Introduction

Thiol collectors are used in the froth flotation of copper sulphide ores. The xanthates, dithiophosphates, dithiocarbamates and mixtures of these on the froth flotation performance obtained with a bornite-rich copper sulphide ore from Okiep Copper Mine with a feed grade of 1.8% copper. Batch flotation tests were used to assess the performance in terms of mass-water recovery, sulphur grade-recovery and copper-grade-recovery relationships and the Klimpel rate constant for copper recovery. The results showed that the di-ethyl-dithiocarbamate (di C2-DTC) was the weakest collector of copper sulphide minerals. Highest copper recoveries were obtained with the di-ethyl-dithiophosphate (di C2-DTP), which were accompanied with more watery froths and lower copper grades demonstrating frothing properties in addition to collector action. Superior copper recoveries were obtained with the 90% ethyl xanthate (C2-X):10% di-ethyl-dithiophosphate (di C2-DTP) and 90% ethyl xanthate (C2-X):10% di-ethyl-dithiocarbamate (di C2-DTC) collector mixtures compared to that obtained with ethyl xanthate at an equivalent collector dosage of 0.139 mol/ton ore (a dosage equivalent to 20 g sodium ethyl xanthate per ton ore). A superior copper grade was obtained with the 90% ethyl xanthate:10% di-ethyl-dithiocarbamate collector mixture at a dosage of 0.0695 mol/ton ore compared to that obtained with ethyl xanthate at the same equivalent dosage.

Keywords: flotation, collector mixtures, copper sulphide ore

An optimum ratio of the constituent collectors of collector mixtures was identified and the benefits of a 90:10 mole % mixture of xanthate and dithiocarbamate collectors in the flotation of pyrite were established (Bradshaw and O’Connor, 1994).

This paper discusses the differences in the performances obtained in the froth flotation of Okiep ore with the selected collectors: ethyl xanthate (C2-X), di-ethyl-dithiophosphate (di C2-DTP) and di-ethyl-dithiocarbamate (di-C2-DTC) at various dosages and the mechanisms responsible. It also evaluates the effectiveness of 90:10 collector mixtures of C2-X and di-C2-DTC or di-C2-DTP.

Experimental details

A copper ore from the Okiep Copper Company in the Okiep area of the Northern Cape province of South Africa was used in all tests. Its average copper grade was 1.8% and mineralogy showed that the main copper sulphide was bornite (Table I). Other copper sulphides noted were chalcocite, chalcopyrite, digenite and possibly enargite. Pyrite was the main sulphide gangue mineral. The chief silicate gangue phases were pyroxene, quartz and K-feldspar. Mica was a minor constituent.

The ore was crushed in a laboratory scale crusher to 70% below 3 mm. It was carefully split into smaller representative samples of approximately 1 kg in mass and milled to 60% below 75 µm in size in a laboratory scale Sala stainless steel rod mill prior to flotation.

Batch flotation tests were done in a modified Leeds laboratory flotation cell with a 3l capacity. The pulp level was controlled with a constant head device to have a froth height of 1.0 cm and the froth was removed manually.

* Cape Peninsula University of Technology, Belleville, Cape Town, South Africa.
† Minerals Processing Research Unit, University of Cape Town, Cape Town, South Africa.
‡ Hacettepe University, Department of Mining Engineering, Ankara, Turkey.
© The South African Institute of Mining and Metallurgy, 2005. SA ISSN 0038-223X/5.00 + 0.00. Paper received Feb. 2005; revised paper received Feb. 2005.
Flotation of a copper sulphide ore from Okiep using thiol collectors and their mixtures

The collectors sodium ethyl xanthate (C2-X), sodium diethyl dithiophosphate (di-C2-DTP) and sodium diethyl dithiocarbamate (di-C2-DTC) were supplied by Senmin Mining Chemicals. Each of their performances was assessed at collector dosages of 0.0348, 0.0695 and 0.139 mol/ton ore respectively (molar equivalent dosages to 5, 10 and 20 g sodium ethyl xanthate/ton ore respectively). In addition, C2-X was tested at a dosage of 0.209 mol/ton ore or 30 g/ton ore. The 90:10 molar collector mixtures of C2-X: di-C2-DTC and C2-X:di-C2-DTP were each tested at total collector dosages of 0.0695 and 0.139 mol/ton ore respectively. Each of the components of the mixtures was injected into the cell simultaneously. The performances of each of the collectors and their mixtures were evaluated by assessing the flotation in terms of the mass, water, sulphur, and copper recoveries; sulphur and copper grades; and the Klimpel rate constants for copper recovery.

