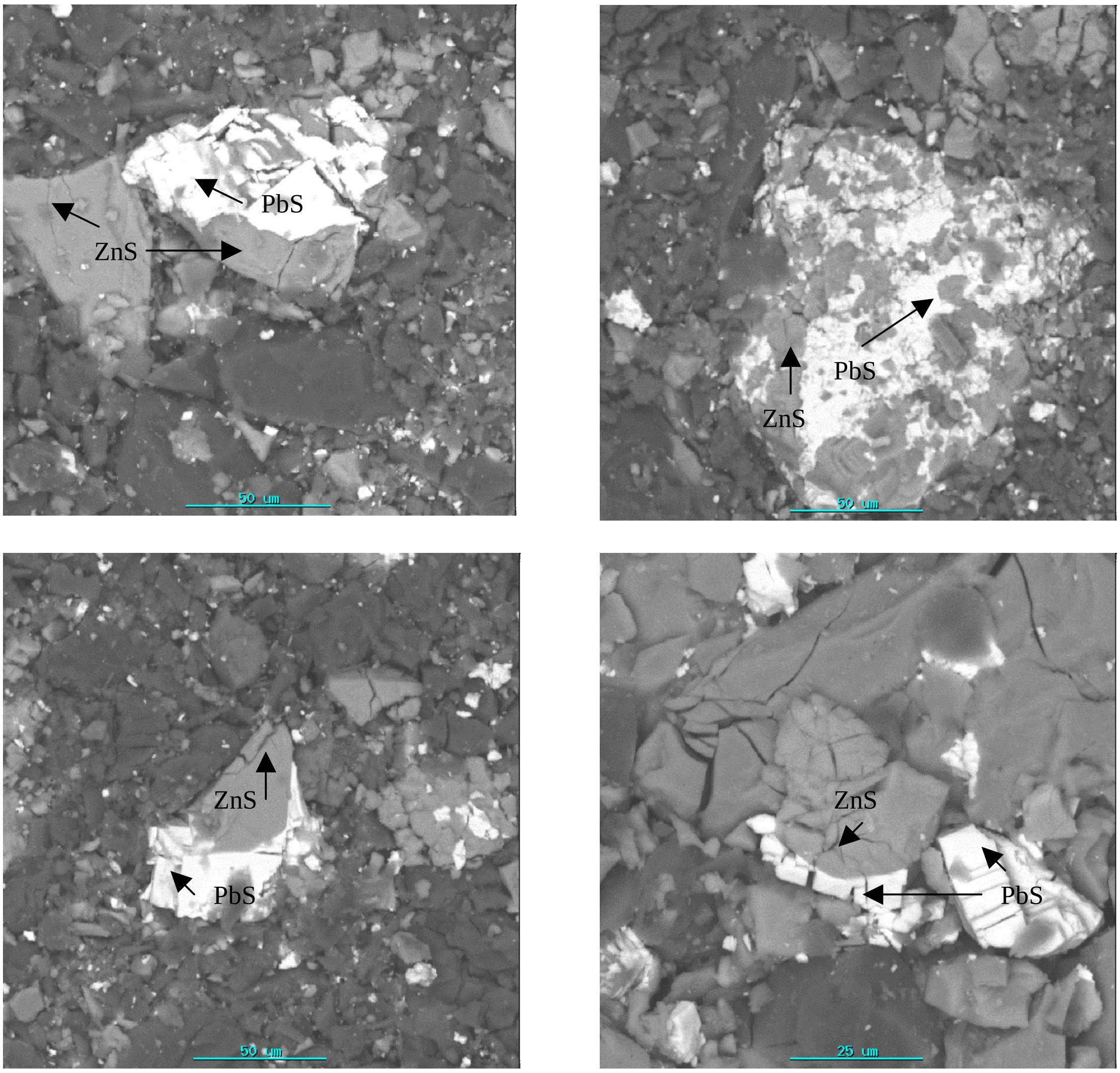

Figure 7.23. SEM- Backscattered images of concentrate showing the association between galena (white) and sphalerite (grey) in the galena concentrate.

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 7.24. 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.

