INVESTIGATING DEPRESSANT BEHAVIOUR IN THE FLOTATION OF SELECTED MERENSKY ORES

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Declaration

I declare that this thesis, submitted for the degree of Master of Science in Engineering at the University of Cape Town, is my own work and has not been submitted prior to this for any degree at this university or any other institution. I know the meaning of plagiarism and declare that all the work in the document, save for that which is properly acknowledged, is my own.

Jennifer Gael Wiese

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Synopsis

This study utilised laboratory batch flotation tests to characterise the flotation performance, with respect to sulfide and gangue minerals, of two Merensky ores with different mineralogy, in the presence of depressants; and contributes to the increased understanding of depressant behaviour in the flotation of Merensky ores.

The ores were obtained from the southern section of the Merensky reef in the Bushveld Igneous Complex. QEMSCAN analysis of the ores showed that Ore B contained almost double the amount of naturally floatable gangue (NFG) than Ore A.

The amount of gangue recovered by entrainment was, for the ores used in this study, quantified using the method developed at UCT: this allows the amount of NFG reporting to the concentrate to be determined. The method assumes that, at 500 g/t depressant dosage the flotation of all NFG is suppressed and that gangue is reporting to the concentrate via entrainment only. The method does not take into account gangue reporting to the concentrate as composite particles with sulfide minerals. Similar entrainability values were obtained for guar and CMC for the two ores evaluated. Results showed that the method is robust for use on Merensky ores, and that sizing and mineralogy are not necessary to determine entrainment. The method has been compared to that of Robertson and was validated by the work on sized concentrates.

The addition of depressant, either guar or CMC, reduced the recovery of NFG to the concentrate progressively as the dosage was increased. At higher dosages their depressing characteristics on NFG were the same, but at lower dosages guar was a stronger depressant than CMC. This has been attributed to the difference in adsorption mechanisms between the two depressants evaluated in this study, with guar adsorbing via hydrogen bonding and CMC via acid / base interactions. At the high depressant dosages used (500 g/t) in the testwork to investigate the effect of collector chain length, the reduced stability of the froth, as determined by water recovery, was controlled by hydrophobic sulfide particles due to the absence of froth

stabilizing gangue. The ability of the highly charged CMC polymer to remove fines from sulfide mineral surfaces at these high dosages was evident.

The effect of the two depressants on the recovery of sulfur was ore dependent in that the iron sulfides in Ore B were less susceptible to reduced recovery by increased depressant dosage than those in Ore A. This indicates that pyrrhotite mineralogy may be different between the two ores and should be confirmed with further work.

At a dosage of 150 g/t, the xanthate collector with the shortest chain length, sodium ethyl xanthate (SEX), yielded the highest iron sulfide mineral recoveries for both ores in the presence of guar and CMC. At the lower collector dosage of 50 g/t, final iron sulfide recoveries for Ore B were similar to those obtained at 150 g/t dosage, but the rate of recovery was retarded. For Ore A iron sulfide recoveries at 50 g/t dosage of SEX were approximately 5% lower than those obtained at 150 g/t. Copper and nickel recoveries were largely unaffected by xanthate chain length or dosage. This work has shown that if high depressant dosages are to be used, collector dosages should be increased to counteract the effects of the depressant on sulfide minerals. Reagents such as frothers and secondary collectors such as DTP, which are surface active and directly affect froth stability, may be used to increase froth stability.

This work has demonstrated the need to evaluate interactions between collectors and depressants as well as the contribution from ore type to the behaviour of both gangue and sulfide minerals in the overall flotation performance of Merensky ores.

Abbreviations

$Å^2$	Angstrom
B.E.T.	Brunauer, Emmet and Teller
BMS	Base metal sulfide
Ca	Calcium
$Ca(NO_3)^2.4H_2O$	Calcium nitrate 4-hydrate
$CaCl_2$	Calcium chloride
C1	First concentrate
C2	Second concentrate
C3	Third concentrate
C4	Fourth concentrate
^oC	Degrees centigrade
CMC	Carboxymethyl cellulose
CMR	Centre for Minerals Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DS	Degree of substitution
DTP	Dithiophosphate
g/t	grams per ton
g/mol	grams
Guar	guar gum
L/min	Litres per minute
Mg	Magnesium
$MgSO_4.7H_2O$	Magnesium sulfate heptahydrate
$Mg(NO_3).6H_2O$	Magnesium nitrate
MnO_2	Manganese dioxide
MLA	Mineral Liberation Analyser
mm	Millimetres
mv	Millivolts
m/v	Mass volume
m^2/g	Square metres per gram
NaCl	Sodium chloride

Na_2CO_3	Sodium carbonate
NFG	Naturally floatable gangue
nm	Nanometres
PAX	Potassium amyl xanthate
PGM	Platinum group mineral
PGE	Platinum group element
PSD	Particle size distribution
QEMSCAN	Quantitative evaluation of minerals using scanning electron microscopy
rpm	Revolutions per minute
SEX	Sodium ethyl xanthate
SIBX	Sodium isobutyl xanthate
SNPX	Sodium normal propyl xanthate
TDS	Total dissolved solids
ToF-SIMS	Time of flight secondary ion mass spectrometry
UCT	University of Cape Town
µm	Micron
X2	Dixanthogen
XRD	X-ray Diffraction
XRF	X-ray Fluorescence

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1 Introduction

1.1 Background

The Merensky Reef in the Bushveld Igneous Complex, South Africa is the worlds' largest deposit of platinum group elements (PGE). Froth flotation is the primary process utilised for the recovery of the valuable minerals hosting these elements. The flotation process relies on the differences in mineral surface properties to maximise the recovery of valuable minerals whilst minimising the recovery of silicate gangue, which constitutes the bulk of the ore, to the concentrate.

The base metal sulfide (BMS) content of the reef is in the region of 1% and consists of chalcopyrite, pentlandite, pyrrhotite and pyrite. The platinum group minerals (PGM) in the reef are strongly associated with these sulfide minerals and the effective recovery of the sulfide minerals is therefore imperative. Collectors are added to impart hydrophobicity to the valuable minerals and polymeric depressants, typically guar gum or carboxymethyl cellulose (CMC), are added to render naturally floatable gangue minerals hydrophilic. It is possible that if the adsorption of the collector on the sulfide minerals is weak or incomplete, the strongly hydrophilic depressant molecules could co-adsorb on the mineral surface and because of the large size of these polysaccharide molecules (molecular weights from 150 000 to 500 000 g/mol compared to the 200 to 300 g/mol molecular weights of the collector) could interfere with particle bubble attachment, and reduce the subsequent recovery of the sulfide minerals.

The batch flotation procedure developed by the Centre for Minerals Research at the University of Cape Town allows for the integrated analysis of reagent interactions by allowing for pulp and froth effects to be decoupled from one another, and for the separate assessment of material recovered by true flotation and that recovered by entrainment. Methods to account for the variations in froth stability, due to both direct and indirect effects of added reagents have been developed and are tested in this work.

Chemical analyses were done for copper, nickel and sulfur, and flotation performance was assessed for the recoveries of these elements. Chalcopyrite was the only copper bearing mineral present in the ores hence the copper assay was directly proportional to chalcopyrite concentration. However, there was significant non sulphide nickel present in the ores in olivine and orthopyroxene (Brough, 2008), as well as nickel in pentlandite. Both pyrite and pyrrhotite were also present in the ores and it was therefore not possible to use chemical assays to accurately represent pentlandite and pyrrhotite behaviour. The nickel and sulfur assays, after accounting for the other minerals, were nevertheless adequate as indicators of pentlandite and pyrrhotite deportment and behaviour

The overall objective of this study was to characterise the flotation behaviour and interactions between depressants (CMC and guar), collectors (xanthates of different chain length) and minerals (sulfides and gangue) obtained in the flotation of two Merensky ores, selected for their differences in modal mineralogy.

1.2 Key Questions

1. Can the method developed at UCT for a Merensky ore, using high depressant dosages, be used to assess the amount of floating gangue independently from the amount of entrained gangue for two different ores with varying mineralogy?

2. How does depressant type and dosage affect both floatable and entrained gangue, as well as sulfide mineral recovery for different Merensky ores and is the behaviour consistent for ores with different amounts of gangue?

3. How do high dosages of depressant influence the different size classes of sulfide and gangue minerals recovered to the concentrate by true flotation, and is this affected by depressant type?

4. How does collector (xanthate) type and dosage affect both floatable and entrained gangue as well as sulfide mineral recovery for different Merensky ores?

5. How does depressant behaviour affect collector / mineral interactions?

1.3 Scope of thesis

The scope of this thesis includes, the evaluation of the flotation performance of two different Merensky ores by analysing chemically for the elements copper, nickel and sulfur, the determination of entrained and floating gangue recovered during batch flotation tests, the evaluation of depressant type and dosage on the flotation of performance of the two ores and the comparison between CMC and guar, the evaluation of xanthate chain-length in the presence of high depressant dosages on the flotation performance of the two ores and the size by size analysis of the concentrates collected during batch flotation tests.

Statistical analysis of the results obtained from the batch flotation tests include error bars on all figures showing standard deviation between duplicate tests, and t tests on selected conditions.

A schematic representation of the parameters investigated in this thesis is illustrated in Figure 1.1. The chemical parameters evaluated in this thesis are the blocks shaded in lilac. The effect of depressant type and dosage as well as collector type and dosage are investigated. The operational parameters investigated are the blocks shaded in light blue. These parameters focus on the two ores with varying mineralogy and evaluate chemical effects on gangue and sulfide. Specific parameters investigated are shown in the areas outlined by the dashed red line.

The thesis does not include analysis for PGE in the flotation concentrates. Although quantitative mineralogy of the feeds was done, analysis of the concentrates and tails was not and this is recommended for future work. The roles and interactions of

reagents other than depressants and collectors (e.g. copper activation) were not investigated. Scale up to plant conditions was also not investigated.

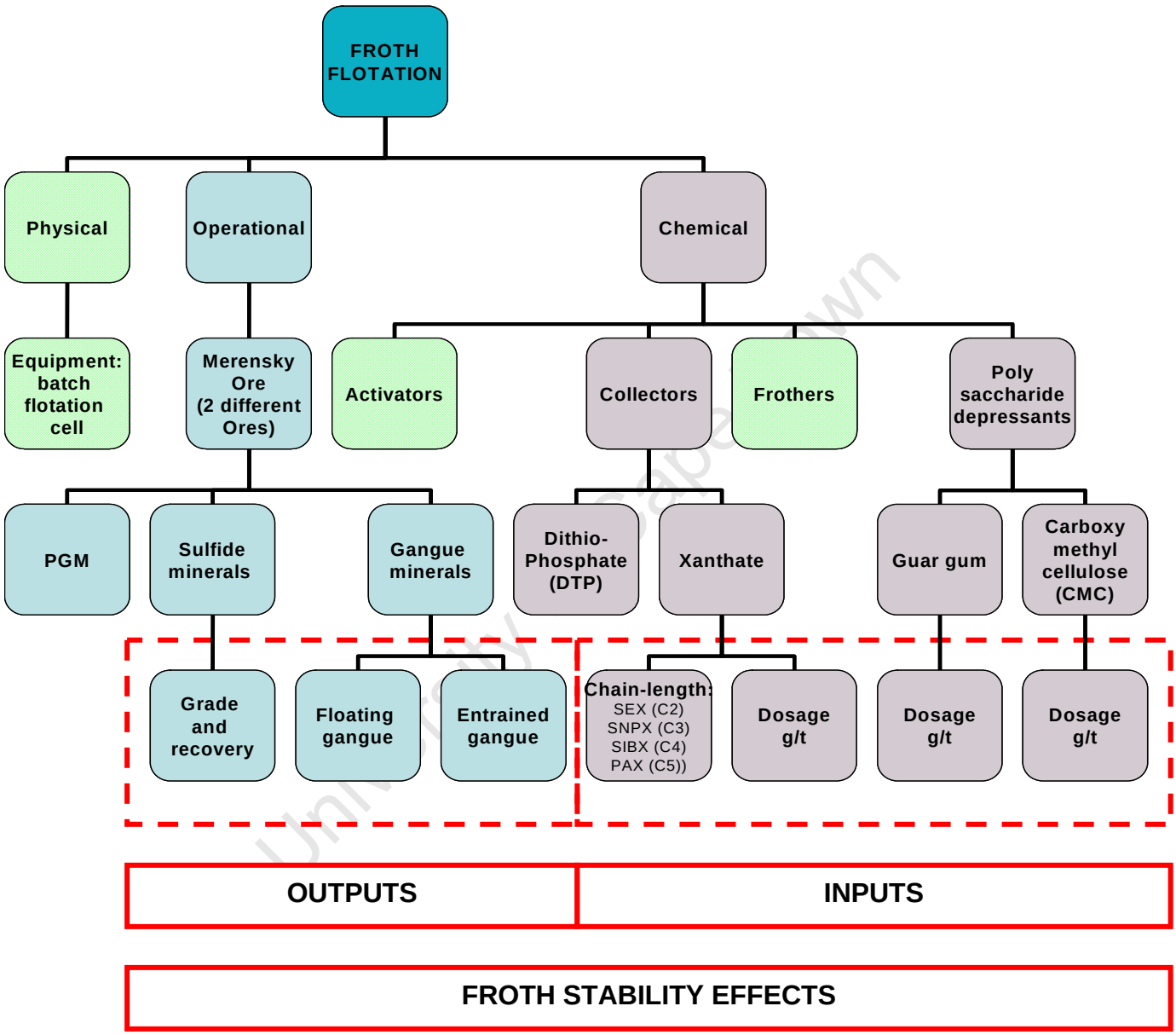

Figure 1.1: Schematic representation of the focus of this thesis. Areas highlighted in red fall within the scope of this study.

2 Literature Review

2.1 Merensky Ore

The Bushveld Complex, South Africa, hosts three major PGE bearing ore bodies which are currently being exploited. These are the Merensky reef, UG2 and Platreef. The focus of this study is the Merensky reef which was discovered in 1924 by Dr Hans Merensky and together with the UG2 chromitite, forms the worlds' major resource of platinum and platinum group elements (Lee, 1996). The Merensky reef consists of a pegmatoidal pyroxenitic layer lying between two thin chromitite layers. The pyroxenite layer varies in thickness across the Merensky Reef.

The Merensky reef is known to vary, with various forms of alteration, depending on where the ore is mined. Brough (2008) investigated the flotation performance of three different reef types mined by Northam Platinum limited which lies in the north-western sector of the Swartklip facies which is located on the Western limb of the Bushveld Complex.

Figure 2.1 shows a geological map of the western limb of the Bushveld Complex, showing the location of platinum mines. The position of Impala Platinum and Lonmin Platinum from which the two Merensky ores used in this investigation were sourced are denoted by yellow stars.

2.1.1 Valuable minerals

The BMS content of the Merensky reef is in the region of 1%. The major BMS is typically pyrrhotite at levels of approximately 45%, followed by pentlandite at approximately 32% and chalcopyrite at approximately 16% (Liddell et al., 1986). PGMs are strongly associated with these BMS (Cawthorn et al., 2002; Schouwstra et al., 2000). The majority of the PGMs are associated with pentlandite, either as inclusions within pentlandite grains or at the grain boundaries between pentlandite and gangue (Liddell et al., 1986). The contribution from the BMS to the total PGM content of the reef is therefore significant (Schouwstra et al., 2000), although this varies from mine to mine. PGE are present in the reef either as discrete PGM or in solid solution with sulfides (Ballhaus and Sylvester, 2000).

Sulfide minerals generally have a lattice-type crystal structure. During grinding, covalent bonds are broken and fresh surfaces are produced. These surfaces are highly reactive and are stabilised by hydrogen bonding to water. Sulfides oxidise readily on exposure to air and water. This affects their floatability as well as their reaction to collectors. The effects of this oxidation depends on the time elapsed between exposure of the freshly milled mineral surface and the onset of the reaction with the collector molecule.

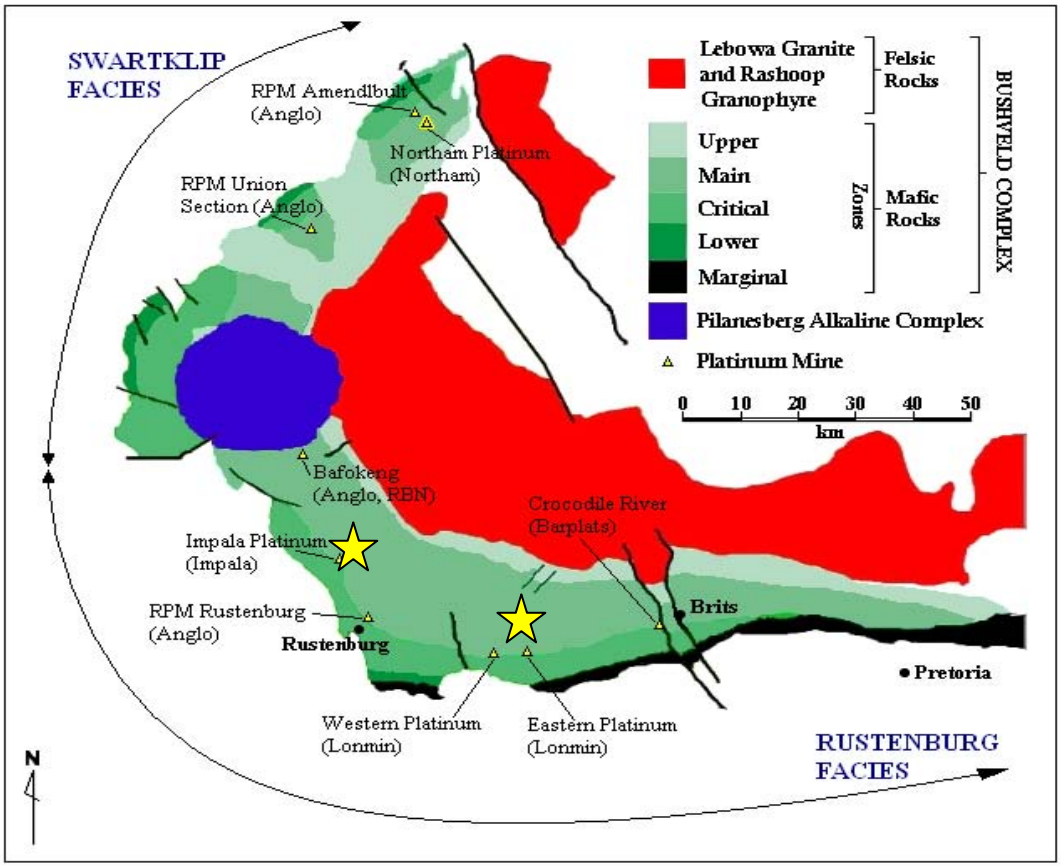

Figure 2.1: A geological map of the western limb of the Bushveld Complex, showing the location of platinum mines and the position of Impala Platinum and Lonmin Platinum from which the two Merensky ores used in this investigation were sourced (Brough, 2008).

Nickel recovery is usually used as a proxy for the recovery of pentlandite in flotation. Significant non sulphide nickel is, however present in Merensky ore. Nickel can be present in the silicate minerals, olivine and orthopyroxene, as well as solid solution traces in pyrrhotite (Brough, 2008). Brough (2008) recorded the non sulphide nickel content in wt% NiO as: olivine 0.47, orthopyroxene 0.089 and pyrrhotite 0.55.

Table 2.1 shows the composition of some of the minerals commonly occurring in the Bushveld complex.

Table 2.1: Minerals common to the Bushveld Complex (Schouwstra et al., 2000).

Mineral group	Mineral	Composition
Pyroxene	**Enstatite** **Augite**	**Mg, Fe silicate** **Mg, Fe, Ca silicate**
Feldspar	**Plagioclase**	**Ca, Na, Al silicate**
Mica	**Phlogopite** **Biotite**	**K, Mg, Al silicate** **K, Mg, Fe, Al silicate**
Chlorite	**Chlorite**	**Hydrated Mg, Fe, Al silicate**
Clay	**Talc**	**Hydrated Mg silicate**
Serpentine	**Serpentine**	**Hydrated Mg, Fe silicate**
Spinel	**Chromite**	**Cr, Fe, Mg oxide**
Sulfide	**Pentlandite** **Chalcopyrite** **Pyrrhotite** **Pyrite**	**Ni, Fe sulfide** **Cu, Fe sulfide** **Fe mono-sulfide** **Fe di-sulfide**

2.1.2 Gangue minerals

The bulk of Merensky ore consists of unwanted silicate gangue made up predominantly of pyroxene (a major rock forming mineral of common occurrence) and plagioclase. Typically silicate minerals consist of a silicon atom surrounded by a tetrahedral group of four oxygen atoms (Fuerstenau, 1982). The major silicate minerals of the Merensky reef comprise orthopyroxene (50-70%), plagioclase (11-25%) and clinopyroxene (2-27%) (Liddell et al., 1986). These amounts may vary along the reef. Significant recovery of orthopyroxene ($[MgFe]_2Si_2O_6$), a magnesium-rich ferro-magnesium inosilicate built on SiO_4 tetrahedral chains, occurs to the flotation concentrate during the processing of Merensky ore (Becker et al., 2006). Feldspars which fall into two main series, alkali feldspars and the most dominant of feldspars, plagioclase ($Na[AlSi_3O_8]$-$Ca[Al_2Si_2O_8]$), constitute approximately 50-60%

of all igneous rocks. Their structure is based on a continuous framework of SiO_4 tetrahedra (Battey and Pring, 1997). The reef contains between 0.5 and 5% talc ($Mg_6Si_8O_{20}[OH]_4$), a layered silicate with hydrophobic planes and hydrophilic edges. The layered sheets of tetrahedra each sharing three oxygen atoms are held together by weak van der Waals forces. Talc is the only naturally floatable silicate mineral in Merensky ore, and may report to the concentrate thus lowering concentrate grade. Talc has a froth stabilising effect which is negated by the addition of depressant. Secondary talc, due to alteration, occurs mainly at the grain boundaries between sulfides and pyroxenes (Liddell et al., 1986). Becker et al. (2006) used QEMSCAN (Quantitative Evaluation of Minerals by SCANing electron microscopy) to analyse the liberation of Merensky ores sampled from the same areas as the samples to be used in this study and noted that partial rims or coatings of talc were present around pyroxene particles which would result in pyroxene being rendered floatable. More recently this has been shown by Jasieniak and Smart (2009) using ToF-SIMS. This study showed that the alteration of the surface layers of pyroxene caused the true flotation of large pyroxene particles (20-150 µm). In Figure 2.2 a photomicrograph depicting a talc rim around orthopyroxene in the Merensky Reef is shown. Due to this phenomenon, talc, which is present in the ore in relatively small quantities, has a disproportionate effect on the recovery of naturally floatable gangue (NFG) (Steenberg and Harris, 1984; Fuerstenau et al., 1988). Rath et al. (1997) and Morris et al. (2002) found that the recovery of talc was independent of pH.

In addition to the alteration of orthopyroxene to talc, serpentinisation is an alteration process that converts olivine, over time, to serpentine under pressure, at an elevated temperature in the presence of water. Serpentinisation can also be accompanied by other alteration processes such as the conversion of pyroxene to talc. In such cases, the talc is often found in veins or fissures in the orebody. The ores used in this study are from the southern limb of the Bushveld Complex where serpentinisation is generally minor, however, alteration areas do exist in some of these deeper mining areas (Kinloch, 1982; Peyerl, 1983).

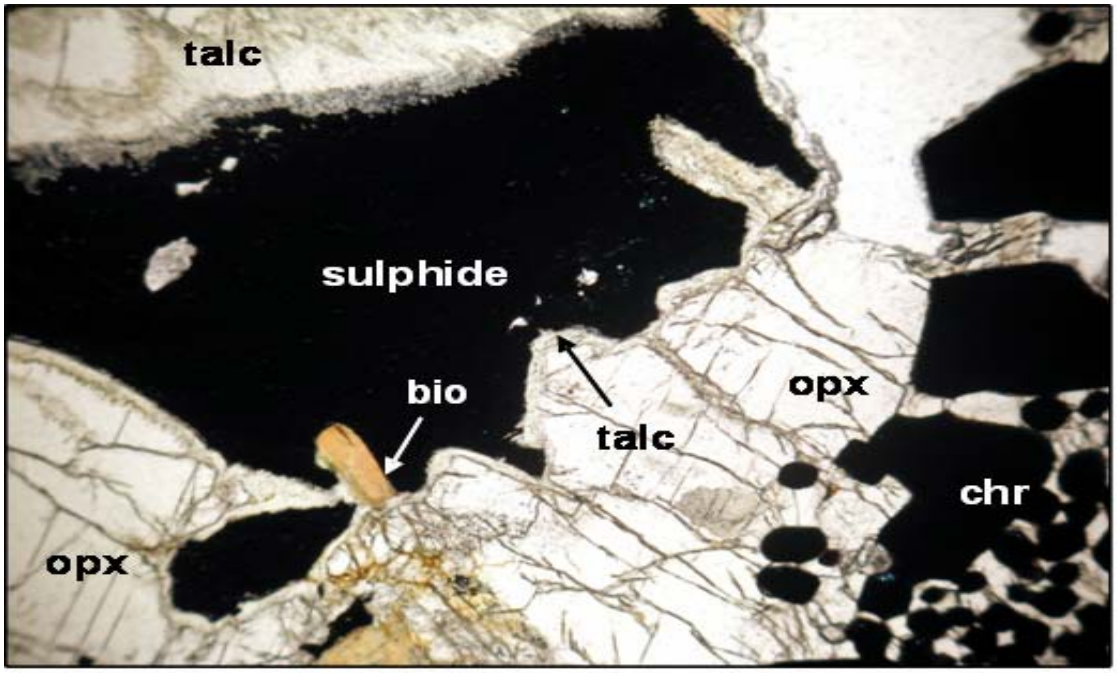

Figure 2.2: Photomicrograph showing a talc rim on the boundary between orthopyroxene (opx) crystals and a sulfide bleb in the Merensky Reef. Other minerals present include biotite (bio) and chromite (chr) (Becker et al., 2006; Lotter et al., 2008).

2.2 Principles of flotation

Flotation is a selective physico – chemical separation process utilising the differences in the surface properties of valuable minerals and unwanted gangue as summarised in Wills and Napier-Munn (2006). The flotation process consists of two distinct phases, the pulp phase in which mineral recovery occurs and the froth phase from which concentrated valuable minerals are separated from the bulk. Recovery of minerals to the froth phase may occur through three main mechanisms (Trahar, 1984; Wills and Napier-Munn, 2006). True flotation is the dominant mechanism for the recovery of valuable minerals, whereby reagents are added to the system to enhance the differences in mineral surface properties. It is directly affected by chemical changes such as collector and depressant addition. The second mechanism is the entrainment of particles in water passing from the pulp phase to the froth phase and the third mechanism, entrapment, aggregation or as composite particles. Entrainment is non-selective and this mechanism together with entrapment results in the recovery of both valuable and gangue minerals to the concentrate.

Gangue may report to the concentrate by true flotation, entrainment, entrapment, or as composites with valuable minerals.

In the pulp phase the necessary environment, both physical and chemical, needs to be created to promote particle - bubble collision, successful attachment of the valuable hydrophobic particles to the bubble and the transport of these mineral laden bubbles to the froth phase. Simultaneously, unwanted gangue minerals are rendered hydrophilic and remain unattached after collision with bubbles and are therefore not transported to the froth phase. The rising bubbles, however, may cause material to report to the froth phase unselectively by entrainment. Entrainment is a mechanical phenomenon which is not directly affected by changes in mineral surface properties, but rather by particle properties such as size and density.

The role of the froth zone in flotation is to facilitate the upgrading of the valuable materials reporting to the concentrate without any loss of these valuables. The structure of the froth allows for drainage of water thereby reducing the non-selective recovery of gangue material by entrainment. Unstable froths continually break down as liquid drains from between the bubbles (Harris, 1982). Dudenkov (1967) postulated that well dispersed hydrophobic particles could rupture froths due to the coalescence of bubbles both in the pulp and the froth. The reaction of the collector with metal ions in solution may form fine hydrophobic precipitates which could lead to froth destabilisation (Dudenkov, 1967). Both lead to lower water recoveries. The recovery of entrained material is proportional to water recovery (Johnson et al., 1974; Engelbrecht and Woodburn, 1975; Savassi, 1998). Thus, by reducing water recovery, entrainment decreases and there is an increase in the valuable mineral grade of the concentrate. Therefore, factors that affect froth stability also affect the amount of material recovered by entrainment.

A froth which is highly stable allows substantial recovery of gangue by entrainment and the upgrading of the valuable material can be inadequate. On the other hand a froth which is highly unstable will result in upgrading of the concentrate, but may be accompanied by a loss in recovery of valuable minerals. The overall rate of flotation is a balance between the various competing mechanisms of collection, attachment and detachment (Jameson, 1984). There is an optimum particle size for flotation (20

– 150 µm), with upper and lower limits. It has been found that for fine particle sizes (<20 µm) the collision efficiency is too low for effective flotation. The presence of fine particles leads to excessive entrainment and a reduction in concentrate grade as well as contributing to operational problems such as high froth stability (King, 1982). Fine particles can also be responsible for the formation of coatings on mineral surfaces due to first order electrostatic forces and results in the depression of particles which would under normal circumstances be recovered by flotation (Jameson, 1984). For large sized particles, detachment from the bubbles becomes more common and effective flotation is also reduced. The probability of this detachment is a function of particle size (King, 1982). For a particle to be recovered by flotation it must collide with and adhere to an air bubble, a complex process in the highly turbulent environment in the flotation cell. A particle should possess sufficient momentum to resist the tendency to follow the streamlines of water that flow around bubbles. Adhesion occurs if the particle penetrates the bubble shell within the required induction time during which the surface of the bubble becomes deformed and the water film between the particle and bubble thins until it finally ruptures (King, 1982).

Flotation is thus a complex process affected by approximately 25 parameters. Klimpel (1984) divided the major variables in flotation into three main groups (Figure 2.3).

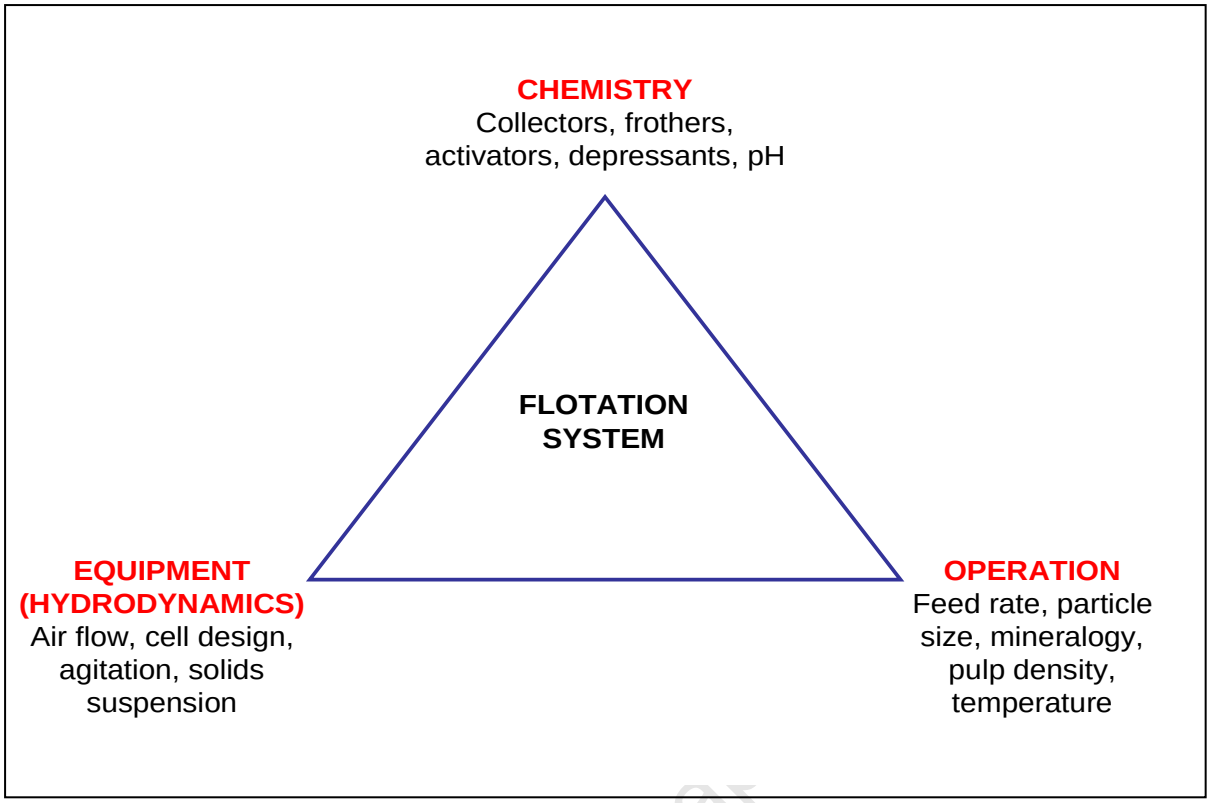

Figure 2.3: Summary of the variables in the flotation system (Adapted from Klimpel, 1984).

Before flotation can take place the ore is subjected to a comminution process consisting of two stages, crushing and grinding to achieve a particle size distribution of appropriate liberation. Crushing is a dry process and produces material of a size suitable to facilitate transportation of the ore to the concentrator. The second stage in the comminution process, grinding, is performed to liberate the valuable minerals from the unwanted gangue minerals and is traditionally a wet process, achieved by the abrasion of the ore by free moving media such as rods, balls or pebbles (Wills and Napier-Munn, 2006).

Liberation is defined as the degree to which a valuable mineral is exposed from the gangue on the basis of volume (Barbery, 1991). The degree of liberation of the valuable minerals may be considered in two ways. Either as liberated composites, separate from silicate gangue or as liberated individual sulfide minerals separated from other sulfides, as well as the silicate gangue. The comminution stage is a balance between sufficient grinding time and valuable mineral liberation. Over-

grinding should be avoided as it results in excessive fine material which is difficult to recover during the flotation process (Merkle & Mckenzie, 2002), whereas under-grinding prevents the liberation of the desired valuable mineral.

2.2.1 Entrainment

Entrainment is the non-selective recovery of both valuable and gangue particles carried upwards by the flow of air bubbles and water out of the flotation cell. The unselective recovery of gangue minerals to the concentrate by entrainment is one of the mechanisms responsible for a reduction in concentrate grade. Entrainment is largely dependent on particle size and density. It is not directly affected by chemical changes or reagent addition, but is affected by the changes in froth stability brought about by chemical changes. Depressant addition affects froth stability and therefore, the extent of entrainment by the removal of froth stabilising gangue. Neethling and Cilliers (2001) determined that there are two types of solids in the froth phase of flotation. Particles attached to bubble lamellae which are assumed to be hydrophobic and unattached particles moving freely through plateau borders which are there due to non-selective entrainment. The amount of entrained material is related to the amount of water recovered (Ekmekçi et al., 2003; Yang and Aldrich, 2006; Boylu and Laskowski, 2007; Johnson, 2005). It has been shown (Smith and Warren, 1989; Wills and Napier-Munn, 2006) that only particles smaller than 45 µm are expected to be recovered by entrainment. Savassi (1998) found that entrainment decreases exponentially with an increase in particle size.

There are three proposed mechanisms for the transport of minerals from the pulp zone to the froth zone via entrainment:

- Transportation of the particle in the wake of a rising air bubble (Yianatos et al., 1988)
- Transport of the particle in the thin water layer surrounding the bubble (Gaudin, 1957; Hemmings, 1981)
- Transport of the particle via water and suspended particles retained in the bubble swarm (Smith and Warren, 1989)

A number a different methods have been used over the years to quantify entrainment. These include flotation of non-floating gangue component (Johnson et al., 1974), flotation without collector (Trahar, 1981), measurement of non-attached material (Savassi, 1998) and the use of a tracer such as MnO_2, which was used by Robertson (2003).

In order to calculate the amount of entrained material from the batch flotation tests conducted in this investigation, two different methods of calculating entrainment were evaluated. In the series of tests to evaluate the effect of depressant type and dosage (Chapter 4) the entrainment function determined by Robertson (2003) was used. The second method made use of an entrainment function calculated using high depressant dosages (500 g/t) (Harris et al., in press a,b). This method was used to quantify entrainment in testwork evaluating xanthate chain-length (Chapter 5). The entrainment function was obtained from the gradient of the graph illustrating total gangue versus water recovered. The extent of entrainment for the system can be obtained by multiplying the entrainment function by the water recovery. This amount, together with the mass of sulfides recovered in the concentrate is subtracted from the total mass recovered to obtain the amount of floatable gangue recovered. The entrainment function calculated from this method has been shown to be equivalent to that obtained by Robertson (2003). The method is more practical than the tracer method as no foreign material is added to the system and it can be applied for any grind size without knowledge of the feed size distribution of the ore. To date the method has been evaluated on Merensky ore only.

2.3 Flotation Reagents

Flotation reagents are added to the pulp to manipulate mineral surface chemistry and thereby enhance differences in mineral hydrophobicity, facilitating the separation of valuable minerals from gangue minerals. A typical reagent suite consists of collectors, frothers, depressants and sometimes activators. It is necessary to evaluate reagent interactions in an integrated way, as in addition to their primary functions, the reagents may interact with each other (Bradshaw et al., 2004). Collectors impart hydrophobicity to the valuable minerals, depressants suppress the

flotation of naturally floatable hydrophobic gangue minerals and frothers aid in bubble formation as well as in froth stabilisation. Activators are sometimes added to enhance the action of the collector. They are typically soluble salts which ionise in solution. The ions in turn react with the mineral surface. An example of this is the addition of copper sulfate during the concentration of Merensky ores to enhance the flotation of pyrrhotite (Wiese et al., 2005a). After the final conditioning stage, air is added to the system and is dispersed by the impeller.

Frothers are added to facilitate a stable froth as well as bubble formation and are heteropolar organic reagents that adsorb at the air-water interface. The formation of a stable froth is of importance in the flotation process in order to retain the valuable minerals for further upgrading (King, 1982). An efficient frother should have negligible collecting characteristics. Lotter et al. (2003) using Tof-SIMS, showed that the polyglycol ether frother, Dowfroth, adsorbed on magnesium rich surfaces of orthopyroxene.

pH modifiers are sometimes added to modify the pH of the pulp so that the optimum conditions for collection, activation or depression may be achieved. Water is also considered to be a reagent, and water quality affects the flotation process.

2.3.1 Collectors

Collectors impart hydrophobicity to mineral surfaces and form the link between mineral surfaces and air bubbles. Typical classes of collector are xanthates, dithiophosphates (DTP) and dithiocarbamates (DTC). Thiol collectors adsorb onto sulfide mineral surfaces mainly via chemisorption and consist of a functional group containing a sulfur atom bonded to either a carbon or a phosphorous atom (Lovell, 1982). Chemisorption is adsorption in which the forces involved are valence forces and of the same type as those involved in the formation of chemical compounds (Everett, 1972). Mixtures of thiol collectors may be used to enhance the flotation performance of sulfide ores. Synergism refers to the enhanced mineral recoveries obtained using collector mixtures over and above the proportional contribution of the individual collectors (Bradshaw, 1997). Helbig et al. (2000) reported synergistic enhancements in the microflotation of pyrite using a mixture of sodium isobutyl

xanthate (SIBX) and di-butyl dithiophosphate which has a pH stability range of 4 – 12 (Fuerstenau, 1982).

2.3.1.1 Xanthates

The most widely used collectors in sulfide mineral flotation are xanthates, due to their low cost and powerful collecting properties. Xanthates are classified as anionic sulfhydryl collectors (King, 1982; Wills and Napier-Munn, 2006) and are oxidation products of alcohols, carbon disulfide and potassium or sodium hydroxide.

$$ROH + KOH\ (Na) + CS_2 \rightarrow ROCS_2K\ (Na) + H_2O$$

The structures of four common xanthate collectors are shown in Figure 2.4.

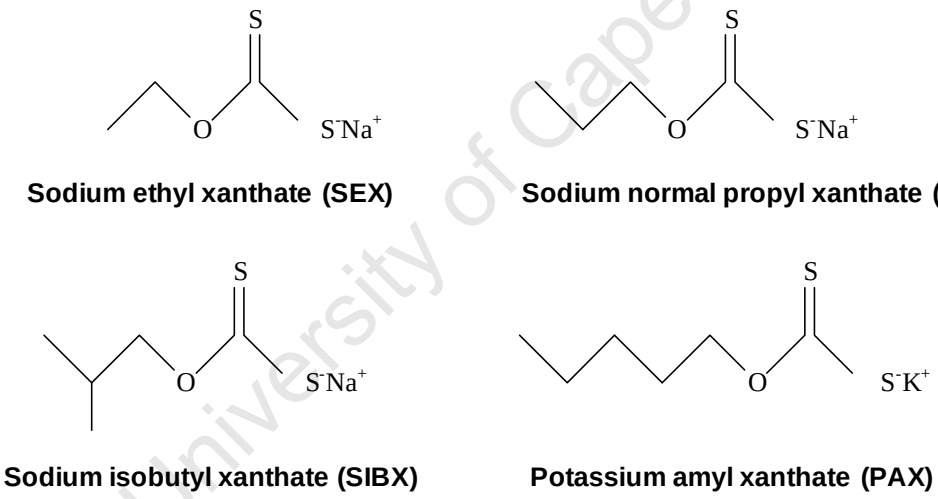

Figure 2.4: Structures of four common xanthate collectors.

The mechanism of xanthate adsorption onto mineral surfaces has been well researched. Xanthates adsorb on the mineral surface and chemically interact with metal ions to form hydrophobic metal xanthates, which can be oxidised to dixanthogen with certain minerals under appropriate conditions (Allison et al., 1972; Fornasiero et al., 1995). Fuerstenau (1982) proposed that cupric and ferric ions oxidise xanthate in solution with oxygen to form dixanthogen as follows:

$$2X^- + ½\ O_2 + H_2O \rightarrow X_2 + 2OH^-$$
$$2X^- + Cu^{2+} \rightarrow CuX(s) + ½\ (X_2)$$
$$2X^- + 2Fe^{3+} \rightarrow 2Fe^{2+} + (X_2)$$

Although thermodynamically favourable, the oxidation of xanthate by dissolved oxygen is kinetically slow. As a result, dixanthogen formation by this mechanism is not expected to occur to any large extent in flotation systems.

Xanthate is known to oxidise completely at pH 2 with Fe^{3+} but does not oxidise at pH 6 and above (Fuerstenau, 1982). In the presence of Cu^{2+}, there is complete oxidation of xanthate up to pH 10, while no oxidation occurs at pH values of 11 and above. Dixanthogen is unstable at pH values of 10.5 and above. This implies that at these alkaline pH values, only xanthate is stable (Fuerstenau, 1982; Montalti et al., 1991).

Xanthates are widely used as collectors of precious metal sulfides. They consist of a polar group which attaches to the mineral and a non-polar group which orients into the pulp thereby inducing hydrophobicity.

Xanthates decompose slowly in alkaline media and have a pH stability range of 8 – 13 (Fuerstenau, 1982). They are thus used in neutral or slightly alkaline media. The natural pH for the flotation of Merensky ore is in the region of 9 as it is a strongly buffered system due to the nature of the gangue minerals present (Ekmeckçi et al., 2005). An increase in xanthate carbon chain-length leads to an increase in xanthate adsorption and thus hydrophobicity (Wills and Napier-Munn, 2006). There is, however a decrease in xanthate selectivity as xanthate chain-length is increased (Mbonambi, 2009). Bradshaw et al. (2005) showed that in batch flotation tests on a Merensky ore increasing collector chain-length led to a reduction in mineral recovery due to its effect on froth stability. Oostendorp et al., (unpublished report, 2003) obtained higher froth stability with SEX than with SIBX in batch flotation tests on a Merensky ore. An increase in collector chain length resulted in a decrease in the recovery of mass and water recovery. Generally non sulfide minerals do not adsorb xanthate and are therefore not floated by them.

2.3.2 Polysaccharide depressants

All concentrators processing Merensky ore use polysaccharide depressants to reduce the recovery of the naturally floatable gangue minerals (mainly silicate) present in the ore by adsorbing onto the surface of these minerals (Steenberg and Harris 1984; Shortridge et al., 2003; Bradshaw et al., 2004) and to allow sufficient upgrading of the valuable minerals. A secondary effect of the depressants is the reduction in the stability of the froth, partly caused by the absence of the froth stabilising talc and partly due to the nature of the polymer itself (Bradshaw et al., 2005). These depressants are either modified guar gum or carboxymethyl cellulose (CMC). The two reagents appear to be almost interchangeable in their efficacy although their basic structures and their effects on froth stability are markedly different (Harris et al., in press a,b). The froth phase in flotation is affected by depressant action and the changes observed in froth stability upon depressant addition, particularly at higher concentrations, need to be taken into account when evaluating depressant performance (Bradshaw et al., 2005).

Laskowski et al. (2007) described the action of a depressant as being opposite to that of a collector, in that it either prevents collector adsorption or renders the surface of the mineral hydrophilic. High depressant dosages may be detrimental to the recovery of the valuable minerals present in the ore. At low collector concentrations high concentrations of polysaccharide depressants can co-adsorb onto sulfide mineral surfaces and so depress them (Steenberg and Harris, 1984). Morris (1997) observed a reduction in the recovery of nickel sulfide minerals in bench scale flotation tests using Kambalda ore (5% talc) from the Western Mining Company. This was attributed to either a reduction in collector adsorption or the adsorption of depressant on sulfide mineral surfaces. Vianna (2004) showed that in the absence of depressant maximum recoveries of sulfide minerals (galena) can be obtained with collector coverage levels in the region of 20%.

In the 1960s the primary adsorption mechanism of polysaccharide depressants on mineral surfaces was proposed as hydrogen bonding and later hydrophobic bonding was suggested (Steenberg and Harris, 1984; Morris, 1997). Hydrogen bonding involves the bonding of hydroxyl groups present in polysaccharide depressants with oxygen atoms on mineral surfaces. Hydrophobic interactions occur between talc

surfaces and the hydrocarbon backbone of depressants. Steenberg and Harris (1984) proposed that a combination of hydrogen and hydrophobic bonding may occur, with hydrophobic bonding taking place on talc faces and hydrogen bonding on talc edges. Maximum talc depression was thus complete when depressant adsorption took place on the talc basal planes and edges. Another proposed mechanism ((Liu and Laskowski 1989; Liu and Laskowski 1999; Liu et al. 2000; Laskowski et al., 2007) was that surface metallic sites were responsible for polysaccharide adsorption which could be categorised as an acid / base interaction, with polysaccharides behaving as acids. Adsorption isotherms indicate the adsorbed concentration of depressant versus the equilibrium solution concentration obtained at constant temperature. The initial gradient of the isotherm indicates the rate at which the depressant molecules find vacant sites on mineral surfaces for adsorption.

Previous work has shown that at high depressant concentrations floating gangue can be completely eliminated from reporting to the concentrate in Merensky ore (Harris et al., in press a,b; Wiese et al., 2009). Under these conditions the only gangue reporting to the concentrate is assumed to be via entrainment in water moving from the pulp phase to the froth phase.

2.3.2.1 Guar gum

Guar gum is derived from the seeds of the Cyamopsis tetragonolobus plant (Mackenzie, 1980) which are modified by alkaline degradation. As illustrated in Figure 2.5, guar is a branched polysaccharide with galactomannan forming the basic unit. The hydroxyl groups are arranged in a cis configuration on the C-2 and C-3 atoms. Typically, guars are uncharged or have very low charge, with an active content in the region of 90%. Guars have zero or very low degrees of substitution (DS), but are soluble in water. Guar has been found to be a stronger depressant of NFG than CMC at low dosages (Shortridge et al., 2003; Wiese et al., 2007; Wiese et al., 2008). Although not a general finding (Morris et al., 2002) Ma and Pawlik (2007) found that the depression of talc by guar was complete at all pH levels even at low concentrations.

Guar adsorption onto talc was found to be unaffected by changes in pH or ionic strength (Rath et al., 1997; Wang et al., 2005). Wang et al. (2005) also found that the

adsorption of guar onto talc was irreversible and occurred mainly through hydrogen bonding. At high concentrations guar could lead to the formation of agglomerates. Figure 2.5 shows the structure of a guar gum molecule.

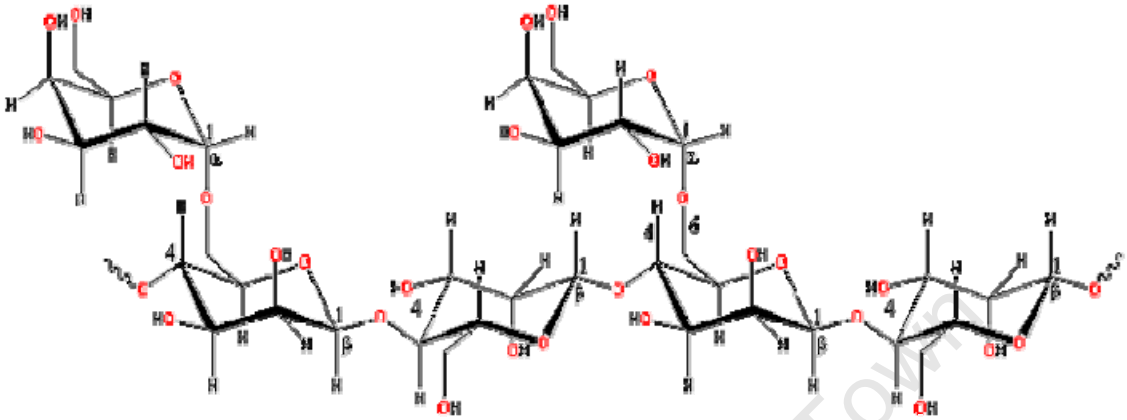

Figure 2.5: Structure of a guar gum molecule. (www.lsbu.ac.uk/water/hygua)

2.3.2.2 Carboxymethyl cellulose

Carboxymethyl cellulose (CMC) is an anionic polysaccharide with high molecular weight (Burdukova, 2007) and as shown in Figure 2.6, has a linear structure. One of the most important properties of CMC is its DS, which is the extent to which carboxyl groups replace hydroxyl groups. CMCs may have a DS of up to 3, but typically the DS of CMC is in the region of or lower than 1. CMC would need to possess a DS of at least 0.5 in order to be soluble in water. The active content of CMC used in flotation is in the region of 70%. Carboxymethyl cellulose molecules have a strong negative charge, causing the surfaces of the gangue minerals to become negatively charged which results in dispersed pulps. This is true even at the high ionic concentrations found on concentrators processing Merensky ore. Depression of talc by CMC is improved in the presence of divalent cations (Shortridge et al., 2003; Parolis et al., 2008). CMC adsorption density onto talc has been found to be strongly dependent on the ionic strength of the solution (Morris et al., 2002; Pawlik et al., 2003; Khraisheh et al., 2005; Parolis et al., 2007; Pawlik and Laskowski 2006). Figure 2.6 shows the structure of a CMC molecule.

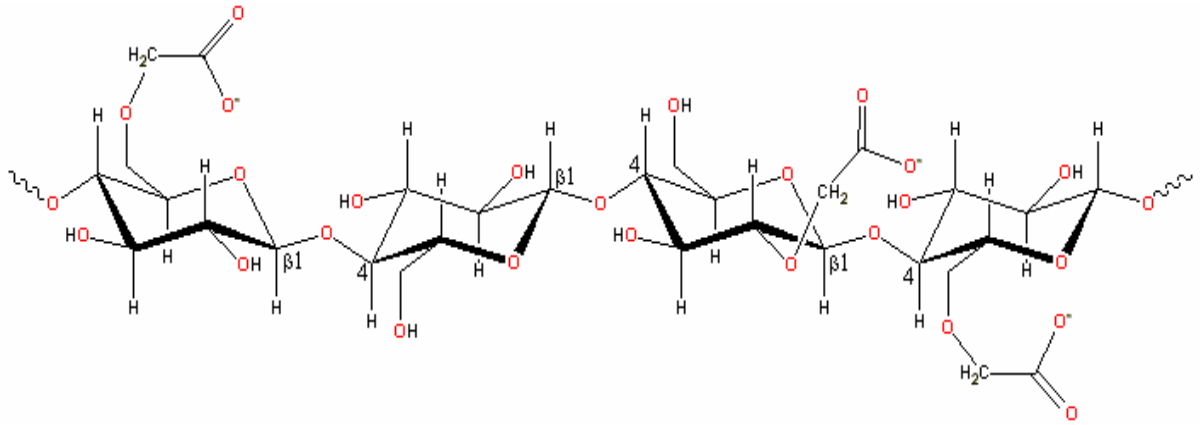

Figure 2.6: Structure of a CMC molecule. (www.lsbu.ac.uk/water/hycmc)

2.4 Reagent / mineral interactions

The various reagents added to a flotation system all fulfil specific roles, but can also interact with one another. Reagents have both direct and indirect effects on the froth phase in a flotation system. Frother addition has a direct influence on froth stability. Frother, being a surface–active compound, affects the stability of the froth by lowering the surface tension of the liquid phase and increasing the stability of the froth films. Frother can also alter bubble-size which, in turn affects froth stability. Other reagents which possess some surface activity (frothing properties), such as some DTP collectors, can also alter froth stability directly. The quality of the water used can also influence the flotation process.

