The Effect of Polysaccharides and Inorganic Dispersants on the Surface Characteristics of Talc and the Effect on the Flotation Performance of a Merensky Ore

Maqbool Ahmed Dalvie

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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. It has not been submitted prior to this for any degree or examination at this or any other university.

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Maqbool Ahmed Dalvie

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Firstly, my Creator without whom there would have been no opportunity or ability to complete the investigation.

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ABSTRACT

Flotation is a physico-chemical process used in South Africa as a primary concentration step in the recovery of PGM metals from the Merensky Reef in the Bushveld Igneous complex. Talc is a gangue mineral present in this ore and its naturally hydrophobic nature and froth stabilisation character reduces the effectiveness of the flotation process. Currently polysaccharides are used to reduce the hydrophobicity of the talc but these reagents are expensive and their method of operation is not well understood.

This dissertation describes an investigation into the combined effect of polysaccharides and an inorganic dispersant on the surface characteristics of talc and how this relates to the flotation performance of Merensky ore. The rationale in investigating the talc changes are due to its naturally flotable nature and the downstream problems that result from its reporting to the concentrate causing difficulties disproportionate to its average concentration of less than 2% in Merensky Ore.

The effect of the various reagents, added both singularly and in combination on the zeta potential of talc was evaluated. It was found that all the reagents added affected the zeta potential in a manner which indicted their charged nature. Also it could be surmised that co-adsorption of the polysaccharides and inorganic dispersant on the talc surface was occurring. Settling tests with talc indicated that electrostatic effects only dominated the coagulation or dispersion of talc at low additions of polysaccharides as steric effects became increasingly dominant at higher additions.

Settling tests with the Merensky ore in tap water showed that even at plant addition levels of depressant to a pulp containing less than 2% talc, that dispersion could be

enhanced with the inorganic dispersant. It was found that a change in dispersion of the pulp manifested itself as a change in flotation performance which was generally an improvement in grade.

Flotation performance could be changed by the addition of the inorganic dispersant in addition to the depressant and thereby allowing greater control of the dispersion of the pulp largely independent of the depression.

This thesis demonstrates the metallurgical benefits of adding these two reagents and it is recommended that this investigation be continued to optimise the benefit.

GLOSSARY

CMC- carboxymethyl cellulose

depression – the reduction of particle's hydrophobicity

FF30 – a carboxymethyl cellulose derivative (F in figures)

guar – a degradation product of the guar bean

IMP4 – a modified guar product (I in figures)

NaHMP – sodium hexametaphosphate (N in figures)

PGM – platinum group metals

polymer – a macromolecule consisting of repetitive building blocks

pzc – point of zero charge

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Chapter 1 INTRODUCTION

Froth flotation is an important concentration step in the recovery of a number of metals particularly those associated with sulphidic minerals. In South Africa froth flotation is used in the recovery of the valuable platinum group metals (PGM's) from the Bushveld complex. There are a number of sub-processes involved and generally froth flotation is described as a physico-chemical process which relies on an understanding of the physical parameters such as cell and circuit design as well as the chemical reagents required for successful flotation. Figure 1-1 indicates the various areas of flotation research and shows the focus of this investigation.

The chemicals which are needed to achieve the necessary concentration of the valuable materials can be classified into the following categories: collectors, frothers, activators, depressants and dispersants. The function of the collectors and activators are to promote the flotation of the valuables, the frothers are used to obtain a stable water-air interface as well as to create fine bubbles such that the valuable material can be collected, the dispersants are used predominantly in applications (In copper operations in South America) where the mineral surfaces need to be cleaned of slimes (ultra fine particles) and the depressants reduce the flotation of unwanted naturally flotable gangue material such as talc. This investigation concentrates on the role of depressants and dispersants and their possible use in combination in a flotation environment.

Polymeric organic polysaccharide depressants are widely used on the Platinum mines in South Africa. Two types are used, namely, modified guar gums (guar) and carboxymethyl cellulose (CMC). The depressants are a major chemical cost at the

mines.

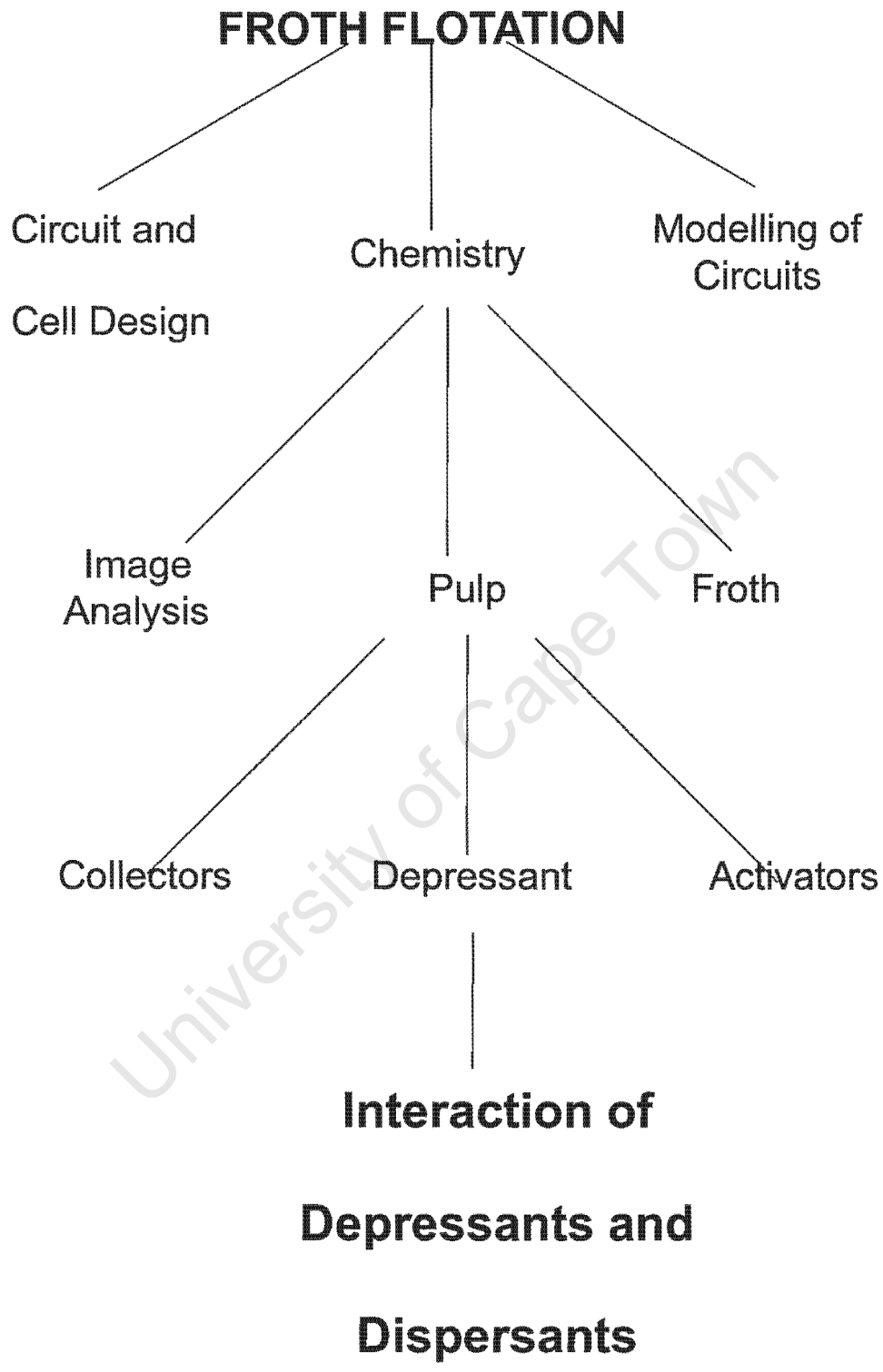

Figure 1-1 - ***An illustration of the focus of this investigation and its position within the flotation research effort***

The guars are considered to be coagulating polymers due to their low charge densities while the CMC's are considered dispersing because they have higher charge. Dispersants can be organic such as CMC or inorganic such as sodium hexametaphosphate (NaHMP). The dispersants are generally highly charged molecules. While CMC's are used in the South African Platinum Industry inorganic dispersants which have a significantly lower cost are not.

The presence of talc in Merensky ore is a major problem in that it floats readily and downstream processing of flotation concentrates is problematic if there is excess talc.

The overall research objective of this investigation was to elucidate the effect of polymeric depressants and inorganic dispersants on the surface characteristics of talc and on Merensky ore to thereby gain an understanding of the role of these reagents in PGM flotation.

The motivation for this investigation is twofold:

1. Splitting of the depression and dispersion function for flotation
2. Reducing the cost of reagent addition as well as improving flotation efficiency

The methods and techniques used to address the overall research objective can be summarised as follows:

- Zeta potential measurements to indicate change in surface characteristics resulting from adsorption of reagent onto mineral
- Settling test to indicate the dispersing or coagulating bulk properties of mineral and ore

- Batch flotation tests to evaluate effect of reagent addition on flotation performance

The report starts by providing background to the theory of talc and its interaction with polymers in an aqueous environment. The experimental techniques are then described followed by the presentation and discussion of results. The conclusions from this investigation are then discussed along with recommendations for future work.

Chapter 2 LITERATURE REVIEW

2.1 Flotation

Flotation is a physico-chemical process used in South Africa to recover PGM (platinum group metals) from the Merensky Reef as the first concentration step. It is based on imparting a hydrophobic nature to the valuable material (sulphides) and rendering the gangue hydrophilic. Chemical reagents are used to achieve this and the primary focus of this investigation is on the depressants which ensure that the gangue remains hydrophilic and therefore not recovered. The mechanism of depressant action is not well understood and it is a major reagent cost.

It should also be noted that particles in a flotation system may be recovered in the concentrate by two mechanisms, the one being flotation (particle attached to bubble due to hydrophobic nature of particle) and the other being entrainment which is a physical process. A more detailed description of the flotation process may be found in Wills (1988).

A bulk-sulphide float is used to recover the base metal sulphides and with it the associated PGM's as well as the liberated PGM's (Liddel et al, 1986). It should be noted that while the flotation is aimed at recovering the sulphides it is only economical due to the value of the PGM's, as the head grade of the sulphur minerals is lower than the tails of most other base metal sulphide operations. For effective processing the ore is required to be a suitable size such that mineral liberation is achieved without producing excessive fine material. The reagent addition is geared towards maximising the wettability of the gangue minerals whilst reducing the

wettability of the valuable minerals. Reagents known as collectors are used to impart a hydrophobic nature to the valuable sulphides and frothers are added to increase the stability of the bubbles in the pulp zone and to create a stable froth zone. It should be noted some material is size selectively (but not mineral selective) recovered by entrainment, and that there is proportionality between the water recovery and mass recovery for flotation systems (Engelbrecht and Woodburn, 1975). Activators are added to improve the functioning of the collectors and depressants are needed to improve the grade of the valuable minerals by reducing the flotation of the gangue (Hochreiter et al, 1985). The flotation of PGM's is performed at the natural buffered pH which is normally in the range of 8.5 to 9 (Liddel et al, 1986).

The talcose nature of the ore necessitates the addition of the depressants (Hochreiter et al, 1985; Liddel et al 1986). This is due to the naturally hydrophobic nature of the talc causing it to report to the froth zone as well as its froth stabilising characteristics. This causes the increased recovery of other gangue minerals thereby increasing the magnesium content of the concentrate by entrainment (Dippenaar, 1982; Harris 1982). Excessive amounts of magnesium in the flotation concentrate causes inefficient smelter operation. The depression of talc is geared towards reducing talc flotation rather than eliminating it due the need to maintain some froth stability.

The flotation performance of a Merensky ore can be evaluated by analysing the sulphides such as pentlandite and chalcopyrite, as the majority of the noble metals are associated with these minerals (Liddel et al 1986).

2.2 Polymers

Polysaccharides have been used and are currently successfully used in the mining industry to depress gangue material in the flotation process. There is a wide range of polymeric depressants, such as guars, CMC and starches, used in various industries. (Pugh, 1988), however in the PGM industry only guars and CMC's are generally used.

Two polymers have been selected for this study to represent the different classes; FF30 (a carboxymethyl cellulose) and IMP4 (a modified guar gum) as well as an inorganic dispersant sodium hexametaphosphate (NaHMP). The polysaccharides have different building blocks and these have differing effects on the surface properties of talc.

2.2.1 Modified Guar Gum

Guar is an agricultural product, derived from Cyamopsis tetragonolobus (Prabhanjan et al, 1989; Mackenzie, 1980), which is chemically modified by alkaline degradation.

Guar has a branched structure and its monomer is shown in Figure 2-1 below. Guar has a low degree of substitution yet is soluble in water. It is thought that the cis-configuration of the OH^- groups and its branched nature increases the solubility.

Shortridge et al (1999a,b) have shown that guars are more effective depressants than CMC's in the absence of ions and that ionic strength had minimal effect on the performance of guars in depressing talc during micro-flotation tests.

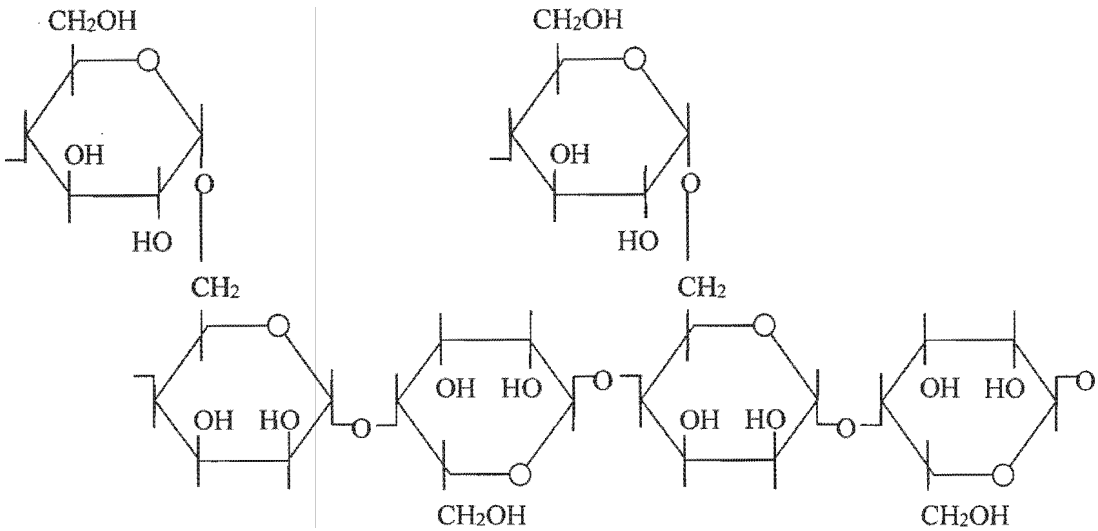

Figure 2-1 – ***Unit of modified guar gum (Guar)***

See section 2.5 for adsorption properties of guar onto talc.

2.2.2 CMC

Carboxymethyl cellulose is a polymer whose manufacture is given by the following chemical reaction (Oliviera and Gomes, 1992) of sodium chloroacetate with alkali cellulose:

$$(C_6H_{10}O_5)_n + NaOH + ClCH_2COONa \longrightarrow (C_6H_9O_5CH_2COONa)n + NaCl +$$

The monomer of the CMC is illustrated in Figure 2-2. The ionic nature of the polymer is due to the high degree of substitution of carboxylic groups along the chain. CMC's have three sites available for substitution (OH groups) and a degree of substitution of 3 implies that all three OH groups have been substituted. A possible degree of substitution would be 0.5 which implies that 1 out of every 6 sites have been substituted. Most commercial CMC's have a degree of substitution of 0.7 to 0.8 (Pugh, 1988).

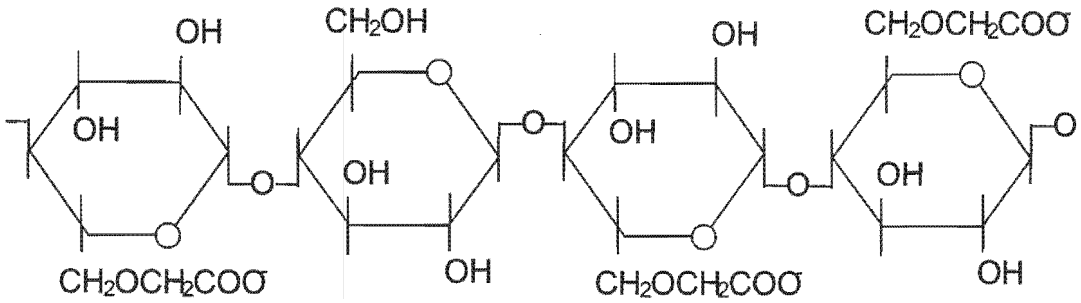

Figure 2-2- ***Unit of carboxymethyl cellulose (CMC)***

For CMC's a degree of substitution of at least 0.4 is required for the polymer to be soluble in water (Steenberg, 1982).

Section 2.5 discusses the adsorption of the CMC onto the talc surface.

2.2.3 NaHMP

The structure of the NaHMP given by Laskowski and Pugh (1992) indicated a cyclic structure. Laskowski (2000) indicated that NaHMP does not polymerise and this implies that it is a very small molecule relative to the polysaccharides. Inorganic dispersants have been used in the mineral processing industry especially in the copper industry in South America as a slime cleaner by imparting a high negative charge to the particles thus causing the particles to repel each other. This is especially useful in applications where ultrafine particles are present which coat the larger (and probably valuable) particles.

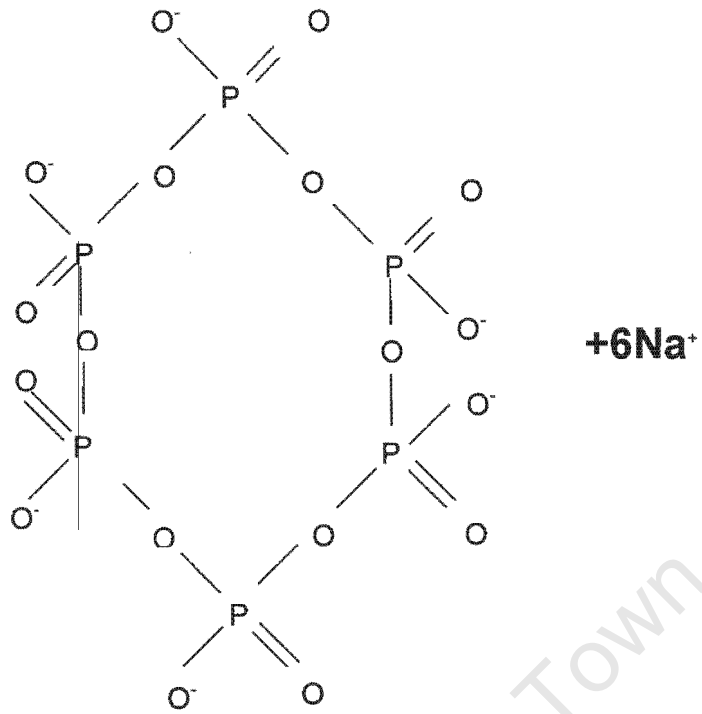

Figure 2-3 - ***The proposed cyclic structure of NaHMP as given by Laskowski and Pugh (1992)***

2.3 Talc

Talc is a gangue mineral present in PGM ores in the Bushveld complex in South Africa (Steenberg, 1982; Liddel et al, 1986). It is naturally flotable and if talc were not depressed would report to the flotation concentrate with the valuable PGM-bearing sulphides. The strong stabilising effect of talc causes increased recovery of other gangue minerals. This leads to difficulties in the downstream processing of the concentrate in the smelter due to the large percentage of magnesium present due to the talc but more importantly the other gangue minerals which are recovered by entrainment due to the talc stabilised froth. Eventhough the percentage of talc in the ore is not large (less than 2%) the effect that it has on the flotation performance is marked. The froth character is largely influenced by the nature of the solids present in the froth Dippenaar (1982) and Harris (1982). They noted that not only was the

hydrophobic nature of the talc involved in the froth character but also that the shape of the talc (sheet-like mineral) promoted a stable froth.

This review aims to describe the structure and properties of talc and how it's naturally flotable nature can be depressed by using polysaccharide reagents.

2.3.1 Mineralogy of Talc

Talc is a layer silicate mineral within the clay mineral class known as phyllosilicates, (Bragg 1937, Morris 1996). The classification of phyllosilicates is given in Figure 2-4 to indicate the talc position within this class.

Silicates are the largest class of minerals with approximately 30% of all minerals within this class and it is thought that approximately 90% of the earth's crust consist of silicates. (Kinlock, 2000). The basic chemical unit of the silicates is SiO_4, which is tetrahedron shaped anionic group.

Phyllosilicates are the sheet silicates and in this instance six member rings are linked to other six membered rings in a plane which produces sheets. The silicon to oxygen ratio is 1:2.5 as only one oxygen is exclusively bonded to the silicon with the other three being shared. The sheets are generally connected to each other by cations which are weakly bonded and often have water or other neutral molecules or atoms trapped within them. This causes the mineral to be fairly soft and have perfect cleavage.

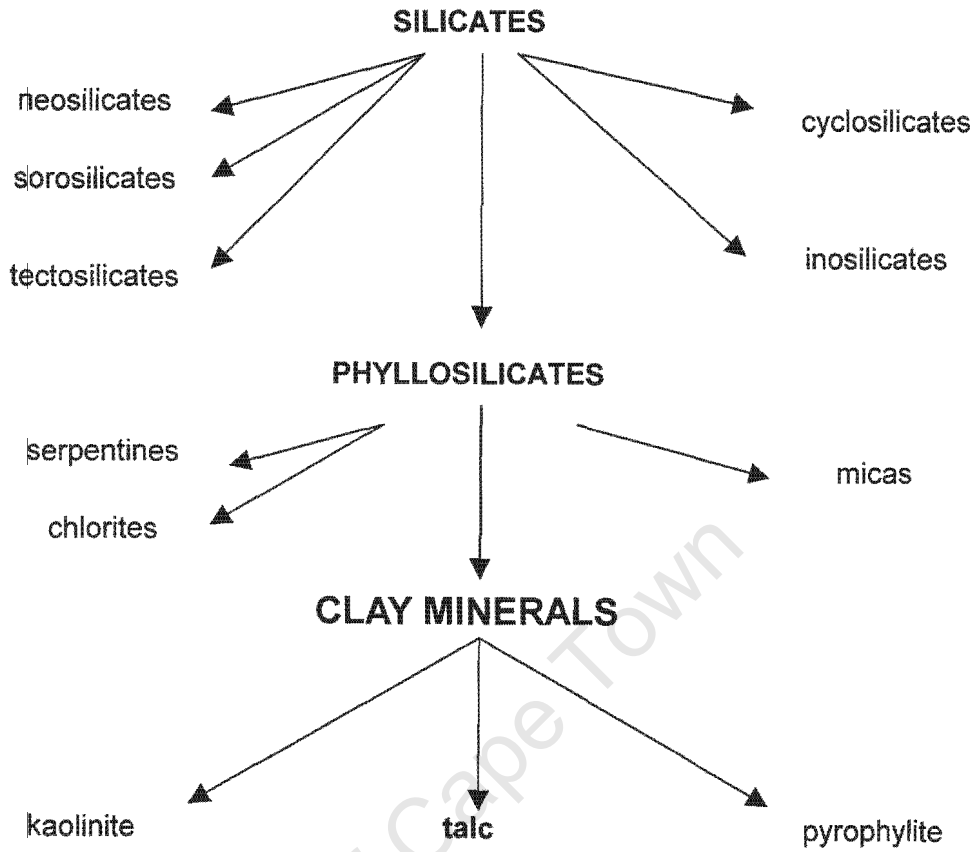

Figure 2-4- ***General Classification of talc within Silicate class (Morris, 1996)***

The physical characteristics of talc are summarised below: (Morris, 1996)

- unit structure is $Mg_3(Si_2O_5)_2(OH)_2$
- a platelike structure with a perfect cleavage plane in the {0 0 1} plane
- density of 2800 kg/m^3
- hardness of 1 on the Mohr scale
- monoclinic crystal system
- crystal habit is platelike
- decomposes at high temperature

2.3.2 Structure of Talc

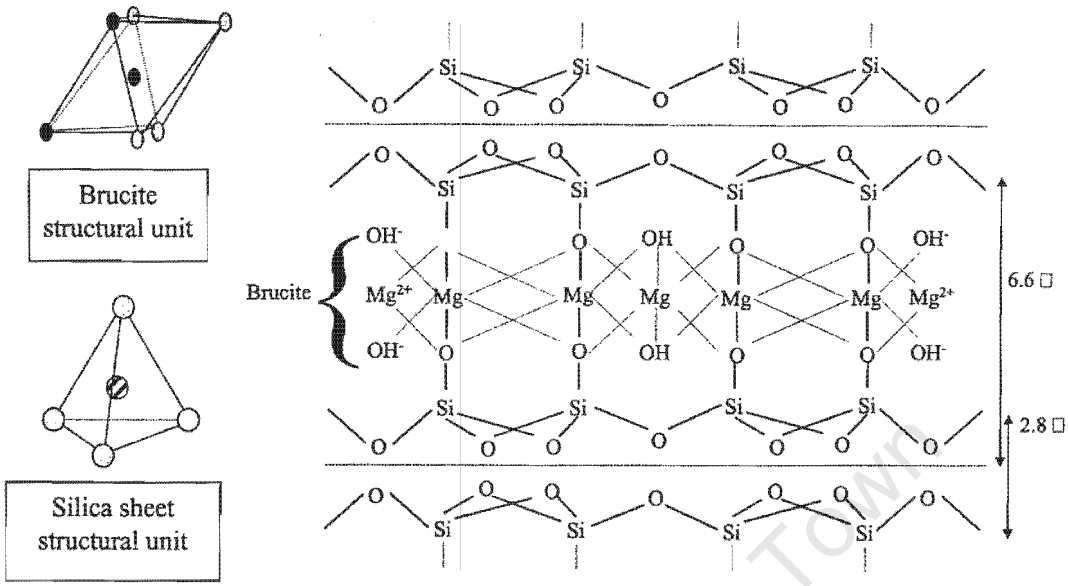

Figure 2-5 - ***The schematic representation of the structure of talc (Morris, 1996)***

Figure 2-5 shows the unit structure of talc. The formula for a unit cell is $Mg_3(Si_2O_5)_2(OH)_2$. As can be seen from the figure there is a brucite sheet sandwiched between two silica sheets. Talc cleavage is (0 0 1) perfect with the cleavage planes being non-polar and hydrophobic and the edges being polar and hydrophilic.

2.3.3 Chemistry and Nature of Talc Surface

The talc surface consists of two natures, that is, the planes (hydrophobic) and the edges (hydrophilic). The characteristic of the talc is therefore dependent on the ratio of these two surfaces (Steenberg and Harris, 1982; Jenkins and Ralston, 1998). Rath and Subramanian (1995) indicated that the Mg^{2+} from the edge dissolves into

solution when the talc is placed in water. This dissolution of Mg^{2+} plays a role in the adsorption of polysaccharides especially guar onto the talc surface (Rath and Subramanian, 1995). The zeta potential of talc is discussed in section 2.4.1

2.4 Electrical Double Layer and Zeta Potential Measurements

The electrical double layer is the term given to describe the separation of electrical charge at an interface (Hiemenz, 1997) but with the overall charge remaining neutral. In general adsorption phenomenon is controlled by the electrical double layer and therefore factors affecting its formation need to be studied. A schematic representation of the electrical double layer is given in Figure 2-6. As can be seen from the figure there is an exponential decline in the zeta potential as one moves from the surface of the mineral to the bulk solution.

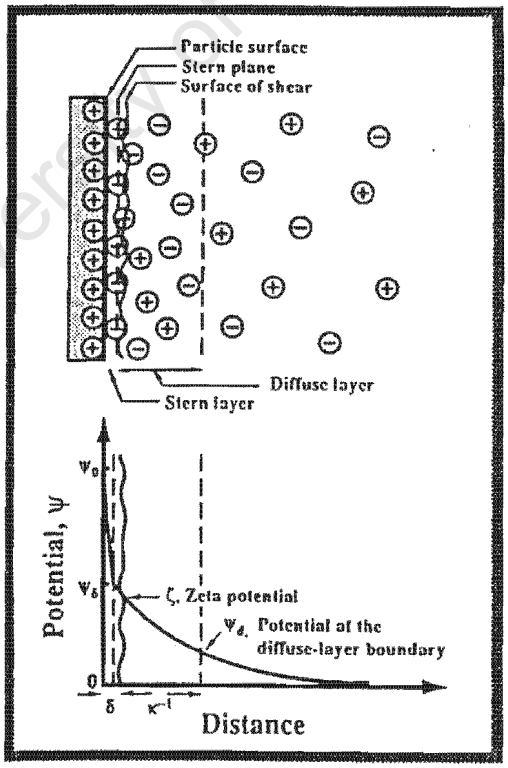

Figure 2-6 - ***Schematic representation of the electrical double layer indicating the position of the Stern Plane and the relative magnitude of the zeta potential***

The distance of closest approach of the counter-ions to the mineral surface is the Stern Plane. The zeta potential is measured at the slipping plane and is indicated on Figure 2-7. This indicates how the charge decays from the surface of the mineral to zero in the bulk solution. The zeta potential was measured at the surface of shear which was within the diffuse layer (Hiemenz, 1997). The exact location of this surface of shear is not known though there is evidence that it is close to the Stern Plane and that is within a couple of molecular diameters of the surface. It can thus be seen that if the surface charge remains constant and the electrical double layer expands then the negative zeta potential must decrease. It can be seen that the zeta potential measurement is affected by charge and thickness of surface adsorbed film, which causes double layer expansion

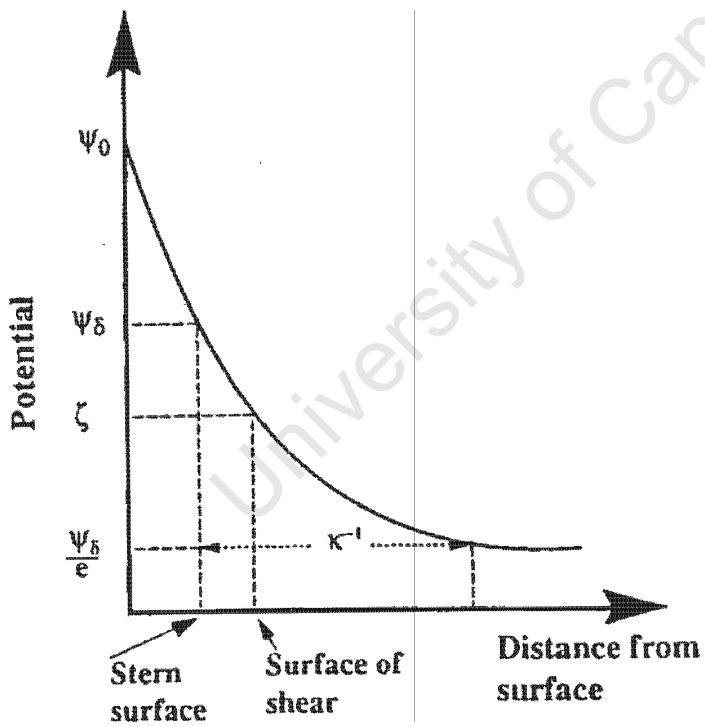

Figure 2-7 - ***Schematic representation of the of the decay of charge from the particle surface to the bulk solution***

It should be noted that in this system the medium is water and thus the properties of water have an important effect on the interaction between the reagents and the

minerals and especially the talc. Water has been widely studied not only because it is the most important fluid but also due to its unique characteristics and anomalous behaviour (Israelachvili, 1992). Two important and rather unique forces or interactions are the hydrogen bond and the hydrophobic effect, both of which have significant influence on the flotation performance.

The hydrogen bond results from the bonding of the hydrogen ion to an ion which is normally highly electronegative like oxygen. This bond is stronger than a normal van der Waals force as it causes a polarisation of the negative and positive charges and thus a polar molecule results. In water the increased density of the liquid to the solid is ascribed to this bond as well as the high work of cohesion of water. (Israelachvili, 1992; Laskowski, 1986) For a particle to be wetted the work of adhesion must exceed the work of cohesion of water.

Laskowski (1986) indicated that a particle with no charge and no hydrogen bonding groups will be hydrophobic. When such a particle is placed in water, the water rearranges itself so as to minimise particle-water contact. Air does not form hydrogen bonds and thus water favours minimising the contact with air. Thus when air and a hydrophobic particle contact in an aqueous medium the water favours surrounding both the particle and air rather than surrounding each separately. It is this that imparts the hydrophobicity to the particle and makes it amenable to concentration by flotation.

2.4.1 Zeta Potential of Talc

The zeta potential of a particle may be defined as the potential at the plane of shear between the slipping plane of liquid adjacent to the particle and the liquid constituting the bulk solution. (Mackenzie, 1995).

The zeta potential of talc is indicated by Figure 2-8 below (Morris, 1996). As can be seen it is negative over the range measured with a pzc of approximately 2.5. The value for the zeta potential is fairly constant from pH 5 upwards at a value of approximately –35mV. According to the DLVO theory (Pashey, 1992) this is sufficient for dispersion which indicates that without reagent addition the talc disperses.

The potential determining ions in aqueous solution have been shown (Morris 1996) to be the adsorbed H^+ and OH^-. The siloxane faces are inert to water except high pH values and therefore do not generally interact with the H^+ or OH^- ions. It is therefore postulated that the interaction with the H^+ and OH^- ions had to be via the edges of the talc mineral.

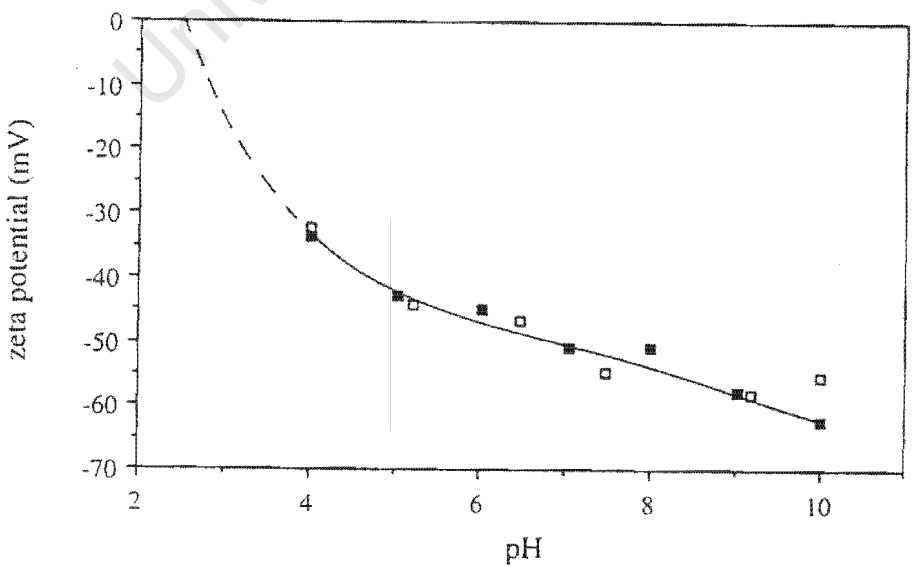

Figure 2-8 - ***The zeta potential as a function of pH as determined by Morris (1996)***

Steenberg and Harris (1984), Jenkins and Ralston (1998) and Rath and Subramanian (1997) have shown that the addition of polysaccharides has an influence on the zeta potential of talc. The CMC increases the negative zeta potential whereas the modified guar gum reduced the zeta potential towards 0. The guar would therefore lead to coagulation if electrostatic forces were considered.

Ouyang et al (1995) have shown that NaHMP increases the negative zeta potential of talc which follows since it is classified as a dispersant. However its manner of modifying zeta potential is bound to be different to the polysaccharides due to its smaller molecular size. The zeta potential measurements indicate that NaHMP adsorbs onto the talc surface yet it does not depress talc indicating that the site of adsorption may be different to that of the polysaccharides.

2.5 Adsorption of Polysaccharides onto Talc

2.5.1 Guar

The guar monomer is low charged and thus electrostatic repulsion between the talc surface and the polymer should be minimised. Jenkins and Ralston, 1998 have reported that electrostatic interaction makes no contribution to the overall thermodynamics of the guar adsorption process onto talc. The major driving force is entropic as guar adsorption leads to the minimisation of talc-H_2O bond. The guar is reported to adsorb onto to the hydrophobic face of the talc and adopts a flat conformation with a "boat type" the most likely which maximises the number of CH/CH_2 group talc contacts. Morris (1996) reported that the polysaccharides absorbed as shown in Figure 2-9. This indicates a large percentage of the polymer

protrudes into the bulk solution possibly indicating the method of double layer expansion.

The effect of guar adsorption on the zeta potential of talc is to reduce the negative value towards zero. This can be ascribed to two factors, i.e., the low charge present on the guar and the expansion of the double layer. As was illustrated in Figure 2-7 the zeta potential is measured at the slipping plane and is close to but not equal to the surface charge of the mineral. Jenkins and Ralston (1998) also reported that the galactose side chain had the effect of increasing the expansion of the electrical double layer which would reduce the negative zeta potential further. This would indicate that the expansion of the electrical double layer would not be homogenous on the talc surface but would be comb-like. The nett effect of guar adsorption is therefore to reduce zeta potential and thereby promote coagulation up to a maximum addition level where the zeta potential should remain constant. However Steenberg (1982) indicated that steric stabilisation could occur at higher reagent dosages negating the effect of reduced zeta potential and leading to dispersed systems.

Previous workers (Rath and Subramanian, 1997) have shown that the adsorption density is independent of the pH of the system. This implies that changes in the charged nature of the talc surfaces do not affect the amount of guar adsorbed indicating that an electrostatic mechanism was not significant. Steenberg (1982) however showed that pH had an effect on adsorption density attributed to the changing polymer conformation. Rath and Subramanian (1997) have stated that the cis-configuration of the hydroxyl groups play an important role in the adsorption of guar onto the talc surface and claim that this is a major reason for the greater adsorption of guar compared to dextrin which has trans-configuration. Jenkins and Ralston (1998) have reported that there is no chemical basis for the adsorption of

guar gum onto the talc edge as neither monomer of a guar unit (galactomannose or galactopyranose) adsorbs onto the talc surface.

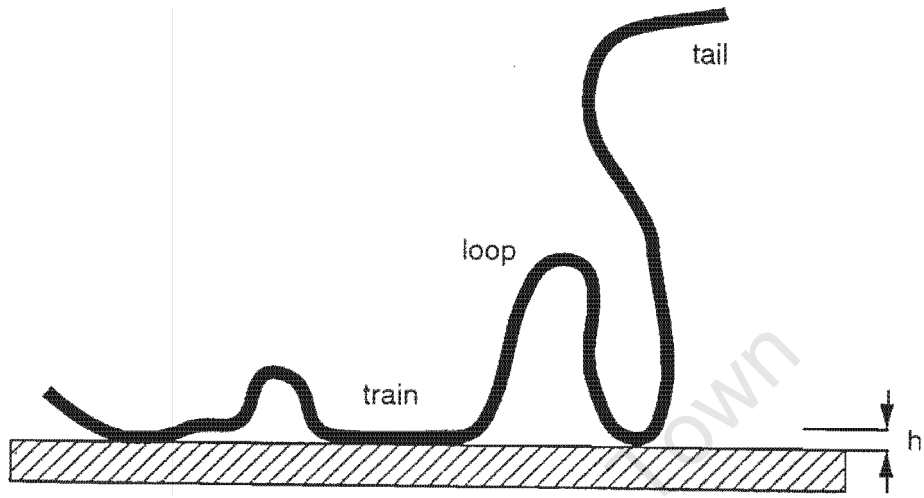

Figure 2-9 - ***A schematic representation of the manner of polymer adsorption on the surface of talc***

Jenkins and Ralston, 1998 reported that hydrophobic interactions of the polysaccharide are the dominant mechanism for adsorption onto the talc face. However Steenberg and Harris (1984) and Mackenzie (1980) indicated that hydrogen bonding onto the talc edge was significant and Rath and Subramanian (1997) substantiated this by doing tests with EDTA which confirmed that adsorption onto the talc edge occurred. It can therefore be postulated that the major mechanism is hydrophobic for adsorption onto the talc face but that a significant role is played by hydrogen bonding onto the edges.

2.5.2 CMC

As discussed in section 2.2.2, CMC's are charged molecules and for CMC adsorption onto the talc surface the electrostatic repulsion between its negative charge and the predominantly negative talc edge has to be overcome.

The CMC is reported to increase the negativity of the zeta potential of talc (Steenberg and Harris, 1982; Morris 1996) and therefore has dispersing properties. It should be noted here that the CMC probably introduces negative charge within the double layer thereby increasing the negative zeta potential but the increase in the double layer thickness also reduces the negative zeta potential. There are therefore counter forces in terms of the zeta potential measurements. It has been shown (Steenberg and Harris, 1982) that the zeta potential decreases rapidly with low CMC addition but as the dosage is increased the zeta potential becomes more neutral but remains more negative than without the polymer adsorption. It can be postulated that the initial increase in negativity is due to the introduction of the negative charge into the double layer but as the dosage is increased the double layer expansion becomes more significant and this actually reduces the negative zeta potential.

Shortridge et al (1999b) indicated that high ionic strength had a beneficial effect on the depression of talc by CMC's during micro-flotation tests. This indicated that soluble metal hydroxide aided the adsorption of the CMC onto the talc. Furthermore the authors indicated that in the absence of depressant, high ionic concentrations were also able to depress talc.

Laskowski and Liu (1999) reported that both the carboxy and hydroxy groups play a role in the adsorption of the CMC onto mineral surfaces. The carboxyl-group interacts with various metallic ionic species but the hydroxyl-group is only considered to react with the metal hydroxy species. This could indicate why the greater depression of talc is achieved with increased ionic strength as reported by Shortridge et al (1999b) as the greater possibility of forming metal hydroxy complexes exists.

Koopal (1992) indicated that in a polydisperse system that the smaller molecules adsorb first onto the mineral surface but that the bigger molecules then displace the smaller ones as a function of time. This is most likely reason for the long adsorption times measured for CMC's by Hoogendam (1998).

2.5.3 NaHMP

NaHMP is a much smaller molecule than the polysaccharides and thus would not affect the size of the electrical double layer significantly. The change in the zeta potential should therefore be a function solely of the introduction of charge within the electrical double layer. Jenkins and Ralston (1998) have reported NaHMP adsorbs via hydrogen bonding probably to the talc edge and that it is limited in extent.

The reported difference in adsorption sites of the polysaccharides and the inorganic dispersant is important in considering the possibility of co-adsorption. It is therefore possible that one could co-adsorb a polysaccharide and the NaHMP, as their preferred sites of adsorption are different but since the polysaccharides also adsorb at the edge there may be competition at the talc edges. Ouyang et al, 1995 had indicated that NaHMP affected the zeta potential and settling nature of talc by increasing the negative zeta potential and dispersing the talc.

2.6 Settling Tests

Settling tests are used to qualitatively describe the coagulative/dispersive nature of a pulp and have been used to test flocculants as well as in water treatment.

It has been shown (Vergouw et al, 1998) that there is a direct relationship between the zeta potential of a system and its settling rate. As a system moves closer to its pzc the settling rate increases. In this system, adsorbed ions were used to modify the zeta potential. Their study was limited to the effect of ions on the settling rate of sulphide minerals. Steric effects were thus not a factor in their investigation.

Steenberg (1982) showed that at low guar additions flocculation of the talc resulted. An increase in the guar addition led to a greater dispersion with maximum flocculation occurring at an addition which results in coverage of 50% of the basal plane. Steenberg (1982) further observed that CMC was an effective dispersant for talc across all dosages. Ouyang et al (1995) indicated that NaHMP was a dispersant for talc at all dosages.

Harris et al (1999) reported that molecular mass had a pronounced effect on the coagulative nature of a platinum PGM bearing ore. IMP4 was shown to have no effect on the settling rate at a 100g/ton whereas the bigger guars increased the coagulation.

2.7 Research Objectives

The overall aim of this investigation was to characterise the effects of a polymeric depressant and NaHMP (singularly as well as mixtures) on the surface properties of talc and the resulting effects on the flotation performance of a PGM ore.

More specifically the research objectives can be summarised by the following key questions:

- How does the addition of pure polymers and NaHMP affect the zeta potential of talc?
- What is the effect of mixing polymers (guar and CMC) and NaHMP on the zeta potential of talc?
- Does the order of addition of reagents affect the measured zeta potential?
- Does polymer and NaHMP addition affect the settling rate of talc?
- Can the settling rate of talc measured be correlated to the zeta potential changes observed with the different polymer additions?
- Can settling tests be used with a PGM Merensky ore to indicate coagulation and dispersion?
- Can using a mixture of inorganic dispersant and polymeric depressant enhance the flotation performance of Merensky ore?
- Can the settling behaviour of the PGM ore be correlated to changes in the flotation performance with corresponding reagent change?

Chapter 3 GENERAL EXPERIMENTAL PROCEDURES

This study investigates the behaviour of polymeric depressants, IMP4 and FF30 and an inorganic dispersant on the surface properties of talc using zeta potential measurements and settling tests. It is extended to Merensky ore with settling tests and float testwork.

3.1 Ore Sample

3.1.1 Sample Preparation

The talc was obtained from Scotia Mines in Barberton and was wet sieved into various size classes using a sieve shaker. The-38μm size fraction was used for the settling tests and was further ground using a mortar and pestle for the zeta potential measurements.

The Merensky ore was obtained from Impala Platinum Mines. The ore was crushed to –2mm and then split into one kg samples. The ore was then rod milled in the laboratory to obtain the required size distribution. This is described in greater detail in Chapter 5.

3.1.2 Mineralogical Composition

The mineralogy of the talc was investigated by XRD's (done by MINTEK) and XRF's (done by the Geology department at UCT). The results are presented in Appendix 1.

The results indicated that talc contained magnesite as an impurity though this was a relatively small amount. It was therefore considered that the talc was suitable to be used for testwork.

Table 3-1 – ***Mineralogy of Merensky Ore***

Mineral	Abundance (%)
Talc	0.5
Feldspar	40
Pyroxene	52
Chromite	3-4
Sulphides	<1
Other	2-3

3.1.3 Size and Surface area

The size for the two experimental techniques (zeta measurements and settling tests) was analysed by the Malvern Particle Size Analyser.

The surface area of the talc sample was determined using BET techniques and these are indicated in Table 3-2.