The error bars in the subsequent figures represent one standard deviation above and below the mean values.

Results

Figures 1 and 2 show the copper and sulphur recoveries and that the lowest recoveries were obtained with di-C2-DTC. Figure 1 shows that the copper recovery by flotation was dependent on the dosage or concentration of C2-X, di-C2-DTP and di-C2-DTC. In the case of the xanthate and the dithiophosphate, the copper recoveries obtained with collector dosages of 0.0695 and 0.139 mol/ton ore were not significantly different and the optimal coverage of the mineral surface for flotation recovery probably occurred nearer the lower dosage. These figures also show that high copper and sulphur recoveries were obtained with di-C2-DTP at dosage of 0.0348 mol/ton ore, implying that sufficient coverage for flotation of the sulphide mineral surface had been achieved at lower dosages than was required with di-C2-DTC and C2-X. The superior rate of flotation of the copper minerals with di-C2-DTP may be attributed to the added hydrophobicity provided by the additional alkyl group of di-C2-DTP compared to C2-X. However, the poor performance of di-C2-DTC was obviously related to the differences in the composition of the functional groups of the collectors. The performance of di-C2-DTC at dosages higher than 0.139 mol/ton ore was not evaluated.

Figures 3 and 4 show mass and water recoveries and that the highest masses were obtained with di-C2-DTP. The large standard deviation in water recovery is noted as is the similarity of water recoveries obtained for all collectors. Figures 1 to 4 show the good recovery obtained at low dosages of di-C2-DTP, indicative of good frothing properties and also that the low sulphur and copper recoveries obtained with di-C2-DTC were not accompanied by particularly low mass recoveries.

Figure 5 shows the differences in Klimpel rate constants for copper recovery. The rate constant increased proportionally with increasing collector dosage with C2-X. With di-C2-DTP, the Klimpel rate constant increased as the collector dosage was increased until a maximum was reached, after which it remained constant. This follows the trend reported by Smar et al. (1994). The flotation rate with di-C2-DTP was almost two times faster than C2-X at low collector dosage. But the superiority of di-C2-DTP over C2-X disappeared at higher dosages, as was also observed with copper recoveries (Figure 1). The rate constants obtained with di-C2-DTC at all dosages were substantially smaller than the other collector types and did not change with increasing dosage. These results showed that d-C2-DTC used in these tests was incapable of floating the copper minerals effectively from the Okiep copper ore.

From the comparison of the particle size distributions of the first concentrates obtained with di-C2-DTP and di-C2-DTC each at a collector dosage of 0.0695 mol/ton ore (Figures 6, 7), it is evident that the use of di-C2-DTP led to greater percentage recoveries of the larger particles compared to di-C2-DTC. In general, the use of di-C2-DTP resulted in larger masses of the sulphide minerals and the copper sulphide minerals than the use of di-C2-DTC (Table II). The biggest difference was in bornite recovery, then chalcocite, with the lowest difference in chalcopyrite recovery (Table II). The difference in the bornite recovery highlights dithiocarbamate as the weaker collector as bornite generally has a larger grain size. Furthermore, it would be expected that the hydrophobicity of the chalcocite surface would be enhanced by the formation of cupric dithiolate after reaction with dithiophosphate (Fuerstenau, 1990) compared to cuprous thiolate formed with dithiocarbamate (Table III, Finkelstein and Goold, 1972). The similar mass recovery of chalcopyrite could be attributed to the high natural floatability of chalcopyrite and not to the action of collectors (Woods, 1984 and Guy and Trahar, 1985).

Discussion

The role of the functional group of the collector

Thiol collectors adsorb on sulphide minerals via a mixed potential mechanism that represents four classes of reactions that depend on the minerals involved, their pretreatment and the collector used (Yoon and Basilio, 1993). These are chemisorption (or underpotential deposition), metathetical substitution, catalytic oxidation and metal-thiol formation.