Other reagents such as collectors, activators and depressants influence froth stability indirectly by altering the nature of the hydrophobic particles entering the froth. All particles that attach to the air / water interface can have a major influence on froth stability. Strongly hydrophobic particles can destabilise froths by bridging the froth films and collapsing bubbles (Bradshaw et al., 2005). Closely packed weakly hydrophobic particles can stabilise froths by attaching at both interfaces and preventing the thinning of the bubble lamellae. The removal of froth stabilising silicate gangue by depressant addition results in a decrease in froth stability. Froth stability is usually dependent on a combination of both direct and indirect effects.

The amount of water recovered during a batch flotation test at a fixed froth height is a measure of froth stability (Bradshaw et al., 2004; Wiese et al., 2009; Harris et al., in press a,b). The higher the amount of water recovered, the more stable the froth and the more material recovered by entrainment. Upon depressant addition, hydrophobic silicate gangue becomes hydrophilic and does not report to the froth. This reduces froth stability, thereby decreasing the amount of water recovered and hence lowering entrainment. The amount of floating gangue at zero or low depressant dosages far exceeds the amount of entrained gangue reporting to the concentrate. At high depressant dosages floating gangue is completely eliminated and the only gangue recovered is via entrainment or the flotation of sulfide / gangue composite particles (Bradshaw et al., 2005).

Competition exists at the mineral surface between thiol reagents and oxidation reaction product formation.

$$2X^- + O_2 + 2H_20 \rightarrow X_2 + 4OH^-$$

The flotation performance of Merensky ores may be evaluated by analysing the flotation behaviour of the three main sulfide minerals, chalcopyrite, pentlandite and pyrrhotite, as they are strongly associated with the PGMs present in Merensky ore (Liddell et al., 1986). It has been shown previously that chalcopyrite is the fastest floating of the sulfide minerals followed by pentlandite and then pyrrhotite.

Collector coverage of mineral particles affects the action of the depressant in the flotation system. Steenberg and Harris (1984) determined that at low dosages, collector adsorption did not occur uniformly over the entire mineral surface and that polymer adsorption occurred on these vacant sites. Thus, at low collector concentrations polymeric depressants may co-adsorb with xanthate onto sulfide mineral surfaces and result in depression the particle. An increase in xanthate carbon chain-length leads to an increase in xanthate adsorption and thus hydrophobicity (Wills and Napier-Munn, 2006). There is, however a decrease in xanthate selectivity as xanthate chain length is increased. Previous work (Bradshaw et al., 2004) determined the anomalous behaviour that enhanced sulfide mineral

recoveries were obtained from a Merensky ore when using SEX than when using the longer chain length SIBX, at low dosages. This work will investigate the use of both low and high dosages of xanthate collectors of varying chain length on the flotation performance of two Merensky ores. Beattie et al. (2005) found that in mixed mineral flotation experiments polymer adsorption was not affected by the presence of collector and vice versa. The UCT batch flotation procedure allows for the collector to be added in the mill, i.e. before depressant addition which ensures that collector adsorption takes place as mineral surfaces are formed. As long as sufficient collector is available for adsorption there should not be interference from depressants added to the system (Wiese et al., 2009).

2.5 Summary of literature

Extensive research has been conducted on quantitatively evaluating and characterising polymeric depressant behaviour on laboratory scale and using microflotation tests. The majority of this work has focused on isolating the mechanism of depressant action by evaluating their behaviour in single mineral systems (Shortridge et al., 2003; Parolis et al., 2008; Khraisheh et al., 2005) and a more rigorous approach is needed to consider other factors.

Harris et al. (in press a,b) determined that different CMC depressants, when used at the same active content, DS and molecular weight had little effect on their ability to reduce the amount of NFG reporting to the concentrate. CMC with lower DS always led to lower froth stability, as measured by water recovery. This in turn leads to lower gangue recoveries. Stronger and more rigorous resesrch is needed for clarification.

Shortridge et al. (1999) investigated the effect of polymer molecular weight and dosage on the depression of talc. It was found that the ionic strength of the system had a large effect on the viscosity characteristics of CMC, but had no effect on the viscosity characteristics of guar. At the conditions evaluated guar was found to be a more effective depressant of talc than CMC. The depression of talc was increased with an increase in the MW of guar. Increasing the MW of CMC did not have a decisive effect on the depression of talc. The talc used for this study was supplied by

Scotia Mine, Barberton South Africa. The same talc was used by Khraisheh et al. (2004) to investigate the effect of molecular weight and concentration of CMC onto talc. Although from a South African operation, the talc was not the same as talc occurring in the Merensky Reef where some iron substitution is known to occur (Becker, unpublished data). Beattie et al. (2005) used talc supplied by Merck, Germany (> 90% pure, PSD 0.5–100 µm) in order to assess the influence of adsorbed polysaccharides on talc flotation. This work needs to be extended and validated on appropriate ore samples.

Although guar and CMC can be considered to be interchangeable in their efficacy as depressants of NFG their basic structures, their efficiency on froth stability and mechanisms of adsorption are different (Harris et al., in press a,b). Steenberg and Harris (1984) and Morris (1997) proposed hydrogen bonding as the adsorption mechanism for guar. Wang et al. (2005) determined that the adsorption of guar onto talc was irreversible and occurred mainly through hydrogen bonding. The proposed adsorption mechanism for CMC (Liu et al., 2000; Laskowski et al., 2007) is that adsorption results from acid / base interactions, with polysaccharides behaving as acids and metal hydroxides on mineral surfaces as bases.

As noted before, Steenberg and Harris (1984) used pure galena and pyrite to evaluate the influence of polymeric depressants on the adsorption of thiol collectors in sulfide flotation. These studies did not take into account the behaviour of sulfide / gangue composite particles. Most of these studies used a narrow size range of mineral particles which did not relate to the particle size distribution of real flotation feed and only focus on size fractions which are normally recovered via true flotation. Mineral size fractions which would be recovered via entrainment in a batch flotation system have been ignored. The microflotation system is a frothless sytem and therefore the effects of reagent / mineral interactions on the froth phase can not be evaluated. The system measures total adsorption of depressants and does not allow for competitive adsorption measurements due to the absence of a gangue phase and a valuable phase. In 2005, Bradshaw et al. conducted microflotation tests using xanthate collectors of varying chain-length and found that the results obtained in this frothless environment could not be sustained in the presence of a froth phase. Mbonambi (2009) used the same four xanthate collectors used in this study to

conduct microflotation tests using a massive sulfide ore, and found that the rate of flotation increased as the xanthate chain length increased in the absence of depressant in a frothless system. This should be validated.

Morris (1997) observed a reduction in the recovery of sulfide minerals in bench scale flotation tests. This was attributed to either a reduction in collector adsorption or the adsorption of depressant on sulfide mineral surfaces. This work aims to use four xanthate collectors at different dosages in the presence of high dosages of polysaccharide depressants in order to determine whether the effect of the depressant can be counteracted by sufficient amounts of collector. The effect of xanthate chain length will be assessed in order to determine whether the findings of Mbonambi (2009), which showed an increase in flotation kinetics with an increase in xanthate chain length, are applicable for the conditions used in this testwork.

This systematic study uses batch flotation tests to address the complexity of the sub-processes of a flotation system and reagent interactions in a flotation environment using real ores and a full suite of reagents in order to evaluate depressant behaviour and the interactions of depressants with other flotation reagents, particularly collectors in an integrated manner. This study also allows for gangue reporting to the concentrate via true flotation to be decoupled from gangue reporting to the concentrate via entrainment. Allowance has also been made for the influence of reagent addition on the stability of the froth to be assessed by measuring water recovery at a fixed froth height. Two ores from different parts of the Merensky reef are assessed in order to determine whether differences in feed mineralogy and alteration results in differences in flotation behaviour. It is expected that the ore containing higher amounts of pyroxene with talc rims (low temperature alteration product of silicate minerals) would result in differences in the amount of gangue recovered to the concentrate. This would be expected to dilute the grade of the concentrate. As CMC adsorption density is strongly dependent on the ionic strength of the solution (Morris et al. 2002; Pawlik et al. 2003; Khraisheh et al. 2004; Parolis et al. 2005), all batch flotation tests are conducted using synthetic plant water, which contains sufficient ions for this purpose.

The method developed at UCT to quantify entrainment using high depressant dosages has not fully been validated, and the effects of differences in feed mineralogy have not been clearly established. It is also not known whether the dispersed pulps resulting from high dosages of CMC addition would result in different amounts of material being entrained compared to the more coagulative pulps achieved due to the addition of high dosages of guar.

Within the context of previous work reviewed here and the limitations and constraints which have been identified, this investigation focuses on the following key questions as given in the introduction.

1. Can the method developed at UCT for a Merensky ore, using high depressant dosages, be used to assess the amount of floating gangue independently from the amount of entrained gangue for two different ores with varying mineralogy?

2. How does depressant type and dosage affect both floatable and entrained gangue, as well as sulfide mineral recovery for different Merensky ores and is the behaviour consistent for ores with different amounts of gangue?

3. How do high dosages of depressant influence the different size classes of sulfide and gangue minerals recovered in the concentrate?

4. How does collector (xanthate) type and dosage affect both floatable and entrained gangue as well as sulfide mineral recovery for different Merensky ores?

5. How does depressant behaviour affect collector / mineral interactions?

3 Experimental details

3.1 Ore

Two samples of Merensky ore weighing approximately 200 kg each were obtained from two separate locations on the southern section of the western limb of the Bushveld Igneous Complex, South Africa in 2004 (Figure 2.2). Throughout this study these samples will be known as Ore A (Impala Merensky ore) and Ore B (Lonmin Merensky ore).

Preparation of the two samples was done at the Centre CMR, UCT. Larger rocks were reduced to pebbles having diameters of approximately 15 mm using a jaw crusher located in the Geological Sciences Department at UCT. This material was then blended with the remainder of the samples which were crushed to 100% passing 3 mm using a cone crusher. The crushed samples were blended, riffled and split into representative 1 kg portions using a rotary sample splitter manufactured by Dickie and Stockler (Allen, 1990). This approach reduces the variation in composition between replicate test charges, since the spinning riffler reduces the group and segregation error, provided that the topsize of the particle size distribution has been matched to Gy's safety Line (Gy, 1979; Lotter and Fragomeni, 2009). This reduces the relative standard deviation of the sample mean paymetal grade.

The mean copper, nickel and sulfur values for the two ores were calculated using the concentrate and tailings values obtained from all the batch flotation tests. These chemical assays indicated that the values obtained for Ore B were higher than those obtained for Ore A as shown in Table 3.1. No analysis for PGE was done.

Table 3.1: Mean calculated feed values for the two ores received in 2004.

Ore sample	Copper, wt %	Nickel, wt %	Sulfur, wt %
Ore A	**0.061**	**0.139**	**0.307**
Ore B	**0.074**	**0.187**	**0.359**

Modal analyses of feed samples of the two ores were conducted using QEMSCAN, developed by the CSIRO (Australia), at Mintek. The system acquires energy

dispersive X-ray spectra and back scattered electron image information to identify minerals (Gottlieb et al., 2000). Gangue minerals and BMS present in the ores are shown in Table 3.2. All BMS are mainly associated with the major gangue minerals pyroxene and plagioclase. In both ore samples there was some association between pyrrhotite with both chalcopyrite and pentlandite. However, there was very little association between chalcopyrite and pentlandite. Consequently, based on liberation data, it would be expected that the flotation behaviour of the BMS in the two ores would be similar and that the flotation behaviour of pentlandite would be distinctly different to that of chalcopyrite (Becker et al., in press). Table 3.2 illustrates that Ore B contains significantly more orthopyroxene than Ore A, which contains double the amount of plagioclase and more serpentine than Ore B. Ore B is also shown to contain more sulfides than Ore A. The modal BMS composition for the two ores is shown in Table 3.3.

Table 3.2: Modal composition: sulfide and gangue minerals present in the two ore samples as determined by QEMSCAN.

Mineral	Feed Ore A (%)	Feed Ore B (%)
Pentlandite	**0.31**	**0.53**
Chalcopyrite	**0.25**	**0.30**
Pyrrhotite	**0.44**	**0.62**
Pyrite	**0.08**	**0.16**
Other Sulfides	**0.02**	**0.03**
TOTAL Sulfides	**1.09**	**1.65**
Plagioclase	**43.38**	**22.69**
Orthopyroxene	**32.60**	**53.89**
Olivine	**0.59**	**0.17**
Clinopyroxene	**7.48**	**11.33**
Talc	**3.51**	**5.02**
Serpentine	**0.80**	**0.52**
Chlorite	**0.83**	**0.20**
Phlogopite	**0.46**	**0.44**
Quartz	**0.67**	**0.66**
Calcite	**0.18**	**0.18**
Oxides	**8.10**	**2.82**
Other	**0.32**	**0.44**
TOTAL	**100.00**	**100.00**

Table 3.3: Modal composition of base metal sulfides present in the two ore samples as determined by QEMSCAN.

Sulfide	Ore A (%)	Ore B (%)
Pentlandite	**35**	**30**
Pyrrhotite	**47**	**55**
Chalcopyrite	**18**	**15**
Pyrite	**0**	**0**
TOTAL	**100**	**100**

As insufficient ore remained after the evaluation of depressant type and dosage (Chapter 4), two new ore samples were received during 2006 for the testwork to be conducted for the size by size analysis of concentrates from quintuplicate batch flotation tests conducted using guar and CMC, as depressants, as well as no depressant. Tests to evaluate the effect of xanthate chain length were also conducted using the new ore samples. The mean feed values copper, nickel and sulfur values for the two new ore samples were calculated using the concentrate and tailings values obtained from all the batch flotation tests in this phase of work. These values are shown in Table 3.4. For Ore A the value obtained for copper was similar to that obtained for the previous ore sample, but the percentage nickel and sulfur in the second sample was higher. For Ore B copper, nickel and sulfur values were higher in the second ore sample.

Table 3.4: Mean calculated feed values for the two ore samples received in 2006 and used in size by size analysis and tests to evaluate the effect of xanthate chain length.

Ore sample	Copper, wt %	Nickel, wt %	Sulfur, wt %
Ore A	**0.063**	**0.171**	**0.321**
Ore B	**0.084**	**0.219**	**0.398**

3.2 Water

All batch flotation tests were conducted using synthetic plant water, whereby distilled water was modified by the addition of various chemical salts to achieve a specific

total dissolved solids content. The ions present in this synthetic plant water are shown in Table 3.5. The ionic concentrations were based on the typical values found at a selected Merensky ore concentrator. Due to the nature of the gangue minerals in the ore it would be expected that these ions would be present in water being used at all concentrators of Merensky ores, although total amounts could vary. The water was prepared in batches of 40 L (see appendix) which was sufficient for 10 – 12 batch flotation tests depending on the conditions being evaluated.

Table 3.5: The concentration of ions present in the synthetic plant water used in all batch flotation tests.

Ion	Ca^{2+}	Mg^{2+}	Na^{+}	Cl^{-}	SO_4^{2-}	NO_3^{-}	NO_2^{-}	CO_3^{2-}	TDS
Concentration (ppm)	**80**	**70**	**153**	**287**	**240**	**176**	**-**	**17**	**1023**

3.3 Flotation reagents

The reagent suite selected for the batch flotation tests in the depressant evaluation phase of this study was developed after three different reagent suites were evaluated on the two ores (Wiese et al, 2005 a) and the optimum reagent suite was selected as that shown in table 3.6.

Table 3.6: Selected reagent suite

Reagent	Reagent ID	Dosage g/t
Collector	**SIBX** **Senkol 5 (DTP)**	**37.5** **37.5**
Frother	**DOW 200**	**40**
Depressant	**Guar** **CMC**	**100 (not corrected for** **100 active content)**

3.3.1 Collectors

In all batch flotation tests to evaluate the influence of depressant type and dosage on the flotation performance of the two ores, SIBX was used as the primary collector together with Senkol 5 (mainly butyl dithiophosphate), with a purity of 45%, as a secondary collector. Each reagent was added at a dosage of 37.5 g/t. In subsequent tests to evaluate collector performance at high depressant concentrations (500 g/t) the following xanthate collectors were used (without the addition of a secondary collector): sodium ethyl xanthate (SEX), sodium normal propyl xanthate (SNPX), sodium isobutyl xanthate (SIBX) and potassium amyl xanthate (PAX). The collector dosages used were 50, 100 and 150 g/t. 1% solutions of the xanthate collectors were prepared fresh each day using distilled water. All xanthate collectors used in this study have a purity of close to 90% and were supplied by Senmin

3.3.2 Depressants

All test conditions were performed using first guar and then CMC as gangue depressants. The guar was Stypres 504, a modified guar gum, manufactured by Chemquest. The CMC was Depramin 267 supplied by AKZO Nobel Functional Chemicals. 1% solutions of the depressants were prepared for use in the batch flotation tests by hydrating the required amount of dry depressant powder in distilled water for two hours using a magnetic stirrer to avoid the formation of lumps. Depressant dosages were calculated on an “as is” basis and were not corrected for active content. Depressants were prepared fresh every second day. The two depressants used in this study were characterised in the Polymer Characterisation Laboratory at UCT (Parolis, unpublished report, 2008). The characteristics of the two depressants are shown in Table 3.7.

Table 3.7: Characteristics of the two depressants used in this study.

Depressant	Molecular Weight g/mol	Purity (%)	D.S.
Depramin 267	**325 000**	**72**	**0.68**
Stypres 504	**230 000**	**89**	**-**

3.3.3 Frother

The frother used in all the batch flotation tests was DOW 200 supplied by Betachem. The frother dosage was kept constant at 40 g/t in all tests.

3.4 Standard batch flotation procedure

Various batch flotation procedures may be used to evaluate reagent / mineral interactions. The batch flotation procedure developed at The Centre for Minerals Research, University of Cape Town (CMR, UCT) provides an ideal system to investigate these interactions. The amount of NFG reporting to the concentrate can be separated from the amount of material entrained (Robertson, 2003; Harris et al., in press a,b) and the variations in froth stability can be taken into account. The system makes use of a modified Leeds flotation machine consisting of a Perspex flotation cell with a capacity of 3 litres and a top driven impeller.

Figure 3.1 shows a photograph of the UCT modified Leeds flotation machine. The cell has a capacity of 3 L and has been extensively used during the development of the standard UCT batch flotation procedure (Robertson, 2003; Bradshaw et al., 2005; Harris et al., in press a,b). The air flow to the cell is controlled by the use of Wilkerson ¼ inch 0-8 bar air regulator. Synthetic plant water is used throughout the comminution and flotation stages of the procedure in order to mimic conditions found on Merensky ore concentrators and to ensure the presence of sufficient divalent cations for effective adsorption of CMC onto talc (Khraisheh et al., 2004).

An Eriez stainless steel laboratory scale rod mill with a diameter of 200 mm was used to mill the ore. The mill was charged with twenty stainless steel rods of varying diameter in the following ratio: 6 x 25 mm, 8 x 20 mm and 6 x 16 mm. The 1 kg portions of the two prepared ore samples were milled at 66% solids in synthetic plant water to achieve a grind of 60% passing 75 µm. The grind of 60% passing 75 µm was chosen as it matches the primary rougher grind used by the operations processing this type of ore. As was expected, the two ore samples required different milling times to achieve this grind. Milling curves for the two ores are shown in Figure 3.2. In all tests conducted the collector was added to the mill prior to grinding.

Figure 3.1: The UCT modified Leeds 3 litre flotation machine.

The milled slurry was transferred to a modified 3 litre Leeds flotation cell. The volume in the cell was made up to produce 35% solids using synthetic plant water. The flotation cell was fitted with a variable speed drive and the pulp level was controlled manually by the addition of synthetic plant water. The sides of the flotation cell were perspex which facilitated pulp level control. The impeller speed was set at 1200 rpm.

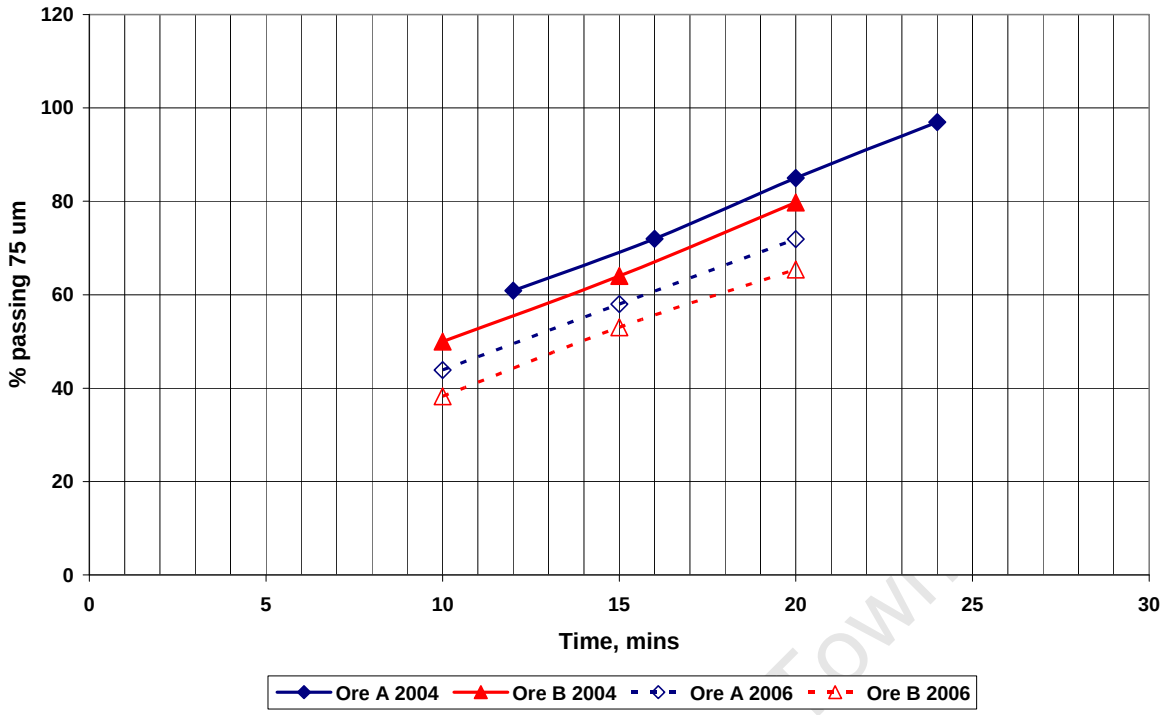

Figure 3.2: Milling curves for Ores A and B received in 2004 and 2006.

The required amount of depressant was added to the slurry and allowed to condition for 2 minutes. Frother was the final reagent to be added and this was conditioned for 1 minute. At this stage the air was turned on and the froth was allowed to develop. The air supply to the flotation cell was maintained at a flow rate of 7 L/min in all tests and the froth height was kept constant at 2 cm throughout the flotation test. Four concentrates were collected at 2, 6, 12 and 20 minutes of flotation time by scraping the froth into a collecting pan every 15 seconds. A feed sample was taken before and a tailings sample after each test. Water recoveries were measured for each test. Feeds, concentrates and tails were filtered, dried and weighed before analysis. All tests were conducted in duplicate. Table 3.8 shows a summary of the flotation procedure used in this study.

Table 3.8: Summary of the batch flotation procedure used in this study.

Action	Time (mins)
Milling	**As determined by milling curve**
Collector	**Added to mill prior to grinding**
Depressant	**0**
Frother	**2**
Air turned on and froth allowed to develop	**3**
C1	**5**
C2	**9**
C3	**15**
C4	**23**

3.5 Validation of chemical assays for sized concentrates

The concentrates from the quintuplicate batch flotation tests conducted in the presence of 300 g/t guar and CMC were assayed individually for copper, nickel and sulfur. The concentrates from the individual batch flotation were then combined and sized. After screening, the individual size fractions for each concentrate were assayed for copper, nickel and sulfur. Comparisons of the results obtained for the total concentrate assays versus the reconstituted sized assays are shown in Figure 3.2 for guar and Figure 3.3 for CMC. The results obtained for the reconstituted analysis of the size fractions compared well with the results obtained from the analysis if the individual concentrates.

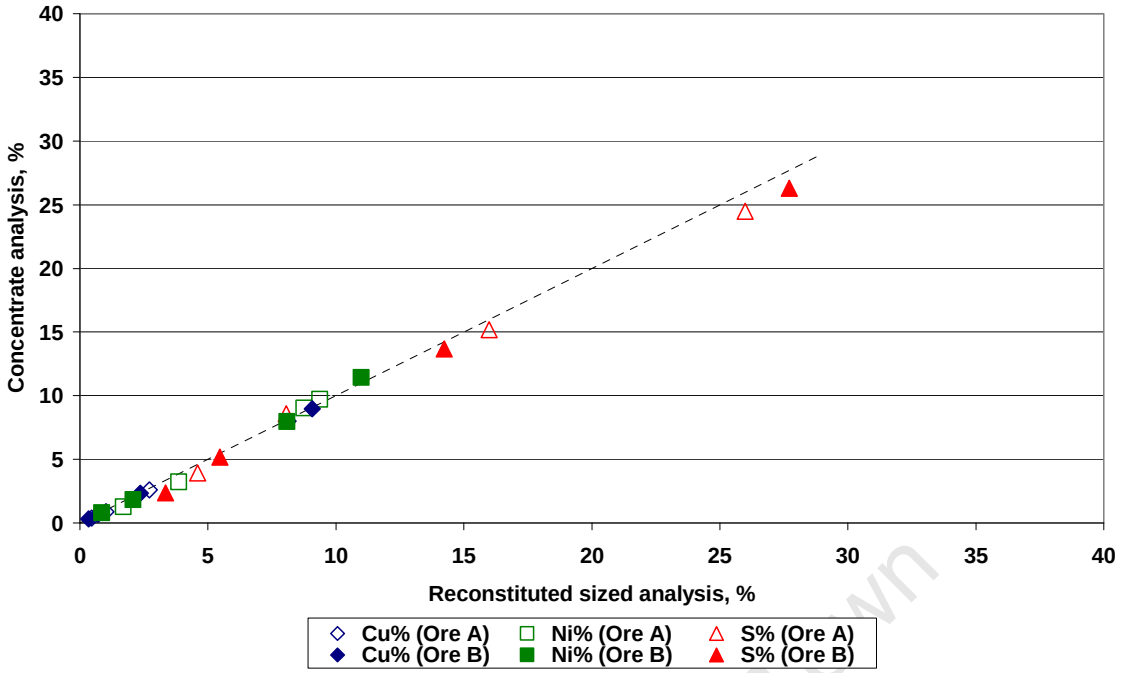

Figure 3.2: Concentrate analysis versus reconstituted sized analysis for tests conducted on both ores in the presence of guar.

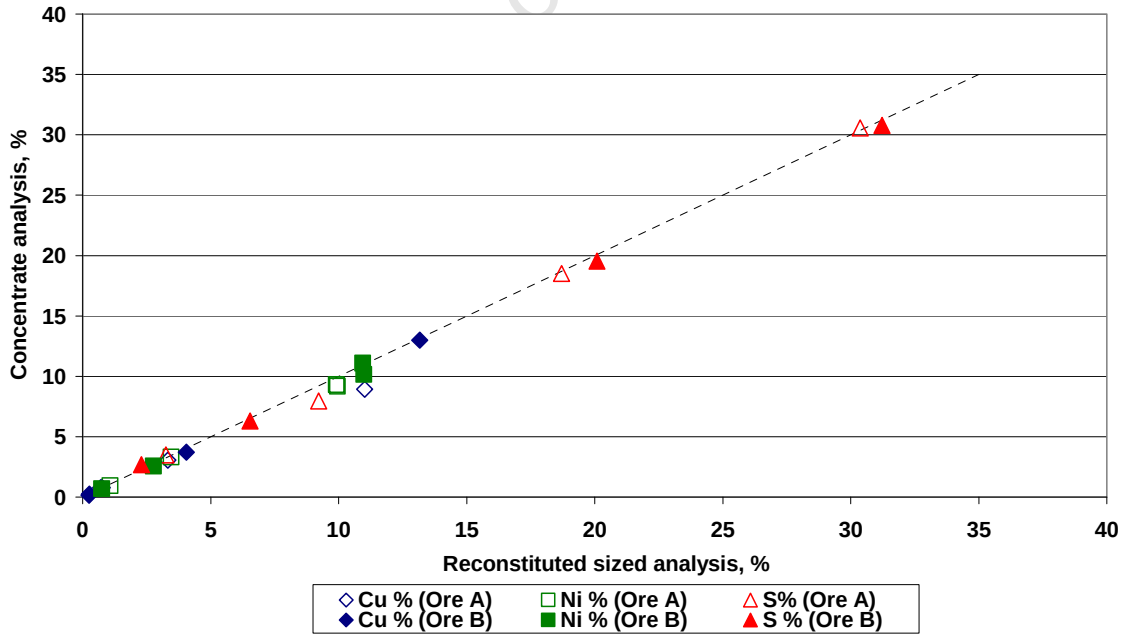

Figure 3.3: Concentrate analysis versus reconstituted sized analysis for tests conducted on both ores in the presence of CMC.

3.6 Determination of depressant in solution

An attempt was made to measure the concentration of the two depressants in solution at the end of the batch flotation tests using the du Bois method (Du Bois et al., 1956). Phenol, in the presence of sulphuric acid, can be used for the quantitative colorimetric determination of sugars.

Pulp was drawn from the batch flotation cell using a syringe. The pulp was centrifuged to remove solid material using a Hettich EBA 20 centrifuge and treated as follows:

- 1ml of test solution was dispensed into glass test tubes using an adjustable air-displacement pipette. One test tube was reserved for a blank to which 1ml of water was added
- 1 ml phenol (5% m/v) was added to each test tube
- 5 ml concentrated sulfuric acid was dispensed rapidly into the middle of the liquid surface in each test tube
- Test tubes were immediately placed on a vortex stirrer for 2 seconds
- Test tubes were allowed to reach room temperature in a fume cupboard (approximately 30 minutes)
- Test tubes were placed in a water bath at 25˚C for 30 minutes

The spectra of test solutions were measured in quartz cuvettes using an Ultrospec Ultra Violet spectrophotometer at 490 nm with respect to a blank. 490 nm is the wavelength determined for use in the measurement of hexoses (du Bois et al., 1956).

3.7 Determination of xanthate in solution

In order to determine xanthate in solution, a small amount of pulp was drawn from the batch flotation cell at the start of each batch flotation test, and once again after 20 minutes of flotation time. The pulp was centrifuged to remove solid material using a Hettich EBA 20 centrifuge.

The clear solutions were dispensed into precision quartz cuvettes with a 3.5 ml capacity and a light path of 10 mm. The solutions were read using an Ultrospec Ultra Violet spectrophotometer with respect to a blank at 270, 300 and 330 nm. The xanthate peak straddles the area between 270 and 330 nm, which are the values at which the peak minimum occurs. The peak height for xanthate occurs in the region of 300 nm.

3.8 Calculation of floating gangue

In order to calculate the amount of NFG reporting to the concentrate the following method was used: The sulfide content in each concentrate was obtained by assuming that the sulfide minerals chalcopyrite (34.64), pentlandite (32.89) and pyrrhotite (39.32) have an average sulfur content of 36.45%. From the sulfur analysis for each concentrate the sulfide content in grams was calculated which was subtracted from the total mass recovered in each concentrate to provide an amount of total gangue in grams. Using the entrainment function calculated by Robertson (2003), entrained gangue was calculated by multiplying water recovery by this function. The tracer method which was employed by Robertson (2003) used MnO_2 as an indicator for entrainment. The assumption is that MnO_2 is not floatable and its presence in the concentrate is thus an indication of entrainment. The amount obtained for entrained gangue was subtracted from total gangue to yield floating gangue in grams.

In the series of tests to evaluate the interaction of xanthate collectors with depressant action (Chapter 6) a new method to determine an entrainment function was evaluated, whereby batch flotation tests were conducted at high depressant dosages (500 g/t). The method assumes that all floatable gangue has been depressed at this dosage and that gangue reporting to the concentrate under these conditions would be present due to entrainment alone. Total gangue after the subtraction of the sulfide mass was graphically presented versus water recovered for all tests and the gradient of the line was determined to be equivalent to an entrainment function. As in the previous method, this entrainment function was used

to calculate floating gangue. The value obtained showed a good correlation to that determined by Robertson (2003).

3.9 Analysis of flotation performance

All feeds, concentrates and tailings samples were analysed in dry powder form. Copper and total nickel analysis of all samples was done using a Bruker S4 Explorer XRF Spectrophotometer. Sulfur analysis was carried out using a LECO DR 423 sulfur analyser.

It has been assumed that the analysis of the sulfide minerals recovered in the concentrates gives an indication of PGM recovery due to the strong association between the sulfides and PGM in these particular ores.

Results for mass recovered per unit of water recovered are an indication of depressant efficacy and illustrate mass reduction and decrease in froth stability as depressant dosage is increased. The results obtained for chemical assays are used to calculate grade and recovery in order to show the percentage of available mineral recovered as well as purity. Results for recovery are shown in relation to the amount of water recovered at a fixed froth height. Presenting the results in this manner eliminates the differences obtained in water recoveries under the various conditions evaluated. These curves complement conventional grade / recovery curves.

Mineral recoveries are reported as copper, nickel and sulfur and not as chalcopyrite, pentlandite and pyrrhotite. Copper recoveries in this work are equivalent to chalcopyrite recoveries, but nickel recoveries are not quite equivalent to pentlandite recoveries as assays were conducted for total nickel and some nickel is associated with the gangue present in these ores. The presence of pyrite in the ores prevents the accurate assessment of pyrrhotite recovery from the balance of the sulfur assay.

4 The effect of depressant type and dosage on the flotation behaviour of gangue and sulfide minerals in Merensky ores

The aim of this work was to evaluate the effect of guar and CMC addition at varying dosages on the flotation behaviour of gangue and sulfide minerals in the two Merensky ores selected for this study. The batch flotation technique developed at UCT was used to conduct this study. The detailed procedure for batch flotation tests is contained in Chapter 3. This chapter is divided into three sections. Section 4.1 compares the baseline performance of the two ores. In Section 4.2 the effect of depressant type and dosage on the flotation of two ores are evaluated by comparing recovery and grade of valuables, and the recovery of floating gangue. Section 4.3 describes the size by size analysis of the concentrates recovered from the two ores. The complete set of flotation results is given in the appendix.

4.1 Baseline comparison of Merensky Ores A and B

The two ores chosen for evaluation were characterised in order to set a baseline to evaluate the effect of depressant and collector addition on the flotation performance of the ores. Table 3.2 shows modal analyses determined by QEMSCAN for the two ores. It can be seen that Ore B contained significantly more orthopyroxene than Ore A, and this may cause differences in the flotation behaviour of the ores as this suggests that Ore B is more altered than Ore A. Table 3.2 also showed that Ore B had a higher sulfide mineral content than Ore A.

4.1.1 Test conditions

Two series of batch flotation tests were conducted on the two ores. The first series was conducted without the addition of a depressant in order to determine the amount of NFG reporting to the concentrate under these conditions, in order to effectively evaluate the influence of depressant type and dosage on the flotation performance of the two ores. The tests were conducted with collector and frother addition only. The collectors used were SIBX and Senkol 5 at dosages of 37.5 g/t each. The second

series of tests was conducted without the addition of collector or depressant in order to establish the floatability of the sulfide minerals in the absence of a collector.

4.1.2 Results

The amount of floating gangue versus water recovered for tests conducted in the absence of a depressant are shown in Figure 4.1 for both ores, and illustrate that almost double the amount of floating gangue was recovered from Ore B than from Ore A. This correlates with the modal analysis of the two ores which indicated the higher pyroxene content of Ore B. Pyroxene should not be floatable in its own right, but QEMSCAN analysis of the ore indicated that talc, although present in the ore in small quantities has a significant effect on gangue floatability due to its association with pyroxene, either as intergrowths or its presence along pyroxene grain boundaries (Becker et al., 2006). As shown in Figure 4.1, 4.2% (42 g) floating gangue was recovered from Ore A which was more than the amount of talc (3.5%) present in the ore. The same applies for Ore B, which yielded a floating gangue recovery of 8% (80 g), and contained 5% talc. For the purpose of this study the following minerals have been classified as floatable gangue: orthopyroxene, clinopyroxene, olivine and talc. Chromite with altered talc-like layers may also be classified as floatable gangue. This is, however, more problematic in UG2 ore than Merensky ore.

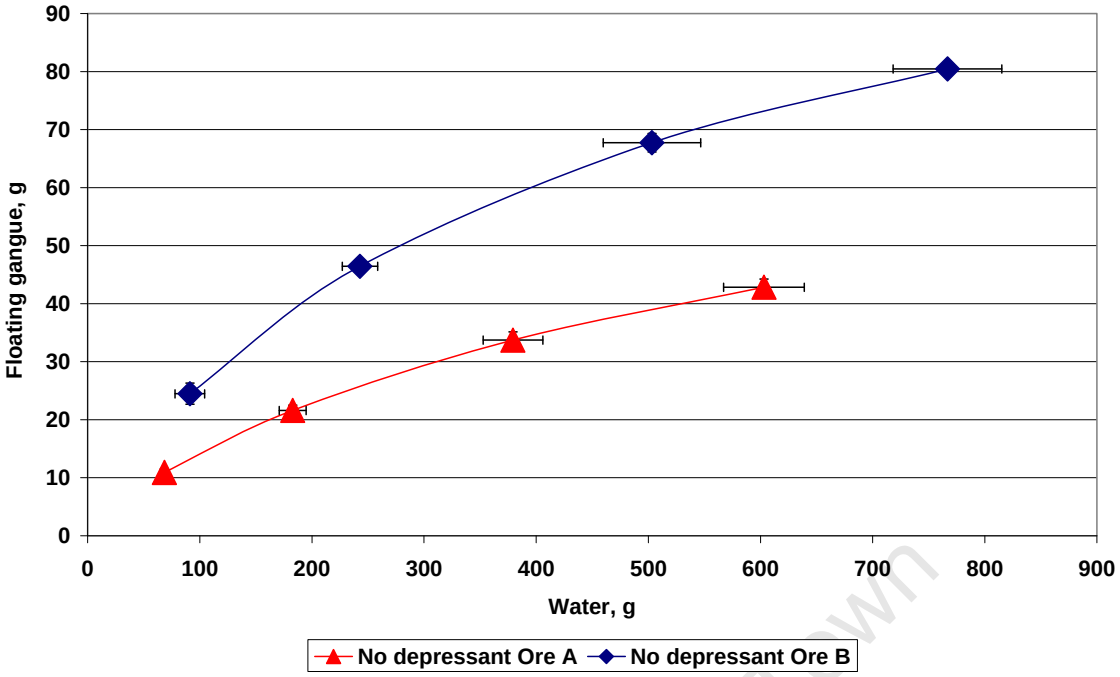

Figure 4.1: Floating gangue versus water recovered for both ores in the absence of a depressant. Error bars represent standard deviation between duplicate tests.

Figure 4.2 shows copper, nickel and sulfur grade versus recovery from tests conducted in the absence of a depressant on the two ores. Ore B contained more sulfide minerals than Ore A, as seen from the modal analysis data (Chapter 3), thus as expected, higher recoveries of copper and nickel were obtained from this ore. The low grades obtained from these tests indicate that final gangue recovery to the concentrates is in the region of 90%. The grades obtained from Ore B were lower than those obtained from Ore A due to the presence of more NFG in the concentrates which diluted the grade (Figure 4.1). The large differences obtained in sulfur grade from the two ores suggest that the behaviour of the iron sulfides between the two ores may be different.

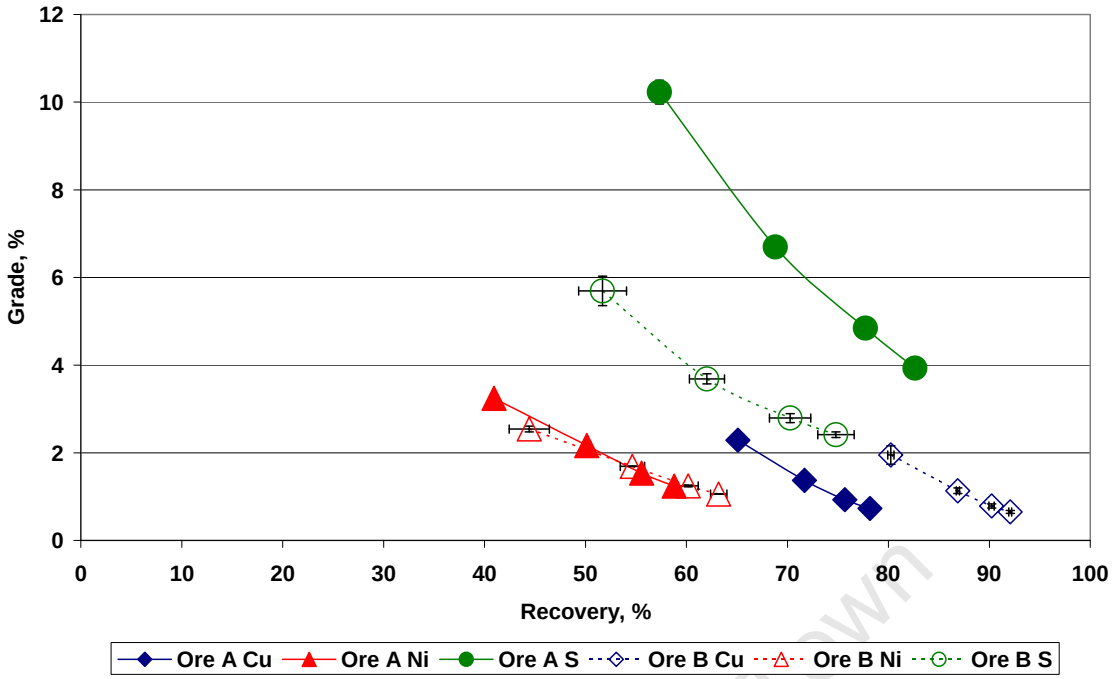

Figure 4.2: Copper, nickel and sulfur grade versus recovery for the two ores in the absence of a depressant. Error bars represent standard deviation between duplicate tests.

The results for copper, nickel and sulfur recoveries for the two ores in the absence of both collector and depressant are shown in Figure 4.3. As copper is present as chalcopyrite, which becomes hydrophobic after limited oxidation at Eh above 200 mv after the formation of polysulfides (Zachwieja et al., 1989), the recovery of copper from both ores was relatively unaffected by the absence of a collector with recoveries in the region of 80% being obtained from both ores. The absence of a collector was detrimental to the recovery of both nickel and sulfur from both ores, with recoveries being in the region of 30% of what would be expected in the presence of a collector. Lower grades were obtained from Ore B which is indicative of the higher mass recoveries obtained, due to higher NFG (pyroxene) content, from this ore. These tests were conducted without the addition of depressant and subsequent tests are expected to elucidate the influence of depressant type and concentration on copper recovery from the two ores.

The batch flotation tests conducted without collector addition show that copper minerals are naturally floatable compared to nickel sulfide minerals which are slightly floatable and iron sulfide minerals which are much less floatable. This is evident from

sulfur analyses, since pyrrhotite is the major sulfide mineral and only about 20% of the sulfur is contained in chalcopyrite.

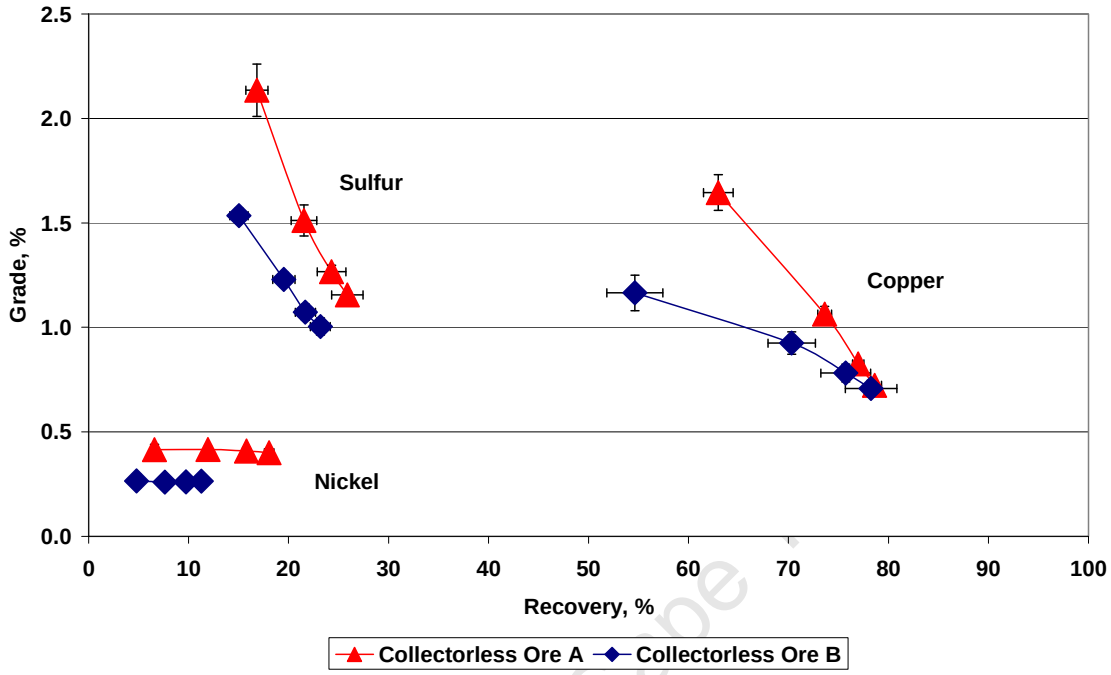

Figure 4.3: Grade versus recovery for copper, nickel and sulfur for both ores in the absence of a collector. Error bars represent standard deviation between duplicate tests.

The results for floating gangue versus water recovered for tests in the absence of a collector are shown in Figure 4.4 for both ores. Compared to tests conducted in the absence of a depressant (Figure 4.1) there was a significant reduction in froth stability as indicated by water recovery for Ore B as well as a slight reduction in floating gangue recovery. For Ore A there was a slight enhancement in the recovery of floating gangue at a similar froth stability compared to the tests conducted in the absence of a depressant.

In all batch flotation tests to evaluate the effect of depressant type and dosage on the flotation performance of the two ores, xanthate was used as the primary collector together with Senkol 5 (mainly butyl DTP), with a purity of 45%, as a secondary collector.

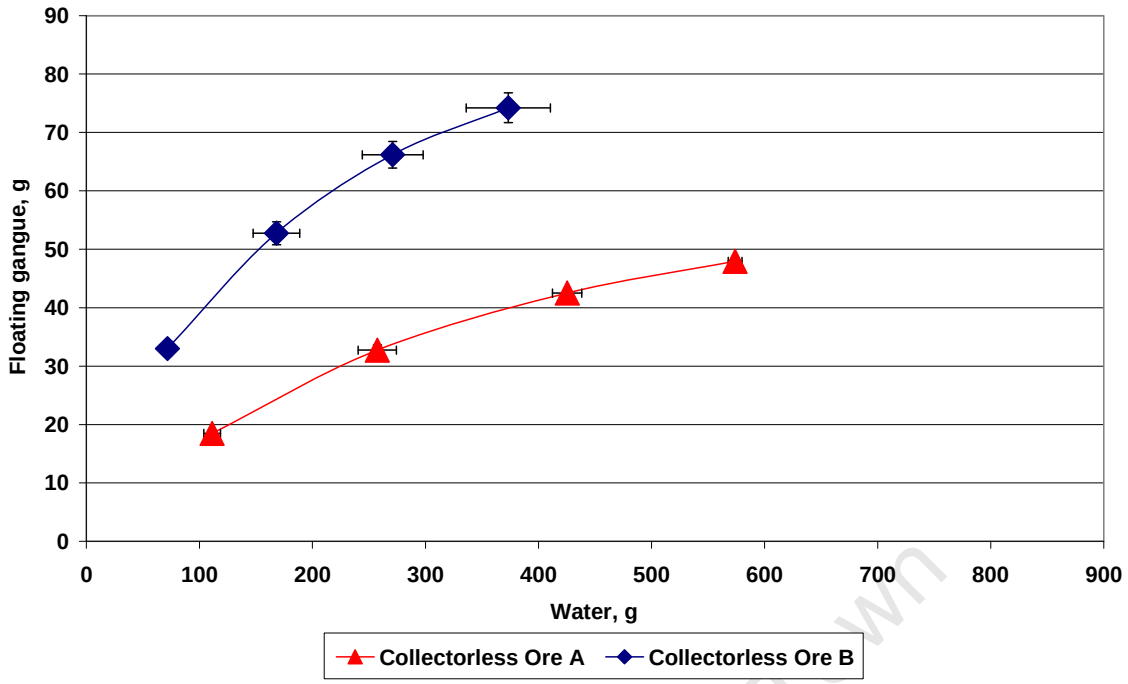

Figure 4.4: Floating gangue versus water recovered for both ores in the absence of a collector. Error bars represent standard deviation between duplicate tests.

The two collectors were chosen for the testwork after initial tests using a series of different reagent suites to evaluate both ores (Wiese et al., 2005a). The dosages used in this series of tests were 37.5 g/t each of SIBX and Senkol 5. At the same time tests were conducted on both ores using SIBX only as the collector at equivalent molar dosage as the SIBX / DTP combination. Upon analysis of the data obtained from these tests as shown in Figures 4.5 for Ore A and 4.6 for Ore B, it was decided to use xanthate alone as a collector in tests to evaluate the effect of xanthate chain length as there was no enhancement of sulfide mineral recovery obtained from these tests in comparison to tests in which xanthate was used as the only collector. The use of the DTP collector led to an increase in frothability which in turn yielded total higher mass recoveries, but no change in flotation performance.

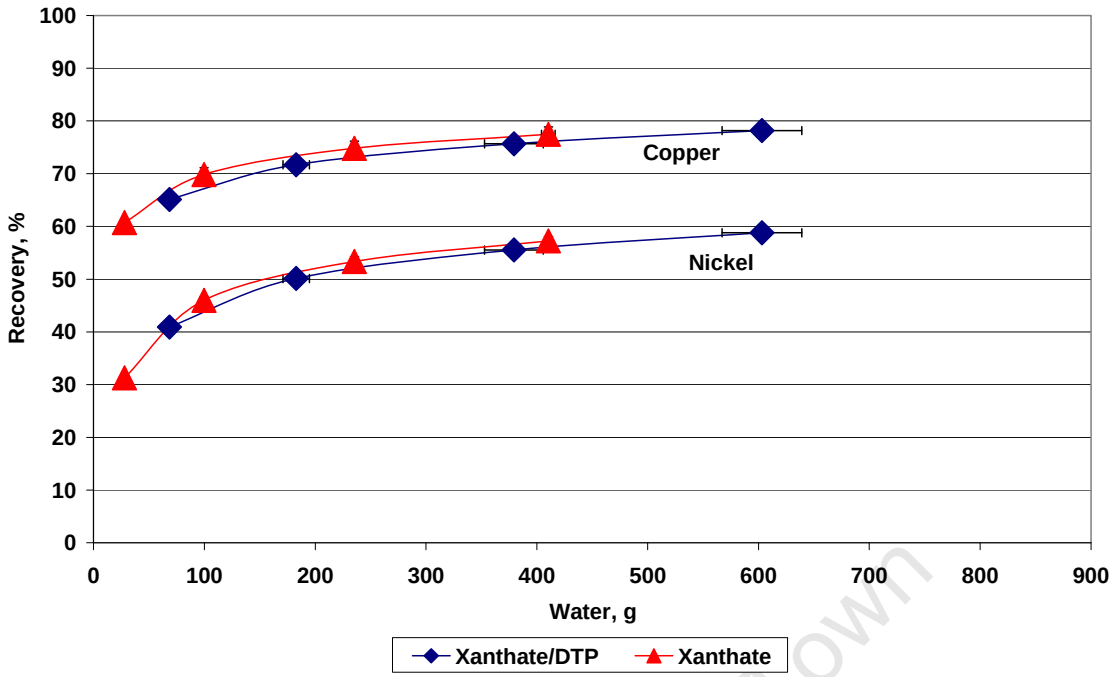

Figure 4.5: Copper and nickel recoveries for Ore A using xanthate alone and a xanthate/DTP mixture. Error bars represent standard deviation between duplicate tests.