Table 3-2 – ***Table indicating the surface area and size of the material used***

Sample	BET surface area(m^2/g)	Size Distribution
Talc for Zeta	2.8	90% passing 20μm
Talc for Settling	3.6	100% passing 38μm
Merensky Ore	1.6	75% passing 60μm

3.2 Characterisation of Depressants

Two depressants were used in this investigation, namely IMP4 (a modified guar gum, obtained from Trohall) and FF30 (analytical grade carboxymethyl cellulose). The characterisation of the depressants was performed by the Depressant Research Facility at the University of Cape Town. The techniques used are described in Appendix 3 and the values obtained were molecular mass, degree of substitution, purity, moisture content, percent insolubles, viscosity and pH and these are indicated below.

Table 3-3- ***Characterisation of the Depressants used in the testwork***

	FF30	IMP4
Purity	98%	79%
pH	5.93	6.17
Viscosity (1.5%)	7.74cPs	6.68cPs
Mw	146 100	190 100
Mn	43 500	28 200
PD	3.4	6.7

The NaHMP was obtained pure from Saarchem.

Chapter 4 RESULTS AND DISCUSSION OF ZETA POTENTIAL AND SETTLING OF TALC

4.1 ZETA POTENTIAL

The changes in zeta potential measurement due to reagent addition can be used as a qualitative measure to determine whether adsorption has occurred. The zeta potential is measured at the slipping plane which is well within the diffuse layer. The magnitude of the surface charge or the charge within the diffuse double layer affects the zeta potential.

The polysaccharides that were added generally had the ability to change zeta potential in two ways by introducing charge or expanding the electrical double layer while the NaHMP, due to relatively low molecular mass, should only affect the zeta potential by charge effects.

The zeta potential measurements were performed to determine whether the polymers adsorb, both singularly or when added in combination, onto the talc surface.

4.1.1 EXPERIMENTAL PROCEDURE

A stock solution of electrolyte (0.1M KNO_3), acid (0.01M HNO_3) and base (0.01M KOH) was prepared. These reagents were all analytical grade and prepared in deionised water. The NaHMP was also analytical grade and supplied by Saarchem and was made up as a 1% solution.

The depressants were made up as a 1% solution, that is 1g in a 100ml of deionised water. The depressant was added at a slow rate to a stirred beaker containing the de-ionised water. The slow addition was necessary to prevent the clumping of the depressant leading to large masses of insoluble balls. The solution was then carefully made up to a 100ml and allowed to equilibrate overnight. The depressants were used for a maximum of four days and then fresh solution was made up.

The calculated amounts of electrolyte (to obtain a final electrolyte strength of 0.001M), and depressant and/or inorganic dispersant were added to a beaker containing de-ionised water. This solution was stirred and then added to a 200ml volumetric flask containing 0.2g of talc (a 0.1% talc solution). This mixture was then stirred and sonicated. The pH modifiers were then added to obtain the desired pH and then the zeta potential was measured using a Zetasizer4. The photograph of the Zetasizer is shown below in Figure 4-1.

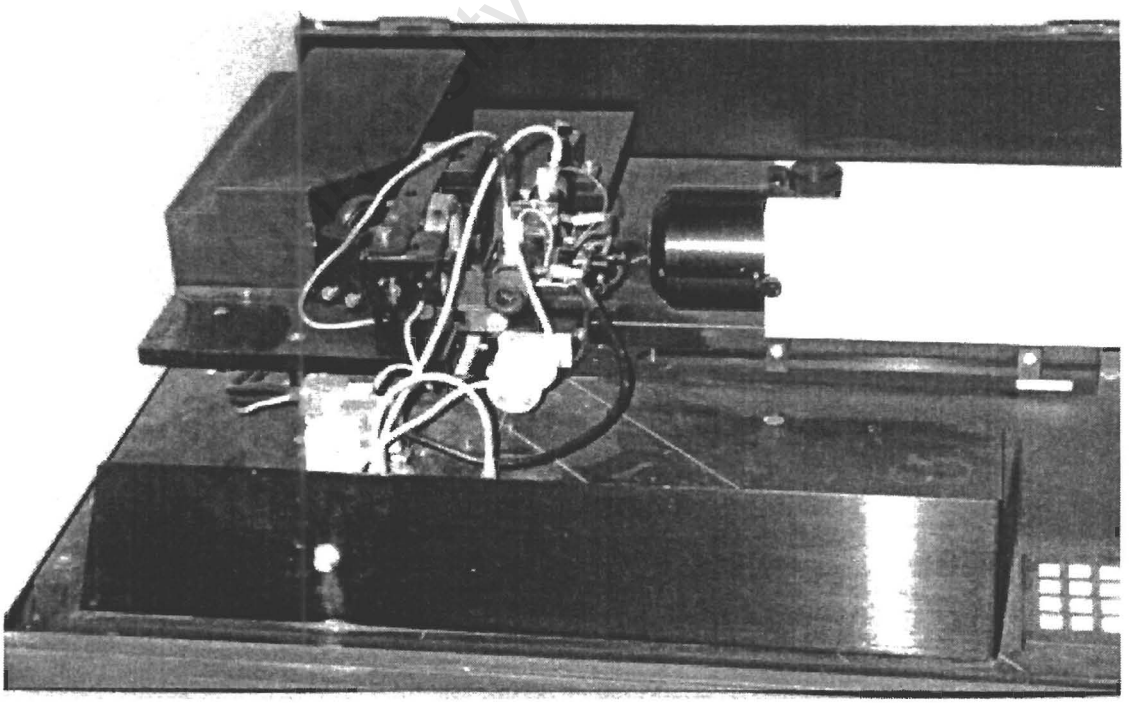

Figure 4-1 - ***Photograph of the Zetasizer4***

4.1.2 PRELIMINARY TESTS TO ESTABLISH OPERATING CONDITIONS

Preliminary tests were required to determine the necessary operating conditions that would be suitable for this system.

4.1.2.1 Pure Talc

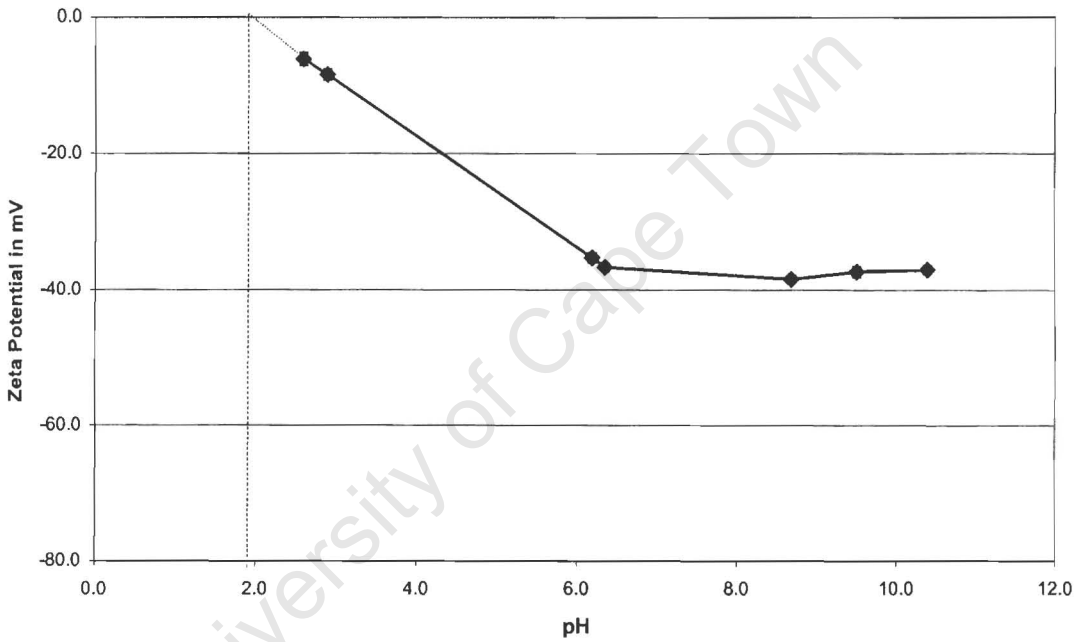

Figure 4-2 - ***Zeta Potential as a function of pH for talc with KNO_3 as electrolyte at a concentration of 0.001M with pzc projected***

The zeta potential of talc across a pH range from 3 to 10 is indicated in Figure 4-2. The relationship is similar to that obtained by previous researchers (Steenberg and Harris (1984), Morris (1996)). The zeta potential was relatively constant over the pH range from 6 to 10 whereas there was a sharp increase in the zeta potential at pH's lower than 6.0. The pzc (indicated by dotted line in Figure 4-2) can be extrapolated to 1.9 pH units which was in the similar region to those reported in the literature by

Morris (1996). It was postulated that this is due to the dissolution of Mg^{2+} ions (Rath et al, 1995) from the talc edge leading to a decrease in the negative zeta potential.

For flotation systems the gangue minerals in typical PGM ores lead to buffered systems in the region of 8.5 to 9.0 pH units (Liddel et al, 1986). This region was therefore the most significant for testwork and it was fortuitous that the zeta potential was constant over that region.

4.1.2.2 Electrolyte

It was necessary to investigate the indifference of the electrolyte to the talc system. For an electrolyte to be indifferent there should be no difference in the pzc with changing electrolyte concentration (Rath et al 1995).

The electrolyte used for the zeta potential tests was potassium nitrate (KNO_3) at a concentration of 0.001M. Figure 4-3 below indicated how ionic strength of the electrolyte affected the zeta potential of the talc. This indicated the indifference of the electrolyte in that ionic strength affected the zeta potential as a function of pH but that the point of zero charge (pzc) remained relatively unchanged.

The expected trend was that the lower ionic strength having a lower absolute zeta potential and thus a flatter curve with the higher ionic strength a greater absolute zeta potential. The reported pzc for talc was low (Steenberg and Harris, (1984); Fuerstenau (1988) and pH of 1.9 estimated from this investigation was within ranges obtained from the literature of 1.0 to 2.5. The pzc's for the three curves are obtained by extrapolation and there is a minimal change (range was 1.9 to 2.0) and it can

therefore be postulated that KNO_3 is an indifferent electrolyte for the talc used as reported by (Rath et al, 1995).

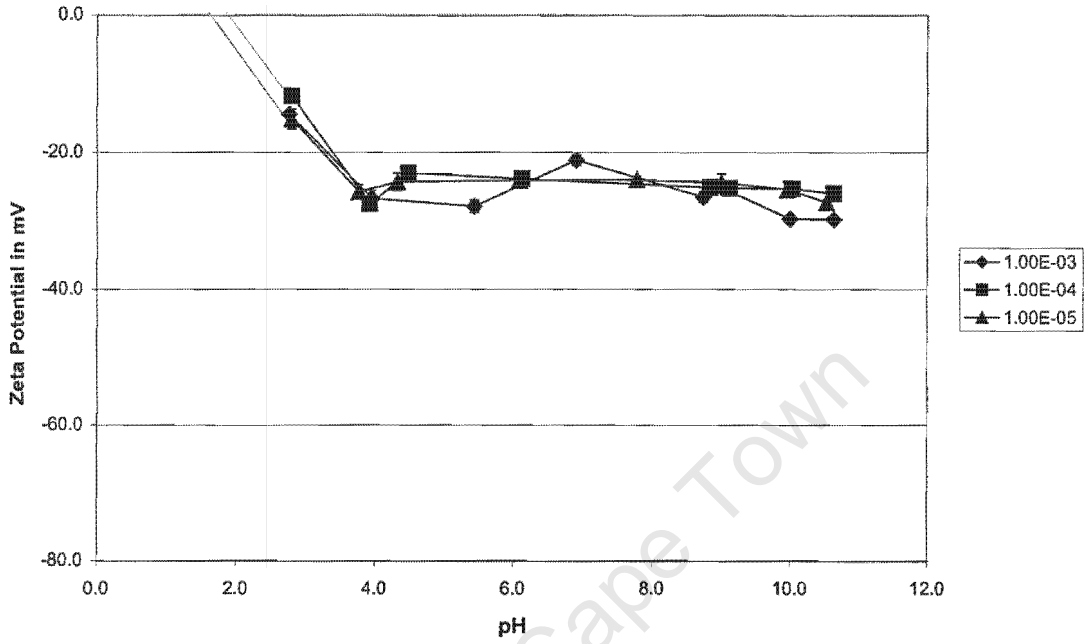

Figure 4-3 - ***The zeta potential of talc at varying electrolyte strength of KNO_3 indicating that the change in pzc (projected) was minimal***

4.1.2.3 Effect of time

It was necessary to determine if there was a variation in the measured zeta potential with time to determine the duration of the conditioning step to obtain a constant zeta potential.

The time dependence of zeta potential at a dosage of 100mg/l for all reagents was illustrated in Figure 4-4. It can be seen that constant values were obtained for all times recorded. The zeta potential measurements remained constant from the first measurement at 15 minutes until the last measurement at 2 hours. It has been

reported in literature (Rath and Subramanian (1997), Jenkins and Ralston (1998)) that the adsorption of polysaccharides reached equilibrium within 15 minutes especially for the guars. However, conversely (Hoogendam, 1998) reported that CMC's adsorbed over a time period that was measured in years. Therefore it was necessary that the zeta potential measurement equilibrium (within the accuracy of the technique and equipment) was measured. It was therefore accepted that equilibrium values could be measured from 15 minutes onwards though the adsorption of FF30 may continue it did not appear to have an effect on the zeta potential.

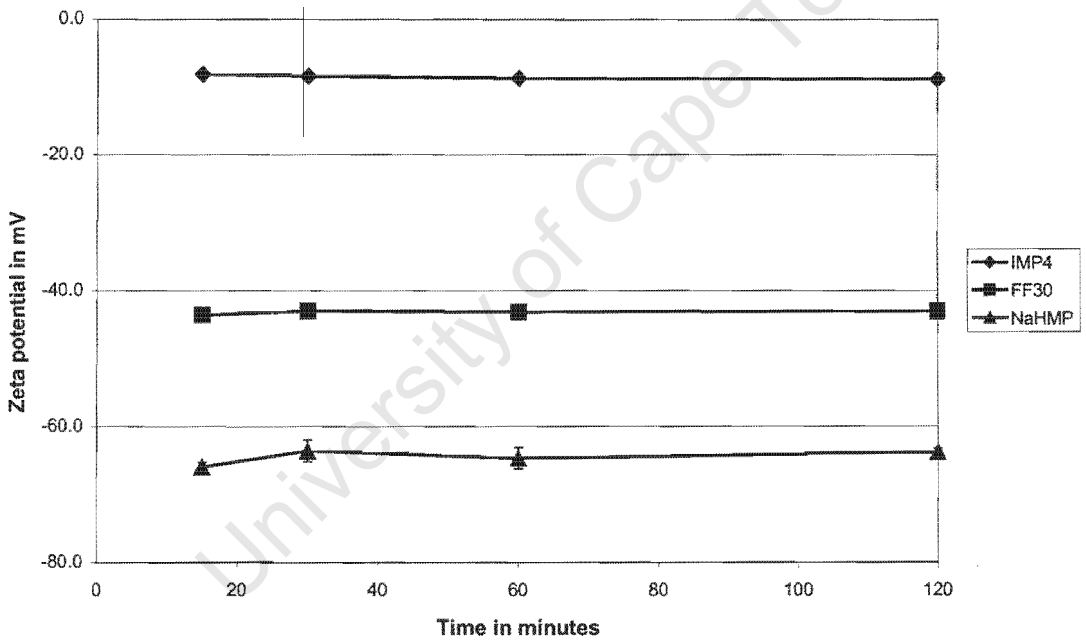

Figure 4-4 - ***The effect of time on the measured zeta potential of talc in the presence of polymers and with an electrolyte KNO_3 at 0.001M at pH 9***

4.1.2.4 Reproducibility

For all the tests five readings were taken with the Zetasizer4. Also the reproducibility of the technique was evaluated by repeating the test for pure talc in 0.001M KNO_3. The results obtained are presented below in Figure 4-5.

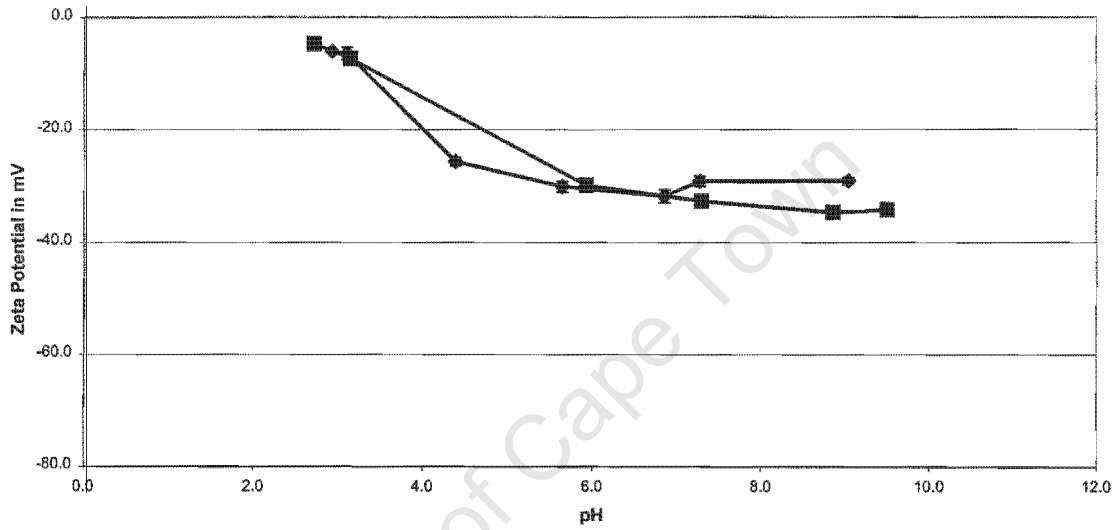

Figure 4-5 - ***The reproducibility of the zeta potential measurement technique for pure talc in 0.001M KNO3 as a function of pH.***

The tests indicated that reproducibility was acceptable though therewas a difference in the neutral to alkaline pH range. However, this difference was not significant when compared to the differences obtained with the varying reagents.

4.1.3 Single Reagent Addition

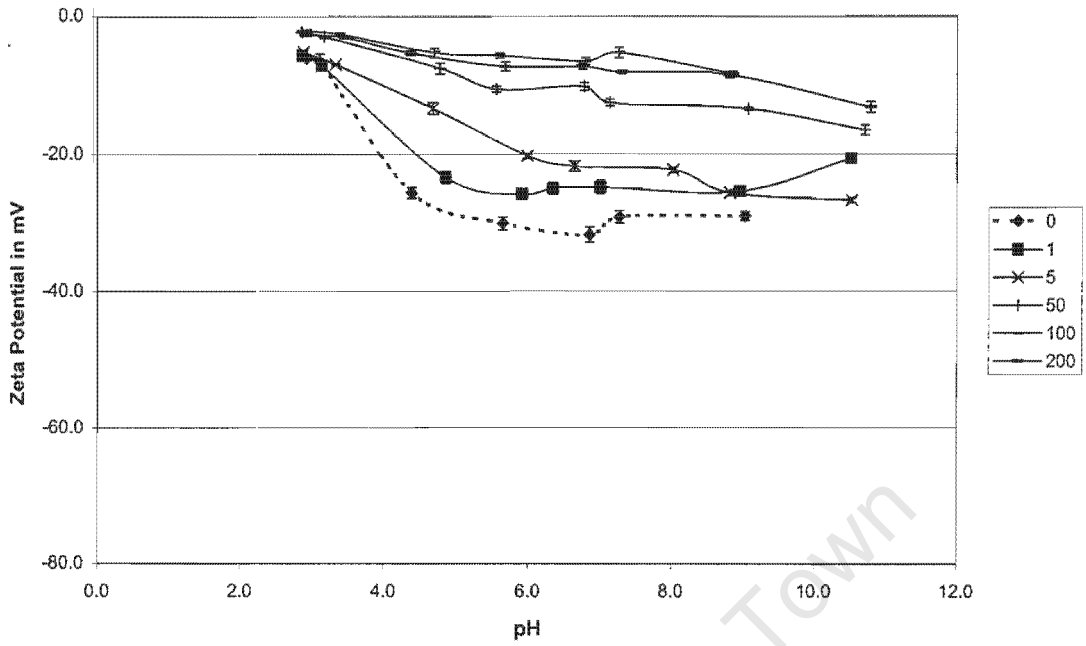

Figure 4-6 - ***The effect of IMP4 addition (indicated in the legend in mg/l) on the zeta potential of talc as a function of pH***

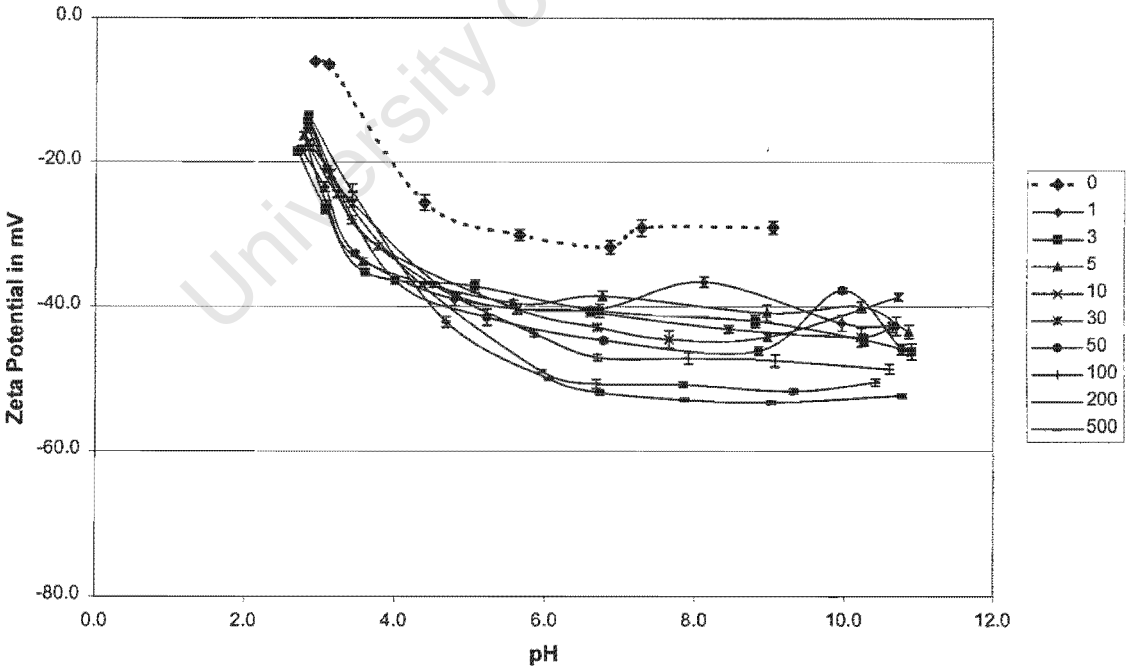

Figure 4-7 - ***The effect of FF30 addition (dosage given in legend as mg/l) on the zeta potential of talc as a function of pH***

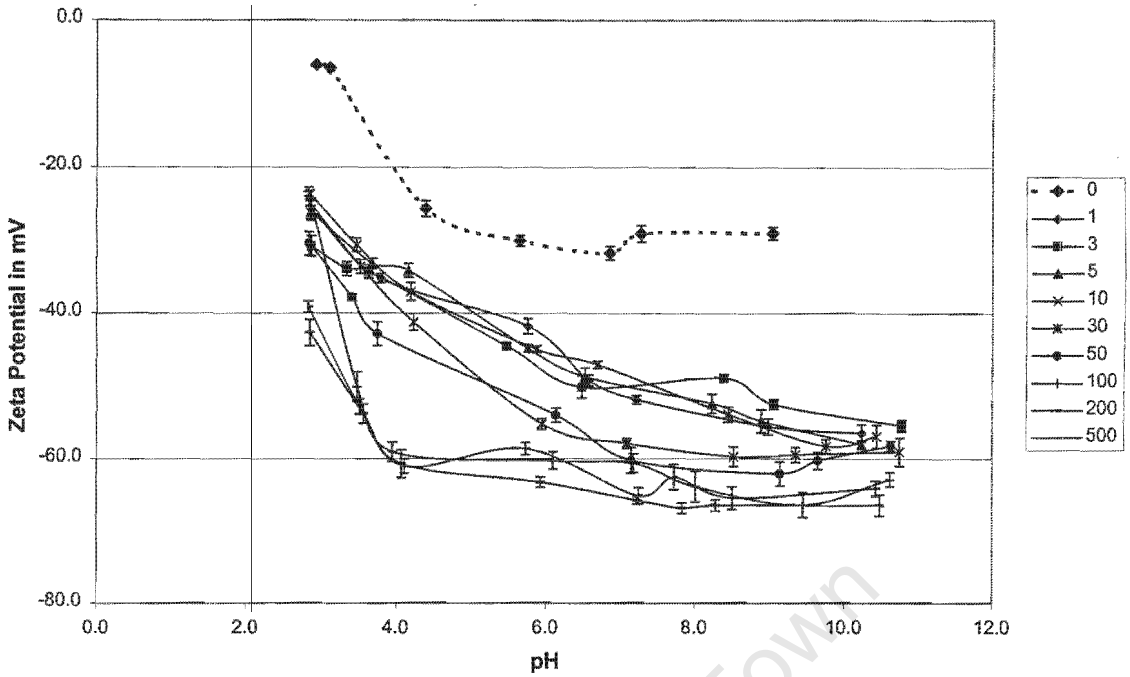

Figure 4-8- ***The effect of NaHMP addition (legend indicates dosage in mg/l) on the zeta potential of talc as a function of pH***

4.1.3.1 Modified Guar (IMP4)

The addition of IMP4 at various dosages was indicated in Figure 4-6 as well as Figure 4-9 and also was in agreement with other workers (Steenberg and Harris (1984), Rath et al (1997) and Jenkins and Ralston, (1998)) who have performed zeta potential tests of modified guars on talc. There was an expected decrease in the negativity of the zeta potential of the talc when IMP4 was added. As shown in Figure 2-1 the IMP4 is a low charged polymer and when it adsorbed onto the talc surface it has the ability to lower the charge within the diffuse layer and therefore the zeta potential. Further, due to the molecular size of the polymer (approximately 200000), it is expected to increase the electrical double layer and this would further reduce the negative zeta potential as discussed in Section 2.

It was interesting to note that even at low additions (1mg/l) there was a marked effect on the zeta potential of talc when compared to pure talc. At this low addition monolayer coverage should not be attained and it was therefore expected that significant expansion of the double layer should not occur and thus the decrease in zeta potential at the lower additions should be due to the decrease in the surface charge of talc.

The increase in the IMP4 addition leads to further reduction in the negative zeta potential measurements until an addition of 100mg/l beyond which the changes are minimal. Expansion of the electrical double layer should be the significant effect at higher dosages of IMP4.

Rath et al (1995) indicated that the effect of increasing guar dosage had a similar effect to a changing concentration of the indifferent electrolyte. The similarity could be seen in that no change in pzc could be noted with the changing IMP4 dosage eventhough the magnitude of the zeta potential was changed. A similar trend was observed in this work.

It has been reported by Jenkins and Ralston (1998) that the mechanism for polymer adsorption can be either hydrophobic, chemical, electrostatic or via hydrogen bonding. Jenkins and Ralston (1998) reported that the driving force for guar adsorption onto the talc plane was via hydrophobic interactions, which agrees with the findings of Steenberg and Harris (1984). Pugh (1989) indicated that depressants function by replacing the water/mineral interface by a depressant/mineral one which causes a strong repulsive hydration force. This force needs to be large enough to repel bubbles such that flotation cannot occur. Jenkins and Ralston (1998) have claimed that this occurs naturally at the talc edge but that the talc face is generally the dominant surface and thus the naturally floatable nature of the talc results. It

would therefore be imperative that a depressant adsorbs onto the talc face to achieve depression.

Jenkins and Ralston (1998) also proposed that the mode of adsorption was that the mannose backbone adsorbed onto the talc surface and that the galactose branch protruded into the bulk solution. This would explain the marked decrease in the negative zeta potential with guar addition as the electrical double layer would be moved further outward by the galactose groups. They described the manner of guar adsorption to be comb-like which was indicative that the expansion of the electrical double layer is not homogenous around the talc surface but that there are peaks and troughs. It should also be noted that the manner of polymer adsorption, with loops and tails (Morris, 1996), also indicates why there is no homogeneity of the adsorption on the talc surface.

Rath et al (1997) reported that a major factor in the adsorption of the guar onto the talc surface is the cis-configuration of the hydroxyl groups. Furthermore tests conducted with EDTA indicated that the metallic sites on the talc edge played an important role in the adsorption of the guar onto the talc surface. It was also shown (Shortridge et al 1998) that guars are more effective depressants than CMC's at conditions of low ionic strength.

4.1.3.2 Carboxymethyl cellulose (FF30)

The effect of FF30 addition on the zeta potential of talc was indicated in Figure 4-7. The increase in the negativity of talc with FF30 addition was marked even at low addition of 1 mg/l. The changes are less marked as the dosage was increased though there was a continual increase in the negative zeta potential. As with the

IMP4 there was a dual mechanism involved in changing the measured zeta potential; charge and film thickness. FF30 had a higher charge density than the IMP4 and thus increased the negative charge in the double layer and therefore increased the negativity of the negative zeta potential. However increasing dosage would have also led to expansion of the electrical double layer which reduced the negativity of the zeta potential. In this instance the mechanisms affecting the zeta potential conflict and have opposing effects. It was postulated that at the low additions, increasing the negative surface charge was the dominant effect whereas at higher additions the expansion of the electrical double layer becomes more marked minimising changes in the zeta potential. Steenberg and Harris (1984) found that at low CMC addition there was a marked increase in the negative zeta potential followed by an decrease in the negative zeta potential with increased dosage which then remained fairly constant as the dosage was increased still further. This was not found at pH 9 but was found at pH 4 (as indicated by Figure 4-9) in this investigation probably due to the difference in charged nature of the talc surface at the different pH's due to the counterions (Steenberg, 1982).

The structure of the FF30 (Shortridge et al, 1998; Pugh, 1988; Morris 1996) is linear and this affects the way in which the zeta potential changed as the polymer was added. Morris (1996) indicated that polysaccharides adsorbed in a train-loop-tail formation as indicated in Chapter 2, Figure 2-9. The multiple conformations that are possible when macromolecules of this type adsorb onto a surface played a role in the time taken for this macromolecule to adsorb onto the surface. However Koopal, 1992 also reported that for a polydisperse system the higher molecular species would adsorb preferentially to the lower molecular species. This would imply that the lower molecular species might get onto the surface of talc first, due to greater diffusion rate, but that they would be replaced by the higher molecular species as a function of time.

This could be a factor in the long adsorption time reported by Hoogendam et al (1998).

The major mechanism for the polymer adsorption on to the talc plane appeared to be hydrophobic interaction as reported by (Jenkins and Ralston, 1998; Oliveira and Gomes, 199&; Morris et al, 1999). Jenkins and Ralston (1998) further reported that hydrogen bonding to the edge played a minor role in the adsorption of the polysaccharide onto the talc.

However there are investigators (Steenberg and Harris, 1984; Rath et al, 1997, Mackenzie, 1980) who have reported that hydrogen bonding played an important role in the adsorption of guar gum onto the talc surface. It should therefore be considered that hydrophobic interactions are important for adsorption onto the talc face and hydrogen bonding could have played a role for adsorption onto the talc edge.

However, it should be noted that the planes are not perfect and that deformations may play a role in the polysaccharide adsorption. The relative importance of the interactions would be dependent on the face to edge ratio as well the deformation of the talc plane.

4.1.3.3 Inorganic Dispersant (NaHMP)

The NaHMP addition increased the negative zeta potential to a greater extent than the CMC. This was to be expected as it had a higher charge density as well as being a smaller molecule had a limited effect on the possible electrical double layer expansion Laskowski and Pugh (1992). This trend was shown in Figure 4-8. The legend indicates dosage in mg/l.

It was expected that the effect of NaHMP on the zeta potential of talc would be similar to that which was observed with the FF30 (Ouyang et al, 1995). The measured zeta potential indicated that a greater negative zeta potential was obtained with the NaHMP than with the FF30. Possibly both effects (charge introduction and lack of increase in double layer expansion) played a role in the greater negative zeta potential being determined with the NaHMP but it was postulated that it was the lack of double layer expansion which was the most significant.

It should also be noted that with the FF30 at low dosages the pH range over which the zeta potential remained constant increased and as the dosage was increased the range returned to similar values obtained with pure talc. On the other hand, the NaHMP addition resulted in an opposite trend in that the range was decreased at low additions and returned to the pure talc type of range at the higher additions. It has been reported by Rath et al, 1995 that the decrease in negative zeta potential was due to the dissolution of the Mg^{2+} ions from the talc edge. This would indicate that at low FF30 dosages the dissolution of the Mg^{2+} was inhibited whereas at the higher dosages it was enhanced. The NaHMP appeared to enhance dissolution of Mg^{2+} at the lower addition and inhibit it at higher additions.

4.1.3.4 Comparison of the effect of the polymers on the zeta potential of talc at pH9

The pH value of 9 was chosen for this representation since the nature of the gangue minerals in PGM-bearing ores leads to buffered slurries in the region of 8.5 to 9 pH units (Liddel et al, 1986).

The effect of the polymers at varying dosages at pH 9 on the zeta potential of talc was indicated in Figure 4-9. The contrasting effect of the polymers can be clearly seen in terms of their charged nature, that is, guar reducing the negative charge while CMC and NaHMP increasing the negative charge of pure talc. As discussed previously the NaHMP increased the negative zeta potential to a greater extent and this was probably due to its smaller molecular mass and thus its minimal effect on the electrical double layer. There appeared to be no further change for all the polymers when the addition exceeded 100mg/l.

At the lower dosages the electrical double layer expansion was not as marked as at the higher dosages where the negative zeta potential was reduced to a greater extent. As the dosage is increased to 10mg/l the decrease in the negative zeta potential is rapid and then the rate decreased. It is postulated that at these dosages (above 10mg/l) that electrical double layer expansion becomes more significant and that the reduction of the negative zeta potential is most probably due to this effect (Steenberg and Harris, 1984). Above 100mg/l the constant zeta potential suggests that maximum adsorption had been reached and that increasing the addition did not lead to increased multilayer adsorption or expansion of the electrical double layer.

FF30, a polysaccharide with a negative charge density, increased the negative zeta potential across all dosages which does not agree with results reported by Steenberg and Harris (1984) which indicated a sharp drop followed by a decrease in the negative zeta potential. However the CMC that they used had a greater molecular mass than FF30. For this polysaccharide, the change in zeta potential was most marked at the lower dosages. Beyond 10mg/l the rate of decrease slowed but continues until 200mg/l (last dosage added). It is thought that the continuous increase in the negative zeta potential beyond 100mg/l indicated that 2 hours may not be sufficient for true equilibrium as reported by Hoogendam et al, 1998. It was

also noted that at the higher dosages used by Steenberg and Harris, 1984, (10mg/l) the measured zeta potential was approximately equal to the one measured for untreated talc. In this study there was a steady increase in the negative zeta potential with dosage. This could be an effect of the difference in molecular mass of the CMC's used.

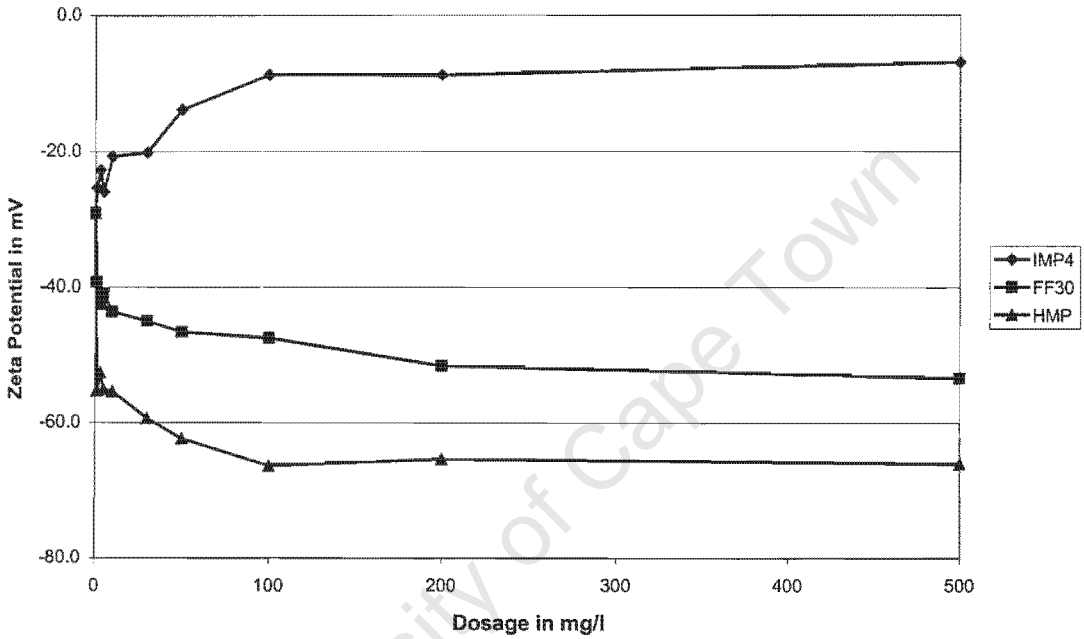

Figure 4-9 - ***The effect of the polymers on the zeta potential of talc at pH 9 as a function of polymer dosage***

The NaHMP had a similar effect on the zeta potential of talc as FF30 but the resultant zeta potential was more negative than the FF30 at the same dosage. This could be due to NaHMP introducing a greater charge to the talc surface or that due to its relatively small size it does not expand the electrical double layer. In this instance the maximum rate of change in the zeta potential was at the low dosages (<5mg/l) and thereafter the rate decreased. However the negative zeta potential still increased faster than the rate observed with the FF30 for comparative additions. After 100mg/l the zeta potential remained relatively constant.

4.1.4 Effect of Mixtures

The co-adsorption of the polymers and the inorganic dispersant was investigated by zeta potential measurements in the presence of a mixture of the polymers. It was inferred that, if the measured zeta potential (of a mixture) was between the zeta potential obtained for the individual additions, then the samples co-adsorbed to a degree. However as this was an indirect measurement it was not possible to differentiate between complex formation in bulk or co-adsorption on the talc surface.

4.1.4.1 Order of Addition

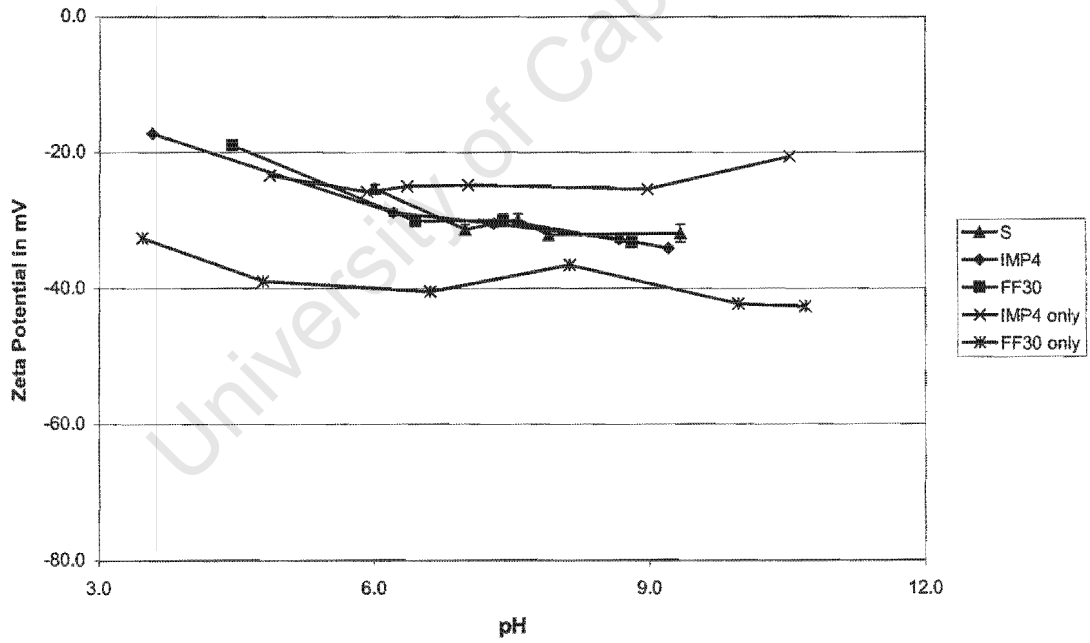

Figure 4-10 - ***The effect of addition order of IMP4 and FF30 (at 1mg/l) on the zeta potential of talc with KNO_3 as electrolyte at 0.001M***

The order of addition was investigated to determine whether the zeta potential was affected by the sequence of polymer addition if the polymers were added sequentially or simultaneously as an indication of strength of adsorption. The results from these tests (for IMP4 and FF30) are shown in Figure 4-10 and Figure 4-11. The legend indicates whether the reagents were added simultaneously (S), or IMP4 first (IMP4) or FF30 first (FF30).

It can be seen that the order of addition had no significant effect on the measured zeta potential for additions of 1mg/l. This indicated that the adsorption of the polymers especially (FF30) is reversible below pH 6 as the final zeta potential approximated the zeta potential of the IMP4 singular addition. However it should be noted that at additions of 1mg/l that the adsorption density was low so that there is sites available for both polymers to adsorb onto the surface. This was an important finding in that it showed that the polymer, which was thermodynamically favoured, would displace (to a degree) any other on the talc surface, which for the polymers tested indicated that IMP4 would displace FF30.

At the higher addition of 50mg/l (Figure 4-11) there appeared to be a difference in the resultant zeta potential with the varying reagent order. However this change was not as expected in that the combined addition had a zeta potential closer to that of IMP4 only than the addition when IMP4 was added first. However it can be seen that the difference is minimal when compared to the difference between the single reagent additions. This indicated that the effect of reagent order was much less than the measured zeta potential differences between the single reagent additions. For remaining tests simultaneous additions was used.

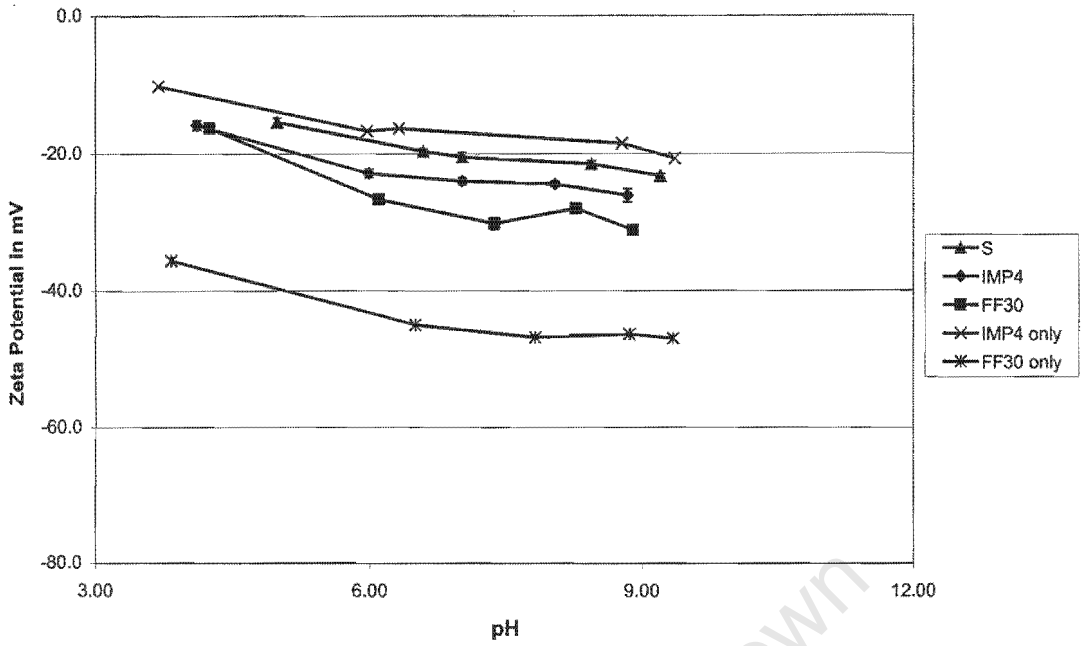

Figure 4-11 - ***The effect of addition order of IMP4 and FF30 (at 50mg/l) on the zeta potential of talc with KNO_3 as electrolyte at 0.001M***

4.1.4.2 IMP4 and NaHMP added together

In Figure 4-12 the effect of IMP4 addition on the zeta potential of talc with NaHMP was indicated. The measured zeta potential indicated that co- adsorption was likely.

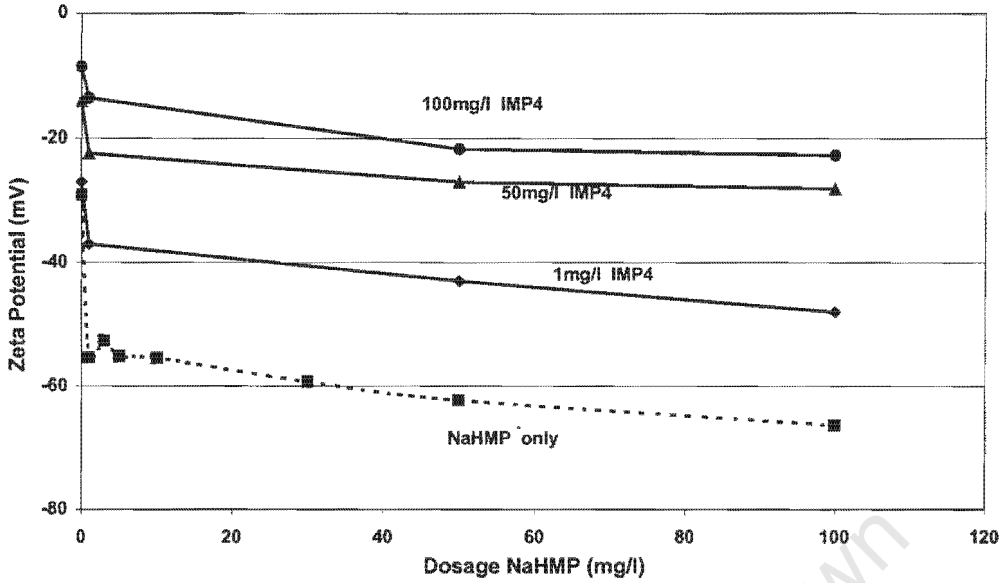

Figure 4-12 - ***The combined effect of IMP4 and NaHMP on the zeta potential of talc at a pH of 9***

It can be seen that even at the high IMP4 addition of 100mg/l that the NaHMP has an effect on the zeta potential by increasing the negative zeta potential. There was a clear trend in that as increasing amounts of NaHMP was added at constant IMP4 addition the zeta potential became more negative. The change in zeta potential is more pronounced at low NaHMP addition (1mg/l) and then the slope of the curve flattens out. The increased adsorption affinity of the IMP4 is borne out by the skewing of the combined zeta potential towards the pure IMP4 value. This is especially marked at higher IMP4 additions but it should be noted that even at 100mg/l IMP4 that the negative zeta potential was increasingly negative with NaHMP addition. This indicated that co-adsorption of IMP4 and NaHMP on the talc surface was possible. However Jenkins and Ralston, 1998 have reported that NaHMP adsorbs onto to talc edge rather than the face which indicated that there might be no competition between IMP4 and NaHMP for adsorption space on the talc mineral. Further work in this area to elucidate the mechanism may require adsorption tests to see if a change in zeta potential can be related to a change in adsorbed amount of IMP4. It may be that

there is no displacement of IMP4 from the talc surface with NaHMP addition but that the NaHMP adsorbs onto the edge. The relative size of the molecules implied that IMP4 would be more dominant as it would expand the electrical double layer as well as reduce the surface charge of the talc mineral.