Table I

<table>
<thead>
<tr>
<th>Copper sulphides</th>
<th>Other sulphides</th>
<th>Chief silicate gangue</th>
<th>Trace minerals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bornite</td>
<td>Cu2Fe3S4</td>
<td>pyrite</td>
<td>Fe-Mg</td>
</tr>
<tr>
<td>Chalcopyrite</td>
<td>Cu2FeS</td>
<td>FeS2</td>
<td>SiO2</td>
</tr>
<tr>
<td>Digenite</td>
<td>Cu2S</td>
<td>pyroxene</td>
<td>KAISiO6</td>
</tr>
<tr>
<td>Enargite</td>
<td>Cu3AsS4</td>
<td>quartz</td>
<td>K10Fe6SiO16(OH, F)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>K-feldspar</td>
<td>Fe3O4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>biotite</td>
<td>Fe2O3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>phlogopite</td>
<td>MgSi2O5(OH)2</td>
</tr>
</tbody>
</table>

Mineralogy of the Okiep Copper Company ore

The Journal of The South African Institute of Mining and Metallurgy

Figure 5 shows the differences in Klimpel rate constants for copper recovery. The rate constant increased proportionally with increasing collector dosage with C2-X. With di-C2-DTP, the Klimpel rate constant increased as the collector dosage was increased until a maximum was reached, after which it remained constant. This follows the trend reported by Smar et al. (1994). The flotation rate with di-C2-DTP was almost two times faster than C2-X at low collector dosage. But the superiority of di-C2-DTP over C2-X disappeared at higher dosages, as was also observed with copper recoveries (Figure 1). The rate constants obtained with di-C2-DTC at all dosages were substantially smaller than the other collector types and did not change with increasing dosage. These results showed that d-C2-DTC used in these tests was incapable of floating the copper minerals effectively from the Okiep copper ore.

From the comparison of the particle size distributions of the first concentrates obtained with di-C2-DTP and di-C2-DTC each at a collector dosage of 0.0695 mol/ton ore (Figures 6, 7), it is evident that the use of di-C2-DTP led to greater percentage recoveries of the larger particles compared to di-C2-DTC. In general, the use of di-C2-DTP resulted in larger masses of the sulphide minerals and the copper sulphide minerals than the use of di-C2-DTC (Table II). The biggest difference was in bornite recovery, then chalcocite, with the lowest difference in chalcopyrite recovery (Table II). The difference in the bornite recovery highlights dithiocarbamate as the weaker collector as bornite generally has a larger grain size. Furthermore, it would be expected that the hydrophobicity of the chalcocite surface would be enhanced by the formation of cupric dithiolate after reaction with dithiophosphate (Fuerstenau, 1990) compared to cuprous thiolate formed with dithiocarbamate (Table III, Finkelstein and Goold, 1972). The similar mass recovery of chalcopyrite could be attributed to the high natural floatability of chalcopyrite and not to the action of collectors (Woods, 1984 and Guy and Trahar, 1985).

Discussion

The role of the functional group of the collector

Thiol collectors adsorb on sulphide minerals via a mixed potential mechanism that represents four classes of reactions that depend on the minerals involved, their pretreatment and the collector used (Yoon and Basilio, 1993). These are chemisorption (or underpotential deposition), metathetical substitution, catalytic oxidation and metal-thiol formation.
Flotation of a copper sulphide ore from Okiep using thiol collectors and their mixtures

Figure 1—The final cumulative copper recovery vs. collector dosage obtained with C2-X, di-C2-DTP and di-C2-DTC in the flotation of the Okiep copper ore

Figure 2—The final cumulative sulphur recovery vs. collector dosage obtained with C2-X, di-C2-DTP and di-C2-DTC in the flotation of the Okiep copper ore

Figure 3—The final cumulative mass recovery vs. collector dosage obtained with C2-X, di-C2-DTP and di-C2-DTC in the flotation of the Okiep copper ore
Flotation of a copper sulphide ore from Okiep using thiol collectors and their mixtures

Figure 4—The final cumulative water recovery vs. collector dosage obtained with C2-X, di-C2-DTP and di-C2-DTC in the flotation of the Okiep copper ore

Figure 5—The Klimpel rate constants for copper recovery obtained with different dosages of C2-X, di-C2-DTP and di-C2-DTC in the flotation of the Okiep copper ore

Figure 6—The particle size distribution of sulphide and iron oxide particles of a first concentrate obtained with di-C2-DTC at a collector dosage of 0.0695 mol/ton ore of in the flotation of the Okiep copper ore
Flotation of a copper sulphide ore from Okiep using thiol collectors and their mixtures

**Table II**
The mineralogy of the first concentrates obtained with di-C2-DTP and di-C2-DTC as collectors each at an equivalent dosage of 0.0695 mol/ton ore