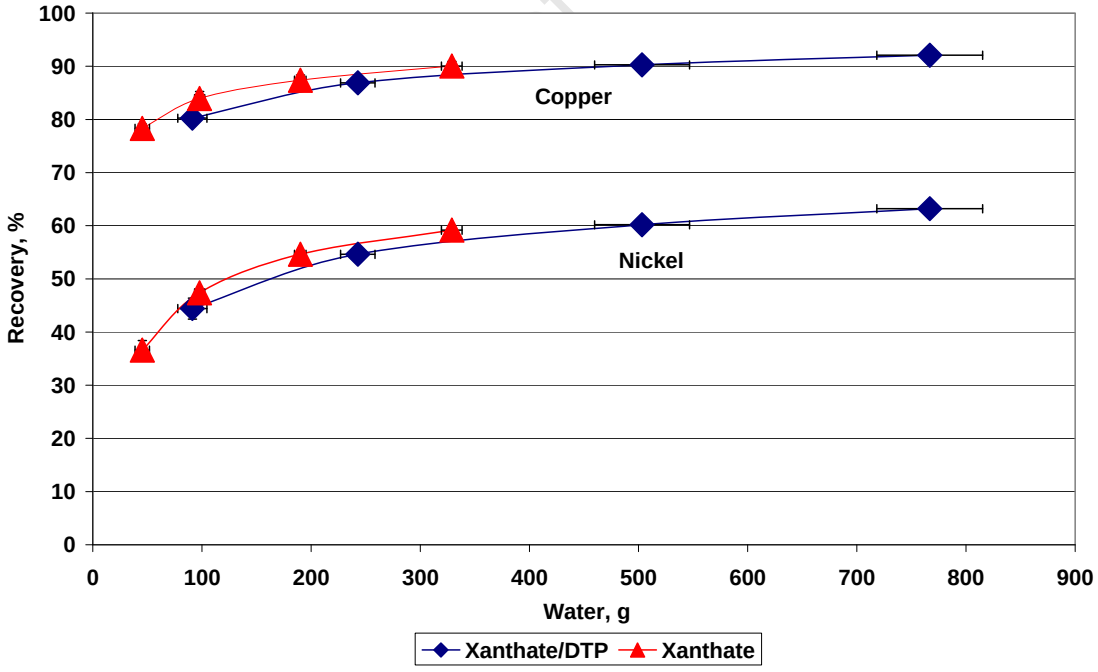

Figure 4.6: Copper and nickel recoveries for Ore B using xanthate alone and a xanthate/DTP mixture. Error bars represent standard deviation between duplicate tests.

4.2 The effect of depressant type and dosage

4.2.1 Test conditions

The conditions used to evaluate the effect of guar and CMC at varying dosages on the flotation behaviour of gangue and sulphide minerals in the two Merensky ores are shown in Table 4.1.

Table 4.1: Conditions for tests to evaluate the effect of guar and CMC at varying dosages on Merensky ores A and B.

Ore types	**Merensky Ores A and B**
Depressant type and dosage	**Guar – Stypres 504** **CMC – Depramin 267** **100, 200 and 300 g/t**
Collector type and dosage	**SIBX 37.5 g/t** **Senkol 5 (DTP) 37.5 g/t**

4.2.2 Results

A summary of results obtained for all conditions used to evaluate the effect of depressant type and dosage on Ores A and B are shown in Table 4.2. The table shows final grades and recoveries which are averages from duplicate tests.

Table 4.2 indicates that for both ores the amount of mass and water recovered from the batch flotation tests decreased as depressant concentration was increased. The highest mass and water recoveries were obtained from tests conducted without the addition of depressant (see section 4.1 – tests conducted without depressant). Greater mass and water recovery was obtained from Ore B than from Ore A. This correlates with the data obtained from the modal analysis of the two ores which indicated that Ore B contained almost double the amount of NFG compared to Ore A.

Table 4.2: Summary of results obtained for all tests evaluating Ores A and B.

Condition	Mass (g)	Water (g)	Cu rec (%)	Cu grade (%)	Ni rec (%)	Ni grade (%)	S rec (%)	S grade (%)	Float gangue (g)	Entrained gangue (g)
Ore A										
CMC 100 g/t	45.8	528	74.3	3.90	56.2	5.48	80.2	17.6	24.3	14.8
CMC 200 g/t	29.1	499	72.0	4.77	52.8	6.16	76.0	19.8	8.9	14.0
CMC 300 g/t	17.4	402	66.3	8.05	51.0	8.38	66.3	26.5	0.6	11.3
Guar 100 g/t	33.8	487	73.2	4.51	53.9	6.43	74.8	18.7	14.1	13.7
Guar 200 g/t	23.0	475	70.0	5.60	51.8	7.48	68.8	20.9	3.9	13.4
Guar 300 g/t	16.7	446	66.3	6.02	47.3	5.35	59.6	20.0	0.0	12.5
Ore B										
CMC 100 g/t	81.6	735	90.8	3.87	58.0	4.70	76.7	11.3	53.8	20.7
CMC 200 g/t	33.7	516	86.0	8.49	54.6	9.60	68.0	23.5	12.4	14.5
CMC 300 g/t	18.8	479	86.6	11.37	53.7	9.37	63.8	27.0	0.0	13.5
Guar 100 g/t	60.8	615	90.6	5.07	56.4	6.38	69.6	14.6	36.7	17.3
Guar 200 g/t	33.7	602	87.6	7.39	57.2	9.68	66.1	20.7	10.2	16.9
Guar 300 g/t	24.1	537	84.1	8.42	53.4	8.87	59.6	21.1	2.3	15.1

The recovery of valuables decreased as depressant concentration was increased, with guar having a greater effect than CMC. Due to the fact that mass recovery decreased, sulfide mineral grades increased as depressant concentration was increased. The recovery of floating gangue was reduced to almost zero for both ores at a depressant dosage of 300 g/t, the exception being Ore B in the presence of guar. More entrained gangue was recovered from Ore B than from Ore A, which correlates with the higher amounts of water recovered from tests on Ore B, as entrainment is directly related to the amount of water recovered.

Figure 4.7 illustrates the impact of increasing depressant dosage on the amount of mass recovered from each test and the froth stability, as indicated by water recovery, for all conditions evaluated. Froth stability decreased as depressant concentration was increased for both guar and CMC. Higher froth stabilities were obtained from tests on Ore B than from Ore A. At lower depressant dosages less mass was recovered from tests in which guar was used as the depressant, and is indicative of guar being a stronger depressant than CMC. At higher dosages their depressing ability was found to be similar, as similar amounts of mass were recovered.

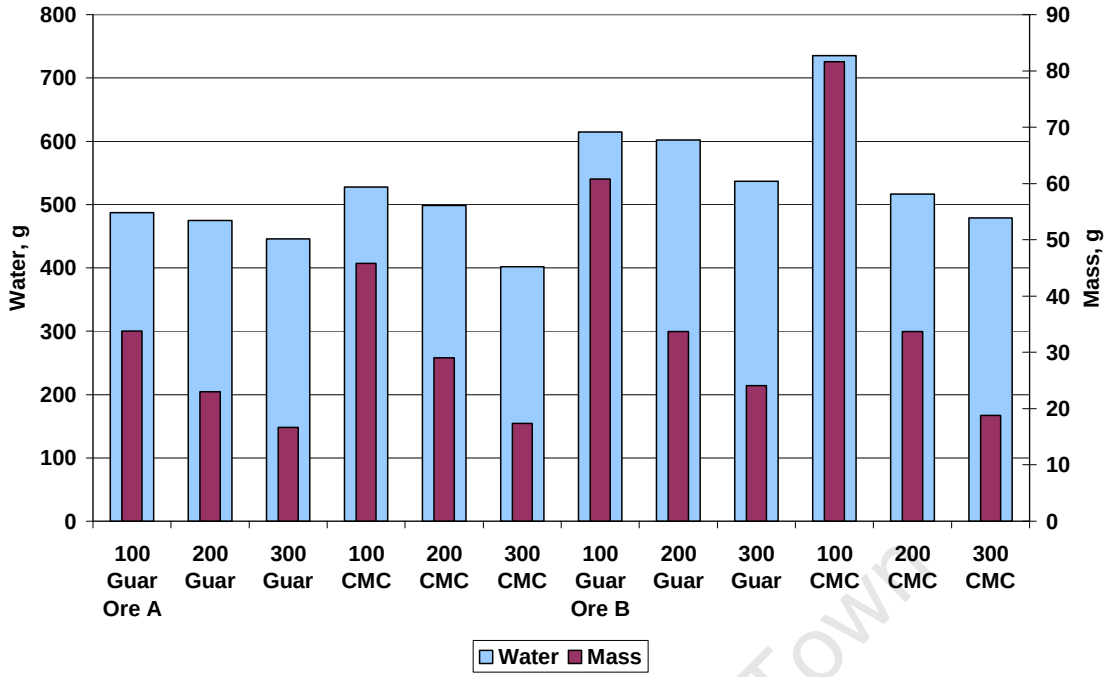

Figure 4.7: Final mass and water recovered from all tests on Ores A and B.

The amount of floating gangue recovered, as determined using the entrainability factor determined by Robertson (2003), as a function of the water recovered for the various conditions is shown in Figures 4.8 for Ore A and 4.9 for Ore B. The figures illustrate that there was a significant reduction in the amount of NFG recovered as the depressant dosage was increased and at a depressant addition of 300 g/t for both ores, the amount of NFG had been reduced to almost zero. At all lower dosages of 100 and 200 g/t the guar depressant produced a greater depression of the NFG than the CMC depressant.

However, when depressant dosage was increased to 300 g/t the depressing behaviour was the same since almost all NFG had been depressed. The greater depressing action of the guar was observed for both ores at dosages of 100 and 200 g/t. Although Ore B contained almost twice the amount of NFG than Ore A, depressant addition, at a dosage of 300 g/t appeared to be sufficient to depress almost all floating gangue present in the ore.

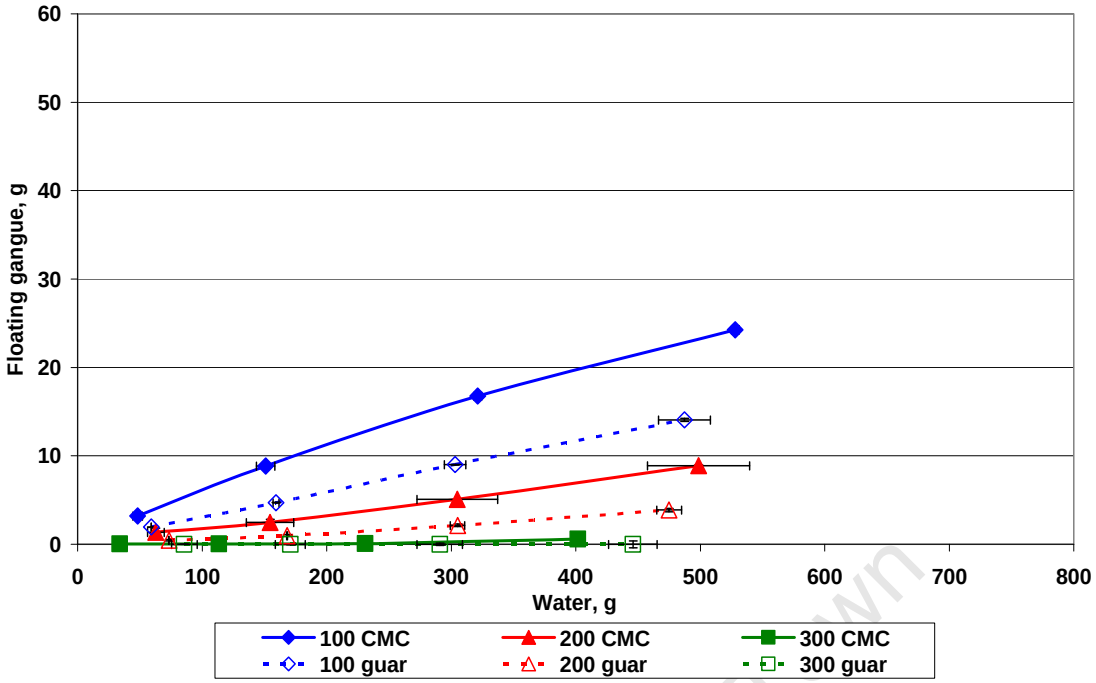

Figure 4.8: Floating gangue vs water recovered for Ore A using guar and CMC dosages of 100, 200 and 300 g/t. Error bars represent standard deviation between duplicate tests.

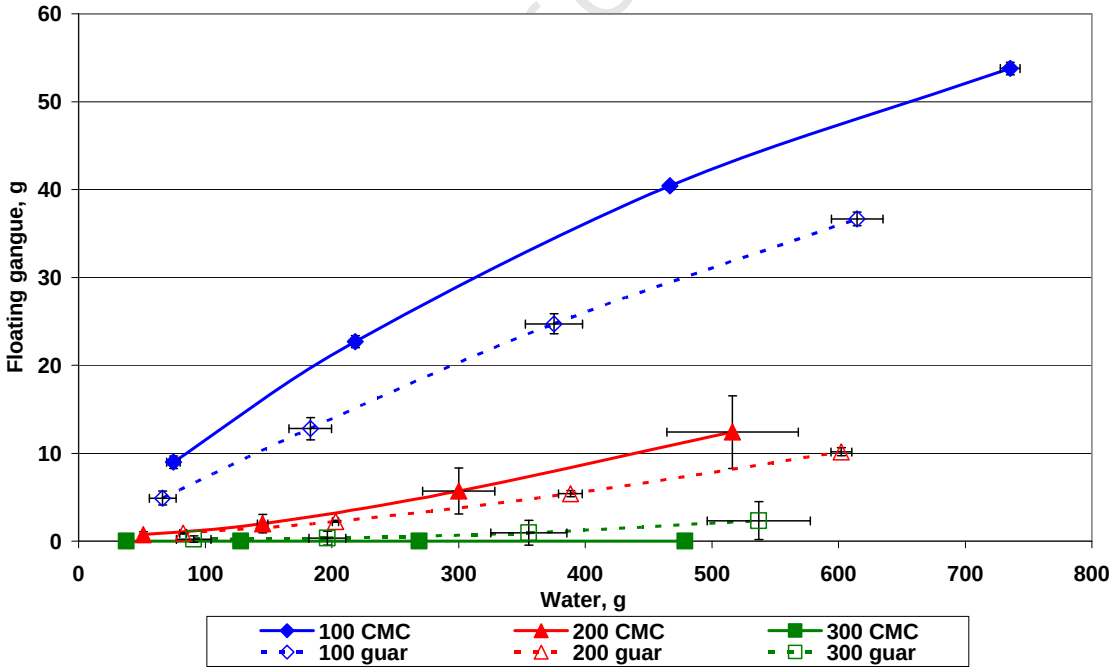

Figure 4.9: Floating gangue vs water recovered for Ore B using guar and CMC dosages of 100, 200 and 300 g/t. Error bars represent standard deviation between duplicate tests.

In order to compare the performance of the two depressants, the amount of NFG recovered at similar froth stabilities, as determined by water recovery, was compared for the two ores at all depressant dosages. This is illustrated in Figure 4.10 where the amount in grams of NFG reporting to the concentrate has been estimated at a water recovery of 400 g, as a function of the dosage of depressant for both ores. This figure shows the greater depressing ability of the guar depressant at equivalent CMC dosages for lower dosages. At depressant dosages of 300 g/t the depressing behaviour of guar and CMC was almost the same for both ores with approximately 2 g NFG obtained from tests on Ore B in the presence of guar. The amount of entrained gangue is included in the figure and, since the recoveries of floating gangue are compared at a fixed water recovery, remains constant. However, it is shown that, at low or zero depressant concentrations the amount of floating gangue greatly exceeds the amount of gangue reporting to the concentrate by entrainment.

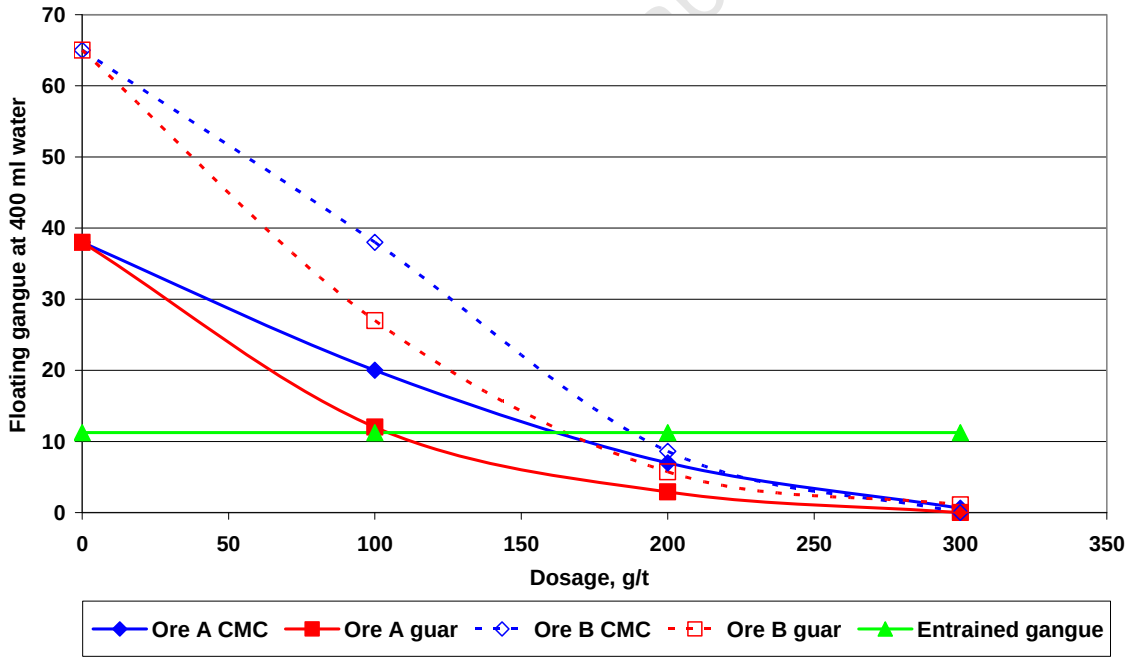

Figure 4.10: Estimated floating gangue and entrained gangue (g) at a water recovery of 400 g for Ores A and B at guar and CMC dosages of 0, 100, 200 and 300 g/t.

When using a depressant, the influence that this reagent has on the recovery of the valuable minerals needs to be considered. It has been shown (Bradshaw et al., 2005) that the presentation of the response of the sulfide minerals as simple grade-recovery graphs does not represent the best method of showing recoveries as it can

mask the effects that froth stability changes have on the system. Since it has been shown that depressants have a major influence on froth stability it is important that the froth stability be taken into account when assessing the effect of depressants on sulfide recovery. The overall effective recovery for the type of batch flotation cell used for this study is limited by the stability of the froth. Hence the use of the recovery as a function of water recovered (froth stability) gives a better indication of the changes in flotation response of any sulfide mineral (Bradshaw et al., 2004; Harris et al, in press a,b). These curves do not replace classic grade-recovery curves which have also been included in this thesis.

All studies on the role of the various reagents in the flotation process thus far have shown that there is very little that affects the optimum recovery of copper bearing minerals and, even in the absence of a collector, recoveries of greater than 80% can be obtained, demonstrating the natural floatability of these minerals. As expected the use of high dosages of both depressants had little effect on the copper recovery from both ores.

Figures 4.11 and 4.12 show copper and nickel grade vs recovery for Ores A and B respectively for all conditions evaluated. The figures illustrate that as depressant dosage was increased mineral grades increased due to the reduction in NFG reporting to the concentrate. The slight reduction in mineral recovery at higher depressant concentrations may be due to the reduction in mass recovery. The fact that Ore B yielded higher copper recoveries than Ore A is once again evident from these figures. The highest grades were obtained when using CMC at a dosage of 300 g/t. This is due to the lower water recoveries obtained and therefore less entrainment. This may also be due to the cleaning of fines from the mineral surfaces by CMC at this higher dosage.

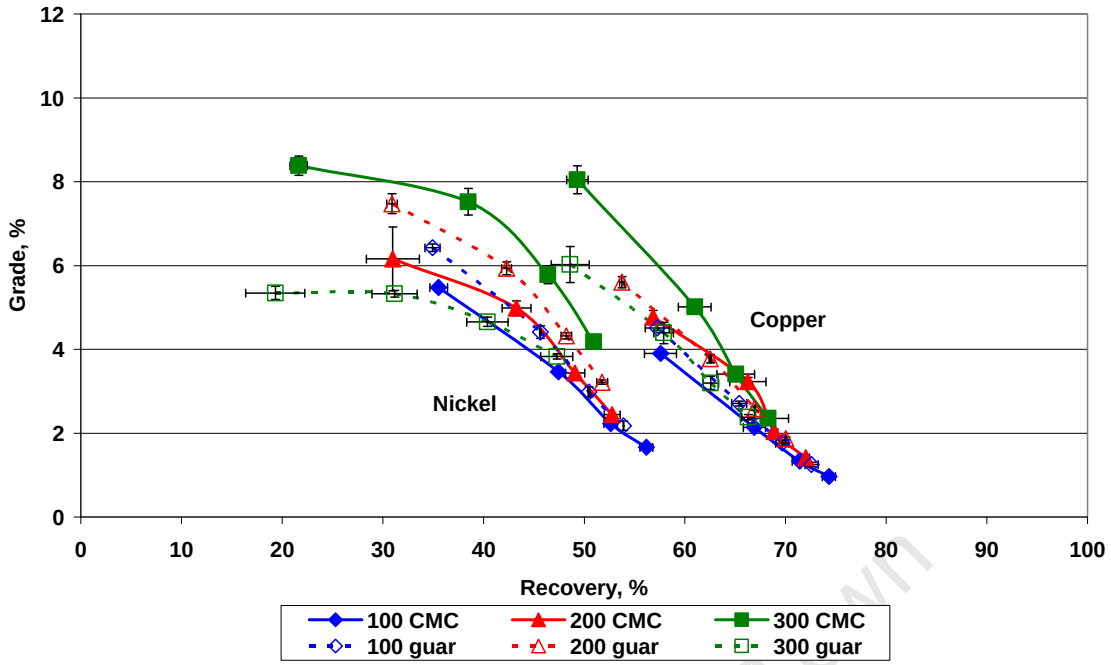

Figure 4.11: Copper and nickel grade vs recovery for Ore A using guar and CMC at dosages of 100, 200 and 300 g/t. Error bars represent standard deviation between duplicate tests.

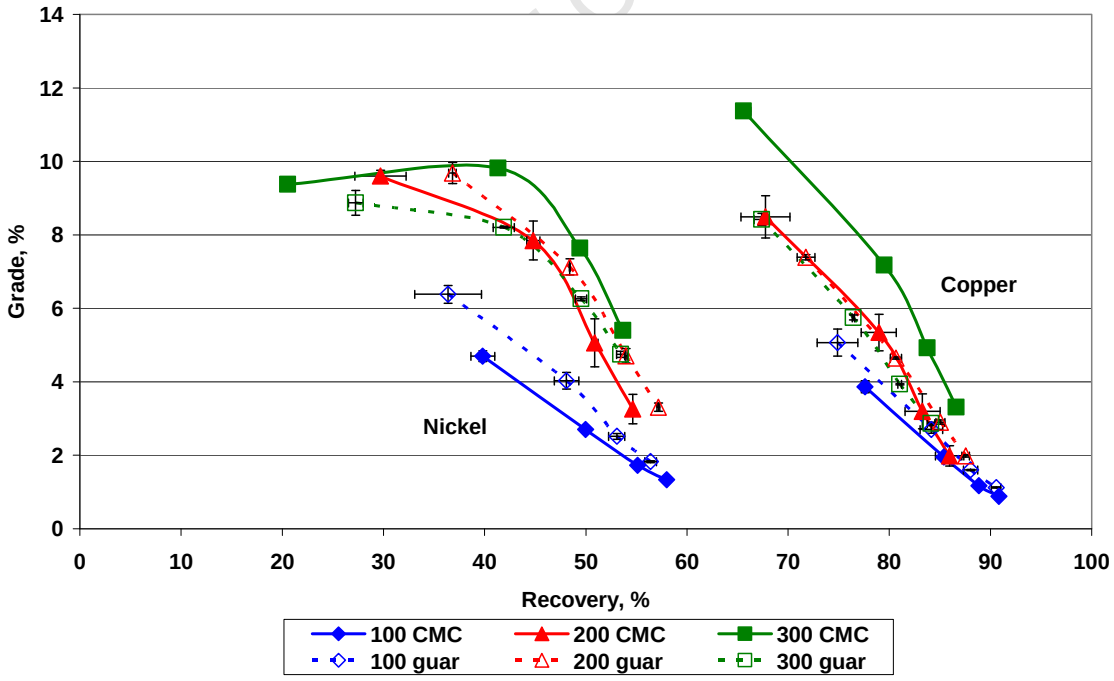

Figure 4.12: Copper and nickel grade vs recovery for Ore B using guar and CMC at dosages of 100, 200 and 300 g/t. Error bars represent standard deviation between duplicate tests.

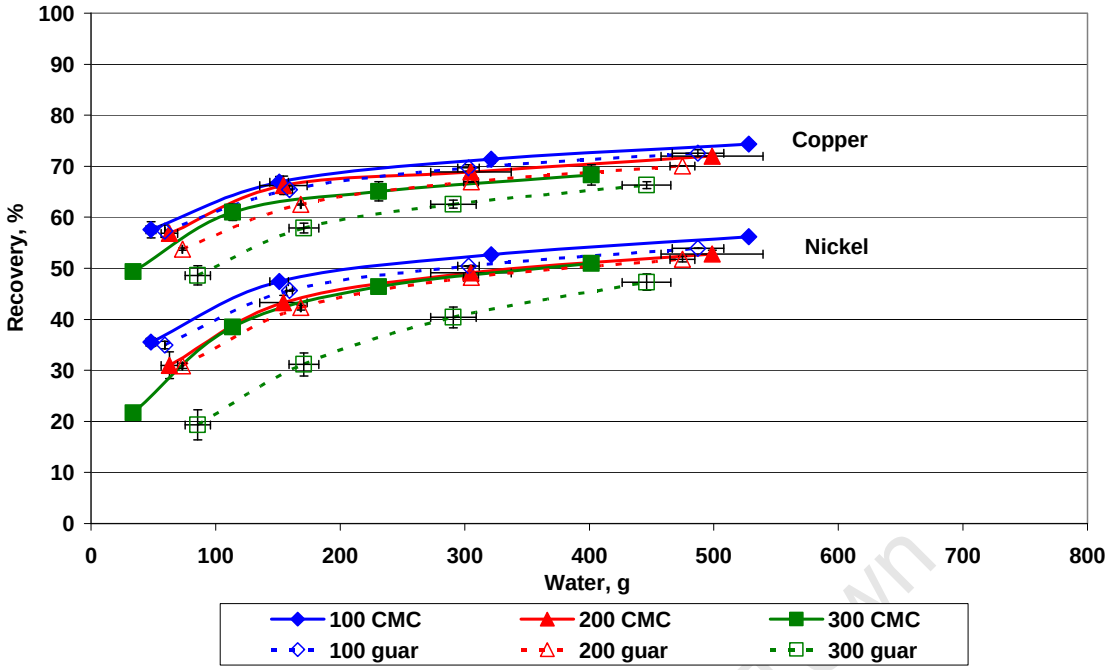

Figure 4.13: Copper and nickel recovery vs water recovered for Ore A using guar and CMC at dosages of 100, 200 and 300 g/t. Error bars represent standard deviation between duplicate tests.

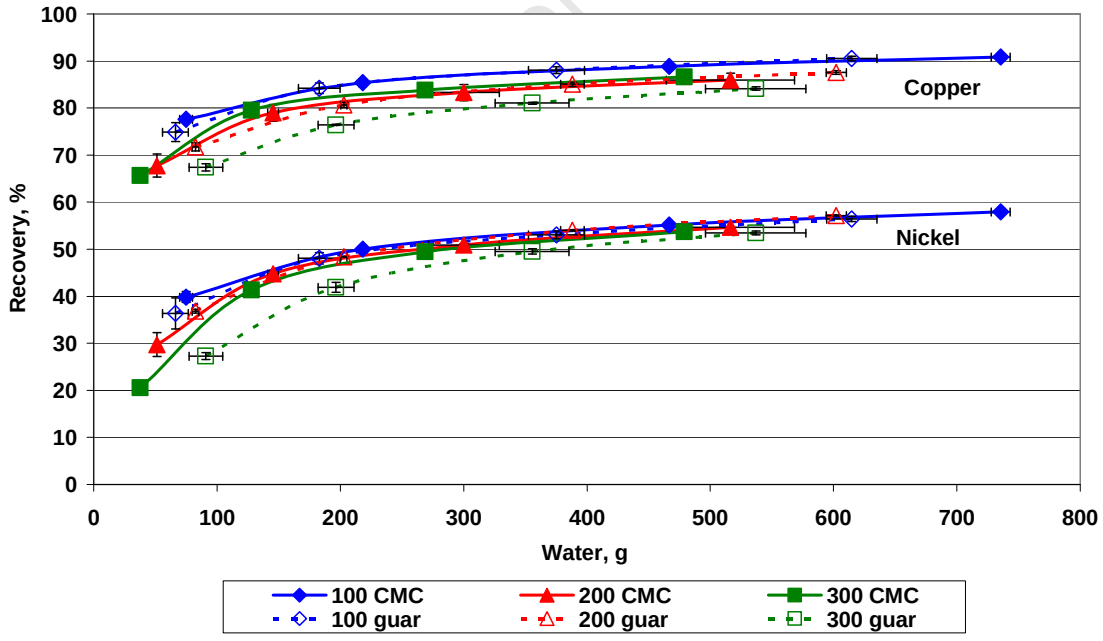

Figure 4.14: Copper and nickel recovery vs water recovered for Ore B using guar and CMC at dosages of 100, 200 and 300 g/t. Error bars represent standard deviation between duplicate tests.

Figures 4.13 and 4.14 show copper and nickel recovery versus water recovered for Ores A and B respectively. For Ore A at the highest depressant dosage (300g/t), it is evident that mineral recoveries were more affected than for Ore B, particularly the effective rate of nickel recovery which was slightly reduced in the presence of the guar depressant but not in the presence of the CMC depressant. This is probably due to the presence of composite particles. The effective rate of nickel bearing mineral recovery was reduced below the froth limiting condition. This was particularly apparent in the initial stages of the flotation test. CMC, which has been shown to be the weaker depressant as far as NFG floatability is concerned, had a minimal influence on the effective recovery rate of liberated copper and nickel bearing particles. These results suggest that the collector adsorption on the nickel minerals, for the collector dosage and combination used, may not form a uniform homogeneous layer on the surface allowing adsorption to take place at these high dosages for the stronger guar depressant. The results obtained for Ore B indicate that the effective rate of nickel bearing mineral recovery was reduced, but not to the same extent as was found with Ore A.

Figures 4.15 and 4.16 show sulfur grade vs sulfur recovery for Ores A and B respectively for all conditions evaluated. As already noted for copper and nickel grade, sulfur grades increased due to the reduction in mass recovery obtained as depressant concentration was increased.

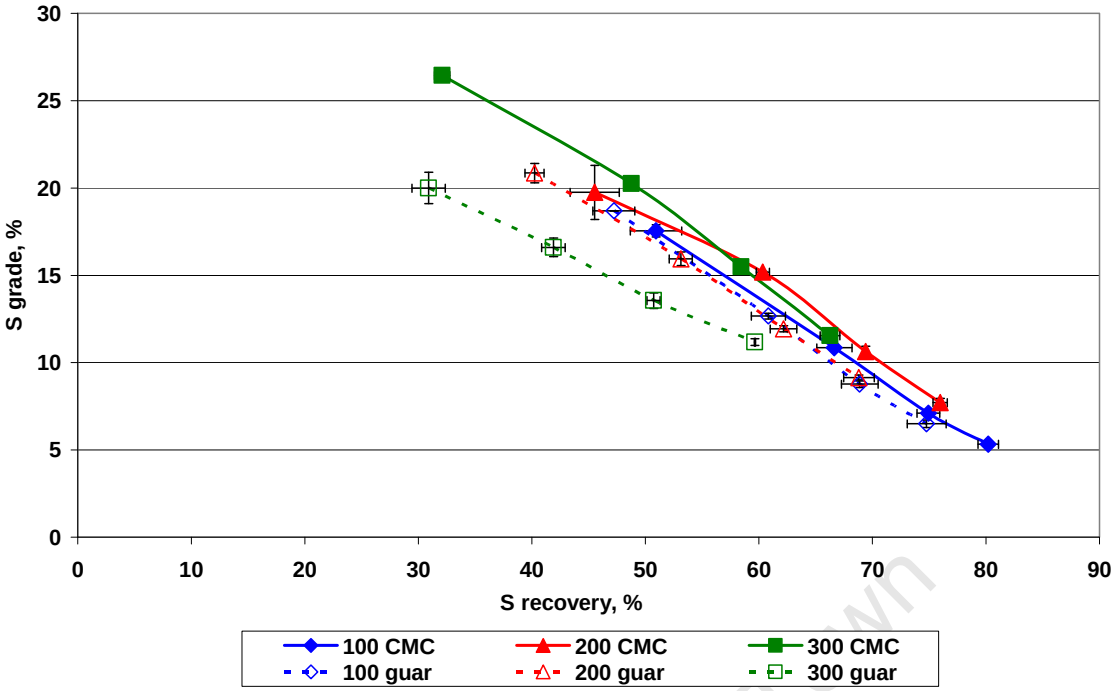

Figure 4.15: Sulfur grade vs sulfur recovery for Ore A using guar and CMC at dosages of 100, 200 and 300 g/t. Error bars represent standard deviation between duplicate tests.

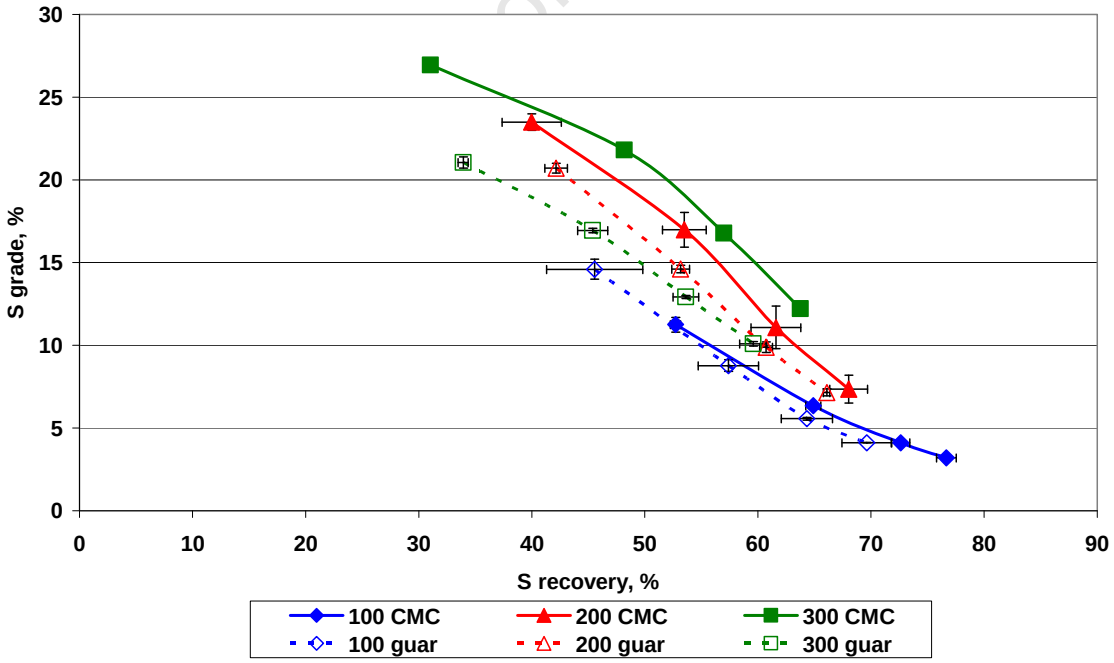

Figure 4.16: Sulfur grade vs sulfur recovery for Ore B using guar and CMC at dosages of 100, 200 and 300 g/t. Error bars represent standard deviation between duplicate tests.

The results for sulfur recovery versus water recovered for all tests evaluating depressant type and dosage using Ore A are shown in Figure 4.17, and the results obtained for Ore B are shown in Figure 4.18. The data illustrate that for both ores, the recovery of sulphur was reduced as depressant concentration was increased from 100 g/t to 300 g/t with guar having a greater depressing effect than CMC.

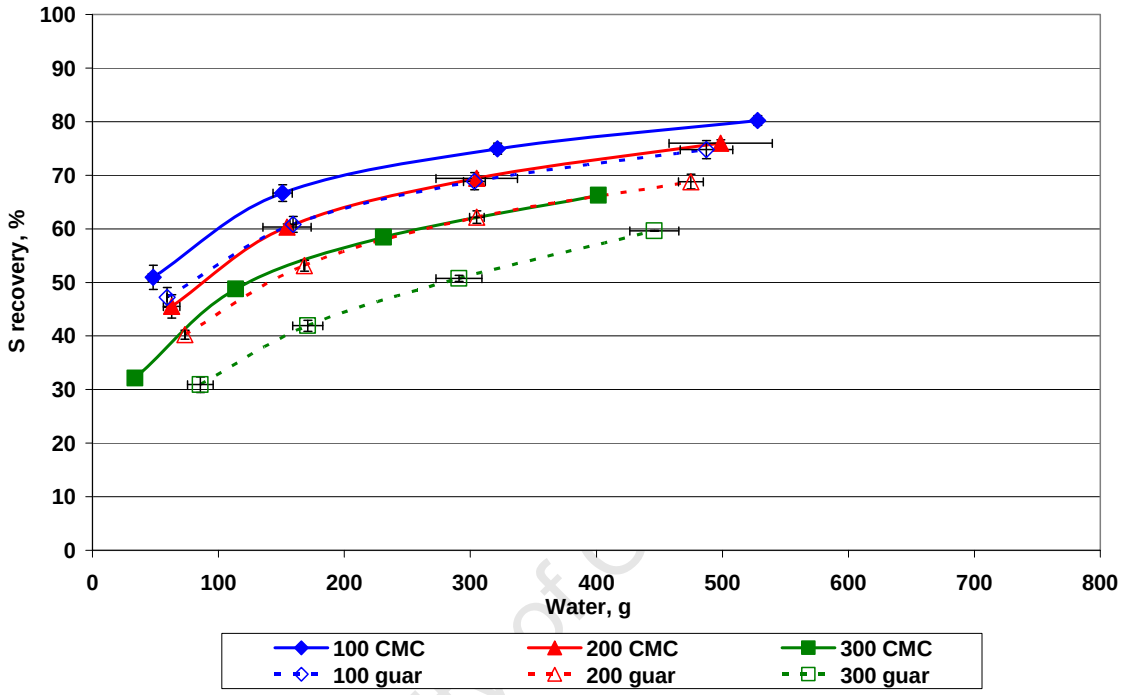

Figure 4.17: Sulfur recovery vs water recovered for Ore A using guar and CMC at dosages of 100, 200 and 300 g/t. Error bars represent standard deviation between duplicate tests.

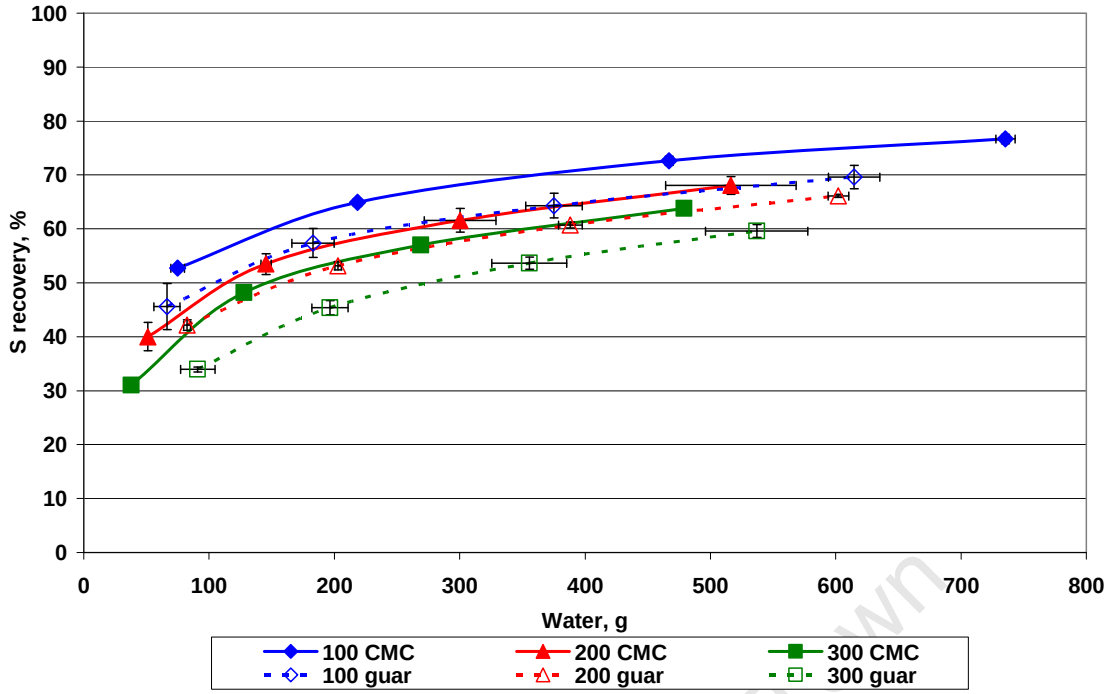

Figure 4.18: Sulfur recovery vs water recovered for Ore B using guar and CMC at dosages of 100, 200 and 300 g/t. Error bars represent standard deviation between duplicate tests.

An attempt was made to measure the concentration of the two depressants in solution at the end of the batch flotation tests using the du Bois method (Du Bois et al, 1956). The results are shown in Figure 4.19 for both ores. The amount of CMC and guar in solution at all three dosages was close to zero and suggests that depressant adsorption, particularly in the presence of calcium (Ca) and magnesium (Mg) ions was relatively strong and that almost all of the polymers were adsorbed even at a dosage of 300g/t. Previous studies (Becker et al., 2006) have indicated that the major mineral occurring in the NFG is pyroxene, which is a hydrophilic mineral and therefore non-floatable. However, recent QEMSCAN studies have shown that there is a strong association between pyroxene and talc and that the presence of pyroxene in the concentrates is likely due to talc-containing pyroxene particles (Becker et al, in press). The mineral requiring depression is therefore talc. The amount of talc present in these ores is usually less than 5%. It is known that these polysaccharides are likely to adsorb on any hydrophilic mineral (Steenberg, 1982; Martinovic, 2004; Parolis et al., 2005) as well as the talc. However, it is not known whether preferential adsorption is likely to occur on the talc surfaces rather than the feldspar / pure pyroxene particles. The fact that such high dosages are

required to depress the small amount of NFG suggests that adsorption is not occurring selectively on the talc.

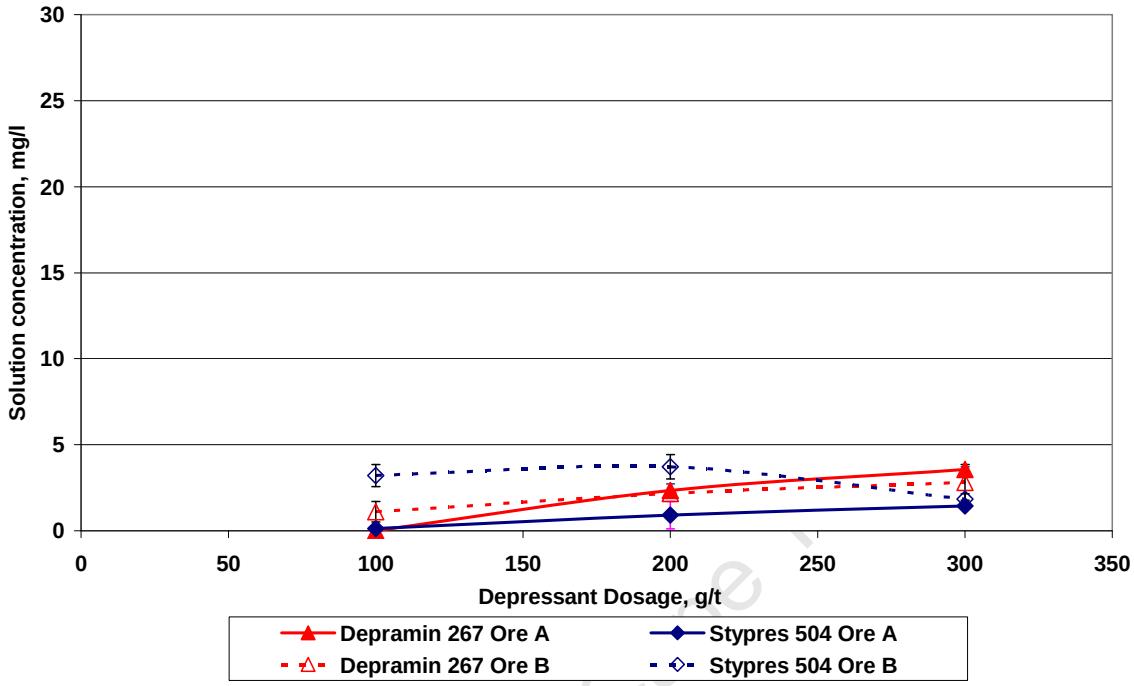

Figure 4.19: Depressant concentration in solution for guar and CMC at the three dosages evaluated for both Ores A and B. Error bars represent standard deviation between duplicate tests.

4.3 Size by size analysis of flotation concentrates

In section 4.2 it was shown that the addition of 300 g/t guar or CMC as a depressant of NFG was sufficient to reduce the recovery of NFG to almost zero. At this dosage it was shown that the concentration of depressant in solution was close to zero, which suggests a strong adsorption of the polymer onto gangue mineral surfaces. A series of batch flotation tests was conducted in quintuplicate in order to generate sufficient concentrate mass for sizing purposes in order to quantify the amount of gangue and sulfide minerals reporting to the concentrate in various size fractions. Sizing of the feeds was not done, and analysis of recovery by size was thus not possible. Tests were conducted on both Ores A and B at zero depressant addition as well as 300 g/t guar and CMC addition.

4.3.1 Test conditions

The UCT standard batch flotation procedure was used to conduct three test conditions for each ore type. The individual concentrates were analysed for copper, nickel and sulphur before being combined. Each combined concentrate was screened to provide the following size fractions: +75 µm, -75+38 µm, -38+20 µm, -20+5 µm and -5 µm. Endecotts stainless steel precision test sieves were used to screen at 75 and 38 µm. The smaller size fractions, -20 and -5 µm, were screened using Nitex Swiss made nylon mesh. After sizing each individual size fraction was assayed for copper, nickel and sulfur.

4.3.2 Results

The results obtained from the batch flotation tests conducted in quintuplicate on both ores are shown in the appendix.

The amount of gangue in each concentrate was calculated by subtracting the mass of the sulfide minerals in each concentrate (obtained from chemical assays) from the total mass recovered in each concentrate. The mass of gangue in grams in each of the five size fractions in each of the four concentrates obtained from tests conducted on Ores A and B using guar as a depressant are shown in Figure 4.20. The mass of gangue for the first concentrate (C1) for both ores was virtually identical for all five size fractions. The amount of gangue in the coarsest size fraction (+75 µm) was very similar for the two ores for all four concentrates. However, for the four finer size fractions, more gangue was always present in the concentrates obtained from Ore B.

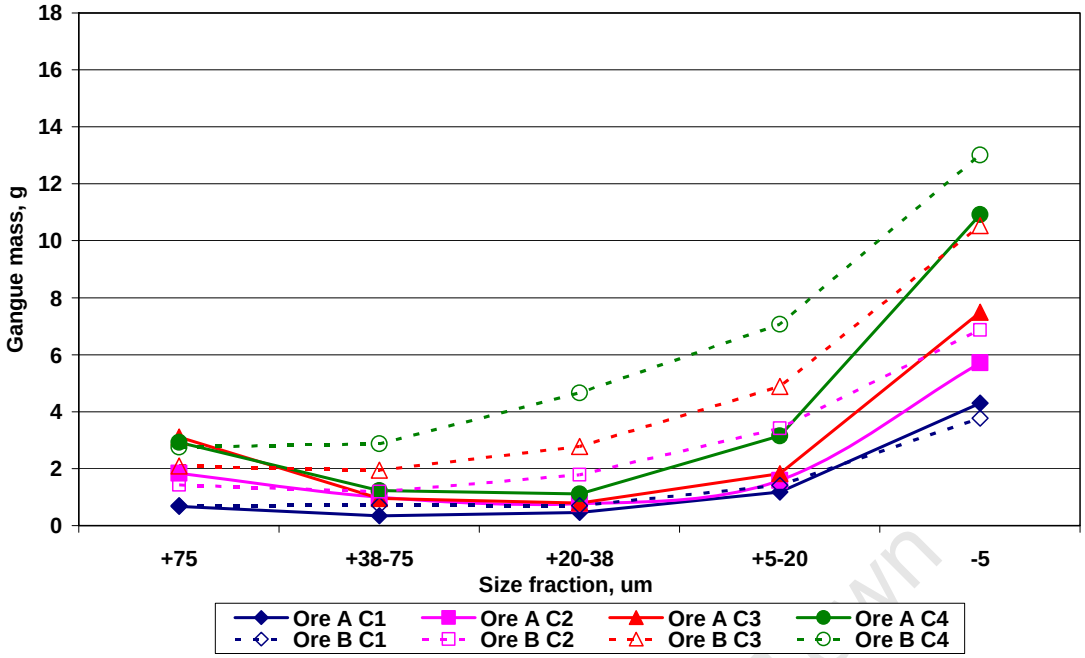

Figure 4.20: Gangue mass in grams per size fraction for the four concentrates, annotated C1 to C4, using 300 g/t guar as a depressant.

The mass of gangue in grams in each of the five size fractions in each of the four concentrates obtained from tests conducted on Ores A and B using CMC as a depressant are shown in Figure 4.21. As with the tests using guar the mass of gangue for the first concentrate (C1) for both ores was virtually identical for all five size fractions. Results obtained for the second concentrate (C2) were also very similar. For the third and fourth concentrates (C3, C4) the amount of gangue was higher in the coarsest size fraction for Ore A, but for the smaller size fractions more gangue was present in concentrates obtained from Ore B. This may be due to the recovery of slow floating sulfide / gangue composite particles.

The highest amount of gangue in most cases was present in the smaller size fractions (-20+5 and -5 µm). This is an indication of entrainment, but the amount of gangue is more than can be attributed to entrainment alone and suggests that at these size fractions gangue was reporting to the concentrate by flotation, possibly as composites with very finely disseminated sulfides.

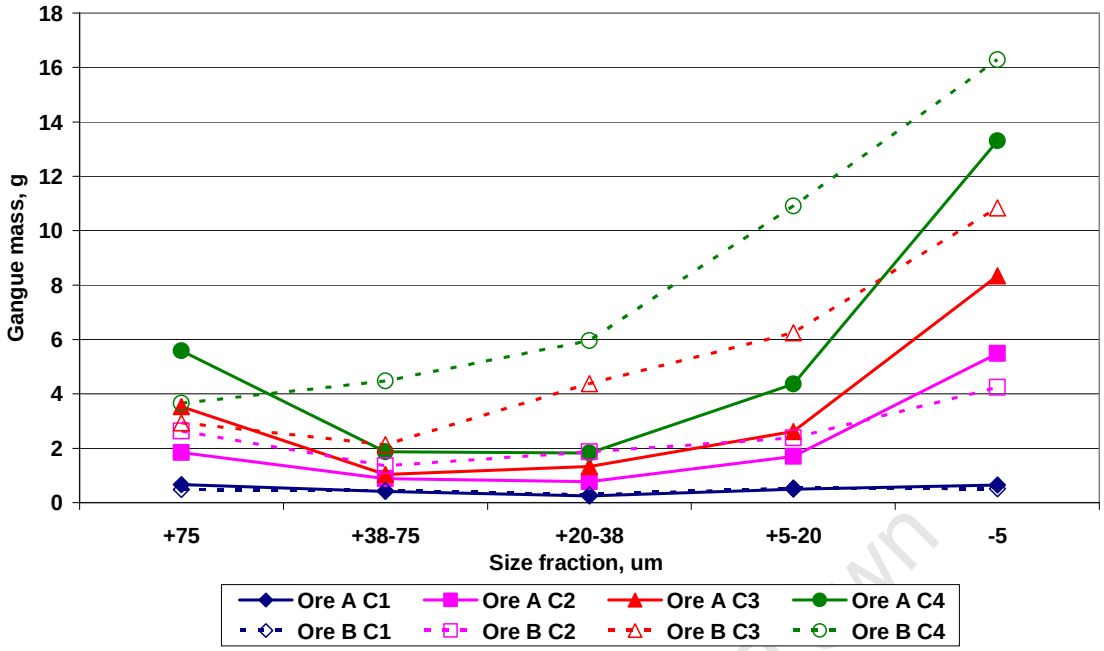

Figure 4.21: Gangue mass in grams per size fraction for the four concentrates, annotated C1 to C4, using 300 g/t CMC as a depressant.

Figure 4.22 shows sulfide mass in grams in the five size fractions and four concentrates for Ores A and B in the presence of 300 g/t guar. The highest mass of sulfides was present in the first concentrate for both ores with the highest amounts being present in the +38-75 µm size fraction. In this size fraction it would be expected that material would report to the concentrate via true flotation. These higher sulfide masses in the first concentrate, which is only 2 minutes in duration, are more than likely due to the presence of copper bearing minerals as they are the fastest floating sulfide minerals recovered mainly at the start of a batch flotation test. Pentlandite and pyrrhotite are slower floating and are recovered consistently throughout a batch flotation test. Higher sulfide masses were obtained from Ore B in the first concentrate. In the presence of CMC as shown in Figure 4.23 the two ores behaved in a similar manner with higher and similar sulphide masses being recovered in the first two concentrates. Ore B yielded higher sulfide masses in the second concentrate than Ore A. Although the sulfide masses varied between the size fractions and concentrates for the two depressants used, similar masses were recovered from the ores for the two depressant types.