It should also be considered that the NaHMP adsorption density was increased due to the presence of the guar in that it was possible that the NaHMP adsorbs onto the guar molecule itself. This would increase the "surface area" available for the NaHMP adsorption as it had been reported (Jenkins and Ralston, 1998) that NaHMP adsorption onto talc was minimal and limited to the edges. However with the guar adsorbed onto the entire talc surface, that "surface area" could become available to the NaHMP. This could explain why the zeta potential was changed with NaHMP addition even when the IMP4 addition was 100mg/l considering that minimal changes were noticed when IMP4 dosage was increased beyond 100mg/l (when compared to the zeta potential changes at the lower dosages).

4.1.4.3 FF30 and NaHMP added together

The relationship between the combined addition of FF30 and NaHMP and the measured zeta potential at a range of pH's are indicated in Figure 4-13. In spite of both polymers being negatively charged a measure of co-adsorption appears to occur. It is interesting to note that there was a crossover at approximately 30mg/l NaHMP in the zeta potential measurements.

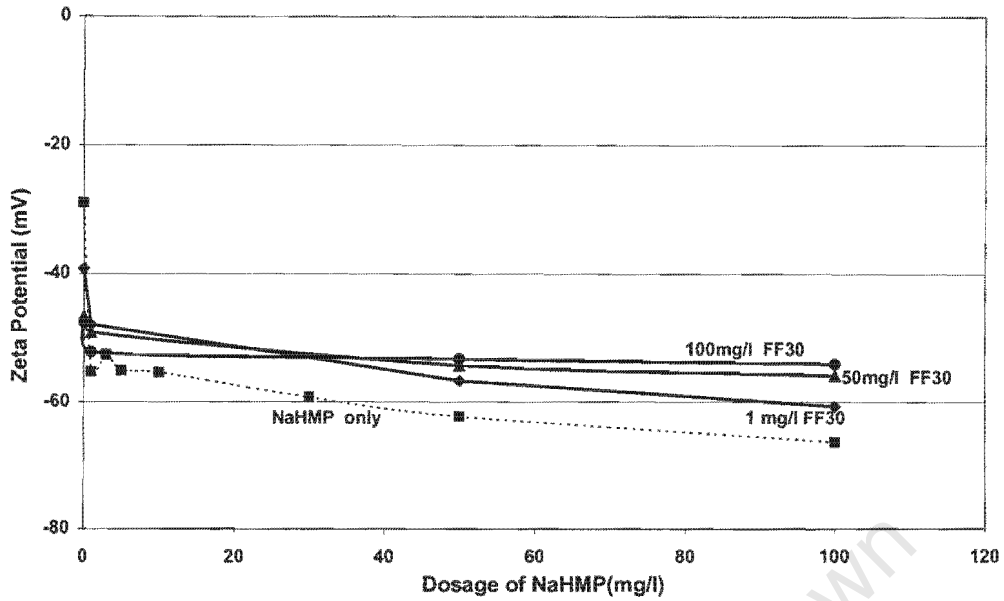

Figure 4-13 - ***The combined effect of FF30 and NaHMP on the zeta potential of talc at a pH of 9***

At low NaHMP additions a similar trend is observed to that seen with the IMP4 and NaHMP mixture in that the NaHMP increases the magnitude of the negative zeta potential which indicated a "compromise" between the individual zeta potentials. The anomaly was that at 1mg/l NaHMP addition the most negative zeta potential was achieved with 100mg/l FF30 followed by 50mg/l and then 1mg/l the least negative zeta potential. This would be expected behaviour if one considers the combined zeta potential to be a linear additive one between the zeta potential of the polymers on their own. However there is a crossover at approximately 30mg/l (estimated from graph) and at 100mg/l NaHMP the order is different in that the most negative zeta potential is obtained with 1 mg/l FF30 and the least negative with 100mg/l FF30. This could be due to expansion of the electrical double layer at increased FF30 additions as the surface charge of the talc should be similar at the higher FF30 and NaHMP additions. This indicated the conflicting mechanisms that dictated the zeta potential in

that increasing charge with the electrical double layer increased the zeta potential but that expansion of the double layer decreased the negative zeta potential.

This indicated that co-adsorption of the high negatively charged polymers was possible onto the talc surface. This suggested that FF30 and NaHMP adsorbed onto different sites on the talc surface with the NaHMP on the talc edge as suggested by Jenkins and Ralston, 1998 but this was not conclusive.

4.1.4.4 IMP4 and FF30 added together

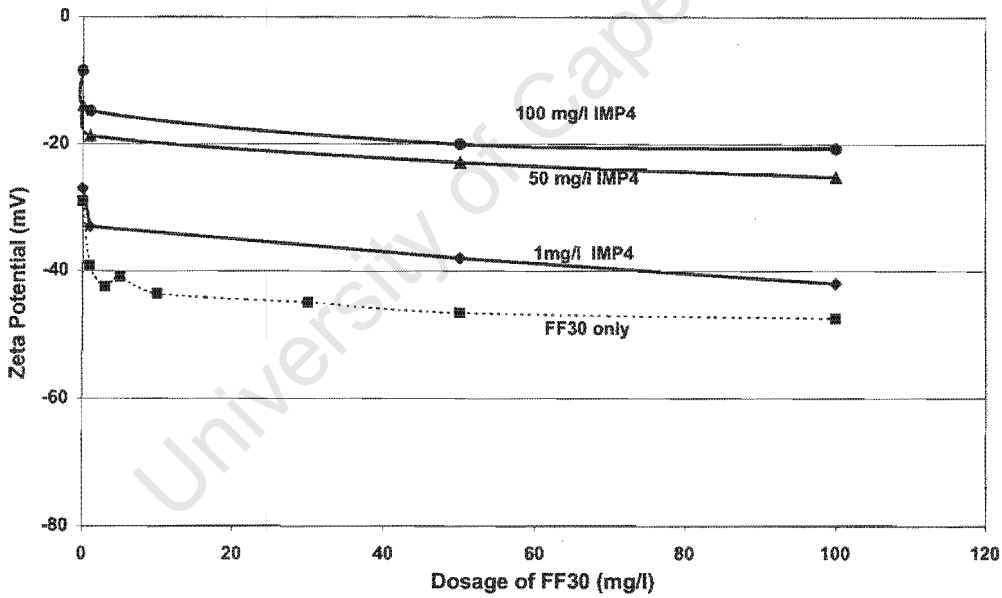

Figure 4-14 - ***The combined effect of IMP4 and FF30 on the zeta potential of talc at a pH of 9***

It has been reported that these polysaccharides both adsorbed on the plane of the talc surface as well as the edge and that IMP4 adsorption was thermodynamically favoured to FF30 (Harris, 2000). Figure 4-14 indicated co-adsorption was achieved even at relatively high additions (100mg/l) of both polysaccharides.

A similar behaviour was displayed to that observed with the IMP4 and NaHMP mixture. There appeared to be co-adsorption in that instance as both IMP4 and FF30 are thought to adsorb onto the talc face and would thus compete for sites. It should be noted that the combined zeta potential is between the zeta potential of the measured zeta potential of the individual additions. As the FF30 dosage is increased the zeta potential becomes increasingly negative though this trend is minimised at the higher IMP4 additions (50 and 100mg/l) which indicated that IMP4 had the greater affinity for the talc surface and that electrical double layer expansion is more significant. However this also indicated that even though sufficient IMP4 was added for monolayer coverage that FF30 was able to co-adsorb onto the talc surface affecting the zeta potential. In this instance adsorption tests are recommended as they would indicate whether the guar was being displaced by the CMC or if the CMC was able to adsorb without displacing a portion of the IMP4.

4.2 SETTLING TESTS

The settling nature of particles in a slurry has been shown to represent the coagulative or dispersive nature of the pulp and is important in a flotation context in that particles in a pulp which are agglomerated may cause a poorer flotation performance. This could be due to valuable minerals being trapped within gangue particles and thus lost or that gangue material attached to valuables float due to this coagulation and thus reduce the grade of the valuables in the concentrate.

The settling characteristics of talc was measured to determine the relationship between zeta potentials and settling rate. It was postulated that near neutral zeta potentials would have led to a coagulated system whereas absolute zeta potentials in excess of 30mV (Pashey, 1992) would have led to dispersed systems.

For the settling tests an image analysis technique was used which measured the luminosity (a more detailed description is available in Chapter 3) down the tube. The scale for the luminosity was from 0 (no light transmitted) to 255 (all light transmitted). This meant that if a low luminosity reading was obtained, at that point the concentration of solids was high. For this tests a point 3cm below the meniscus was used at a time of 10 minutes after mixing.

4.2.1 Experimental

The reagents were made up as described in section 4.1.1 and similar conditions were used to that of the zeta potential measurements. In this instance 2g of talc of-38μm was used in a 100ml of solution. The depressant and or polymer were added with the calculated amount of the KNO_3 stock solution to obtain 0.001M electrolyte strength. KOH and HNO_3 were used as the pH modifiers.

The talc was added to the solution containing the reagents in a beaker and was stirred. It was then transferred to a cylindrical settling test vessel for the settling test and de-ionised water added to makeup the 100ml volume of pulp. This was then mixed for a further five minutes by continuously inverting the mixture. The solution was sonicated for a further minute.

The settling setup is illustrated below in Figure 4-15. The settling vessel (length 23 cm and diameter of 28mm) was placed in a water-bath which maintained a constant temperature of 25°C. A black and white video camera captured the image which was then analysed by the software package OPTIMAS. The macro which was used and sample output can be found in APPENDIX 4. Essentially the length of the slurry (18cm) was divided into 180 points along the centre. The luminosity was measured at

each point at various times for a period of one hour. These values were then exported to the spreadsheet package Excel, where the data was analysed. For analysis a value 3cm below the meniscus was used for evaluation purposes.

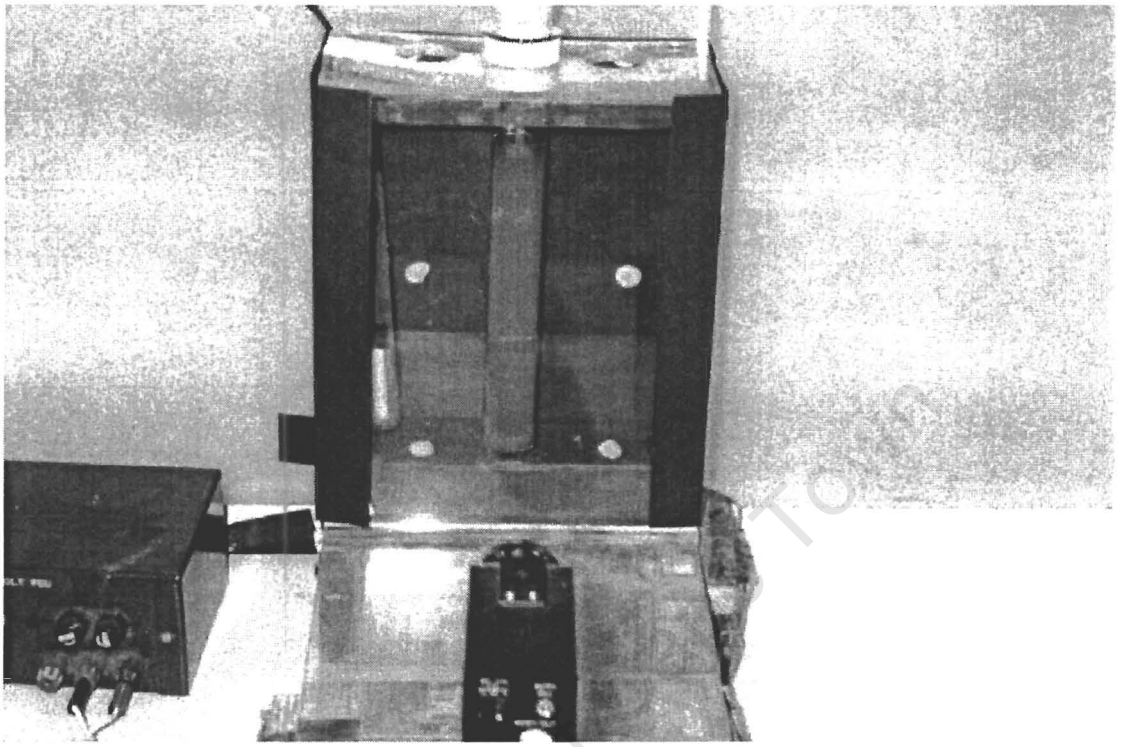

Figure 4-15 - ***Photograph of Settling Test Apparatus***

4.2.2 Reproducibility

The reproducibility of the experimental technique is shown in Figure 4-16 below. It can be seen that similar results are obtained when similar conditions are tested. This would imply that any luminosity variation greater than 10 units can be considered significant.

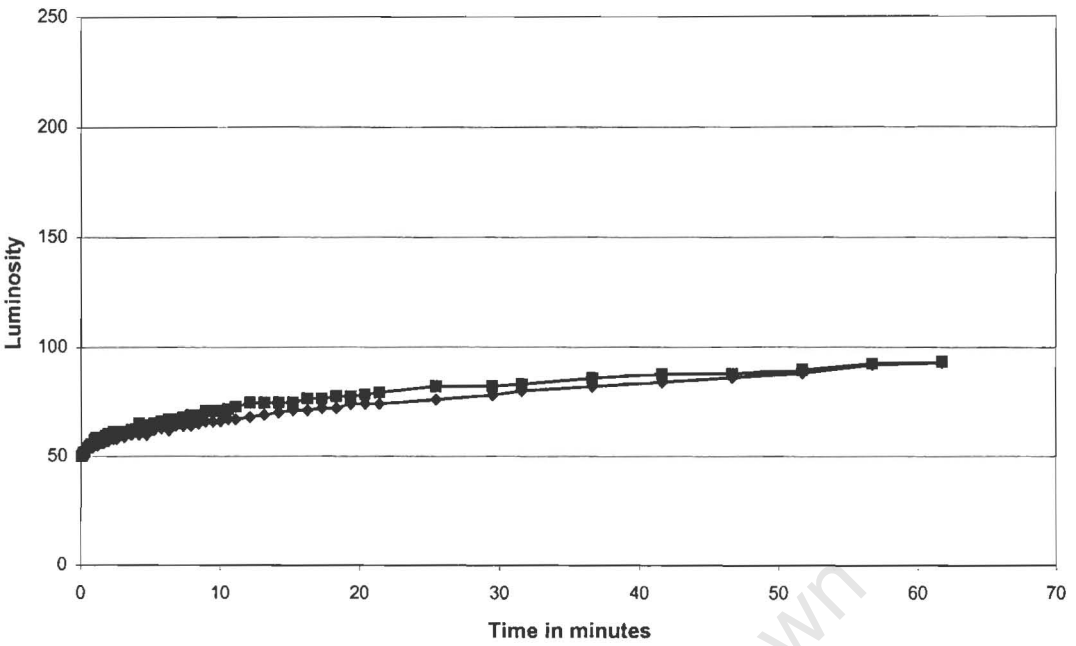

Figure 4-16 - ***The reproducibility of the experimental technique for 1mg/l NaHMP at pH 3***

4.2.3 Single Reagent Addition

The effect of IMP4 dosage at a pH of 4 on the settling character of talc was shown in Figure 4-17. The change in pH investigation is due to the greater change in zeta potential at a pH of 4 rather than at 9 which implies that greater changes in the settling behaviour could be observed. These tests were used primarily to determine whether zeta potential changes could be seen to change settling character. It can be seen that at low dosages the effect of the guar can be deduced from the zeta potential measurements in that the lowering of the zeta potential led to a more coagulating system. However as the dosage was increased the system became more dispersed which was contrary to the zeta potential measurements. It would therefore appear that a correlation between zeta potential measurements and settling character was only possible at low dosages.

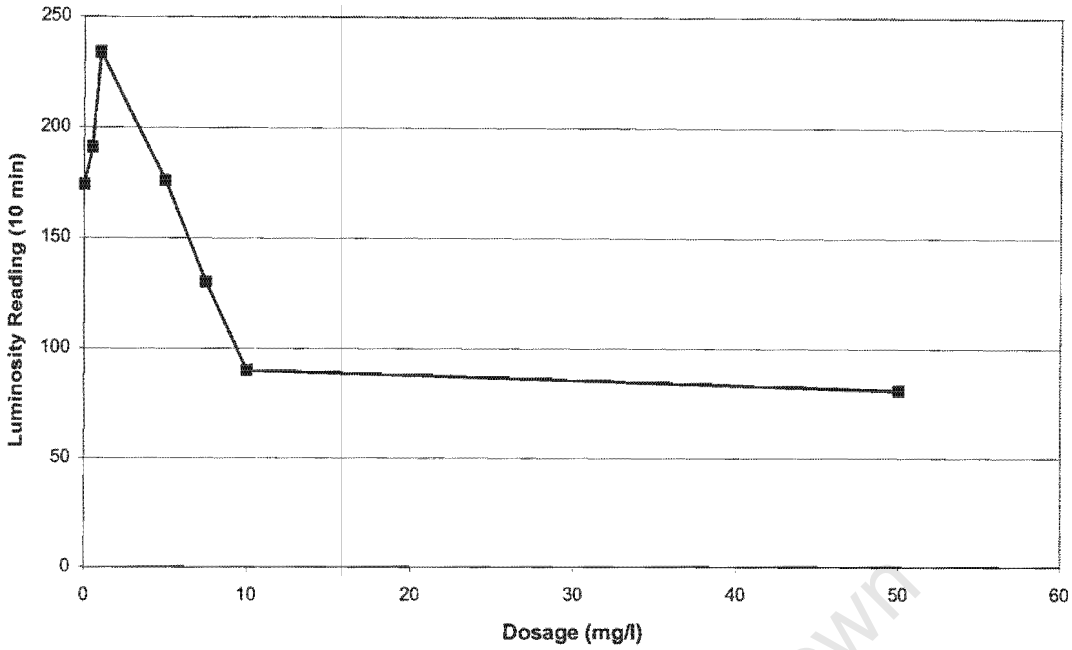

Figure 4-17 - ***The effect of IMP4 dosage on the settling nature of talc at pH 4.***

It can be seen that at low additions (up to 1mg/l) there was a correlation with zeta potentials (see Figure 4-6 in Chapter 4) in that the settling rate increased implying greater coagulation which was predicted from the zeta potential measurements. However as the dosage was increased beyond this level, dispersion increased and the talc settled at a slower rate. This was not in agreement with the zeta potential measurements which became less negative with increasing IMP4 addition and therefore implied greater coagulation and therefore a faster settling rate, however similar results have been reported by Steenberg (1982).

It has been shown (Hiemenz, 1997) that particles can be stabilised electrostatically or sterically. The electrostatic stabilisation can be predicted by the zeta potentials in that like charged particles (of relatively high magnitude) will repel each other and thus not coagulate. Steric stabilisation was ascribed to comprehensive coverage of the particles and thus preventing particles from approaching close enough to coagulate.

Steenberg (1982) has reported that guars do stabilise talc slurries when the addition led to adsorption greater than half of the basal plane.

Vergouw et al (1998) investigated the relationship between zeta potential and settling character. They indicated that good agreement was found between the zeta potential measurements and the settling nature in that lower zeta potentials led to faster settling but they investigated the effect of ions on galena and pyrite. In that system steric effects were minimal if any.

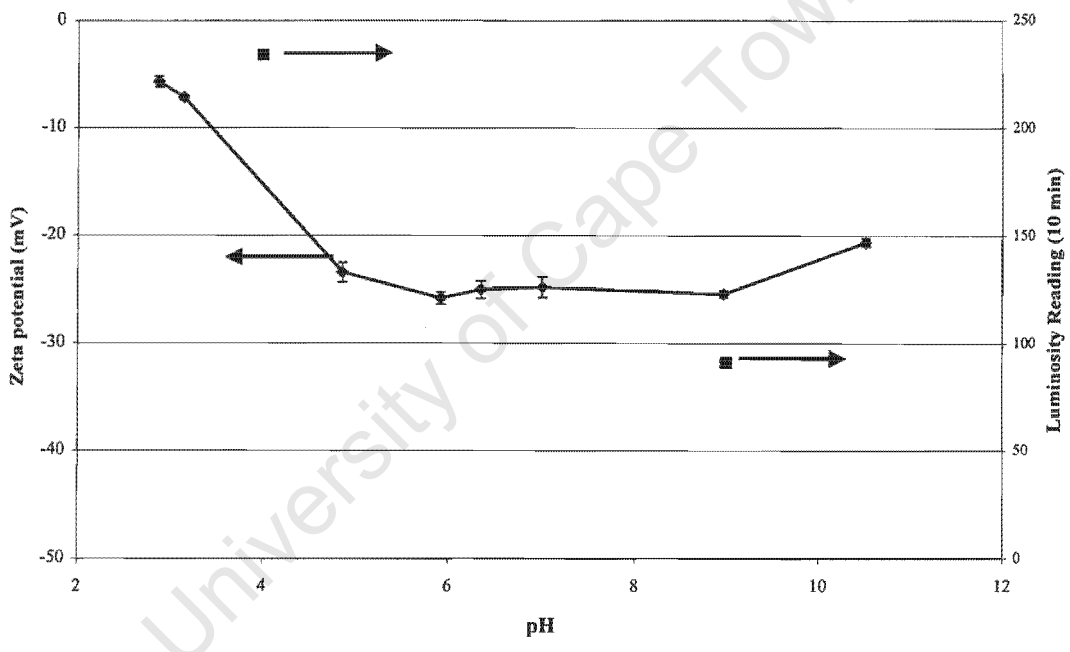

Figure 4-18 - ***The comparative effect of IMP4 at 1mg/l on the zeta potential and settling nature of talc as a function of pH.***

The comparison between zeta potential and settling character as a function of pH, at a dosage of 1mg/l of IMP4, was shown in Figure 4-18. This dosage was chosen due to the correlation between the measured zeta potentials and the settling rate which was not evident at the higher dosages. The graph indicated that at these low dosages that the settling character could be predicted from the zeta potential

measurements or vice versa. This indicated that electrostatic effect was dominant at this dosage as the lower zeta potential compared to a faster settling pulp. It should however be noted that the tests were conducted in quiescent conditions in that no agitation was present during the test which may affect the stability of any agglomerates formed. It should also be noted that a zeta potential of–25mV led to a fairly dispersed system while the zeta potential of approximately –15mV led to a coagulated system. This was in agreement with (Pashley, 1992) who indicated that a zeta potential of –30 mV was required to obtain dispersion. Vergouw et al, 1998 stated that zeta potentials of magnitude 15 mV was not sufficient for dispersion. However it should be noted that while steric effects are minimised at 1mg/l addition they are not completely non-effective and might still contribute to the stabilisation sterically.

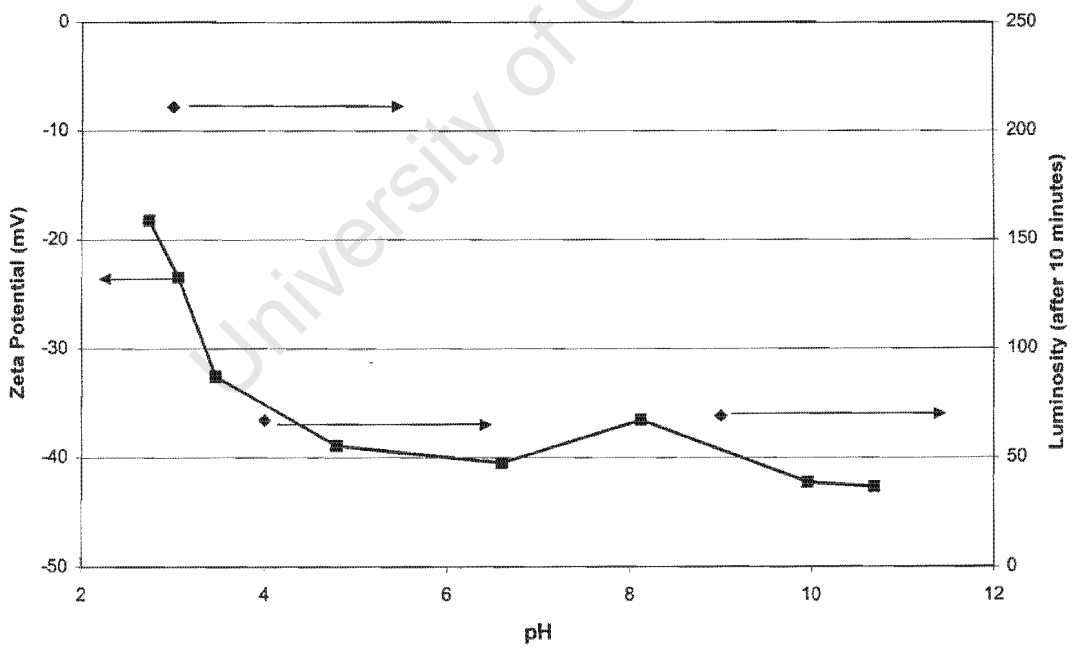

Figure 4-19 - ***The comparative effect of FF30 at 1mg/l on the zeta potential and settling nature of talc as a function of pH.***

The effect of FF30 at 1mg/l with varying pH on the settling nature of talc as compared to equivalent zeta potential measurements was shown in Figure 4-19. The low addition was chosen to minimise the effect of steric stabilisation. It can be seen that there was a correlation between the zeta potential measurements and the settling tests. It was expected that as with the guar that steric effects would dominate at higher dosages and thus settling behaviour could not be determined from the zeta potential measurements. The dispersion effect of CMC's was reported by Steenberg (1982) for all dosages. It should be noted that for this polymer the steric effect and electrostatic effect both promote stabilisation. For this polymer it can be seen that at the lower pH (3) that a zeta potential of approximately –18mV was measured and that the system was fairly coagulated. At the higher pH's measured (4 and 9) the zeta potential was approximately –38mV and this led to dispersed systems which was in agreement with the prediction of Pashley (1992).

The effect of NaHMP on the settling rate of talc at 1mg/l with varying pH was shown in Figure 4-20. The trend indicated was similar to that observed with the zeta potential measurements though the system remained dispersed over the pH range. While the zeta potential measurements varied from approximately –42mV at pH 5.8 to –25mV at pH 3, there was minimal change in the luminosity readings though they did follow a similar trend. The settling tests were not as sensitive as the zeta potential measurements. However it should be noted that the least negative zeta potential measured was approximately –25mV which is close to the value of –30mV indicated by Pashley, 1992 for dispersion. The change from –25mV to –42mV did not lead to marked changes in the luminosity but this can be attributed to the sensitivity of the settling measurements in that further dispersive effects could not be observed.

Ouyang et al, 1995 indicated that NaHMP increased the dispersion and the negative zeta potential of talc markedly. However the reason that they reported that NaHMP

introduced steric effects into their system was that it was a larger molecule than the sodium decyl ammonium sulphate that they were comparing. However compared to the polysaccharides, NaHMP steric stabilisation was insignificant.

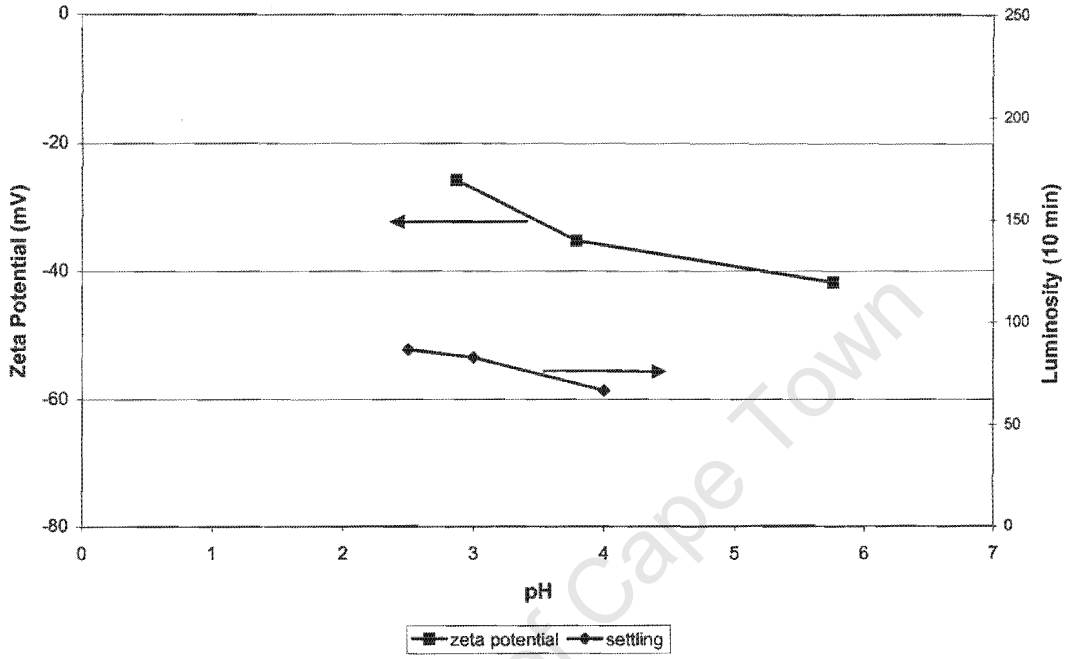

Figure 4-20 - ***The comparison between settling behaviour and zeta potential for talc in the presence of 1mg/l NaHMP and varying pH.***

4.2.4 IMP4 and FF30 added together

The combined effect of the polysaccharides on the settling nature of talc was shown in Figure 4-21 and Figure 4-22. There was a clear indication that a similar trend could be noticed to the zeta potential measurements but that the settling tests were not as sensitive as the zeta potential tests.

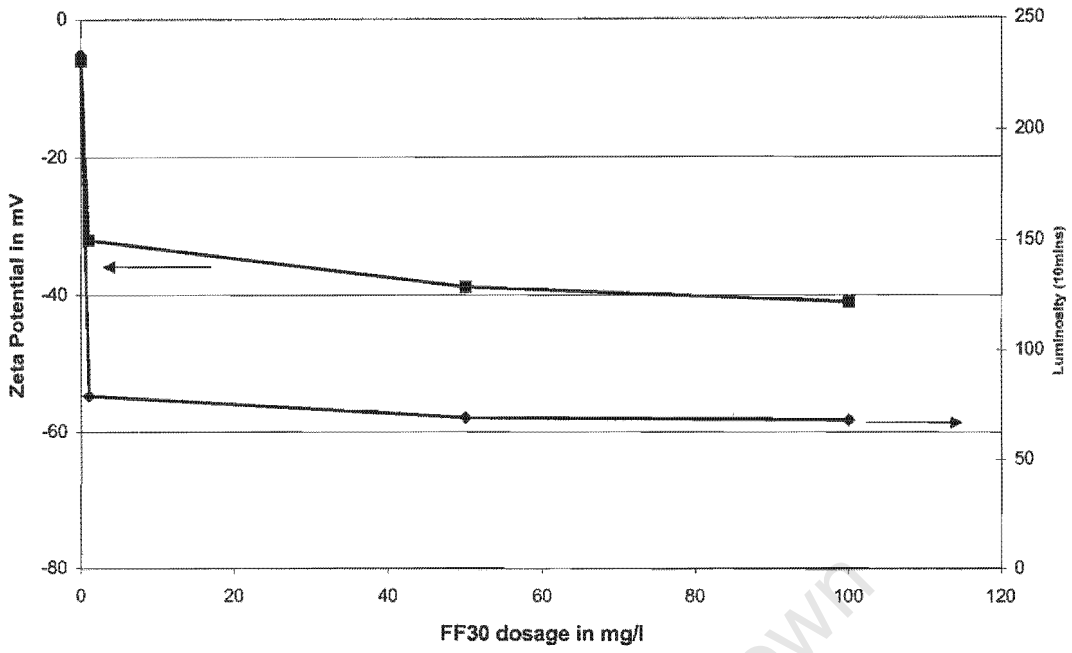

Figure 4-21 - ***The effect of combined effect of IMP4 (at 1mg/l) and varying FF30 addition on the zeta potential and settling nature of talc at pH 4.***

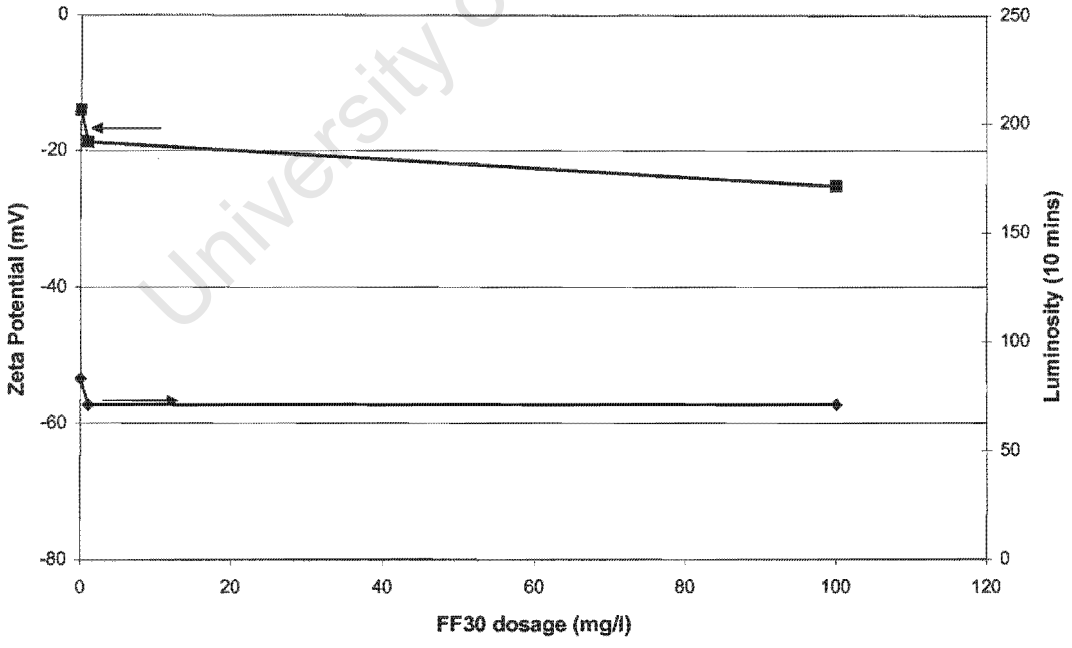

Figure 4-22 - ***The effect of IMP4 (at 50mg/l) and varying FF30 dosage on the zeta potential and settling character of talc at pH 4***

It can be seen that there was agreement in that higher zeta potential (without any FF30) was more coagulated. With the increase in FF30 dosage from 0mg/l to 1mg/l there was an increase in the negative zeta potential from –27 to –33mV. However whilst increasing the FF30 dosage had an effect on the zeta potential, in terms of increasing the negative zeta potential, the settling rate remained reasonably constant. This could be due to the limitation of the settling system. However it can also be seen that the lower end of the settling tests also masked the additional stability which should be due to steric effects.

Figure 4-22 indicated the effect of combining varying dosages of FF30 to IMP4 at 50mg/l at pH 4 on the zeta potential and settling character of talc. A similar effect to the lower IMP4 addition can be seen. It should be noted that in this instance as well that a similar settling nature was observed with the low and high FF30 addition. This was probably due to the limitation of the settling tests in that the pulp may have been more dispersed at the greater FF30 addition but this change was not measurable by the equipment.

4.3 CONCLUDING REMARKS

The measurement of zeta potential clearly demonstrated the effect of polymer adsorption on the surface charge of talc.

The guar, IMP4, was confirmed to be of low charge while the inorganic dispersant (NaHMP) and the CMC (FF30) had relatively high negative charge densities, resulting in more negative zeta potentials.

It appeared that expansion of the electrical double layer was significant at higher dosages of the polysaccharides which are large molecules while that, predictably, with the much smaller NaHMP, expansion played no part in the NaHMP adsorption. It was for this reason that the zeta potential had a greater negative value with the NaHMP rather than the FF30.

Zeta potential measurements suggested that IMP4 had the greater adsorption affinity than the FF30, which in turn had a greater affinity for the talc surface than the NaHMP. This correlated to the observation that guar was considered to be a more effective depressant for talc than CMC in systems with no ions added.

For all polymers, the greatest rate of change in zeta potential occurred at the low additions of reagent and then the effect reduced in magnitude with increasing dosage. This indicated that changes in the charge within the electrical double layer which occurred at the lower additions had a greater effect than double layer expansion which would become significant at the higher dosages. Increasing the dosage beyond a 100mg/l for all the reagents had a minimal effect indicating that maximum adsorption was achieved at this level.

The polymers appeared to co-adsorb on the talc surface when added in combination. However the mechanism of co-adsorption cannot be clearly defined from the tests performed. An analysis of the talc surface was required to determine whether the polymers competed for sites on the talc surface or whether they were associated with each other. This is especially pertinent for the NaHMP which may adsorb onto the talc edge or may find sites on the polysaccharide.

Zeta potential measurements obtained with the IMP4 and NaHMP mixture indicated that co-adsorption of these reagents onto the talc surface was possible. The NaHMP

affected the zeta potential of talc even when 100mg/l IMP4 was present. This indicated that eventhough no further change was noted when IMP4 dosage was increased beyond 100mg/l the NaHMP effected a change in zeta potential.

The effect of expansion of the electrical double layer was shown in Figure 4-13 in which there is a crossover for the measured zeta potential with combined addition of FF30 and NaHMP. As both these polymers are negatively charged they introduced negative charge within the electrical double layer and therefore increased the negative zeta potential.

The zeta potential measurements can be used to predict the settling character of a talc pulp at low polymer addition. It would appear that zeta potentials of magnitude 30mV were required to obtain a dispersive environment when steric effects were minimised.

At low IMP4 dosages (<1mg/l) the settling nature can be predicted from the zeta potential measurements in that decreasing the negative zeta potential of talc led to an increased coagulation and therefore faster settling rate. However as the dosage of the IMP4 was increased the pulp became stabilised and thus settled slower. This was contrary to what was expected from the zeta potential which became progressively less negative with increasing dosage. Steric effects are therefore significant at the higher polysaccharide addition and thus electrostatic effects are minimised at these dosages.

At a dosage of 1mg/l for all the polymers the settling behaviour as a function of pH could be predicted from the zeta potential measurements.

The measuring of the settling nature was not sufficiently sensitive to differentiate between degrees of dispersion. This sensitivity would have to be improved to obtain a greater correlation to the zeta potential measurements.

Chapter 5 RESULTS AND DISCUSSION OF MERENSKY SETTLING AND FLOTATION TESTS

5.1 SETTLING TESTS

As discussed in the previous section, the results obtained using settling tests with talc pulp were compared to zeta potential measurements with the same talc sample. In this chapter tests were extended to use Merensky ore. It is proposed that the coagulative / dispersive nature of the pulp may affects the flotation performance in that recovery could be reduced if the ore coagulates and valuable minerals are trapped between the gangue particles. However the flotation process is followed by a solid-liquid separation step which would be difficult to handle if the particles did not settle in a reasonable amount of time due to high dispersive properties.

The settling characteristics of a typical PGM ore, Merensky ore from Impala in the presence of flotation reagents was evaluated to determine whether the effect of the polymers could be observed at the dosages that were added in typical flotation conditions. While CMC's and NaHMP are known to be dispersing and the guars coagulating under certain conditions, it was not sure if that was the case at typical plant conditions. It must also be noted that the talc content was approximately 1%.

5.1.1 Experimental

The experimental set-up (in terms of equipment–see Figure 4-15) was the one used for the talc settling tests with the difference for these tests being the operating variables such as ore, particle size, solids concentration and the reagent addition.

For these tests conditions similar to those that were to be used for the batch flotation tests were used. The ore was Merensky ore which was obtained from Impala Platinum Mine (see Chapter 3 for the mineralogy). Prior to the settling tests, a sample was milled to 60% passing 75μm was split into 30 samples.

Each sample was then added to tap water and well mixed using a magnetic stirrer. Collector, namely sodium isobutyl xanthate (SIBX), at a dosage of 45g/ton was then added. This was followed by 5 minutes later by $CuSO_4$ at 30g/ton as an activator for the sulphide minerals. Two minutes thereafter the depressant and or the inorganic dispersant as specified was added. The conditioning was continued for a further two minutes. Thereafter the pulp was transferred to the settling vessel and the volume made up to a 100ml by adding tap water.

The sample was then further conditioned by inverting the settling vessel for a further 2 minutes and then sonicated for one minute. The settling tests with Merensky ore were conducted in the same way as the talc settling tests.

5.1.2 Reproducibility

The ore system with standard reagent addition excluding any depressant or dispersant addition gave the settling characteristics as shown in Figure 5-1. The tests were conducted in duplicate to ascertain the reproducibility of the test procedure. The luminosity values increased rapidly after approximately 6.5 minutes and reached a value of approximately 170 at the end of the test. It should be noted that a clear supernatant at the point of interest would have resulted in a luminosity of 250. This indicated that though the system was coagulating without any polymer there were still significant amounts of particles that had not settled. It should be noted

that these tests were conducted in tap water and therefore the effect of ions was excluded except for the addition of $CuSO_4$. The increased ionic strength would be expected to increase the coagulative nature of the system due to the formation of the metal hydroxides which coat the particles (Vergouw et al, 1998) as well as compress the double layer.

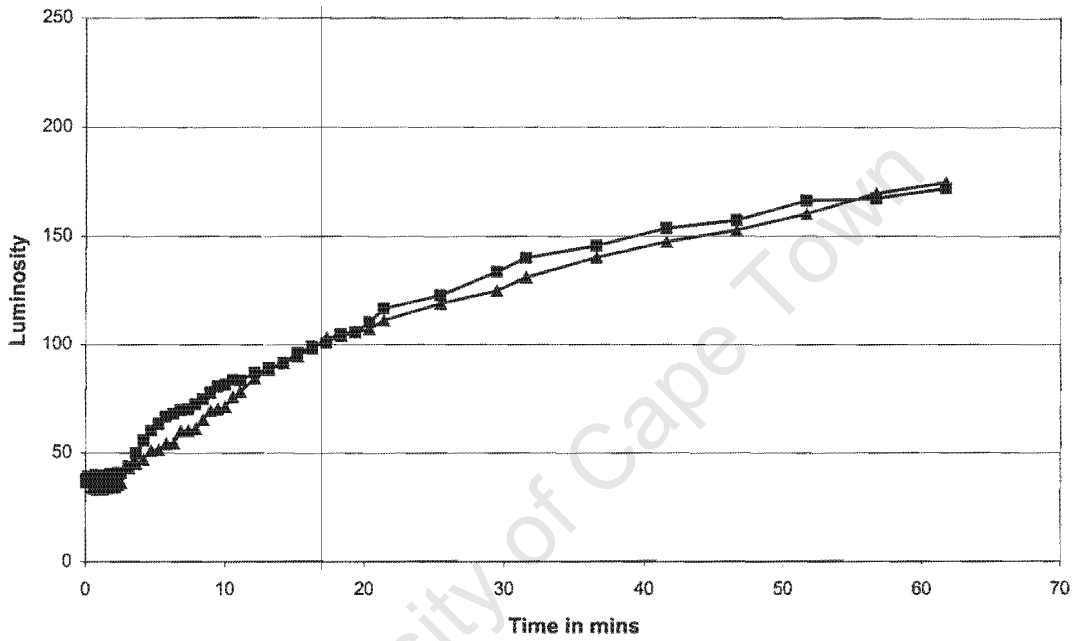

Figure 5-1 - ***The settling character of Merensky ore with the addition of collector SIBX(45g/ton) and $CuSO_4$ but without the addition of polysaccharides or inorganic dispersants in duplicate at natural buffered pH (in the range of 8.5 to 9.2) and a temperature of 25°C***

The coagulative nature of the system without depressant or dispersant could be attributed to the effect of the $CuSO_4$ that is known to aid coagulation (Harris, 2000). It should be considered that homo-coagulation would be beneficial to the flotation process provided valuable minerals agglomerates do not become too big to be floated but that heterocoagulation would be disadvantageous as that would involve the agglomeration of valuable and gangue material, lowering the grade of the concentrate.

5.1.3 Single reagent addition

The effect of the reagents on the settling rate is shown in Figure 5-2. It can be seen that the only reagent addition that increased the coagulative nature of the pulp was IMP4 at 40g/ton. All the other reagents increased the dispersity of the slurry which was expected for the FF30 as well as the NaHMP. It was noted that comparable dispersities were obtained when the similar reagent additions of NaHMP and FF30 were compared.