<table>
<thead>
<tr>
<th>Mineral</th>
<th>di-C2-DTP</th>
<th>di-C2-DTC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mass percentage (%)</td>
<td>Mass in concentrate (g)</td>
</tr>
<tr>
<td>Bornite</td>
<td>35.6</td>
<td>17.27</td>
</tr>
<tr>
<td>Chalcopyrite</td>
<td>2.3</td>
<td>1.12</td>
</tr>
<tr>
<td>Chalcocite</td>
<td>2.5</td>
<td>1.21</td>
</tr>
<tr>
<td>Digenite</td>
<td>0.1</td>
<td>0.05</td>
</tr>
<tr>
<td>Pyrite</td>
<td>0.5</td>
<td>0.24</td>
</tr>
<tr>
<td>Fe oxide</td>
<td>3.2</td>
<td>1.55</td>
</tr>
<tr>
<td>Total sulphides</td>
<td>41.6</td>
<td>20.18</td>
</tr>
<tr>
<td>Fe oxide</td>
<td>100.0</td>
<td>48.51</td>
</tr>
<tr>
<td>Other sulphides</td>
<td>0.6</td>
<td>0.29</td>
</tr>
<tr>
<td>Total sulphides</td>
<td>41.6</td>
<td>20.18</td>
</tr>
<tr>
<td>Fe oxide</td>
<td>3.2</td>
<td>1.55</td>
</tr>
<tr>
<td>Gangue</td>
<td>55.2</td>
<td>26.78</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>48.51</td>
</tr>
</tbody>
</table>

**Table III**
Species responsible for the surface hydrophobicity of minerals

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Collector</th>
<th>C2-X</th>
<th>di-C2-DTP</th>
<th>di-C2-DTC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Species responsible for hydrophobicity</td>
<td>Species responsible for hydrophobicity</td>
<td>Species responsible for hydrophobicity</td>
<td></td>
</tr>
<tr>
<td>Bornite CuFeS$_4$</td>
<td>CuX</td>
<td>1,5</td>
<td>Cu(DTP)$_2$</td>
<td>3</td>
</tr>
<tr>
<td>Chalcopyrite CuFeS$_2$</td>
<td>X$_2$</td>
<td>1,7,8,9,10</td>
<td>Cu(DTP)$_2$</td>
<td>3</td>
</tr>
<tr>
<td>Chalcocite Cu$_2$S</td>
<td>CuX*, Cu(X)$_2$</td>
<td>2,5,6,8,9, 10</td>
<td>Cu(DTP)$_2$</td>
<td>Cu(DTP)*</td>
</tr>
<tr>
<td>Covellite CuS</td>
<td>X$_2$, CuX</td>
<td>1,4,8</td>
<td>Cu(DTP)$_2$</td>
<td>3</td>
</tr>
</tbody>
</table>

*Depends upon the degree of oxidation of the chalcocite surface (Cu(X)$_2$ or Cu(DTP) is formed on the oxidized mineral)

References for Table II
Flotation of a copper sulphide ore from Okiep using thiol collectors and their mixtures

These mechanisms respectively involve the chemisorption of a monolayer of the thiol collector, the substitution of oxidation products on mineral surfaces by a thiol collector, the physiosorption of an uncharged dithiolate on the mineral surface and the formation of a metal thiol compound on the surface. Table III lists the reported reaction products of xanthates, dithiophosphates and dithiocarbamates on copper sulphide minerals. Generally, the expected reaction mechanism was metal-thiol formation and cuprous thiolate and cupric dithiolate were responsible for surface hydrophobicity. An exception was chalcopyrite in the presence of xanthate where catalytic oxidation produced the physisorbed dithiobis, dixanthogen.

Different responses with respect to total copper and sulphur recoveries were obtained with the same number of moles of C2-X, di-C2-DTP and di-C2-DTC. The optimal surface coverage for flotation would be expected to be the same unless the hydrophobicity of the copper-collector species was different or there was a preferential adsorption. As each of the collectors had a similar probability of attachment, preferential adsorption was unlikely. Cuprous ethyl xanthate has a lower solubility product than cupric ethyl dithiophosphate and cupric ethyl dithiocarbamate (Fuerstenau, 1990), indicating that the xanthate has the highest attraction for copper ions. On this basis, a greater rate of adsorption of the xanthate ion and subsequently greater flotation rate of copper recovery due to added hydrophobicity may have been anticipated. However, as all the collectors have a tendency to interact with copper, the final copper recovery should have been similar. Figure 5 shows no significant differences in the rates of copper recovery obtained with the xanthate or the dithiophosphate at medium collector dosages, but they were significantly greater compared to those obtained with the dithiocarbamate.