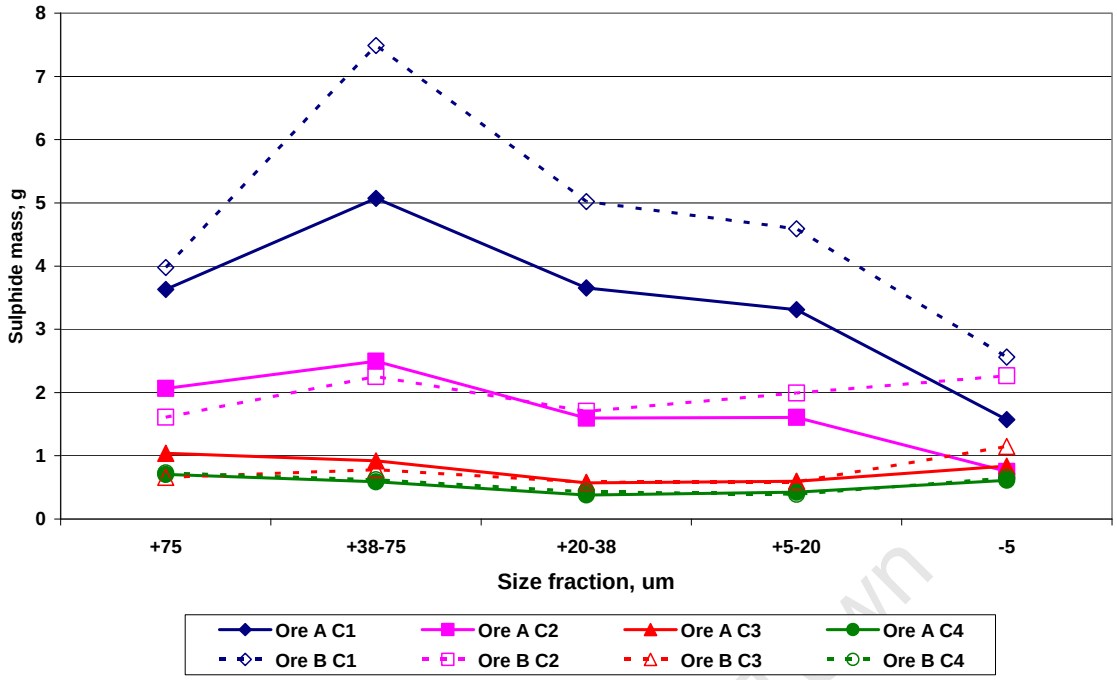

Figure 4.22: Sulfide mass in grams per size fraction for the four concentrates, annotated C1 to C4, using 300 g/t guar as a depressant.

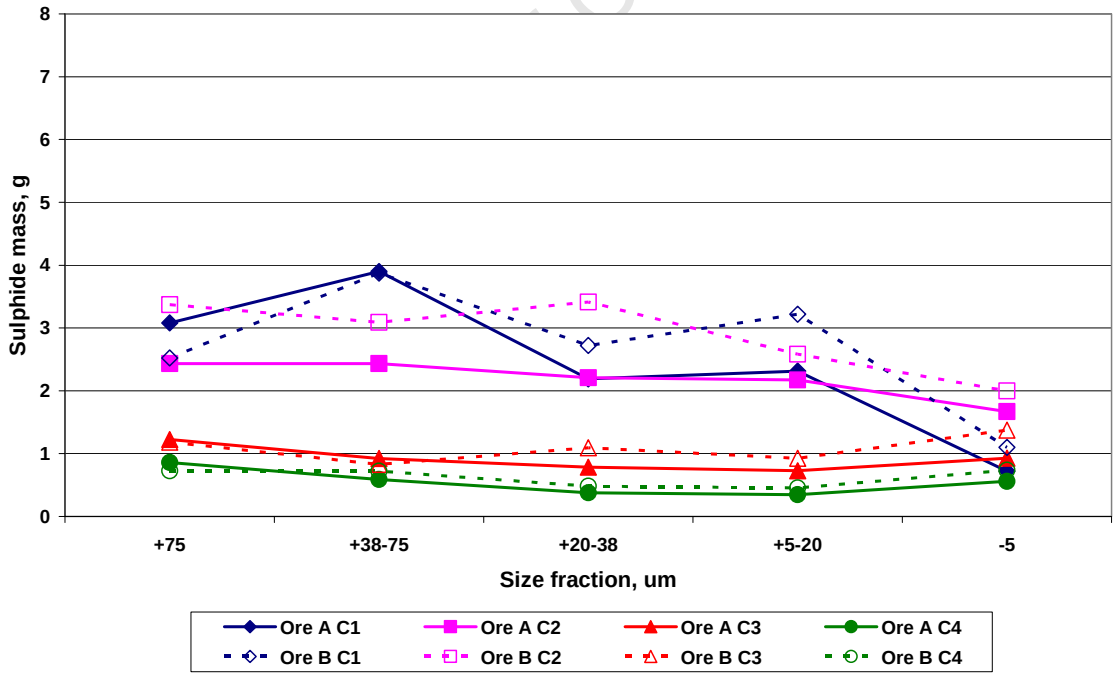

Figure 4.23: Sulfide mass in grams per size fraction for the four concentrates, annotated C1 to C4, using 300 g/t CMC as a depressant.

4.4 Key findings

Ore B contained almost double the amount of NFG than Ore A. This was determined by modal analysis of the feeds using QEMSCAN which showed that Ore A contained 44% NFG compared to just over 70% for Ore B. This was confirmed by conducting batch flotation tests without depressant addition. For Ore A the amount of NFG recovered to the concentrate was 4.2%, with Ore B yielding 8% NFG. The ratios of NFG recovered to the concentrate were very similar to those determined by QEMSCAN for the feeds. Although Ore B contained almost double the amount of floating gangue compared to Ore A, the NFG was similarly reduced at a depressant dosage of 300 g/t.

Higher copper and nickel recoveries were obtained from Ore B. The grades obtained from Ore B were however lower than those obtained from Ore A due to the presence of more NFG in the concentrates from Ore B which diluted the grade.

In the absence of a collector, copper recoveries were in the region of 80% for both ores. However, the absence of a collector had a detrimental effect on the recovery of nickel and sulfur from both ores. This highlights the natural floatability of chalcopyrite compared to that of pentlandite and pyrrhotite or pyrite.

The use of DTP as a co-collector with xanthate did not lead to any enhancement in sulfide mineral recovery. DTP addition resulted in increased frothability alone and xanthate was selected as the only collector for subsequent tests. This may be due to non-optimal combination of xanthate and DTP. Mingione (1984) reported that the synergy between two collector types developed only at a particular mass ratio of 60-70%, in avour of the DTP.

At a depressant dosage of 300 g/t almost all NFG had been removed from the system for both ores. Floating gangue reporting to the concentrate may be present due to sulfide / gangue composites.

At the lower depressant dosages evaluated, guar was a more effective depressant than CMC, but at a dosage of 300 g/t their depressing behaviour was the same. The

higher dosages of both depressants had a minimal effect on chalcopyrite recovery from both ores. Higher guar dosages led to a reduction in the initial rate of nickel recovery for both ores. Higher dosages of CMC had little effect on the recovery of nickel from the two ores.

The effect of the two depressants on the recovery of sulfur was ore dependent. For Ore A the rate of sulfur recovery was steadily reduced as depressant dosage was increased. This was observed for both depressants. The recovery of sulfur from Ore B was far less susceptible to depressant type and dosage.

Higher copper grades were obtained from tests using CMC than from tests using guar. This may be due to the differences in properties of the two depressants. The use of CMC leads to dispersed pulps and guar although uncharged does not alter the coagulative nature on ions present in the pulp. High dosages of CMC may also result in the cleaning of fines from the surfaces of particles.

The greatest amount of gangue was present in size fractions smaller than 38 µm. This is likely to be due to entrainment as the coarser size fractions are not as affected by entrainment, and particles are more likely to be present due to true flotation.

5 The effect of xanthate chain length on the flotation behaviour of gangue and sulfide minerals in Merensky ores at high depressant dosages

The aim of this work was to determine the influence of depressant action (guar and CMC) on gangue and sulfide minerals in Merensky Ores A and B by evaluating collector / depressant interactions using xanthate collectors of varying chain length.

Section 5.2.1 describes the results obtained in the presence of high dosages of guar. The results for the testwork conducted in the presence of CMC are described in section 5.2.2.

5.1 Test conditions

As with the testwork to evaluate the effect of depressant type and dosage (Chapter 4), the batch flotation procedure developed at UCT was used in this phase of work. The conditions used to evaluate the effect of varying xanthate chain length and dosage at CMC and guar concentrations of 500 g/t on the flotation behaviour of gangue and sulfide minerals in the two Merensky ores are shown in Table 5.1.

Table 5.1: Reagents and dosages for tests to evaluate the effect of xanthate chain length on Merensky Ores A and B in the presence of depressants.

Ore types	**Merensky Ores A and B**
Depressant type and dosage	**Guar – Stypres 504** **CMC – Depramin 267** **500 g/t**
Collector type and dosage	**SEX, SNPX, SIBX, PAX (guar)** **SEX, SIBX (CMC)** **50, 100, 150 g/t**

Tests were conducted on Ores A and B using four xanthate collectors of varying alkyl chain length (C2 – C5) in the presence of guar depressant at a dosage of 500

g/t. The four xanthate collectors used were SEX, SNPX, SIBX and PAX. All collectors were added at equimolar dosages. For tests conducted in the presence of CMC depressant on the two ores, only two xanthate collectors were evaluated, namely SEX and SIBX.

5.2 Results

Results for testwork conducted in the presence of guar are discussed before results obtained from testwork conducted in the presence of CMC. All figures except those for final mass and water recovered, show the results obtained from tests using xanthate dosages of 50 and 150 g/t only. The results for xanthate dosage of 100 g/t have been omitted for simplicity as the results invariably lie between those obtained for 50 and 150 g/t.

5.2.1 Guar gum

A summary of the results obtained for all tests to evaluate the effect of collector chain length and dosage in the presence of high dosages of guar are shown in Table 5.2.

In general froth stability, as indicated by the amount of water recovered, decreased as xanthate concentration was increased. For Ore A the highest froth stabilities were obtained from tests in which PAX was used. This resulted in increased mass recoveries. Copper recoveries were relatively unaffected by changes in xanthate chain length or dosage, with the highest recoveries being obtained from tests in which SEX was used as the collector. Overall, copper grades and recoveries obtained from Ore B were higher than those obtained from Ore A, once again an indication of the higher sulfide content of Ore B. The same phenomenon is true for nickel and sulfur recoveries. Entrainment was similar for both ores and as a depressant dosage of 500 g/t was used in all tests no floating gangue was recovered from any of the tests.

Table 5.2: Summary of results obtained for Ores A and B using four xanthate collectors of varying chain length in the presence of guar (500 g/t). At this depressant dosage no NFG is recovered to the concentrate. Values are final recoveries from duplicate tests.

Condition	Mass (g)	Water (g)	Cu rec (%)	Cu grade (%)	Ni rec (%)	Ni grade (%)	S rec (%)	S grade (%)	Entrained gangue (g)
Ore A									
SEX 50 g/t	11.80	307.0	82.8	11.02	44.9	7.36	53.7	22.00	7.37
SEX 100 g/t	10.90	232.8	83.4	12.25	48.8	9.91	60.8	27.95	5.59
SEX 150 g/t	10.67	246.0	82.3	14.04	47.7	10.58	58.5	32.90	5.9
SNPX 50 g/t	10.89	273.7	80.9	9.88	44.2	7.73	53.7	21.90	6.57
SNPX 100 g/t	11.30	232.8	81.9	9.32	51.2	9.45	57.8	26.30	5.59
SNPX 150 g/t	10.86	219.3	80.9	13.77	46.2	10.76	62.1	34.75	5.26
SIBX 50 g/t	10.46	259.3	76.8	10.35	42.8	7.74	51.7	21.20	6.22
SIBX 100 g/t	10.93	248.7	81.2	9.16	48.6	9.44	54.3	26.65	5.97
SIBX 150 g/t	11.78	259.1	83.2	10.33	50.7	10.20	61.1	30.35	6.22
PAX 50 g/t	14.15	409.2	81.5	9.81	46.2	6.85	51.2	20.50	9.82
PAX 100 g/t	13.87	348.7	79.5	8.42	50.1	9.68	61.0	26.10	8.37
PAX 150 g/t	17.83	507.4	82.9	9.80	52.9	10.21	63.0	29.90	12.18
Ore B									
SEX 50 g/t	15.20	313.1	87.4	15.78	50.9	9.88	62.8	27.55	7.51
SEX 100 g/t	14.26	243.4	87.6	14.89	51.7	11.71	69.5	30.55	5.82
SEX 150 g/t	11.59	163.4	85.9	16.89	46.5	12.16	65.0	33.60	5.57
SNPX 50 g/t	14.16	317.8	85.6	15.15	51.4	9.85	58.1	26.25	7.63
SNPX 100 g/t	13.17	231.8	83.6	14.78	50.9	11.75	60.6	32.40	5.56
SNPX 150 g/t	11.16	150.1	81.6	17.05	43.4	12.22	62.5	35.30	3.60
SIBX 50 g/t	11.44	261.8	82.8	16.88	46.5	8.98	48.7	25.00	6.28
SIBX 100 g/t	11.38	215.0	83.0	12.62	48.9	11.71	56.1	30.90	5.16
SIBX 150 g/t	13.03	232.2	83.6	12.23	50.1	11.67	63.2	32.50	6.62
PAX 50 g/t	11.86	293.0	82.9	15.82	46.3	8.69	44.2	22.45	7.03
PAX 100 g/t	12.00	258.1	83.7	13.89	49.9	11.04	54.3	28.45	6.19
PAX 150 g/t	14.40	282.8	82.2	11.75	50.4	11.73	58.4	32.15	6.79

The results obtained for final mass and water are shown in Figure 5.1 for all conditions evaluated. At the depressant dosage used in this testwork, stabilisation of the froth did not occur due to the absence of sufficient hydrophobic gangue particles. For both ores the use of SEX resulted in a decrease in mass recovery and froth stability with an increase in collector concentration. The same trend was observed for Ore B when SNPX was used. Tests on Ore A resulted in a decrease in froth stability as SNPX dosages were increased, but mass recovery remained relatively constant across the range of SNPX dosages. There was an increase in the amount of mass recovered for both ores with an increase in SIBX dosage. The use of PAX at a dosage of 150 g/t for Ore A, resulted in the highest froth stability and mass recovery.

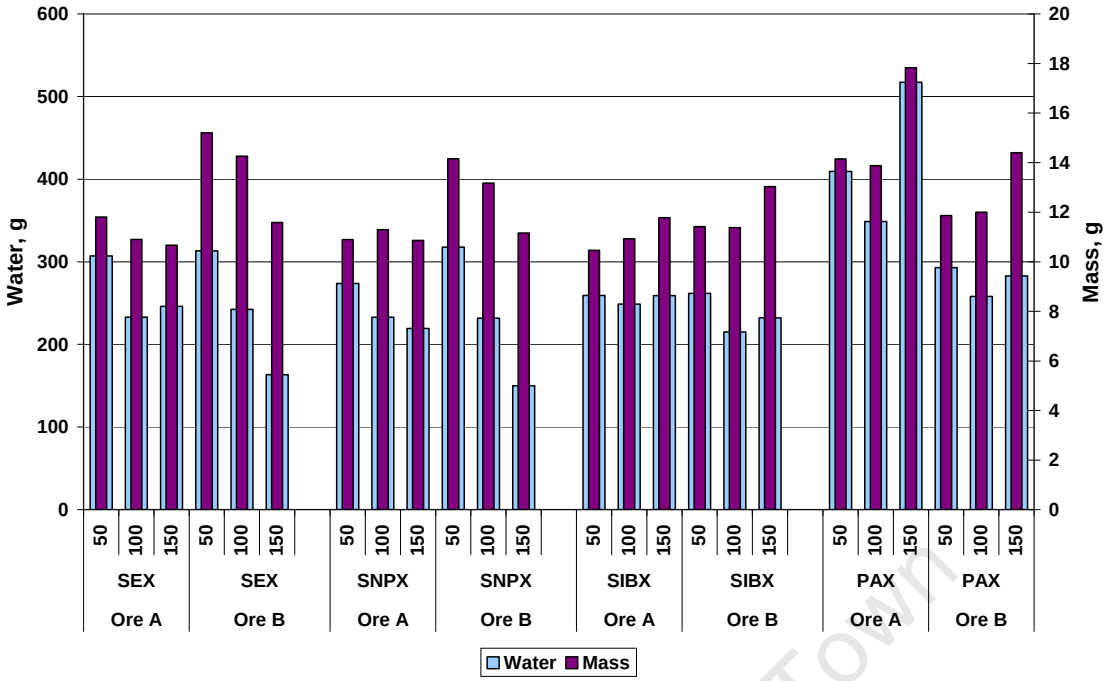

Figure 5.1: Final mass and water recovered for all conditions in the presence of 500 g/t guar.

The results for cumulative mass versus cumulative water recovered are shown in Figure 5.2 for Ore A. Lower mass recovery per unit water recovered was obtained for all tests conducted using the four xanthate collectors at a dosage of 50 g/t. The results for tests using the four collectors at 150 g/t indicate higher and similar mass per unit water recoveries. The higher froth stabilities which resulted from the use of PAX are evidenced by the highest water recovery. Due to the high contact angle of PAX it would be expected that its use would result in destabilised froths. The results obtained in this testwork indicate that PAX possesses frothing properties. This was more evident for Ore A than for Ore B. The results obtained for tests on Ore B are shown in Figure 5.3. The results for Ores A and B at xanthate dosages of 150 g/t have a similar gradient and indicate similar mass recovery per unit water recovered. Similar behaviour was observed for Ore A at xanthate dosages of 50 g/t. The results obtained for Ore B at xanthate dosages of 50 g/t indicate varying mass recovery per unit water.

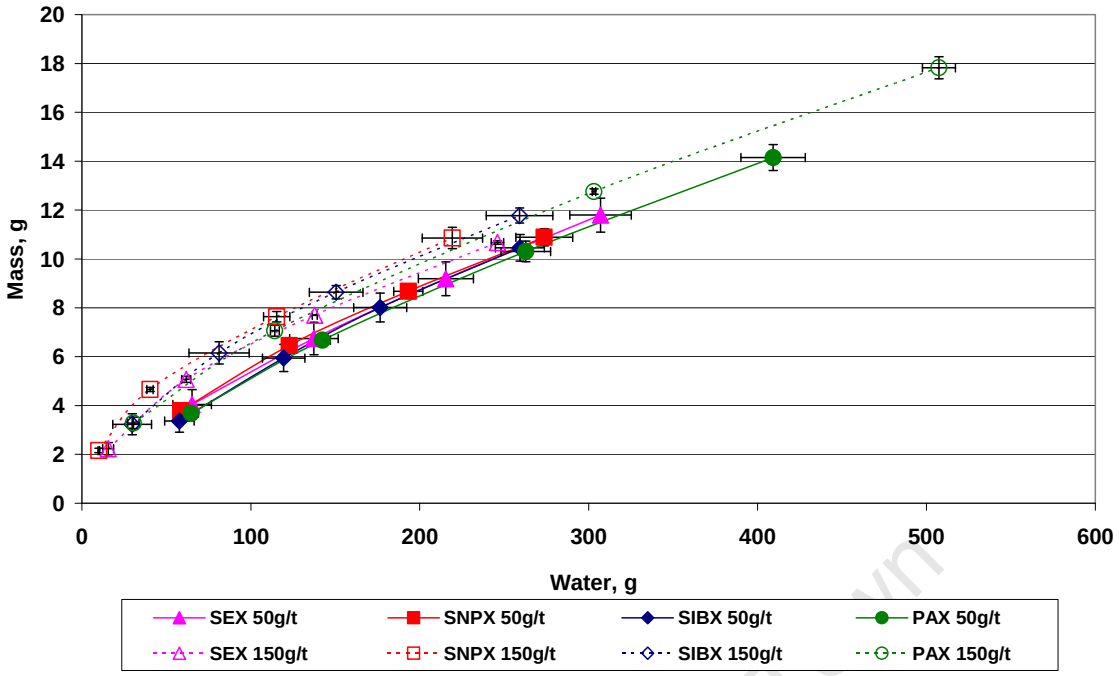

Figure 5.2: Cumulative mass versus water recovered for Ore A for different xanthate chain-lengths at dosages of 50 and 150 g/t in the presence of guar. Error bars represent standard deviation between duplicate tests.

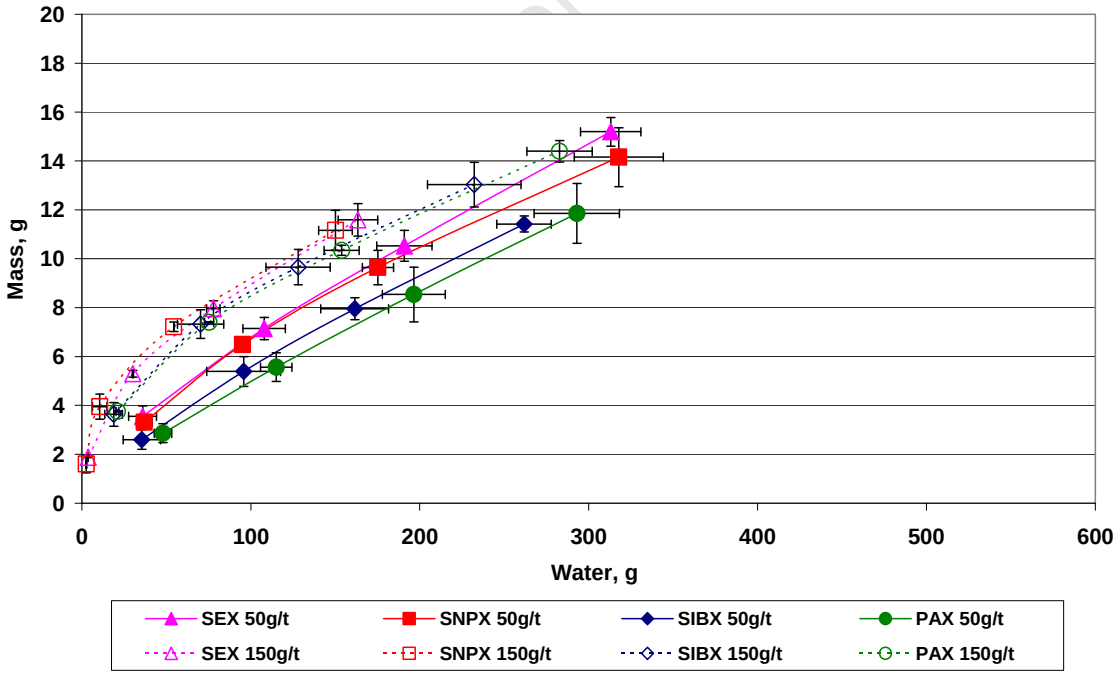

Figure 5.3: Cumulative mass versus water recovered for Ore B for different xanthate chain-lengths at dosages of 50 and 150 g/t in the presence of guar. Error bars represent standard deviation between duplicate tests.

Figure 5.4 shows total gangue versus water recovered for all the batch flotation tests performed at 500 g/t depressant dosage on both Ores A and B using four different xanthate collectors at different dosages. The data displayed are for conditions to evaluate the flotation performance of the two ores using four xanthate collectors of varying chain length at three different concentrations. The gradient of the line for tests conducted on Ore A was determined as 0.0236 which equated to 0.0236 g of entrained material per 1 ml water recovered, or 2.36 g per 100 ml (2.36 % entrainment). In the same way the entrainment function for Ore B was determined as 0.0245 which equated to 0.0245 g of entrained material per 1 ml water recovered, or 2.45 g per 100 ml (2.45 % entrainment). The values determined for the two ores under these conditions were very similar. For continuity, it was decided to use a common entrainment function for both ores. The average value was therefore used (0.0240). This was obtained from the entrainment functions for Ore A (0.0236) and Ore B (0.0245).

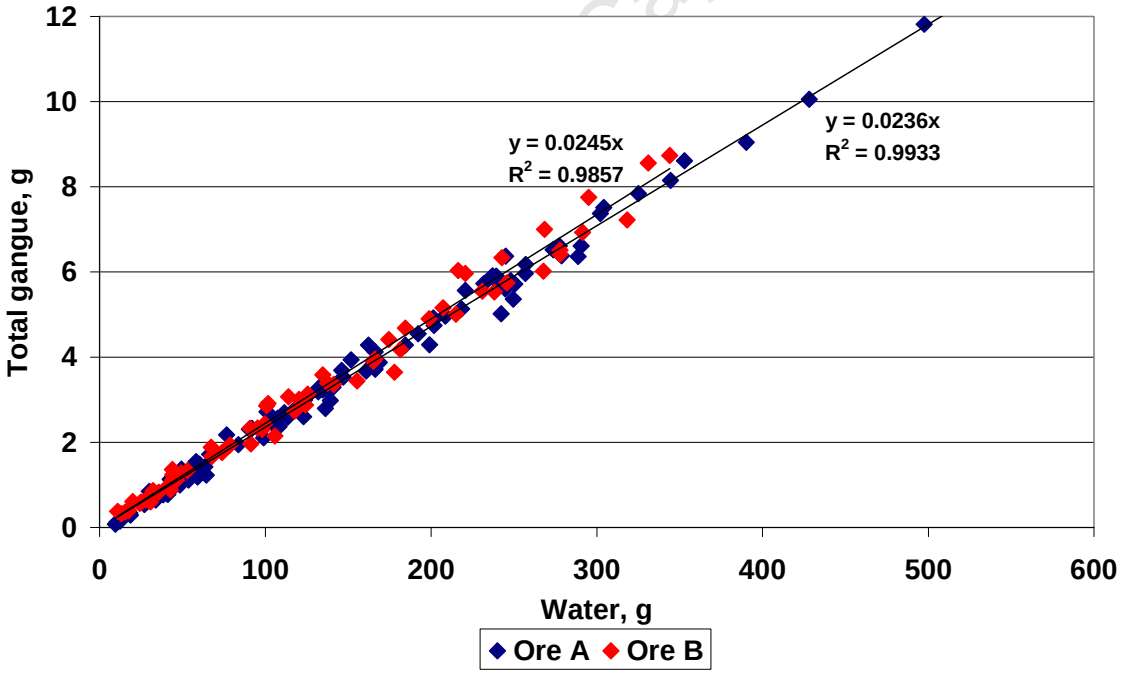

Figure 5.4: Total gangue versus water recovered for both ores using four different xanthate collectors. Equations showing the gradient of the line (entrainability value) are shown on the graph.

Figure 5.5 shows total total gangue vs water recovered for Ore A for all four xanthate collectors at three different dosages using guar as the depressant. The data indicate that there was no difference in the results obtained, and that there was no effect on the entrainment of gangue by changing xanthate chain length or dosage. The results for Ore B are shown in Figure 5.6. Similarly to Figure 5.5, there was no effect on entrainment of gangue by changing xanthate chain length or dosage.

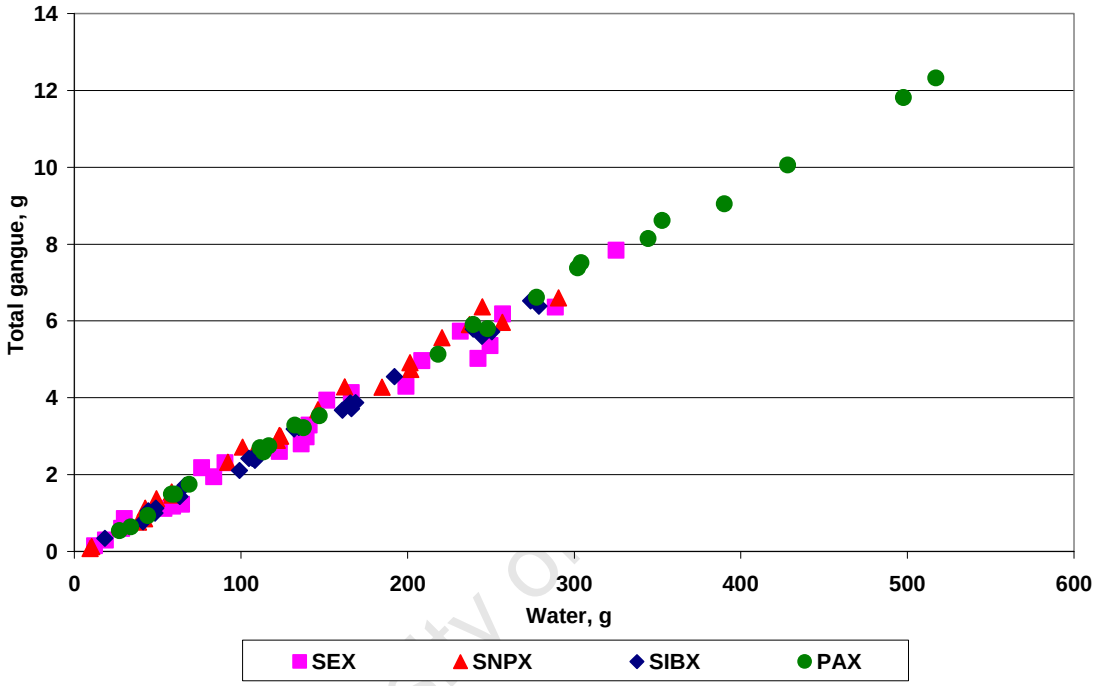

Figure 5.5: Total gangue versus water recovered for Ore A using four different xanthate collectors.

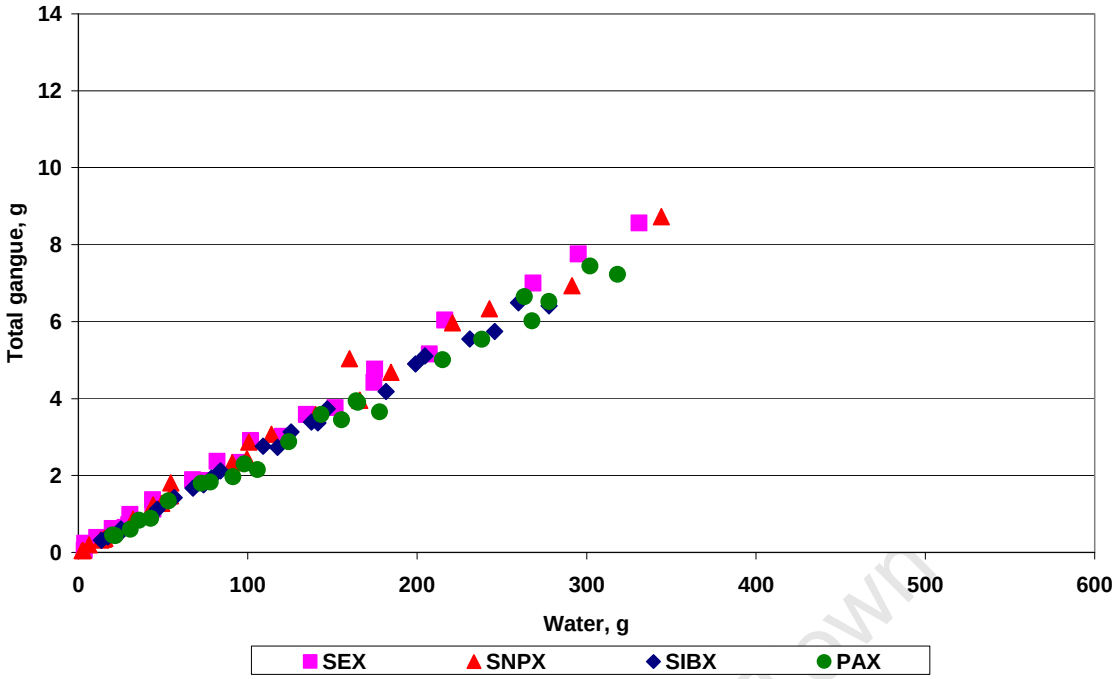

Figure 5.6: Total gangue vs water recovered for Ore B using four different xanthate collectors.

The results obtained from these tests were compared to the results obtained from tests using the method developed by Robertson (2003) to measure entrainment by making use of a MnO_2 tracer. A similar ore to the ores used in this study was used by Robertson (2003) and the tests were performed under the same pulp density and operating conditions in the flotation cell. The entrainability factor calculated from these tests was compared to that which was determined by Robertson (0.0281) and was found to show a good correlation with this value. The method to calculate entrainment using high depressant concentrations is a quick, easy method for determination of the entrainment for any system. It is evident that because the entrainment values for the different xanthate collectors was the same, the nature of the pulp was not being altered by the different xanthates

The results obtained for copper and nickel grade versus recovery are shown in Figures 5.7 for Ore A and 5.8 for Ore B.

The results for copper grade versus copper recovery for Ore A indicate that copper recovery was largely unaffected by changes in collector type or dosage. This was largely expected as chalcopyrite floats readily with very little affecting its flotation performance, with recoveries in the region of 80% being obtained from tests

conducted in the absence of a collector (Chapter 4). The highest grades were obtained from tests in which SEX and SNPX were used at dosages of 150 g/t due to the fact that the lowest froth stabilities were obtained from these tests resulting in the lowest amount of entrained gangue reporting to the concentrates. The behaviour of Ore B was very similar to that of Ore A in that copper recovery was largely unaffected by changes in collector type or dosage. As with Ore A, the highest grades were obtained from tests in which SEX and SNPX were used at dosages of 150 g/t. Copper recoveries and grades obtained from Ore B were slightly higher than those obtained from Ore A, an indication of the higher sulfide content of Ore B.

As shown in Figures 5.7 and 5.8 the effect of the different collector dosages was more apparent for nickel than for copper. The lowest grades and recoveries of nickel for both ores were obtained from tests conducted at collector dosages of 50 g/t. This suggests that this dosage may not be sufficient to counteract the effects of the guar at the dosage of 500 g/t used in these tests.

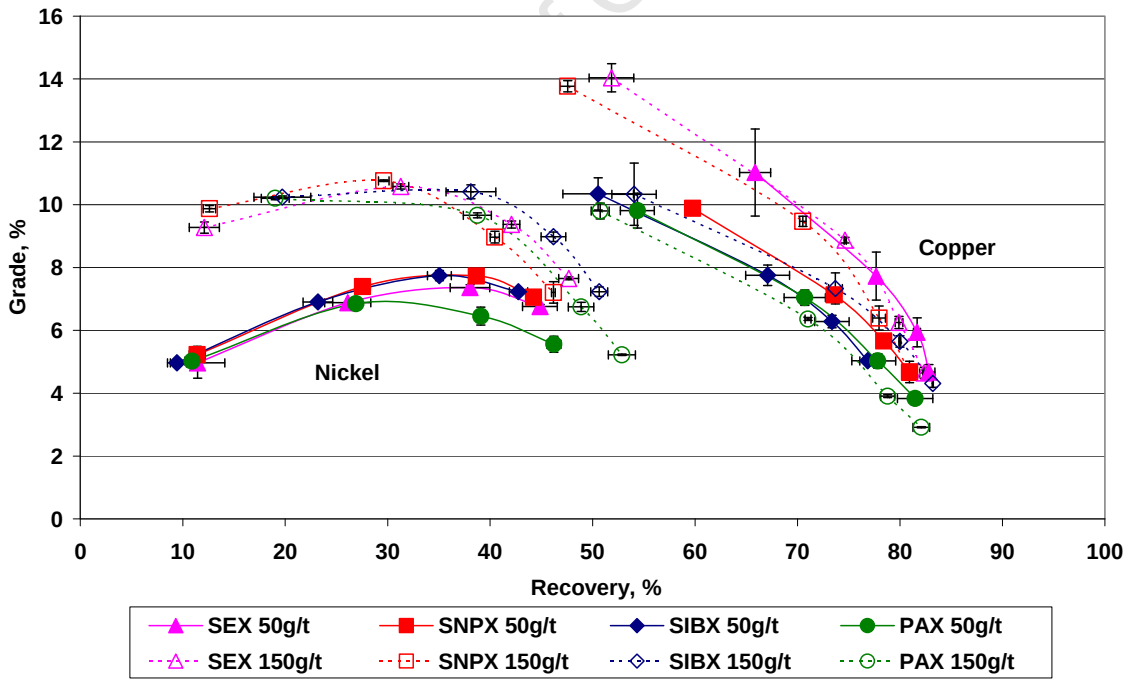

Figure 5.7: Copper and nickel grade versus recovery for Ore A for different xanthate chain-lengths at dosages of 50 and 150 g/t in the presence of guar. Error bars represent standard deviation between duplicate tests.

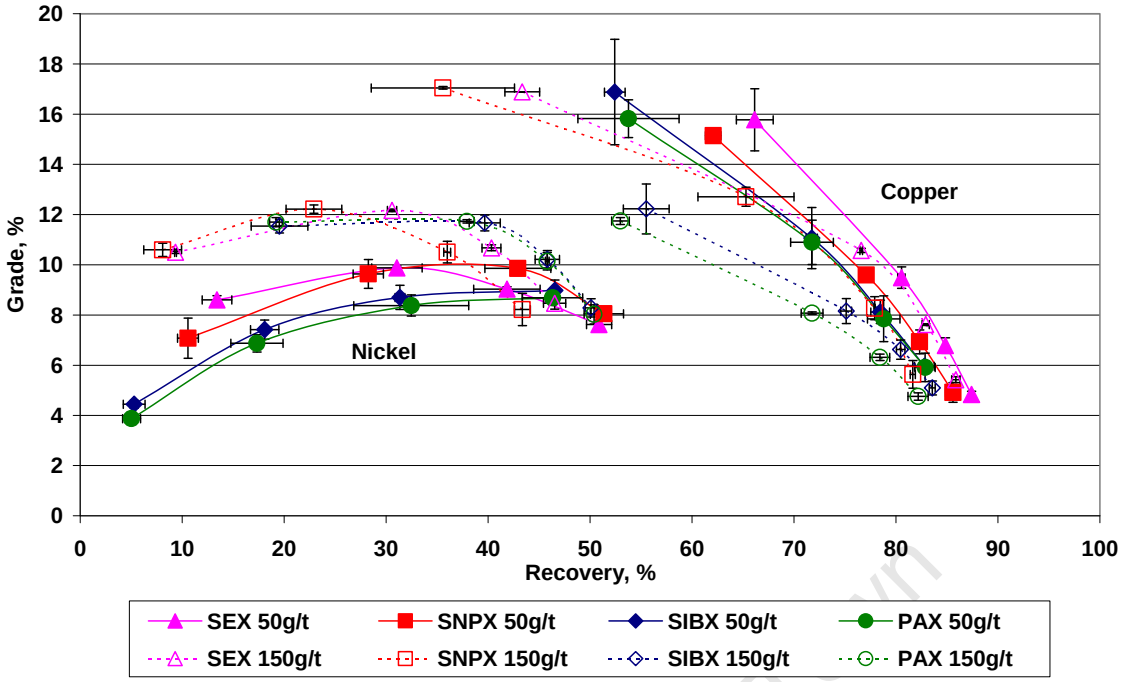

Figure 5.8: Copper and nickel grade versus recovery for Ore B for different xanthate chain-lengths at dosages of 50 and 150 g/t in the presence of guar. Error bars represent standard deviation between duplicate tests.

Figures 5.9 and 5.10 show copper and nickel recovery versus water recovered for Ores A and B. Plotting sulfide recovery against water recovered eliminates the differences created by changes in froth stability obtained under the various test conditions due to the froth limiting nature of the flotation cell used for this testwork.

For both ores the initial rate of flotation of copper was slower for tests in which 50 g/t collector dosages were used than when dosages of 150 g/t were used. The fastest initial rates of flotation were obtained from tests in which SEX and SNPX were used at dosages of 150 g/t. Slower rates of flotation were obtained from tests in which SIBX and PAX were used at the same high collector dosage. However, by the end of the batch flotation test the rate of flotation of copper had recovered sufficiently for there to be virtually no difference in the copper recoveries obtained from the various conditions evaluated.

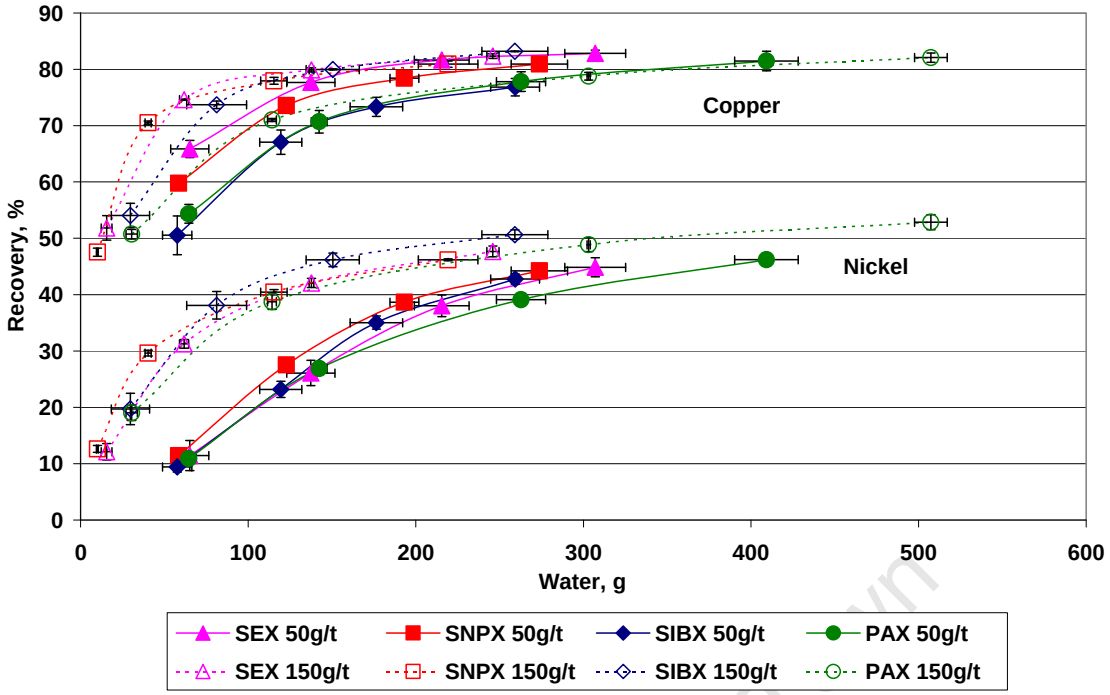

Figure 5.9: Copper and nickel recovery versus water recovered for Ore A for different xanthate chain lengths at dosages of 50 and 150 g/t in the presence of guar. Error bars represent standard deviation between duplicate tests.

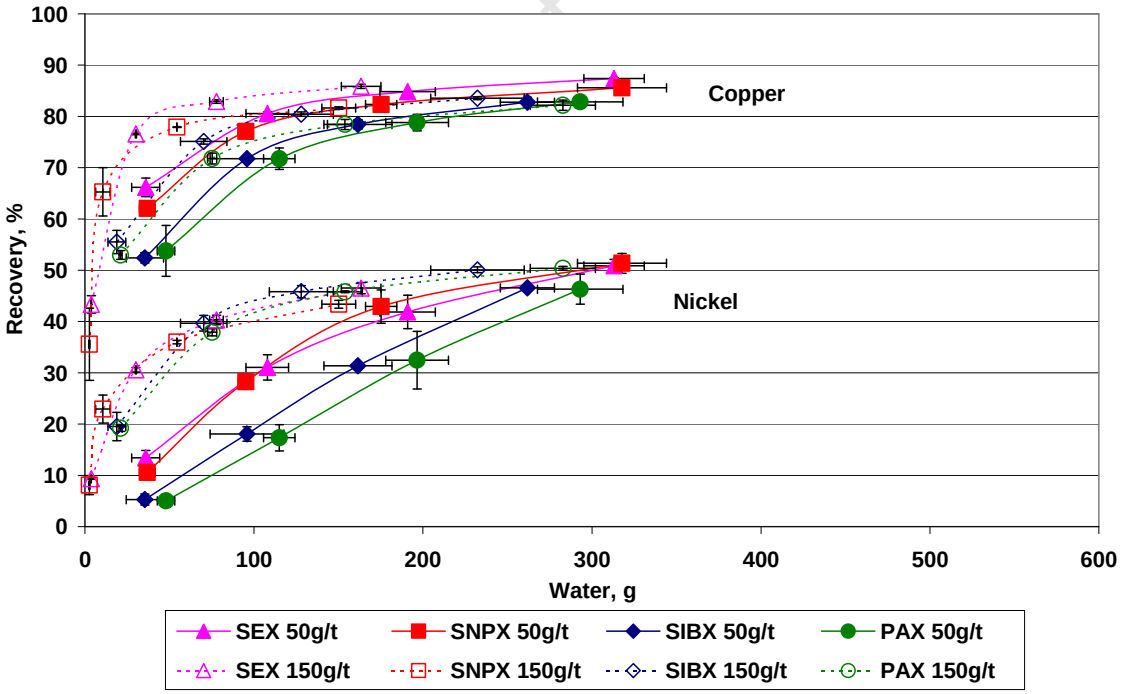

Figure 5.10: Copper and nickel recovery versus water recovered for Ore B for different xanthate chain lengths at dosages of 50 and 150 g/t in the presence of guar. Error bars represent standard deviation between duplicate tests.

The results for nickel shown in Figure 5.9 illustrate that at the lowest collector dosage of 50 g/t the initial rate of flotation of nickel was significantly reduced. This was the case for all four collectors evaluated. The results for Ore B shown in Figure 5.10, exhibit a similar trend to those obtained for Ore A.

The results for sulfur grade versus recovery for Ores A and B are shown in Figures 5.11 and 5.12. The figures illustrate the large impact of the high concentration of guar depressant (500 g/t) on the recovery and grade of sulfur obtained from tests in which the collector concentration of 50 g/t was used. The effects of using SIBX and PAX at dosages of 50 g/t were greater on Ore B than on Ore A, and suggests that the flotation behaviour of the iron sulfides in the two ore samples may be different.

The results for sulfur recovery versus water recovered as shown for Ores A and B in Figures 5.13 and 5.14 illustrate the large impact of the high guar concentration (500 g/t) on the rate of sulfur flotation and the final sulfur recoveries from the two ores. To a certain extent the use of higher concentrations of collector counteracted the influence of the depressant. The result of using low concentrations of collector was detrimental to the recovery of sulfur from the two ores.

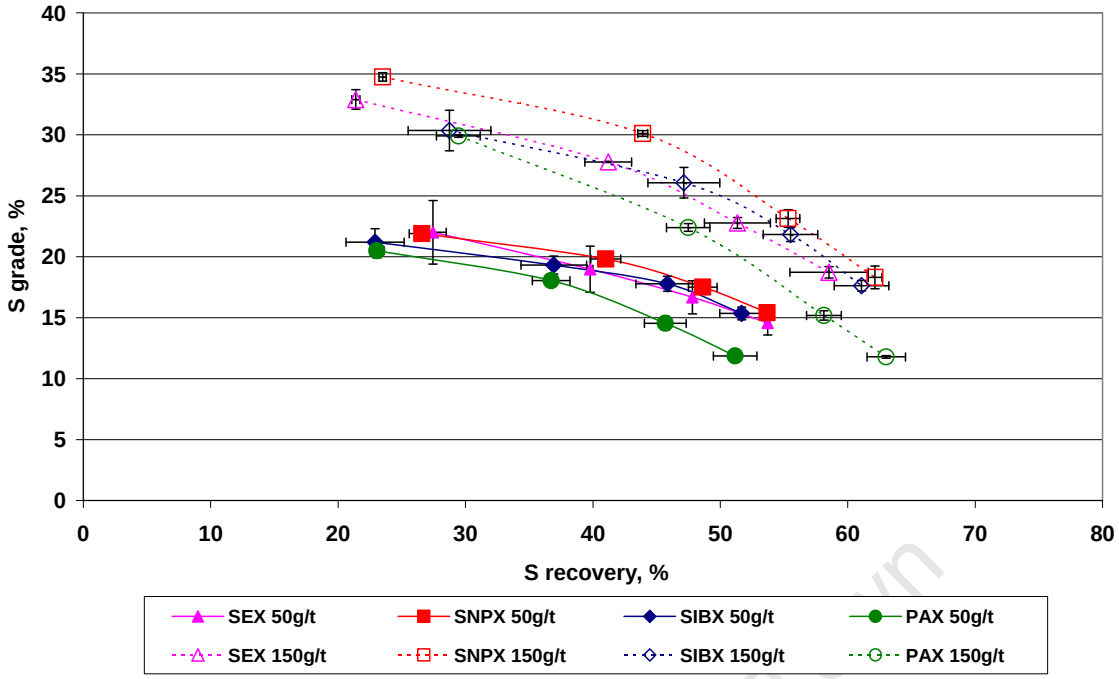

Figure 5.11: Sulfur grade versus sulfur recovery for Ore A for different xanthate chain lengths at dosages of 50 and 150 g/t in the presence of guar. Error bars represent standard deviation between duplicate tests.

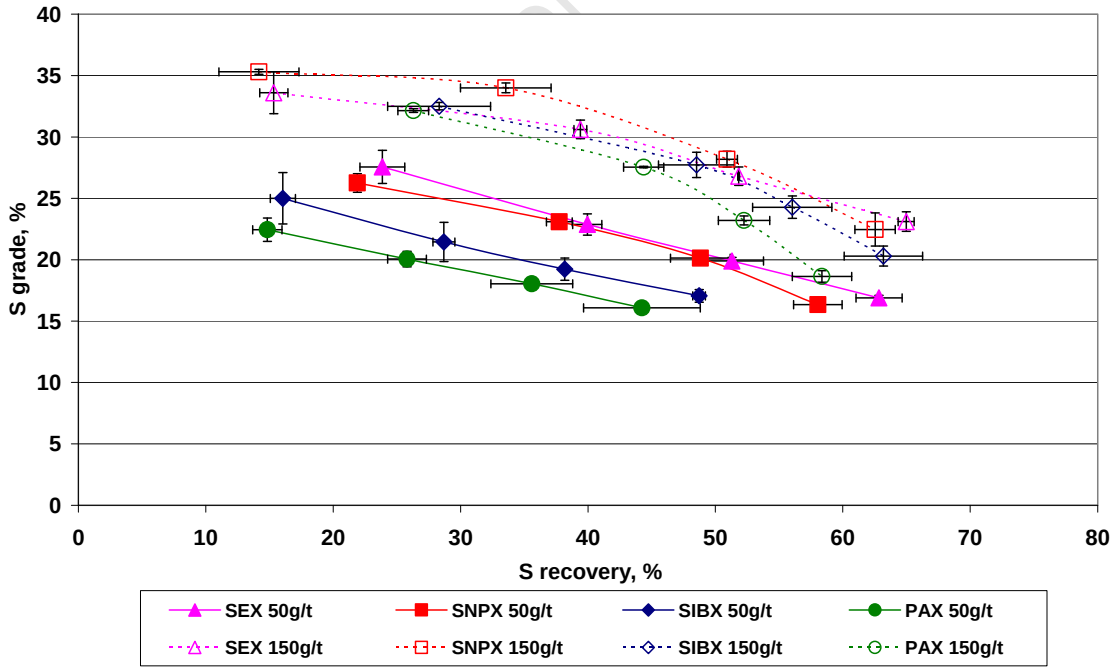

Figure 5.12: Sulfur grade versus sulfur recovery for Ore B for different xanthate chain lengths at dosages of 50 and 150 g/t in the presence of guar. Error bars represent standard deviation between duplicate tests.

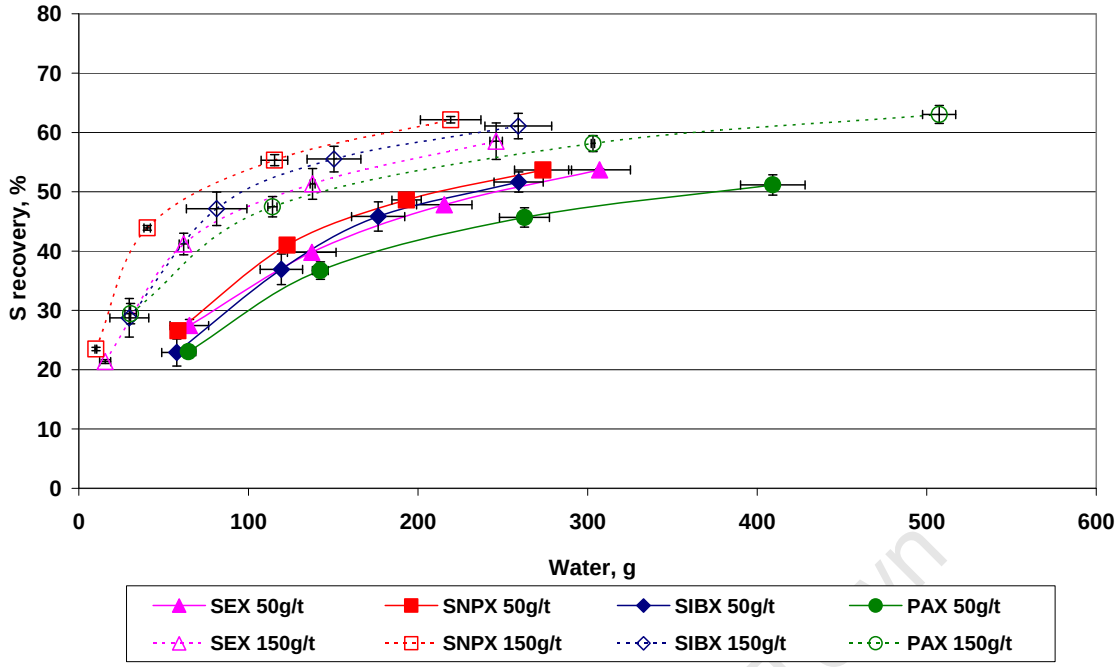

Figure 5.13: Sulfur recovery versus water recovered for Ore A for different xanthate chain lengths at dosages of 50 and 150 g/t in the presence of guar. Error bars represent standard deviation between duplicate tests.