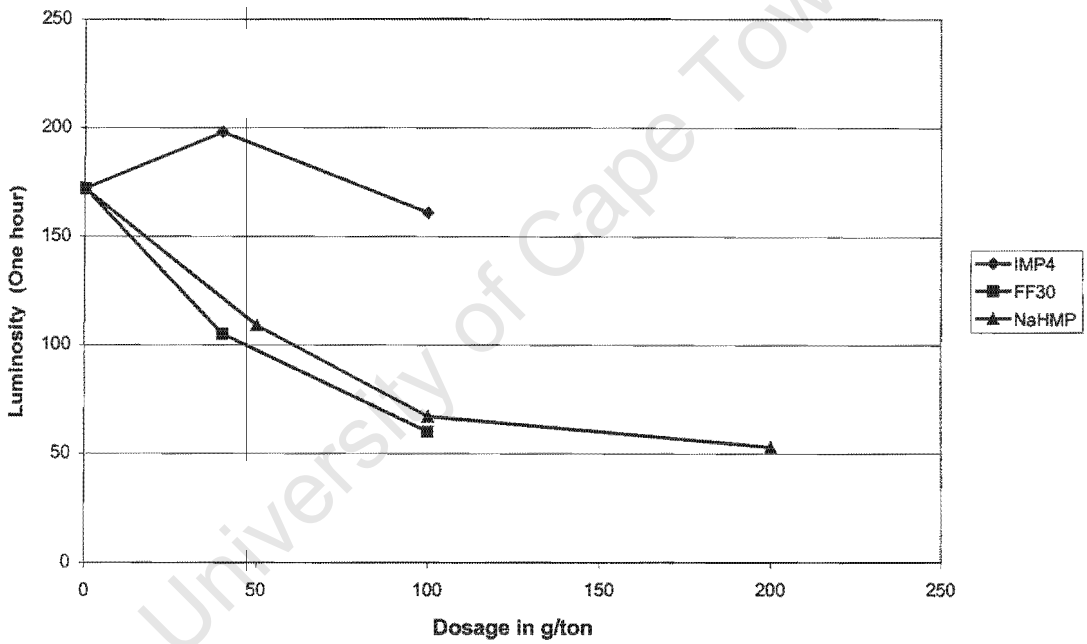

Figure 5-2 - ***The final luminosity (1 hour) for the slurry with varying singular reagent addition at a point 3 cm below the meniscus.***

The addition of IMP4 at 100g/ton did not lead to a increased coagulation but to a system which was more dispersed than the 40g/ton addition and was similar to the slurry without any polysaccharide or inorganic dispersant.

This indicated that steric stabilisation effects were present at the IMP4 addition of 100g/ton. While the difference in luminosity between the blank and the IMP4 at 100g/ton was not marked the difference between the two IMP4 additions was significant. This would indicate that at typical plant conditions, steric effects might be significant in terms of the settling characteristics of an ore. Though it should be noted that these tests were conducted in tap water rather than plant water and thus limited in its applicability to the plant conditions.

These results show that in tap water at plant depressant dosages which are in the order of 100g/ton that the guar does not act as a coagulant for this system. This could be the reason for the high dosages used on the PGM flotation plants and if a dispersing environment could be achieved with lower guar additions, flotation performance may be improved at lower reagent addition. Work done by Harris et al, 1999 (also done in tap water) showed that guars were coagulative but that IMP4 was not as effective a coagulant as larger guars and that energy input has an important effect on the coagulation. This would be an important consideration as the lower energy input (energy/mass treated) would imply that the coagulants would not be as easily broken up in industrial cells. This could be one of the reasons for reagents performing differently in the laboratories compared to plant-scale tests. It should also be noted that the use of inorganic dispersants could be considered a chemical method of introducing high intensity conditioning. Thus perhaps adding larger guars, which may be stronger depressants, but promote coagulation of the pulp in industrial size cells produce poorer flotation performance than expected.

The trend with FF30 addition was as expected (indicated in Figure 5-2) with increasing FF30 dosage leading to an increased degree of dispersion. This would be expected from the zeta potential results which indicated that the FF30 increased the negative zeta potential across the dosage range. The increased charge introduced

onto the particle surfaces should lead to greater electrostatic repulsion which would lead to dispersion. However as was demonstrated with the IMP4 effect on settling character, steric stabilisation should also play a role at the higher polysaccharide addition (Steenberg, 1982). It was probably due to this added effect that there was such a marked change in the luminosity (and therefore degree of dispersion) between the 40 and 100g/ton additions.

The expected trend with the NaHMP addition was shown in Figure 5-2. The dispersion increased as NaHMP addition was increased even moving from 100g/ton to 200g/ton. This indicated the effect of increasing charge on the particle surface and the effect that this had on the settling rate. It was not expected that the NaHMP would stabilise the slurry sterically due to its relatively low molecular size. It should be noted that similar settling characteristics were noted for the NaHMP and the FF30 at similar additions eventhough from the zeta potential measurements the NaHMP was shown to impart a greater negative zeta potential onto talc. Talc constitutes less than 2% of the ore and thus effects obtained with ore and talc are not expected to be identical. This difference in settling behaviour could also have indicated the additional stability imparted by steric effects with the FF30 but also may be due to the effect on the other minerals present in the ore. It should also be noted that complete dispersion was achieved with the 200g/ton dosage which indicated that flotation at this dosage (or greater additions) may not be feasible due to solid-liquid separation problems downstream, though if flotation performance is enhanced enough then it may be economically feasible. It should however be noted that NaHMP was not expected to have a depressing effect in that it adsorbs onto the talc edge rather than the hydrophobic face (Jenkins and Ralston, 1998) and therefore does not reduce the flotability of talc. However the dispersive effect could improve recovery of the valuables by releasing valuables trapped within gangue agglomerates as well as increasing grade by cleaning up the sulphide surface of fine gangue material.

5.1.4 IMP4 and NaHMP added together

The addition of IMP4 and NaHMP together was studied as it provided an opportunity to investigate a system where dispersion and depression could be achieved by different reagents. The guar (IMP4) was known to be a good depressant for talc (Shortridge et al 1999a) and was thought to coagulate the pulp by reducing the charge whereas the NaHMP was expected to stabilise the pulp by introducing charge.

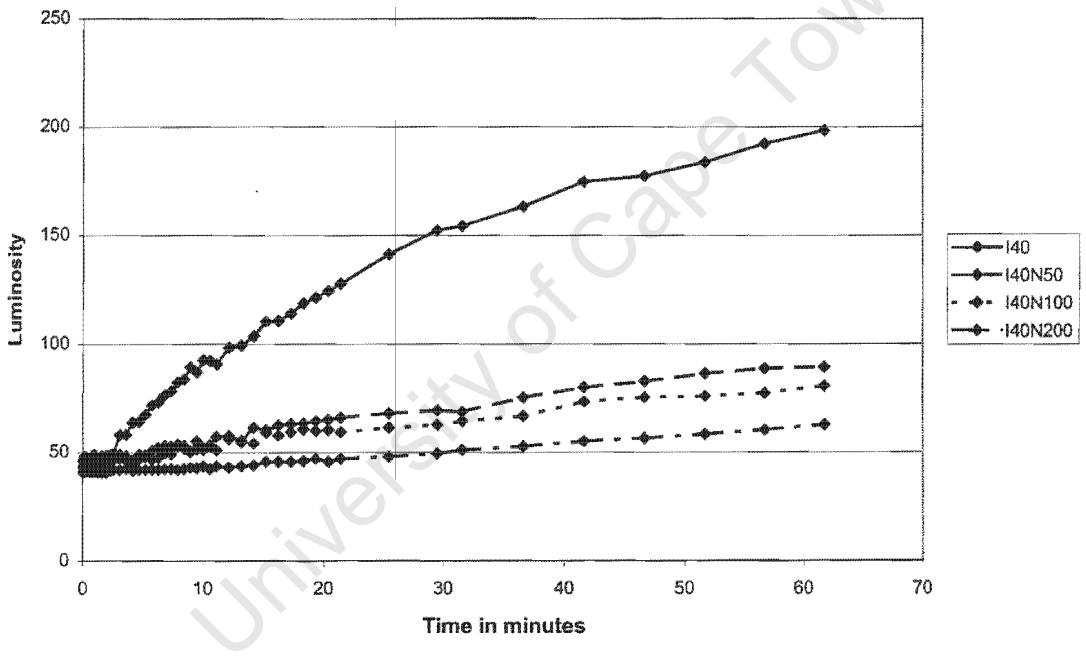

Figure 5-3 - ***The effect of NaHMP addition on the settling character of Merensky ore with a constant IMP4 dosage of 40g/ton.(where I40 = 40g/ton IMP4 only; I40N50 40g/ton IMP4 and 50g/ton NaHMP; I40N100 40g/ton IMP4 and 100g/ton NaHMP; I40N200 40g/ton IMP4 and 200g/ton NaHMP)***

The combined effect of IMP4 at 40g/ton and varying NaHMP additions on the settling rate of a Merensky ore is shown in Figure 5-3. At this dosage of IMP4 the addition of

NaHMP increased the dispersity of the pulp when compared to IMP4 alone. At the 200g/ton NaHMP addition the pulp was effectively fully dispersed.

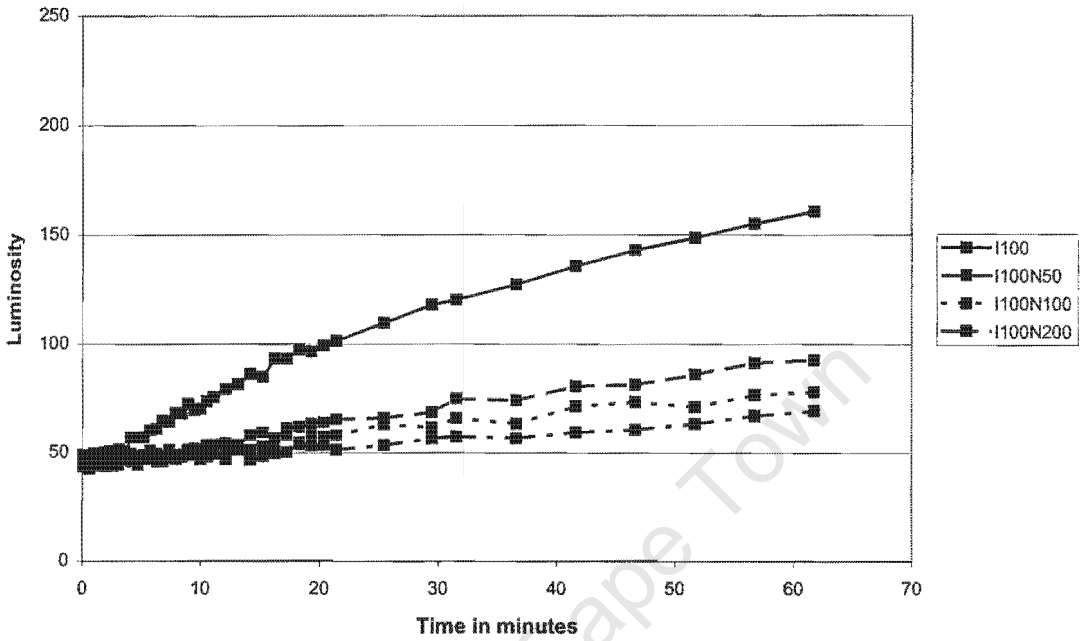

Figure 5-4 - ***The effect of NaHMP addition on the settling character of Merensky ore with a constant IMP4 dosage of 100g/ton. (where I100 = 100g/ton IMP4 only; I100N50 100g/ton IMP4 and 50g/ton NaHMP; I100N100 100g/ton IMP4 and 100g/ton NaHMP; I100N200 100g/ton IMP4 and 200g/ton NaHMP)***

It should be noted that even at the 50g/ton NaHMP addition the pulp was more dispersing than the blank which indicated that the NaHMP had a greater effect on the settling nature than the IMP4 at these dosages as expected due to its greater charged nature.

The combined effect of IMP4 (at a 100g/ton) and varying NaHMP on the settling characteristics of pulp is shown in Figure 5-4. A similar trend was noticed for the settling test in terms of the luminosity. With increasing NaHMP addition the dispersion of the pulp increased though the change was most marked at the low

NaHMP addition, that is, moving from no NaHMP to 50g/ton. However, therewas still a change moving up to 200g/ton, which indicated that there was still adsorption of the NaHMP on the particles and that it could affect the settling character of the Merensky ore.

Figure 5-5 indicated the combined effect of NaHMP and IMP4 on settling characteristics of Merensky pulp. It was shown that at the higher IMP4 dosage of a 100g/ton the slurry was more dispersing than without any polymer addition. Therefore it was possible at the 100g/ton IMP4 addition steric stabilisation was occurring and that the dispersion was enhanced with the addition of NaHMP at 50g/ton. With increasing NaHMP from 100 to 200 g/ton addition (at the 40 and 100g/ton IMP4) the dispersion achieved remained relatively constant. It would appear that at this concentration, the increased charge that the NaHMP introduced was offset by the electrical double layer expansion of the guar.

The increased dispersion achieved with combined IMP4 (40g/ton) and NaHMP (50g/ton) greater than the NaHMP added alone at 50g/ton addition indicated that enhanced NaHMP adsorption may result from the presence of the polysaccharide. At this level of IMP4 addition steric stabilisation was not significant as a singular IMP4 addition of 40g/ton led to a more coagulated pulp than the blank test as indicated in Figure 5-1.

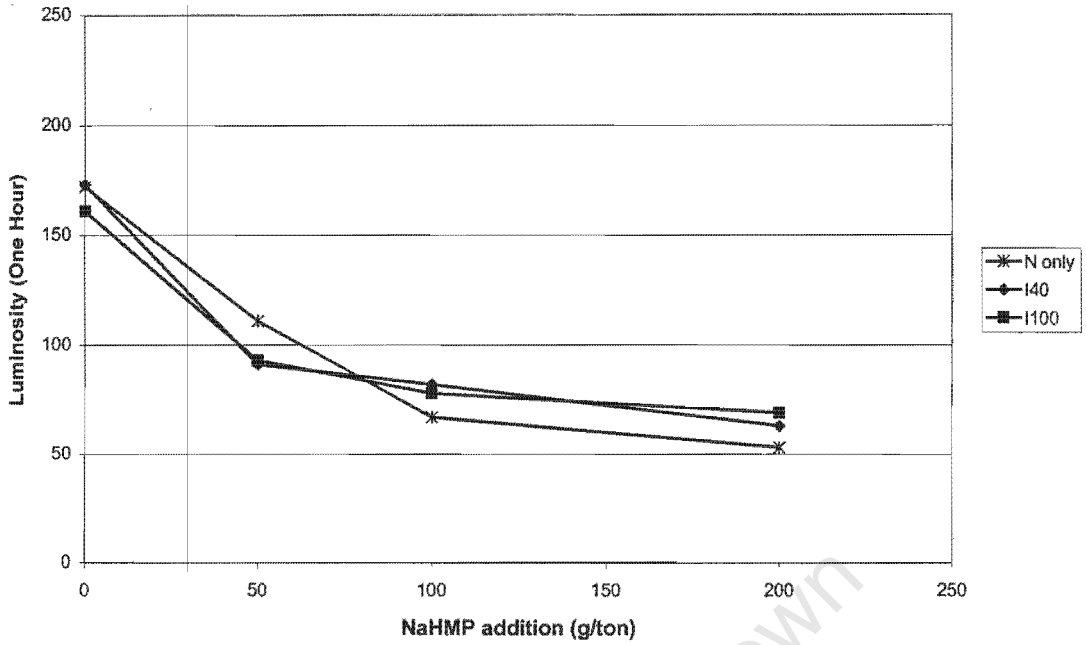

Figure 5-5 - ***The combined effect of IMP4 and NaHMP on the settling nature of Merensky ore (where N only = NaHMP added alone; I40 = IMP4 at 40g/ton with various NaHMP additions;I100 = IMP4 at 100g/ton with various NaHMP additions)***

It should be noted that anomalous behaviour occurred when 50g/ton NaHMP was added in combination with the IMP4 at both dosages. The luminosity was lower (indicating a more dispersed system) when the IMP4 was combined with the NaHMP than the NaHMP on its own. There is a crossover at approximately 80g/ton (estimated from graph) whereby higher luminosity readings would be obtained in the presence of IMP4 than without which was the expected situation.

5.1.5 FF30 and NaHMP added together

The effect of FF30 and NaHMP added together on the settling rate of Merensky pulp was shown in Figure 5-6. The combined addition led to a more dispersed system than the individual additions, which was expected. This would indicate that solid

liquid separation would not be achieved easily and that flotation with such mixtures may not be feasible due to the downstream difficulties.

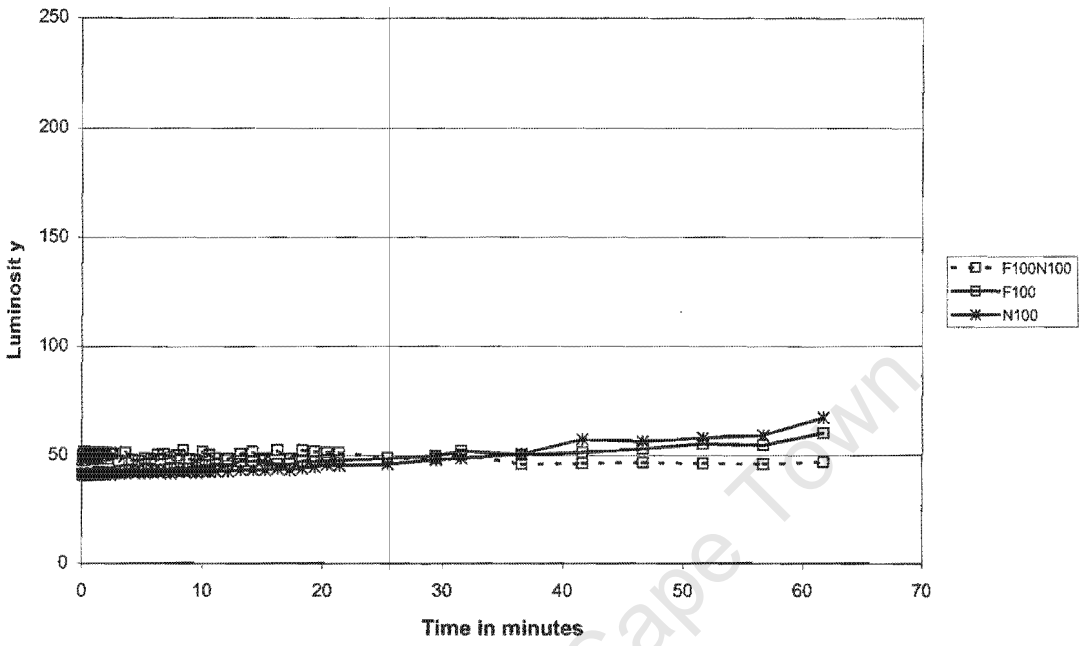

Figure 5-6 - ***The combined effect of FF30 and NaHMP on the settling nature of Merensky ore***

It should be noted that addition of the mixture led to an increased degree of dispersion which was expected due to the increase addition of charge. It was noted that the least dispersed system resulted from the NaHMP addition at 100g/ton compared to FF30 at 100g/ton. The zeta potential measurements of talc, reported in Chapter 4, indicated that a greater charge was imparted with the NaHMP than the FF30. However that was found with a pure talc system whereas in the ore talc constituted less than 2% of the ore and thus overall zeta potential, if it could be measured, would be expected to be different. However the greater stabilisation may be due to the additional stabilisation due to steric effects.

It can be seen that the combined addition of FF30 and NaHMP resulted in a system that was still completely dispersed (similar value in luminosity at the end of the hour

compared to the first reading) after the length of test. This would indicate that solid liquid separation may prove difficult after flotation.

5.2 BATCH FLOTATION OF MERENSKY ORE

Batch flotation tests are a valuable tool used in determining the effect of reagent changes on the flotation performance of an ore. The change in flotation behaviour, due to reagent changes, can be easily determined in a controlled laboratory environment without the disturbances usually obtained on a plant. The effect due to the reagent can therefore be evaluated independently. However changes that are observed in 3-litre batch floats are not necessarily correlated to those observed on the plants, normally due to the difference in physical conditions such as the difference in energy input and water quality.

The flotation performance of Merensky ore is represented by copper assays to represent chalcopyrite and nickel assays to represent pentlandite, although there is some non-sulphide nickel, this representation is adequate for this thesis. The recovery and grade analysis was calculated based on concentrate and tail analyses of copper and nickel.

The batch flotation tests were performed to determine whether differences in pulp condition as demonstrated by the settling behaviour, led to variations in the flotation performance in order to test the hypothesis that increased dispersion leads to increased flotation performance. The focus of the testwork was on IMP4-NaHMP mixtures and these tests were done at dosages of several levels and a few tests with FF30 combined with NaHMP were also done.

5.2.1 Procedure

The ore used for the batch flotation tests was Merensky ore obtained from Impala Platinum Mines. The ore was split into approximately 1kg samples. The samples were milled in the laboratory rod mill to obtain a size classification of 60% passing 75µm and then floated immediately. Single tests were conducted at each condition. See Chapter 3 for the mineralogy of Merensky ore.

The flotation was performed in a three-litre modified Leeds Cell (Bacus, 2000). The machine had a variable speed drive and the pulp level was controlled by a constant head device. A photograph of the equipment is shown below in Figure 5-7.

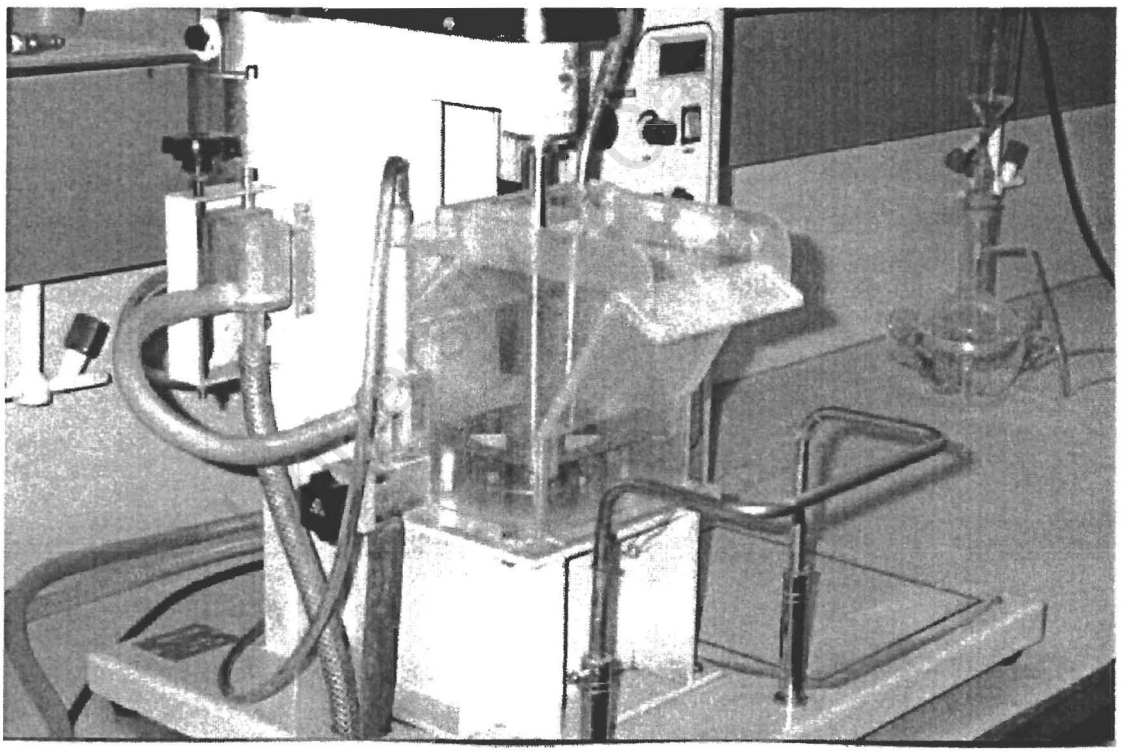

Figure 5-7 - ***Photograph of the modified 3-litre Leeds Cell***

The milling was done with the 1kg of ore and 600ml of tap water. After milling the pulp was transferred to the modified Leeds cell and made up to the necessary level with tap water. The impeller was set to 1200rpm and the collector (sodium isobutyl

xanthate) was added at 45g/ton. The pulp was then conditioned for 5 minutes before the $CuSO_4$ was added at 30g/ton. Two minutes later the depressant and or the inorganic dispersant was added. A further minute later the frother Dow200 was added and a minute thereafter the air was switched on at 6l/min.

The concentrates were collected by scraping the froth every 15s. The first concentrate was collected for the period 0 to 1 minute, the second from 1 to 4 minutes, the third from 4 to 13 minutes and the final concentrate from 13 to 25 minutes.

Water recovery was also measured for the same time periods. The water mass was determined by weighing the total mass recovered and subtracting the solid's mass as well as the mass of the water that is added to wash the scraper.

The copper and nickel assaying was done by an acid digestion technique which is detailed in Appendix 5. The recovery calculations were based on concentrate and tails analysis.

5.2.2 Reproducibility Tests

The flotation tests were a preliminary investigation and only singular tests were conducted to determine the effect of depressant and dispersant addition on the performance. The reproducibility of the float tests was obtained from a parallel investigation using similar ore (Bacus, 2000) and showed that for 8 tests the std deviations were:

nickel recovery 1.94; nickel grade 0.61; copper recovery 4.6 and copper grade 0.36

5.2.3 Results of Batch Flotation

A summary table of the conditions and performance is presented in the table below.

Table 5-1 – ***Summary Table for Batch Flotation Tests***

IMP4 Addition (g/ton)	FF30 Addition (g/ton)	NaHMP Addition (g/ton)	Final Cu Recovery (%)	Final Cu Grade (%)	Final Ni Recovery (%)	Final Ni Grade (%)	Mass Recovery (%)	Water Recovery (g)
0	40	0	86.0	0.64	66.4	1.14	10.9	983
0	100	0	83.5	0.93	61.3	1.6	7.2	685
0	0	0	76.2	0.52	61.1	1.02	11.0	969
40	0	0	79.0	0.58	59.2	1.16	9.4	835
40	0	50	65.8	0.72	44.1	1.25	8.0	920
40	0	100	79.9	0.94	58.1	1.54	7.1	520
40	0	200	79.4	0.94	58.4	1.63	6.6	549
100	0	50	80.1	1.93	58.1	3.30	3.2	502
100	0	100	77.6	1.16	55.0	1.91	5.1	612
100	0	200	78.4	1.26	58.6	2.31	4.8	570
100	0	0	78.4	1.32	60.5	2.5	4.7	525
0	0	50	78.7	0.75	59.9	1.34	8.5	660
0	0	100	77.7	0.60	59.7	1.18	9.1	662
0	100	100	81.1	1.31	63.0	2.61	4.8	629

5.2.3.1 Water and Mass Recovery

The water recovery for all the flotation tests was shown in Figure 5-8 and the mass recovery in Figure 5-9. The legend indicates the reagent type (I-IMP4, F-FF30 and N-NaHMP) and the dosage in g/ton.

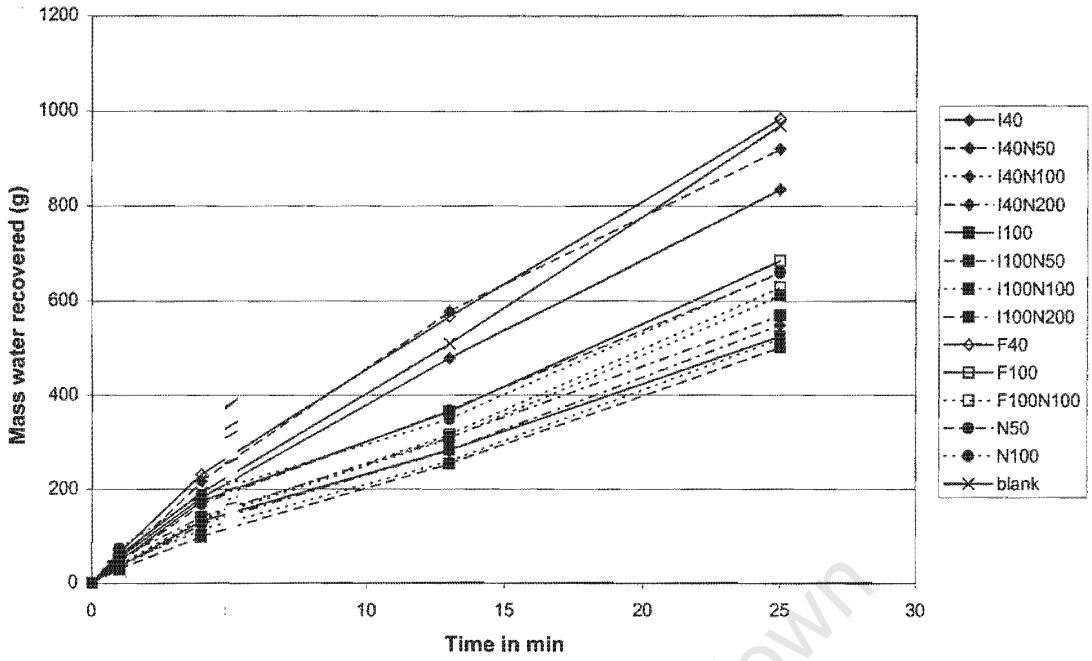

Figure 5-8 - ***WatereRecovery as function of time for various conditions tested***

The greatest wacer recovery was obtained for the conditions with no or low depressant and dæspersant. The rest of the tests were reasonably similar in water recovery. There ie a greater variation with the mass recovered than with the water recovery but the ltighest mass recovered was still with no polymer addition followed by the low additiorr of depressant and dispersant addition.

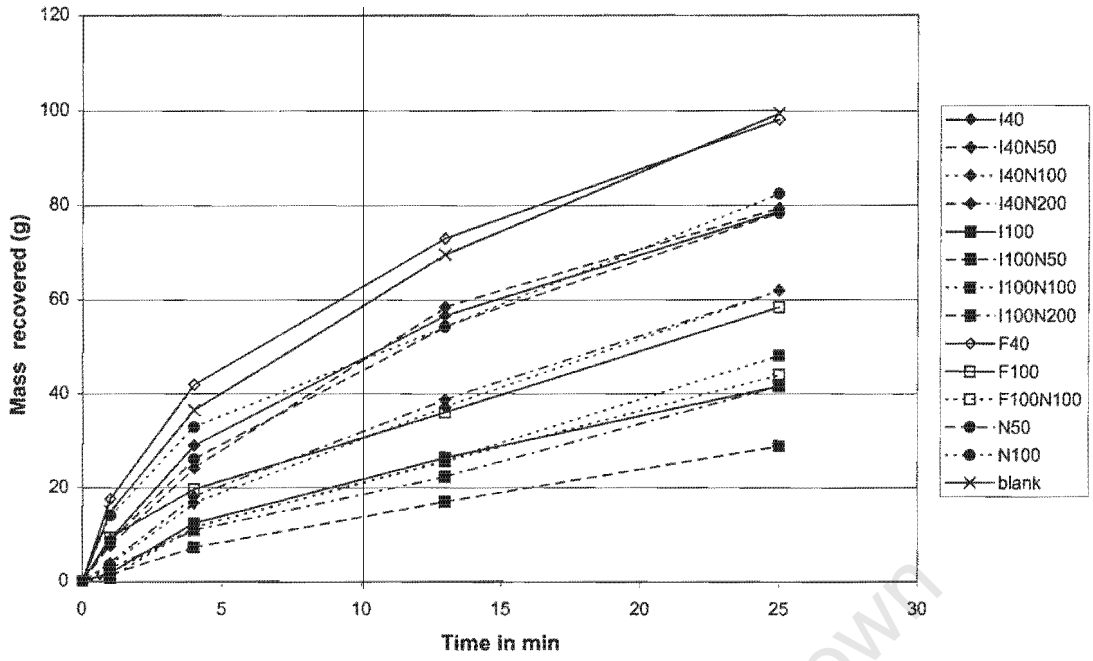

Figure 5-9 - ***Mass recovered as a function of time for conditions tested***

This was expected in that greater water recovery implied a more stable froth which should result in a greater mass carryover (Engelbrecht and Woodburn, 1975). Thus more stable froth implies a lower separation efficiency in the froth and therefore lower grades. There is an optimum froth stability such that further concentration of the valuables occurs but that the froth is sufficiently stable to flow in a plant situation.

5.2.3.2 Single Reagent Addition

5.2.3.2.1 IMP4

The effect of IMP4 addition on the flotation performance is indicated by Figure 5-10 and Figure 5-11. The flotation response was evaluated by grade recovery curves for copper and nickel.

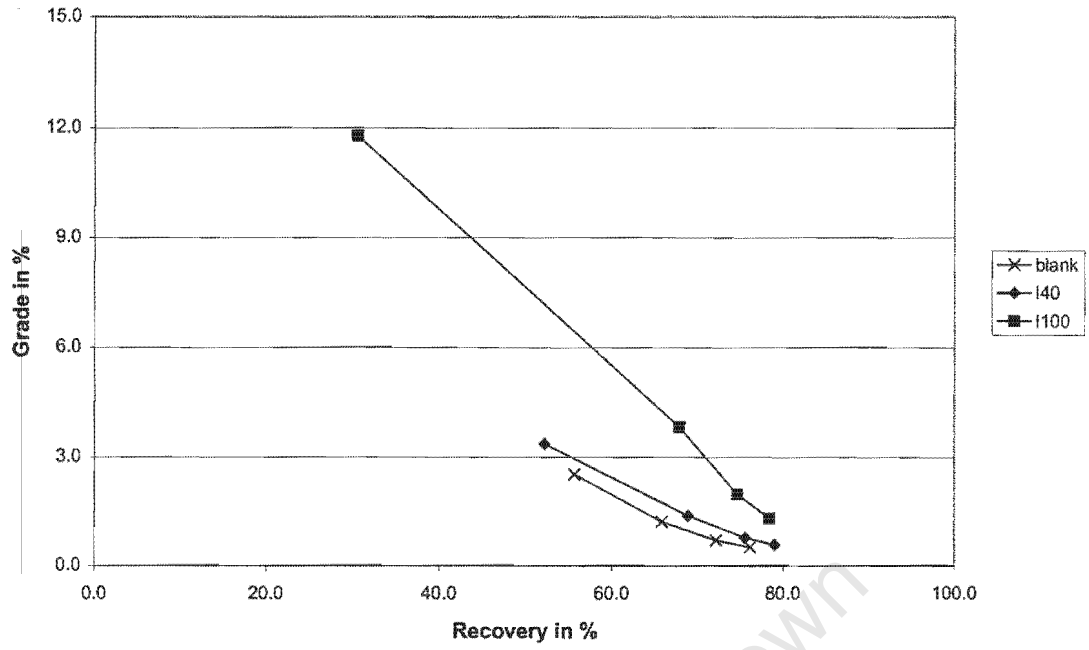

Figure 5-10 - ***The effect of IMP4 addition on the flotation performance analysed by copper assays***

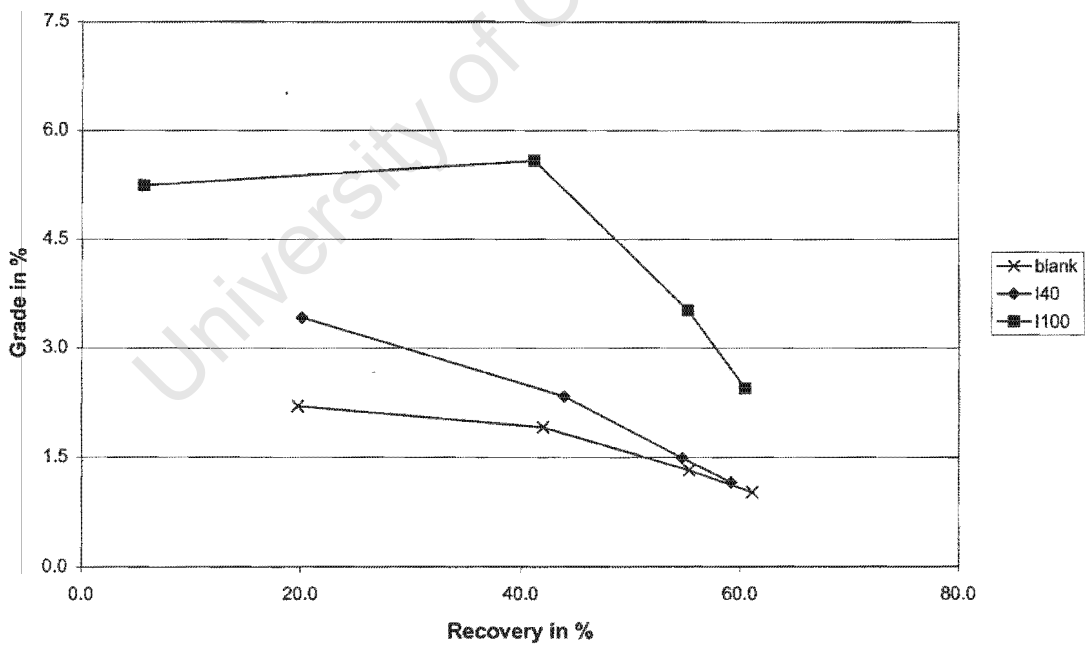

Figure 5-11- ***The effect of IMP4 addition on the flotation performance analysed by nickel assays***

It can be seen from the graphs that minimal effect on flotation performance was noticed at the low depressant addition (40g/ton) but at a 100g/ton a significant

improvement in the final grade was obtained at similar recoveries. This would indicate that at 40g/ton IMP4 is ineffective as a depressant. In Figure 5-10 the effect of IMP4 addition on the flotation performance (analysed via copper assaying) was shown. Increasing the dosage to a 100g/ton improved the final grade significantly without a loss in recovery. This is borne out by the mass recovery where the IMP4 at 40g/ton had a similar mass pull to the blank test. It should also be noted that at 40g/ton the IMP4 coagulated the pulp whilst at 100g/ton the pulp was more dispersed than the blank as indicated by the settling tests in section 5.1. This effect, may also contribute to the poor flotation performance obtained at 40g/ton.

The effect of IMP4 on the nickel flotation performance was shown in Figure 5-11. The trend was similar to that observed with the copper analysis in terms of the similar performance observed with IMP4 at 40g/ton and the blank and the marked improvement in grade when the IMP4 addition was increased to 100g/ton though the recovery was similar. The froth limiting nature at the initial stage of the float can be seen (for the 100g/ton) in that the cumulative grade of nickel improved for the second concentrate than for the first one. The high grade of copper recovered in the first concentrate limited the flotation of the nickel and once the majority of the copper was floated then the nickel followed. The additional feature of the 100g/ton IMP4 addition was the low initial recoveries of both copper and nickel which can be ascribed to the low mass pull, but the final recovery was similar for all tests.

5.2.3.2.2 FF30

The effect of FF30 on the flotation performance was shown in Figure 5-12 and Figure 5-13. For the copper analysis, FF30 increased both recovery and grade at

both 40 and 100g/ton. However the grade obtained with the FF30 at 100g/ton was less than that achieved with the IMP4 at the same dosage.

The copper analysis indicated that at both FF30 dosages there was a marked increase in the recovery but that the final grade was only slightly improved when compared to the blank test. For this depressant increasing the dosage above 40g/ton did not significantly improve the copper flotation response. It was however noted that the mass pull and grade with the FF30 at 40g/ton was similar to that achieved with no depressant. This indicated that at this addition the FF30 was not effectively acting as a depressant though it improved flotation performance in terms of sulphide recovery, and could therefore to be seen to aid collector efficiency. This could be due to the dispersing effect as well as the surface cleaning effect of the FF30 which had allowed sulphides which had agglomerated to the gangue to be recovered. Wellham et al (1992) also reported that CMC acted as a nickel activator rather than a magnesia depressor. When the FF30 dosage was increased to 100g/ton there was a decrease in the mass pull and an increase in initial copper grade and decrease in final recovery. It would thus appear for FF30 to act as a depressant a dosage greater than 40g/ton was required. However this does not imply that 100g/ton would be the optimum dosage for this ore.

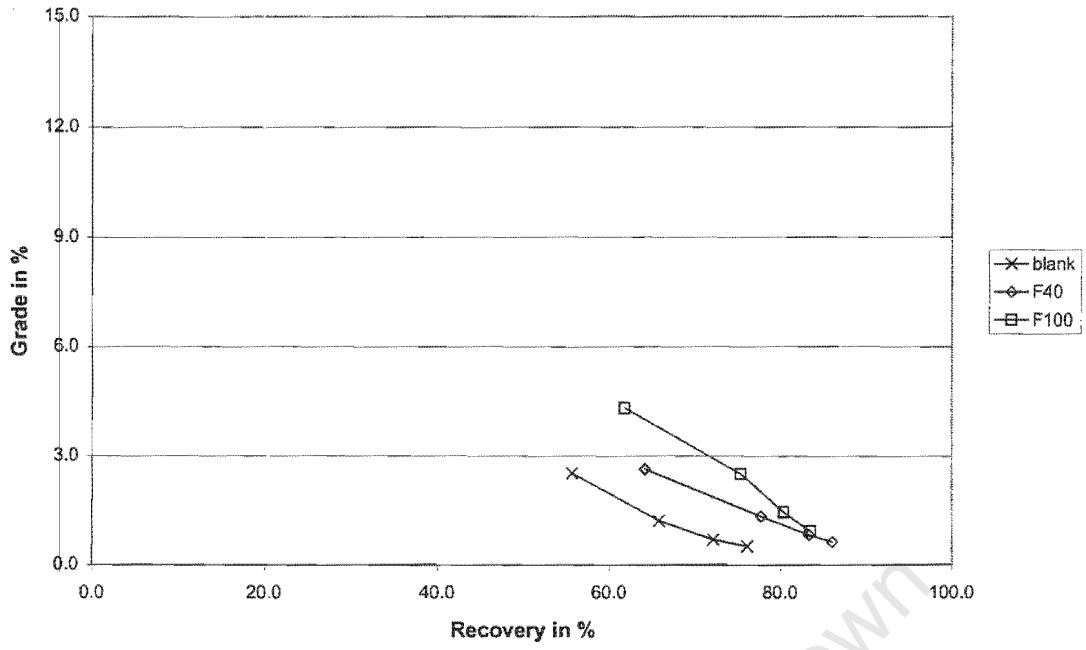

Figure 5-12- ***The effect of FF30 addition on the flotation performance analysed by copper assays***

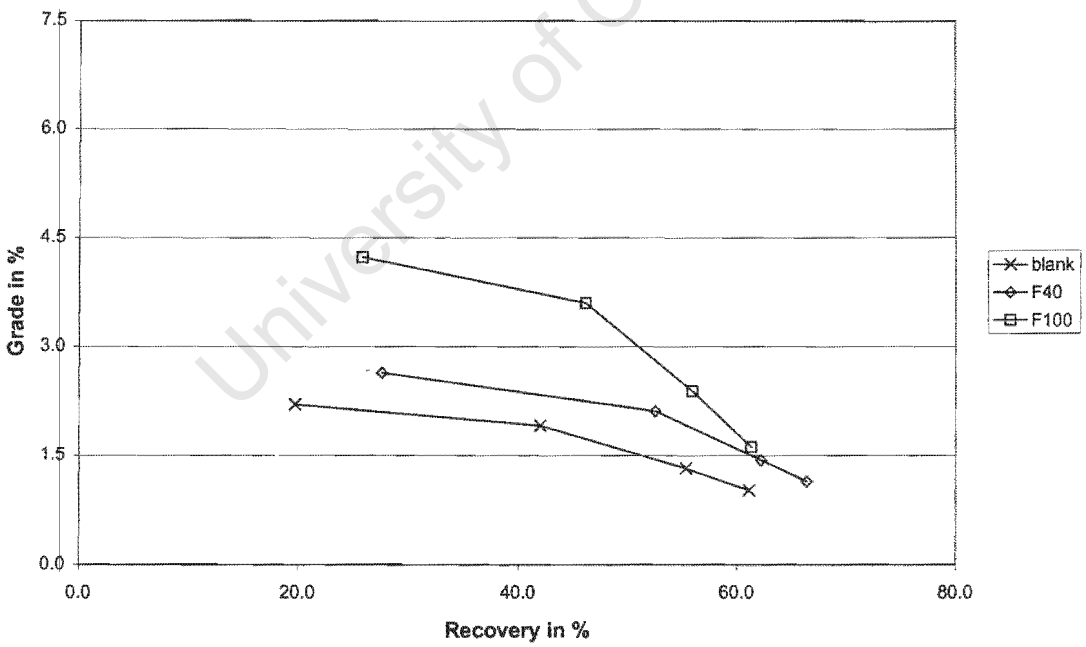

Figure 5-13 - ***The effect of FF30 addition on the flotation performance analysed by nickel assays***

The nickel analysis indicated a similar trend to that observed with the copper analysis in that there was an increase in both final grade and recovery with 40g/ton FF30. However as with the copper analysis although the recoveries were highest the improvement in grade was not as marked as with the 100g/ton IMP4 addition. The difference in performance may be due to the nature of the pulp as the FF30 resulted in a more dispersed pulp than that obtained with the IMP4.

5.2.3.2.3 NaHMP

The effect of NaHMP addition on the flotation performance of Merensky ore is shown in Figure 5-14 and Figure 5-15. From the copper analysis there was virtually no improvement in the flotation performance with NaHMP addition. There was a slight increase in recovery possibly due to the dispersing function probably preventing valuable minerals from being entrapped with gangue minerals, a form of slime cleaning. This indicated that the dispersion obtained with the NaHMP as shown in the settling tests did not result in improved flotation performance. Dispersion without depression did not markedly improve flotation performance compared to the blank.

The nickel analysis indicated minimal influence of the NaHMP on the flotation performance in that final grade and recovery were not significantly different to that achieved with the blank There was however a slight increase in the initial nickel grade with the NaHMP addition which may be due to slime cleaning.