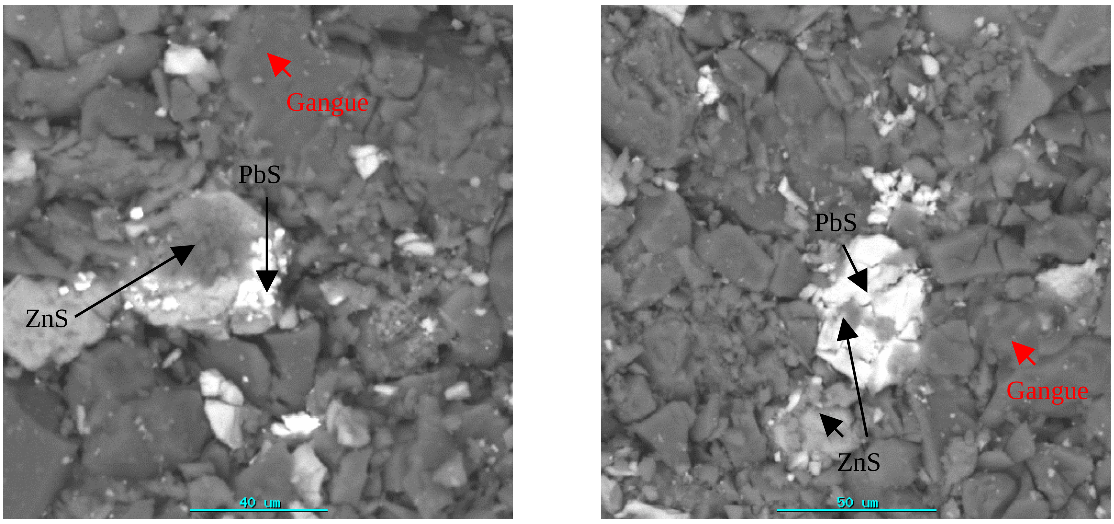

Figure 7.24. SEM- Backscattered images showing the association between galena and sphalerite in the lead rougher tailings.

As seen in Figure 7.25, 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.

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.

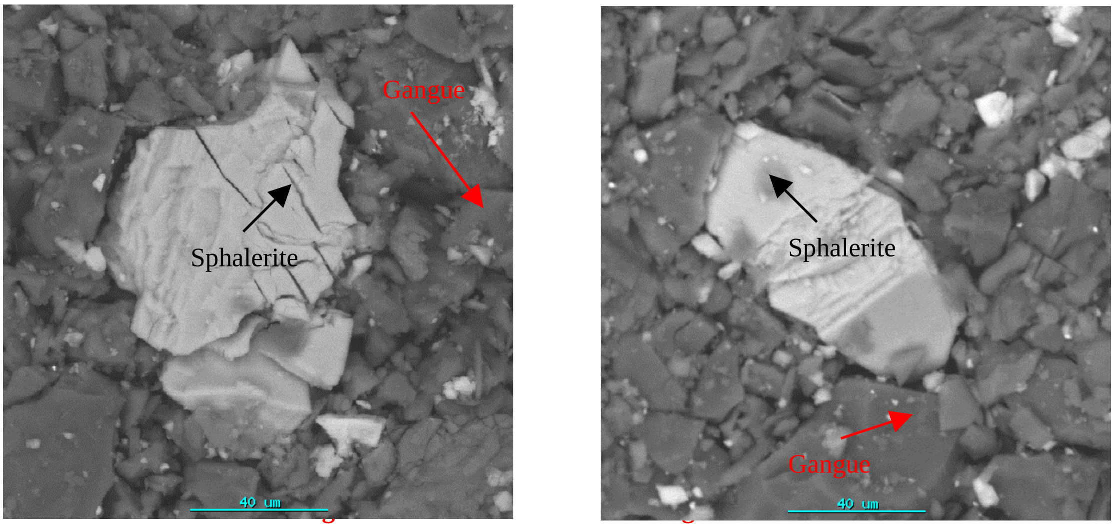

Figure 7.25. SEM- Backscattered images showing the general appearance of the rougher tailings. The flotation experiment was carried out in the presence of 100 g/t NaCN and 50 g/t SNPX.

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, which is shown in Figure 7.26, by including a cyclone and re-grind mill after the rougher flotation stage as shown in Figure 7.27.

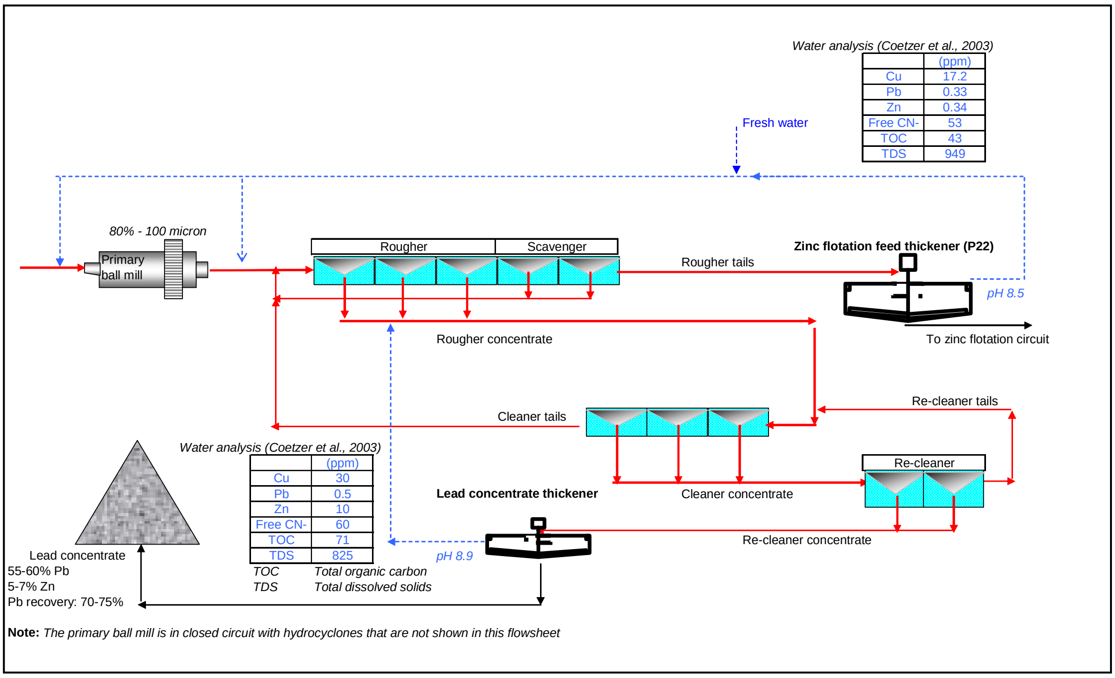

Figure 7.26. Current flowsheet diagram of the lead flotation circuit at the Rosh Pinah Mine