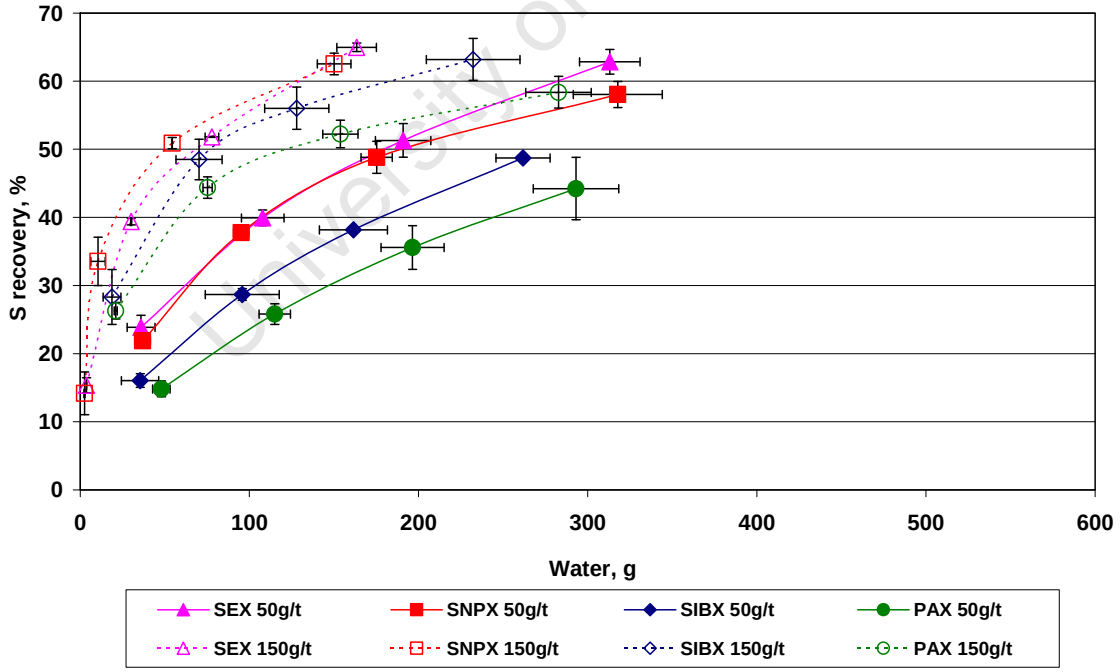

Figure 5.14: Sulfur recovery versus water recovered for Ore B for different xanthate chain lengths at dosages of 50 and 150 g/t in the presence of guar. Error bars represent standard deviation between duplicate tests.

5.2.2 Carboxymethyl cellulose

Batch flotation tests were conducted on Ores A and B using SEX and SIBX as collectors in the presence of 500 g/t CMC. The collector dosages used were 50, 100 and 150 g/t. A summary of the results obtained from these tests are shown in Table 5.3.

Table 5.3: Summary of results obtained for Ores A and B using two xanthate collectors in the presence of CMC (500 g/t).). At this depressant dosage no NFG is recovered to the concentrate. Values are final recoveries from duplicate tests.

Condition	Mass (g)	Water (g)	Cu rec (%)	Cu grade (%)	Ni rec (%)	Ni grade (%)	S rec (%)	S grade (%)	Entrained gangue (g)
Ore A									
SEX 50 g/t	9.77	173.0	83.2	13.88	50.1	10.32	66.9	33.05	4.08
SEX 100 g/t	8.47	117.9	82.4	13.30	48.7	10.53	68.4	34.40	2.78
SEX 150 g/t	9.54	147.8	83.3	11.66	50.3	10.14	70.6	32.80	3.49
SIBX 50 g/t	9.07	176.3	84.0	17.47	48.1	10.40	57.7	34.75	4.16
SIBX 100 g/t	10.12	177.8	83.1	14.14	49.1	10.94	62.8	35.10	4.20
SIBX 150 g/t	9.91	159.2	83.3	13.67	50.3	11.31	63.4	34.65	3.76
Ore B									
SEX 50 g/t	16.10	335.3	88.1	16.93	51.7	12.23	65.9	33.30	9.19
SEX 100 g/t	12.27	166.1	86.1	15.57	50.2	12.70	66.7	34.30	4.55
SEX 150 g/t	12.84	166.3	85.9	15.63	50.5	12.55	68.2	34.25	4.56
SIBX 50 g/t	12.06	261.9	87.6	22.69	47.8	10.11	49.9	31.65	7.17
SIBX 100 g/t	11.66	208.1	85.8	18.99	48.1	11.96	53.5	33.25	5.70
SIBX 150 g/t	12.17	180.0	85.7	15.69	50.0	12.86	61.3	34.05	4.93

For Ore A mass recovered for all conditions was very similar. For Ore B the highest mass was recovered for tests in which SEX at a dosage of 50 g/t was used as the collector. This condition resulted in the highest froth stability, as determined by water recovery, and would thus have the highest amount of gangue reporting to the concentrate as shown in Table 5.3

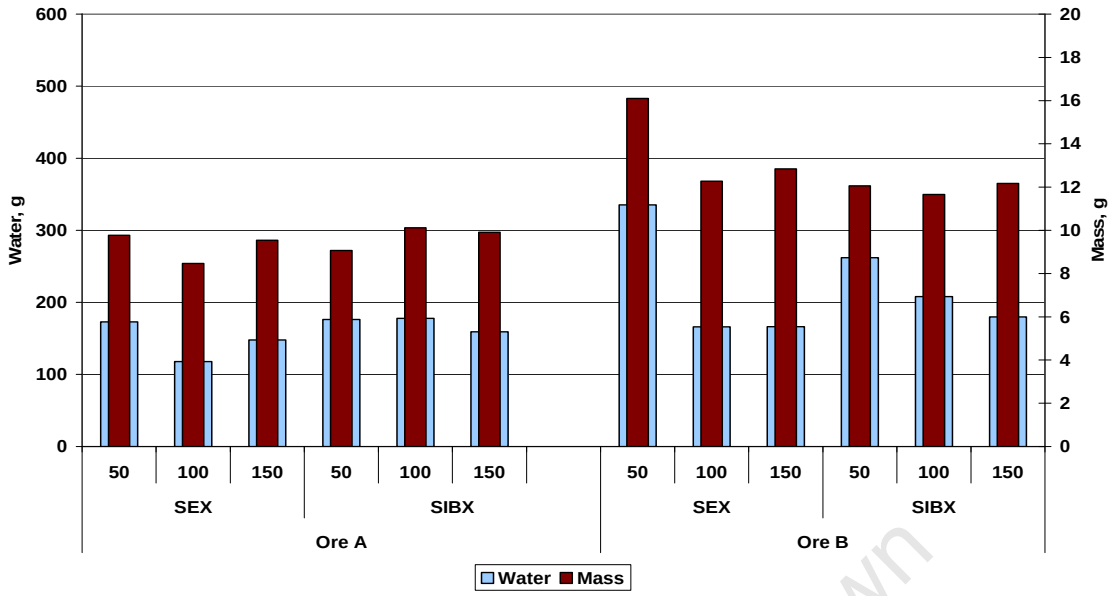

Figure 5.15: Final mass and water recovered for Ores A and B using SEX and SIBX in the presence of 500 g/t CMC.

Figure 5.15 shows final mass and water recovered for all conditions to evaluate the flotation performance of both ores in the presence of SEX and SIBX together with CMC. For tests in which Ore A was evaluated, changing the depressant from guar to CMC led to much lower water recoveries although the same trends were obtained for the various conditions. For tests in which Ore B was used, changing the depressant did not lead to such a significant difference in froth stability (see Figure 5.1). Once again more mass was obtained from Ore B indicative of its higher sulfide content. The addition of SEX at a dosage of 50 g/t was less destabilising than SIBX at the same dosage which resulted in higher mass recoveries.

Figures 5.16 and 5.17 show cumulative mass versus cumulative water recovered for Ores A and B respectively. Figure 5.19 illustrates that there was no significant difference in the recovery of mass or water between SEX and SIBX at the dosages evaluated for tests conducted using Ore A. The results obtained from tests conducted on Ore B as shown in Figure 5.20 indicate that more water was recovered from tests conducted at 50 g/t addition of SEX and SIBX.

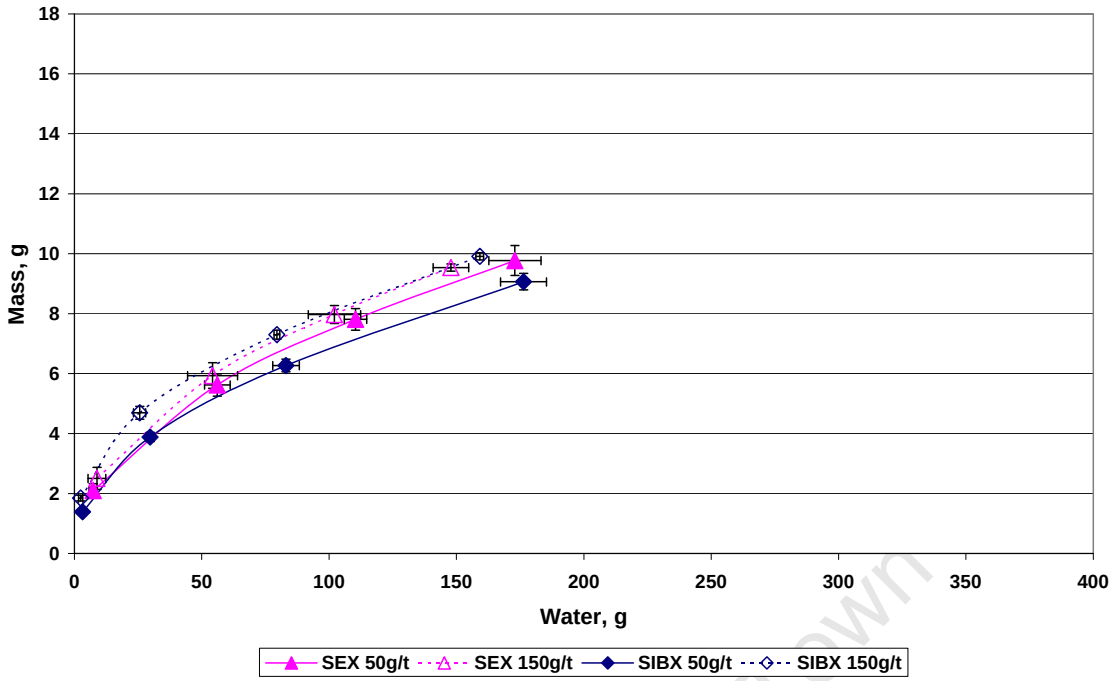

Figure 5.16: Cumulative mass versus water recovered for tests on Ore A using SEX and SIBX in the presence of CMC. Error bars represent standard deviation between duplicate tests.

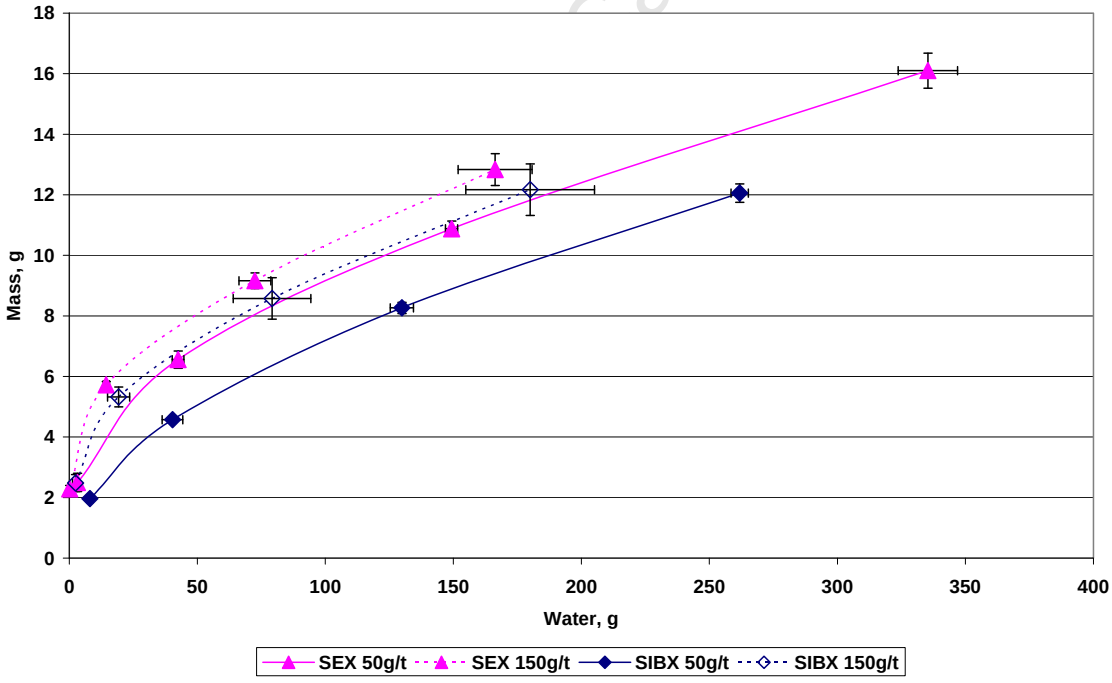

Figure 5.17: Cumulative mass versus water recovered for tests on Ore B using SEX and SIBX in the presence CMC. Error bars represent standard deviation between duplicate tests.

Figure 5.18 shows total gangue versus water recovered for all the batch flotation tests performed at 500 g/t depressant dosage on both Ores A and B using SEX and SIBX as collectors at different dosages. The gradient of the line for tests conducted

on Ore A was determined as 0.0245 which was equal to 0.0245 g of entrained material per 1 ml water recovered, or 2.45 g per 100 ml (2.45 % entrainment). In the same way, the entrainment function for Ore B was determined as 0.0264 which was equal to 0.0264 g of entrained material per 1 ml water recovered, or 2.64 g per 100 ml (2.64 % entrainment). A slightly different entrainment function was obtained for the two ores when CMC was used as the depressant. At the CMC dosage of 500 g/t, the filtration times for the concentrates was significantly slower than times obtained when guar was used as a depressant. This is indicative of the system being strongly dispersed as opposed to the coagulative nature of the pulp when using guar. The energy and turbulence in the pulp in the flotation cell used in this testwork would be sufficient to counteract this. The entrainment value obtained for Ore A using CMC is identical to the value obtained for Ore A using guar. The value obtained for Ore B using CMC was 0.0264 compared to 0.0236 when guar was used as the depressant. Ore B has been shown to contain higher amounts of sulfide minerals than Ore A, and this may lead to the presence of more froth destabilising hydrophobic sulphide particles being present in the froth.

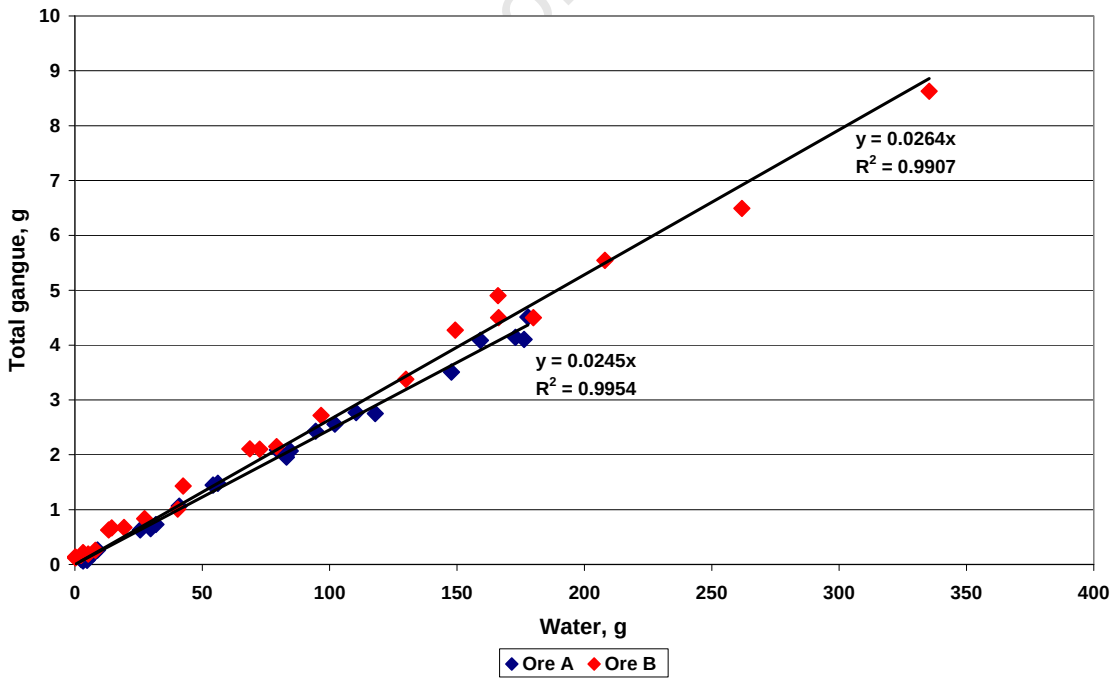

Figure 5.18: Total gangue vs water recovered for both ores using SEX and SIBX as collectors in the presence of CMC. Equations for the gradient of the line (entrainment function) are displayed on the chart.

Figure 5.19 shows total gangue versus water recovered for SEX and SIBX at varying dosages for the two ores. The data indicate that there was no difference in the results obtained for each ore type and that there was very little effect on the entrainment of gangue by changing xanthate chain-length or dosage.

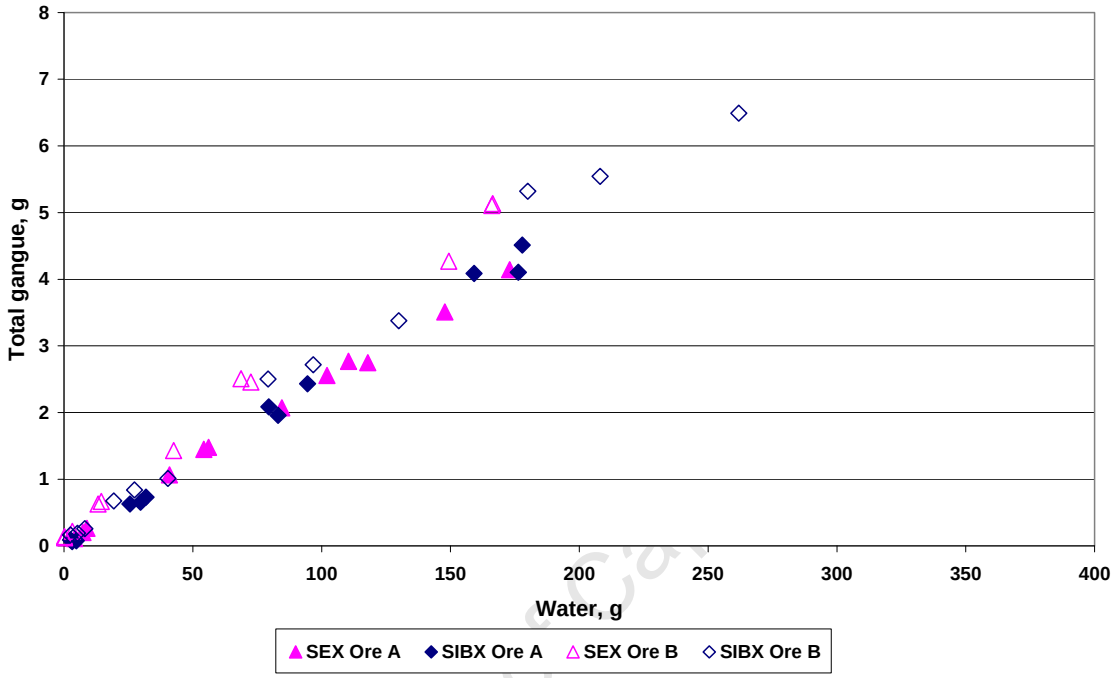

Figure 5.19: Total gangue vs water recovered for both ores using SEX and SIBX in the presence of CMC.

The results for copper, nickel and sulfur grade versus recovery for tests conducted in the presence of CMC are shown in Figure 5.20 for Ore A and 5.21 for Ore B. Similar recoveries of copper were obtained from Ore A and B irrespective of the collector dosage or xanthate type. The recovery of nickel from Ore B was slightly lower from tests using SIBX at 50 g/t. For both ores the highest recovery of sulfur was obtained from tests using 150 g/t SEX, as the collector with the lowest recoveries being obtained from tests using SIBX at 50 g/t.

The results for copper, nickel and sulfur recoveries versus water recovered are shown in Figures 5.22 and 5.23 for Ore A and Figures 5.24 and 5.25 for Ore B. The results indicate similar copper recoveries were obtained from Ore A irrespective of collector dosage or xanthate type. The results obtained from Ore B suggest a slight decrease in the initial rate of copper recovery at 50 g/t addition for both SEX and SIBX. There

was, however, no influence of the 500 g/t dosage of CMC on the final recovery of copper. The highest copper grades were obtained from tests using SIBX for both ores, whereas for the tests in which guar was used (Figures 5.7 and 5.8), the highest copper grades were obtained from tests using SEX.

There was an effect of the high CMC dosage on the recovery of nickel from the two ores. It was observed that the rate of nickel recovery was lower when using SIBX compared to SEX at dosages of 50 g/t for both ores and the reduction in floatability appeared to be greater with Ore B than with the Ore A. At a collector dosage of 150 g/t the rate of nickel recovery was greatly improved, but there were differences in the response obtained from the two ores in that, for Ore A slightly enhanced nickel floatability was obtained with SIBX, whereas for Ore B the rate of nickel recovery was greatest with SEX as the collector although the differences were small.

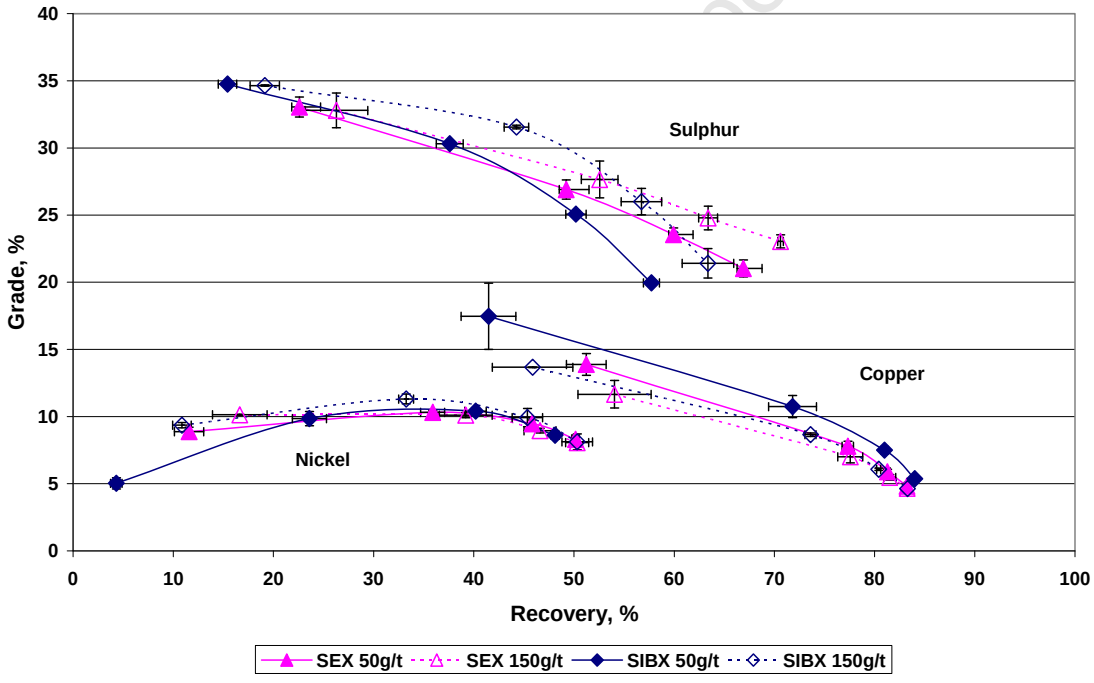

Figure 5.20: Copper, nickel and sulfur grades versus recoveries for Ore A using SEX and SIBX as collectors in the presence of CMC. Error bars represent standard deviation between duplicate tests.

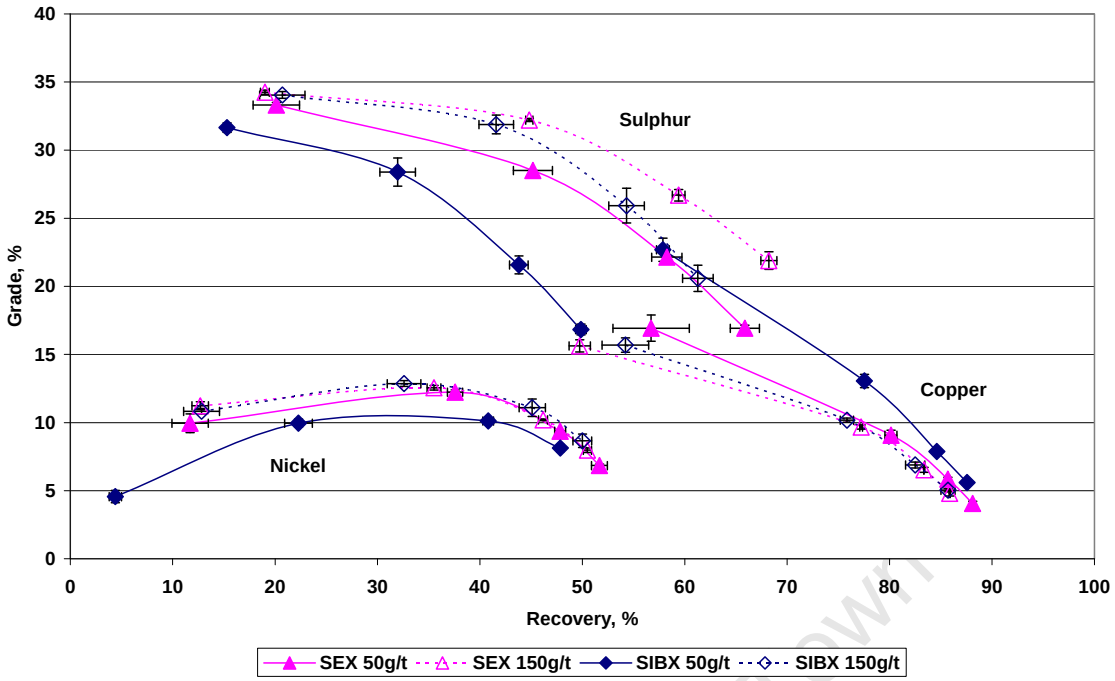

Figure 5.21: Copper, nickel and sulfur grades versus recoveries for Ore B using SEX and SIBX as collectors in the presence of CMC. Error bars represent standard deviation between duplicate tests.

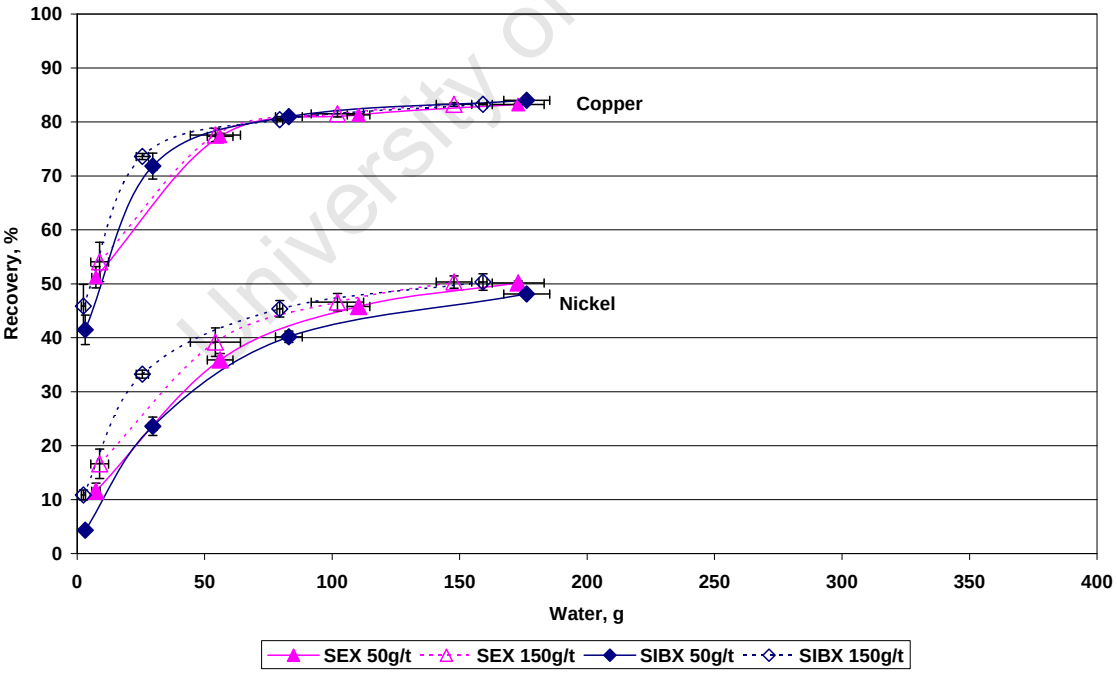

Figure 5.22: Copper and nickel recoveries versus water for Ore A using SEX and SIBX as collectors in the presence of CMC. Error bars represent standard deviation between duplicate tests.

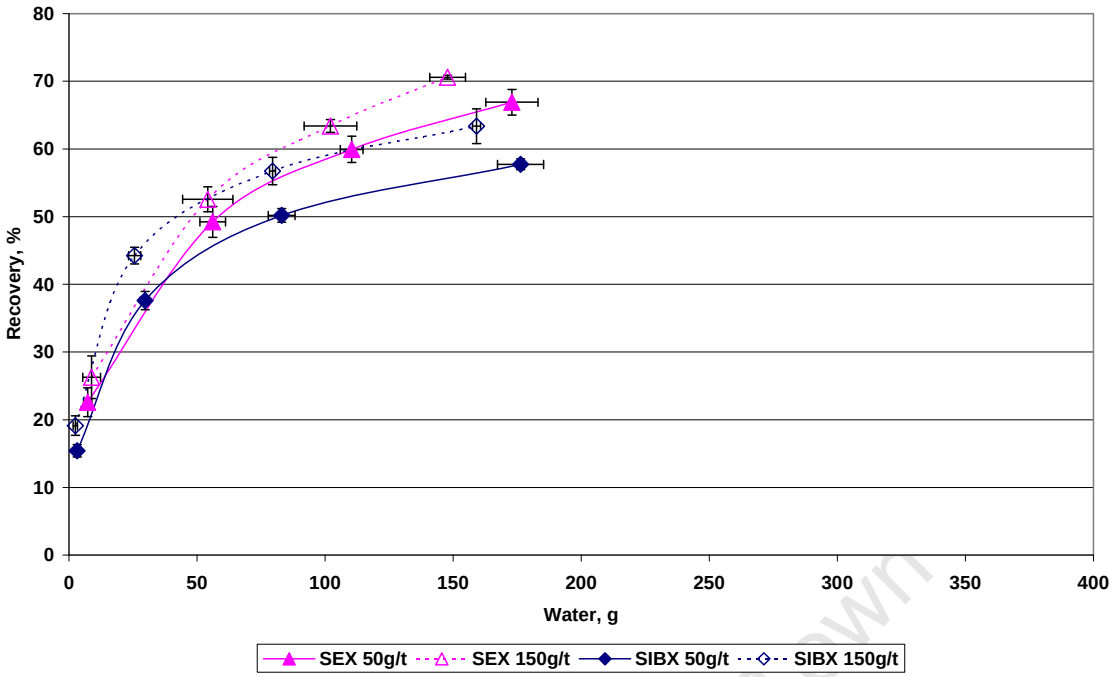

Figure 5.23: Sulfur recoveries versus water for Ore A using SEX and SIBX as collectors in the presence of CMC. Error bars represent standard deviation between duplicate tests.

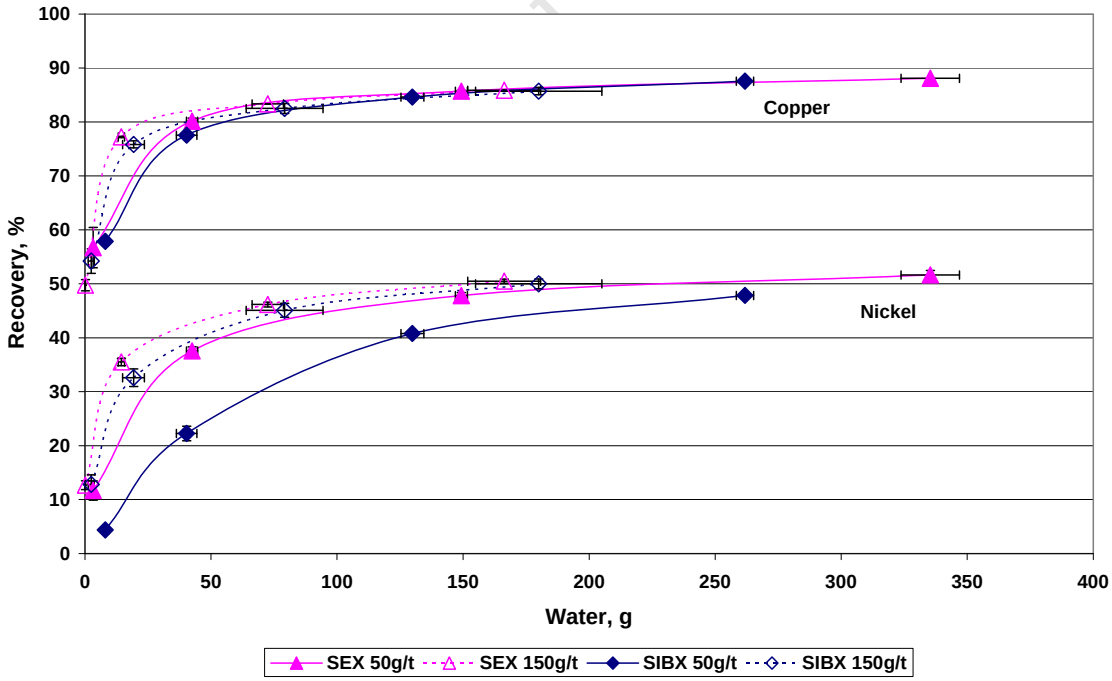

Figure 5.24: Copper and nickel recoveries versus water for Ore B using SEX and SIBX as collectors in the presence of CMC. Error bars represent standard deviation between duplicate tests.

The recovery of sulfur from the two ores was greatest in the presence of SEX at a dosage of 150 g/t. This is illustrated in Figures 5.23 and 5.24 which show the recoveries of copper, nickel and sulfur versus water recovered. The lowest recoveries were obtained in the presence of SIBX at a dosage of 50 g/t with the greatest effect on the recovery of sulfur from Ore B.

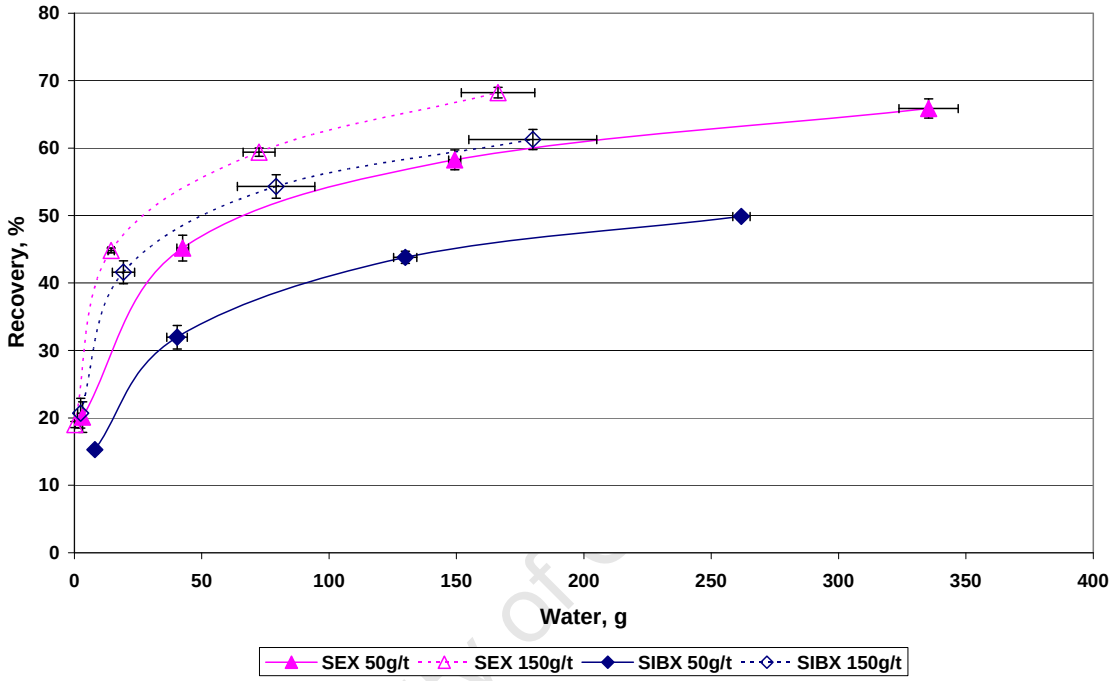

Figure 5.25: Sulfur recoveries versus water for Ore B using SEX and SIBX as collectors in the presence of CMC. Error bars represent standard deviation between duplicate tests.

Figures 5.26 and 5.27 show xanthate concentrations in the flotation cell before the commencement of the flotation tests for both ores at the three dosages evaluated for the different xanthates in the presence of guar as determined using UV spectroscopy. The results indicate that for all conditions evaluated there was sufficient collector in solution and that the batch flotation tests were not being conducted under conditions of collector starvation.

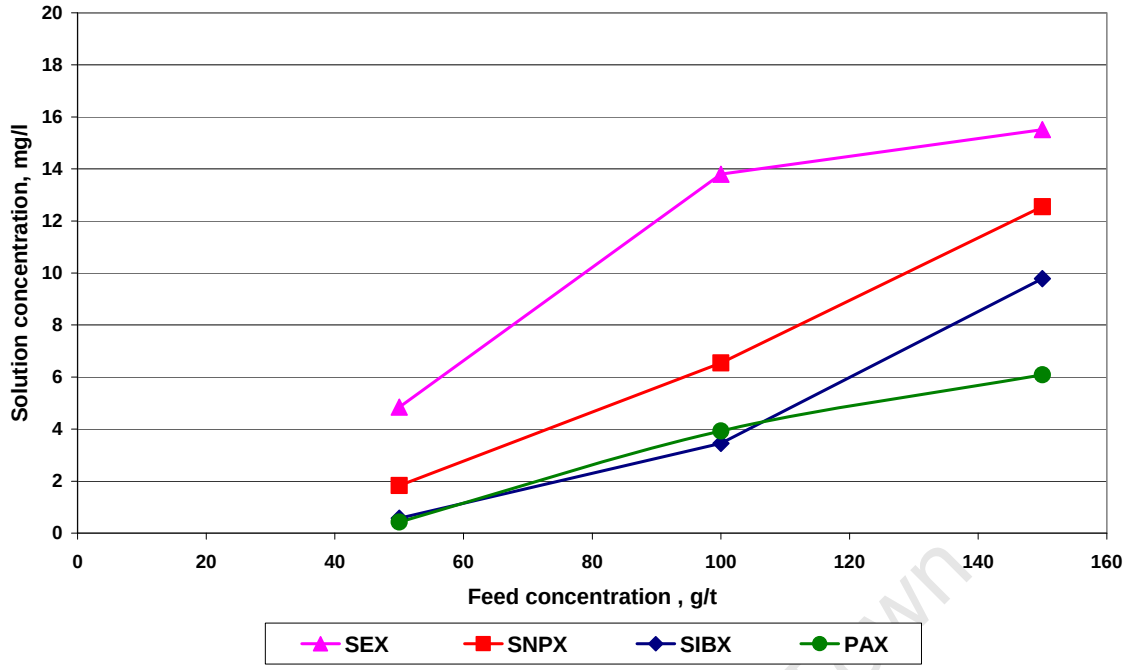

Figure 5.26: Xanthate concentration (mg/l) in solution for all xanthate collector types and dosages evaluated for Ore A in the presence of guar.

The collectors were added to the mill which allowed for collector adsorption on the sulfide mineral surfaces to occur as the particle surfaces were being freshly exposed. For both ores at a dosage of 50 g/t SIBX and PAX were below detection limits. When the dosage was increased, SIBX and PAX were detected in solution with higher concentration obtained for Ore A than for Ore B. For Ore B the amount of SIBX and PAX in solution at 150 g/t dosage was approximately 4 mg/l. At this dosage the amounts obtained for Ore A were 6 mg/l for PAX and 10 mg/l for SIBX. For both ores, the concentration of SEX in solution at a dosage of 50 g/t was in the region of 4 mg/l. The concentration of SEX in solution increased as dosage increased and at the highest dosage of 150 g/t for Ore A, the amount in solution was approximately 16 mg/l and for Ore B, 18 mg/l. The results for SNPX were between those obtained for SIBX/PAX and SEX for both ores. For the shorter chain length xanthates, SEX and SNPX, higher solution concentrations were obtained with Ore B. This was reversed for SIBX and PAX in that higher solution concentrations were obtained with Ore A.

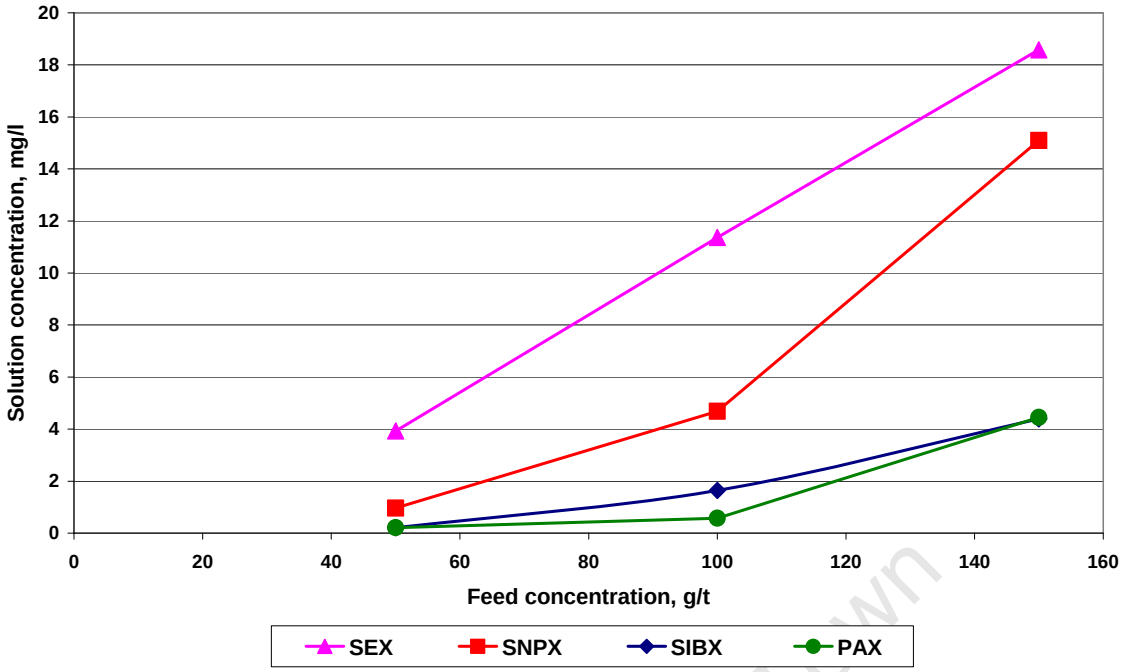

Figure 5.27: Xanthate concentration (mg/l) in solution for all xanthate collector types and dosages evaluated for Ore B in the presence of guar.

Table 5.4 shows the percentage of added xanthate collector adsorbed at the three dosages evaluated on both Ore A and B. The values complement the data contained in Figures 5.26 and 5.27 and show that for the longer chain length collectors, SIBX and PAX high percentages of the added xanthate had been adsorbed at all three dosages evaluated for both ores. For SNPX, adsorption levels at a dosage of 50 g/t were high, but decreased as dosage was increased. The lowest degree of adsorption was obtained using SEX, the xanthate with the shortest chain length.

Both ores were milled to 60% < 75µm and the surface areas of the two ores, as measured by the B.E.T. (Brunauer, Emmet and Teller) gas adsorption method, were similar at a value of 1.5 m^2/g. It has been assumed that the surface area of the sulfide minerals in the ore was similar to the surface area of the bulk ore. It was possible from the sulfide content of the ores, the area a xanthate molecule occupies on the sulfide surface (35$Å^2$) (Granville et al., 1971) and the amount of xanthate adsorbed, assuming that xanthate adsorption only occurs on the sulfide minerals, to estimate the adsorption densities of the xanthate collectors (in terms of potential monolayer surface coverage). This suggests that at xanthate addition of 50g/t, enough xanthate had been adsorbed to form between 2 to 3 monolayers on the

sulfide mineral surfaces and at a dosage of 150 g/t the amount of xanthate adsorbed was between 5 to 9 monolayers.

Table 5.4: Percentage of xanthate adsorbed for all dosages evaluated on both ores in the presence of guar.

Xanthate Type	% adsorbed 50 g/t dosage	% adsorbed 100 g/t dosage	% adsorbed 150 g/t dosage
Ore A			
SEX	**66.8**	**52.7**	**64.4**
SNPX	**88.6**	**79.6**	**73.9**
SIBX	**96.7**	**90.1**	**82.3**
PAX	**97.9**	**90.4**	**90.1**
Ore B			
SEX	**73.1**	**61.0**	**57.6**
SNPX	**94.0**	**85.4**	**68.6**
SIBX	**98.8**	**95.3**	**91.6**
PAX	**99.0**	**98.6**	**92.8**

Figure 5.28 shows xanthate concentrations in the flotation cell before the commencement of the flotation tests for both ores at the three dosages evaluated for SEX and SIBX in the presence of CMC. For both ores SIBX at a dosage of 50 g/t was below detection limits, whereas for SEX under the same conditions there was approximately 4 mg/l in solution. At a dosage of 100 g/t for SEX, there were about 12 mg/l in solution for Ore A and 11 mg/l for Ore B. These values increased to 20 mg/l and 15 mg/l for Ores A and B respectively, at SEX dosages of 150 g/t. For SIBX the trends were the same as for SEX in that a higher concentration in solution was always found with Ore A. The solution concentrations obtained for SIBX were however significantly lower than those obtained for SEX.

The solution concentrations obtained for CMC were similar to those obtained when guar was used as the depressant and suggests that depressant type did not affect collector adsorption.

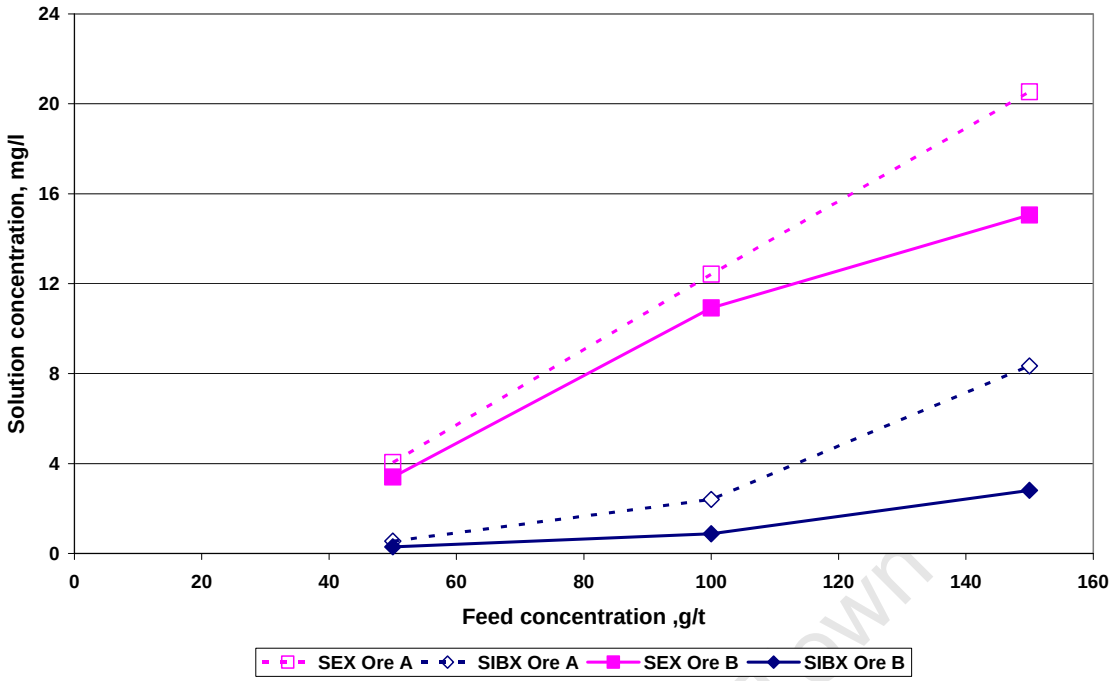

Figure 5.28: Xanthate concentration (mg/l) in solution for SEX and SIBX at all dosages evaluated for both ores in the presence of CMC

5.3 Key Findings

In this testwork four xanthate collectors (SEX, SNPX, SIBX and PAX) of varying chain length were evaluated in the presence of high dosages of guar. In order to evaluate the xanthate collectors in the presence of CMC, two collectors (SEX and SIBX) were selected for evaluation as

At the depressant dosages used in this testwork (500 g/t), it was found that guar was a stronger depressant than CMC, particularly at lower collector dosages. At the highest collector dosage of 150 g/t, faster flotation kinetics (based on water recovery) were obtained with CMC than with guar, possibly due to improved cleaning of fines from mineral surfaces by the highly-charged CMC polymer.

At low collector dosages the higher recoveries obtained with SEX rather than with SIBX indicate that the uniformity of the collector coating may be more important than contact angle in flotation recovery when polymeric depressants are used. At low collector dosages, the residual SIBX concentration was close to zero whereas SEX was still present in solution and this may have an influence on the homogeneity of the collector coating.

The lowest froth stabilities, as indicated by the lowest water recoveries, were obtained from tests using SEX which suggests that destabilisation of the froth was occurring when SEX, which has the lowest contact angle (60°), was used. This suggests that other factors, such as the homogeneity of the surface coating, affecting the ease of movement of the three phase boundary may be more important than contact angle in causing froth destabilisation, and this should be further investigated.

The different response obtained from the two Merensky ores evaluated suggests that the properties of the minerals vary along the Merensky reef and that the nature of mineral surfaces may have an influence on froth stability.

This testwork has demonstrated that the interactions between collectors and depressants as well as the contribution from ore type on the behaviour of both gangue and sulfide minerals on the overall flotation performance of Merensky ores.

6 Discussion

The method developed at UCT which relies on batch flotation tests to assess the amount of floating gangue independently from the amount of entrained gangue reporting to the concentrate was used to determine amounts of floating and entrained gangue for two ores with different mineralogy (Section 5.2). The method relies on batch flotation tests being conducted at depressant dosages of 500 g/t. At this dosage it has been assumed that all floating gangue has been eliminated from the system and that the only gangue reporting to the concentrate would be present due to entrainment. The values determined for the two ores were consistent, which equated to very similar amounts of material entrained per unit of water recovered, despite differences in feed mineralogy between the two ores and the many different conditions evaluated.

Ore B contained larger amounts of pyroxene and sulphide minerals, but lower amounts of talc and plagioclase than Ore A. Although Ore B contained more NFG than Ore A this work has shown that this did not influence the amount of entrained gangue, per unit of water recovered, reporting to the concentrate. The amount of entrained material reporting to the concentrate has been shown to be directly related to the amount of water recovered during flotation (Ekmekci et al., 2003; Yang and Aldrich, 2006; Boylu and Laskowski, 2007; Johnson, 2007).