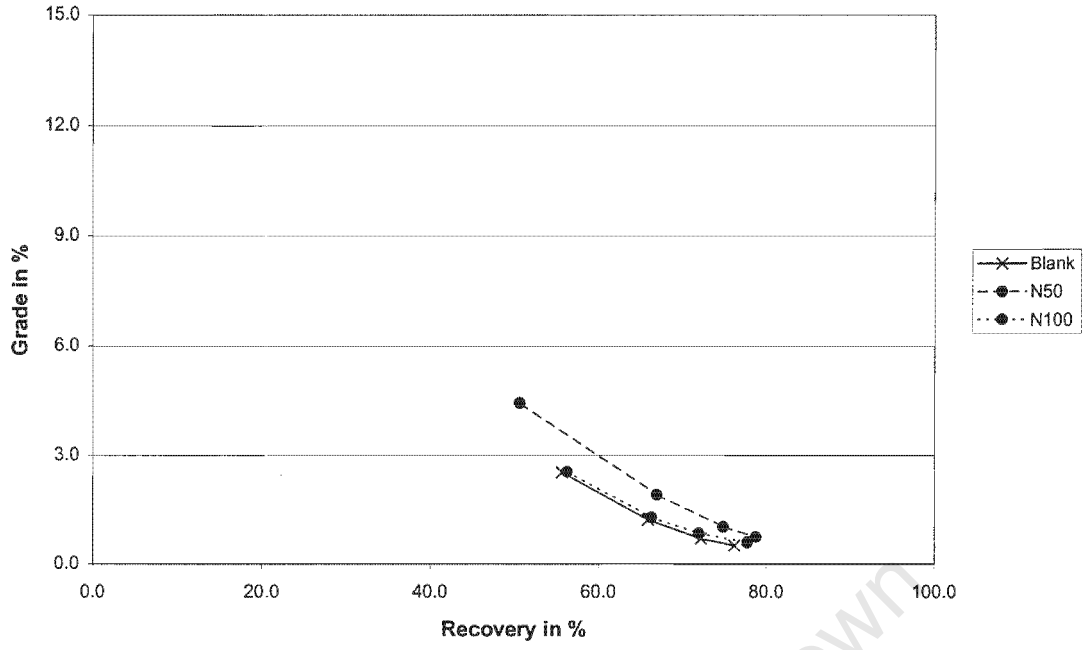

Figure 5-14 - ***The effect of NaHMP addition on the flotation performance analysed by copper assays***

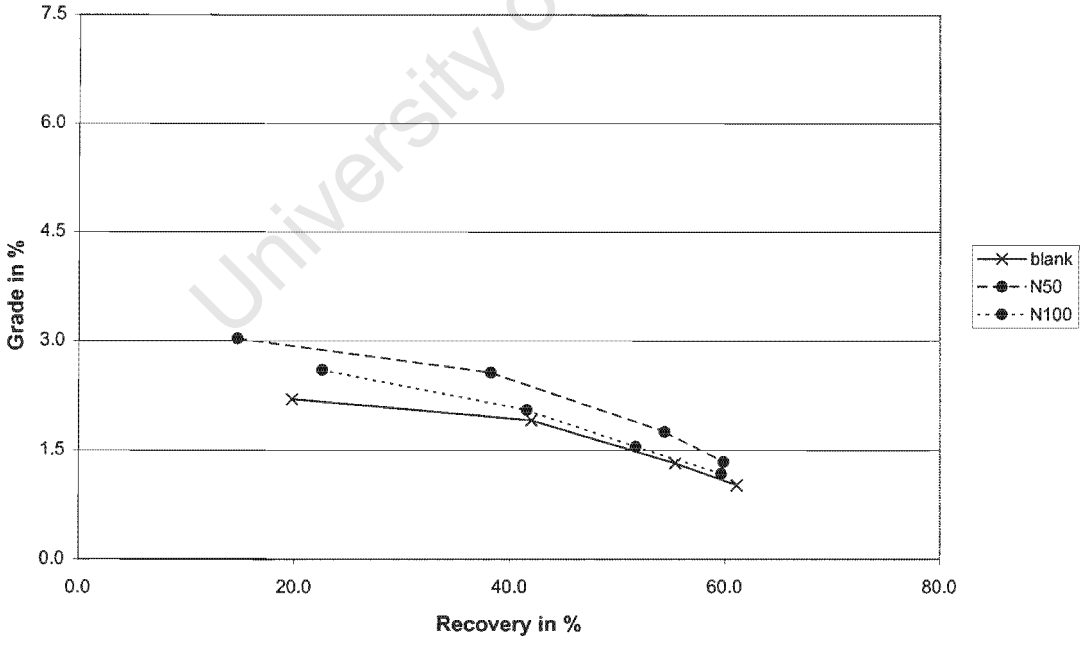

Figure 5-15 - ***The effect of NaHMP addition on the flotation performance analysed by nickel assays***

5.2.3.3 IMP4 and NaHMP added together

The addition of IMP4 and NaHMP together was evaluated at 2 dosages of IMP4 (40,100 g/ton) and 4 dosages of NaHMP (0,50,100,200 g/ton). At the low IMP4 (40g/ton) addition there was an increased final copper grade obtained with NaHMP at 100 and 200g/ton when compared to the singular IMP4 addition at 40g/ton as indicated by Figure 5-16. There was no significant difference in the final recovery though there was a slight increase with the NaHMP additions. However at the low addition of NaHMP of 50g/ton the recovery was significantly reduced when compared to the IMP4 on its own. The grade with the lower NaHMP addition was also increased when compared to the IMP4 singular addition. The mechanism for improved flotation performance could be due to slime cleaning in that at this addition of IMP4 coagulation was favoured and that the addition of NaHMP removed gangue from the valuable mineral surface. The detrimental impact of the lower NaHMP addition could be ascribed to the change in the settling behaviour as described in Chapter 6. With the 50g/ton NaHMP with guar at 40g/ton addition the system was more dispersed than 50g/ton NaHMP addition on its own. This implied that the guar was acting as a dispersant at this dosage.

The initial copper grades were also significantly improved with NaHMP addition at all additions though the recovery was lower. This indicated that less mass was floated in the initial stages which indicated that NaHMP could be acting as a depressant when used in conjunction with IMP4. However the dispersing function of the NaHMP could be leading to the cleaning of the sulphide surfaces thereby reducing gangue carryover which could be the mechanism for the higher grades.

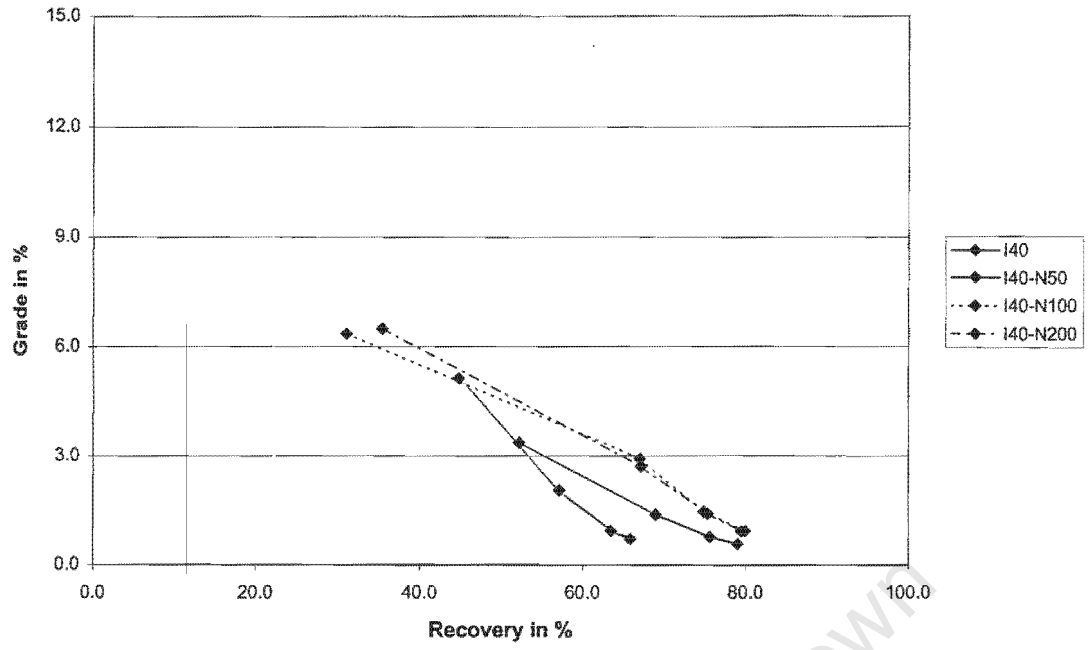

Figure 5-16 - ***The effect of NaHMP addition on the flotation performance with IMP4 at 40g/ton analysed by copper assays***

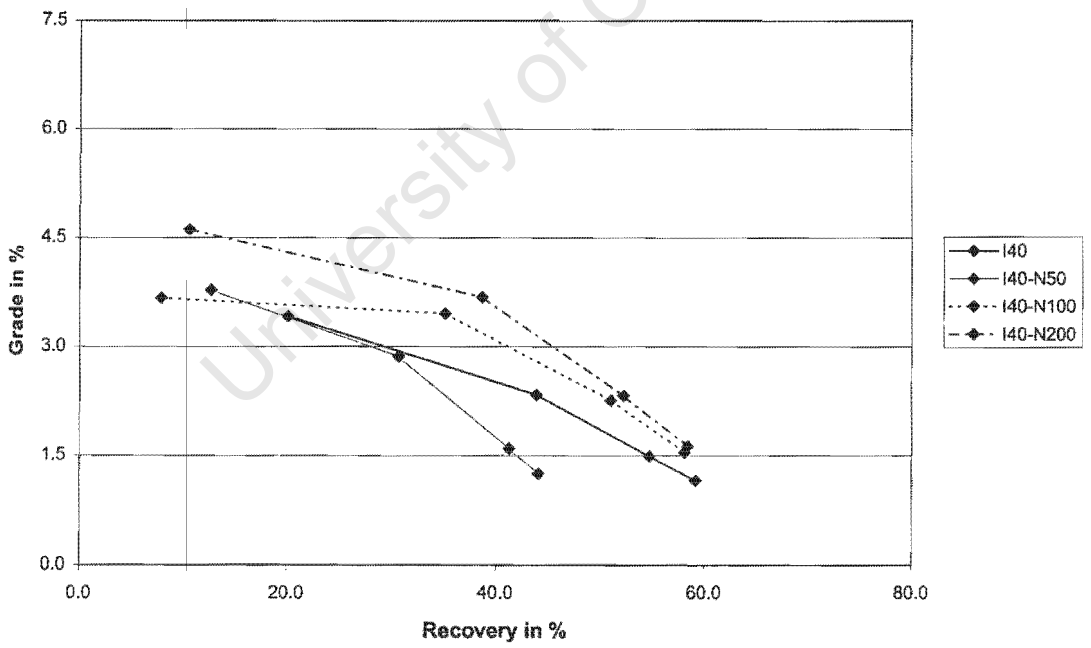

Figure 5-17 - ***The effect of NaHMP addition on the flotation performance with IMP4 at 40g/ton analysed by nickel assays***

For the nickel analysis, Figure 5-17, a similar trend was observed in that the 100 and 200g/ton improved the final grade when compared to the single IMP4 addition. In this instance the recovery was reduced though this was not marked. The lower addition of 50g/ton NaHMP decreased nickel recovery noticeably at similar final grade to the singular IMP4 addition. This would indicate that without sufficient depressant increasing the dispersion of the pulp had a deleterious effect on the flotation performance.

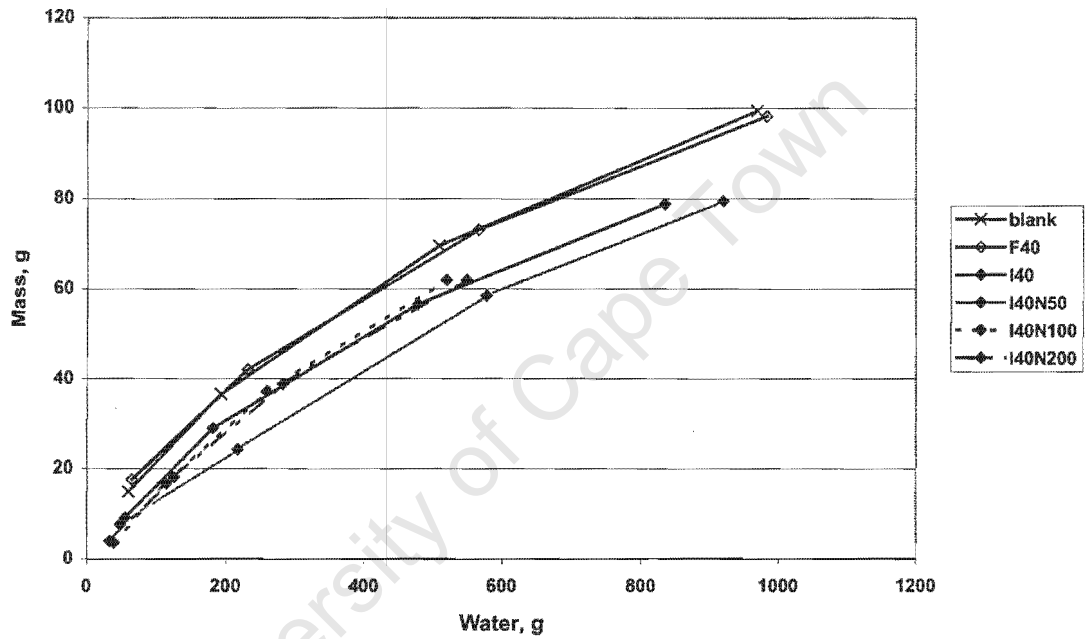

Figure 5-18 – ***A comparison of water and mass recoveries for depressant addition of 40g/ton with NaHMP varying to determine froth nature.***

From Figure 5-18 it can be seen that at comparable water recoveries the mixture of IMP4 at 40g/ton with NaHMP at 50g/ton resulted in the lowest mass recoveries than the other conditions indicated. This would imply less gangue flotation, as the ore is predominantly (approximately 80%) gangue and thus at similar entrainment values lower gangue mass was floated. This would imply that for the tests shown that the IMP4 and NaHMP at 50g/ton ~~was the best depressant. It can also be seen that at this~~ dosage of depressant (and test conditions) that IMP4 was the better depressant than

FF30 as lower mass was recovered with the IMP4 than the FF30 at the same water recoveries. It can be concluded that at 40g/ton FF30 did not act as a depressant as its performance is similar to the blank.

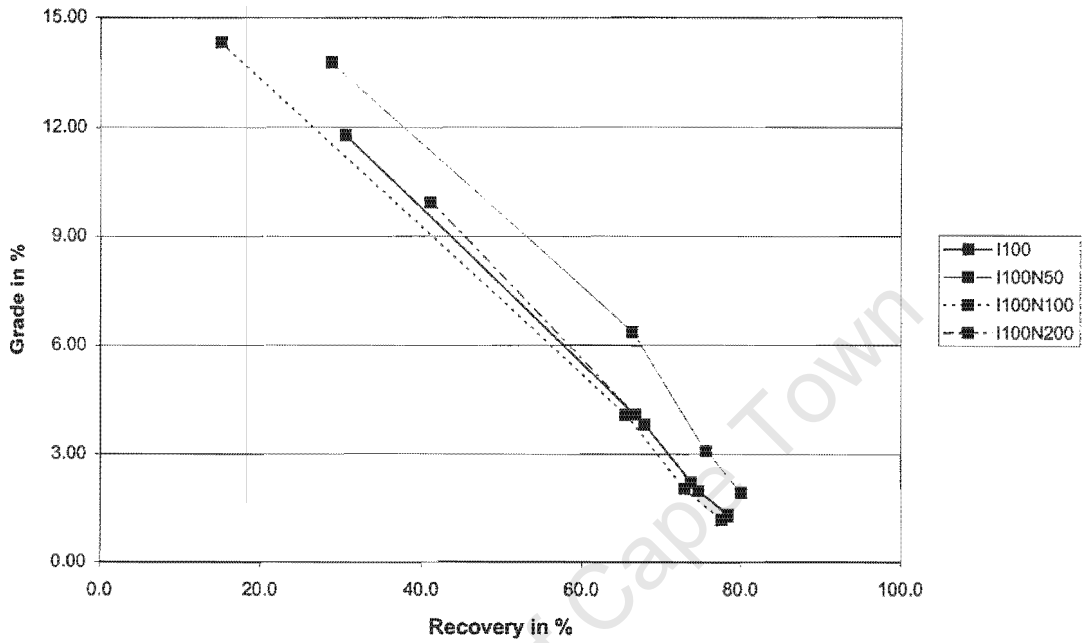

Figure 5-19 - ***The effect of NaHMP addition on the flotation performance with IMP4 at 100g/ton analysed by copper assays***

The initial nickel grades were also improved significantly as was observed with the copper analysis. This probably indicated the effect of slime cleaning in that the sulphide surfaces are cleaned of fine gangue particles which improved the grade initially. However as the availability of the sulphides decreased, it appeared the gangue flotation increased due to the insufficient depression.

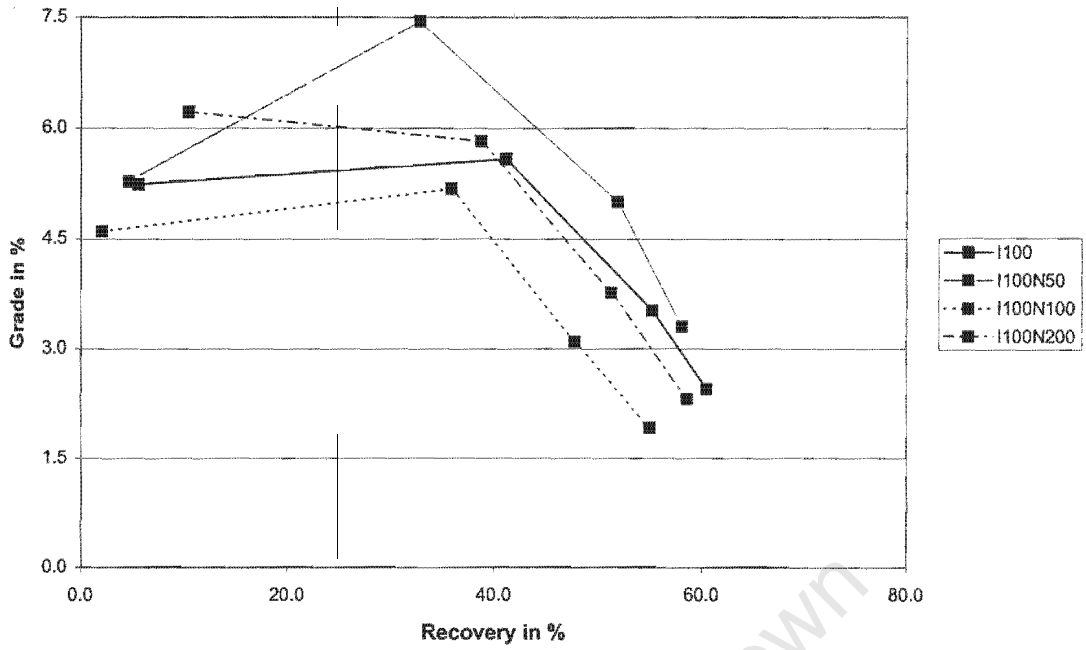

Figure 5-20 - ***The effect of NaHMP addition on the flotation performance with IMP4 at 100g/ton analysed by nickel assays***

The effect of adding NaHMP to IMP4 at 100g/ton (Figure 5-19 and Figure 5-20) appeared to benefit both copper and nickel flotation at low dosage (50g/ton). The copper flotation was only changed at the low NaHMP addition in which there was a marked increase in both final grade and recovery. The higher NaHMP dosages (100 and 200g/ton) had no effect on the final grade and recovery though the initial grade was improved with 100g/ton and lowered with 200g/ton. At this dosage of IMP4 the effect of the NaHMP is not as marked and seemed reversed when compared to the 40g/ton where benefit was seen at the higher dosages rather than 50g/ton.

For the nickel flotation performance there was a decrease in recovery when NaHMP was added at all dosages though this was compensated for by a higher final grade at 50g/ton addition. The initial increase in grade could be ascribed to the high copper content depressing the flotation of the nickel

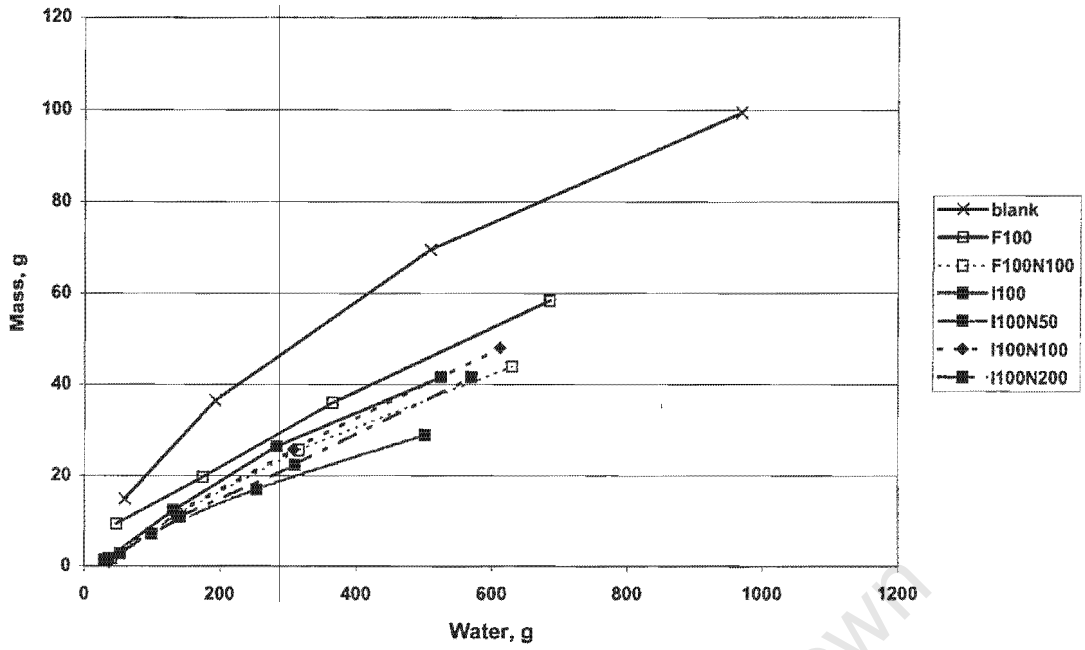

Figure 5-21 - ***A comparison of water and mass recoveries for depressant addition of 100g/ton with NaHMP varying to determine froth nature***

Figure 5-21 indicated that the lowest mass recovered at comparable water recoveries was achieved with the IMP4 (at 100g/ton) and NaHMP (at 50g/ton). This implied that the froth nature was less stable with the IMP4 (100g/ton) and NaHMP (50g/ton) mixture and thus less gangue would be entrained with the float. This concurred with the assaying in which the highest grade was achieved with this mixture. This substantiates the perception that IMP4 is a better depressant than FF30 as the mass recovered with IMP4 was less than that achieved with FF30 at comparable water recoveries and thus similar entrainment performance.

5.2.3.4 FF30 and NaHMP added together

This mixture was not the focus of the investigation and only one mixture was investigated.

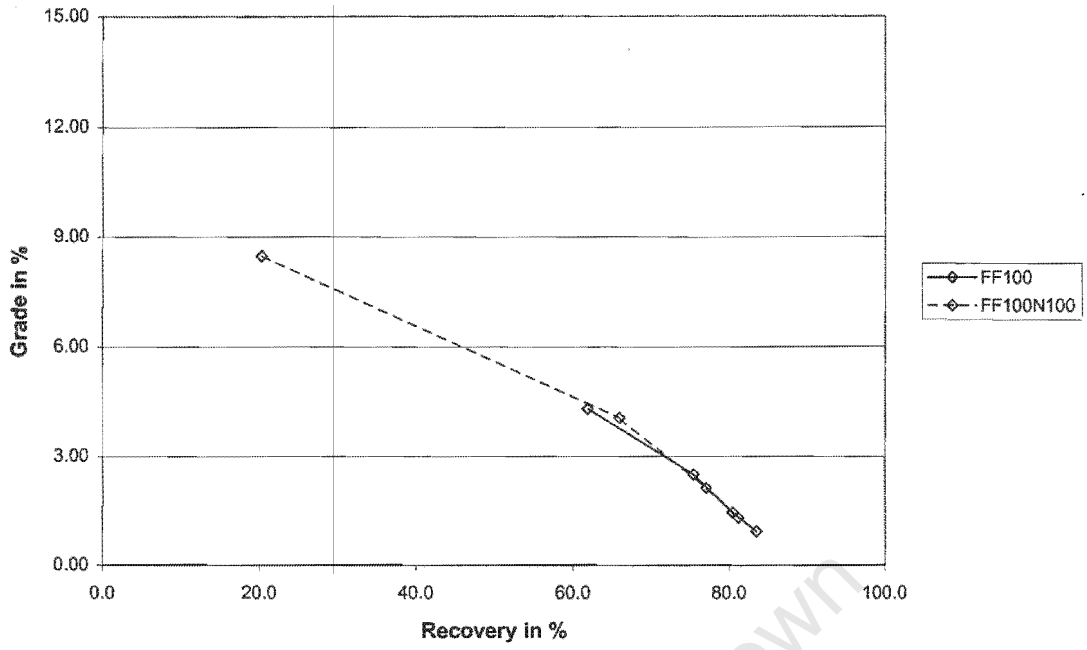

Figure 5-22 - ***The effect of NaHMP addition on the flotation performance with FF30 at 100g/ton analysed by copper assays***

The results of one test of the combined effect of FF30 and NaHMP on the copper flotation performance was shown in Figure 5-22. The addition of the NaHMP improved the final grade of the concentrate at a slightly reduced recovery. This indicated that even in dispersed systems (FF30 at 100g/ton was dispersed) that the addition of the dispersant appeared to affect the flotation response. The initial grade was increased though the difference in recovery for the first concentrate was significant with over 60% of the copper being recovered without the NaHMP compared to below 21% with the NaHMP.

The nickel flotation performance (Figure 5-23) was improved with the addition of NaHMP in terms of both final grade and recovery. The increase in grade with the second concentrate was marked. The initial grades (for first concentrate) were similar but the recovery was slightly lower with the NaHMP addition.

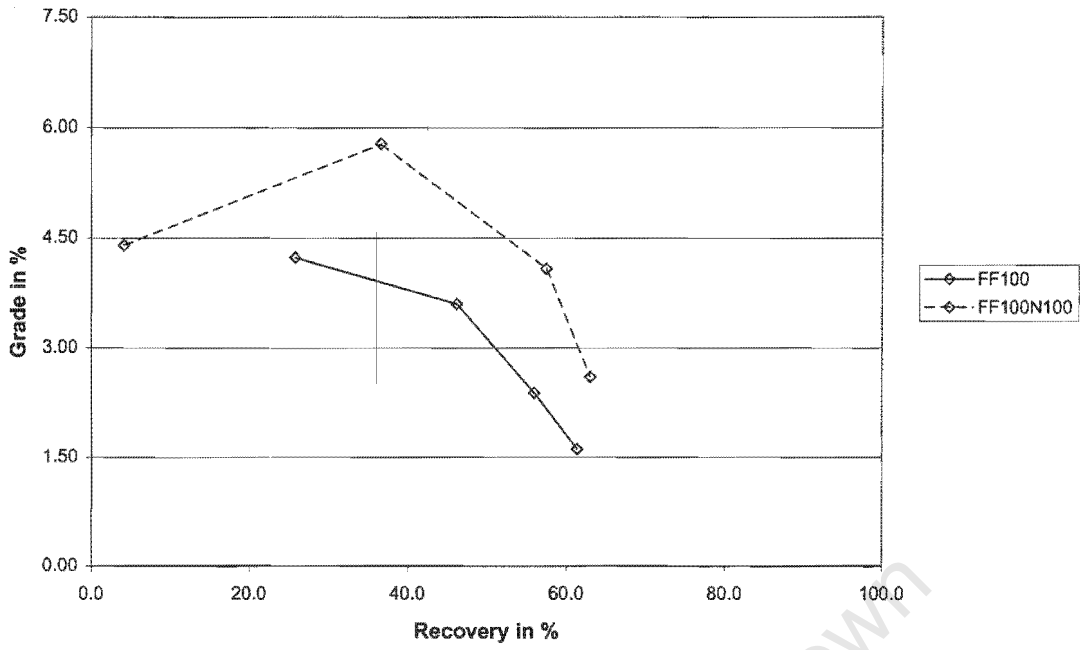

Figure 5-23 - ***The effect of NaHMP addition on the flotation performance with FF30 at 100g/ton analysed by nickel assays***

For the copper flotation there was an increase in final grade and a decrease in the recovery. The initial grade is also significantly improved though the recovery is lower. This probably indicated the slime cleaning effect of the NaHMP in that less gangue is being associated with the valuable sulphides.

For the nickel analysis there was an improvement in final grade and slightly in recovery. The initial grades were similar but then with the NaHMP the grade increased initially whereas with the FF30 only there was a decrease.

5.2.3.5 Relative Rates of flotation of Copper and Nickel

Figure 5-24 below indicates the ratio of copper to nickel in the concentrates when IMP4 at 40g/ton was used as the depressant and varying amounts of NaHMP as the

dispersant. It can be seen that even without any depressant or dispersant, that is the blank, there was a promotion of the copper flotation relative to the nickel flotation. However when combinations of IMP4 and NaHMP the promotion of the copper relative to the nickel was further enhanced. This was indicative of the froth limiting conditions that were obtained with the NaHMP addition as copper recovery was not enhanced but maintained whilst nickel recovery was reduced. This would indicate that chalcopyrite (predominant source of copper) floated to such an extent that the pentlandite was depressed. The varying additions of NaHMP did not appear to affect the copper nickel ratio in the first concentrate. However when the copper was recovered the nickel recovery increased such that similar final ratios were obtained for all the tests.

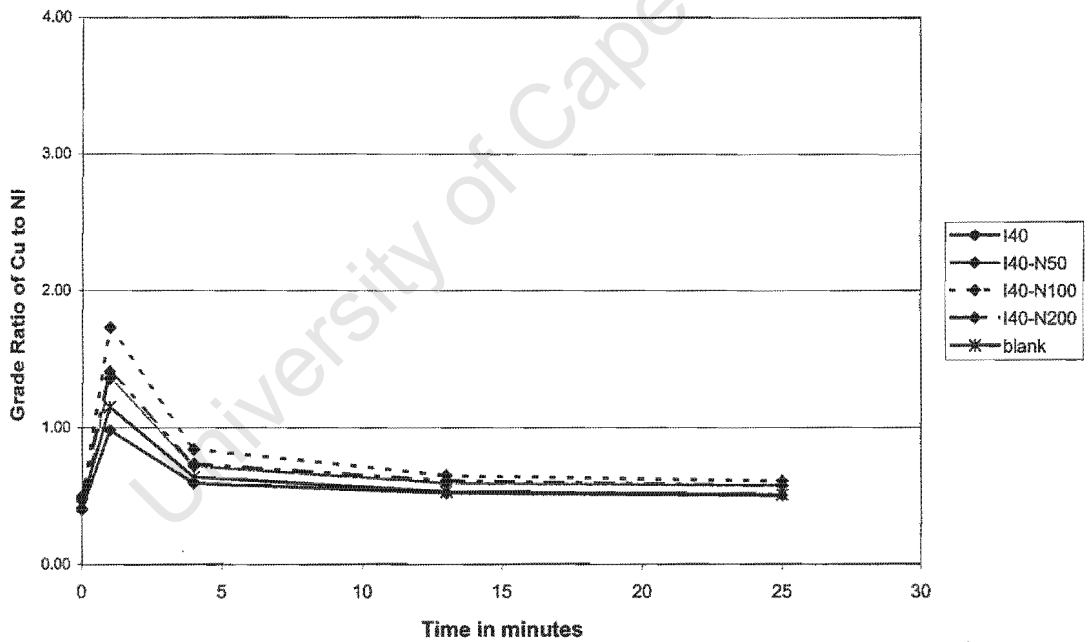

Figure 5-24 –***The ratio of copper to nickel in the concentrates during the flotation of Merensky ore using IMP4 at 40g/ton (I40) with varying additions of NaHMP (N).***

The effect of NaHMP addition on the copper nickel ratio with a 100g/ton IMP4 addition was shown in Figure 5-25. A similar trend was observed though the 100g/ton IMP4 singular addition also had a significant effect on the increased copper

to nickel ratio. It should be noted that at this dosage of IMP4 that 50 and 100g/t NaHMP increased the ratio while 200g/ton reduced it to below the IMP4 addition. When compared to the 40g/ton IMP4 addition the greatest increase was observed with the 100g/ton NaHMP addition while the 50 and 200g/ton had similar effects. This would tend to indicate that the optimum dosage of NaHMP, in terms of increasing the initial copper to nickel ratio, was between 50 to 100g/ton. This was in the same region as the crossover observed in the settling tests (Chapter 6) which indicated that the settling behaviour did effect the flotation performance. Though the limited additions tested indicated that more dosages would have to be tested before conclusive findings can be determined.

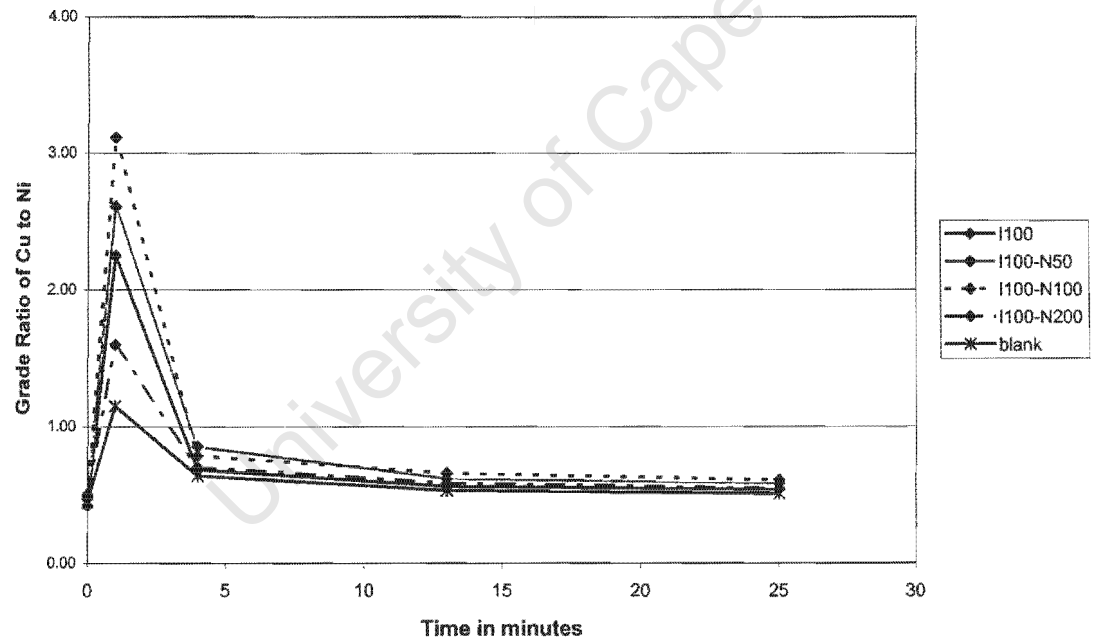

Figure 5-25 - ***The ratio of copper to nickel in the concentrates during the flotation of Merensky ore using IMP4 at 100g/ton (I100) and varying additions of NaHMP (N).***

It can be surmised that lower NaHMP addition, that is 50g/ton, the adsorption is enhanced in the presence of IMP4 such that the dispersion of the slurry was increased when compared to the NaHMP on its own. However as the dosage was

increased the dispersion was greater with NaHMP on its own than in the presence of IMP4.

5.3 CONCLUDING REMARKS

The settling tests indicated that in general the polymer addition increased the dispersity of the slurry except the singular addition of IMP4 at 40g/ton. IMP4 has a low charge density and was expected to coagulate the slurry especially at low additions. The CMC and NaHMP both dispersed the slurry at all dosages tested which was expected due to their high charge density and therefore its ability to stabilise the ore.

The 100g/ton IMP4 dosage reduced the coagulation of the slurry relative to the 40g/ton IMP4 addition and this was ascribed to steric stabilisation. However the settling nature was similar to the blank which indicated that steric stabilisation is a weak disperser.

It was also interesting to note that when the IMP4 was mixed with NaHMP at 50g/ton greater dispersion was achieved than with the NaHMP on its own. It would appear that the addition of the IMP4 enhanced the adsorption of the NaHMP and this led to greater dispersion at this dosage. With increasing NaHMP addition the expected trend was observed in that greater dispersion was observed with the singular NaHMP addition rather than the corresponding addition with IMP4. The enhanced adsorption at the lower NaHMP addition could be due that the IMP4 increased the co-adsorption of the NaHMP. This would increase the charge within the electrical double layer and increase the dispersion.

The combined addition of the dispersing reagents, NaHMP and FF30, led to a slurry with greater dispersity than the individual additions. This indicated that both the polysaccharide and the inorganic dispersant affected particle surface and increased the charge or sterically stabilised the pulp.

There was a benefit to flotation performance with the introduction of NaHMP in combination with the polysaccharide depressant. The addition of 50g/ton NaHMP with a 100g/ton IMP4 resulted in the highest grades of both copper and nickel. It would therefore appear that separating the dispersion and depression reagents had potential benefits for flotation performance. However the performance of the FF30 at 100g/ton combined with a 100g/ton NaHMP was also significantly improved but from the settling tests solid-liquid separation may prove to be the stumbling block for such a reagent system.

The initial copper grades were improved significantly when the NaHMP was combined with one of the polysaccharides and this can mainly be attributed to the decreased mass pull, as the mass of copper in the first concentrate was reasonably constant. However the initial grade of nickel was lowered probably due to the high grade of copper suppressing the flotation of the pentlandite. As the float time increased, the nickel grade improved as the copper was depleted. This could be an indication that with these reagent additions, froth limiting conditions were experienced.

It was also noted that anomalous behaviour was noticed in the settling tests in that at an addition of 50g/ton NaHMP greater dispersity was observed with the IMP4 than no NaHMP addition also manifested itself in the flotation behaviour. At 40g/ton IMP4 addition the flotation performance was improved with 100 and 200g/ton NaHMP additions but at 50g/ton NaHMP the flotation performance was significantly reduced

in both recovery and grade. However the trend was reversed at 100g/ton where the benefit was only observed at 50g/ton NaHMP whereas no change was noted at the 100 and 200g/ton additions.

The IMP4 single additions indicated that the low IMP4 dosage of 40g/ton was not sufficient for depression as no change could be noticed between that test and one containing no depressant or dispersant. This could be due to the increased coagulative nature of the pulp as shown in the settling test. This could imply that while the IMP4 may adsorb onto the talc and render it hydrophilic that it may coat onto the valuable sulphides and may be recovered in this way. However the introduction of NaHMP at this IMP4 addition did not improve the grade significantly though there was an improvement at the 100 and 200g/ton NaHMP additions. This improvement could be attributed to increased dispersion, as the NaHMP did not indicate any depressing ability on its own. Increasing the IMP4 addition to 100g/ton improved the flotation performance significantly and it should be noted that not only was the depression action improved (by adding more depressant) but also the dispersion was improved when compared to the 40g/ton addition. It could be surmised that the optimum dosage of IMP4 might not solely be governed by the amount required for depression but that the dosage also requires reduced coagulation.

The results obtained with single FF30 additions indicated that it might not be as efficient a depressant as the IMP4 in that the grades obtained with the IMP4 at 100g/ton was the highest. The marked improvement with FF30 addition was with recovery of both copper and nickel rather than improvement of grade. This would indicate that the FF30 aided sulphide recovery rather than a depressant for gangue. This could be due to increased dispersion which reduce coagulation of the valuable minerals to the gangue and probably led to the recovery of the valuables which may

have been locked within gangue with the FF30. It would appear that this would be an important effect for this type of depressant though the underlying function of a depressant should be increased grade.

The results with only NaHMP addition indicated that this reagent did not act as a depressant at the dosages tested and the settling tests indicated that higher dosages may not be feasible due to possible downstream solid-liquid separation difficulties. This could have been predicted considering that the NaHMP did not adsorb onto the talc face but rather the edge and the face is the hydrophobic surface.

It can therefore be concluded that the mixture of polysaccharide (especially guar) and NaHMP improved the flotation performance by improving the grade of the concentrate. This could be ascribed to differences in dispersion of the ore as the NaHMP did not act as a depressant when added alone.

Chapter 6 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Zeta potential tests indicated that the polymers and the NaHMP adsorbed onto the talc surface when added both singularly and in combination.

The changes in zeta potential with reagent mixture addition indicated that co-adsorption of the polymers and NaHMP occurred on the talc surface though the mechanism cannot be deduced.

Maximum change in the zeta potential occurred at the lower reagent additions with the magnitude of the change decreasing with increased addition indicating that optimum performance may be obtained with lower dosages.

At low additions of polymer there was a correlation between zeta potential measurements and settling behaviour with a zeta potential of approximately –30mV required to achieve a dispersive pulp. At higher additions steric effects were dominant thereby affect settling behaviour, and reducing correlation between techniques.

The settling tests with Merensky ore showed that NaHMP was capable of affecting the settling nature of the pulp even in the presence of polymeric depressants.

The settling and flotation tests conducted on the Merensky ore indicated that dispersants could be used to improve flotation performance but had to be used with a polymeric depressant.

At the addition levels tested the NaHMP on its own had no effect on the flotation performance. For single depressants best results were obtained with IMP4 (improved grades).

Improved flotation performance was achieved using a depressant (IMP4 at 100g/ton) and a dispersant (NaHMP) at 50g/ton. Increasing the NaHMP addition had a negative effect on the flotation performance.

The major improvement in flotation performance with the combined used of IMP4 with NaHMP was a higher final grade of both copper and nickel.

It can therefore be concluded that the addition of NaHMP in conjunction with IMP4 benefits the flotation performance by increasing grades of both copper and nickel. It has been shown that dispersion of the pulp was an important parameter in optimising flotation performance though complete dispersion is not desirable due to potential downstream difficulties.

6.2 RECOMMENDATIONS

The mechanism of the co-adsorption of the NaHMP and a polysaccharide should be elucidated to determine whether both reagents adsorb onto the talc surface. This may require adsorption tests to determine whether IMP4 adsorption is reduced in the presence of the NaHMP.

A more comprehensive set of batch flotation tests is required to confirm the effect of dispersion / coagulation on flotation and determine whether the optimum depressant/dispersant mixture can be obtained for a batch flotation system. The effect of ions need to be investigated as plant water also contains high concentrations of ions. The analysis of the batch tests also need to be expanded to include the behaviour of talc. Currently no reliable method exists to determine talc content in an ore and mineralogical examination may be required.

In this batch flotation tests copper and nickel assays were used to assess flotation performance and this programme should be extended to include PGM assays.

The suitability of adding dispersants prior to flotation also need to be evaluated on downstream processing and thus filtration tests after a float step may be required.

Other dispersants and depressant combinations should be evaluated to optimise the synergistic effect between depressant and dispersant in flotation.