Figures 1 and 2 show that the order of hydrophobicity from strong to weak was CuDTP > CuX > CuDTC. The greater hydrophobicity of CuDTP relative to CuX may be attributed to its additional ethyl group. Furthermore, generally cupric dithiolate is expected with di-C2-DTP as opposed to the cuprous thiolate or the physisorbed dixanthogen expected with di-C2-X (Table III). This would contribute to the greater hydrophobicity of CuDTP and explain the observed trend of hydrophobicity.

Figures 1, 2, 3 and 5 show that superior copper, sulphur and mass recoveries and Klimpel rate constants were obtained with di-C2-DTP and C2-X compared to those obtained with di-C2-DTC, i.e. di-C2-DTC was the weakest collector of sulphide minerals and copper sulphide minerals. These results agree with Bradshaw and O’Connor (1994) but contradict the order of collector strength for sulphide minerals identified by Nagaraj (1988): dithiocarbamate > xanthate > dithiophosphate. They also disagree with Bhaskar Raju and Forsling’s (1991) statement that ‘dithiocarbamates are particularly selective and exhibit several advantages as collectors for copper minerals’. Neither a superior selectivity, as would have been evidenced by a superior copper grade, nor other advantages were observed with the Okiep copper ore.

A comparison of Figures 1 and 3 shows that the differences in final copper recoveries obtained with di-C2-DTC compared to those obtained with C2-X or di-C2-DTP were disproportionately large compared to the differences in mass recoveries. Also, Table II shows that di-C2-DTC recovered less total sulphides and copper sulphides than di-C2-DTP in a first concentrate obtained at a collector dosage of 0.0695 mol/ton ore. This may be attributed to the differences in the chemical reactions at the mineral surface, particularly cupric dithiolate formation or the lack thereof in the case of di-C2-DTC (Table II and Finkelstein and Poling, 1977).

Generally, it may be assumed that cupric dithiolate was responsible for the flotation of copper minerals with di-C2-DTC and di-C2-DTP (Table III) and that the reaction mechanism was metal thiol formation. An exception was chalcopyrite after reaction with di-C2-DTC where the cuprous thiolate would be expected (Mangalam and Khangoankar, 1985) and Bhaskar Raju and Khangoankar, 1984), while another was oxidized chalcolite where the cuprous thiolate and cupric dithiolate were formed after reaction with di-C2-DTP (Chander and Fuestenau, 1974). For the most part therefore, the formation of the cupric dithiolate was thermodynamically feasible with di-C2-DTP and di-C2-DTC. The thermodynamic feasibility of a process does not, however, guarantee that it does indeed occur as its kinetics also play a role (Woods (1984)).

The di-C2-DTC concentration that corresponded to the optimal adsorption density in the chalopyrite-di-C2-DTC system was 8.3 x 10^4 mol/L at a pH of 9 (Mangalam and Khangoankar, 1985). Furthermore, maximum copper recoveries occurred at a collector concentration in the region of 5 x 10^-4 mol/L (Bhaskar Raju and Khangoankar, 1984). This suggests that the optimal concentration of di-C2-DTC for maximum copper recovery lies in the range 5 x 10^-5 mol/L. The maximum concentration of di-C2-DTC used in this work is 4.6 x 10^-5 mol/L at an order of magnitude below the lowest concentration in the range. It is therefore proposed that the poor performance of di-C2-DTC observed was in part attributable to the less than optimal concentration of this collector. Furthermore, the concentration was too low for the formation of the cupric dithiolate and this would have compromised the floatability of the minerals (Finkelstein and Poling, 1977).

The variations in mass and water recoveries can be accepted as an indication of the variations in the froth phase. Water recovery values increased up to a critical collector dosage and then decreased at higher dosages (Figures 3 and 4). The mass recovery followed the trend of the water recovery to reach the maximum recovery values at collector dosages where maximum water recoveries were obtained but remained almost constant at higher dosages unlike water recovery. Therefore, lower water recoveries obtained at high collector dosages were attributed to presence of strongly hydrophobic particles, which may increase the rate of bubble coalescence and hence decrease the water recovery (Dippemaar, 1978 and Harris, 1982). The higher mass and water recoveries (generally accompanied by poorer copper grades) obtained with di-C2-DTP compared to those obtained with C2-X or di-C2-DTC, each at dosages of 0.0348 or 0.139 mol/ton ore (Figures 3 and 4), suggested that the froth properties were different with the di-C2-DTP. These differences may be attributed to synergy between the diothiophosphate and the frother (Dai et al., 2001). The improved copper recoveries (Figure 1) and rates of copper recovery (Figure 5) obtained with di-C2-DTP at collector dosages of 0.0548 and 0.0695 mol/ton ore possibly represented evidence of this synergy.
The effect of collector mixtures on the flotation performance

The benefits of collector mixtures over pure collectors include lower dosage requirements, improved selectivity, rates and recovery and an increase in the recovery of coarse particles (Bradshaw et al., 1998).