A number a different methods have been used over the years to quantify entrainment. These include the flotation of non-floating gangue component method proposed by Johnson et al. (1974). This method assumes that all sulfides in the ore are liberated and that gangue present in the concentrate is an indication of entrainment. This use of this method is limited when sulfides present in the ore are not liberated or when gangue is hydrophobic e.g. talc. Another method developed by Trahar (1981) assumes that true flotation does not take place in the absence of a collector. True flotation is thus the difference between tests carried out with and without collector. This method does not take into account naturally floatable material, such as talc and chalcopyrite, and would need a system with no naturally floatable components present for the successful measurement of entrainment. The measurement of non-attached material as used by Savassi (1998) relies on a device

being placed in a flotation cell at a point just below the pulp / froth interface to capture non-attached particles only. The method requires the existence of a quiescent zone below the interface, which is not likely in to exist in highly turbulent batch flotation cells. The tracer method which was employed by Robertson (2003) used MnO_2 as an indicator for entrainment. The assumption is that MnO_2 is not floatable and its presence in the concentrate is thus an indication of entrainment.

The method developed at UCT to quantify entrainment by making use of high depressant dosages allowed for the flotation performance of the two ores to be distinguished from one another. The entrainability values which were determined in this study correlated well with the value determined by Robertson (2003) using the tracer method which was 0.0281.

The entrainability values determined for the two ores using guar and CMC are shown in Table 6.1.

Table 6.1: Entrainability values for the two ores determined from the gradient of the line for results of total gangue versus water recovered.

Ore	Depressant type	Entrainability value
Ore A	**Guar**	**0.0236**
	CMC	**0.0245**
Ore B	**Guar**	**0.0245**
	CMC	**0.0264**

The UCT method is simple and does not require the use of specialised equipment. It may be applied to any ore type without prior knowledge of grind. The method applies to the entire particle size distribution of the feed. NFG, both coarse and fine, would have been prevented from reporting to the concentrate by the high dosage of depressant (500 g/t) used. Sulfides, irrespective of particle size reported to the concentrate by true flotation, and entrained gangue has been assumed to be of a size less than 38 µm. This was confirmed by the size by size analysis of flotation concentrates which showed that the highest amounts of gangue were present in the size fractions smaller than 38 µm. It has previously been shown (Smith and Warren, 1989; Wills and Napier-Munn, 2006) that only particles smaller than 45 µm are expected to be recovered by entrainment. Savassi (1998) found that entrainment

decreases exponentially with an increase in particle size. This study suggests that a particle size of 45 µm is possibly an overestimation of the size of material recovered by entrainment and that the results obtained for gangue present in various size fractions of flotation concentrates are in agreement with the findings of Savassi (1998).

This thesis has shown that the method has, to this point been successfully used to quantify entrainment in Merensky ores with different mineralogy. Ores used to evaluate the method were milled to 60% passing 75 µm. The method has not been evaluated on other ore types or a particle size distribution other than 60% passing 75 µm. The method does not make allowance for the presence of gangue in concentrates as gangue / sulfide composites.

In the testwork to determine the effect of depressant type and dosage on the flotation performance of the two selected Merensky ores, guar and CMC were both effective depressants of NFG (Section 4.2). Floating gangue for these tests was determined using the entrainability value determined by Robertson (2003). At the lower dosages evaluated (100 and 200 g/t) guar was found to be a stronger depressant than CMC for both ores. This agrees with the findings of Shortridge et al. (2003) and Steenberg and Harris (1984) and can be related to increased adsorption. Guar has been shown to adsorb via hydrogen bonding (Steenberg and Harris, 1984; Morris, 1997)) and CMC via an acid / base interaction involving surface metallic sites (Liu et al., 2000; Laskowski et al., 2007).

At dosages of 300 g/t the effect of guar and CMC on NFG was virtually identical in that this dosage was sufficient to reduce NFG to almost zero for both ores in the presence of guar and CMC. Ore B contained almost double the amount of NFG compared to Ore A. In the absence of a depressant (Figure 4.1), 42 g of NFG was recovered from Ore A and 80 g from Ore B, but at a depressant dosage of 300 g/t this NFG was reduced to the same amount (Figures 4.8 and 4.9). Figure 4.19 shows that for both ores the amount of CMC and guar in solution at all three dosages was close to zero and suggests that depressant adsorption, particularly in the presence of calcium (Ca) and magnesium (Mg) ions was strong and that almost all of the polymers were adsorbed at a dosage of 300g/t virtually removing NFG from the

system. The amount of entrained gangue per unit water was the same for both ores and both depressants at all dosages evaluated. This is more than likely due to the fact that both ores were milled to 60% passing 75 µm, and therefore probably contained similar amounts of material in the size ranges normally recovered by entrainment.

The concentration of the two depressants in solution at the end of the batch flotation tests was measured using the du Bois method (Du Bois et al., 1956). The amount of CMC and guar in solution at all three dosages was close to zero and suggests that depressant adsorption, particularly in the presence of Ca and Mg ions was relatively strong and that almost all of the polymers were adsorbed even at a dosage of 300g/t. Previous studies (Becker et al., 2006) have indicated that the major mineral occurring in the NFG is pyroxene, which is a hydrophilic mineral and therefore non-floatable. However, recent QEMSCAN studies have shown that there is a strong association between pyroxene and talc and that the presence of pyroxene in the concentrates is likely due to composite orthopyroxene-talc particles (Becker et al, in press). The mineral requiring depression is thus talc. The amount of talc present in these ores is usually less than 5%. It is known that these polysaccharides are likely to adsorb on any hydrophilic mineral (Steenberg, 1982; Martinovic, 2004; Parolis et al., 2005) as well as the talc. However, it is not known whether preferential adsorption is likely to occur on the talc surfaces rather than the feldspar / pure pyroxene particles. The fact that such high dosages are required to depress the small amount of NFG suggests that adsorption is not occurring selectively on the talc. This may be related to the distribution of talc in that it is preferentially found on the surfaces of orthopyroxene particles.

Froth stability, as indicated by water recovery, was reduced as depressant dosage was increased. This was due to the removal of froth stabilising silicate gangue, e.g. talc, by depressants adsorbing onto gangue mineral surfaces (Steenberg and Harris 1984; Shortridge et al., 2003; Bradshaw et al., 2004).

In the series of batch flotation tests conducted in quintuplicate to evaluate the influence of high dosages of depressant on the different size classes of sulphide and gangue minerals recovered in the concentrate, froth stability effects were different for

the two ores. In tests conducted on Ore A the low masses indicated that froth stability was markedly reduced upon depressant addition (guar and CMC at a dosage of 300 g/t). Although higher masses were recovered from Ore B during the tests conducted in the absence of a depressant, than for Ore A, froth stability was lower than obtained with Ore A. In tests conducted on Ore B there was very little difference in froth stability between tests with no depressant addition and the addition of 300 g/t guar or CMC. This may be as a result of differences in talc liberation between the two ores and the fact that Ore B is more altered, and suggests that there is more liberated talc in Ore A. Liberated talc particles would attach at both interfaces in the froth to keep bubble films apart and therefore lead to stable froths in the absence of depressant.

Of the three major sulfide minerals (chalcopyrite, pentlandite and pyrrhotite) chalcopyrite is known to be the most rapidly floating mineral. Pyrrhotite recovery can be problematic since it constitutes the major sulfide mineral present in the Merensky Reef, but has the slowest rate of recovery. Platinum is often found in varying concentrations in solid solution with pyrrhotite (Kinloch, 1982; Peyerl, 1983). Thus, operations recovering platinum from Merensky ore should focus on ways to overcome this in order to maximise platinum recovery. Pentlandite has a flotation rate lying between the other two sulfide minerals. As depressant dosage was increased, mineral grades increased due to the reduction in NFG reporting to the concentrate which diluted the grade. The slight reduction in mineral recovery at higher depressant concentrations may be due to the reduction in mass recovery. The depression of sulphide-gangue composite particles may also result in a decrease in recovery. Higher sulphide mineral recoveries were obtained from Ore B. The highest grades were obtained when using CMC at a dosage of 300 g/t. This is due to lower froth stabilities obtained and therefore less entrained material reporting to the concentrate to dilute the grade. The entrainability values determined for the two ores relate to a fixed amount of solids entrained per unit water recovered. The lower the amount of water recovered, the lower the amount of entrained solids. This may also be due to the cleaning of fines from the mineral surfaces by CMC at this higher dosage. The sulfur recoveries from both ores were reduced as depressant dosage was increased with guar having a greater depressing effect than CMC. The sulfur recoveries from Ore A were more affected by increased depressant dosage than the

recovery of sulphur from Ore B. This may indicate differences in pyrrhotite mineralogy between the two ores.

In a batch flotation system such as that used for this testwork, it would be expected that particles bigger than 20 µm in size would be recovered by true flotation and that particles less than 20 µm in size are recovered by true flotation and entrainment.

The recovery of more gangue from Ore A in the coarse (+75 µm) size fraction (Figures 4.33 and 4.34) suggests recovery of a greater amount of sulfide / gangue composite particles. This size fraction is too coarse to be recovered by entrainment and its presence is therefore due to flotation. The gangue is likely to be present as composites with chalcopyrite. The chalcopyrite is most likely present as small blebs on gangue particles which reduces the probability of recovery by flotation.

The greatest amount of gangue in most cases was present in the smaller size fractions (-20+5 and -5 µm) as shown in Figures 4.33 and 4.34. This is an indication of entrainment. The amount of gangue in the smaller size fractions is however more than can be attributed to entrainment alone and suggests that at these size fractions gangue was reporting to the concentrate by flotation, possibly as sulfide / gangue composite particles.

In the coarser size fractions gangue would be present either as gangue / sulfide composites or as liberated naturally floatable particles. The results (Figures 4.8 and 4.9) have shown that the depressant dosage (300 g/t) used in the testwork was not sufficient to completely eliminate NFG from the concentrate.

The greatest mass of sulfides was present in the first concentrate (C1) for both ores with the greatest amounts being present in the +38-75 µm size fraction. In this size fraction it would be expected that material would report to the concentrate via true flotation. These higher sulfide masses in the first concentrate, which is only 2 minutes in duration, are due to the fact that because it is the fastest floating sulphide mineral, most of the chalcopyrite in the ore is recovered during the first concentrate of a batch flotation test with very little being recovered in subsequent concentrates.

Pentlandite and pyrrhotite are slower floating and are recovered consistently throughout a batch flotation test.

Greater sulfide masses were obtained from Ore B in the first concentrate (Figure 4.35) in the presence of guar. In the presence of CMC as shown in Figure 4.36 the two ores behaved in a similar manner with higher and similar sulfide masses being recovered in the first two concentrates. Ore B yielded higher sulfide masses in the second concentrate than Ore A. Although the sulfide masses varied between the size fractions and concentrates for the two depressants used, similar masses were recovered from the ores for the two depressant types showing that at the dosage of depressant used (300 g/t) for guar and CMC the valuables present were similarly affected.

Bradshaw et al. (2005); Bradshaw et al. (2006) and Oostendorp (unpublished report) determined the anomalous behaviour that enhanced sulfide mineral recoveries were obtained from a Merensky ore when using SEX than when using the longer chain-length SIBX, at low dosages. Bradshaw et al. (2005) showed that in batch flotation tests on a Merensky ore, lower mass and water recoveries were obtained with the longer chain-length SIBX than with SEX. These tests (Bradshaw et al., 2005) were also conducted at low dosages of depressant. The testwork for this thesis investigated the use of high depressant concentrations as a tool to investigate collector behaviour.

In this study, at the depressant dosage evaluated (500 g/t), all froth stabilising gangue had been prevented from reporting to the concentrate (Figures 5.7 and 5.8 for guar, and Figures 5.24 and 5.25 for CMC). In these tests the stability of the froth was controlled by sulfide minerals attached at the air / water interface. It has been assumed that the hydrophilic gangue particles entrained in the froth would not have any influence on the stability of the froth in these tests. The amount of water recovered varies by more than 100% and indicates that there were significant changes in the ability of the sulfides to destabilise the froth for the different conditions. It has been shown that the destabilisation of froth by hydrophobic solid particles is largely dependent on the contact angle of attachment at the air/water interface. Classical antifoaming solids invariably have contact angles significantly

greater than 90° and it was considered that 90° would be a minimum value necessary to cause destabilisation. Dippenaar (1978) observed that destabilisation may occur at contact angles of lower than 90° depending on the nature and crystal structure of the solid which allowed movement of the 3-phase boundary across the solid. It was established that SIBX (contact angle ~ 70°) adsorption on galena surfaces led to destabilised froths whereas SEX (contact angle ~ 60°) did not. Bradshaw et al. (2004) showed that at low collector dosages (60 g/t) SEX produced more stabilising froths than SIBX irrespective of depressant dosage and that the expected benefits of increasing xanthate collector chain-length were not seen due to the secondary effects of particle hydrophobicity on froth stability. Similarly, Harris et al (in press a,b) observed significantly lower water recoveries (as a measure of froth stability) at lower depressant dosages when using SIBX as the collector than when SEX was used. This suggests that the use of SIBX resulted in froth destabilisation. This work indicates that the low collector dosage of 50 g/t SIBX resulted in lower water recoveries than SEX for both ores. At increased collector dosages SEX produced lower water recoveries than SIBX which was contrary to expected behaviour and suggests that other factors affect the ability of the hydrophobic solids to destabilise froth, particularly in the absence of any stabilising gangue particles.

Mbonambi (2009) investigated the effect of xanthate collector chain length using microflotation tests, on a massive sulphide ore from Nkomati. The rate of flotation increased as the xanthate chain length increased, with the fastest flotation rate achieved with the longest chain length collector. Xanthate chain length had little effect on final recoveries as was found in this study. Oostendorp et al. (unpublished report, 2003) determined that mass and water recoveries decreased as xanthate chain length increased.

On comparison of the two depressants under these conditions it is apparent that the high dosage of CMC had much less of a detrimental effect than the high dosage of guar on sulphide mineral recoveries (particularly at collector dosages of 50 g/t) and at a collector dosage of 150 g/t the initial recoveries of copper and nickel when CMC was used were slightly greater than those obtained when using guar. It should be noted that the final recoveries in all tests conducted using CMC and guar (after 20 minutes of flotation) of the sulfide minerals at the low collector dosage of 50 g/t were

very close to the final recoveries obtained from tests conducted at collector dosages of 150 g/t and that the detrimental effects of the depressant were seen only in the initial stages of the flotation test i.e. the rate of flotation was affected by the high depressant dosages.

Xanthate coated sulfide surfaces are negatively charged and in the presence of negatively charged CMC molecules, repulsion of the two negative charges would occur. This would minimise CMC action on the sulfide minerals even under conditions in which the sulfide mineral surfaces were partially coated by collector. Guar is uncharged and collector dosages when using guar as a depressant would need to be increased in order to counteract the influence of guar on sulfide mineral surfaces.

This testwork indicates that if high depressant dosages are used, collector dosages should be increased to levels around 150 g/t in order to counteract the effects the depressant on mineral recoveries. The results obtained from the determination of the amount of xanthate adsorbed on sulfide mineral surfaces suggest that at the low dosage of 50g/t, there should be sufficient xanthate adsorption to result in multilayer surface coverage. Since severe retardation in the rate of nickel recovery was observed particularly with SIBX, it suggests that the collector coating obtained from the slower-reacting SEX was more uniform than that obtained from SIBX, since guar should not influence the floatability of sulfide particles with a homogeneous hydrophobic surface.

The results obtained from this study suggest that SEX and SNPX, the shorter chain length xanthates, impart a more uniform coverage of sulfide mineral surfaces than the two longer chain length xanthates, SIBX and PAX. In the presence of the shorter chain length xanthates oxidation of the sulfide surfaces can occur rendering the surfaces hydrophilic. More of the longer chain length xanthates react with sulfides resulting in more xanthate present on the surfaces under these conditions. The fact that under these conditions sulfide recovery is reduced may be due to adsorption occurring only on high energy sites on sulfide mineral particles leaving sites vacant for polymer adsorption. That higher recovery of iron sulfides were obtained using SEX may be due to the fact that pyrrhotite and pyrite are recovered via a

dixanthogen mechanism (Hangone et al., 2005; Woods, 1984). SEX oxidises more easily than longer chain length xanthates and would lead to the production of dixanthogen at a higher concentration from SEX than from SIBX. An increase in alkyl chain length decreases the concentration of collector required for effective flotation, and decreases the solubility of the metal salt formed (Kakovsky, 1957). This would need to be proved using surface analytical techniques e.g. ToF-SIMS.

At high depressant concentrations (300 g/t) it has been shown that there was a reduction in sulfide mineral recovery / rate of sulfide mineral recovery. Since depressant is added to the flotation system after collector addition it would not be expected to interfere with collector adsorption and the formation of a hydrophobic surface on sulphide minerals. For the floatability of the sulfide minerals to be impaired by high depressant dosages, adsorption of the depressant on the sulphide mineral surface would need to occur. Since the adsorption of the hydrophilic depressant molecules is considered to occur mainly via hydrogen bonding and long range van der Waals forces it is indicative that the collector coating on the sulfide mineral particles may not be homogeneous and that areas on the sulfide minerals were available where these polymers could interact. The flotation response of sulphide minerals at high depressant dosages may be used to identify the optimum collector type and dosage for the formation of a uniformly hydrophobic surface. It has been shown (Vianna, 2004) that in the absence of polymeric depressants maximum recovery of sulfide minerals such as galena can be achieved at collector coverage levels of around 20%. Buckley and Woods (1991) noticed similar trends with collector coverage in the region of 10%. However, if polymeric depressants are added to the system at significant concentrations (above 300 g/t) optimum collector concentrations for maximum particle surface coverage should be used. When conducting batch flotation tests at depressant dosages of 500 g/t froth stability is not affected by floating gangue, but by hydrophobic sulphide minerals which can cause bubbles to burst and reduce froth stability and entrainment. This leads to an increase in grade, but may result in a decrease in recovery.

On comparison of the two depressants used in this testwork it was apparent that the high dosage of CMC had much less of a detrimental effect than the high dosage of guar on sulfide mineral recoveries (particularly at collector dosages of 50 g/t) and at

a collector dosage of 150 g/t the initial recoveries of copper and nickel when CMC was used were slightly greater than those obtained when using guar. It should be noted that the final recoveries in all tests conducted using CMC and guar (after 20 minutes of flotation) of the sulfide minerals at the low collector dosage of 50 g/t were very close to the final recoveries obtained from tests conducted at collector dosages of 150 g/t and that the detrimental effects of the depressant were seen only in the initial stages of the flotation test i.e. the rate of flotation was affected by the high depressant dosages.

7 Conclusions and Recommendations

7.1 Conclusions

The conclusions are presented as answers to the key questions.

Can the method developed at UCT for a Merensky ore, using high depressant dosages, be used to assess the amount of floating gangue independently from the amount of entrained gangue for two different ores with varying mineralogy?

The amount of material recovered to the concentrate by entrainment has, for the ores used in this study, been successfully quantified using the method developed at UCT. This has allowed the amount of NFG reporting to the concentrate to be determined. The values determined for the two ores were consistent, which equated to very similar amounts of material entrained per unit of water recovered despite differences in feed mineralogy between the two ores. The method assumes that at 500 g/t depressant dosage all floatable gangue has been eliminated from the system and that the only gangue reporting to the concentrate is via entrainment. The method does not take into account gangue reporting to the concentrate as composite particles with sulfide minerals. The entrainability values determined for guar and CMC for the two ores evaluated were very similar. This suggests that for the flotation machine used for this testwork the action of the impeller was such that it was able to counteract the coagulative / dipersive nature of the pulp which would be expected when using high dosages of depressants. The results have shown that the assumptions are valid and that the method is robust. Sizing and mineralogy are not necessary to determine entrainment. This has been validated with the method used by Robertson (2003) as well as by the data obtained from the sized concentrates.

How does depressant type and dosage affect both floatable and entrained gangue, as well as sulfide mineral recovery for different Merensky ores and is the behaviour consistent for ores with different amounts of gangue?

This study has shown that at a depressant dosage of 300 g/t both guar and CMC were found to be effective depressants in eliminating almost all NFG from the system for both ores. Although Ore B contained almost double the amount of floating gangue compared to Ore A, the NFG was similarly reduced at this dosage. At the

lower depressant dosages evaluated, guar was a more effective depressant of NFG than CMC. This may be due to the different adsorption mechanisms of guar and CMC onto mineral surfaces. The adsorption of guar on mineral surfaces occurs via hydrogen bonding. The presence of divalent cations is necessary for the adsorption of CMC, which occurs via an acid / base interaction involving surface metallic sites.

The use of guar at higher dosages led to a reduction in sulfide mineral recovery for both ores, whereas higher dosages of CMC had little effect on the recovery of sulfides from the two ores. This is possibly due to the differences in the adsorption mechanisms and interactions of guar and CMC, with CMC being more effective at reducing the adsorption of fines on sulfide surfaces due to its charge nature. At high dosages CMC has a destabilising effect and reduces froth stability, which is an indication of improved hydrophobicity resulting from the removal of fines.

The effect of the two depressants on the recovery of sulfur was ore dependent in that iron sulfides in Ore B were less susceptible to increased depressant dosage than those in Ore A. This indicates that pyrrhotite mineralogy may be different between the two ores and should be further investigated.

How do high dosages of depressant influence the different size classes of sulfide and gangue minerals recovered to the concentrate by true flotation, and is this affected by depressant type?

This study has shown that for the batch flotation system used, entrainment of material occurred in the size fractions smaller than 20 µm as seen in the results for gangue mass per size fraction for concentrates collected during the batch flotation tests. The amount of gangue present in the coarse size fraction (+75 µm) in the final concentrate collected from Ore A suggests the recovery of sulfide / gangue composite particles. Chalcopyrite is known to be the most rapidly floating mineral and therefore is relatively unaffected by depressant addition. Pyrrhotite recovery can be problematic since it constitutes the major sulfide mineral present in the Merensky Reef, but has the slowest rate of recovery, being recovered throughout a btach flotation test. Pentlandite has a flotation rate lying between the other two sulfide minerals.

The evaluation of the use of high dosages of both guar and CMC as depressants has shown that in the absence of hydrophobic gangue particles the froth was unstable. Depressant addition resulted in these froth stabilising NFG particles being rendered hydrophilic. Due to the reduction in froth stability the amount of material recovered via entrainment was also reduced. The stability of the froth under these conditions was controlled by the hydrophobic sulfide minerals which attach at the air / water interface. In some cases (guar with SIBX) the reduced froth stability resulted in a decrease in the recovery of valuables. If high depressant dosages are to be used, collector dosages should be increased to counteract the effects of the depressant. Reagents such as frothers and secondary collectors such as DTP which are surface active and directly affect froth stability may be used to increase froth stability.

How does collector (xanthate) type and dosage affect both floatable and entrained gangue as well as sulfide mineral recovery for different Merensky ores?

The xanthate collector with the shortest chain length, SEX, at a dosage of 150 g/t yielded the highest iron sulfide mineral recoveries for both ores in the presence of guar and CMC. At the lower collector dosage of 50 g/t final recoveries for Ore B were similar to those obtained for the 150 g/t dosage. The rate of recovery was, however retarded. For Ore A recoveries at the 50 g/t dosage were approximately 5% lower than those obtained at the xanthate dosage of 150 g/t. Copper and nickel recoveries were largely unaffected by xanthate chain length or dosage in this testwork.

How does depressant behaviour affect collector / mineral interactions?

This work has demonstrated the interactions between collectors and depressants as well as the contribution from ore type on the behaviour of both gangue and sulfide minerals on the overall flotation performance of Merensky ores. At the high depressant dosage used, it was apparent that guar was a stronger depressant than CMC, particularly at lower collector dosages. At the highest collector dosage of 150g/t, faster flotation kinetics (based on water recovery) were obtained with CMC than with guar, possibly due to the better cleaning fines from of sulfide mineral particles by the highly-charged CMC polymer.

7.2 Recommendations

On the basis of the contributions and findings from this study, recommendations for future wok in this field are listed below:

The various size fractions of the concentrates from the batch flotation tests conducted in the presence of 300 g/t guar and CMC, and no depressant should be submitted for Quantitative Mineralogical Analysis. This would elucidate whether differences observed in the flotation behaviour of the two ores can be confirmed mineralogically. This would also show which minerals are affected by depressant addition (sulphide and gangue) and to what extent sulfide / gangue composite particles are recovered or not recovered in the presence of a depressant.

XRD should be used to determine whether the differences in pyrrhotite flotation between the two ores are due to the hexagonal or monoclinic structure of pyrrhotite.

Concentrates from selected tests should be submitted for PGM analysis in order to determine the effect of depressant type and dosage and collector chain length and dosage on the recovery of PGMs in these ores.

The feeds of the two ores evaluated should be sized in order for recovery of the sulfide minerals by size to be calculated.

Investigations using batch flotation tests should be conducted using Merensky ores milled to different sizes to establish to what extent the entrainment of fine material varies between samples of different particle size distributions and how significant these variations are. The effect of reagents such as frother and activator should also be investigated.

This study has focused on the characterisation of two Merensky ores. It is recommended that a similar investigation be carried out using UG2 ores.

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http://www.lsbu.ac.uk/water/hygua

http://www.Isbu.ac.uk/water/hycmc

Appendix A
Experimental procedures

A1 Batch Flotation Procedure

Mill ore to 60% passing 75 µm in the presence of collector at 66% solids in synthetic plant water using charge as specified

Transfer to Perspex flotation cell and make up to mark (35% solids) using synthetic plant water

Take feed sample
0 minutes Add depressant
2 minutes Add frother
3 minutes Turn air on and allow froth to develop
5 minutes First concentrate
9 minutes Second concentrate
15 minutes Third concentrate
23 minutes Fourth concentrate
Turn air off
Take tailings sample
Filter all samples (feed, concentrates and tailings)
Dry overnight at 65ºC

A2 Du Bois method to determine depressant in solution

Equipment:

Test tubes
Test tube holder
Water bath
Phenol
Sulphuric acid
Quartz cuvettes
Adjustable air-displacement pipette
UV spectrophotometer

- Add 1ml of test solution to glass test tubes reserving one test tube for the blank to which 1ml of water is added
- Add 1 ml phenol (5% m/v) to each test tube
- Dispense 5 ml concentrated sulphuric acid rapidly into the middle of the liquid surface in each test tube
- Immediately place test tube on vortex stirrer for 2 seconds
- Allow test tubes to reach room temperature in a fume cupboard (approximately 30 minutes)
- Place the test tubes in a water bath at 25˚C for 30 minutes

The spectra of test solutions are measured using quartz cuvettes on an Ultrospec Ultra Violet spectrophotometer with respect to a blank at a wavelength of 490 nm. 490 nm is the wavelength determined for use in the measurement of hexoses (du Bois et al., 1956).

A3 Synthetic plant water

Recipe for a 40 litre batch

Chemical Salt	Mass in grams
$MgSO_4.7H_2O$	24.60
$Mg(NO_3).6H_2O$	4.28
$Ca(NO_3)^2.4H_2O$	9.44
$CaCl_2$	4.44
NaCl	14.24
Na_2CO_3	1.20

Add chemical salts to 40 litres of distilled water in the order in which they are listed. Stir well after each addition to ensure that salt is dissolved before subsequent additions.

All salts are CP (chemically pure) grade.

Appendix B
Batch flotation data

Flotation conditions	Sample ID	Time mins	Mass g	Cum mass g	Cum water g	Copper grade %	Copper recovery %	Nickel grade %	Nickel recovery %	Sulphur grade %	Sulphur recovery %	Entrained gangue g	Floating gangue g
ORE A	C1	2	21.71	21.71	103.99	1.73	64.5	0.44	6.8	2.26	17.9	2.50	17.9
No collector	C2	6	17.65	39.36	240.5	1.10	74.3	0.43	12.0	1.59	22.8	5.77	31.9
No depressant	C3	12	14.94	54.30	412.4	0.83	77.5	0.42	16.2	1.30	25.7	9.90	42.5
DOW 200 40 g/t	C4	20	9.74	64.04	567.7	0.72	79.3	0.41	18.5	1.17	27.4	13.63	48.4
	Feed		1039.82										
	Tails		975.78										
ORE A	C1	2	23.23	23.23	118.6	1.56	61.5	0.39	6.4	2.01	15.7	2.85	19.1
No collector	C2	6	18.61	41.84	274.3	1.03	72.9	0.40	11.9	1.44	20.3	6.58	33.6
No depressant	C3	12	13.08	54.92	438.3	0.82	76.4	0.40	15.4	1.24	22.9	10.52	42.5
DOW 200 40 g/t	C4	20	8.52	63.44	580.0	0.72	77.9	0.39	17.6	1.14	24.3	13.92	47.5
	Feed		1038.15										
	Tails		974.71										
ORE B	C1	2	34.82	34.82	68.0	1.25	57.4	0.30	5.2	1.57	14.1	1.63	31.7
No collector	C2	6	21.48	56.30	147.6	0.98	72.7	0.29	8.1	1.26	18.4	3.54	50.8
No depressant	C3	12	15.66	71.96	244.1	0.82	78.2	0.29	10.3	1.11	20.7	5.86	63.9
DOW 200 40 g/t	C4	20	10.15	82.11	336.0	0.75	80.8	0.29	11.8	1.05	22.2	8.06	71.7
	Feed		1041.08										
	Tails		958.97										
ORE B	C1	2	37.71	37.71	75.8	1.08	51.8	0.23	4.4	1.50	15.9	1.82	34.3
No collector	C2	6	23.55	61.26	188.8	0.87	68.0	0.23	7.1	1.19	20.6	4.53	54.7
No depressant	C3	12	16.56	77.82	297.8	0.74	73.2	0.23	9.2	1.03	22.7	7.15	68.5
DOW 200 40 g/t	C4	20	11.15	88.97	410.5	0.67	75.7	0.24	10.7	0.96	24.2	9.85	76.8
	Feed		1027.7										
	Tails		938.73										

Flotation conditions	Sample ID	Time mins	Mass g	Cum mass g	Cum water g	Copper grade %	Copper recovery %	Nickel grade %	Nickel recovery %	Sulphur grade %	Sulphur recovery %	Entrained gangue g	Floating gangue g
ORE A	C1	2	12.19	12.19	29.8	2.94	60.18	3.33	31.3	11.3	46.8	0.84	7.6
SIBX 50 g/t mill	C2	6	15.08	27.27	102.6	1.50	68.6	2.15	45.2	6.96	64.5	2.88	19.2
DOW 200 40 g/t	C3	12	18.13	45.40	234.8	0.96	73.4	1.50	52.5	4.87	75.1	6.60	32.7
No depressant	C4	20	16.52	61.92	416.5	0.73	76.1	1.18	56.4	3.87	81.4	11.70	43.6
	Feed		1004.95										
	Tails		943.03										
ORE A	C1	2	11.17	11.17	26.1	3.38	61.3	3.77	31.3	12.90	44.1	0.73	6.5
SIBX 50 g/t mill	C2	6	14.91	26.08	96.7	1.68	71.1	2.41	46.7	7.90	63.0	2.72	17.7
DOW 200 40 g/t	C3	12	18.92	45.00	235.9	1.04	76.2	1.62	54.2	5.38	74.1	6.63	31.7
No depressant	C4	20	15.59	60.59	404.2	0.80	78.8	1.29	58.1	4.31	79.9	11.36	42.1
	Feed		996.9										
	Tails		936.31										
ORE A	C1	2	17.35	17.35	64.9	2.36	64.8	3.32	40.7	10.50	56.7	1.82	10.5
SIBX 37.5 g/t mill	C2	6	14.17	31.52	170.9	1.43	71.2	2.24	50.0	6.92	67.9	4.80	20.7
Senkol 5 (DTP) 37,5 g/	C3	12	17.54	49.06	352.8	0.97	75.0	1.60	55.4	5.04	77.0	9.91	32.4
DOW 200 40 g/t	C4	20	15.58	64.64	567.2	0.76	77.5	1.28	58.7	4.08	82.1	15.94	41.5
No depressant	Feed		1025.24										
	Tails		960.6										
ORE A	C1	2	18.37	18.37	72.0	2.21	65.4	3.17	41.2	9.96	57.9	2.02	11.3
SIBX 37.5 g/t mill	C2	6	15.66	34.03	194.8	1.32	72.2	2.09	50.2	6.47	69.7	5.47	22.5
Senkol 5 (DTP) 37,5 g/	C3	12	19.31	53.34	405.8	0.89	76.3	1.48	55.7	4.65	78.5	11.40	35.1
DOW 200 40 g/t	C4	20	16.09	69.43	639.0	0.71	78.8	1.20	58.9	3.78	83.2	17.96	44.3
No depressant	Feed		1011.45										
	Tails		942.02										

Flotation conditions	Sample ID	Time mins	Mass g	Cum mass g	Cum water g	Copper grade %	Copper recovery %	Nickel grade %	Nickel recovery %	Sulphur grade %	Sulphur recovery %	Entrained gangue g	Floating gangue g
ORE B	C1	2	21.25	21.25	38.8	3.03	77.5	3.22	34.8	8.11	43.2	1.09	15.4
SIBX 50 g/t mill	C2	6	18.04	39.29	93.2	1.74	82.6	2.35	46.9	5.43	53.6	2.62	30.8
DOW 200 40 g/t	C3	12	21.99	61.28	184.9	1.17	86.4	1.75	54.7	4.11	63.2	5.20	49.2
No depressant	C4	20	21.17	82.45	319.5	0.90	89.2	1.41	59.3	3.40	70.3	8.98	65.8
	Feed		1080.81										
	Tails		998.36										
ORE B	C1	2	27.7	27.70	51.9	2.52	79.1	2.83	38.4	7.06	46.0	1.46	20.9
SIBX 50 g/t mill	C2	6	16.78	44.48	102.4	1.69	85.2	2.19	47.9	5.12	53.6	2.88	35.3
DOW 200 40 g/t	C3	12	21.38	65.86	195.3	1.18	88.4	1.69	54.5	3.99	61.8	5.49	53.2
No depressant	C4	20	21.30	87.16	338.3	0.92	90.9	1.38	59.0	3.35	68.6	9.51	69.7
	Feed		1131.82										
	Tails		1044.66										
ORE B	C1	2	34.31	34.31	104.5	1.74	79.9	2.48	46.4	5.36	54.1	2.94	26.3
SIBX 37.5 g/t mill	C2	6	26.39	60.70	258.6	1.07	87.0	1.69	55.9	3.57	63.8	7.27	47.5
enkol 5 (DTP) 37,5 g	C3	12	30.78	91.48	546.7	0.74	90.5	1.23	61.2	2.69	72.3	15.36	69.4
DOW 200 40 g/t	C4	20	19.52	111.00	815.2	0.62	92.2	1.06	64.0	2.35	76.6	22.91	80.9
No depressant	Feed		935.97										
	Tails		824.97										
ORE B	C1	2	29.81	29.81	77.9	2.16	80.6	2.61	42.4	6.03	49.3	2.19	22.7
SIBX 37.5 g/t mill	C2	6	28.01	57.82	227.1	1.20	86.7	1.69	53.4	3.80	60.3	6.38	45.4
enkol 5 (DTP) 37,5 g	C3	12	28.06	85.88	459.7	0.84	90.0	1.26	59.2	2.90	68.2	12.92	66.1
DOW 200 40 g/t	C4	20	21.57	107.45	718.3	0.68	91.9	1.06	62.4	2.48	73.0	20.18	80.0
No depressant	Feed		1027.07										
	Tails		919.62										

Flotation conditions	Sample ID	Time mins	Mass g	Cum mass g	Cum water g	Copper grade %	Copper recovery %	Nickel grade %	Nickel recovery %	Sulphur grade %	Sulphur recovery %	Entrained gangue g	Floating gangue g
ORE A	C1	2	9.23	9.23	52.0	3.85	59.2	5.43	36.4	17.20	53.2	1.46	3.41
SIBX/DTP 37.5 g/t mill	C2	6	9.84	19.07	158.5	2.14	68.0	3.41	47.2	10.67	68.2	4.45	9.03
DOW 200 40 g/t	C3	12	12.79	31.86	324.4	1.36	72.2	2.24	52.0	7.11	75.9	9.11	16.53
CMC 100 g/t	C4	20	13.48	45.34	530.0	0.99	75.0	1.69	55.6	5.34	81.1	14.89	23.81
	Feed		993.24										
	Tails		947.9										
ORE A	C1	2	8.42	8.42	44.2	3.95	56.0	5.53	34.7	17.90	48.67	1.24	3.04
SIBX/DTP 37.5 g/t mill	C2	6	9.82	18.24	143.4	2.14	65.8	3.51	47.7	11.05	65.10	4.03	8.68
DOW 200 40 g/t	C3	12	14.04	32.28	318.3	1.30	70.7	2.22	53.3	7.09	73.94	8.94	17.05
CMC 100 g/t	C4	20	13.97	46.25	526.1	0.95	73.7	1.65	56.8	5.31	79.31	14.78	24.73
	Feed		1002.47										
	Tails		956.22										
ORE A	C1	2	6.85	6.85	56.2	4.61	57.0	5.40	28.4	18.20	43.36	1.58	1.85
SIBX/DTP 37.5 g/t mill	C2	6	4.49	11.34	135.4	3.33	68.0	4.81	41.8	15.15	59.76	3.80	2.82
DOW 200 40 g/t	C3	12	6.93	18.27	272.6	2.10	69.1	3.44	48.2	10.93	69.45	7.66	5.13
CMC 200 g/t	C4	20	9.43	27.70	457.6	1.45	72.4	2.45	52.0	7.95	76.60	12.86	8.80
	Feed		984.25										
	Tails		956.55										
ORE A	C1	2	6.75	6.75	69.4	4.93	56.7	6.92	33.6	21.30	47.7	1.95	0.85
SIBX/DTP 37.5 g/t mill	C2	6	5.3	12.05	173.5	3.14	64.4	5.15	44.7	15.23	60.9	4.88	2.14
DOW 200 40 g/t	C3	12	8.2	20.25	337.4	1.99	68.7	3.43	50.0	10.32	69.4	9.48	5.03
CMC 200 g/t	C4	20	10.15	30.40	539.6	1.38	71.6	2.45	53.6	7.47	75.3	15.16	9.01
	Feed		979.38										
	Tails		948.98										
ORE A	C1	2	3.8	3.80	35.5	7.72	48.3	8.15	22.5	26.10	32.8	1.00	0.08
SIBX/DTP 37.5 g/t mill	C2	6	3.6	7.40	116.4	4.87	59.4	7.20	38.7	19.97	48.8	3.27	0.07
DOW 200 40 g/t	C3	12	4.04	11.44	231.3	3.36	63.2	5.57	46.3	15.32	57.9	6.50	0.13
CMC 300 g/t	C4	20	5.88	17.32	398.9	2.32	66.3	4.02	50.5	11.43	65.4	11.21	0.68
	Feed		977.55										
	Tails		960.23										
ORE A	C1	2	3.56	3.56	32.1	8.38	50.4	8.61	20.8	26.80	31.4	0.90	0.04
SIBX/DTP 37.5 g/t mill	C2	6	3.64	7.20	110.9	5.15	62.6	7.83	38.3	20.53	48.7	3.12	0.03
DOW 200 40 g/t	C3	12	4.23	11.43	230.7	3.47	66.9	6.00	46.5	15.65	58.9	6.48	0.04
CMC 300 g/t	C4	20	6.04	17.47	404.4	2.38	70.3	4.33	51.4	11.66	67.1	11.36	0.52
	Feed		987.11										
	Tails		969.64										

Flotation conditions	Sample ID	Time mins	Mass g	Cum mass g	Cum water g	Copper grade %	Copper recovery %	Nickel grade %	Nickel recovery %	Sulphur grade %	Sulphur recovery %	Entrained gangue g	Floating gangue g
ORE A	C1	2	7.44	7.44	59.1	4.45	58.5	6.33	35.7	18.70	49.1	1.66	1.96
SIBX/DTP 37.5 g/t mill	C2	6	6.69	14.13	161.8	2.65	66.1	4.26	45.6	12.51	62.3	4.55	4.74
DOW 200 40 g/t	C3	12	9.16	23.29	311.7	1.71	70.3	2.86	50.4	8.58	70.5	8.76	9.05
Guar 100 g/t	C4	20	11.19	34.48	508.2	1.20	73.2	2.07	53.9	6.29	76.5	14.28	14.25
	Feed		994.40										
	Tails		959.92										
ORE A	C1	2	7.38	7.38	59.1	4.58	56.1	6.52	34.2	18.70	45.38	1.66	1.93
SIBX/DTP 37.5 g/t mill	C2	6	6.7	14.08	156.9	2.76	64.6	4.56	45.7	12.82	59.35	4.41	4.72
DOW 200 40 g/t	C3	12	8.79	22.87	294.5	1.82	69.0	3.11	50.5	8.94	67.27	8.27	8.98
Guar 100 g/t	C4	20	10.23	33.10	466.5	1.31	71.9	2.29	53.9	6.71	73.05	13.11	13.90
	Feed		1024.09										
	Tails		990.99										
ORE A	C1	2	5.9	5.90	73.5	5.74	53.5	7.72	31.4	21.40	41.08	2.07	0.37
SIBX/DTP 37.5 g/t mill	C2	6	4.29	10.19	168.6	3.87	62.4	6.08	42.8	16.33	54.15	4.74	0.89
DOW 200 40 g/t	C3	12	5.89	16.08	311.0	2.63	66.9	4.39	48.8	12.10	63.33	8.74	2.00
Guar 200 g/t	C4	20	7.15	23.23	484.9	1.91	70.0	3.26	52.3	9.28	70.16	13.63	3.69
	Feed		990.50										
	Tails		967.27										
ORE A	C1	2	5.91	5.91	73.2	5.47	54.0	7.24	30.4	20.30	39.4	2.06	0.56
SIBX/DTP 37.5 g/t mill	C2	6	4.28	10.19	168.0	3.68	62.6	5.78	41.8	15.56	52.1	4.72	1.12
DOW 200 40 g/t	C3	12	5.61	15.80	299.2	2.54	67.0	4.25	47.7	11.75	61.0	8.41	2.30
Guar 200 g/t	C4	20	6.97	22.77	465.0	1.84	70.0	3.17	51.2	9.02	67.5	13.07	4.07
	Feed		1013.81										
	Tails		991.04										
ORE A	C1	2	5.24	5.24	95.8	5.59	50.5	5.50	22.3	19.10	32.4	2.69	0.00
SIBX/DTP 37.5 g/t mill	C2	6	3.02	8.26	182.9	4.14	58.8	5.24	33.4	16.07	42.9	5.14	0.00
DOW 200 40 g/t	C3	12	3.84	12.10	309.1	3.04	63.3	4.54	42.4	13.11	51.3	8.69	0.00
Guar 300 g/t	C4	20	4.69	16.79	465.4	2.31	66.9	3.77	48.9	10.99	59.7	13.08	0.00
	Feed		986.46										
	Tails		969.67										
ORE A	C1	2	4.46	4.46	75.4	6.45	46.7	5.19	16.4	20.90	29.4	2.12	0.00
SIBX/DTP 37.5 g/t mill	C2	6	3.09	7.55	158.8	4.64	56.9	5.41	28.9	17.13	40.9	4.46	0.00
DOW 200 40 g/t	C3	12	3.79	11.34	272.7	3.36	61.8	4.77	38.3	14.00	50.1	7.66	0.00
Guar 300 g/t	C4	20	5.23	16.57	426.6	2.44	65.7	3.89	45.7	11.38	59.6	11.99	0.00
	Feed		1023.89										
	Tails		1007.32										

Flotation conditions	Sample ID	Time mins	Mass g	Cum mass g	Cum water g	Copper grade %	Copper recovery %	Nickel grade %	Nickel recovery %	Sulphur grade %	Sulphur recovery %	Entrained gangue g	Floating gangue g
ORE B	C1	2	15.07	15.07	69.6	4.03	77.2	4.84	38.6	11.70	52.2	1.96	8.28
SIBX/DTP 37.5 g/t mill	C2	6	19.05	34.12	215.3	1.98	85.6	2.76	49.9	6.49	65.6	6.05	22.00
DOW 200 40 g/t	C3	12	25.76	59.88	467.7	1.17	89.0	1.73	55.0	4.14	73.4	13.14	39.94
CMC 100 g/t	C4	20	20.82	80.70	727.8	0.89	91.0	1.35	57.8	3.24	77.5	20.45	53.07
	Feed		1027.73										
	Tails		947.03										
ORE B	C1	2	16.98	16.98	80.2	3.70	78.0	4.55	41.0	10.80	53.17	2.25	9.70
SIBX/DTP 37.5 g/t mill	C2	6	18.71	35.69	221.3	1.92	85.1	2.65	50.1	6.21	64.23	6.22	23.39
DOW 200 40 g/t	C3	12	25.1	60.79	466.0	1.18	88.7	1.71	55.2	4.07	71.80	13.09	40.90
CMC 100 g/t	C4	20	21.76	82.55	743.1	0.88	90.7	1.33	58.1	3.17	75.79	20.88	54.50
	Feed		1023.65										
	Tails		941.10										
ORE B	C1	2	5.33	5.33	50.7	9.06	65.3	9.45	27.2	24.00	37.37	1.42	0.397
SIBX/DTP 37.5 g/t mill	C2	6	4.45	9.78	141.3	5.84	77.2	8.38	44.2	18.04	51.54	3.97	0.970
DOW 200 40 g/t	C3	12	6.65	16.43	271.6	3.67	81.5	5.71	50.6	12.37	59.39	7.63	3.220
CMC 200 g/t	C4	20	11.27	27.70	464.3	2.26	84.6	3.66	54.7	8.20	66.36	13.05	8.419
	Feed		975.38										
	Tails		947.68										
ORE B	C1	2	6.88	6.88	51.7	7.91	70.2	9.75	32.2	23.00	42.6	1.45	1.09
SIBX/DTP 37.5 g/t mill	C2	6	6.04	12.92	149.6	4.84	80.7	7.32	45.5	15.93	55.4	4.20	3.07
DOW 200 40 g/t	C3	12	11.26	24.18	328.8	2.73	85.0	4.40	51.2	9.80	63.8	9.24	8.44
CMC 200 g/t	C4	20	15.56	39.74	568.3	1.71	87.4	2.86	54.5	6.51	69.7	15.97	16.67
	Feed		1026.57										
	Tails		986.83										
ORE B	C1	2	4.14	4.14	39.4	11.21	64.9	9.29	20.3	26.70	30.8	1.11	0.00
SIBX/DTP 37.5 g/t mill	C2	6	3.82	7.96	130.5	7.14	79.5	9.78	41.2	21.61	47.9	3.67	0.00
DOW 200 40 g/t	C3	12	4.15	12.11	271.8	4.94	83.6	7.66	49.0	16.81	56.6	7.64	0.00
CMC 300 g/t	C4	20	6.35	18.46	480.0	3.35	86.4	5.45	53.2	12.36	63.5	13.49	0.00
	Feed		972.96										
	Tails		954.50										
ORE B	C1	2	4.15	4.15	36.2	11.53	66.3	9.46	20.8	27.20	31.3	1.02	0.03
SIBX/DTP 37.5 g/t mill	C2	6	3.8	7.95	125.4	7.22	79.5	9.86	41.5	21.99	48.5	3.52	0.00
DOW 200 40 g/t	C3	12	4.39	12.34	266.1	4.91	83.9	7.63	49.8	16.73	57.3	7.48	0.00
CMC 300 g/t	C4	20	6.79	19.13	477.8	3.28	86.8	5.35	54.2	12.06	64.1	13.43	0.00
	Feed		1019.03										
	Tails		999.90										

Flotation conditions	Sample ID	Time mins	Mass g	Cum mass g	Cum water g	Copper grade %	Copper recovery %	Nickel grade %	Nickel recovery %	Sulphur grade %	Sulphur recovery %	Entrained gangue g	Floating gangue g
ORE B	C1	2	12.76	12.76	76.9	4.70	76.9	6.14	39.7	14.00	49.8	2.16	5.70
SIBX/DTP 37.5 g/t mill	C2	6	12.83	25.59	199.8	2.60	85.3	3.80	49.3	8.41	60.1	5.62	14.07
DOW 200 40 g/t	C3	12	18.02	43.61	397.9	1.59	88.7	2.44	53.9	5.47	66.6	11.18	25.88
Guar 100 g/t	C4	20	18.74	62.35	635.2	1.14	91.0	1.80	57.0	4.13	71.8	17.85	37.44
	Feed		1006.91										
	Tails		944.56										
ORE B	C1	2	9.81	9.81	56.0	5.43	72.9	6.62	33.1	15.20	41.31	1.57	4.15
SIBX/DTP 37.5 g/t mill	C2	6	11.83	21.64	166.1	2.81	83.0	4.25	46.9	9.13	54.71	4.67	11.55
DOW 200 40 g/t	C3	12	18.01	39.65	352.7	1.61	87.3	2.59	52.3	5.65	62.04	9.91	23.59
Guar 100 g/t	C4	20	19.6	59.25	594.3	1.11	90.1	1.85	55.8	4.11	67.42	16.70	35.87
	Feed		989.05										
	Tails		929.80										
ORE B	C1	2	7.59	7.59	85.2	7.31	72.6	9.40	37.2	20.40	43.15	2.39	0.95
SIBX/DTP 37.5 g/t mill	C2	6	5.86	13.45	205.4	4.62	81.2	6.91	48.5	14.39	53.95	5.77	2.37
DOW 200 40 g/t	C3	12	9.52	22.97	397.8	2.84	85.5	4.52	54.1	9.58	61.29	11.18	5.76
Guar 200 g/t	C4	20	11.35	34.32	610.3	1.96	87.9	3.20	57.3	6.94	66.36	17.15	10.64
	Feed		1023.86										
	Tails		989.54										
ORE B	C1	2	7.26	7.26	79.8	7.46	70.9	9.97	36.5	21.00	41.2	2.24	0.83
SIBX/DTP 37.5 g/t mill	C2	6	5.82	13.08	200.3	4.68	80.1	7.35	48.4	14.83	52.4	5.63	2.13
DOW 200 40 g/t	C3	12	8.75	21.83	378.8	2.96	84.6	4.90	53.8	10.21	60.2	10.64	5.07
Guar 200 g/t	C4	20	11.26	33.09	594.0	2.01	87.2	3.42	57.0	7.37	65.8	16.69	9.71
	Feed		1018.66										
	Tails		985.57										
ORE B	C1	2	6.69	6.69	77.3	8.59	66.6	9.21	28.0	21.40	34.4	2.17	0.59
SIBX/DTP 37.5 g/t mill	C2	6	4.88	11.57	181.9	5.68	76.3	8.18	42.9	16.80	46.7	5.11	1.13
DOW 200 40 g/t	C3	12	6.2	17.77	325.5	3.92	80.8	6.21	50.1	12.83	54.8	9.15	2.37
Guar 300 g/t	C4	20	7.63	25.40	496.2	2.84	83.7	4.67	53.8	9.96	60.8	13.94	4.51
	Feed		1128.10										
	Tails		1102.70										
ORE B	C1	2	6.46	6.46	104.6	8.25	68.1	8.53	26.5	20.70	33.5	2.94	0.45
SIBX/DTP 37.5 g/t mill	C2	6	3.84	10.30	211.0	5.81	76.6	8.24	40.9	17.08	44.1	5.93	1.03
DOW 200 40 g/t	C3	12	5.81	16.11	385.5	3.94	81.2	6.31	49.0	13.01	52.5	10.83	1.98
Guar 300 g/t	C4	20	6.68	22.79	577.7	2.90	84.5	4.83	53.0	10.23	58.4	16.23	3.99
	Feed		1024.14										
	Tails		1001.35										

Flotation conditions	Sample ID	Time mins	Mass g	Cum mass g	Cum water g	Copper grade %	Copper recovery %	Nickel grade %	Nickel recovery %	Sulphur grade %	Sulphur recovery %	Entrained gangue g	Floating gangue g
ORE A	C1	2	14.85	14.85	79.8	3.46	75.3	4.05	34.38	9.90	43.57	1.91	8.90
SIBX 100 g/t mill	C2	6	13.6	28.45	197.1	1.99	83.0	3.04	49.55	6.73	56.71	4.73	18.47
DOW 200 40 g/t	C3	12	15.3	43.75	369.0	1.34	86.2	2.21	55.27	4.98	64.60	8.86	28.91
No depressant	C4	20	13.81	57.56	570.1	1.05	88.2	1.78	58.53	4.08	69.59	13.68	37.44
	Feed		1027.93										
	Tails		970.37										
ORE A	C1	2	11.61	11.61	52.9	4.10	72.1	4.18	28.43	10.90	36.58	1.27	6.87
SIBX 100 g/t mill	C2	6	14.41	26.02	163.9	2.07	81.6	3.13	47.70	6.90	51.91	3.93	17.16
DOW 200 40 g/t	C3	12	15.51	41.53	323.7	1.35	85.0	2.22	54.01	5.04	60.51	7.77	28.02
No depressant	C4	20	15.11	56.64	528.4	1.02	87.4	1.73	57.46	4.03	66.02	12.68	37.69
	Feed		1044.64										
	Tails		988.00										
ORE A	C1	2	13.27	13.27	63.5	3.91	73.9	4.33	33.61	10.70	42.13	1.52	7.85
SIBX 100 g/t mill	C2	6	13.37	26.64	169.3	2.15	81.8	3.24	50.43	7.06	55.78	4.06	17.42
DOW 200 40 g/t	C3	12	16.51	43.15	344.5	1.38	85.2	2.25	56.92	5.08	64.99	8.27	28.87
No depressant	C4	20	14.83	57.98	546.3	1.06	87.3	1.77	60.18	4.09	70.36	13.11	38.36
	Feed		1060.97										
	Tails		1002.99										
ORE A	C1	2	9.75	9.75	42.2	4.84	69.3	4.43	24.04	12.00	33.35	1.01	5.53
SIBX 100 g/t mill	C2	6	14.23	23.98	148.0	2.32	81.6	3.54	47.18	7.67	52.45	3.55	15.38
DOW 200 40 g/t	C3	12	17.89	41.87	335.5	1.40	85.9	2.36	54.92	5.33	63.56	8.05	27.70
No depressant	C4	20	14.04	55.91	529.1	1.07	88.2	1.87	58.11	4.32	68.89	12.70	36.58
	Feed		1048.35										
	Tails		992.44										
ORE A	C1	2	13.44	13.44	68.9	3.69	72.3	3.92	29.09	10.40	39.98	1.65	7.95
SIBX 100 g/t mill	C2	6	14.20	27.64	181.4	2.05	82.5	3.07	46.90	6.95	54.93	4.35	18.02
DOW 200 40 g/t	C3	12	17.17	44.81	367.6	1.32	86.0	2.17	53.83	5.02	64.40	8.82	29.81
No depressant	C4	20	15.23	60.04	587.9	1.01	88.4	1.72	57.23	4.08	70.07	14.11	39.21
	Feed		1034.92										
	Tails		974.88										