Chapter 7 REFERENCES and BIBILIOGRAPHY

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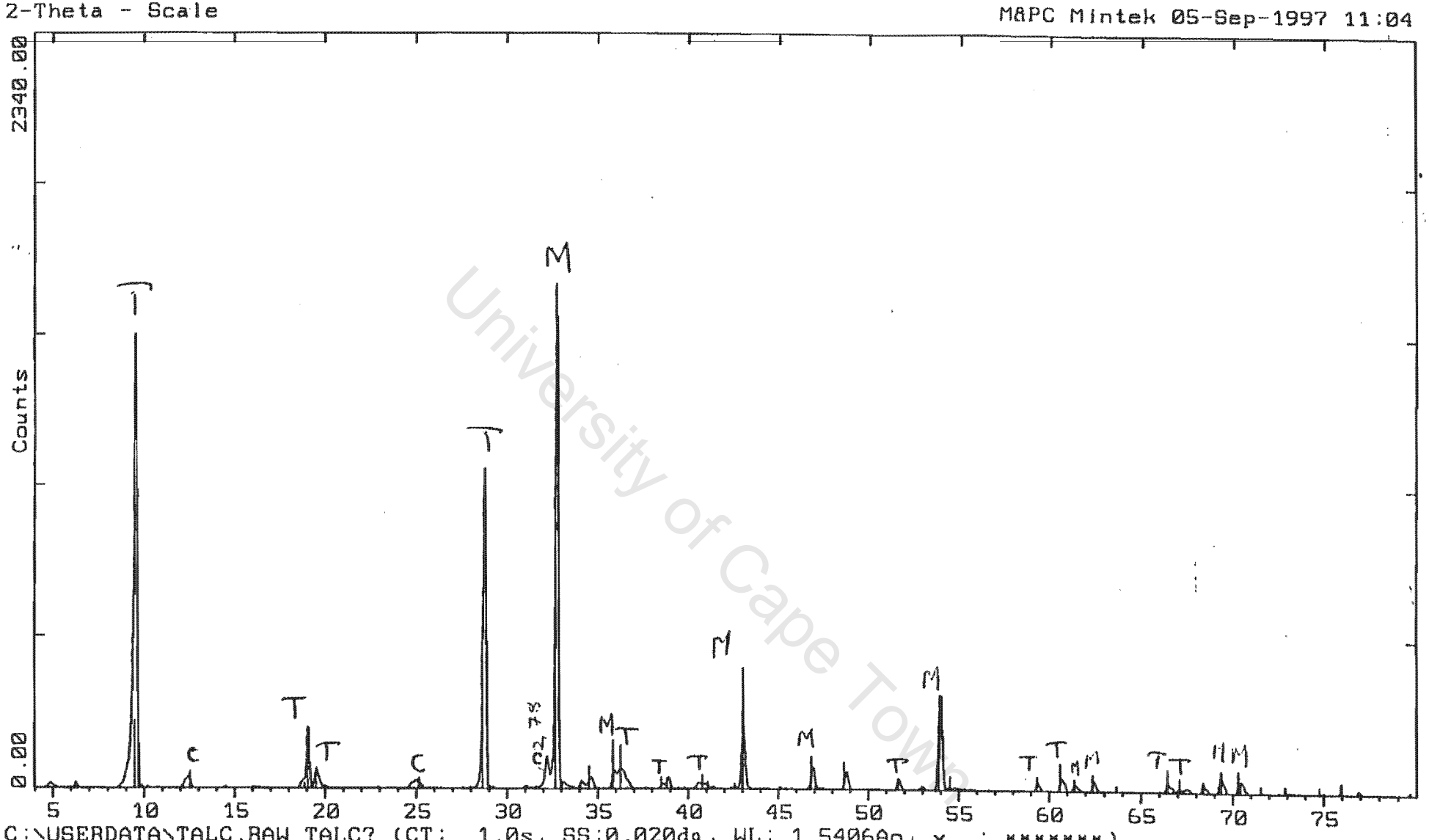
APPENDIX 1 XRF and XRD Analysis of Talc



T = TALC

M = MAGNESITE

C = CLINOCHLORE

HEMENG, TKC

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	58.802 keV	5.728 keV			
	0.021 nm	0.216 nm			
2	27.000 deg	92.000 deg	0.050 deg	0.05 s	9.97 min
	6.074 keV	1.971 keV			
	0.204 nm	0.629 nm			
3	11.000 deg	29.000 deg	0.020 deg	0.05 s	6.82 min
	2.540 keV	0.972 keV			
	0.488 nm	1.275 nm			
4	37.000 deg	45.000 deg	0.050 deg	0.50 s	2.44 min
	0.767 keV	0.636 keV			
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2	60	45	OUT	FINE	PE002	1	25	75	FL
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	0.021 nm	0.216 nm			
2	27.000 deg	92.000 deg	0.050 deg	0.05 s	9.97 min
	6.074 keV	1.971 keV			
	0.204 nm	0.629 nm			
3	11.000 deg	29.000 deg	0.020 deg	0.05 s	6.82 min
	2.540 keV	0.972 keV			
	0.488 nm	1.275 nm			
4	37.000 deg	45.000 deg	0.050 deg	0.50 s	2.44 min
	0.767 keV	0.636 keV			
	1.615 nm	1.948 nm			

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9-JUN-97 10:05

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2	27.000 deg 6.074 keV 0.204 nm	92.000 deg 1.971 keV 0.629 nm	0.050 deg	0.05 s	9.97 min
3	11.000 deg 2.540 keV 0.488 nm	29.000 deg 0.972 keV 1.275 nm	0.020 deg	0.05 s	6.82 min

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CAMG 1 step scan Total time: 8.07 minut
Spinner: OUT Channel mask: SMALL

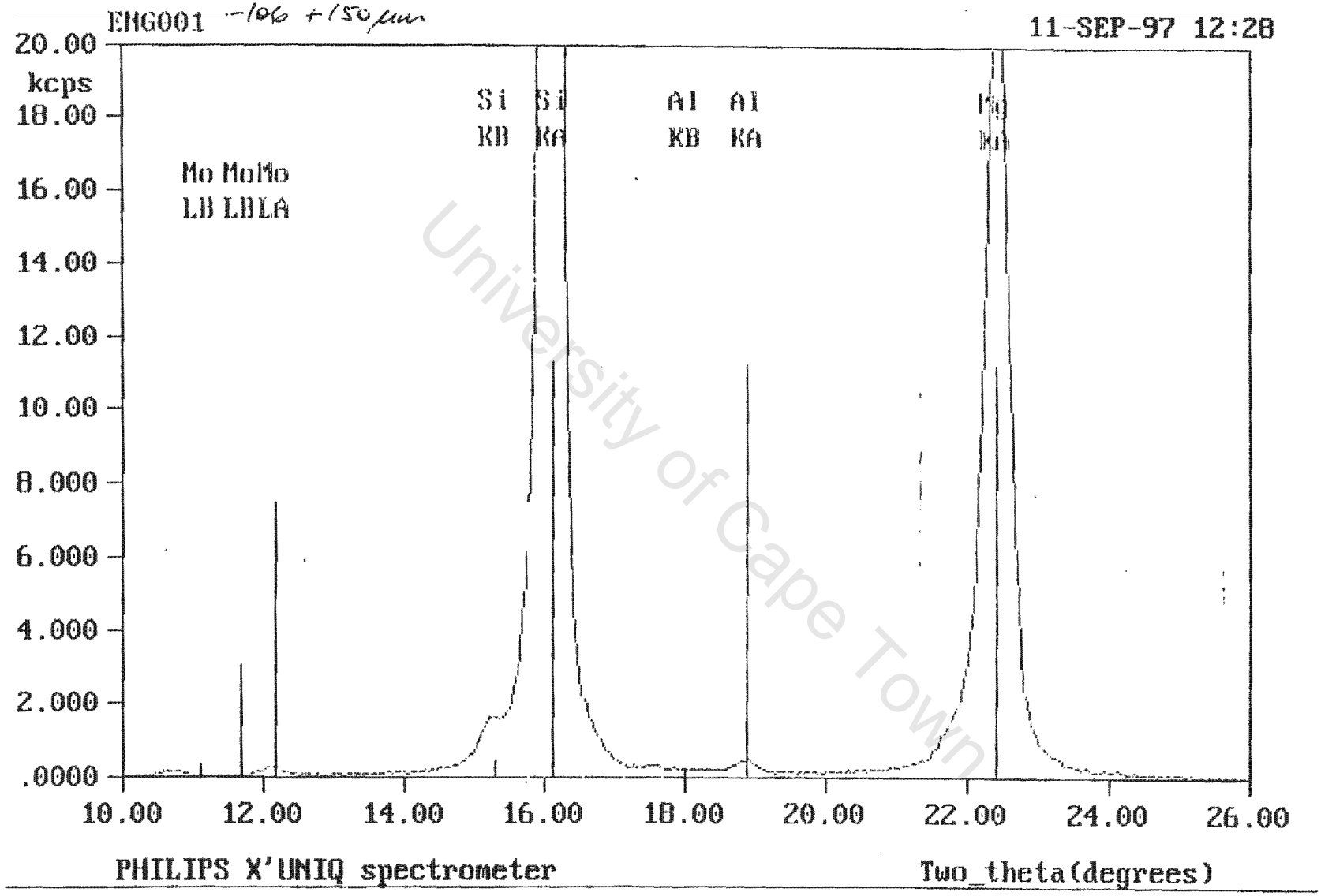
No.	Start scan	End scan	Step width	Time/point	Time/scan
1	18.000 deg	26.000 deg	0.040 deg	2.00 s	8.07 min
	1.556 keV	1.082 keV			
	0.796 nm	1.145 nm			

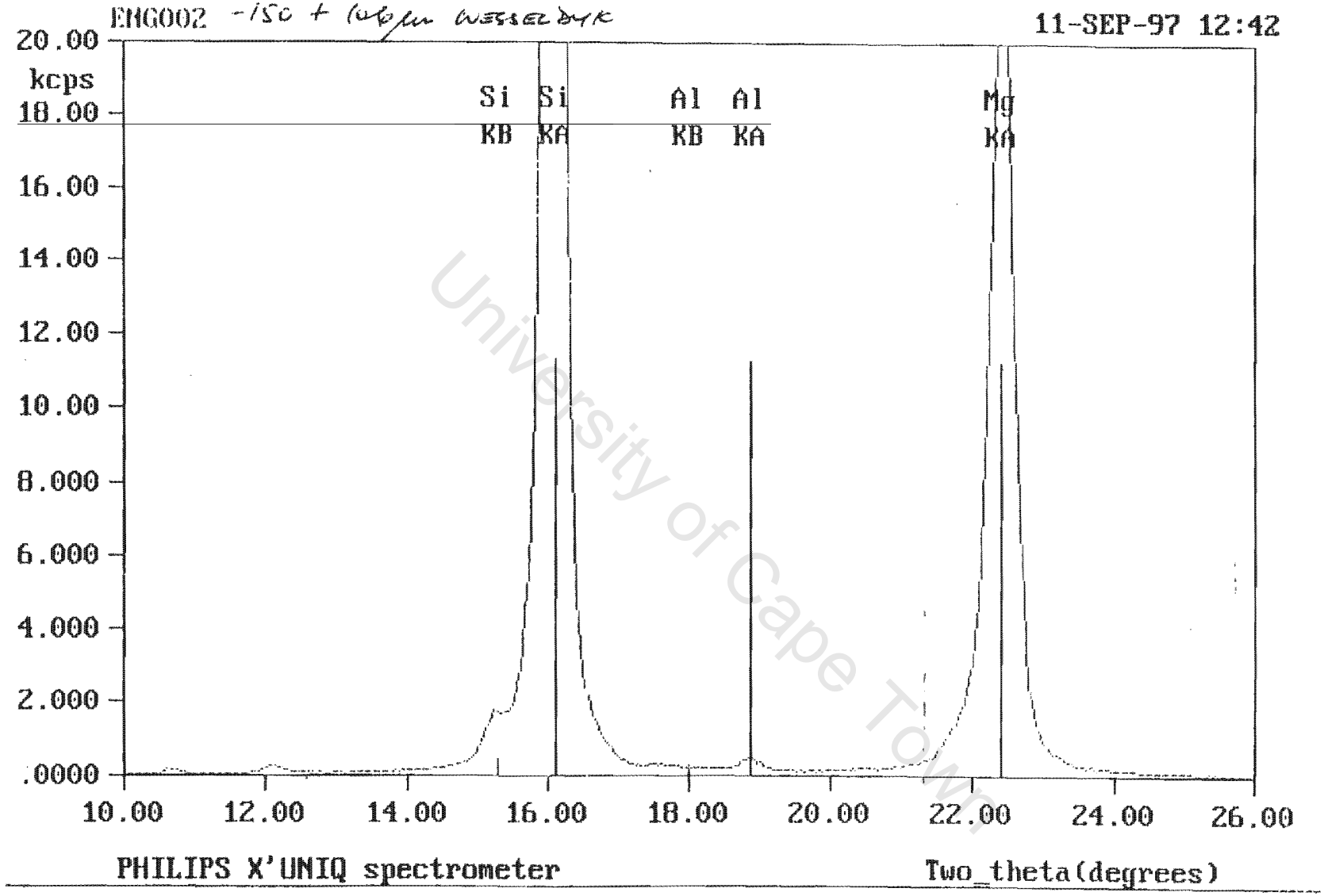
No.	x-ray tube kV	mA	filter	Collimator	Xtal	Order	Discriminator levels lower	upper	Detector
1	40	65	OUT	FINE	PX-1	1	38	66	FL

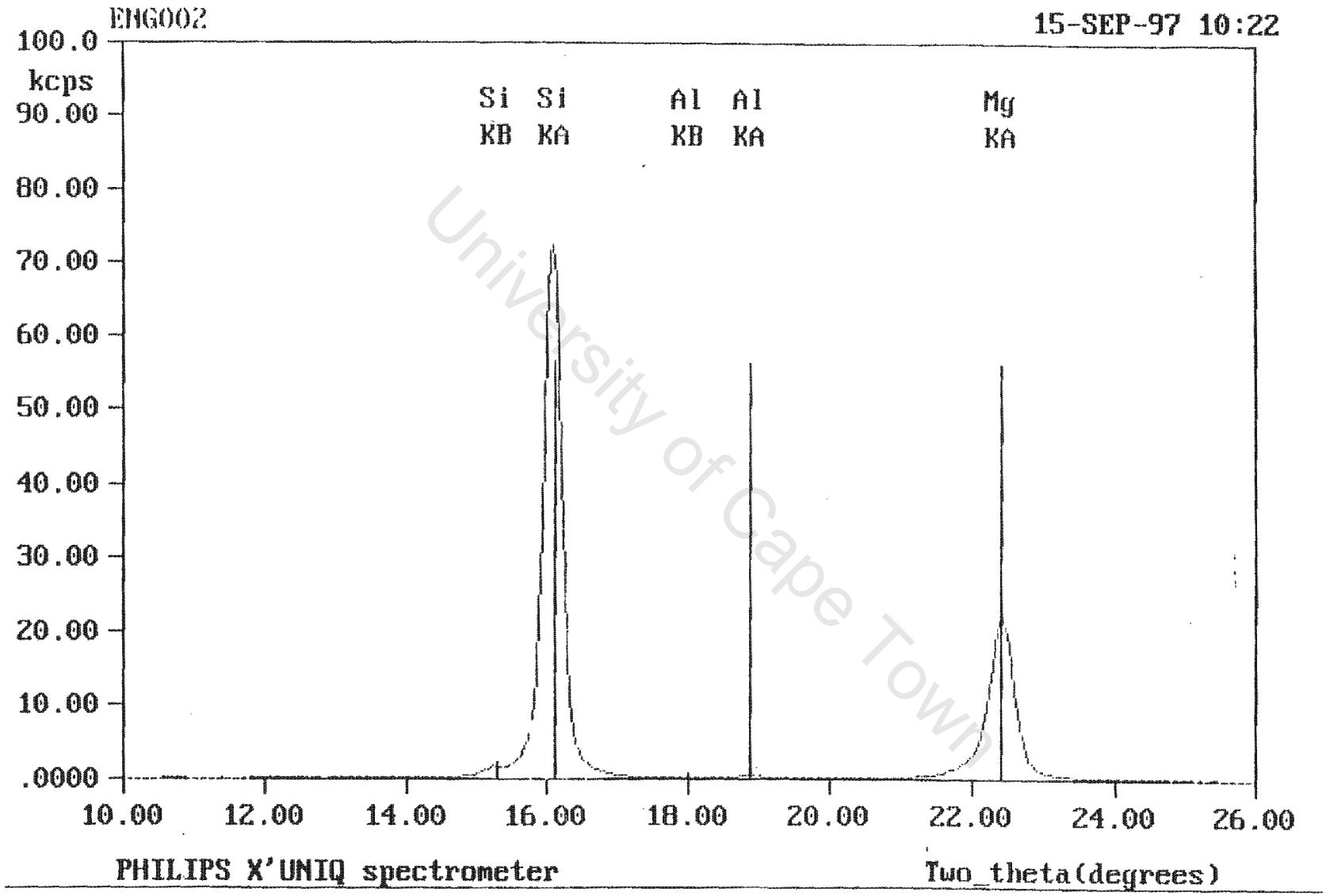
SV005 — ▷ TACC

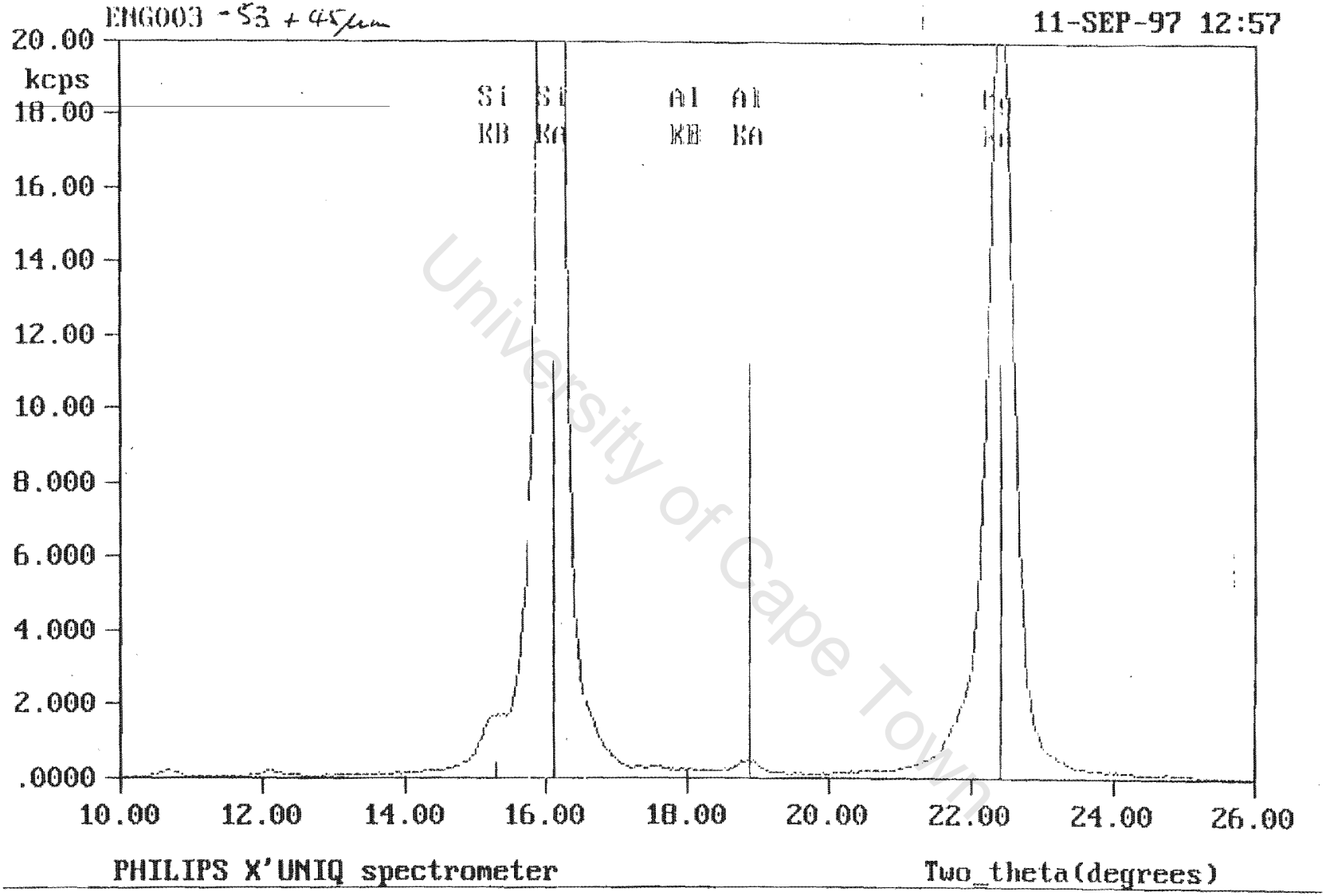
SV006A — ▷ TACC (10° - 26°)

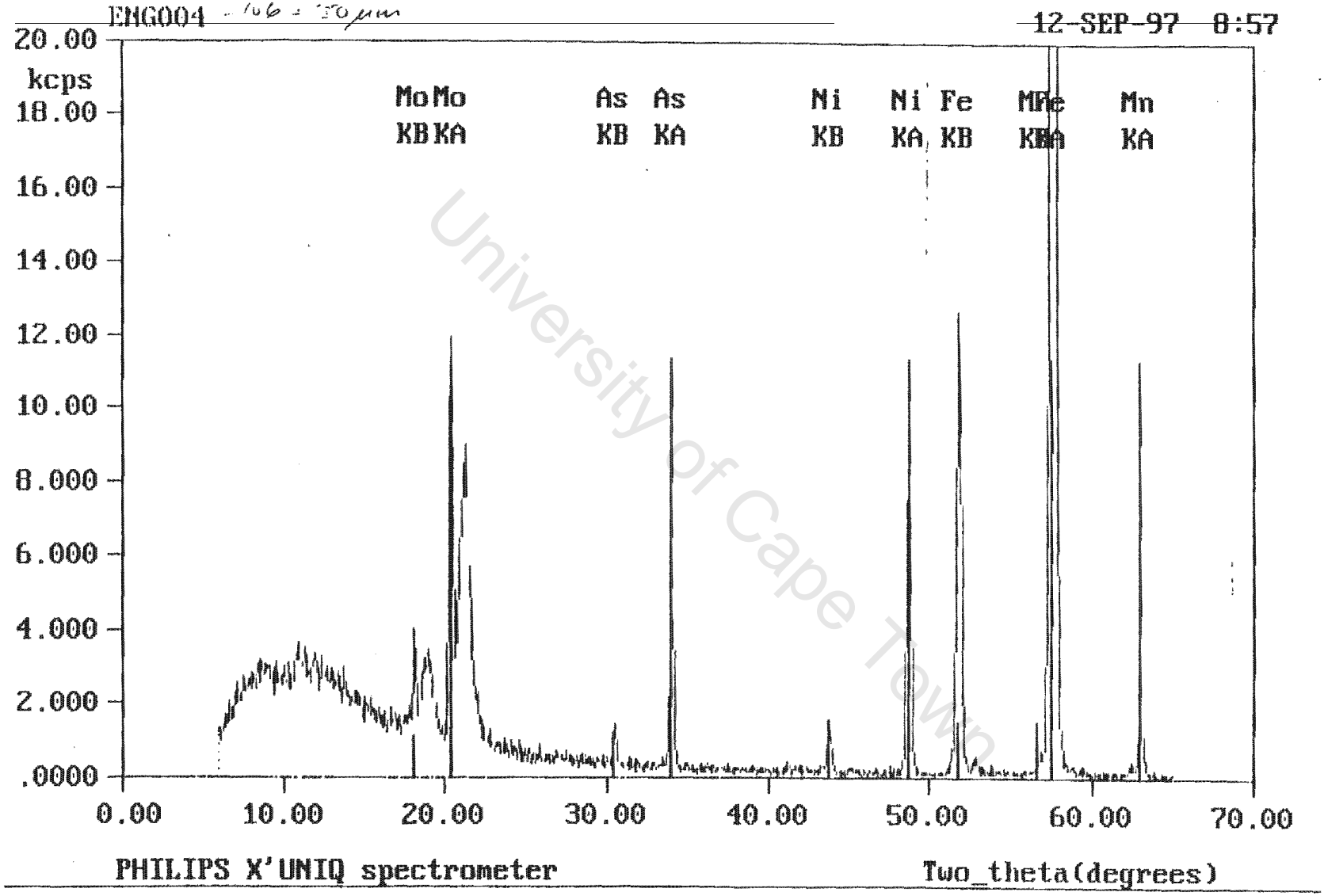
Mo/Si ARE

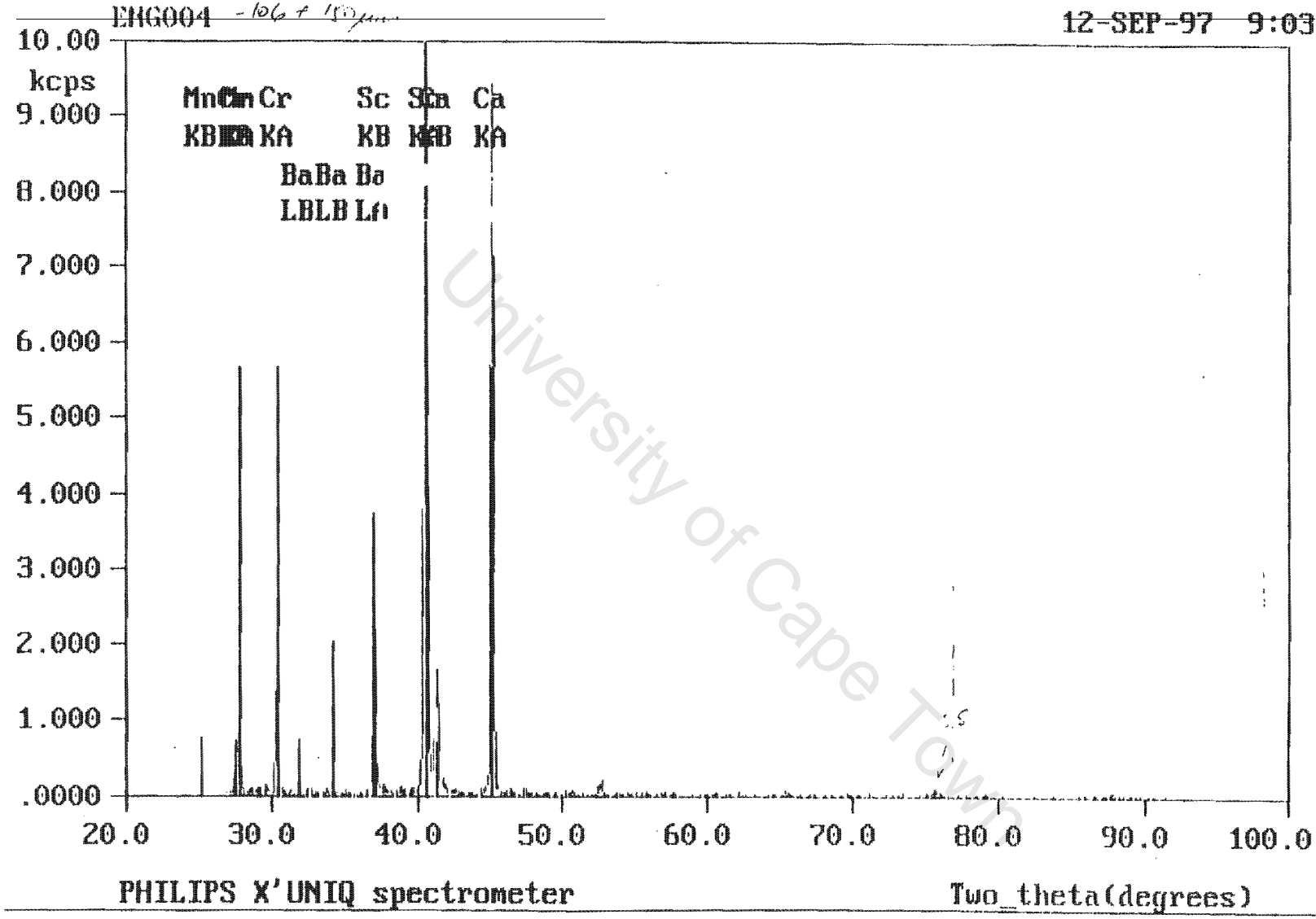


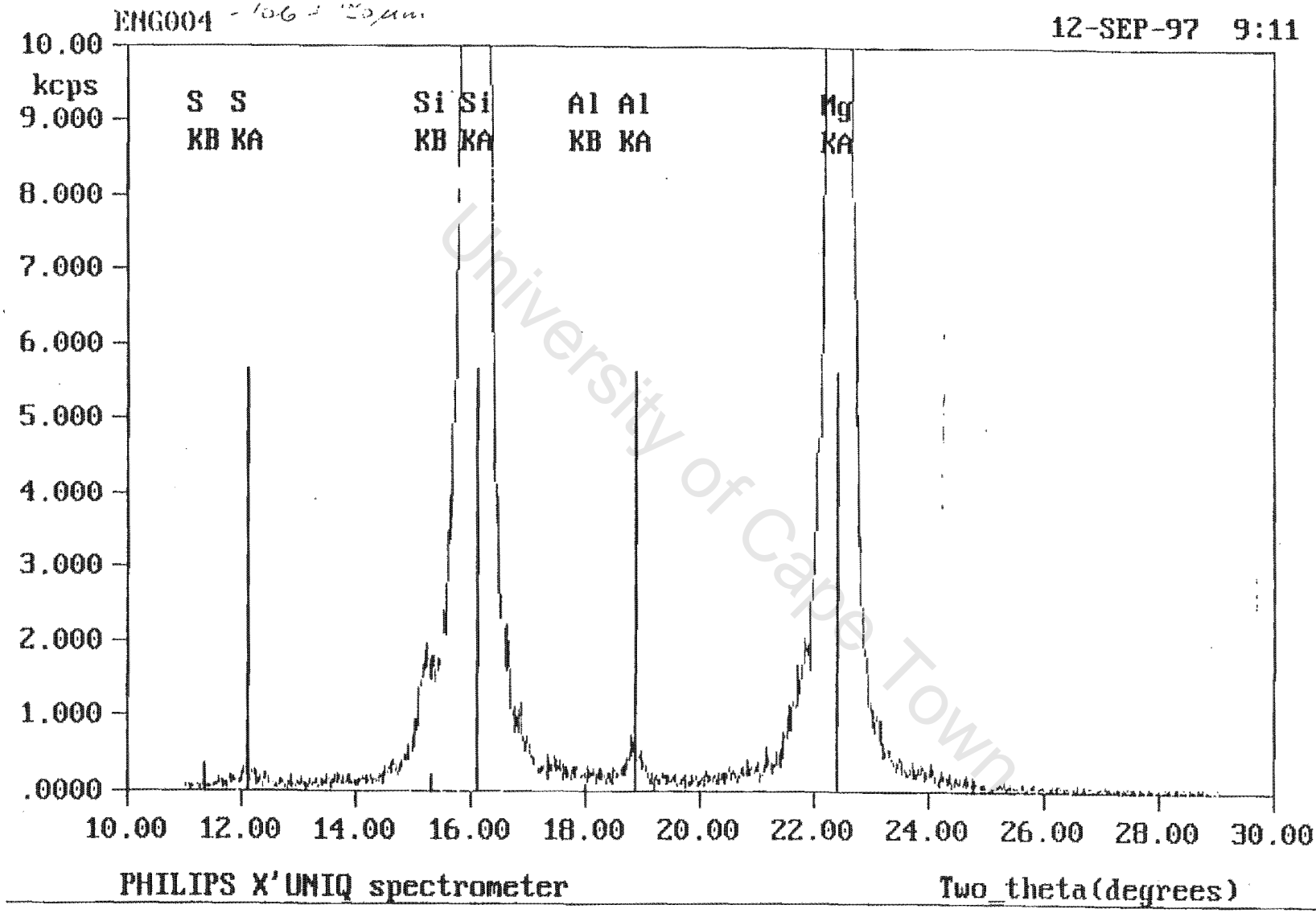












Talc for Settling Tests

SAMPLE DIRECTORY/NUMBER: CAT /341
SAMPLE ID: Fine Talc
SUBMITTER: Maqbool Dalvie
OPERATOR: Helen
UNIT NUMBER: 1
ANALYSIS GAS: Nitrogen

START 15:05:43 06/07/00
COMPL 16:11:04 06/07/00
REPRT 16:11:05 06/07/00
SAMPLE WT: 4.6617 g
FREE SPACE: 35.4415 cc
EQUIL INTRVL: 10 sec

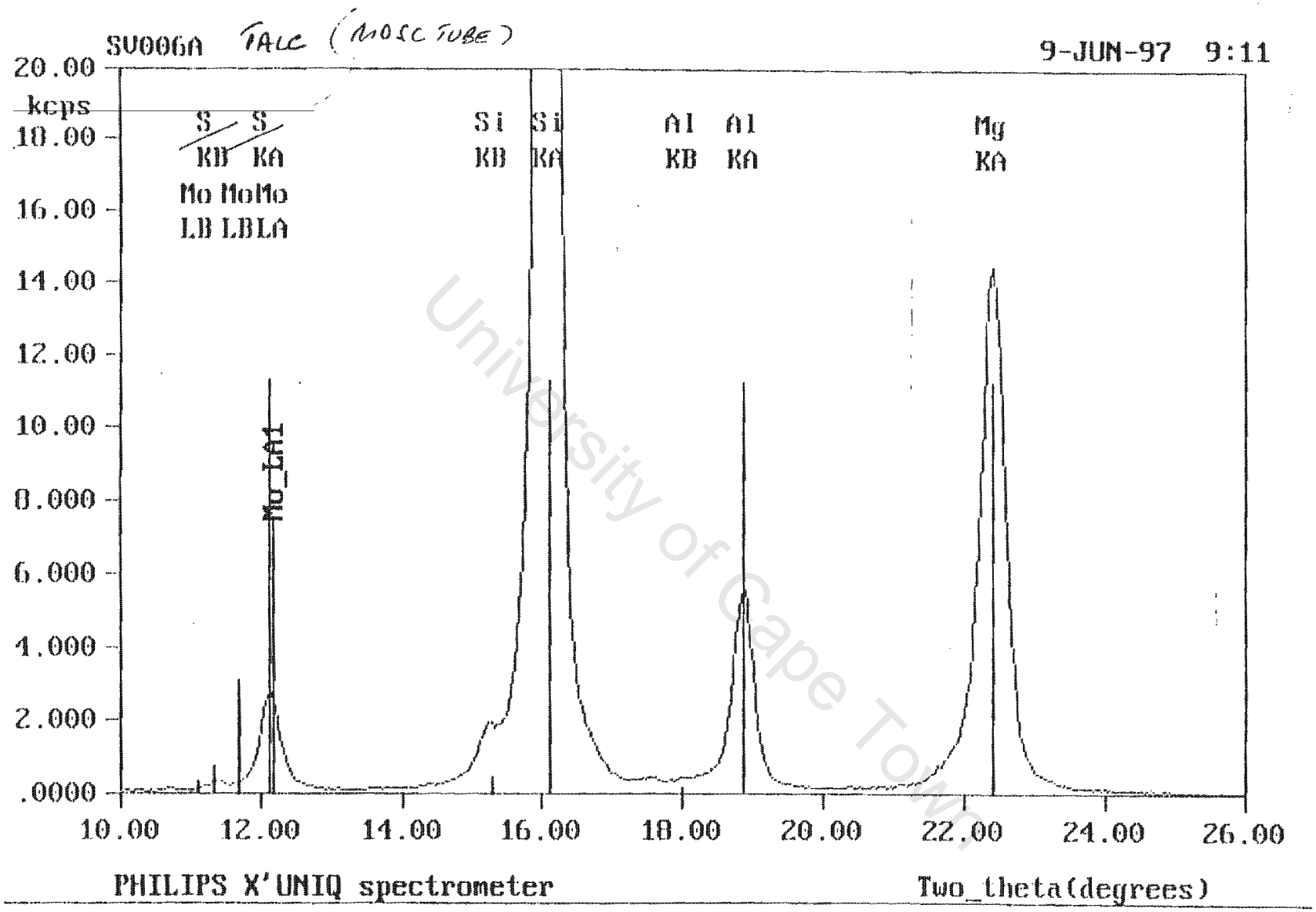
SUMMARY REPORT

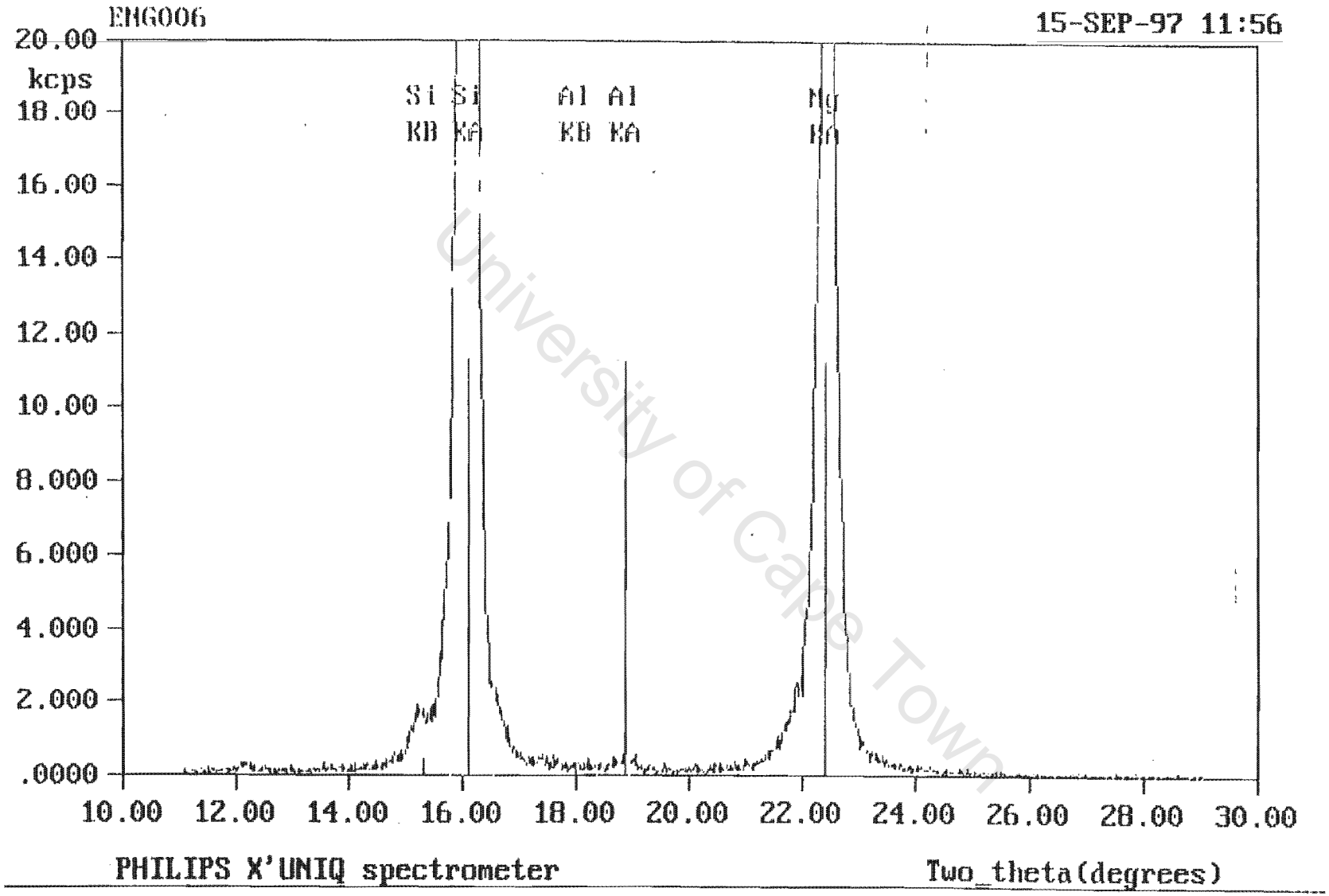
AREA

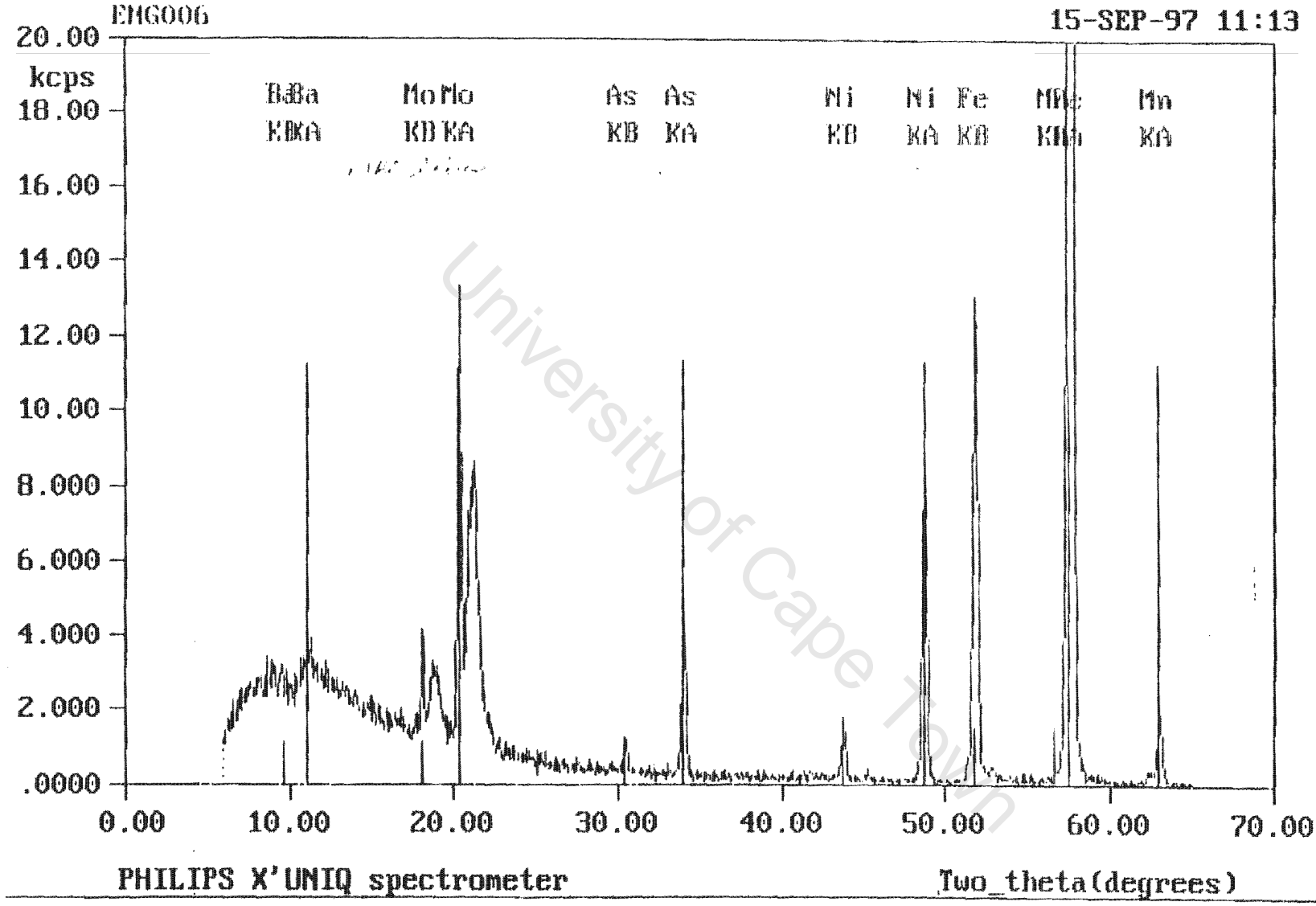
BET SURFACE AREA:	2.8152	sq. m/g
SINGLE POINT SURFACE AREA AT P/Po 0.1997:	2.6683	sq. m/g

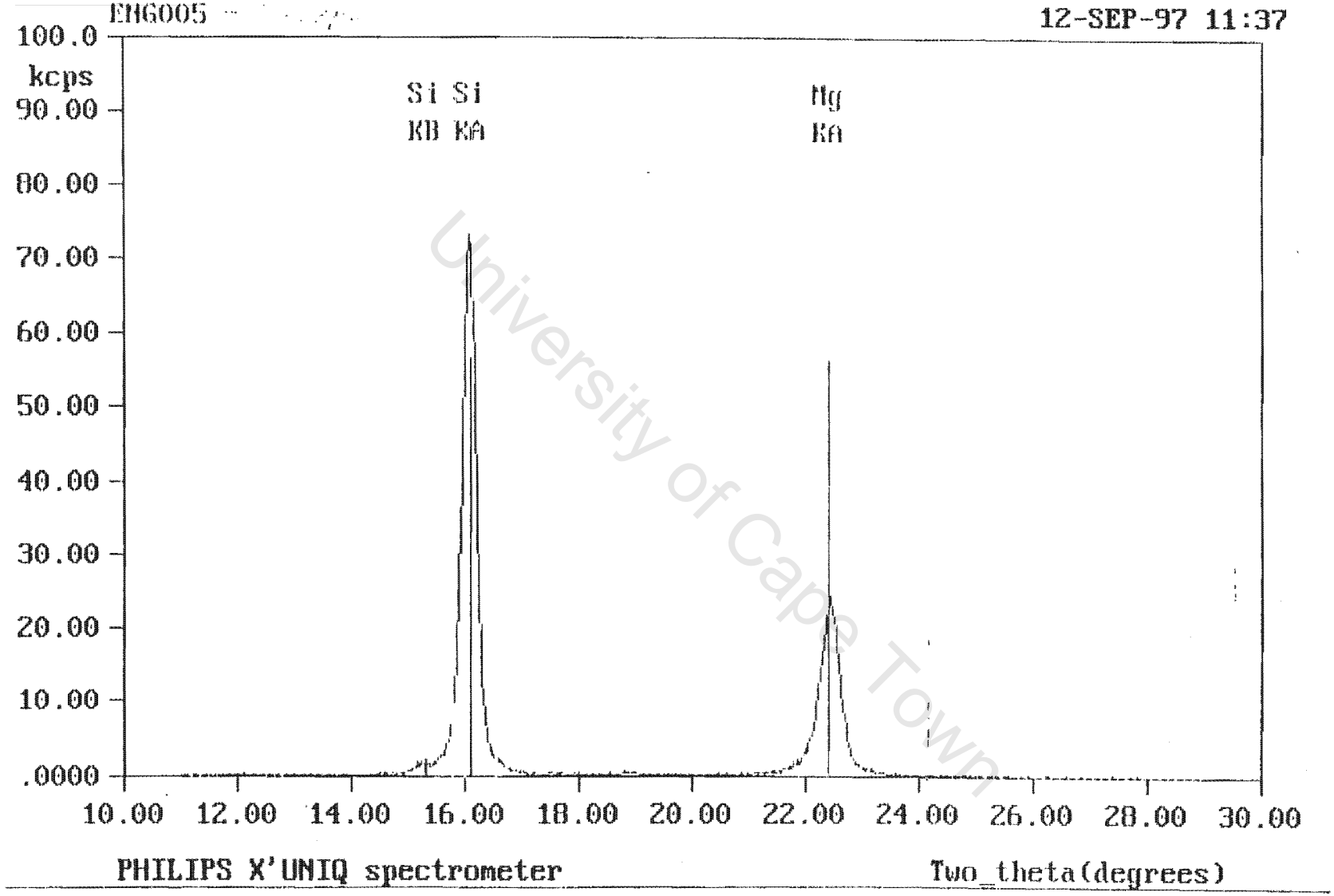
Talc for Zeta Potential Tests

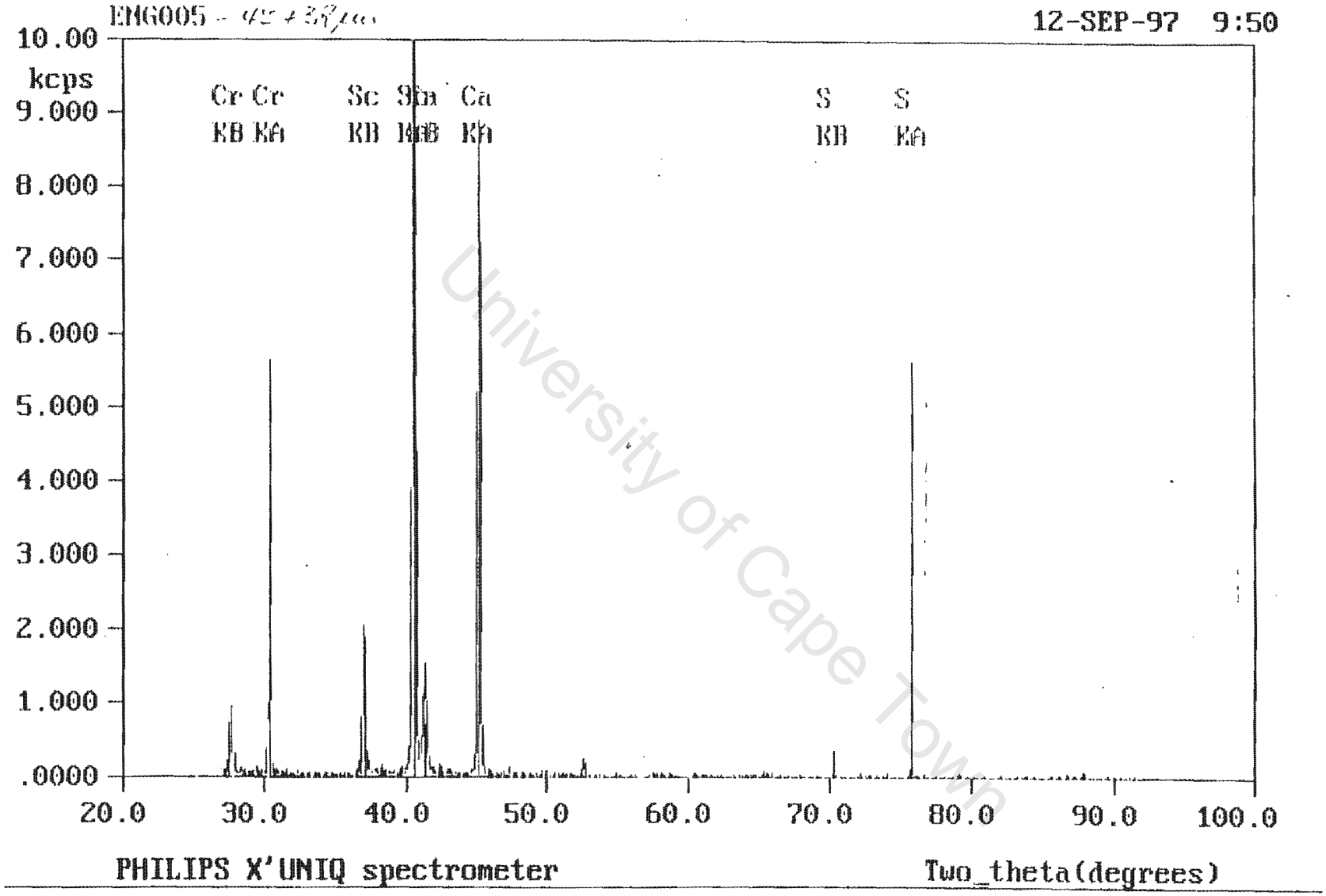
APPENDIX 2 - BET's and Size Data of Talc and Merensky Ore