Based on the previous works performed with mixture of collectors using similar collectors, the ratio of the collectors were determined as 90% C2-X:10% di-C2-DTP and 90% C2-X:10% di-C2-DTC. A slightly superior copper recovery and grade to that obtained with C2-X was observed with 90% C2-X:10% di-C2-DTC collector mixture at an equivalent collector dosage of 0.0695 mol/ton ore (Figure 8). The results showed that flotation performance of di-C2-DTC was very low as a single collector but improved when used as mixture with C2-X. From an earlier discussion, the optimum hydrophobicity of the mineral surface occurred near a collector dosage of 0.0695 mol/ton ore with C2-X. It is therefore proposed that the maximum hydrophobicity with the collector mixtures was also near this dosage. In the case of the mixtures, however, the mineral surface would have been more hydrophobic, attributable to the adsorption of either di-C2-DTP or di-C2-DTC instead of C2-X at some of the adsorption sites.

The superior copper recoveries obtained with the collector mixtures compared to that obtained with C2-X at a collector dosage of 0.139 mol/ton ore were accompanied by significantly greater water recoveries (Figure 9). This suggested that the froths obtained with the mixtures were more stable than with C2-X (Bradshaw et al., 1998). This may be attributable to the presence of moderately hydrophobic particles, such as coarse sulphide particles, locked particles and/or excessively oxidized particles, that might be floated due to the synergistic effect of collector mixture and stabilized the froths. Moreover, adsorption of collectors in patchy multilayers on the mineral surface might have also contributed to lowering of hydrophobicity of the particles (Bradshaw and O’Connor, 1996).

The processes that affected the hydrophobicity of the particles and consequently affected copper recovery and grade may have been the selective adsorption of the different collectors on particular sites or changes in the orientation of...
Flotation of a copper sulphide ore from Okiep using thiol collectors and their mixtures

the alkyl chains resulting in superior surface coverage (Bradshaw and O’Connor, 1994). In addition, for a mixture of xanthate and dithiophosphate there may have been enhanced co-adsorption of collectors at low collector concentrations (Wakamatsu and Numata, 1980). These phenomena may have played a role in determining the degree of hydrophobicity of the mineral surface and may therefore have been responsible for the differences in froth properties (Harris, 1982) and Dippenaar, 1978).

Conclusions
Contrary to expectations based on other work, the dithiocarbamate, di-C2-DTP, was the weakest and least selective collector of copper sulphide minerals in the Okiep copper ore at the collector dosages tested, with only chalcopyrite recovery similar to that obtained with di-C2-DTP.

The dithiophosphate, di-C2-DTP, gave superior copper recoveries compared to the xanthate, C2-X, in the flotation of the Okiep copper ore: especially at the lowest dosage tested. This was attributed to the additional alkyl chain in the structure of di-C2-DTP.

The mineralogical investigation showed that the dithiophosphate, di-C2-DTP, gave superior recoveries of bornite and chalcocite compared to the dithiocarbamate, di-C2-DTP, in the flotation of the Okiep ore.

There was a slight but statistically significant enhancement of copper recovery and loss of copper grade obtained with the C2-X:di-C2-DTP and C2-X:di-C2-DTC collector mixtures at an equivalent collector dosage of 0.139 mol/ton ore.

Slight enhancements of both copper recovery and grade were obtained with the C2-X:di-C2-DTP collector mixture at an equivalent collector dosage of 0.695 mol/ton ore in the flotation of the Okiep copper ore. This was attributed to the synergistic effect of the mixtures of collectors, which improved flotation of slow floating particles and changed the froth structure.

Acknowledgement
The financial and technical support Senmin and useful discussions with the MPRU are gratefully acknowledged.

References


Woods, R. Chemisorption of thiol and its role in flotation, A. Sutulov Memorial Volume: vol. 2 Flotation, IV Meeting of the Southern Hemisphere on Mineral Technology; and III Latin American Congress on Froth Flotation, S. Castro and J. Alvarez (eds.), Universidad de Concepcion, Concepcion - Chile, (1994)