Flotation conditions	Sample ID	Time mins	Mass g	Cum mass g	Cum water g	Copper grade %	Copper recovery %	Nickel grade %	Nickel recovery %	Sulphur grade %	Sulphur recovery %	Entrained gangue g	Floating gangue g
ORE A	C1	2	4.49	4.49	72.2	8.56	59.9	9.75	25.26	25.50	36.57	1.73	0.01
SIBX 100 g/t mill	C2	6	3.73	8.22	154.5	5.86	75.1	9.38	44.46	20.83	54.67	3.71	0.01
DOW 200 40 g/t	C3	12	3.20	11.42	241.3	4.47	79.6	7.67	50.50	17.35	63.29	5.79	0.19
Guar 300 g/t	C4	20	4.06	15.48	353.2	3.41	82.3	5.99	53.48	13.89	68.67	8.48	1.10
	Feed		1030.48										
	Tails		1015.00										
ORE A	C1	2	4.88	4.88	39.7	8.05	61.7	9.67	26.15	24.40	34.28	0.95	0.66
SIBX 100 g/t mill	C2	6	3.87	8.75	127.0	5.54	76.2	9.37	45.43	20.20	50.89	3.05	0.85
DOW 200 40 g/t	C3	12	3.60	12.35	226.6	4.17	81.0	7.55	51.67	16.79	59.72	5.44	1.22
Guar 300 g/t	C4	20	4.41	16.76	350.3	3.17	83.5	5.89	54.72	13.46	64.94	8.41	2.16
	Feed		1035.88										
	Tails		1019.12										
ORE A	C1	2	4.66	4.66	54.2	8.42	60.2	9.65	25.75	25.10	35.56	1.30	0.15
SIBX 100 g/t mill	C2	6	3.88	8.54	137.4	5.77	75.5	9.42	46.06	20.60	53.49	3.30	0.41
DOW 200 40 g/t	C3	12	3.66	12.20	239.5	4.29	80.2	7.57	52.93	17.10	63.43	5.75	0.73
Guar 300 g/t	C4	20	4.72	16.92	374.6	3.19	82.7	5.80	56.25	13.42	69.05	8.99	1.70
	Feed		1041.47										
	Tails		1024.55										
ORE A	C1	2	5.49	5.49	70.4	6.79	57.1	8.94	27.51	21.60	34.14	1.69	0.55
SIBX 100g/t mill	C2	6	3.77	9.26	152.8	5.15	73.1	8.94	46.42	19.20	51.18	3.67	0.71
DOW 200 40g/t	C3	12	3.63	12.89	254.3	3.99	78.7	7.34	53.06	16.26	60.33	6.10	1.04
Guar 300 g/t	C4	20	4.11	17.00	369.3	3.13	81.4	5.92	56.41	13.36	65.41	8.86	1.90
	Feed		1018.41										
	Tails		1001.41										
ORE A	C1	2	4.68	4.68	48.2	8.20	57.8	10.53	25.44	25.80	35.43	1.16	0.21
SIBX 100g/t mill	C2	6	4.17	8.85	134.6	5.62	74.9	9.91	45.27	20.66	53.66	3.23	0.60
DOW 200 40g/t	C3	12	4.05	12.90	243.7	4.13	80.3	7.82	52.08	16.76	63.44	5.85	1.12
Guar 300 g/t	C4	20	4.73	17.63	382.0	3.12	82.9	6.03	54.84	13.12	67.87	9.17	2.12
	Feed		1031.39										
	Tails		1013.76										

Flotation conditions	Sample ID	Time mins	Mass g	Cum mass g	Cum water g	Copper grade %	Copper recovery %	Nickel grade %	Nickel recovery %	Sulphur grade %	Sulphur recovery %	Entrained gangue g	Floating gangue g
ORE A	C1	2	3.93	3.93	31.0	9.86	59.9	9.85	22.07	28.30	33.47	0.74	0.13
SIBX 100 g/t mill	C2	6	4.47	8.40	114.2	5.98	77.7	9.58	45.85	21.86	55.26	2.74	0.62
DOW 200 40 g/t	C3	12	4.13	12.53	212.5	4.23	82.0	7.36	52.56	17.25	65.04	5.10	1.50
CMC 300 g/t	C4	20	5.80	18.33	344.8	2.97	84.3	5.33	55.74	12.73	70.23	8.28	3.65
	Feed		1020.71										
	Tails		1002.38										
ORE A	C1	2	2.37	2.37	12.3	12.26	48.7	9.90	14.08	31.90	24.07	0.29	0.00
SIBX 100 g/t mill	C2	6	4.25	6.62	76.9	6.84	76.0	10.18	40.45	24.20	50.99	1.85	0.38
DOW 200 40 g/t	C3	12	4.28	10.90	175.9	4.45	81.3	7.50	49.03	18.33	63.61	4.22	1.20
CMC 300 g/t	C4	20	5.35	16.25	295.9	3.07	83.6	5.38	52.46	13.43	69.45	7.10	3.16
	Feed		1038.02										
	Tails		1021.77										
ORE A	C1	2	2.58	2.58	17.8	11.02	47.2	10.02	14.72	30.70	25.35	0.43	0.00
SIBX 100 g/t mill	C2	6	4.38	6.96	87.7	6.36	73.5	10.05	39.81	23.59	52.54	2.11	0.35
DOW 200 40 g/t	C3	12	4.26	11.22	184.1	4.26	79.4	7.66	48.96	18.35	65.89	4.42	1.15
CMC 300 g/t	C4	20	6.17	17.39	326.5	2.84	82.1	5.35	52.93	13.03	72.53	7.83	3.34
	Feed		1039.34										
	Tails		1021.95										
ORE A	C1	2	3.16	3.16	19.6	11.14	54.8	9.97	17.76	30.60	31.13	0.47	0.04
SIBX 100 g/t mill	C2	6	4.19	7.35	91.3	6.53	74.8	10.07	41.73	23.76	56.23	2.19	0.37
DOW 200 40 g/t	C3	12	4.04	11.39	190.2	4.49	79.7	7.81	50.14	18.76	68.81	4.56	0.96
CMC 300 g/t	C4	20	5.86	17.25	330.0	3.06	82.1	5.55	54.00	13.52	75.11	7.92	2.93
	Feed		1041.22										
	Tails		1023.97										
ORE A	C1	2	2.65	2.65	16.2	11.47	49.0	9.86	14.72	31.50	25.55	0.39	0.00
SIBX 100 g/t mill	C2	6	4.33	6.98	88.9	6.59	74.2	9.91	39.01	24.06	51.39	2.13	0.24
DOW 200 40 g/t	C3	12	4.74	11.72	203.7	4.24	80.2	7.37	48.69	18.14	65.09	4.89	1.00
CMC 300 g/t	C4	20	6.52	18.24	363.1	2.81	82.8	5.11	52.54	12.81	71.52	8.71	3.12
	Feed		1027.56										
	Tails		1009.32										

Flotation conditions	Sample ID	Time mins	Mass g	Cum mass g	Cum water g	Copper grade %	Copper recovery %	Nickel grade %	Nickel recovery %	Sulphur grade %	Sulphur recovery %	Entrained gangue g	Floating gangue g
ORE B	C1	2	22.13	22.13	43.1	3.38	77.7	3.87	36.0	8.00	43.7	1.04	16.24
SIBX 100 g/t mill	C2	6	18.11	40.24	119.5	2.04	85.3	2.92	49.4	5.51	54.6	2.87	31.29
DOW 200 40 g/t	C3	12	18.50	58.74	226.8	1.45	88.4	2.22	54.9	4.34	62.9	5.44	46.30
No depressant	C4	20	16.98	75.72	364.8	1.15	90.4	1.82	58.0	3.70	69.1	8.75	59.28
	Feed		1026.51										
	Tails		950.79										
ORE B	C1	2	20.86	20.86	46.2	3.61	78.3	3.88	33.8	8.08	42.7	1.11	15.13
SIBX 100 g/t mill	C2	6	17.16	38.02	110.0	2.17	85.9	3.02	47.9	5.54	53.3	2.64	29.60
DOW 200 40 g/t	C3	12	18.94	56.96	211.4	1.51	89.4	2.28	54.4	4.36	62.8	5.07	45.08
No depressant	C4	20	19.54	76.50	364.1	1.15	91.4	1.81	57.9	3.61	70.0	8.74	60.18
	Feed		1040.98										
	Tails		964.48										
ORE B	C1	2	20.16	20.16	39.9	3.65	78.2	3.72	33.1	7.99	41.2	0.96	14.78
SIBX 100 g/t mill	C2	6	18.48	38.64	109.1	2.10	86.2	2.84	48.6	5.39	53.3	2.62	30.31
DOW 200 40 g/t	C3	12	20.57	59.21	220.8	1.42	89.4	2.10	55.0	4.19	63.5	5.30	47.11
No depressant	C4	20	16.03	75.24	345.7	1.14	91.3	1.75	58.1	3.58	69.0	8.30	59.55
	Feed		1036.57										
	Tails		961.33										
ORE B	C1	2	19.14	19.14	38.1	3.78	77.1	3.93	33.0	8.78	42.0	0.91	13.62
SIBX 100 g/t mill	C2	6	17.13	36.27	100.4	2.19	84.8	3.08	49.0	5.94	53.9	2.41	27.95
DOW 200 40 g/t	C3	12	18.56	54.83	195.7	1.51	88.0	2.33	55.9	4.65	63.8	4.70	43.14
No depressant	C4	20	19.53	74.36	344.8	1.14	90.4	1.84	59.8	3.82	71.0	8.28	58.29
	Feed		1031.11										
	Tails		956.75										
ORE B	C1	2	21.00	21.00	43.1	3.41	78.2	3.44	33.3	7.85	41.7	1.04	15.44
SIBX 100 g/t mill	C2	6	17.07	38.07	106.6	2.07	86.0	2.72	47.6	5.42	52.2	2.56	29.85
DOW 200 40 g/t	C3	12	19.31	57.38	208.5	1.43	89.4	2.06	54.4	4.22	61.3	5.00	45.73
No depressant	C4	20	17.39	74.77	342.1	1.12	91.6	1.68	57.8	3.56	67.4	8.21	59.25
	Feed		1007.26										
	Tails		932.49										

Flotation conditions	Sample ID	Time mins	Mass g	Cum mass g	Cum water g	Copper grade %	Copper recovery %	Nickel grade %	Nickel recovery %	Sulphur grade %	Sulphur recovery %	Entrained gangue g	Floating gangue g
ORE B	C1	2	5.68	5.68	33.5	9.24	63.0	11.96	29.3	27.30	37.5	0.80	0.62
SIBX 100 g/t mill	C2	6	5.23	10.91	106.8	5.98	78.3	10.29	48.4	21.16	55.9	2.56	2.01
DOW 200 40 g/t	C3	12	5.21	16.12	190.5	4.27	82.7	7.58	52.7	16.07	62.7	4.57	4.44
Guar 300 g/t	C4	20	6.53	22.65	290.6	3.14	85.2	5.63	55.0	12.14	66.6	6.98	8.13
	Feed		1011.92										
	Tails		989.27										
ORE B	C1	2	6.60	6.60	52.2	8.33	65.9	11.02	33.2	24.70	40.4	1.25	0.88
SIBX 100 g/t mill	C2	6	4.93	11.53	127.3	5.75	79.3	9.33	49.0	19.70	56.3	3.05	2.24
DOW 200 40 g/t	C3	12	5.22	16.75	213.1	4.16	83.5	6.98	53.3	15.07	62.6	5.11	4.71
Guar 300 g/t	C4	20	6.79	23.54	315.5	3.05	86.0	5.18	55.6	11.37	66.3	7.57	8.63
	Feed		1034.63										
	Tails		1011.09										
ORE B	C1	2	6.50	6.50	47.2	8.84	68.0	11.56	33.3	26.30	40.1	1.13	0.68
SIBX 100 g/t mill	C2	6	4.64	11.14	121.5	6.09	80.2	9.94	49.0	20.84	54.5	2.92	1.85
DOW 200 40 g/t	C3	12	5.08	16.22	210.0	4.39	84.3	7.39	53.0	15.90	60.5	5.04	4.10
Guar 300 g/t	C4	20	6.60	22.82	320.1	3.21	86.8	5.48	55.3	11.98	64.2	7.68	7.64
	Feed		1017.18										
	Tails		994.36										
ORE B	C1	2	5.73	5.73	37.2	9.42	65.9	11.53	29.7	27.30	39.6	0.89	0.55
SIBX 100g/t mill	C2	6	4.83	10.56	108.2	6.17	79.6	10.08	47.8	21.13	56.4	2.60	1.84
DOW 200 40g/t	C3	12	5.02	15.58	192.8	4.41	83.9	7.45	52.1	16.02	63.1	4.63	4.11
Guar 300 g/t	C4	20	6.39	21.97	293.7	3.22	86.5	5.52	54.5	12.07	67.1	7.05	7.65
	Feed		1012.53										
	Tails		990.56										
ORE B	C1	2	6.44	6.44	47.0	9.10	66.0	11.03	31.2	25.90	40.5	1.13	0.74
SIBX 100g/t mill	C2	6	4.89	11.33	119.8	6.20	79.0	9.86	49.1	20.72	57.0	2.87	2.02
DOW 200 40g/t	C3	12	5.45	16.78	213.0	4.40	83.1	7.26	53.5	15.72	64.1	5.11	4.43
Guar 300 g/t	C4	20	6.88	23.66	323.4	3.21	85.5	5.37	55.9	11.83	68.0	7.76	8.22
	Feed		1021.79										
	Tails		998.13										

Flotation conditions	Sample ID	Time mins	Mass g	Cum mass g	Cum water g	Copper grade %	Copper recovery %	Nickel grade %	Nickel recovery %	Sulphur grade %	Sulphur recovery %	Entrained gangue g	Floating gangue g
ORE B	C1	2	3.84	3.84	11.6	10.70	52.6	11.11	18.6	29.40	26.8	0.28	0.46
SIBX 100 g/t mill	C2	6	5.74	9.58	67.4	6.25	76.6	10.82	45.2	22.87	51.9	1.62	1.95
DOW 200 40 g/t	C3	12	6.66	16.24	154.8	3.95	82.2	7.39	52.4	15.89	61.2	3.71	5.45
CMC 300 g/t	C4	20	8.93	25.17	268.3	2.63	84.8	5.05	55.4	11.08	66.1	6.44	11.08
	Feed		1032.93										
	Tails		1007.76										
ORE B	C1	2	2.79	2.79	6.8	15.47	49.6	10.91	14.2	31.70	21.8	0.16	0.20
SIBX 100 g/t mill	C2	6	5.21	8.00	54.7	8.58	78.8	11.10	41.3	24.99	49.3	1.31	1.20
DOW 200 40 g/t	C3	12	6.04	14.04	138.4	5.24	84.5	7.71	50.4	17.51	60.7	3.32	3.97
CMC 300 g/t	C4	20	8.43	22.47	255.1	3.39	87.4	5.13	53.6	11.88	65.9	6.12	9.03
	Feed		1018.19										
	Tails		995.72										
ORE B	C1	2	2.89	2.89	6.3	14.31	49.5	10.71	14.4	32.20	22.0	0.15	0.19
SIBX 100 g/t mill	C2	6	5.60	8.49	55.5	7.68	78.1	10.94	43.3	24.28	48.8	1.33	1.50
DOW 200 40 g/t	C3	12	6.45	14.94	139.0	4.68	83.7	7.37	51.3	16.55	58.5	3.34	4.82
CMC 300 g/t	C4	20	8.70	23.64	251.2	3.05	86.3	4.92	54.3	11.27	63.1	6.03	10.30
	Feed		1026.62										
	Tails		1002.98										
ORE B	C1	2	2.83	2.83	7.1	13.64	48.3	10.84	14.2	32.00	22.4	0.17	0.18
SIBX 100 g/t mill	C2	6	5.18	8.01	52.3	7.62	76.3	11.13	41.3	24.76	49.1	1.25	1.31
DOW 200 40 g/t	C3	12	6.59	14.60	140.4	4.50	82.2	7.44	50.3	16.62	60.1	3.37	4.57
CMC 300 g/t	C4	20	9.32	23.92	265.1	2.84	84.9	4.83	53.6	11.00	65.2	6.36	10.34
	Feed		1028.70										
	Tails		1004.78										
ORE B	C1	2	3.37	3.37	11.4	12.70	54.7	11.07	17.2	31.40	25.6	0.27	0.19
SIBX 100 g/t mill	C2	6	5.21	8.58	66.4	7.18	78.7	10.91	43.1	24.30	50.5	1.59	1.27
DOW 200 40 g/t	C3	12	6.19	14.77	160.2	4.44	83.8	7.40	50.4	16.71	59.8	3.85	4.15
CMC 300 g/t	C4	20	9.01	23.78	295.5	2.85	86.5	4.86	53.3	11.24	64.7	7.09	9.35
	Feed		1004.36										
	Tails		980.58										

Flotation conditions	Sample ID	Time mins	Mass g	Cum mass g	Cum water g	Copper grade %	Copper recovery %	Nickel grade %	Nickel recovery %	Sulphur grade %	Sulphur recovery %	Entrained gangue g	Floating gangue g
ORE A	C1	2	4.65	4.65	76.58	9.64	67.37	5.45	14.10	19.40	28.49	1.84	0.00
SEX 50 g/t mill	C2	6	2.76	7.41	151.68	6.96	77.57	6.88	28.35	17.09	39.99	3.64	0.00
DOW 200 40 g/t	C3	12	2.47	9.88	231.77	5.48	81.32	7.27	39.95	15.32	47.79	5.56	0.00
Guar 500 g/t	C4	20	2.61	12.49	325.23	4.44	83.41	6.70	46.55	13.57	53.52	7.81	0.00
	Feed		1006.98										
	Tails		994.49										
ORE A	C1	2	3.44	3.44	53.8	12.41	64.34	4.48	8.78	24.60	26.4	1.29	0.00
SEX 50 g/t mill	C2	6	2.64	6.08	123.0	8.49	77.80	6.89	23.85	20.87	39.6	2.95	0.00
DOW 200 40 g/t	C3	12	2.42	8.50	199.2	6.40	82.00	7.46	36.10	18.03	47.8	4.78	0.00
Guar 500 g/t	C4	20	2.60	11.10	288.8	4.91	82.23	6.83	43.17	15.56	53.9	6.93	0.00
	Feed		1023.28										
	Tails		1012.18										
ORE A	C1	2	2.97	2.97	28.5	12.86	59.79	8.22	13.39	29.10	27.1	0.68	0.00
SEX 100 g/t mill	C2	6	2.86	5.83	83.8	8.39	76.59	9.76	31.20	24.29	44.4	2.01	0.00
DOW 200 40 g/t	C3	12	2.13	7.96	140.9	6.49	80.89	9.59	41.89	21.38	53.4	3.38	0.00
Guar 500 g/t	C4	20	2.14	10.10	208.6	5.25	82.97	8.51	47.18	18.53	58.7	5.01	0.00
	Feed		1008.27										
	Tails		998.17										
ORE A	C1	2	3.21	3.21	30.1	11.64	59.94	8.96	16.26	26.80	26.9	0.72	0.00
SEX 100 g/t mill	C2	6	3.15	6.36	90.4	7.59	77.48	10.07	36.23	23.23	46.3	2.17	0.00
DOW 200 40 g/t	C3	12	2.67	9.03	166.4	5.64	81.77	9.04	46.17	19.79	56.0	3.99	0.00
Guar 500 g/t	C4	20	2.66	11.69	257.0	4.47	83.86	7.64	50.51	17.18	62.9	6.17	0.00
	Feed		1021.04										
	Tails		1009.15										
ORE A	C1	2	2.48	2.48	18.7	13.59	54.02	9.45	13.58	21.71	32.9	0.45	0.00
SEX 150 g/t mill	C2	6	2.71	5.19	64.5	8.96	74.54	10.66	32.05	39.38	27.8	1.55	0.00
DOW 200 40 g/t	C3	12	2.51	7.70	136.3	6.44	79.53	9.26	41.28	48.75	22.8	3.27	0.00
Guar 500 g/t	C4	20	2.9	10.60	242.4	4.82	81.92	7.61	46.70	55.46	18.7	5.82	0.00
	Feed		991.41										
	Tails		980.81										
ORE A	C1	2	1.99	1.99	12.3	14.49	49.67	9.10	10.64	33.70	21.1	0.30	0.00
SEX 150 g/t mill	C2	6	2.95	4.94	59.1	8.78	74.73	10.50	30.50	27.73	43.0	1.42	0.00
DOW 200 40 g/t	C3	12	2.75	7.69	139.2	6.06	80.28	9.48	42.88	22.32	53.9	3.34	0.00
Guar 500 g/t	C4	20	3.05	10.74	249.7	4.47	82.77	7.70	48.64	18.26	61.6	5.99	0.00
	Feed		1042.12										
	Tails		1031.38										

Flotation conditions	Sample ID	Time mins	Mass g	Cum mass g	Cum water g	Copper grade %	Copper recovery %	Nickel grade %	Nickel recovery %	Sulphur grade %	Sulphur recovery %	Entrained gangue g	Floating gangue g
ORE A	C1	2	3.79	3.79	58.6	9.95	59.78	5.49	12.21	22.3	27.53	1.4064	0.00
SNPX 50 g/t mill	C2	6	2.66	6.45	121.9	7.18	73.36	7.48	28.30	20.07	42.2	2.92	0.00
DOW 200 40 g/t	C3	12	2.02	8.47	184.6	5.81	78.00	7.88	39.12	18.03	49.7	4.43	0.00
Guar 500 g/t	C4	20	2.06	10.53	256.9	4.83	80.57	7.25	44.78	15.79	54.2	6.17	0.00
	Feed		1015.38										
	Tails		1004.85										
ORE A	C1	2	3.78	3.78	58.4	9.82	59.75	4.96	10.63	21.50	25.6	1.40	0.00
SNPX 50 g/t mill	C2	6	2.69	6.47	123.8	7.08	73.80	7.31	26.78	19.55	39.8	2.97	0.00
DOW 200 40 g/t	C3	12	2.41	8.88	201.8	5.51	78.81	7.59	38.19	16.98	47.5	4.84	0.00
Guar 500 g/t	C4	20	2.36	11.24	290.5	4.49	81.30	6.86	43.69	15.02	53.2	6.97	0.00
	Feed		1012.29										
	Tails		1001.05										
ORE A	C1	2	4.06	4.06	42.6	9.34	58.44	9.22	19.93	26.30	30.2	1.02	0.00
SNPX 100 g/t mill	C2	6	2.56	6.62	92.0	7.07	72.07	9.84	34.68	23.63	44.2	2.21	0.00
DOW 200 40 g/t	C3	12	2.04	8.66	146.1	5.74	76.54	9.46	43.64	20.92	51.2	3.51	0.00
Guar 500 g/t	C4	20	2.40	11.06	220.6	4.80	81.86	8.70	51.25	18.10	56.6	5.30	0.00
	Feed		1039.09										
	Tails		1028.03										
ORE A	C1	2	4.22	4.22	49.3	9.31	55.13	9.07	20.43	24.60	32.6	1.18	0.00
SNPX 100 g/t mill	C2	6	2.61	6.83	101.0	6.99	66.99	9.06	33.04	21.96	47.0	2.42	0.00
DOW 200 40 g/t	C3	12	2.18	9.01	162.2	6.10	77.13	9.41	45.30	19.12	54.0	3.89	0.00
Guar 500 g/t	C4	20	2.52	11.53	245.0	5.06	81.94	8.30	51.10	16.32	59.0	5.88	0.00
	Feed		1020.78										
	Tails		1009.25										
ORE A	C1	2	2.25	2.25	10.5	13.95	48.28	9.98	13.23	34.40	23.8	0.25	0.00
SNPX 150 g/t mill	C2	6	2.49	4.74	42.2	9.63	70.21	10.79	30.13	29.88	43.5	1.01	0.00
DOW 200 40 g/t	C3	12	2.68	7.42	107.5	6.78	77.33	9.15	40.01	23.86	54.4	2.58	0.00
Guar 500 g/t	C4	20	3.00	10.42	201.5	5.01	80.37	7.55	46.34	19.24	61.6	4.83	0.00
	Feed		1065.17										
	Tails		1054.75										
ORE A	C1	2	2.07	2.07	9.5	13.59	46.83	9.77	12.00	35.10	23.2	0.23	0.00
SNPX 150 g/t mill	C2	6	2.5	4.57	38.4	9.31	70.82	10.73	29.10	30.34	44.3	0.92	0.00
DOW 200 40 g/t	C3	12	3.28	7.85	123.2	6.01	78.57	8.78	40.90	22.43	56.2	2.96	0.00
Guar 500 g/t	C4	20	3.44	11.29	237.1	4.34	81.50	6.87	46.00	17.38	62.7	5.69	0.00
	Feed		1035.75										
	Tails		1024.46										

Flotation conditions	Sample ID	Time mins	Mass g	Cum mass g	Cum water g	Copper grade %	Copper recovery %	Nickel grade %	Nickel recovery %	Sulphur grade %	Sulphur recovery %	Entrained gangue g	Floating gangue g
ORE A	C1	2	2.91	2.91	48.9	10.86	47.10	5.06	8.51	22.3	20.6	1.17	0.00
SIBX 50 g/t mill	C2	6	2.48	5.39	106.9	8.08	64.94	6.99	21.76	20.05	34.3	2.57	0.00
DOW 200 40 g/t	C3	12	2.03	7.42	160.8	6.48	71.67	7.90	33.88	18.39	43.4	3.86	0.00
Guar 500 g/t	C4	20	2.49	9.91	244.8	5.10	75.30	7.31	41.87	15.86	50.0	5.87	0.00
	Feed		1045.56										
	Tails		1035.65										
ORE A	C1	2	3.83	3.83	66.4	9.83	53.98	4.87	10.35	20.10	25.2	1.59	0.00
SIBX 50 g/t mill	C2	6	2.67	6.50	131.9	7.43	69.22	6.82	24.62	18.58	39.5	3.17	0.00
DOW 200 40 g/t	C3	12	2.1	8.60	192.2	6.09	75.04	7.58	36.20	17.17	48.3	4.61	0.00
Guar 500 g/t	C4	20	2.4	11.00	273.8	4.97	78.37	7.15	43.67	14.83	53.4	6.57	0.00
	Feed		1044.23										
	Tails		1033.23										
ORE A	C1	2	3.96	3.96	44.4	9.39	57.72	9.37	21.44	26.70	28.9	1.07	0.00
SIBX 100 g/t mill	C2	6	2.75	6.71	104.8	7.06	73.54	9.71	37.66	23.30	42.8	2.51	0.00
DOW 200 40 g/t	C3	12	2.03	8.74	165.7	5.82	78.92	9.04	45.65	20.35	48.7	3.98	0.00
Guar 500 g/t	C4	20	2.26	11.00	250.5	4.79	81.76	7.84	49.84	17.49	52.7	6.01	0.00
	Feed		1028.17										
	Tails		1017.17										
ORE A	C1	2	3.69	3.69	48.4	8.94	55.67	9.52	19.60	26.60	29.4	1.16	0.00
SIBX 100 g/t mill	C2	6	2.73	6.42	108.3	6.59	71.45	9.98	35.78	22.99	44.2	2.60	0.00
DOW 200 40 g/t	C3	12	2.08	8.50	168.8	5.39	77.28	9.08	43.09	19.83	50.5	4.05	0.00
Guar 500 g/t	C4	20	2.36	10.86	247.0	4.40	80.61	7.81	47.32	17.17	55.9	5.93	0.00
	Feed		1041.08										
	Tails		1030.22										
ORE A	C1	2	3.66	3.66	41.2	9.34	56.20	10.20	22.48	28.70	32.0	0.99	0.00
SIBX 150 g/t mill	C2	6	2.95	6.61	99.0	6.85	74.37	10.19	40.55	24.82	50.0	2.38	0.00
DOW 200 40 g/t	C3	12	2.3	8.91	166.3	5.47	80.08	8.83	47.38	21.25	57.7	3.99	0.00
Guar 500 g/t	C4	20	3.17	12.08	278.8	4.19	83.14	7.08	51.48	17.19	63.2	6.69	0.00
	Feed		998.18										
	Tails		986.10										
ORE A	C1	2	2.8	2.80	18.3	11.32	51.89	10.28	16.94	32.00	25.5	0.44	0.00
SIBX 150 g/t mill	C2	6	2.9	5.70	63.4	7.83	73.03	10.64	35.68	27.32	44.3	1.52	0.00
DOW 200 40 g/t	C3	12	2.67	8.37	134.6	5.83	79.89	9.13	44.98	22.40	53.4	3.23	0.00
Guar 500 g/t	C4	20	3.1	11.47	239.4	4.43	83.25	7.38	49.82	18.06	58.9	5.75	0.00
	Feed		1045.6										
	Tails		1034.13										

Flotation conditions	Sample ID	Time mins	Mass g	Cum mass g	Cum water g	Copper grade %	Copper recovery %	Nickel grade %	Nickel recovery %	Sulphur grade %	Sulphur recovery %	Entrained gangue g	Floating gangue g
ORE A	C1	2	3.85	3.85	69.0	9.26	52.72	5.17	11.63	19.90	22.5	1.66	0.00
PAX 50 g/t mill	C2	6	2.98	6.83	147.0	6.80	68.68	6.75	26.95	17.59	35.2	3.53	0.00
DOW 200 40 g/t	C3	12	3.9	10.73	277.5	4.79	76.07	6.17	38.68	13.99	44.0	6.66	0.00
Guar 500 g/t	C4	20	3.95	14.68	428.2	3.67	79.75	5.31	45.53	11.48	49.5	10.28	0.00
	Feed		1025.06										
	Tails		1010.38										
ORE A	C1	2	3.53	3.53	60.3	10.37	56.02	4.88	10.21	21.10	23.6	1.45	0.00
PAX 50 g/t mill	C2	6	2.99	6.52	137.7	7.29	72.72	6.95	26.87	18.49	38.2	3.30	0.00
DOW 200 40 g/t	C3	12	3.37	9.89	248.1	5.26	79.57	6.74	39.51	15.09	47.3	5.95	0.00
Guar 500 g/t	C4	20	3.73	13.62	390.2	3.99	83.20	5.81	46.92	12.25	52.9	9.37	0.00
	Feed		1025.41										
	Tails		1011.79										
ORE A	C1	2	4.56	4.56	58.4	7.77	54.31	9.51	22.78	24.50	33.5	1.40	0.00
SIBX 100 g/t mill	C2	6	3.21	7.77	132.5	5.88	70.02	9.62	39.25	21.03	49.0	3.18	0.00
DOW 200 40 g/t	C3	12	3.28	11.05	239.4	4.50	76.25	8.00	46.43	16.98	56.3	5.75	0.00
Guar 500 g/t	C4	20	3.08	14.13	352.9	3.65	79.04	6.72	49.87	14.24	60.3	8.47	0.00
	Feed		1031.35										
	Tails		1017.22										
ORE A	C1	2	3.87	3.87	44.1	9.07	53.84	9.69	21.16	27.70	33.3	1.06	0.00
PAX 100 g/t mill	C2	6	3.09	6.96	113.6	6.58	70.23	9.74	38.26	22.86	49.4	2.73	0.00
DOW 200 40 g/t	C3	12	3.22	10.18	218.4	4.91	76.60	8.00	45.92	18.07	57.1	5.24	0.00
Guar 500 g/t	C4	20	3.42	13.60	344.4	3.83	79.91	6.57	50.38	14.62	61.7	8.27	0.00
	Feed		1025.13										
	Tails		1011.53										
ORE A	C1	2	3.05	3.05	27.1	10.05	49.87	10.16	17.67	30.00	27.7	0.65	0.00
PAX 150 g/t mill	C2	6	3.79	6.84	111.5	6.41	71.30	9.58	37.38	22.08	45.8	2.68	0.00
DOW 200 40 g/t	C3	12	5.81	12.65	304.1	3.86	79.47	6.60	47.63	14.81	56.8	7.30	0.00
Guar 500 g/t	C4	20	4.73	17.38	497.6	2.93	82.89	5.20	51.54	11.68	61.5	11.94	0.00
	Feed		1033.32										
	Tails		1015.94										
ORE A	C1	2	3.52	3.52	33.8	9.55	51.61	10.25	20.38	29.80	31.2	0.81	0.00
PAX 150 g/t mill	C2	6	3.77	7.29	116.9	6.32	70.73	9.74	40.12	22.72	49.2	2.80	0.00
DOW 200 40 g/t	C3	12	5.58	12.87	302.2	3.95	78.10	6.89	50.11	15.56	59.5	7.25	0.00
Guar 500 g/t	C4	20	5.41	18.28	517.1	2.90	81.27	5.25	54.18	11.88	64.5	12.41	0.00
	Feed		1043.64										
	Tails		1025.36										

Flotation conditions	Sample ID	Time mins	Mass g	Cum mass g	Cum water g	Copper grade %	Copper recovery %	Nickel grade %	Nickel recovery %	Sulphur grade %	Sulphur recovery %	Entrained gangue g	Floating gangue g
ORE B	C1	2	3.98	3.98	44.2	14.54	67.96	8.43	14.87	26.20	25.62	1.06	0.00
SEX 50 g/t mill	C2	6	3.62	7.60	120.5	9.06	80.90	9.95	33.52	22.01	41.1	2.89	0.00
DOW 200 40 g/t	C3	12	3.56	11.16	207.3	6.47	84.85	9.12	45.11	19.61	53.8	4.98	0.00
Guar 500 g/t	C4	20	4.62	15.78	331.0	4.71	87.25	7.45	52.11	16.68	64.6	7.94	0.00
	Feed		1011.81										
	Tails		996.03										
ORE B	C1	2	3.13	3.13	27.7	17.01	64.34	8.77	11.96	28.90	22.1	0.67	0.00
SEX 50 g/t mill	C2	6	3.56	6.69	95.3	9.92	80.17	9.81	28.60	23.74	38.8	2.29	0.00
DOW 200 40 g/t	C3	12	3.21	9.90	174.5	7.09	84.82	8.95	38.60	20.19	48.8	4.19	0.00
Guar 500 g/t	C4	20	4.71	14.61	295.2	4.96	87.55	7.80	49.65	17.10	61.0	7.08	0.00
	Feed		1014.86										
	Tails		1000.25										
ORE B	C1	2	2.79	2.79	10.8	15.70	56.26	10.26	12.98	31.50	21.6	0.26	0.00
SEX 100 g/t mill	C2	6	3.4	6.19	43.9	9.91	78.76	11.85	33.26	28.42	43.2	1.05	0.00
DOW 200 40 g/t	C3	12	2.96	9.15	101.6	7.16	84.16	10.99	45.59	24.86	55.8	2.44	0.00
Guar 500 g/t	C4	20	4.66	13.81	216.3	4.91	87.10	8.20	51.34	20.52	69.5	5.19	0.00
	Feed		1003.21										
	Tails		989.4										
ORE B	C1	2	3.27	3.27	20.0	14.08	62.16	10.17	15.04	29.60	23.9	0.48	0.00
SEX 100 g/t mill	C2	6	3.57	6.84	67.5	8.69	80.23	11.57	35.79	26.42	44.7	1.62	0.00
DOW 200 40 g/t	C3	12	3.02	9.86	134.6	6.40	85.20	10.55	47.02	23.20	56.5	3.23	0.00
Guar 500 g/t	C4	20	4.85	14.71	268.5	4.43	87.99	7.81	51.96	19.11	69.5	6.44	0.00
	Feed		976.36										
	Tails		1000.82										
ORE B	C1	2	1.86	1.86	3.7	16.89	41.64	10.54	9.25	31.90	14.2	0.09	0.00
SEX 150 g/t mill	C2	6	3.57	5.43	30.5	10.66	76.71	12.11	31.03	29.86	38.9	0.73	0.00
DOW 200 40 g/t	C3	12	2.85	8.28	81.8	7.59	83.26	10.56	41.25	26.05	51.8	1.96	0.00
Guar 500 g/t	C4	20	3.98	12.26	175.1	5.31	86.27	8.23	47.61	22.30	65.6	4.20	0.00
	Feed		1007.99										
	Tails		995.73										
ORE B	C1	2	1.89	1.89	3.6	16.88	45.04	10.45	9.44	35.30	16.4	0.09	0.00
SEX 150 g/t mill	C2	6	3.27	5.16	29.8	10.49	76.45	12.22	30.13	31.37	39.9	0.72	0.00
DOW 200 40 g/t	C3	12	2.48	7.64	73.8	7.65	82.55	10.79	39.40	27.55	51.9	1.77	0.00
Guar 500 g/t	C4	20	3.28	10.92	151.7	5.54	85.45	8.70	45.43	23.90	64.3	3.64	0.00
	Feed		978.44										
	Tails		967.52										

Flotation conditions	Sample ID	Time mins	Mass g	Cum mass g	Cum water g	Copper grade %	Copper recovery %	Nickel grade %	Nickel recovery %	Sulphur grade %	Sulphur recovery %	Entrained gangue g	Floating gangue g
ORE B	C1	2	3.28	3.28	41.6	15.15	61.32	6.28	9.55	25.50	21.4	1.00	0.00
SNPX 50 g/t mill	C2	6	3.09	6.37	99.6	9.74	76.59	9.06	26.77	22.54	36.7	2.39	0.00
DOW 200 40 g/t	C3	12	2.57	8.94	166.0	7.40	81.63	9.58	39.69	20.32	46.5	3.98	0.00
Guar 500 g/t	C4	20	4.01	12.95	291.5	5.31	84.87	8.23	49.42	16.94	56.1	6.99	0.00
	Feed		978.51										
	Tails		965.56										
ORE B	C1	2	3.34	3.34	32.2	15.14	62.82	7.88	11.60	27.00	22.4	0.77	0.00
SNPX 50 g/t mill	C2	6	3.27	6.61	90.7	9.45	77.57	10.21	29.74	23.64	38.8	2.18	0.00
DOW 200 40 g/t	C3	12	3.73	10.34	184.5	6.46	83.00	10.13	46.15	19.94	51.2	4.43	0.00
Guar 500 g/t	C4	20	5.02	15.36	344.1	4.52	86.28	7.87	53.29	15.73	59.9	8.26	0.00
	Feed		996.79										
	Tails		981.43										
ORE B	C1	2	3.27	3.27	15.5	14.49	56.62	10.74	15.94	32.40	25.1	0.37	0.00
SNPX 100 g/t mill	C2	6	3	6.27	49.1	9.79	73.35	11.88	33.81	29.00	43.0	1.18	0.00
DOW 200 40 g/t	C3	12	2.95	9.22	113.9	7.17	79.02	10.89	45.59	24.30	53.0	2.73	0.00
Guar 500 g/t	C4	20	4.31	13.53	242.8	5.08	82.11	8.34	51.19	19.38	62.1	5.83	0.00
	Feed		1018.39										
	Tails		1004.86										
ORE B	C1	2	2.93	2.93	13.2	15.06	56.59	10.28	14.10	32.40	22.5	0.32	0.00
SNPX 100 g/t mill	C2	6	2.91	5.84	44.2	10.10	75.66	11.63	31.80	28.71	39.8	1.06	0.00
DOW 200 40 g/t	C3	12	2.72	8.56	100.7	7.45	81.83	10.92	43.77	24.26	49.2	2.42	0.00
Guar 500 g/t	C4	20	4.25	12.81	220.8	5.18	85.14	8.43	50.58	19.47	59.1	5.30	0.00
	Feed		994.82										
	Tails		982.01										
ORE B	C1	2	1.97	1.97	2.9	17.00	42.61	10.86	9.94	35.50	17.3	0.07	0.00
SNPX 150 g/t mill	C2	6	2.49	4.46	14.7	12.34	70.00	12.39	25.66	33.60	37.1	0.35	0.00
DOW 200 40 g/t	C3	12	2.56	7.02	54.3	8.73	77.97	10.94	35.67	28.82	50.1	1.30	0.00
Guar 500 g/t	C4	20	3.32	10.34	140.1	6.19	81.40	8.87	42.60	23.81	60.9	3.36	0.00
	Feed		1015.21										
	Tails		1004.89										
ORE B	C1	2	1.24	1.24	2.2	17.10	28.53	10.33	6.23	35.10	11.0	0.05	0.00
SNPX 150 g/t mill	C2	6	2.2	3.44	6.3	13.09	60.58	12.06	20.18	34.40	30.0	0.15	0.00
DOW 200 40 g/t	C3	12	3.97	7.41	54.4	7.81	77.85	10.07	36.32	27.54	51.7	1.31	0.00
Guar 500 g/t	C4	20	4.57	11.98	160.1	5.08	81.89	7.57	44.13	21.12	64.1	3.84	0.00
	Feed		1001.94										
	Tails		989.96										

Flotation conditions	Sample ID	Time mins	Mass g	Cum mass g	Cum water g	Copper grade %	Copper recovery %	Nickel grade %	Nickel recovery %	Sulphur grade %	Sulphur recovery %	Entrained gangue g	Floating gangue g
ORE B	C1	2	3.00	3	46.44	14.78	53.43	4.6	6.37	22.9	17.0	1.11	0.00
SIBX 50 g/t mill	C2	6	3.00	6.00	117.6	9.85	71.18	7.04	19.47	19.85	29.5	2.82	0.00
DOW 200 40 g/t	C3	12	2.4	8.40	181.6	7.66	77.53	8.22	31.84	18.32	38.2	4.36	0.00
Guar 500 g/t	C4	20	3.35	11.75	277.8	5.78	81.81	8.57	46.48	16.55	48.2	6.67	0.00
	Feed		982.52										
	Tails		970.77										
ORE B	C1	2	2.2	2.20	24.4	18.98	51.41	4.29	4.22	27.10	15.1	0.59	0.00
SIBX 50 g/t mill	C2	6	2.58	4.78	74.0	12.28	72.29	7.80	16.69	23.05	27.8	1.78	0.00
DOW 200 40 g/t	C3	12	2.73	7.51	141.4	8.58	79.37	9.19	30.87	20.12	38.2	3.39	0.00
Guar 500 g/t	C4	20	3.58	11.09	245.7	6.13	83.74	9.39	46.60	17.57	49.2	5.90	0.00
	Feed		989.28										
	Tails		978.19										
ORE B	C1	2	3.06	3.06	17.4	12.95	53.35	11.22	16.13	31.70	24.4	0.42	0.00
SIBX 100 g/t mill	C2	6	3.4	6.46	67.7	8.52	74.06	11.71	35.55	27.02	44.0	1.63	0.00
DOW 200 40 g/t	C3	12	2.22	8.68	125.5	6.85	80.09	10.89	44.42	23.30	50.9	3.01	0.00
Guar 500 g/t	C4	20	2.28	10.96	199.0	5.65	83.32	9.43	48.56	20.14	55.6	4.78	0.00
	Feed		971.62										
	Tails		960.66										
ORE B	C1	2	3.47	3.47	25.1	12.28	55.04	11.27	18.08	30.10	26.0	0.60	0.00
SIBX 100 g/t mill	C2	6	3.31	6.78	78.6	8.39	73.47	11.60	36.38	26.05	43.9	1.89	0.00
DOW 200 40 g/t	C3	12	2.23	9.01	137.6	6.80	79.14	10.77	44.89	22.74	51.0	3.30	0.00
Guar 500 g/t	C4	20	2.79	11.80	231.0	5.43	82.70	9.03	49.28	19.30	56.7	5.54	0.00
	Feed		982.5										
	Tails		970.7										
ORE B	C1	2	4.12	4.12	24.0	11.23	57.75	11.81	22.31	32.20	32.4	0.58	0.00
SIBX 150 g/t mill	C2	6	3.79	7.91	83.9	7.66	75.64	11.35	41.19	26.69	51.5	2.01	0.00
DOW 200 40 g/t	C3	12	2.47	10.38	147.0	6.24	80.87	9.87	46.99	23.36	59.1	3.53	0.00
Guar 500 g/t	C4	20	3.56	13.94	259.9	4.82	83.85	7.92	50.66	19.49	66.3	6.24	0.00
	Feed		1005.48										
	Tails		991.54										
ORE B	C1	2	3.15	3.15	13.6	13.22	53.26	11.27	16.77	32.80	24.3	0.33	0.00
SIBX 150 g/t mill	C2	6	3.59	6.74	56.6	8.65	74.58	11.98	38.14	28.75	45.5	1.36	0.00
DOW 200 40 g/t	C3	12	2.2	8.94	109.0	7.00	80.03	10.57	44.62	25.20	52.9	2.62	0.00
Guar 500 g/t	C4	20	3.18	12.12	204.6	5.37	83.27	8.65	49.52	21.11	60.1	4.91	0.00
	Feed		1010.86										
	Tails		998.74										

Flotation conditions	Sample ID	Time mins	Mass g	Cum mass g	Cum water g	Copper grade %	Copper recovery %	Nickel grade %	Nickel recovery %	Sulphur grade %	Sulphur recovery %	Entrained gangue g	Floating gangue g
ORE B	C1	2	3.25	3.25	53.1	15.07	58.72	4.06	5.91	21.50	15.98	1.27	0.00
PAX 50 g/t mill	C2	6	2.9	6.15	124.3	10.02	73.86	7.21	19.89	19.43	27.3	2.98	0.00
DOW 200 40 g/t	C3	12	3.51	9.66	215.1	6.94	80.38	8.80	38.11	17.56	38.8	5.16	0.00
Guar 500 g/t	C4	20	3.42	13.08	318.3	5.35	83.85	8.40	49.27	16.32	48.8	7.64	0.00
	Feed		992.84										
	Tails		979.76										
ORE B	C1	2	2.48	2.48	42.8	16.57	48.82	3.68	4.15	23.40	13.7	1.03	0.00
PAX 50 g/t mill	C2	6	2.5	4.98	105.7	11.78	69.66	6.52	14.77	20.69	24.3	2.54	0.00
DOW 200 40 g/t	C3	12	2.44	7.42	177.9	8.76	77.20	7.96	26.84	18.52	32.4	4.27	0.00
Guar 500 g/t	C4	20	3.21	10.63	267.8	6.48	81.85	8.98	43.37	15.83	39.6	6.43	0.00
	Feed		999.5										
	Tails		988.87										
ORE B	C1	2	3.16	3.16	30.8	14.26	54.79	10.13	14.69	29.50	23.1	0.74	0.00
SIBX 100 g/t mill	C2	6	3.3	6.46	91.3	9.34	73.39	11.13	32.98	25.36	40.7	2.19	0.00
DOW 200 40 g/t	C3	12	2.35	8.81	155.3	7.43	79.62	10.74	43.40	22.20	48.5	3.73	0.00
Guar 500 g/t	C4	20	2.73	11.54	238.3	5.92	83.00	9.31	49.28	18.97	54.3	5.72	0.00
	Feed		985.58										
	Tails		974.04										
ORE B	C1	2	3.36	3.36	35.7	13.52	55.79	9.90	15.07	27.40	23.1	0.86	0.00
PAX 100 g/t mill	C2	6	3.27	6.63	98.0	9.05	73.72	10.95	32.89	23.80	39.6	2.35	0.00
DOW 200 40 g/t	C3	12	2.51	9.14	165.1	7.16	80.34	10.57	43.78	20.89	47.9	3.96	0.00
Guar 500 g/t	C4	20	3.31	12.45	277.9	5.52	84.37	8.94	50.43	17.37	54.3	6.67	0.00
	Feed		1002.76										
	Tails		990.31										
ORE B	C1	2	3.78	3.78	21.9	11.61	52.11	11.88	19.82	32.30	27.5	0.53	0.00
PAX 150 g/t mill	C2	6	3.64	7.42	78.0	8.02	70.70	11.80	38.63	27.49	45.9	1.87	0.00
DOW 200 40 g/t	C3	12	3.13	10.55	164.2	6.18	77.46	9.80	45.62	22.84	54.3	3.94	0.00
Guar 500 g/t	C4	20	4.28	14.83	302.1	4.61	81.17	7.65	50.04	18.17	60.7	7.25	0.00
	Feed		1012.26										
	Tails		997.43										
ORE B	C1	2	3.73	3.73	20.2	11.88	53.84	11.52	18.57	32.00	25.1	0.48	0.00
PAX 150 g/t mill	C2	6	3.65	7.38	72.6	8.12	72.84	11.66	37.21	27.60	42.8	1.74	0.00
DOW 200 40 g/t	C3	12	2.76	10.14	143.4	6.44	79.38	10.49	45.97	23.57	50.2	3.44	0.00
Guar 500 g/t	C4	20	3.82	13.96	263.5	4.90	83.16	8.41	50.73	19.10	56.0	6.32	0.00
	Feed		1000.73										
	Tails		986.77										

Flotation conditions	Sample ID	Time mins	Mass g	Cum mass g	Cum water g	Copper grade %	Copper recovery %	Nickel grade %	Nickel recovery %	Sulphur grade %	Sulphur recovery %	Entrained gangue g	Floating gangue g
ORE A	C1	2	2.33	2.33	8.96	13.07	53.20	9.20	13.04	32.30	24.71	0.21	0.00
SEX 50 g/t mill	C2	6	3.66	5.99	61.1	7.44	77.89	10.18	37.09	26.19	51.5	1.44	0.00
DOW 200 40 g/t	C3	12	2.18	8.17	114.8	5.71	81.54	9.21	45.78	23.07	61.9	2.71	0.00
CMC 500 g/t	C4	20	2.10	10.27	183.1	4.65	83.47	7.97	49.78	20.40	68.8	4.32	0.00
	Feed		1051.58										
	Tails		1041.31										
ORE A	C1	2	1.87	1.87	5.7	14.69	49.23	8.56	10.12	33.80	20.5	0.13	0.00
SEX 50 g/t mill	C2	6	3.38	5.25	51.1	8.16	76.77	10.46	34.70	27.62	47.0	1.21	0.00
DOW 200 40 g/t	C3	12	2.20	7.45	106.0	6.07	81.03	9.74	45.83	24.04	58.0	2.50	0.00
CMC 500 g/t	C4	20	1.82	9.27	162.8	4.99	82.97	8.62	50.51	21.66	65.0	3.84	0.00
	Feed		1047.37										
	Tails		1038.1										
ORE A	C1	2	1.88	1.88	3.4	13.17	48.99	9.68	12.40	34.50	21.7	0.08	0.00
SEX 100 g/t mill	C2	6	3.24	5.12	39.7	7.56	76.61	10.65	37.18	29.31	50.2	0.94	0.00
DOW 200 40 g/t	C3	12	1.83	6.95	80.3	5.88	80.88	9.71	45.99	26.44	61.4	1.90	0.00
CMC 500 g/t	C4	20	1.24	8.19	113.0	5.09	82.51	8.92	49.82	24.96	68.3	2.67	0.00
	Feed		981.21										
	Tails		973.02										
ORE A	C1	2	2.03	2.03	4.8	13.43	50.27	9.26	11.76	34.30	22.4	0.11	0.00
SEX 100 g/t mill	C2	6	3.30	5.33	42.1	7.74	76.08	10.41	34.69	28.73	49.3	0.99	0.00
DOW 200 40 g/t	C3	12	2.10	7.43	88.7	5.89	80.65	9.39	43.63	25.50	61.1	2.09	0.00
CMC 500 g/t	C4	20	1.32	8.75	122.8	5.10	82.27	8.69	47.55	24.29	68.5	2.90	0.00
	Feed		1042.33										
	Tails		1033.58										
ORE A	C1	2	2.87	2.87	12.4	10.64	57.69	10.17	19.37	31.50	29.4	0.29	0.00
SEX 150 g/t mill	C2	6	3.49	6.36	64.0	6.56	78.82	9.91	41.82	26.29	54.4	1.51	0.00
DOW 200 40 g/t	C3	12	1.91	8.27	112.4	5.25	82.10	8.78	48.20	23.91	64.3	2.65	0.00
CMC 500 g/t	C4	20	1.39	9.66	154.8	4.58	83.60	8.03	51.47	22.56	70.9	3.65	0.00
	Feed		978.63										
	Tails		968.97										
ORE A	C1	2	2.14	2.14	5.4	12.68	50.39	10.10	13.91	34.10	23.1	0.13	0.00
SEX 150 g/t mill	C2	6	3.37	5.51	44.4	7.46	76.32	10.31	36.56	29.02	50.7	1.05	0.00
DOW 200 40 g/t	C3	12	2.16	7.67	91.8	5.68	80.91	9.12	45.01	25.67	62.4	2.17	0.00
CMC 500 g/t	C4	20	1.75	9.42	140.8	4.74	82.91	8.11	49.17	23.54	70.3	3.32	0.00
	Feed		1031.93										
	Tails		1022.51										