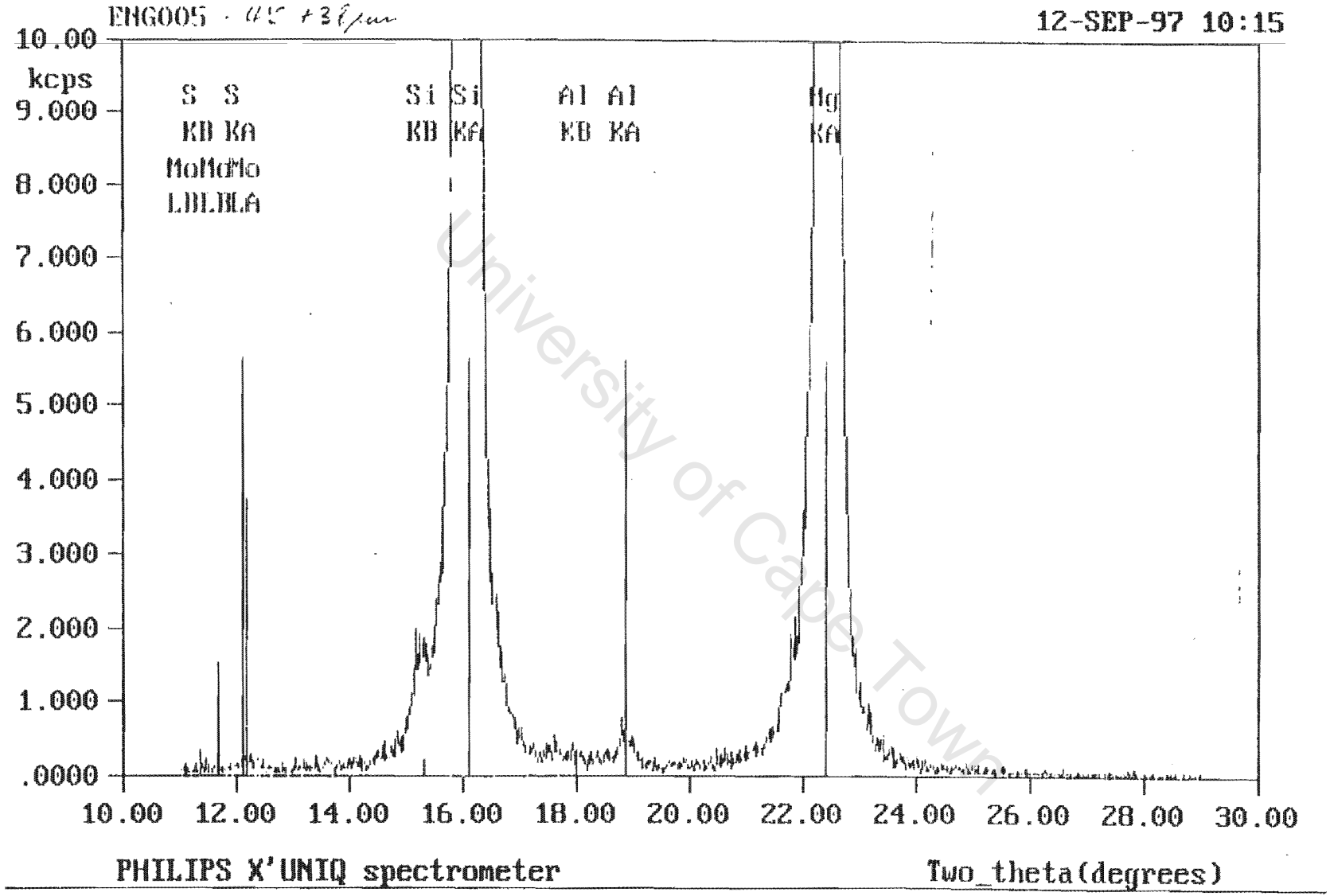


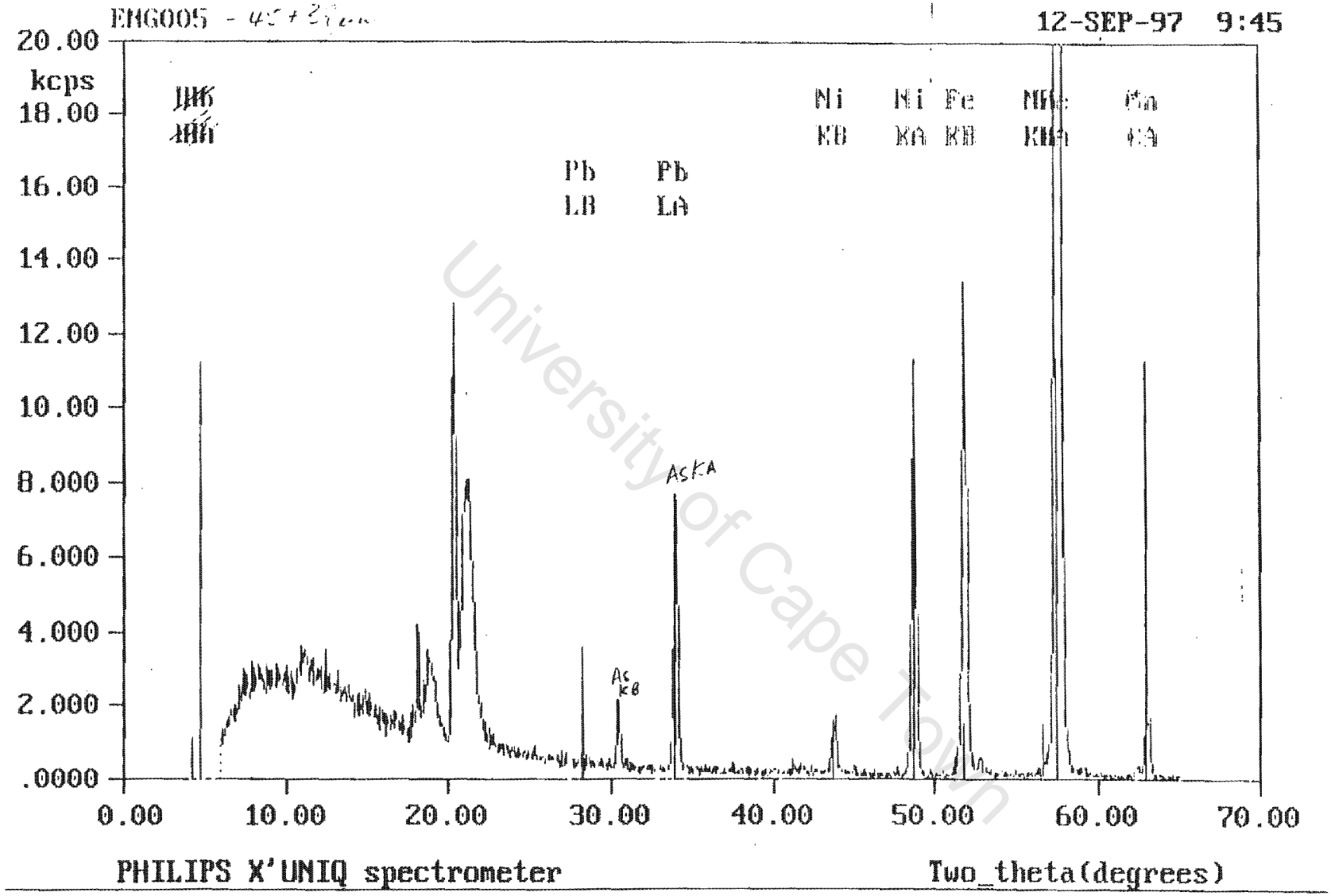


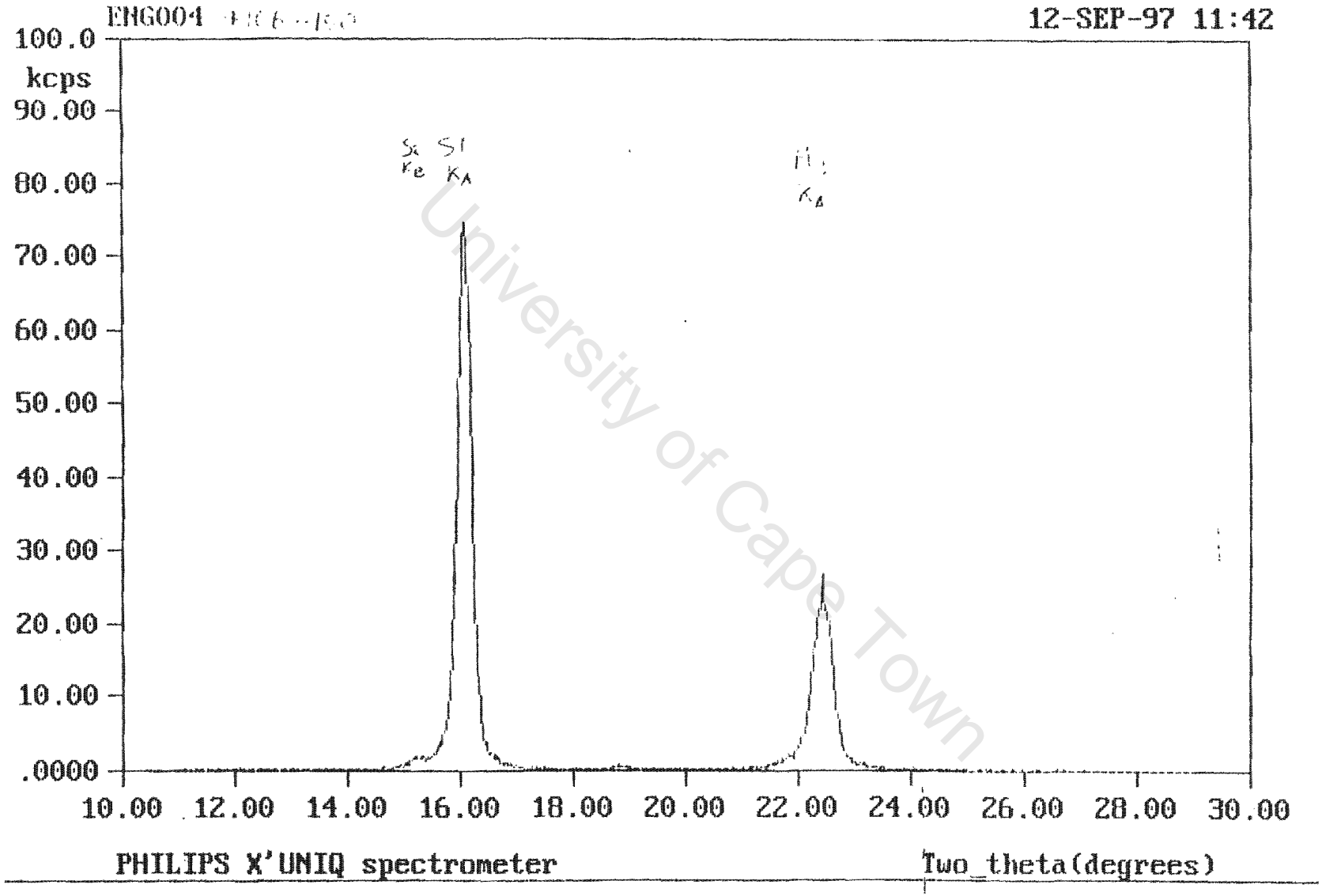












Result: Analysis Table

ID: Talc-38u
File: HELEN
Path: C:\SIZERS\

Run No: 7
Rec. No: 119

Measured: 13/8/1998 12:33
Analysed: 13/8/1998 12:33
Source: Analysed

Range: 300RF mm
Presentation: 3PHD
Modifications: None

Beam: 2.40 mm
Analysis: Polydisperse

Sampler: MS17

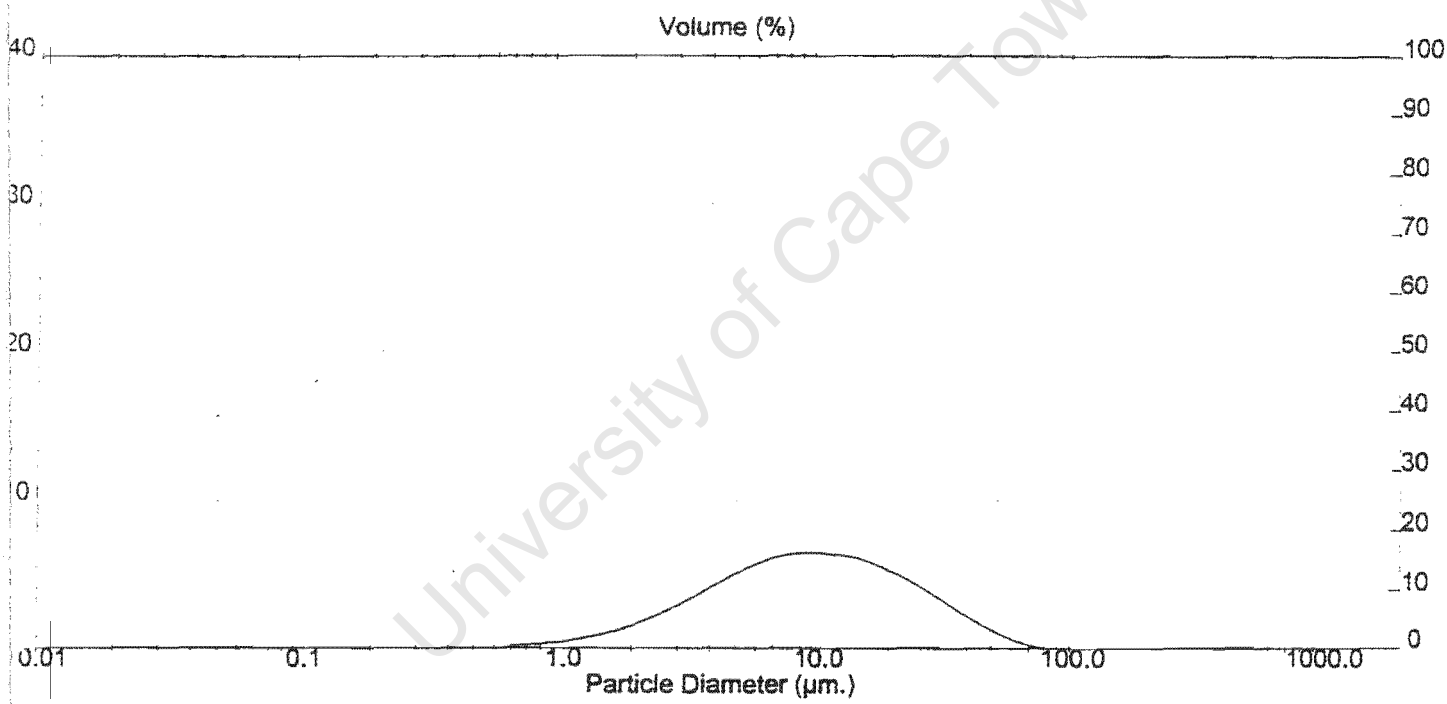
Obs: 30.1 %
Residual: 0.588 %

Conc. = 0.0283 %Vol
Distribution: Volume
D(v, 0.1) = 2.96 um
Span = 2.707E+00

Density = 3.200 g/cm^3
D[4, 3] = 13.54 um
D(v, 0.5) = 9.82 um
Uniformity = 8.380E-01

S.S.A. = 0.2943 m^2/g
D[3, 2] = 6.37 um
D(v, 0.9) = 29.52 um

Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %
0.05	0.00	0.58	0.00	5.63	6.15	76.32	0.00
0.06	0.00	0.67	0.18	7.72	6.38	88.91	0.00
0.07	0.00	0.78	0.26	9.00	6.47	103.58	0.00
0.08	0.00	0.91	0.37	10.48	6.42	120.67	0.00
0.09	0.00	1.06	0.51	12.21	6.27	140.58	0.00
0.11	0.00	1.24	0.71	14.22	6.08	163.77	0.00
0.13	0.00	1.44	0.97	16.57	5.67	190.80	0.00
0.15	0.00	1.68	1.28	19.31	5.16	222.28	0.00
0.17	0.00	1.95	1.69	22.49	4.55	258.95	0.00
0.20	0.00	2.28	2.16	26.20	3.87	301.68	0.00
0.23	0.00	2.65	2.72	30.53	3.14	351.46	0.00
0.27	0.00	3.09	3.32	35.56	2.41	409.45	0.00
0.31	0.00	3.60	3.98	41.43	1.72	477.01	0.00
0.36	0.00	4.19	4.63	48.27	1.11	555.71	0.00
0.42	0.00	4.88	5.25	56.23	0.61	647.41	0.00
0.48	0.00	5.69	5.77	65.51	0.24	754.23	0.00
0.58		6.63		76.32		878.67	



SAMPLE DIRECTORY/NUMBER: MINP /3
SAMPLE ID: -38 PGS
SUBMITTER: MA DALVEY
OPERATOR: A.RAMPLIN
UNIT NUMBER: 1
ANALYSIS GAS: Nitrogen

START 10:21:13 06/19/98
COMPL 13:16:05 06/19/98
REPRT 13:29:21 06/19/98
SAMPLE WT: 0.9353 g
FREE SPACE: 62.3944 cc
EQUIL INTRVL: 10 sec

SUMMARY REPORT

AREA

BET SURFACE AREA:	3.6285	sq. m/g
SINGLE POINT SURFACE AREA AT P/Po 0.1998:	3.3046	sq. m/g
BJH CUMULATIVE ADSORPTION SURFACE AREA OF PORES BETWEEN 17.0000 AND 3000.0000 A DIAMETER:	4.4563	sq. m/g
BJH CUMULATIVE DESORPTION SURFACE AREA OF PORES BETWEEN 17.0000 AND 3000.0000 A DIAMETER:	4.8979	sq. m/g
MICROPORE AREA:	-0.8226	sq. m/g

VOLUME

SINGLE POINT TOTAL PORE VOLUME OF PORES LESS THAN 2189.7935 A DIAMETER AT P/Po 0.9911:	0.015835	cc/g
BJH CUMULATIVE ADSORPTION PORE VOLUME OF PORES BETWEEN 17.0000 AND 3000.0000 A DIAMETER:	0.015971	cc/g
BJH CUMULATIVE DESORPTION PORE VOLUME OF PORES BETWEEN 17.0000 AND 3000.0000 A DIAMETER:	0.013172	cc/g
MICROPORE VOLUME:	-0.000480	cc/g

PORE SIZE

AVERAGE PORE DIAMETER (4V/A BY BET):	174.5631	A
BJH ADSORPTION AVERAGE PORE DIAMETER (4V/A):	143.3553	A
BJH DESORPTION AVERAGE PORE DIAMETER (4V/A):	107.5634	A

Merensky Material for Batch Flotation and Settling Tests

SAMPLE DIRECTORY/NUMBER: CAT /325
SAMPLE ID: PGM Test 14 Feed
SUBMITTER: Maqbool Dalvie
OPERATOR: Helen
UNIT NUMBER: 1
ANALYSIS GAS: Nitrogen

START 12:21:29 04/04/00
COMPL 16:09:49 04/04/00
REPRT 16:09:49 04/04/00
SAMPLE WT: 7.6452 g
FREE SPACE: 31.9295 cc
EQUIL INTRVL: 10 sec

SUMMARY REPORT

AREA

BET SURFACE AREA:	1.5991	sq. m/g
SINGLE POINT SURFACE AREA AT P/Po 0.1993:	1.5476	sq. m/g
BJH CUMULATIVE ADSORPTION SURFACE AREA OF PORES BETWEEN 17.0000 AND 3000.0000 A DIAMETER:	1.5614	sq. m/g
BJH CUMULATIVE DESORPTION SURFACE AREA OF PORES BETWEEN 17.0000 AND 3000.0000 A DIAMETER:	1.7428	sq. m/g

VOLUME

SINGLE POINT TOTAL PORE VOLUME OF PORES LESS THAN 1308.9791 A DIAMETER AT P/Po 0.9850:	0.004100	cc/g
BJH CUMULATIVE ADSORPTION PORE VOLUME OF PORES BETWEEN 17.0000 AND 3000.0000 A DIAMETER:	0.004652	cc/g
BJH CUMULATIVE DESORPTION PORE VOLUME OF PORES BETWEEN 17.0000 AND 3000.0000 A DIAMETER:	0.004772	cc/g

PORE SIZE

AVERAGE PORE DIAMETER (4V/A BY BET):	102.5605	A
BJH ADSORPTION AVERAGE PORE DIAMETER (4V/A):	119.1824	A
BJH DESORPTION AVERAGE PORE DIAMETER (4V/A):	109.5310	A

APPENDIX 4 - Macro used for Optimas and Example of Raw Data for Settling Tests

DEPRESSANT RESEARCH FACILITY
MINERAL PROCESSING RESEARCH UNIT
UNIVERSITY OF CAPE TOWN

Methods for Depressant Characterisation

April, 2000

Prepared by Meron Lewis, Dr Lesley Parolis & Prof Peter Harris

Depressant Research Facility

Moisture

Weigh 3 to 5g of the "as received" sample into a 100mL beaker. Dry overnight in an oven at 105°C. Remove from the oven and place in a dessicator for 30 minutes until cool. Weigh.

Calculate:

$$\text{Moisture} = \frac{(A-B)x100}{A}$$

A = mass of "as received" sample
B = mass of dry sample

Purity

Weigh 4g of the "as received" sample into a 400mL beaker. Add 150mL of 80% ethanol that has been heated to 60-65°C and then immerse the beaker into a water bath that is at 60-65°C. Cover with a foil lid as much as possible and stir for 10 minutes with an overhead stirrer. Stop stirring and allow the solid to settle. Decant the supernatant liquid through a fritted glass filtering crucible. Add another 150mL of 80% ethanol at 60-65°C and repeat the procedure.

Transfer the solid into the filtering crucible using 80% ethanol that is at 60-65°C. Be careful to scrape all solid from the beaker and the stirrer. Usually about 250mL of 80% ethanol is required to complete the transfer and to wash the solid in the crucible. Wash the residue in the crucible with 50mL of 95% ethanol then dry the solid as much as possible using the suction. Place the crucible in an oven at 105°C and dry overnight.

Remove crucible and place in a dessicator for 30 minutes until cool. Weigh.

$$Purity = \frac{(Ax10000)}{(Bx(100-C))}$$

A = mass of purified sample
B = mass of "as received" sample
C = moisture of sample

Degree of Substitution

Weigh approximately 0.5g of purified sample into a metal crucible. Ignite the sample over a bunsen burner flame until the sample becomes charred. Place in an oven at 650°C for 45 minutes. The remaining ash should be greyish white. Grind the ash with a pestle until no lumps remain. Dissolve the ash in a small amount of water, add methyl red indicator and titrate using 0.1N H_2SO_4. Calculate:

$$DS = \frac{(0.162xB)}{(1-0.080xB)}$$

$B = 0.1x\,{}^{b}\!/_{G}$ = milliequivalents Na/g of pure CMC

b = consumption of 0.1N H_2SO_4, mL
G = weight of pure CMC, g

NB: Guar depressants are not characterized for degree of substitution

pH

Make up a 1% solution of the guar or CMC in deionised water. Measure the pH using a pH meter.

Viscosity

Make up a solution of a concentration equal to that of the highest concentration required using deionised water. Dilute this solution to give the other concentrations required, using deionised water. Add 16mL of each solution to be tested into the Brookfield heat jacketed vessel. Attach it to the viscometer and turn the motor on. Allow to temperature equilibrate for about 10 minutes. Record all of the readings.

% Insoluble Material

Weigh approximately 1g of sample and dissolve it in approximately 100mL of deionised water. Stir for two hours. Centrifuge the sample for 10 minutes. Decant the clear liquid off and add more water to the centrifuge tube, breaking up the gel. Centrifuge again for 10 minutes. Repeat. Decant the clear liquid off and wash the remaining solid onto a pre-weighed filter paper (Whatman No.1). Filter under gravity until excess water is filtered off and then dry the filter paper in an oven at 105°C. Weigh the filter paper and calculate.

NB: Very viscous samples may require extra washing and centrifuging.

$$\%Insol.Material = \frac{(A-B)}{C} x100$$

A = mass of filter paper and insoluble material (corrected for loss of water from filter paper)
B = mass of filter paper
C = mass of dry sample

Size exclusion chromatography

Sample preparation .- Add 60 mg purified polymer slowly to 20 mL 0.01 M $NaNO_3$ in a beaker and stir until dissolved (1.5 –2 h). Centrifuge at 5000 rpm for 20 min. Decant supernatant, filter (0.45 μm) and inject ~2 mL into chromatograph and start recording file. Sample loop is 100 μL and should be overfilled at least 5 times. $NaNO_3$ eluent must be filtered (0.45 um filter) and degassed before use.

Chromatographic system - Waters Ultrahydrogel Linear column (0.78 x 30 cm) and guard column. Waters 510 solvent delivery system, eluent 0.2 M $NaNO_3$ at a flow rate of 0.6 mL/min, column temperature 45 °C. Waters R401 detector (35 °C), attenuation x 4. Rheodyne injector with 100 uL sample loop. Data capture using A/D data logger with REFLOG3 program (EW Randall, UCT). One point per second recorded and every 2 points averaged to give one data point per 2 seconds. Data from file is transferred to MS Excel and analysed on a template spreadsheet containing sample information, the linear regression equation from the calibration curve, and calculations of Mw, Mn and DP.

Calibration curve - Record the chromatograms for the 7 polyethylene oxide standards. Plot a graph of the elution volume at the peak *vs* log of the molecular weight (given by manufacturer). Calculate the equation of the linear regression line (a straight line with $y = mx + c$). To obtain the molecular weight of an unknown polymer, multiply the measured elution volume by the slope and add the intercept and then take the antilog.

Calculation of molecular weight averages.-
Weight average molecular weight (Mw) is calculated as follows:

$$Mw = \frac{\Sigma (\text{detector response}_I \times Mw_i)}{\Sigma (\text{detector response}_I)}$$

Number average molecular weight (Mn) is calculated as follows:

$$Mn = \frac{\Sigma (\text{detector response}_I)}{\Sigma (\text{detector response}_I / Mw_i)}$$

Polydispersity (PD) is defined as Mw/Mn

APPENDIX 4 - Macro used for Optimas and Example of Raw Data for Settling Tests

```
// Start of Running Macro to Control Camera and
// Measure rate of settling in a Measuring
// Flask.
// Written by Greg Dickason, Chem Eng Dept
// University of Cape Town.
// March 1997.
// First set up the system parameters. 100 Length vector for Line Luminance.
// Set Black and white camera on Channel 3.
// Calibrate system for Maqbool's unique geometry.

LineCNVFactors[0..6] = 0.0 : 1.0 : -1.0 : 180.0 : 0.0 : 3.0;
SetColorMode ( 0 : 1 : 8 : 1 : 1 : 3 );
SelectInputChannel ( 3 );
OpenConfiguration ("C:\\OPTIMAS5\\CONFIG\\ANDREWD.CFG");
Calibrate ();
Calibrate (AndrewD);
CloseWindow ("Spatial Calibration");

Acquire();

Freeze();

// ** Show("Please draw the line you want to be measured. Press OK when done.");

SelectFullScreen (3);
SetExport (mLnPoints, 1,True);
MultipleExtract (True);
Ai = mLnPoints;
Clearscreen();

// Overall Timer for running the show.
```

```
Long                                    TimeV                                   =
(2:4:6:8:10:15:20:25:30:35:40:45:50:55:60:70:80:90:100:110:120:150:180:210:240:2
70:300:330:360:390:420:450:480:510:540:570:600:660:720:780:840:900:960:1020:1080
:1140:1200:1440:1680:1800:2100:2400:2700:3000:3300:3600);

Integer PhotoNum = Vectorlength( TimeV ) + 1;

Show("Press OK to start timer.");
Long TimeO = Dostime();
Long Times = TimeV + TimeO;



Integer Limit = 200;
ActivateMeasurementSet("AndrewD");
// End of Setup; Loops to run the rest:
Loopcount = 2;
LoopC = 1;
for ( Counter = 1; counter < Photonum ; ++counter )
{
Acquire();
Freeze();
// ** CreateLine ( Ai );



CreateLine ( 14.86:24.70:14.86:2.14,,);

SetExport(mLnLuminance,1,True);
MultipleExtract(True);

Integer Stepvector = mLnLuminance - Limit;
Integer leveldesc = Vectorlength( Stepvector[ Stepvector > 0]);
```

```
hChansheet1 = DDEInitiate ("Excel", "Sheet1");
DDEPoke (hChanSheet1, "r" : ToText(LoopCount), leveldesc );
GetDateTime();
DDEPoke (hChanSheet1, "r" : ToText(LoopCount++) : "c3", DateTime);
DDETerminate (hChanSheet1);
DataCollection (1);
hChansheet2 = DDEInitiate ("Excel", "Sheet2");
DDEPoke (hChanSheet2, "r1c" : totext(Counter), DateTime);
DDETerminate (hChanSheet2);



LinkMeasurementSet(1,"[andrew.xls]Sheet2",3,Counter,TRUE);
ExportMeasurementSet ();
CloseWindow ("Data Collection");

//label waiter
//if ( times[LoopC] > dostime() ) goto waiter;

DelayMS( (times[loopC]-times[loopC-1])*1000);



loopC++;
}
Integer Stepvector = mLnLuminance - Limit;
Integer leveldesc = Vectorlength( Stepvector[ Stepvector > 0]);
hChansheet1 = DDEInitiate ("Excel", "Sheet1");
DDEPoke (hChanSheet1, "r" : ToText(LoopCount++), leveldesc );
DDETerminate (hChanSheet1);
Show ( "Macro Complete.");
```

	Position		Luminosity																
Time	min	0.00	0.07	0.13	0.20	0.25	0.37	0.48	0.60	0.72	0.83	0.95	1.07	1.17	1.27	1.38	1.57	1.75	1.95
	1	37	36	37	37	37	36	37	37	36	37	38	38	38	38	39	39	41	42
	2	37	36	37	37	36	37	37	36	37	37	38	37	38	38	38	39	40	41
	3	38	37	36	37	36	36	36	36	37	37	38	38	37	38	40	39	41	41
	4	37	36	37	36	35	37	37	37	37	37	37	37	37	37	38	38	39	41
	5	37	36	35	36	37	36	38	37	37	38	38	37	37	39	37	39	39	41
	6	36	36	36	36	36	37	38	36	37	35	37	38	38	38	38	39	39	42
	7	36	36	37	36	37	37	36	36	37	36	37	36	36	36	37	38	39	41
	8	36	37	37	37	37	37	37	38	37	38	37	38	38	38	38	38	38	42
	9	37	37	37	37	37	37	38	37	37	37	38	38	38	38	37	38	39	40
	10	38	37	37	38	37	38	38	37	38	37	38	38	37	39	36	38	39	40
	11	37	37	37	38	37	36	38	37	39	38	38	38	37	38	38	40	39	41
	12	37	37	37	37	38	38	36	38	37	38	38	38	38	38	38	38	40	41
	13	37	37	38	37	37	37	37	38	38	37	38	38	37	38	39	38	39	40
	14	38	38	39	37	37	38	38	38	37	39	37	38	39	39	39	38	38	40
	15	37	37	37	39	38	38	38	38	38	38	38	39	38	37	39	39	38	40
	16	38	38	38	38	37	38	37	39	38	39	39	39	38	39	39	38	39	40
	17	37	39	37	37	38	38	38	39	39	39	39	39	39	39	39	39	38	40
	18	38	38	39	37	38	38	38	38	37	39	38	39	38	39	40	39	40	40
	19	38	38	39	37	39	37	37	37	38	39	39	38	38	39	40	39	39	40
	20	38	38	37	37	39	37	38	37	37	38	38	38	39	38	40	38	39	39
	21	38	37	37	37	37	38	38	37	37	39	39	38	38	39	38	39	40	40
	22	37	37	38	38	38	37	37	38	38	39	39	39	39	39	39	40	39	38
	23	38	37	38	38	38	38	38	39	38	37	39	39	38	38	40	39	40	40
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96	97	103	105	107	109	110	151	118	128	133	138	142	185	152	158	161	163	
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95	99	102	105	107	108	110	153	118	128	133	138	143	186	152	158	160	165	
95	99	102	105	107	109	109	152	119	128	133	136	143	185	151	159	161	165	
96	99	102	105	108	109	111	151	120	126	134	137	142	188	150	158	161	164	
95	99	102	106	108	110	112	152	118	128	133	136	142	184	151	158	159	164	
96	100	103	107	109	111	114	153	120	129	134	137	144	184	151	159	160	165	
97	100	103	107	110	112	114	154	121	131	135	138	145	183	152	159	161	165	
97	101	103	109	111	111	115	155	119	130	135	139	145	184	152	160	161	164	
100	102	103	110	113	113	114	155	122	129	135	139	145	184	152	161	161	164	
100	103	104	110	113	114	115	155	122	129	135	139	145	185	153	161	162	165	
100	101	104	110	112	113	114	154	124	128	135	139	144	183	153	160	162	166	
100	102	106	109	112	112	114	154	124	127	135	138	144	184	153	159	160	166	
100	102	105	110	112	114	113	153	125	129	136	139	144	184	153	161	161	165	
99	101	105	109	109	113	113	152	122	126	134	138	142	182	152	158	159	163	
101	102	106	111	110	115	114	155	124	126	135	141	145	184	153	160	161	165	
103	103	107	110	112	116	114	155	124	127	136	141	146	186	154	160	161	166	
101	103	108	111	114	116	114	154	124	129	136	141	145	184	153	158	160	163	
100	102	110	111	113	115	116	155	124	130	137	141	145	185	152	159	162	165	
101	102	109	111	112	117	117	155	125	131	136	141	146	185	153	161	162	165	
101	103	110	111	114	116	118	154	125	131	136	143	145	186	154	162	163	165	
101	104	111	111	113	116	119	154	124	129	137	143	142	185	153	161	162	165	
104	105	110	112	115	117	119	155	126	130	136	144	146	185	152	162	164	167	
104	105	112	112	115	117	120	158	126	132	136	143	146	186	155	163	165	167	
106	106	111	112	116	118	121	157	126	132	137	144	146	186	154	164	165	168	
106	109	113	112	117	119	120	158	127	131	139	144	148	187	154	164	164	169	
106	110	113	113	118	120	120	155	126	132	139	144	147	188	155	163	164	169	
106	110	112	115	118	121	120	158	126	129	139	144	147	188	155	163	164	169	
107	112	115	119	119	122	121	159	125	130	140	144	147	188	157	164	164	170	
106	113	112	120	120	124	122	158	125	130	139	144	146	185	155	163	163	168	
106	112	116	121	120	123	123	159	124	130	138	143	146	187	154	163	164	167	
107	114	116	120	123	124	123	160	126	133	140	145	147	187	155	165	165	168	
107	114	117	120	123	125	123	160	126	133	141	145	147	188	156	164	166	168	
108	114	119	121	123	124	125	162	127	132	140	145	148	188	156	165	166	169	
108	114	118	122	124	124	126	164	129	134	141	145	148	187	156	166	166	169	
106	115	119	120	122	125	126	163	130	133	141	145	147	188	155	164	166	169	
107	115	120	120	124	124	126	164	130	132	141	144	148	188	155	165	166	170	
108	115	122	120	123	124	127	165	130	133	141	145	149	189	156	165	168	172	
107	115	122	122	124	124	128	166	131	135	140	144	149	189	156	166	168	171	
107	114	121	123	121	124	127	167	133	135	139	145	149	187	154	168	167	172	
106	115	121	122	121	124	127	167	133	135	139	145	149	188	156	166	167	172	
107	116	123	123	121	123	127	168	134	134	140	146	150	188	156	164	168	172	
105	114	124	123	121	124	128	169	134	133	139	146	148	189	157	164	168	172	
105	116	123	124	122	123	130	167	135	134	138	146	149	189	156	165	168	171	
106	115	123	124	126	125	130	168	133	133	139	147	147	189	156	164	167	170	
106	115	123	124	128	125	131	168	135	134	139	146	148	190	157	165	168	172	
102	114	122	126	130	125	131	168	135	133	139	145	146	188	156	165	166	171	
102	113	123	126	129	130	132	168	134	132	138	146	146	189	157	165	167	172	
102	112	121	129	130	134	132	169	131	131	139	146	145	188	156	165	167	172	

99	110	120	129	129	133	129	170	131	131	140	145	148	188	156	165	166	172
95	109	119	128	129	132	128	169	131	130	138	143	148	188	156	164	167	172
93	105	117	126	127	130	126	168	132	131	138	144	149	188	157	164	167	171
89	103	114	122	127	129	126	165	132	131	137	142	147	188	157	165	167	171
85	100	111	119	125	126	124	165	130	130	136	142	146	186	156	163	167	169
81	96	109	117	124	127	123	162	128	131	137	142	147	186	156	165	167	170
77	91	103	114	122	125	122	157	125	129	137	143	147	185	156	165	167	171
69	84	97	109	116	122	119	155	121	127	135	142	145	185	154	163	165	169
54	74	89	101	109	117	114	150	116	125	133	141	145	184	154	164	165	170
48	56	76	90	99	106	107	140	111	120	130	137	143	184	153	160	163	169
49	48	55	73	88	97	98	133	106	116	126	134	142	183	151	160	163	167
49	49	51	52	65	80	88	126	97	111	123	132	140	182	150	158	162	167
48	49	49	51	52	58	68	114	88	103	117	126	136	179	147	155	161	167
48	49	50	50	50	52	51	92	67	94	109	119	130	176	143	152	158	162
48	49	50	50	52	51	51	86	55	77	98	108	119	164	134	146	149	155
49	49	50	50	52	53	53	87	54	58	83	93	106	151	119	130	134	140
48	48	50	51	51	51	51	87	53	54	60	71	90	139	107	118	122	125
48	48	48	49	49	50	48	84	50	50	53	55	81	118	92	104	109	114
48	47	49	50	49	50	48	84	49	50	51	54	53	90	58	72	76	85
48	47	49	49	50	50	48	84	49	49	51	55	53	89	53	55	53	54
47	48	48	49	50	50	48	84	50	50	51	54	52	88	51	55	53	52
48	47	50	48	49	49	47	84	49	49	50	54	51	88	50	54	52	52
47	47	48	49	47	48	48	85	49	49	50	53	52	88	50	53	50	52
48	47	48	50	49	48	47	83	49	48	50	52	51	88	50	54	51	52
48	47	49	48	48	47	47	84	50	48	49	53	51	87	50	54	50	51
47	47	47	49	49	47	47	83	49	47	50	53	51	88	48	53	50	50
47	47	47	48	49	49	48	83	49	48	50	54	51	88	49	53	49	51
47	47	48	48	49	49	48	83	49	49	50	53	51	86	50	53	49	51
47	46	48	48	49	48	47	84	49	48	51	53	51	86	49	54	50	51
46	47	48	47	47	48	47	84	49	48	49	52	50	86	49	53	50	51
46	47	48	48	48	48	46	84	49	48	49	52	51	86	49	52	49	51
47	49	48	49	49	48	46	84	49	47	49	53	51	87	49	54	50	50
47	46	48	48	47	49	46	83	48	47	48	53	50	87	49	53	50	49
46	47	46	47	48	48	47	83	49	48	49	52	49	87	48	53	50	50
47	48	48	48	47	48	47	83	49	49	49	53	50	87	49	52	50	51
46	47	49	49	48	48	46	84	48	48	49	52	51	86	48	53	51	50
46	46	48	48	48	48	46	83	48	48	49	52	50	87	48	53	50	50
46	47	48	47	48	49	46	84	48	47	49	52	50	86	49	52	50	50
46	47	48	47	48	48	47	82	48	48	49	53	50	85	48	52	49	49
46	47	48	48	46	47	47	82	48	48	49	52	50	85	48	52	49	48
47	46	48	48	47	48	46	82	49	48	49	52	50	85	47	52	49	49
47	47	48	48	48	49	46	83	49	48	49	53	50	86	48	52	49	50
47	48	47	48	49	48	47	83	48	47	50	53	51	86	47	53	50	49
46	47	48	49	49	47	48	84	48	48	50	53	51	86	50	52	50	49
47	47	49	48	47	49	47	82	49	47	48	52	50	86	49	52	49	49
48	46	49	47	47	49	48	83	50	48	50	53	50	86	49	52	49	50
47	47	48	48	48	49	47	83	49	49	49	54	50	86	48	52	49	49
47	47	47	49	48	48	47	83	48	49	49	53	50	86	49	53	49	50
47	48	48	47	48	47	48	85	47	48	49	53	50	86	48	51	50	49
47	46	48	47	47	48	47	83	48	47	48	51	50	86	48	51	48	49
46	46	46	46	48	48	46	82	47	48	48	51	50	85	49	51	49	48
46	46	47	47	47	46	46	82	48	47	48	51	49	85	48	52	49	48
46	45	47	47	46	47	45	83	47	48	47	52	48	85	48	52	48	48
45	45	47	47	47	48	45	81	47	48	49	51	49	84	47	51	48	48
46	45	47	47	47	46	46	81	48	48	48	51	49	84	47	50	48	48
46	45	46	46	47	47	46	82	47	47	48	50	48	85	47	51	49	49
45	46	48	47	47	47	47	83	47	48	49	51	49	85	47	51	48	49
46	46	47	47	48	47	47	82	47	47	48	51	49	86	47	51	48	48
46	46	47	47	48	47	47	81	48	47	48	52	48	85	47	51	48	49
47	46	47	46	47	47	47	82	48	47	48	52	49	86	47	50	48	48
47	46	47	47	47	48	48	82	47	47	48	52	49	86	47	51	48	48
46	45	47	47	47	47	46	83	47	46	48	52	49	85	48	50	48	49
45	46	47	46	47	46	47	82	47	47	49	51	48	86	48	51	48	49
46	47	48	47	48	47	46	82	48	47	48	52	49	85	49	51	49	48
46	47	48	47	48	48	46	82	48	47	48	52	49	86	48	52	49	48
47	47	47	47	47	46	47	82	49	48	49	52	50	85	47	52	48	48
46	47	47	47	48	48	46	82	48	48	48	51	50	85	47	51	48	49
47	46	47	48	48	48	47	82	48	47	48	52	49	86	48	53	50	48
47	47	47	48	47	46	84	48	48	50	53	51	86	49	52	49	49
46	48	47	48	48	48	47	82	49	49	49	53	50	87	50	53	50	51
48	48	50	50	50	50	49	84	51	48	50	54	52	89	50	54	52	50

APPENDIX 5 - Sample Calculation and Raw Data of Flotation Tests and the Acid Digestion Technique

DIGESTION METHOD (ex Karbochem R & D Lab)

Principle

The finely milled ore sample is dissolved in aqua regia with the addition of hydrofluoric acid and perchloric acid. The sample is made up to a known volume, filtered and read on the AA spectrophotometer.

Reagents

Hydrofluoric acid	CP	approx. 40%
Nitric Acid	CP	approx. 60%
Perchloric acid	CP	concentrated
Hydrochloric acid	CP	approx. 30%

For use: Mix 4 parts HCl to 1 part HF per volume.

Sample preparation:
Samples should be finely ground.

Method:

1.Sample is weighed out according to the type, into a 250ml wide-mouthed Erlenmeyer flask as follows:

Concentrates	0.1g
Tails and feed (head)	0.5g

2. Digest:
Add 10 ml of the HCl/HF mixture to sample and heat to boiling.
Add 10ml HNO_3 to flask and boil until sample volume is approx. 2ml.
Add 5ml $HClO_4$ to flask and boil until sample volume is approx. 2ml
(A white cloud will form which will rise once reaction has taken place)

3. Make up to volume and filter:
Transfer the sample quantitatively to a 100ml volumetric flask and make up to 100 with distilled H_2O. Filter through Whatman No1 into sample bottle. Filtrate to be read on AA. Store in fridge if delay in reading.