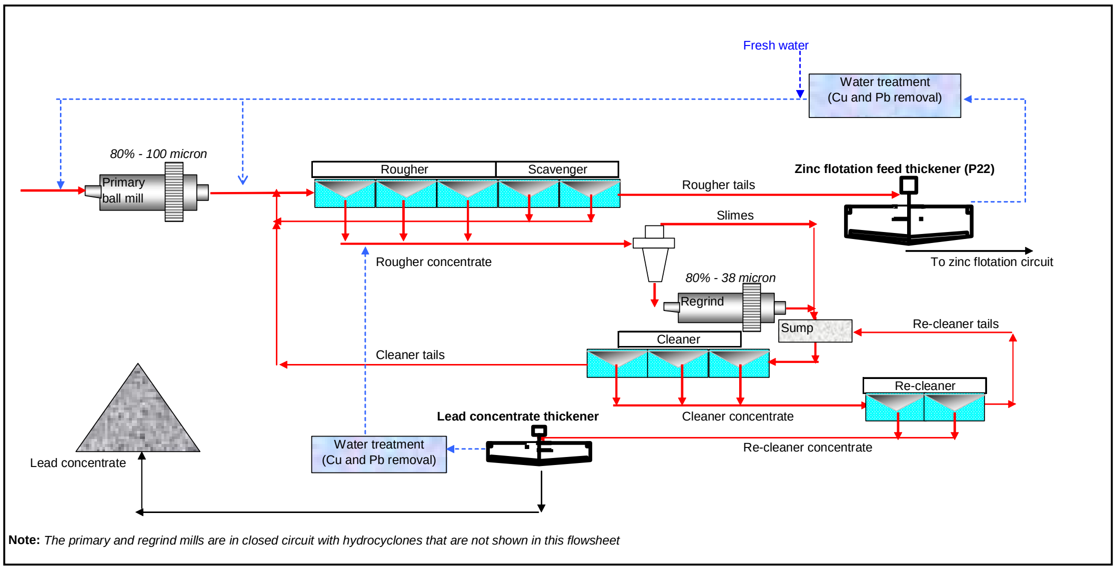

Figure 7.27. Proposed flowsheet diagram of the lead flotation circuit at the Rosh Pinah Mine.

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 7.27);
- Regrinding of the middlings from the rougher concentrate to improve the liberation of galena and sphalerite particles prior to the cleaning stages (Figure 7.27);
- Cleaning of the rougher concentrate to achieve the required smelter grade (Figure 7.27). Figure 7.22 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.

Since the dissolved heavy metals found in the process water are detrimental to the efficient performance of the flotation plant (Chapters 5-6), water quality surveys should be conducted regularly in order to correlate water quality with the flotation plant performance. The possible seasonal changes in the quality of process water can thus be identified and the water treated accordingly prior to the milling and flotation operations.

As stated in the section 7.4, this Chapter did not take into account the presence of substantial amount of $Cu(CN)_3^{2-}$ present in the recycle water, which is used in both the milling and the lead flotation circuits. This effect was discussed in details in Chapter 6. However, recent results of Katabua and Molelekoe (2004) have confirmed that the depression of sphalerite with high dosages of sodium cyanide is not effective when the concentrate mass pull increases in the range of 20-30% (Table 7.6).

Table 7.6. Metallurgical results of the Rosh Pinah composite after flotation with 15 g/t SNPX (Katabua and Molelekoe, 2003).

Reagents (g/t)		Mass Pull	Recovery (%)		Grade (%)	
$CuSO_4$	NaCN	(%)	Pb	Zn	Pb	Zn
0	0	32.8	85.8	49.3	10.0	16.5
10	0	34.6	91.1	59.0	8.9	14.5
0	120	23.2	88.6	52.0	13.4	19.4
10	120	26.6	91.3	51.3	11.3	16.4

They conducted their testwork at the Rosh Pinah plant and used 10g/t of copper sulphate to activate sphalerite prior to the flotation of galena. It was observed that the dosage of cyanide (120g/t) used was higher enough to suppress the effect of 10g/t $CuSO_4$ on the activation of sphalerite. As demonstrated in this study, the high recovery of sphalerite is believed to be due to the high mass pull and to the complex mineralogical occurrence of the Rosh Pinah ore body. The high concentrate mass pull is usually related to poor liberation of various minerals, entrainment and overdosing of the frother.

7.7. 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.