Flotation conditions	Sample ID	Time mins	Mass g	Cum mass g	Cum water g	Copper grade %	Copper recovery %	Nickel grade %	Nickel recovery %	Sulphur grade %	Sulphur recovery %	Entrained gangue g	Floating gangue g
ORE A	C1	2	1.49	1.49	3.89	15.00	38.74	5.44	4.90	34.50	16.3	0.09	0.00
SIBX 50 g/t mill	C2	6	2.55	4.04	31.4	9.92	69.43	10.38	25.31	30.33	38.9	0.74	0.00
DOW 200 40 g/t	C3	12	2.44	6.48	88.3	7.20	80.90	10.54	41.24	24.86	51.2	2.08	0.00
CMC 500 g/t	C4	20	2.86	9.34	185.3	5.18	83.79	8.61	48.52	19.72	58.5	4.37	0.00
	Feed		1032.79										
	Tails		1023.45										
ORE A	C1	2	1.29	1.29	2.5	19.93	44.20	4.61	3.74	35.00	14.5	0.06	0.00
SIBX 50 g/t mill	C2	6	2.44	3.73	28.1	11.57	74.21	9.32	21.88	30.29	36.3	0.66	0.00
DOW 200 40 g/t	C3	12	2.33	6.06	77.8	7.78	81.06	10.25	39.10	25.30	49.2	1.84	0.00
CMC 500 g/t	C4	20	2.73	8.79	167.3	5.57	84.22	8.62	47.71	20.18	56.9	3.95	0.00
	Feed		1041.31										
	Tails		1032.52										
ORE A	C1	2	1.90	1.90	3.9	14.48	49.21	8.64	9.97	35.30	20.8	0.09	0.00
SIBX 100 g/t mill	C2	6	2.60	4.50	28.4	9.07	73.01	11.05	30.22	31.26	43.6	0.67	0.00
DOW 200 40 g/t	C3	12	2.63	7.13	84.8	6.24	79.60	9.84	42.63	25.04	55.4	2.00	0.00
CMC 500 g/t	C4	20	2.47	9.60	163.3	4.80	82.35	8.19	47.76	20.65	61.5	3.85	0.00
	Feed		1039.49										
	Tails		1029.89										
ORE A	C1	2	2.23	2.23	5.6	13.80	51.50	9.09	12.37	34.90	23.7	0.13	0.00
SIBX 100 g/t mill	C2	6	2.79	5.02	35.3	8.93	75.03	10.84	33.21	30.51	46.6	0.83	0.00
DOW 200 40 g/t	C3	12	2.84	7.86	104.2	6.17	81.19	9.37	44.95	24.26	58.1	2.46	0.00
CMC 500 g/t	C4	20	2.78	10.64	192.4	4.71	83.94	7.75	50.35	19.80	64.1	4.54	0.00
	Feed		1043.29										
	Tails		1032.65										
ORE A	C1	2	1.75	1.75	1.6	13.68	41.84	9.56	9.93	34.60	17.7	0.04	0.00
SIBX 150 g/t mill	C2	6	3.16	4.91	28.0	8.51	73.06	11.66	33.99	31.70	45.5	0.66	0.00
DOW 200 40 g/t	C3	12	2.54	7.45	80.6	6.16	80.22	10.60	46.88	27.00	58.8	1.90	0.00
CMC 500 g/t	C4	20	2.58	10.03	160.7	4.75	83.21	8.71	51.86	22.50	65.9	3.79	0.00
	Feed		1037.61										
	Tails		1027.58										
ORE A	C1	2	1.94	1.94	3.3	13.65	49.88	9.17	11.78	34.70	20.6	0.08	0.00
SIBX 150 g/t mill	C2	6	2.54	4.48	23.2	8.79	74.15	10.95	32.51	31.41	43.0	0.55	0.00
DOW 200 40 g/t	C3	12	2.67	7.15	78.4	5.98	80.59	9.25	43.83	25.02	54.7	1.85	0.00
CMC 500 g/t	C4	20	2.64	9.79	157.6	4.52	83.35	7.52	48.79	20.31	60.8	3.72	0.00
	Feed		966.69										
	Tails		956.90										

Flotation conditions	Sample ID	Time mins	Mass g	Cum mass g	Cum water g	Copper grade %	Copper recovery %	Nickel grade %	Nickel recovery %	Sulphur grade %	Sulphur recovery %	Entrained gangue g	Floating gangue g
ORE B	C1	2	2.80	2.80	3.7	15.96	60.45	10.64	13.47	33.10	22.39	0.10	0.00
SEX 50 g/t mill	C2	6	4.04	6.84	44.8	8.72	80.72	12.39	38.32	28.49	47.1	1.23	0.00
DOW 200 40 g/t	C3	12	4.29	11.13	151.7	5.70	85.87	9.40	47.29	22.21	59.7	4.16	0.00
CMC 500 g/t	C4	20	5.55	16.68	346.9	3.91	88.14	6.75	50.89	16.70	67.3	9.51	0.00
	Feed		1019.87										
	Tails		1003.19										
ORE B	C1	2	2.20	2.20	2.7	17.90	52.98	9.26	9.92	33.50	17.8	0.07	0.00
SEX 50 g/t mill	C2	6	4.07	6.27	40.2	9.43	79.56	12.06	36.83	28.50	43.3	1.10	0.00
DOW 200 40 g/t	C3	12	4.36	10.63	146.9	5.98	85.50	9.35	48.37	22.06	56.8	4.03	0.00
CMC 500 g/t	C4	20	4.89	15.52	323.7	4.22	88.07	6.94	52.45	17.15	64.4	8.87	0.00
	Feed		1011.30										
	Tails		995.78										
ORE B	C1	2	2.27	2.27	0.1	15.58	51.15	11.42	12.86	34.00	20.7	0.00	0.00
SEX 100 g/t mill	C2	6	3.28	5.55	15.5	9.64	77.37	12.77	35.15	31.81	47.3	0.42	0.00
DOW 200 40 g/t	C3	12	3.21	8.76	72.8	6.60	83.61	10.56	45.87	24.85	58.3	1.99	0.00
CMC 500 g/t	C4	20	3.45	12.21	173.7	4.87	86.04	8.23	49.85	20.74	67.8	4.76	0.00
	Feed		1009.92										
	Tails		997.71										
ORE B	C1	2	1.81	1.81	0.3	15.55	40.64	11.26	10.37	34.60	15.3	0.01	0.00
SEX 100 g/t mill	C2	6	3.37	5.18	10.9	10.21	76.36	12.63	33.29	32.58	41.2	0.30	0.00
DOW 200 40 g/t	C3	12	3.41	8.59	64.6	6.72	83.35	10.43	45.56	26.99	56.6	1.77	0.00
CMC 500 g/t	C4	20	3.73	12.32	158.5	4.84	86.10	8.06	50.54	21.81	65.6	4.34	0.00
	Feed		1020.63										
	Tails		1008.31										
ORE B	C1	2	2.17	2.17	0.1	16.08	48.70	10.94	11.88	34.40	18.6	0.00	0.00
SEX 150 g/t mill	C2	6	3.45	5.62	13.2	9.83	77.09	12.38	34.84	32.31	45.2	0.36	0.00
DOW 200 40 g/t	C3	12	3.28	8.90	66.3	6.71	83.34	10.26	45.73	27.11	60.0	1.82	0.00
CMC 500 g/t	C4	20	3.41	12.31	151.9	5.00	85.92	8.13	50.10	22.54	69.0	4.16	0.00
	Feed		1021.39										
	Tails		1009.08										
ORE B	C1	2	2.40	2.40	0.1	15.18	50.78	11.52	13.48	34.10	19.4	0.00	0.00
SEX 150 g/t mill	C2	6	3.43	5.83	15.7	9.52	77.35	12.73	36.19	32.10	44.5	0.43	0.00
DOW 200 40 g/t	C3	12	3.59	9.42	78.7	6.35	83.36	10.14	46.59	26.27	58.8	2.16	0.00
CMC 500 g/t	C4	20	3.94	13.36	180.8	4.61	85.80	7.81	50.89	21.24	67.4	4.95	0.00
	Feed		1044.35										
	Tails		1030.99										

Flotation conditions	Sample ID	Time mins	Mass g	Cum mass g	Cum water g	Copper grade %	Copper recovery %	Nickel grade %	Nickel recovery %	Sulphur grade %	Sulphur recovery %	Entrained gangue g	Floating gangue g
ORE B	C1	2	1.94	1.94	6.7	23.53	57.23	4.12	3.81	32.00	15.07	0.18	0.00
SIBX 50 g/t mill	C2	6	2.61	4.55	36.3	13.55	77.27	9.66	20.92	27.35	30.2	0.99	0.00
DOW 200 40 g/t	C3	12	3.90	8.45	125.3	7.99	84.61	10.01	40.27	20.91	42.9	3.43	0.00
CMC 500 g/t	C4	20	3.91	12.36	258.5	5.65	87.51	8.07	47.52	16.44	49.3	7.08	0.00
	Feed		1050.54										
	Tails		1038.18										
ORE B	C1	2	1.99	1.99	9.4	21.84	58.49	5.02	5.00	31.30	15.5	0.26	0.00
SIBX 50 g/t mill	C2	6	2.61	4.60	44.4	12.57	77.80	10.26	23.62	29.43	33.7	1.22	0.00
DOW 200 40 g/t	C3	12	3.48	8.08	134.4	7.78	84.61	10.22	41.33	22.22	44.7	3.68	0.00
CMC 500 g/t	C4	20	3.67	11.75	265.2	5.54	87.62	8.19	48.17	17.22	50.4	7.27	0.00
	Feed		974.70										
	Tails		962.95										
ORE B	C1	2	2.18	2.18	4.8	18.84	54.10	8.11	8.21	33.10	16.1	0.13	0.00
SIBX 100 g/t mill	C2	6	2.96	5.14	29.4	11.16	75.58	12.11	28.91	30.16	34.7	0.80	0.00
DOW 200 40 g/t	C3	12	3.08	8.22	93.6	7.62	82.51	11.45	43.68	24.89	45.7	2.57	0.00
CMC 500 g/t	C4	20	3.60	11.82	207.1	5.49	85.49	9.01	49.46	19.52	51.6	5.67	0.00
	Feed		1081.63										
	Tails		1070.81										
ORE B	C1	2	2.14	2.14	5.6	19.13	55.88	8.26	8.48	33.40	18.5	0.15	0.00
SIBX 100 g/t mill	C2	6	2.60	4.74	25.3	11.80	76.31	11.80	26.84	30.38	37.2	0.69	0.00
DOW 200 40 g/t	C3	12	3.36	8.10	99.7	7.55	83.43	10.69	41.55	23.71	49.6	2.73	0.00
CMC 500 g/t	C4	20	3.39	11.49	209.1	5.49	86.15	8.47	46.71	18.70	55.5	5.73	0.00
	Feed		1001.10										
	Tails		989.61										
ORE B	C1	2	2.76	2.76	3.7	15.15	56.48	11.03	14.58	33.80	22.9	0.10	0.00
SIBX 150 g/t mill	C2	6	2.89	5.65	23.6	10.02	76.49	12.65	34.24	31.19	43.3	0.65	0.00
DOW 200 40 g/t	C3	12	3.61	9.26	94.4	6.67	83.43	10.46	46.38	24.65	56.1	2.59	0.00
CMC 500 g/t	C4	20	3.76	13.02	205.1	4.91	86.39	8.17	50.92	19.63	62.8	5.62	0.00
	Feed		1023.47										
	Tails		1010.45										
ORE B	C1	2	2.20	2.20	1.25	16.22	51.93	10.63	11.07	34.30	18.49	0.03	0.00
SIBX 150 g/t mill	C2	6	2.80	5.00	14.9	10.33	75.18	13.08	30.95	32.56	39.9	0.41	0.00
DOW 200 40 g/t	C3	12	2.89	7.89	64.0	7.10	81.57	11.73	43.81	27.19	52.6	1.75	0.00
CMC 500 g/t	C4	20	3.43	11.32	154.9	5.16	85.03	9.16	49.09	21.55	59.8	4.24	0.00
	Feed		1024.59										
	Tails		1013.27										

Appendix C
T tests

Ore A Guar vs CMC 100 g/t (Water recovered)

t-Test: Paired Two Sample for Means

	CMC	*guar*
Mean	528.010	487.335
t Stat	2.155	
P(T<=t) two-tail	0.277	
t Critical two-tail	12.706	

Ore A Guar vs CMC 100 g/t (Floating gangue)

t-Test: Paired Two Sample for Means

	CMC	*guar*
Mean	13.284	7.439
t Stat	2.967	
P(T<=t) two-tail	0.059	
t Critical two-tail	3.182	

Ore A Guar vs CMC 200 g/t (Water recovered)

t-Test: Paired Two Sample for Means

	CMC	*guar*
Mean	498.62	474.92
t Stat	0.465	
P(T<=t) two-tail	0.723	
t Critical two-tail	12.706	

Ore A Guar vs CMC 200 g/t (Floating gangue)

t-Test: Paired Two Sample for Means

	CMC	*guar*
Mean	4.450	1.875
t Stat	2.802	
P(T<=t) two-tail	0.068	
t Critical two-tail	3.182	

Ore A Guar vs CMC 300 g/t (Water recovered)

t-Test: Paired Two Sample for Means

	CMC	*guar*
Mean	401.64	445.97
t Stat	-2.004	
P(T<=t) two-tail	0.295	
t Critical two-tail	12.706	

Ore A Guar vs CMC 300 g/t (Floating gangue)

t-Test: Paired Two Sample for Means

	CMC	*guar*
Mean	0.199	0
t Stat	1.492	
P(T<=t) two-tail	0.232	
t Critical two-tail	3.182	

Ore B Guar vs CMC 100 g/t (Water recovered)

t-Test: Paired Two Sample for Means

	CMC	*guar*
Mean	735.455	614.71
t Stat	4.296	
P(T<=t) two-tail	0.146	
t Critical two-tail	12.706	

Ore B Guar vs CMC 100 g/t (Floating gangue)

t-Test: Paired Two Sample for Means

	CMC	*guar*
Mean	31.465	19.77
t Stat	3.921	
P(T<=t) two-tail	0.030	
t Critical two-tail	3.182	

Ore B Guar vs CMC 200 g/t (Water recovered)

t-Test: Paired Two Sample for Means

	CMC	*guar*
Mean	516.335	602.175
t Stat	-1.428	
P(T<=t) two-tail	0.389	
t Critical two-tail	12.706	

Ore B Guar vs CMC 200 g/t (Floating gangue)

t-Test: Paired Two Sample for Means

	CMC	*guar*
Mean	5.2	4.68
t Stat	0.888	
P(T<=t) two-tail	0.440	
t Critical two-tail	3.182	

Ore B Guar vs CMC 300 g/t (Water recovered)

t-Test: Paired Two Sample for Means

	CMC	*guar*
Mean	478.87	536.95
t Stat	-1.389	
P(T<=t) two-tail	0.397	
t Critical two-tail	12.706	

Ore B Guar vs CMC 300 g/t (Floating gangue)

t-Test: Paired Two Sample for Means

	CMC	*guar*
Mean	0.005	0.958
t Stat	-1.954	
P(T<=t) two-tail	0.146	
t Critical two-tail	3.182	

Ore A vs Ore B CMC 100 g/t (Water recovered)

F-Test Two-Sample for Variances

	Ore A	*Ore B*
Mean	528.01	735.455
Variance	7.683	117.504
F	0.065	
P(F<=f) one-tail	0.159	
F Critical one-tail	0.006	

t-Test: Two-Sample Assuming Equal Variances

	Ore A	*Ore B*
Mean	528.01	735.455
Variance	7.683	117.504
t Stat	-26.220	
P(T<=t) two-tail	0.001	
t Critical two-tail	4.303	

Ore A vs Ore B CMC 100 g/t (Floating gangue)

F-Test Two-Sample for Variances

	Ore A	*Ore B*
Mean	13.284	31.465
Variance	84.592	387.059
F	0.219	
P(F<=f) one-tail	0.122	
F Critical one-tail	0.108	

t-Test: Two-Sample Assuming Equal Variances

	Ore A	*Ore B*
Mean	13.284	31.465
Variance	84.592	387.059
t Stat	-1.674	
P(T<=t) two-tail	0.145	
t Critical two-tail	2.447	

Ore A vs Ore B CMC 200 g/t (Water recovered)

F-Test Two-Sample for Variances

	Ore A	*Ore B*
Mean	498.62	516.335
Variance	3360.360	5406.960
F	0.621	
P(F<=f) one-tail	0.425	
F Critical one-tail	0.006	

t-Test: Two-Sample Assuming Equal Variances

	Ore A	*Ore B*
Mean	498.62	516.335
Variance	3360.360	5406.960
t Stat	-0.268	
P(T<=t) two-tail	0.814	
t Critical two-tail	4.303	

Ore A vs Ore B CMC 200 g/t (Floating gangue)

F-Test Two-Sample for Variances

	Ore A	*Ore B*
Mean	4.450	5.2
Variance	11.212	27.546
F	0.407	
P(F<=f) one-tail	0.240	
F Critical one-tail	0.108	

t-Test: Two-Sample Assuming Equal Variances

	Ore A	*Ore B*
Mean	4.450	5.2
Variance	11.212	27.546
t Stat	-0.241	
P(T<=t) two-tail	0.818	
t Critical two-tail	2.447	

Ore A vs Ore B CMC 300 g/t (Water recovered)

F-Test Two-Sample for Variances

	Ore A	*Ore B*
Mean	401.64	478.87
Variance	15.015	2.42
F	6.205	
P(F<=f) one-tail	0.243	
F Critical one-tail	161.448	

t-Test: Two-Sample Assuming Equal Variances

	Ore A	*Ore B*
Mean	401.64	478.87
Variance	15.015	2.42
t Stat	-26.157	
P(T<=t) two-tail	0.001	
t Critical two-tail	4.303	

Ore A vs Ore B CMC 300 g/t (Floating gangue)

F-Test Two-Sample for Variances

	Ore A	*Ore B*
Mean	0.199	0.005
Variance	0.071	0.000
F	712.168	
P(F<=f) one-tail	0.000	
F Critical one-tail	9.277	

t-Test: Two-Sample Assuming Unequal Variances

	Ore A	*Ore B*
Mean	0.199	0.005
Variance	0.071	0.000
t Stat	1.454	
P(T<=t) two-tail	0.242	
t Critical two-tail	3.182	

Ore A vs Ore B Guar 100 g/t (Water recovered)

F-Test Two-Sample for Variances

	Ore A	*Ore B*
Mean	487.335	614.710
Variance	868.194	835.587
F	1.039	
P(F<=f) one-tail	0.494	
F Critical one-tail	161.448	

t-Test: Two-Sample Assuming Equal Variances

	Ore A	*Ore B*
Mean	487.335	614.710
Variance	868.194	835.587
t Stat	-4.364	
P(T<=t) two-tail	0.049	
t Critical two-tail	4.303	

Ore A vs Ore B Guar 100 g/t (Floating gangue)

F-Test Two-Sample for Variances

	Ore A	*Ore B*
Mean	7.439	19.770
Variance	27.982	193.237
F	0.145	
P(F<=f) one-tail	0.073	
F Critical one-tail	0.108	

t-Test: Two-Sample Assuming Equal Variances

	Ore A	*Ore B*
Mean	7.439	19.770
Variance	27.982	193.237
t Stat	-1.658	
P(T<=t) two-tail	0.148	
t Critical two-tail	2.447	

Ore A vs Ore B Guar 200 g/t (Water recovered)

F-Test Two-Sample for Variances

	Ore A	*Ore B*
Mean	474.920	602.175
Variance	198.802	132.356
F	1.502	
P(F<=f) one-tail	0.436	
F Critical one-tail	161.448	

t-Test: Two-Sample Assuming Equal Variances

	Ore A	*Ore B*
Mean	474.920	602.175
Variance	198.802	132.356
t Stat	-9.889	
P(T<=t) two-tail	0.010	
t Critical two-tail	4.303	

Ore A vs Ore B Guar 200 g/t (Floating gangue)

F-Test Two-Sample for Variances

	Ore A	*Ore B*
Mean	1.875	4.680
Variance	2.283	16.981
F	0.134	
P(F<=f) one-tail	0.067	
F Critical one-tail	0.108	

t-Test: Two-Sample Assuming Equal Variances

	Ore A	*Ore B*
Mean	1.875	4.680
Variance	2.283	16.981
t Stat	-1.278	
P(T<=t) two-tail	0.248	
t Critical two-tail	2.447	

Ore A vs Ore B Guar 300 g/t (Water recovered)

F-Test Two-Sample for Variances

	Ore A	*Ore B*
Mean	445.97	536.95
Variance	751.169	3316.237
F	0.227	
P(F<=f) one-tail	0.283	
F Critical one-tail	0.006	

t-Test: Two-Sample Assuming Equal Variances

	Ore A	*Ore B*
Mean	445.97	536.95
Variance	751.169	3316.237
t Stat	-2.017	
P(T<=t) two-tail	0.181	
t Critical two-tail	4.303	

Ore A vs Ore B Guar 300 g/t (Floating gangue)

F-Test Two-Sample for Variances

	Ore A	*Ore B*
Mean	0	0.958
Variance	0	0.940
F	0	
P(F<=f) one-tail	0	
F Critical one-tail	0.108	

t-Test: Two-Sample Assuming Unequal Variances

	Ore A	*Ore B*
Mean	0	0.958
Variance	0	0.940
t Stat	-1.975	
P(T<=t) two-tail	0.143	
t Critical two-tail	3.182	

Ore A vs Ore B No depressant (Water recovered)

F-Test Two-Sample for Variances

	Ore A	*Ore B*
Mean	603.125	766.755
Variance	2575.466	4695.774
F	0.548	
P(F<=f) one-tail	0.406	
F Critical one-tail	0.006	

t-Test: Two-Sample Assuming Equal Variances

	Ore A	*Ore B*
Mean	603.125	766.755
Variance	2575.466	4695.774
t Stat	-2.714	
P(T<=t) two-tail	0.113	
t Critical two-tail	4.303	

Ore A vs Ore B No depressant (Floating gangue)

F-Test Two-Sample for Variances

	Ore A	*Ore B*
Mean	27.285	54.783
Variance	194.718	604.736
F	0.322	
P(F<=f) one-tail	0.188	
F Critical one-tail	0.108	

t-Test: Two-Sample Assuming Equal Variances

	Ore A	*Ore B*
Mean	27.285	54.783
Variance	194.718	604.736
t Stat	-1.945	
P(T<=t) two-tail	0.100	
t Critical two-tail	2.447	

Ore A vs Ore B No depressant (Water recovered) sized concentrates

F-Test Two-Sample for Variances

	Ore A	*Ore B*
Mean	552.364	352.3
Variance	683.019	124.562
F	5.483	
P(F<=f) one-tail	0.064	
F Critical one-tail	6.388	

t-Test: Two-Sample Assuming Equal Variances

	Ore A	*Ore B*
Mean	552.364	352.3
Variance	683.019	124.562
t Stat	15.742	
P(T<=t) two-tail	0.000	
t Critical two-tail	2.306	

Ore A Guar vs CMC, SEX 50 g/t (Nickel recovery)

t-Test: Paired Two Sample for Means

	CMC	*guar*
Mean	35.856	30.107
t Stat	2.757	
P(T<=t) two-tail	0.070	
t Critical two-tail	3.182	

Ore A Guar vs CMC, SEX 50 g/t (Sulphur recovery)

t-Test: Paired Two Sample for Means

	CMC	*guar*
Mean	49.664	42.184
t Stat	1.787	
P(T<=t) two-tail	0.172	
t Critical two-tail	3.182	

Ore A Guar vs CMC, SEX 150 g/t (Nickel recovery)

t-Test: Paired Two Sample for Means

	CMC	*guar*
Mean	38.190	33.283
t Stat	4.475	
P(T<=t) two-tail	0.021	
t Critical two-tail	3.182	

Ore A Guar vs CMC, SEX 150 g/t (Sulphur recovery)

t-Test: Paired Two Sample for Means

	CMC	*guar*
Mean	53.207	43.116
t Stat	5.792	
P(T<=t) two-tail	0.010	
t Critical two-tail	3.182	

Ore B Guar vs CMC, SEX 50 g/t (Nickel recovery)

t-Test: Paired Two Sample for Means

	CMC	*guar*
Mean	37.192	34.301
t Stat	1.440	
P(T<=t) two-tail	0.246	
t Critical two-tail	3.182	

Ore B Guar vs CMC, SEX 50 g/t (Sulphur recovery)

t-Test: Paired Two Sample for Means

	CMC	*guar*
Mean	47.349	44.484
t Stat	1.223	
P(T<=t) two-tail	0.309	
t Critical two-tail	3.182	

Ore B Guar vs CMC, SEX 150 g/t (Nickel recovery)

t-Test: Paired Two Sample for Means

	CMC	*guar*
Mean	36.212	31.694
t Stat	8.274	
P(T<=t) two-tail	0.004	
t Critical two-tail	3.182	

Ore A Guar vs CMC, SEX 150 g/t (Sulphur recovery)

t-Test: Paired Two Sample for Means

	CMC	*guar*
Mean	47.858	42.885
t Stat	5.041	
P(T<=t) two-tail	0.015	
t Critical two-tail	3.182	

T test explanations

Ore A CMC vs guar (100 g/t)

- **Cumulative water (g)**

  - data:

	CMC	guar
Float 1	529.97	508.17
Float 2	526.05	466.50

  - calculations:

    The samples are dependent since the same ore was used, but with different depressants (CMC vs guar), therefore a 't-test: paired two sample for means' was used in excel.

  - conclusions:

    Since the calculated t stat (2.155) is less than the critical t stat (12.706 - two-tailed critical value), it was concluded that there was not a significant difference at the 5% significance level.

    OR

    Since the p-value (0.277 - two-tailed value), is greater than 0.05 (since the chosen significance level is 5%), it was concluded that there was not a significant difference at the 5% significance level.

- **Average floating gangue (g)**

  - data:

	CMC	guar
C1	3.22	1.95
C2	8.85	4.73
C3	16.79	9.01
C4	24.27	14.07

  - calculations:

The samples are dependent since the same ore was used, but with different depressants (CMC vs guar), therefore a 't-test: paired two sample for means' was used in excel.

- conclusions:

Since the calculated t stat (2.967) is less than the critical t stat (3.182 - two-tailed critical value), it was concluded that there was not a significant difference at the 5% significance level.

OR

Since the p-value (0.059 - two-tailed value), is greater than 0.05 (since the chosen significance level is 5%), it was concluded that there was not a significant difference at the 5% significance level.

Ore A CMC vs guar (200 g/t)

- **Cu Cumulative water (g)**

  - data:

	CMC	guar
Float 1	457.63	484.89
Float 2	539.61	464.95

  - calculations:

The samples are dependent since the same ore was used, but with different depressants (CMC vs guar), therefore a 't-test: paired two sample for means' was used in excel.

  - conclusions:

Since the calculated t stat (0.465) is less than the critical t stat (12.706 - two-tailed critical value), it was concluded that there was not a significant difference at the 5% significance level

OR

Since the p-value (0.723 - two-tailed value), is greater than 0.05 (since the chosen significance level is 5%), it was concluded that there was not a significant difference at the 5% significance level.

- **Average floating gangue (g)**

  - data:

	CMC	guar
C1	1.35	0.47
C2	2.48	1.00
C3	5.07	2.15
C4	8.89	3.88

- calculations:

  The samples are dependent since the same ore was used, but with different depressants (CMC vs guar), therefore a 't-test: paired two sample for means' was used in excel.

- conclusions:

  Since the calculated t stat (2.802) is less than the critical t stat (3.182 - two-tailed critical value), it was concluded that there was not a significant difference at the 5% significance level.

  OR

  Since the p-value (0.068 - the two-tailed value), is greater than 0.05 (since the chosen significance level is 5%), it was concluded that there was not a significant difference at the 5% significance level.

Ore A CMC vs guar (300 g/t)

- **Cumulative water (g)**

  - data:

	CMC	guar
Float 1	398.90	465.35
Float 2	404.38	426.59

  - calculations:

    The samples are dependent since the same ore was used, but with different depressants (CMC vs guar), therefore a 't-test: paired two sample for means' was used in excel.

  - conclusions:

    Since the calculated t stat (-2.004) is less than the critical t stat (12.706 - two-tailed critical value), it was concluded that there was not a significant difference at the 5% significance level.

OR

Since the p-value (0.294 - two-tailed value), is greater than 0.05 (since the chosen significance level is 5%), it was concluded that there was not a significant difference at the 5% significance level.

- **Average floating gangue (g)**

  - data:

	CMC	guar
C1	0.06	0
C2	0.05	0
C3	0.09	0
C4	0.60	0

  - calculations:

The samples are dependent since the same ore was used, but with different depressants (CMC vs guar), therefore a 't-test: paired two sample for means' was used in excel.

  - conclusions:

Since the calculated t stat (1.492) is less than the critical t stat (3.182 - two-tailed critical value), it was concluded that there was not a significant difference at the 5% significance level.

OR

Since the p-value (0.232 - two-tailed value), is greater than 0.05 (since the chosen significance level is 5%), it was concluded that there was not a significant difference at the 5% significance level.

Ore B CMC vs guar (100 g/t)

- **Cumulative water (g)**

  - data:

	CMC	guar
Float 1	727.79	635.15
Float 2	743.12	594.27

  - calculations:

The samples are dependent since the same ore was used, but with different depressants (CMC vs guar), therefore a ‘t-test: paired two sample for means’ was used in excel.

- conclusions:

Since the calculated t stat (4.296) is less than the critical t stat (12.706 - two-tailed critical value), it was concluded that there was not a significant difference at the 5% significance level.

OR

Since the p-value (0.146 - two-tailed value), is greater than 0.05 (since the chosen significance level is 5%), it was concluded that there was not a significant difference at the 5% significance level.

- **Average floating gangue (g)**

- data:

	CMC	guar
C1	8.97	4.90
C2	22.69	12.79
C3	40.42	24.73
C4	53.78	36.66

- calculations:

The samples are dependent since the same ore was used, but with different depressants (CMC vs guar), therefore a ‘t-test: paired two sample for means’ was used in excel.

- conclusions:

Since the calculated t stat (3.921) is greater than the critical t stat (3.182 - two-tailed critical value), it was concluded that there was a significant difference at the 5% significance level

OR

Since the p-value (0.030 - two-tailed value), is less than 0.05 (since the chosen significance level is 5%), it was concluded that there was a significant difference at the 5% significance level.

Ore B CMC vs guar (200 g/t)

- **Cumulative water (g)**

  - data:

	CMC	guar
Float 1	464.34	610.31
Float 2	568.33	594.04

  - calculations:

    The samples are dependent since the same ore was used, but with different depressants (CMC vs guar), therefore a 't-test: paired two sample for means' was used in excel.

  - conclusions:

    Since the calculated t stat (-1.428) is less than the critical t stat (12.706 - two-tailed critical value), it was concluded that there was not a significant difference at the 5% significance level.

    OR

    Since the p-value (0.389 - two-tailed value), is greater than 0.05 (since the chosen significance level is 5%), it was concluded that there was not a significant difference at the 5% significance level.

- **Average floating gangue (g)**

  - data:

	CMC	guar
C1	0.73	0.89
C2	1.97	2.25
C3	5.69	5.41
C4	12.41	10.17

  - calculations:

    The samples are dependent since the same ore was used, but with different depressants (CMC vs guar), therefore a 't-test: paired two sample for means' was used in excel.

  - conclusions:

Since the calculated t stat (0.888) is less that the critical t stat (3.182 - two-tailed critical value), it was concluded that there was not a significant difference at the 5% significance level.

OR

Since the p-value (0.440 - the two-tailed value), is greater than 0.05 (since the chosen significance level is 5%), it was concluded that there was not a significant difference at the 5% significance level.

Ore B CMC vs guar (300 g/t)

- **Cumulative water (g)**

  - data:

	CMC	guar
Float 1	479.97	496.23
Float 2	477.77	577.67

  - calculations:

    The samples are dependent since the same ore was used, but with different depressants (CMC vs guar), therefore a 't-test: paired two sample for means' was used in excel.

  - conclusions:

    Since the calculated t stat (-1.389) is less than the critical t stat (12.706 - two-tailed critical value), it was concluded that there was not a significant difference at the 5% significance level.

    OR

    Since the p-value (0.397 - two-tailed value), is greater than 0.05 (since the chosen significance level is 5%), it was concluded that there was not a significant difference at the 5% significance level.

- **Average floating gangue (g)**

  - data:

	CMC	guar
C1	0.02	0.22
C2	0	0.33
C3	0	0.95
C4	0	2.33

- calculations:

  The samples are dependent since the same ore was used, but with different depressants (CMC vs guar), therefore a 't-test: paired two sample for means' was used in excel.

- conclusions:

  Since the calculated t stat (-1.954) is less that the critical t stat (3.182 - two-tailed critical value), it was concluded that there was not a significant difference at the 5% significance level.

  OR

  Since the p-value (0.146 - two-tailed value), is greater than 0.05 (since the chosen significance level is 5%), it was concluded that there was not a significant difference at the 5% significance level.

Ore A vs Ore B (CMC 100 g/t)

- **Cumulative water (g)**

- data:

	Ore A	Ore B
Float 1	529.97	727.79
Float 2	526.05	743.12

- calculations:

  The samples are independent since different ore were used under the same conditions, therefore a 't-test: two-sample assuming equal/unequal variances' was used in excel. Firstly, an 'F-test two-sample for variances' was used in excel to determine whether the variances are equal/unequal, and then the corresponding t-test was performed.

- conclusions:

  Since the p-value for the F-test (0.159) is greater than 0.05, it was concluded that the variances were not significantly different i.e. they were equal (at the 5% significance level).

  Since the calculated t stat (-26.220) is less than the critical t stat (-4.303 - two-tailed critical value; the negative of the excel number since the t-stat was two-sided i.e. the limits were 4.303 and -4.303), it was

concluded that there was a significant difference at the 5% significance level.

OR

Since the p-value (0.001 - two-tailed value), is less than 0.05 (since the chosen significance level is 5%), it was concluded that there was a significant difference at the 5% significance level.

- **Average floating gangue (g)**

  - data:

	Ore A	Ore B
C1	3.22	8.97
C2	8.85	22.69
C3	16.79	40.42
C4	24.27	53.78

  - calculations:

The samples are independent since different ores were used under the same conditions therefore a 't-test: two-sample assuming equal/unequal variances' was used in excel. Firstly, an 'F-test two-sample for variances' was used in excel to determine whether the variances were equal/unequal, and then the corresponding t-test was performed.

  - conclusions:

Since the p-value for the F-test (0.122) is greater than 0.05, it was concluded that the variances were not significantly different i.e. they were equal (at the 5% significance level).

Since the calculated t stat (-1.674) is less than the critical t stat (2.447 - two-tailed critical value), it was concluded that there was not a significant difference at the 5% significance level.

OR

Since the p-value (0.145 - two-tailed value), is greater than 0.05 (since the chosen significance level is 5%), it was concluded that there was not a significant difference at the 5% significance level.

Ore A vs Ore B (CMC 200 g/t)

- **Cumulative water (g)**

- data:

	Ore A	Ore B
Float 1	457.63	464.34
Float 2	539.61	568.33

- calculations:

The samples are independent since different ores were used under the same conditions, therefore a 't-test: two-sample assuming equal/unequal variances' was used in excel. Firstly, an 'F-test two-sample for variances' was used in excel to determine whether the variances were equal/unequal, and then the corresponding t-test was performed.

- conclusions:

Since the p-value for the F-test (0.425) is greater than 0.05, it was concluded that the variances were not significantly different i.e. they were equal (at the 5% significance level).

Since the calculated t stat (-0.268) is less than the critical t stat (4.303 - two-tailed critical value), it was concluded that there was not a significant difference at the 5% significance level.

OR

Since the p-value (0.814 - two-tailed value), is greater than 0.05 (since the chosen significance level is 5%), it was concluded that there was not a significant difference at the 5% significance level.

- **Average floating gangue (g)**

- data:

	Ore A	Ore B
C1	1.35	0.73
C2	2.48	1.97
C3	5.07	5.69
C4	8.89	12.41

- calculations:

The samples are independent since different ores were used under the same conditions, therefore a 't-test: two-sample assuming equal/unequal variances' was used in excel. Firstly, an 'F-test two-sample for variances' was used in excel to determine whether the

variances were equal/unequal, and then the corresponding t-test was performed.

- conclusions:

  Since the p-value for the F-test (0.240) is greater than 0.05, it was concluded that the variances were not significantly different i.e. they were equal (at the 5% significance level).

  Since the calculated t stat (-0.241) is less than the critical t stat (2.447 - two-tailed critical value), it was concluded that there was not a significant difference at the 5% significance level.

  OR

  Since the p-value (0.818 - two-tailed value), is greater than 0.05 (since the chosen significance level is 5%), it was concluded that there was not a significant difference at the 5% significance level.

Ore A vs Ore B (CMC 300 g/t)

- **Cumulative water (g)**

  - data:

	Ore A	Ore B
Float 1	398.90	479.97
Float 2	404.38	477.77

  - calculations:

    The samples are independent since different ores were used under the same conditions, therefore a 't-test: two-sample assuming equal/unequal variances' was used in excel. Firstly, an 'F-test two-sample for variances' was used in excel to determine whether the variances were equal/unequal, and then the corresponding t-test was performed.

  - conclusions:

    Since the p-value for the F-test (0.243) is greater than 0.05, it was concluded that the variances were not significantly different i.e. they were equal (at the 5% significance level).

    Since the calculated t stat (-26.157) is less than the critical t stat (-4.303 - two-tailed critical value), it was concluded that there was a significant difference at the 5% significance level.

    OR

Since the p-value (0.001 - two-tailed value), is less than 0.05 (since the chosen significance level is 5%), it was concluded that there was a significant difference at the 5% significance level.

- **Average floating gangue (g)**

  - data:

	Ore A	Ore B
C1	0.06	0.02
C2	0.05	0
C3	0.09	0
C4	0.60	0

  - calculations:

    The samples are independent since different ores were used under the same conditions, therefore a 't-test: two-sample assuming equal/unequal variances' was used in excel. Firstly, an 'F-test two-sample for variances' was used in excel to determine whether the variances were equal/unequal, and then the corresponding t-test was performed.

  - conclusions:

    Since the p-value for the F-test (0.000) is less than 0.05, it was concluded that the variances were significantly different i.e. they were unequal (at the 5% significance level).

    Since the calculated t stat (1.454) is less than the critical t stat (3.182 - two-tailed critical value), it was concluded that there was not a significant difference at the 5% significance level.

    OR

    Since the p-value (0.242 - two-tailed value), is greater than 0.05 (since the chosen significance level is 5%), it was concluded that there was not a significant difference at the 5% significance level.

Ore A vs Ore B (guar 100 g/t)

- **Cumulative water (g)**

  - data:

	Ore A	Ore B
Float 1	508.17	635.15

Float 2	466.50	594.27

- calculations:

  The samples are independent since different ores were used under the same conditions, therefore a 't-test: two-sample assuming equal/unequal variances' was used in excel. Firstly, an 'F-test two-sample for variances' was used in excel to determine whether the variances were equal/unequal, and then the corresponding t-test was performed.

- conclusions:

  Since the p-value for the F-test (0.494) is greater than 0.05, it was concluded that the variances were not significantly different i.e. they were equal (at the 5% significance level).

  Since the calculated t stat (-4.364) is less than the critical t stat (-4.303 - two-tailed critical value), it was concluded that there was a significant difference at the 5% significance level

  OR

  Since the p-value (0.049 - two-tailed value), is less than 0.05 (since the chosen significance level is 5%), it was concluded that there was a significant difference at the 5% significance level.

- **Average floating gangue (g)**

  - data:

	Ore A	Ore B
C1	1.95	4.90
C2	4.73	12.79
C3	9.01	24.73
C4	14.07	36.66

  - calculations:

    The samples are independent since different ores were used under the same conditions, therefore a 't-test: two-sample assuming equal/unequal variances' was used in excel. Firstly, an 'F-test two-sample for variances' was used in excel to determine whether the variances were equal/unequal, and then the corresponding t-test ws performed.

  - conclusions:

Since the p-value for the F-test (0.073) is greater than 0.05, it was concluded that the variances were not significantly different i.e. they were equal (at the 5% significance level).

Since the calculated t stat (-1.658) is less than the critical t stat (2.447 - two-tailed critical value), it was concluded that there was not a significant difference at the 5% significance level.

OR

Since the p-value (0.148 - two-tailed value), is greater than 0.05 (since the chosen significance level is 5%), it was concluded that there was not a significant difference at the 5% significance level.

Ore A vs Ore B (guar 200 g/t)

- **Cumulative water (g)**

  - data:

	Ore A	Ore B
Float 1	484.89	610.31
Float 2	464.95	594.04

  - calculations:

The samples are independent since different ores were used under the same conditions, therefore a 't-test: two-sample assuming equal/unequal variances' was used in excel. Firstly, an 'F-test two-sample for variances' was used in excel to determine whether the variances were equal/unequal, and then the corresponding t-test was performed.

  - conclusions:

Since the p-value for the F-test (0.436) is greater than 0.05, it was concluded that the variances were not significantly different i.e. they were equal (at the 5% significance level).

Since the calculated t stat (-9.889) is less than the critical t stat (-4.303 -two-tailed critical value), it was concluded that there was a significant difference at the 5% significance level

OR

Since the p-value (0.010- two-tailed value), is less than 0.05 (since the chosen significance level is 5%), it was concluded that there was a significant difference at the 5% significance level.

- **Average floating gangue (g)**

  - data:

	Ore A	Ore B
C1	0.47	0.89
C2	1.00	2.25
C3	2.15	5.41
C4	3.88	10.17

  - calculations:

    The samples are independent since different ores were used under the same conditions, therefore a 't-test: two-sample assuming equal/unequal variances' was used in excel. Firstly, an 'F-test two-sample for variances' was used in excel to determine whether the variances were equal/unequal, and then the corresponding t-test was performed.

  - conclusions:

    Since the p-value for the F-test (0.067) is greater than 0.05, it was concluded that the variances were not significantly different i.e. they were equal (at the 5% significance level).

    Since the calculated t stat (-1.278) is less than the critical t stat (2.447 - two-tailed critical value), it was concluded that there was not a significant difference at the 5% significance level.

    OR

    Since the p-value (0.248 - two-tailed value), is greater than 0.05 (since the chosen significance level is 5%), it was concluded that there was not a significant difference at the 5% significance level.

Ore A vs Ore B (guar 300 g/t)

- **Cumulative water (g)**

  - data:

	Ore A	Ore B
Float 1	465.35	496.23
Float 2	426.59	577.67

  - calculations:

    The samples are independent since different ores were used under the same conditions, therefore a 't-test: two-sample assuming

equal/unequal variances' was used in excel. Firstly, an 'F-test two-sample for variances' was used in excel to determine whether the variances were equal/unequal, and then the corresponding t-test was performed.

- conclusions:

  Since the p-value for the F-test (0.227) is greater than 0.05, it was concluded that the variances were not significantly different i.e. they were equal (at the 5% significance level).

  Since the calculated t stat (-2.017) is less than the critical t stat (4.303 - two-tailed critical value), it was concluded that there was not a significant difference at the 5% significance level.

  OR

  Since the p-value (0.181 - two-tailed value), is greater than 0.05 (since the chosen significance level is 5%), it was concluded that there was not a significant difference at the 5% significance level.

- **Average floating gangue (g)**

  - data:

	Ore A	Ore B
C1	0	0.22
C2	0	0.33
C3	0	0.95
C4	0	2.33

  - calculations:

    The samples are independent since different ores were used under the same conditions, therefore a 't-test: two-sample assuming equal/unequal variances' was used in excel. Firstly, an 'F-test two-sample for variances' was used in excel to determine whether the variances were equal/unequal, and then the corresponding t-test was performed.

  - conclusions:

    Since the p-value for the F-test (0) is less than 0.05, it was concluded that the variances were significantly different i.e. they were unequal (at the 5% significance level).

    Since the calculated t stat (-1.975) is less than the critical t stat (3.182 - two-tailed critical value), it was concluded that there was not a significant difference at the 5% significance level.

OR

Since the p-value (0.143 - two-tailed value), is greater than 0.05 (since the chosen significance level is 5%), it was concluded that there was not a significant difference at the 5% significance level.

Ore A vs Ore B (no depressant)

- **Cumulative water (g)**

  - data:

	Ore A	Ore B
Float 1	567.24	815.21
Float 2	639.01	718.30

  - calculations:

The samples are independent since different ores were used under the same conditions, therefore a 't-test: two-sample assuming equal/unequal variances' was used in excel. Firstly, an 'F-test two-sample for variances' was used in excel to determine whether the variances were equal/unequal, and then the corresponding t-test was performed.

  - conclusions:

Since the p-value for the F-test (0.406) is greater than 0.05, it was concluded that the variances were not significantly different i.e. they were equal (at the 5% significance level).

Since the calculated t stat (-2.714) is less than the critical t stat (4.303 - two-tailed critical value), it was concluded that there was not a significant difference at the 5% significance level.

OR

Since the p-value (0.113 - two-tailed value), is greater than 0.05 (since the chosen significance level is 5%), it was concluded that there was not a significant difference at the 5% significance level.

- **Average floating gangue (g)**

  - data:

	Ore A	Ore B
C1	10.92	24.49
C2	21.62	46.44

C3	33.74	67.75
C4	42.86	80.45

- calculations:

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The samples are independent since different ores were used under the same conditions, therefore a 't-test: two-sample assuming equal/unequal variances' was used in excel. Firstly, an 'F-test two-sample for variances' was used in excel to determine whether the variances were equal/unequal, and then the corresponding t-test was performed.

- conclusions:

Since the p-value for the F-test (0.188) is greater than 0.05, it was concluded that the variances were not significantly different i.e. they were equal (at the 5% significance level).

Since the calculated t stat (-1.945) is less than the critical t stat (2.447 - two-tailed critical value), it was concluded that there was not a significant difference at the 5% significance level.

OR

Since the p-value (0.100 - two-tailed value), is greater than 0.05 (since the chosen significance level is 5%), it was concluded that there was not a significant difference at the 5% significance level.

Ore A vs Ore B (Sized concentrates no depressant)

- **Cumulative water (g)**

- data:

	Ore A	Ore B
Float 1	570.11	364.76
Float 2	528.40	364.12
Float 3	546.34	345.67
Float 4	529.06	344.81
Float 5	587.91	342.14

- calculations:

The samples are independent since different ores were used under the same conditions, therefore a 't-test: two-sample assuming equal/unequal variances' was used in excel. Firstly, an 'F-test two-sample for variances' was used in excel to determine whether the

variances were equal/unequal, and then the corresponding t-test was performed.

- conclusions:

  Since the p-value for the F-test (0.064) is greater than 0.05, it was concluded that the variances were not significantly different i.e. they were equal (at the 5% significance level).

  Since the calculated t stat (15.742) is greater than the critical t stat (2.306 -two-tailed critical value), it was concluded that there was a significant difference at the 5% significance level.

  OR

  Since the p-value (0.000 - two-tailed value), is less than 0.05 (since the chosen significance level is 5%), it was concluded that there was a significant difference at the 5% significance level.

Ore A CMC vs guar (SEX 50 g/t)

- **Average nickel recovery %**

  - data:

	CMC	guar
C1	11.58	11.44
C2	35.90	26.10
C3	45.80	38.03
C4	50.14	44.86

  - calculations:

    The samples are dependent since the same ore was used, but with different depressants, therefore a ‘t-test: paired two sample for means’ was used in excel.

  - conclusions:

    Since the calculated t stat (2.757) is less than the critical t stat (3.182 - two-tailed critical value), it was concluded that there was not a significant difference at the 5% significance level.

    OR

    Since the p-value (0.070 - two-tailed value), is greater than 0.05 (since the chosen significance level is 5%), it was concluded that there was not a significant difference at the 5% significance level.

- **Average sulphur recovery %**

  - data:

	CMC	guar
C1	22.59	27.44
C2	49.23	39.78
C3	59.94	47.80
C4	66.90	53.71

  - calculations:

    The samples are dependent since the same ore used, but with different depressants, therefore a 't-test: paired two sample for means' was used in excel.

  - conclusions:

    Since the calculated t stat (1.787) is less than the critical t stat (3.182 - two-tailed critical value), it was concluded that there was not a significant difference at the 5% significance level

    OR

    Since the p-value (0.172 - two-tailed value), is greater than 0.05 (since the chosen significance level is 5%), it was concluded that there was not a significant difference at the 5% significance level.

Ore A CMC vs guar (SEX 150 g/t)

- **Average nickel recovery %**

  - data:

	CMC	guar
C1	16.64	12.11
C2	39.19	31.27
C3	46.60	42.08
C4	50.32	47.67

  - calculations:

    The samples are dependent since the same ore was used, but with different depressants, therefore a 't-test: paired two sample for means' was used in excel.

- conclusions:

  Since the calculated t stat (4.475) is greater than the critical t stat (3.182 - two-tailed critical value), it was concluded that there was a significant difference at the 5% significance level.

  OR

  Since the p-value (0.021 - two-tailed value), is less than 0.05 (since the chosen significance level is 5%), it was concluded that there was a significant difference at the 5% significance level.

- **Average sulphur recovery %**

  - data:

	CMC	guar
C1	26.28	21.39
C2	52.56	41.20
C3	63.39	51.34
C4	70.61	58.53

  - calculations:

    The samples are dependent since the same ore was used, but with different depressants, therefore a 't-test: paired two sample for means' was used in excel.

  - conclusions:

    Since the calculated t stat (5.792) is greater than the critical t stat (3.182 - two-tailed critical value), it was concluded that there was a significant difference at the 5% significance level.

    OR

    Since the p-value (0.010 - two-tailed value), is less than 0.05 (since the chosen significance level is 5%), it was concluded that there was a significant difference at the 5% significance level.

Ore B CMC vs guar (SEX 50 g/t)

- **Average nickel recovery %**

  - data:

CMC	guar

C1	11.69	13.41
C2	37.58	31.06
C3	47.83	41.85
C4	51.67	50.88

- calculations:

  The samples are dependent since the same ore was used, but with different depressants, therefore a 't-test: paired two sample for means' was used in excel.

- conclusions:

  Since the calculated t stat (1.440) is less than the critical t stat (3.182 - two-tailed critical value), it was concluded that there was not a significant difference at the 5% significance level.

  OR

  Since the p-value (0.246 - two-tailed value), is greater than 0.05 (since the chosen significance level is 5%), it was concluded that there was not a significant difference at the 5% significance level.

- **Average sulphur recovery %**

  - data:

	CMC	guar
C1	20.12	23.86
C2	45.17	39.94
C3	58.25	51.30
C4	65.86	62.84

  - calculations:

    The samples are dependent since the same ore was used, but with different depressants, therefore a 't-test: paired two sample for means' was used in excel.

  - conclusions:

    Since the calculated t stat (1.223) is less than the critical t stat (3.182 - two-tailed critical value), it was concluded that there was not a significant difference at the 5% significance level.

    OR

Since the p-value (0.309 - two-tailed value), is greater than 0.05 (since the chosen significance level is 5%), it was concluded that there was not a significant difference at the 5% significance level.

Ore B CMC vs guar (SEX 150 g/t)

- **Average nickel recovery %**

  - data:

	CMC	guar
C1	12.68	9.35
C2	35.51	30.58
C3	46.16	40.33
C4	50.50	46.52

  - calculations:

    The samples are dependent since the same ore was used, but with different depressants, therefore a 't-test: paired two sample for means' was used in excel.

  - conclusions:

    Since the calculated t stat (8.274) is greater than the critical t stat (3.182 - two-tailed critical value), it was conclude that there was a significant difference at the 5% significance level.

    OR

    Since the p-value (0.004 - two-tailed value), is less than 0.05 (since the chosen significance level is 5%), it was concluded that there was a significant difference at the 5% significance level.

- **Average sulphur recovery %**

  - data:

	CMC	guar
C1	19.00	15.34
C2	44.81	39.40
C3	59.40	51.82
C4	68.21	64.97

  - calculations:

The samples are dependent since the same ore was used, but with different depressants, therefore a ‘t-test: paired two sample for means’ was used in excel.

- conclusions:

Since the calculated t stat (5.041) is greater than the critical t stat (3.182 - two-tailed critical value), it was concluded that there was a significant difference at the 5% significance level.

OR

Since the p-value (0.015 - two-tailed value), is less than 0.05 (since the chosen significance level is 5%), it was concluded that there was a significant difference at the 5% significance level.