4. Read on AA.

5.Calculation:

eg %Cu in sample $= \frac{R \text{ (in ppm)}}{100 \times a \text{ (sample mass)}}$

Test No	3	
IMP4 add	0	g/ton
FF30 add	40	g/ton
NaHMP add	0	g/ton

Mass Calcs

	Tray Mass	Tot Tray Mass	Dry Paper	Corr paper	Paper+sample	Sample Mass	Acc Mass	Time	% Acc Mass	Water
	g	g	g	g	g	g	g	g		g
Feed			3.08	3	3	0	0.0	0	0.00	
Conc 1	378.1	460.5	3.02	2.94	20.57	17.63	17.6	1	1.95	64.82
Conc 2	363.9	555.0	3.1	3.02	27.34	24.32	42.0	4	4.64	166.76
Conc 3	370.2	736.5	3.4	3.32	34.42	31.1	73.1	13	8.09	335.16
Conc 4	369.8	811.6	3.4	3.32	28.43	25.11	98.2	25	10.87	416.68
Blank			3.39	-0.08	3.31	3.39				
Tail			7.44	7.36	812.47	805.11				
						903.27				983.4

Analysis

	Assays			Mass			Cum Recovery(F+C)			Cum Recovery(T+C)		Cumulative Grade		
	S	Cu	Ni	S	Cu	Ni	S	Cu	Ni	Cu	Ni	S	Cu	Ni
	%	%	%	g	g	g	%	%	%	%	%	%	%	%
Feed	0.687	0.08	0.18	6.21	0.70	1.62						0.69		
Conc 1	20.3	2.64	2.64	3.58	0.47	0.47	57.67	66.67	28.70	64.19	27.60	20.30	2.64	2.64
Conc 2	6.29	0.40	1.73	1.53	0.10	0.42	82.32	80.75	54.64	77.75	52.55	12.18	1.34	2.11
Conc 3	1.44	0.13	0.52	0.45	0.04	0.16	89.54	86.58	64.69	83.36	62.21	7.61	0.83	1.43
Conc 4	0.64	0.08	0.28	0.16	0.02	0.07	92.13	89.35	69.02	86.03	66.38	5.82	0.64	1.14
Tail		0.01	0.07		0.10	0.57								

Test No	5	
IMP4 add	0	g/ton
FF30 add	100	g/ton
NaHMP add	0	g/ton

Mass Calcs

	Tray Mass	Tot Tray Mass	Dry Paper	Corr paper	Paper+sample	Sample Mass	Acc Mass	Time	% Acc Mass	Water
	g	g	g	g	g	g	g	g		g
Feed			3.33	3.25	3	-0.25	0.0	0	0.00	
Conc 1	366.7	423.2	3.38	3.3	12.67	9.37	9.4	1	1.16	47.11
Conc 2	363.9	501.6	3.17	3.09	13.4	10.31	19.7	4	2.43	127.42
Conc 3	369.9	576.6	3.22	3.14	19.48	16.34	36.0	13	4.45	190.38
Conc 4	378.9	721.6	3.26	3.18	25.58	22.4	58.4	25	7.22	320.24
Blank			3.37	-0.08	3.29	3.37				
Tail			7.13	7.05	757.95	750.9				
						809.32				685.2

Analysis

	Assays			Mass			Recovery(F+C)			Recovery(T+C)		Cumulative Grade		
	S	Cu	Ni	S	Cu	Ni	S	Cu	Ni	Cu	Ni	S	Cu	Ni
	%	%	%	g	g	g	%	%	%	%	%	%	%	%
Feed	0.653	0.07	0.17	5.28	0.57	1.38						0.65		
Conc 1	35.15	4.31	4.23	3.29	0.40	0.40	62.32	71.29	28.81	61.81	25.80	35.15	4.31	4.23
Conc 2	10.45	0.86	3.03	1.08	0.09	0.31	82.71	86.94	51.51	75.38	46.13	22.21	2.50	3.60
Conc 3	2.705	0.2	0.92	0.44	0.03	0.15	91.07	92.70	62.44	80.38	55.92	13.36	1.46	2.38
Conc 4	1.085	0.09	0.37	0.24	0.02	0.08	95.67	96.26	68.46	83.47	61.31	8.65	0.93	1.61
Tail		0.01	0.08		0.11	0.59								

Test No	13	
IMP4 add	40	g/ton
FF30 add	0	g/ton
NaHMP add	0	g/ton

Mass Calcs

	Tray Mass	Tot Tray Mass	Dry Paper	Corr paper	Paper+sample	Sample Mass	Acc Mass	Time	% Acc Mass	Water
	g	g	g	g	g	g	g	g		g
Feed			3.36	3.37	3	-0.37	0.0	0	0.00	
Conc 1	378.1	441.6	3.39	3.4	12.45	9.05	9.1	1	1.07	54.5
Conc 2	363.9	510.9	3.37	3.38	23.29	19.91	29.0	4	3.44	127.11
Conc 3	369.9	694.5	3.12	3.13	30.8	27.67	56.6	13	6.73	296.99
Conc 4	369.8	748.0	3.18	3.19	25.33	22.14	78.8	25	9.36	356.12
Blank			3.16	0.01	3.17	3.16				
Tail			7	7.01	770.23	763.22				
						841.99				834.7

Analysis

	Assays			Mass			Recovery(F+C)			Recovery(T+C)		Cumulative Grade		
	S	Cu	Ni	S	Cu	Ni	S	Cu	Ni	Cu	Ni	S	Cu	Ni
	%	%	%	g	g	g	%	%	%	%	%	%	%	%
Feed	0.4755	0.08	0.2	4.00	0.67	1.68						0.48		
Conc 1	20.85	3.36	3.42	1.89	0.30	0.31	47.13	45.14	18.38	52.18	20.11	20.85	3.36	3.42
Conc 2	5.93	0.49	1.84	1.18	0.10	0.37	76.62	59.63	40.13	68.92	43.92	10.59	1.39	2.33
Conc 3	1.55	0.14	0.6	0.43	0.04	0.17	87.33	65.38	49.99	75.57	54.71	6.17	0.78	1.49
Conc 4	0.6945	0.09	0.31	0.15	0.02	0.07	91.17	68.34	54.07	78.98	59.17	4.63	0.58	1.16
Tail		0.02	0.08		0.12	0.63								

Test No	9	
IMP4 add	0	g/ton
FF30 add	0	g/ton
NaHMP add	0	g/ton

Mass Calcs

	Tray Mass	Tot Tray Mass	Dry Paper	Corr paper	Paper+sample	Sample Mass	Acc Mass	Time	% Acc Mass	Water
	g	g	g	g	g	g	g	g		g
Feed			3.21	3.2	3	-0.2	0.0	0	0.00	
Conc 1	378.1	452.6	3.17	3.16	18.06	14.9	14.9	1	1.64	59.57
Conc 2	363.9	518.7	3.2	3.19	24.8	21.61	36.5	4	4.02	133.2
Conc 3	369.9	719.2	3.08	3.07	36.18	33.11	69.6	13	7.67	316.24
Conc 4	369.8	859.6	3.14	3.13	32.95	29.82	99.4	25	10.96	460.01
Blank			3.15	-0.01	3.14	3.15				
Tail			7.13	7.12	814.85	807.73				
						907.17				969.0

Analysis

	Assays			Mass			Recovery(F+C)			Recovery(T+C)		Cumulative Grade		
	S	Cu	Ni	S	Cu	Ni	S	Cu	Ni	Cu	Ni	S	Cu	Ni
	%	%	%	g	g	g	%	%	%	%	%	%	%	%
Feed	0.4955	0.08	0.18	4.50	0.73	1.63						0.50		
Conc 1	13.5	2.53	2.2	2.01	0.38	0.33	44.75	51.94	20.07	55.64	19.74	13.50	2.53	2.20
Conc 2	5.25	0.32	1.71	1.13	0.07	0.37	69.99	61.47	42.70	65.84	41.99	8.62	1.22	1.91
Conc 3	1.82	0.13	0.67	0.60	0.04	0.22	83.39	67.40	56.29	72.20	55.35	5.38	0.70	1.32
Conc 4	0.7595	0.09	0.32	0.23	0.03	0.10	88.43	71.10	62.13	76.16	61.09	4.00	0.52	1.02
Tail		0.02	0.08		0.16	0.65								

Test No	17	
IMP4 add	40	g/ton
FF30 add	0	g/ton
NaHMP add	50	g/ton

Mass Calcs

	Tray Mass	Tot Tray Mass	Dry Paper	Corr paper	Paper+sample	Sample Mass	Acc Mass	Time	% Acc Mass	Water
	g	g	g	g	g	g	g	g		g
Feed			3.98	3.97	3	-0.97	0.0	0	0.00	
Conc 1	378.1	434.0	3.93	3.92	11.52	7.6	7.6	1	0.77	48.28
Conc 2	175.0	360.2	3.87	3.86	20.43	16.57	24.2	4	2.43	168.61
Conc 3	369.9	765.4	3.88	3.87	38.15	34.28	58.5	13	5.88	361.28
Conc 4	378.9	741.6	3.76	3.75	24.75	21	79.5	25	8.00	341.62
Blank			3.38	-0.01	3.37	3.38				
Tail			7.63	7.62	921.54	913.92				
						993.37				919.8

Analysis

	Assays			Mass			Recovery(F+C)			Recovery(T+C)		Cumulative Grade		
	S	Cu	Ni	S	Cu	Ni	S	Cu	Ni	Cu	Ni	S	Cu	Ni
	%	%	%	g	g	g	%	%	%	%	%	%	%	%
Feed	0.378	0.07	0.17	3.75	0.70	1.69						0.38		
Conc 1	18.7	5.13	3.78	1.42	0.39	0.29	37.85	56.07	17.01	44.76	12.73	18.70	5.13	3.78
Conc 2	7.06	0.65	2.44	1.17	0.11	0.40	69.00	71.56	40.95	57.12	30.65	10.72	2.06	2.86
Conc 3	1.805	0.16	0.7	0.62	0.05	0.24	85.48	79.45	55.16	63.42	41.29	5.49	0.95	1.59
Conc 4	0.626	0.1	0.3	0.13	0.02	0.06	88.98	82.47	58.89	65.83	44.08	4.21	0.72	1.25
Tail		0.03	0.14		0.30	1.26								

Test No	19	
IMP4 add	40	g/ton
FF30 add	0	g/ton
NaHMP add	100	g/ton

Mass Calcs

	Tray Mass	Tot Tray Mass	Dry Paper	Corr paper	Paper+sample	Sample Mass	Acc Mass	Time	% Acc Mass	Water
	g	g	g	g	g	g	g	g		g
Feed			4.13	4.12	3	-1.12	0.0	0	0.00	
Conc 1	370.5	413.0	4.09	4.08	7.64	3.56	3.6	1	0.41	38.98
Conc 2	363.9	451.9	3.95	3.94	17.09	13.15	16.7	4	1.91	74.86
Conc 3	370.2	535.9	3.87	3.86	24.34	20.48	37.2	13	4.25	145.19
Conc 4	369.8	655.9	3.86	3.85	28.62	24.77	62.0	25	7.08	261.37
Blank			3.91	-0.01	3.9	3.91				
Tail			7.57	7.56	820.75	813.19				
						875.15				520.4

Analysis

	Assays			Mass			Recovery(F+C)			Recovery(T+C)		Cumulative Grade		
	S	Cu	Ni	S	Cu	Ni	S	Cu	Ni	Cu	Ni	S	Cu	Ni
	%	%	%	g	g	g	%	%	%	%	%	%	%	%
Feed	0.382	0.08	0.17	3.34	0.70	1.49						0.38		
Conc 1	20.2	6.35	3.67	0.72	0.23	0.13	21.51	32.29	8.78	31.04	7.94	20.20	6.35	3.67
Conc 2	10.6	1.99	3.4	1.39	0.26	0.45	63.21	69.67	38.83	66.98	35.11	12.65	2.92	3.46
Conc 3	3.525	0.28	1.28	0.72	0.06	0.26	84.80	77.62	56.45	74.81	51.05	7.62	1.46	2.26
Conc 4	1.27	0.15	0.47	0.31	0.04	0.12	94.21	83.13	64.28	79.92	58.12	5.08	0.94	1.54
Tail		0.02	0.08		0.15	0.69								

Test No	20	
IMP4 add	40	g/ton
FF30 add		g/ton
NaHMP add	200	g/ton

Mass Calcs	Tray Mass	Tot Tray Mass	Dry Paper	Corr paper	Paper+sample	Sample Mass	Acc Mass	Time	% Acc Mass	Water
	g	g	g	g	g	g	g	g		g
Feed			4.13	4.14	3	-1.14	0.0	0	0.00	
Conc 1	370.5	407.2	4.16	4.17	8.15	3.98	4.0	1	0.42	32.7
Conc 2	363.9	470.9	4.2	4.21	18.35	14.14	18.1	4	1.93	92.89
Conc 3	370.2	547.6	4.21	4.22	24.91	20.69	38.8	13	4.13	156.72
Conc 4	369.8	660.1	4.09	4.1	27.27	23.17	62.0	25	6.60	267.12
Blank			4.07	0.01	4.08	4.07				
Tail			6.87	6.88	884.48	877.6				
						939.58				549.4

Analysis	Assays			Mass			Recovery(F+C)			Recovery(T+C)		Cumulative Grade		
	S	Cu	Ni	S	Cu	Ni	S	Cu	Ni	Cu	Ni	S	Cu	Ni
	%	%	%	g	g	g	%	%	%	%	%	%	%	%
Feed	0.3885	0.09	0.18	3.65	0.85	1.69						0.39		
Conc 1	21.4	6.5	4.61	0.85	0.26	0.18	23.33	30.59	10.85	35.39	10.64	21.40	6.50	4.61
Conc 2	9.865	1.64	3.42	1.39	0.23	0.48	61.55	58.02	39.44	67.11	38.69	12.40	2.71	3.68
Conc 3	3.29	0.29	1.13	0.68	0.06	0.23	80.19	65.11	53.27	75.31	52.25	7.54	1.42	2.32
Conc 4	1.245	0.13	0.46	0.29	0.03	0.11	88.10	68.67	59.57	79.43	58.43	5.19	0.94	1.63
Tail		0.02	0.08		0.15	0.72								

Test No	21	
IMP4 add	100	g/ton
FF30 add	0	g/ton
NaHMP add	50	g/ton

Mass Calcs

	Tray Mass	Tot Tray Mass	Dry Paper	Corr paper	Paper+sample	Sample Mass	Acc Mass	Time	% Acc Mass	Water
	g	g	g	g	g	g	g	g		g
Feed			3.24	3.26	3	-0.26	0.0	0	0.00	
Conc 1	370.5	401.6	3.23	3.25	4.7	1.45	1.5	1	0.16	29.66
Conc 2	363.9	439.3	3.24	3.26	9.05	5.79	7.2	4	0.81	69.65
Conc 3	369.9	534.0	3.24	3.26	13.05	9.79	17.0	13	1.90	154.29
Conc 4	369.8	629.5	4.21	4.23	16.06	11.83	28.9	25	3.23	247.9
Blank			4.19	0.02	4.21	4.19				
Tail			6.94	6.96	872.63	865.67				
						894.53				501.5

Analysis

	Assays			Mass			Recovery(F+C)			Recovery(T+C)		Cumulative Grade		
	S	Cu	Ni	S	Cu	Ni	S	Cu	Ni	Cu	Ni	S	Cu	Ni
	%	%	%	g	g	g	%	%	%	%	%	%	%	%
Feed	0.3985	0.08	0.17	3.56	0.72	1.52						0.40		
Conc 1	33.9	13.78	5.28	0.49	0.20	0.08	13.79	27.92	5.03	28.79	4.66	33.90	13.78	5.28
Conc 2	26.6	4.5	7.99	1.54	0.26	0.46	56.99	64.33	35.46	66.32	32.84	28.06	6.36	7.45
Conc 3	9.275	0.66	3.19	0.91	0.06	0.31	82.47	73.36	55.99	75.63	51.86	17.26	3.08	5.00
Conc 4	2.495	0.26	0.86	0.30	0.03	0.10	90.75	77.66	62.68	80.06	58.06	11.21	1.93	3.30
Tail		0.02	0.08		0.14	0.69								

Test No	22	
IMP4 add	100	g/ton
FF30 add	0	g/ton
NaHMP add	100	g/ton

Mass Calcs

	Tray Mass	Tot Tray Mass	Dry Paper	Corr paper	Paper+sample	Sample Mass	Acc Mass	Time	% Acc Mass	Water
	g	g	g	g	g	g	g	g		g
Feed			3.28	3.28	3	-0.28	0.0	0	0.00	
Conc 1	378.1	415.5	3.32	3.32	4.08	0.76	0.8	1	0.08	36.6
Conc 2	363.9	472.9	3.41	3.41	14.25	10.84	11.6	4	1.23	98.14
Conc 3	370.2	557.2	3.39	3.39	17.63	14.24	25.8	13	2.75	172.7
Conc 4	378.9	705.5	3.34	3.34	25.64	22.3	48.1	25	5.12	304.27
Blank			3.31	0	3.31	3.31				
Tail			7	7	898.58	891.58				
						939.72				611.7

Analysis

	Assays			Mass			Recovery(F+C)			Recovery(T+C)		Cumulative Grade		
	S	Cu	Ni	S	Cu	Ni	S	Cu	Ni	Cu	Ni	S	Cu	Ni
	%	%	%	g	g	g	%	%	%	%	%	%	%	%
Feed	0.3515	0.08	0.17	3.30	0.75	1.60						0.35		
Conc 1	33.2	14.33	4.6	0.25	0.11	0.03	7.64	14.49	2.19	15.07	2.09	33.20	14.33	4.60
Conc 2	16.25	3.36	5.22	1.76	0.36	0.57	60.97	62.94	37.61	65.47	35.87	17.36	4.08	5.18
Conc 3	4.42	0.38	1.4	0.63	0.05	0.20	80.02	70.13	50.09	72.96	47.77	10.23	2.04	3.10
Conc 4	1.37	0.15	0.54	0.31	0.03	0.12	89.27	74.58	57.63	77.59	54.96	6.13	1.16	1.91
Tail		0.02	0.08		0.16	0.75								

Test No	23	
IMP4 add	100	g/ton
FF30 add	0	g/ton
NaHMP add	200	g/ton

Mass Calcs										
	Tray Mass	Tot Tray Mass	Dry Paper	Corr paper	Paper+sample	Sample Mass	Acc Mass	Time	% Acc Mass	Water
	g	g	g	g	g	g	g	g		g
Feed			3.44	3.44	3	-0.44	0.0	0	0.00	
Conc 1	378.1	433.5	3.27	3.27	6.04	2.77	2.8	1	0.32	52.67
Conc 2	175.0	271.4	3.36	3.36	11.51	8.15	10.9	4	1.25	88.27
Conc 3	370.2	550.2	3.15	3.15	14.58	11.43	22.4	13	2.55	168.54
Conc 4	369.8	649.4	3.22	3.22	22.5	19.28	41.6	25	4.75	260.38
Blank			3.28	0	3.28	3.28				
Tail			6.6	6.6	840.6	834				
						875.63				**569.9**

Analysis														
	Assays			Mass			Recovery(F+C)			Recovery(T+C)		Cumulative Grade		
	S	Cu	Ni	S	Cu	Ni	S	Cu	Ni	Cu	Ni	S	Cu	Ni
	%	%	%	g	g	g	%	%	%	%	%	%	%	%
Feed	0.3485	0.09	0.18	3.05	0.79	1.58						0.35		
Conc 1	29.7	9.93	6.22	0.82	0.28	0.17	26.96	34.90	10.93	41.08	10.49	29.70	9.93	6.22
Conc 2	14.6	2.11	5.69	1.19	0.17	0.46	65.95	56.72	40.35	66.77	38.74	18.43	4.09	5.82
Conc 3	5.105	0.41	1.8	0.58	0.05	0.21	85.07	62.67	53.41	73.77	51.27	11.62	2.21	3.77
Conc 4	1.67	0.16	0.62	0.32	0.03	0.12	95.63	66.59	60.99	78.38	58.55	7.01	1.26	2.31
Tail		0.02	0.08		0.14	0.68								

Test No	24	
IMP4 add	100	g/ton
FF30 add	0	g/ton
NaHMP add	0	g/ton

Mass Calcs

	Tray Mass	Tot Tray Mass	Dry Paper	Corr paper	Paper+sample	Sample Mass	Acc Mass	Time	% Acc Mass	Water
	g	g	g	g	g	g	g	g		g
Feed			3.57	3.56	3	-0.56	0.0	0	0.00	
Conc 1	370.5	407.9	3.48	3.47	5.28	1.81	1.8	1	0.20	35.59
Conc 2	363.9	470.4	3.53	3.52	14.12	10.6	12.4	4	1.40	95.89
Conc 3	370.2	535.5	3.32	3.31	17.3	13.99	26.4	13	2.98	151.24
Conc 4	369.8	627.5	3.35	3.34	18.53	15.19	41.6	25	4.69	242.49
Blank			3.36	-0.01	3.35	3.36				
Tail			6.75	6.74	851.94	845.2				
						886.79				**525.2**

Analysis

	Assays			Mass			Recovery(F+C)			Recovery(T+C)		Cumulative Grade		
	S	Cu	Ni	S	Cu	Ni	S	Cu	Ni	Cu	Ni	S	Cu	Ni
	%	%	%	g	g	g	%	%	%	%	%	%	%	%
Feed	0.369	0.08	0.19	3.27	0.71	1.68						0.37		
Conc 1	31.4	11.78	5.24	0.57	0.21	0.09	17.37	30.05	5.63	30.54	5.64	31.40	11.78	5.24
Conc 2	15.2	2.46	5.64	1.61	0.26	0.60	66.61	66.81	41.11	67.89	41.16	17.56	3.82	5.58
Conc 3	4.845	0.34	1.69	0.68	0.05	0.24	87.32	73.52	55.14	74.70	55.21	10.82	1.98	3.52
Conc 4	1.595	0.17	0.58	0.24	0.03	0.09	94.72	77.16	60.37	78.40	60.45	7.45	1.32	2.45
Tail		0.02	0.08		0.15	0.67								

Test No	25	
IMP4 add	0	g/ton
FF30 add	0	g/ton
NaHMP add	50	g/ton

Mass Calcs										
	Tray Mass	Tot Tray Mass	Dry Paper	Corr paper	Paper+sample	Sample Mass	Acc Mass	Time	% Acc Mass	Water
	g	g	g	g	g	g	g	g		g
Feed			3.88	3.83	3	-0.83	0.0	0	0.00	
Conc 1	370.5	421.8	3.48	3.43	11.94	8.51	8.5	1	0.92	42.75
Conc 2	363.9	506.4	3.41	3.36	20.94	17.58	26.1	4	2.83	124.937
Conc 3	370.2	598.6	3.43	3.38	31.63	28.25	54.3	13	5.89	200.09
Conc 4	378.9	695.2	3.46	3.41	27.56	24.15	78.5	25	8.50	292.14
Blank			3.5	-0.05	3.45	3.5				
Tail			7.36	7.31	851.86	844.55				
						923.04				659.9

Analysis														
	Assays			Mass			Recovery(F+C)			Recovery(T+C)		Cumulative Grade		
	S	Cu	Ni	S	Cu	Ni	S	Cu	Ni	Cu	Ni	S	Cu	Ni
	%	%	%	g	g	g	%	%	%	%	%	%	%	%
Feed	0.375	0.08	0.19	3.46	0.74	1.75						0.38		
Conc 1	13.85	4.44	3.03	1.18	0.38	0.26	34.05	51.17	14.70	50.64	14.73	13.85	4.44	3.03
Conc 2	5.66	0.69	2.34	1.00	0.12	0.41	62.80	67.60	38.16	66.90	38.23	8.33	1.91	2.57
Conc 3	2.8	0.21	1	0.79	0.06	0.28	85.65	75.63	54.27	74.85	54.37	5.46	1.03	1.75
Conc 4	1.135	0.12	0.4	0.27	0.03	0.10	93.57	79.55	59.78	78.74	59.89	4.13	0.75	1.34
Tail		0.02	0.08		0.16	0.70								

Test No	26	
IMP4 add	0	g/ton
FF30 add	0	g/ton
NaHMP add	100	g/ton

Mass Calcs

	Tray Mass	Tot Tray Mass	Dry Paper	Corr paper	Paper+sample	Sample Mass	Acc Mass	Time	% Acc Mass	Water
	g	g	g	g	g	g	g	g		g
Feed			3.6	3.47	3	-0.47	0.0	0	0.00	
Conc 1	378.1	466.1	3.53	3.4	17.5	14.1	14.1	1	1.56	73.94
Conc 2	175.0	308.1	3.71	3.58	22.41	18.83	32.9	4	3.65	114.33
Conc 3	369.9	551.8	3.28	3.15	24.5	21.35	54.3	13	6.01	160.57
Conc 4	369.8	711.5	3.35	3.22	31.44	28.22	82.5	25	9.14	313.48
Blank			3.37	-0.13	3.24	3.37				
Tail			6.73	6.6	826.87	820.27				
						902.77				662.3

Analysis

	Assays			Mass			Recovery(F+C)			Recovery(T+C)		Cumulative Grade		
	S	Cu	Ni	S	Cu	Ni	S	Cu	Ni	Cu	Ni	S	Cu	Ni
	%	%	%	g	g	g	%	%	%	%	%	%	%	%
Feed	0.401	0.07	0.16	3.62	0.63	1.44						0.40		
Conc 1	11.95	2.55	2.6	1.68	0.36	0.37	46.54	56.90	25.38	56.26	22.56	11.95	2.55	2.60
Conc 2	4.16	0.34	1.64	0.78	0.06	0.31	68.18	67.03	46.76	66.28	41.57	7.50	1.29	2.05
Conc 3	2.175	0.17	0.77	0.46	0.04	0.16	81.01	72.77	58.14	71.96	51.68	5.40	0.85	1.55
Conc 4	1.15	0.13	0.46	0.32	0.04	0.13	89.97	78.58	67.13	77.70	59.67	3.95	0.60	1.18
Tail		0.02	0.08		0.14	0.66								

Test No	27	
IMP4 add	0	g/ton
FF30 add	100	g/ton
NaHMP add	100	g/ton

Mass Calcs

	Tray Mass	Tot Tray Mass	Dry Paper	Corr paper	Paper+sample	Sample Mass	Acc Mass	Time	% Acc Mass	Water
	g	g	g	g	g	g	g	g		g
Feed			3.28	3.26	3	-0.26	0.0	0	0.00	
Conc 1	370.5	411.9	3.3	3.28	4.98	1.7	1.7	1	0.19	39.74
Conc 2	363.9	470.8	3.27	3.25	13.08	9.83	11.5	4	1.26	97.11
Conc 3	370.2	562.9	3.31	3.29	17.39	14.1	25.6	13	2.79	178.55
Conc 4	378.9	711.0	3.23	3.21	21.6	18.39	44.0	25	4.80	313.68
Blank			3.23	-0.02	3.21	3.23				
Tail			7.14	7.12	880.26	873.14				
						917.16				629.1

Analysis

	Assays			Mass			Recovery(F+C)			Recovery(T+C)		Cumulative Grade		
	S	Cu	Ni	S	Cu	Ni	S	Cu	Ni	Cu	Ni	S	Cu	Ni
	%	%	%	g	g	g	%	%	%	%	%	%	%	%
Feed	0.66	0.08	0.19	6.07	0.73	1.74						0.66		
Conc 1	41.3	8.47	4.4	0.70	0.14	0.07	11.57	19.62	4.29	20.29	4.11	41.30	8.47	4.40
Conc 2	35.4	3.29	6.02	3.48	0.32	0.59	68.93	63.70	38.25	65.87	36.60	36.27	4.05	5.78
Conc 3	10.1	0.56	2.69	1.42	0.08	0.38	92.40	74.46	60.02	76.99	57.42	21.87	2.13	4.08
Conc 4	1.9	0.16	0.55	0.35	0.03	0.10	98.16	78.47	65.82	81.14	62.98	13.53	1.31	2.61
Tail		0.02	0.08		0.13	0.67								

Sample Calculation for Batch Flotation Testwork

Data obtained from test:

Mass of all concentrates and tail (m_{conc} and m_{tail}))

Water recovery for all concentrates

From Chemical Analysis of concentrates and tails the copper (Cu) and nickel (Ni) content was obtained. (See Acid digestion technique in this Appendix for further explanation).

Recovery Calculation was based on the concentrate and feed analysis.

$$m_{feed} = m_{concs} + m_{tail}$$

$$Cu_{feed} = Cu_{all\ conc} + Cu_{tail}$$

$$\text{Recovery in \%} = Cu_{conc} * m_{conc} / (Cu_{feed} * m_{feed}) * 100$$

For cumulative recovery the cumulative grade of concentrates was calculated and multiplied by the cumulative mass of the concentrate to obtain the cumulative copper recovered.

For example the formula for the cumulative grade (g) of Cu for the entire concentrate:

$$gCu_{conc1\text{-}4} = (gCu_{conc1} * m_{conc1} + gCu_{conc2} * m_{conc2} + gCu_{conc3} * m_{conc3} + gCu_{conc4} * m_{conc4}) / \text{total mass}$$

APPENDIX 6 - Raw Data for Zeta Potential Tests

0 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
9.04	-29.0	0.61	-29.5	-28.0	-29.4	-29.3	-28.9
7.28	-29.1	0.88	-29.5	-29.5	-30.1	-28.5	-27.9
6.86	-31.8	1.12	-32.3	-30.8	-30.4	-33.1	-32.2
5.65	-30.1	0.94	-30.9	-29.1	-30.4	-30.9	-29.0
4.39	-25.6	0.75	-25.2	-25.9	-25.6	-24.7	-26.7
3.11	-6.5	1.08	-6.3	-8.2	-6.7	-5.4	-5.8
2.93	-6.1	0.30	-6.6	-6.0	-5.9	-5.9	-5.9

1 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
10.52	-20.6	0.37	-20.4	-20.3	-21.0	-21.0	-20.3
8.97	-25.4	0.31	-24.9	-25.4	-25.7	-25.4	-25.6
7.01	-24.8	0.98	-26.3	-24.8	-24.9	-24.2	-23.7
6.35	-25.0	0.81	-26.0	-23.9	-24.5	-25.3	-25.3
5.92	-25.8	0.56	-25.3	-25.8	-26.2	-26.5	-25.2
4.86	-23.4	0.90	-23.0	-22.8	-24.1	-24.6	-22.5
3.14	-7.1	0.26	-7.0	-7.1	-7.0	-7.0	-7.6
2.87	-5.7	0.53	-5.6	-4.8	-6.1	-6.0	-5.9

3 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
10.59	-29.8	0.97	-29.7	-31.0	-30.5	-28.6	-29.2
9.06	-22.8	0.75	-22.5	-22.3	-23.5	-22.0	-23.7
6.63	-22.2	0.30	-22.3	-22.5	-21.9	-22.3	-21.8
6.41	-22.0	0.32	-21.8	-21.9	-22.1	-22.5	-21.7
5.65	-20.6	0.22	-20.7	-20.7	-20.6	-20.7	-20.2
4.49	-19.2	0.63	-19.5	-20.0	-19.1	-19.0	-18.3
3.03	-5.8	0.43	-5.8	-6.3	-5.4	-6.2	-5.4
2.88	-5.1	0.48	-5.4	-5.2	-4.3	-5.5	-5.0

5 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
10.53	-26.7	0.35	-26.5	-26.7	-27.3	-26.4	-26.7
8.83	-25.6	0.38	-25.2	-26.2	-25.7	-25.4	-25.6
8.03	-22.3	0.42	-23.0	-22.3	-22.0	-22.1	-22.0
6.65	-21.7	0.73	-22.9	-21.2	-21.1	-21.5	-21.9
5.99	-20.2	0.37	-20.3	-20.3	-20.0	-19.7	-20.7
4.68	-13.4	0.85	-12.3	-14.4	-13.7	-12.7	-13.7
3.33	-7.0	0.18	-7.0	-6.8	-7.2	-7.1	-6.8
2.89	-5.2	0.30	-5.5	-5.5	-5.1	-4.9	-4.9

10 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
10.71	-25.6	0.46	-25.7	-24.8	-25.9	-25.9	-25.7
8.84	-20.3	0.84	-21.1	-19.2	-20.3	-21.1	-19.7
7.29	-21.5	0.87	-21.4	-22.2	-22.4	-20.2	-21.3
6.72	-19.6	0.42	-20.1	-19.3	-19.9	-19.4	-19.1
5.88	-18.5	0.51	-19.0	-18.3	-19.0	-18.6	-17.8
4.68	-15.2	0.44	-15.2	-14.9	-15.5	-14.7	-15.8
3.11	-5.7	0.60	-6.4	-6.1	-5.1	-5.1	-6.0
2.91	-4.4	0.67	-3.9	-4.1	-4.3	-5.6	-4.3

30 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
10.46	-18.6	0.42	-18.9	-18.1	-19.1	-18.8	-18.3
8.84	-19.9	0.70	-20.1	-20.7	-20.2	-19.8	-18.8
7.35	-15.9	0.46	-15.4	-16.3	-15.7	-16.4	-15.5
6.63	-14.5	0.43	-14.9	-14.0	-14.9	-14.6	-14.1
5.86	-13.1	0.29	-13.4	-13.1	-12.9	-13.3	-12.7
4.80	-10.4	0.31	-10.0	-10.5	-10.1	-10.7	-10.6
3.20	-0.8	0.29	-0.6	-0.9	-1.3	-0.6	-0.8
2.87	-2.6	0.18	-2.5	-2.7	-2.7	-2.3	-2.7

50 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
10.71	-16.5	0.70	-17.3	-16.8	-16.3	-16.6	-15.4
9.08	-13.4	0.23	-13.6	-13.5	-13.2	-13.7	-13.2
7.14	-12.5	0.50	-13.0	-11.7	-12.7	-12.3	-12.7
6.78	-10.2	0.54	-10.8	-10.4	-10.4	-9.7	-9.5
5.56	-10.5	0.47	-10.7	-10.2	-9.9	-11.0	-10.9
4.78	-7.5	0.78	-8.4	-7.1	-7.5	-8.2	-6.5
3.17	-3.0	0.18	-2.9	-2.7	-3.0	-3.2	-3.0
2.86	-2.2	0.15	-2.4	-2.0	-2.3	-2.2	-2.2

100 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
10.71							
8.87	-8.4	0.41	-8.9	-8.1	-8.0	-8.1	-8.7
7.27	-5.3	0.72	-6.3	-4.4	-5.6	-5.0	-5.0
6.80	-6.5	0.52	-7.1	-6.0	-5.9	-6.6	-6.8
5.60	-5.7	0.36	-5.4	-5.2	-6.0	-5.7	-6.0
4.70	-5.3	0.65	-4.9	-5.4	-6.3	-5.1	-4.6
3.38	-2.6	0.19	-2.5	-2.7	-2.5	-2.8	-2.3
2.92	-2.1	0.14	-2.2	-2.2	-2.0	-1.9	-2.2

200 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
10.79	-13.2	0.76	-14.2	-13.1	-12.8	-12.2	-13.6
8.82	-8.5	0.42	-8.4	-8.3	-9.2	-8.5	-8.1
7.31	-8.1	0.22	-8.1	-8.0	-8.0	-8.4	-7.8
6.76	-7.3	0.42	-7.4	-6.7	-7.4	-7.8	-7.0
5.68	-7.3	0.64	-7.0	-6.6	-7.1	-8.3	-7.4
4.37	-5.3	0.34	-5.8	-5.1	-5.5	-5.1	-5.0
3.46	-3.1	0.13	-3.0	-2.9	-3.2	-3.2	-3.1
2.92	-2.7	0.15	-2.9	-2.5	-2.7	-2.8	-2.7

500 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
10.83	-10.4	0.48	-10.8	-11.0	-10.0	-10.3	-9.9
8.89	-6.8	0.60	-5.9	-6.9	-7.0	-6.5	-7.5
7.30	-6.3	0.46	-6.0	-5.9	-6.6	-6.9	-5.9
6.84	-5.8	1.30	-8.0	-5.7	-4.9	-4.8	-5.4
5.65	-5.0	0.47	-4.3	-5.0	-5.0	-5.2	-5.6
4.45	-4.2	0.26	-4.5	-4.0	-4.0	-4.5	-4.1
3.36	-2.7	0.38	-2.5	-2.3	-2.7	-3.3	-2.6
2.87	-2.3	0.17	-2.4	-2.4	-2.0	-2.3	-2.2

1 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
10.69	-42.7	1.27	-44.6	-42.7	-43.1	-41.7	-41.4
9.96	-42.3	1.11	-43.3	-43.4	-42.3	-41.6	-40.8
8.12	-36.6	0.71	-37.6	-36.8	-35.7	-36.6	-36.2
6.60	-40.5	0.47	-40.2	-41.1	-40.0	-40.9	-40.3
4.79	-38.9	1.00	-38.5	-39.1	-40.6	-38.1	-38.4
3.47	-32.6	0.42	-32.8	-32.7	-32.4	-32.0	-33.1
3.06	-23.5	0.65	-24.3	-23.9	-23.4	-22.7	-23.0
2.74	-18.2	0.50	-18.9	-18.6	-17.7	-17.9	-18.1

3 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
10.90	-46.3	1.11	-47.9	-46.0	-46.5	-46.1	-44.8
10.26	-44.6	0.79	-44.9	-45.7	-44.7	-44.2	-43.6
8.81	-42.0	0.86	-42.8	-41.9	-41.1	-43.0	-41.3
6.72	-40.6	0.93	-41.1	-41.9	-40.1	-40.3	-39.5
5.06	-37.2	0.88	-38.7	-37.0	-36.8	-37.0	-36.4
3.60	-35.3	0.46	-35.7	-35.7	-35.1	-34.6	-35.2
3.07	-26.5	0.64	-27.3	-26.4	-25.8	-27.0	-26.0
2.70	-18.5	0.30	-18.6	-19.0	-18.5	-18.2	-18.4

5 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
10.86	-43.5	0.94	-44.0	-44.6	-43.2	-43.6	-42.1
10.22	-40.0	0.70	-40.7	-39.3	-40.0	-40.7	-39.3
8.96	-40.9	1.14	-42.0	-41.9	-40.6	-40.7	-39.2
6.76	-38.5	0.69	-39.3	-38.7	-37.8	-39.0	-37.8
5.57	-39.5	0.41	-39.3	-40.1	-39.0	-39.5	-39.6
3.57	-33.8	0.49	-33.1	-34.4	-33.9	-33.9	-33.5
3.09	-25.9	0.59	-26.3	-26.6	-25.9	-25.6	-25.1
2.78	-16.3	0.52	-16.2	-16.7	-16.8	-15.5	-16.5

10 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
10.64	-42.8	0.72	-43.3	-42.8	-42.0	-42.2	-43.7
10.22	-44.2	1.29	-45.2	-43.8	-42.5	-45.8	-43.9
8.45	-43.1	0.50	-43.9	-43.1	-43.0	-42.5	-43.2
6.60	-40.8	0.55	-41.1	-40.9	-40.2	-41.5	-40.3
4.84	-38.6	0.47	-38.7	-39.2	-37.9	-38.6	-38.4
3.44	-25.8	0.51	-26.3	-25.0	-26.0	-26.0	-25.5
3.14	-21.6	0.61	-22.5	-21.8	-21.5	-20.8	-21.6
2.85	-17.4	0.42	-17.4	-17.5	-18.0	-17.1	-16.9

30 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
10.72	-38.7	0.52	-39.0	-39.1	-38.2	-39.0	-38.0
8.97	-44.2	0.58	-44.3	-44.0	-45.2	-44.0	-43.7
7.65	-44.6	1.19	-46.0	-44.6	-45.3	-44.0	-42.9
6.69	-42.9	0.38	-43.1	-43.3	-42.9	-42.3	-42.8
5.62	-40.4	0.74	-41.6	-40.5	-39.9	-40.0	-39.8
3.77	-31.7	0.39	-31.9	-31.4	-32.0	-31.1	-31.9
3.22	-24.5	0.48	-24.9	-24.0	-24.9	-23.9	-24.6
2.85	-18.0	0.36	-18.0	-18.5	-18.1	-17.9	-17.5

50 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
10.77	-46.0	0.70	-46.5	-46.3	-46.6	-45.2	-45.2
9.97	-37.7	0.36	-37.7	-38.2	-38.0	-37.5	-37.3
8.85	-46.2	0.60	-46.7	-45.6	-46.2	-46.8	-45.5
6.78	-44.7	0.29	-44.6	-45.1	-44.8	-44.3	-44.7
5.22	-41.5	1.14	-43.4	-41.2	-40.8	-41.6	-40.5
4.00	-36.4	0.45	-36.8	-36.8	-36.4	-36.4	-35.7
3.09	-21.0	0.49	-20.9	-20.6	-21.2	-21.7	-20.5
2.83	-15.4	0.67	-15.0	-15.8	-16.3	-15.0	-14.7

100 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
10.60	-48.7	0.65	-49.6	-48.9	-48.1	-48.0	-48.8
9.07	-47.5	0.83	-46.2	-47.9	-48.4	-47.8	-47.3
7.91	-47.2	0.78	-47.8	-47.5	-47.7	-47.0	-45.9
6.70	-47.1	0.44	-47.4	-46.5	-46.9	-47.6	-46.9
5.85	-43.7	0.46	-44.2	-43.8	-44.0	-43.7	-43.0
4.50	-36.9	0.38	-37.5	-37.1	-36.7	-36.9	-36.5
3.42	-28.0	0.58	-28.8	-27.9	-27.4	-28.3	-27.5
2.83	-14.2	0.30	-14.1	-14.5	-14.3	-14.3	-13.7

200 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
10.41	-50.5	0.46	-50.8	-50.8	-50.6	-50.6	-49.7
9.32	-51.8	0.36	-51.8	-51.8	-51.3	-51.6	-52.3
7.84	-50.8	0.35	-50.5	-50.6	-50.6	-51.2	-51.2
6.68	-50.7	0.61	-50.9	-51.7	-50.2	-50.3	-50.5
5.95	-49.0	0.19	-48.9	-49.0	-48.9	-48.8	-49.3
4.34	-36.9	0.31	-37.1	-37.3	-36.5	-36.8	-36.8
3.35	-25.2	0.29	-25.4	-25.0	-25.6	-25.2	-24.9
2.84	-13.9	0.40	-13.9	-13.8	-14.5	-13.7	-13.4

500 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
10.77	-52.3	0.33	-52.6	-52.6	-51.8	-52.4	-52.3
9.02	-53.3	0.23	-53.4	-53.1	-53.5	-53.5	-53.0
7.86	-52.9	0.18	-52.7	-52.8	-52.9	-53.1	-53.1
6.73	-51.9	0.35	-52.3	-52.3	-51.6	-51.9	-51.6
6.05	-50.0	0.19	-49.9	-50.1	-50.3	-49.8	-50.1
4.68	-42.1	0.72	-41.9	-41.1	-42.1	-42.6	-43.0
3.43	-24.1	1.06	-25.2	-24.2	-22.5	-23.8	-24.9
2.84	-13.4	0.36	-13.0	-13.7	-13.2	-13.8	-13.1

1 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
10.24	-56.5	1.19	-57.3	-55.5	-57.2	-57.5	-54.9
8.98	-55.6	1.08	-57.0	-55.3	-56.1	-55.3	-54.1
7.22	-51.9	0.55	-52.7	-51.3	-51.5	-52.1	-51.7
6.58	-49.2	0.76	-49.2	-50.1	-48.3	-49.8	-48.6
5.76	-41.8	1.07	-42.8	-43.0	-40.9	-41.5	-40.7
3.79	-35.2	0.62	-35.4	-34.5	-35.7		
2.87	-25.8	1.51	-26.0	-27.5	-26.4	-25.5	-23.4

3 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
10.78	-55.4	0.80	-56.2	-55.9	-54.3	-55.9	-54.9
9.06	-52.5	0.70	-53.0	-52.9	-52.2	-53.0	-51.4
8.39	-48.9	0.47	-49.1	-48.3	-49.5	-49.1	-48.6
6.49	-50.1	1.52	-51.8	-48.7	-48.8	-49.7	-51.7
5.48	-44.5	0.36	-44.6	-44.1	-44.8	-44.9	-44.2
3.63	-34.3	0.93	-35.7	-33.5	-33.4	-34.4	-34.4
3.34	-33.9	0.94	-34.3	-34.9	-34.5	-32.6	-33.3
2.87	-30.8	1.39	-32.8	-31.6	-30.3	-29.3	-30.0

5 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
10.24	-58.0	0.58	-58.7	-57.4	-58.0	-58.5	-57.5
8.89	-54.8	1.59	-56.8	-55.6	-54.7	-54.4	-52.5
8.23	-52.4	1.31	-52.1	-51.7	-54.7	-52.2	-51.4
6.53	-48.7	1.21	-49.8	-50.2	-47.5	-48.0	-48.0
5.76	-44.8	0.53	-45.0	-44.5	-45.3	-45.3	-44.1
4.16	-34.1	0.96	-35.6	-34.5	-34.0	-33.2	-33.4
3.68	-33.2	0.71	-33.4	-34.2	-32.3	-33.3	-32.8
2.86	-26.2	0.90	-26.4	-27.6	-25.6	-25.3	-26.0

10 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
10.44	-56.9	1.57	-57.9	-58.9	-54.9	-56.0	-56.8
9.76	-58.2	0.98	-57.4	-57.8	-57.8	-59.9	-58.3
8.45	-53.9	1.06	-54.7	-55.0	-54.1	-52.4	-53.3
6.70	-47.1	0.49	-47.1	-46.8	-47.8	-46.5	-47.2
5.88	-44.9	0.44	-44.8	-44.9	-45.7	-44.7	-44.6
4.19	-37.1	1.24	-38.8	-37.8	-36.8	-36.0	-35.9
3.47	-30.6	0.94	-32.1	-31.0	-29.9	-29.8	-30.4
2.85	-23.7	0.53	-23.4	-24.1	-23.7	-24.2	-22.9

30 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
10.75	-59.0	1.93	-61.5	-60.6	-57.5	-58.5	-57.1
9.35	-59.4	1.03	-60.5	-59.8	-60.2	-58.4	-58.3
8.52	-59.7	1.37	-61.3	-59.6	-57.6	-60.4	-59.6
7.09	-57.9	0.70	-59.1	-57.7	-57.6	-57.7	-57.3
5.95	-55.2	0.75	-56.3	-55.3	-55.4	-54.6	-54.4
4.23	-41.2	1.17	-39.8	-41.5	-42.9	-41.3	-40.5
3.52	-33.6	0.95	-35.2	-32.9	-33.7	-32.9	-33.3
2.85	-24.9	0.33	-25.0	-25.4	-24.9	-24.8	-24.5

50 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
10.63	-58.2	0.66	-59.2	-58.2	-57.9	-58.3	-57.4
9.65	-60.2	1.18	-62.2	-59.7	-60.3	-59.9	-59.1
9.14	-62.1	1.67	-63.9	-63.7	-61.2	-60.1	-61.4
7.15	-60.2	1.78	-62.6	-60.9	-57.7	-59.8	-60.1
6.14	-54.0	0.95	-54.8	-54.7	-54.5	-53.5	-52.6
3.75	-42.8	1.64	-44.5	-44.2	-43.1	-40.9	-41.3
3.41	-37.8	0.45	-38.2	-37.8	-37.8	-38.2	-37.1
2.84	-30.5	1.62	-33.1	-30.4	-29.9	-30.2	-28.7

100 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
10.62	-62.8	0.94	-62.9	-62.6	-62.7	-64.3	-61.7
9.45	-66.4	1.74	-67.6	-68.6	-66.4	-64.9	-64.5
8.01	-63.9	2.11	-66.7	-65.1	-62.9	-61.2	-63.4
7.18	-60.6	1.33	-60.0	-62.2	-61.9	-59.4	-59.6
6.10	-60.3	1.19	-61.8	-61.3	-59.5	-59.4	-59.3
3.95	-59.0	1.29	-61.0	-59.0	-59.1	-58.7	-57.4
3.48	-50.1	2.04	-52.0	-48.8	-52.5	-47.8	-49.5
2.83	-23.3	0.59	-23.3	-24.2	-23.4	-22.6	-23.0

200 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
10.43	-64.1	1.05	-65.1	-64.8	-64.6	-63.1	-62.8
8.50	-65.4	1.59	-67.9	-64.9	-65.8	-64.9	-63.6
7.72	-62.5	1.74	-63.9	-62.0	-64.7	-61.7	-60.4
7.25	-65.1	1.12	-64.3	-66.2	-63.6	-65.9	-65.6
5.73	-58.6	0.82	-59.3	-59.5	-57.5	-58.2	-58.6
4.11	-61.0	0.98	-61.7	-60.6	-62.3	-60.7	-59.8
3.51	-52.8	1.07	-53.6	-53.8	-52.1	-53.2	-51.3
2.83	-39.1	0.81	-39.9	-38.9	-38.7	-40.0	-38.1

500 mg/l

pH	Zeta Potential	Std Dev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	mV	mV	mV	mV	mV	mV
10.48	-66.5	1.46	-66.7	-68.2	-67.4	-64.6	-65.4
8.28	-66.5	0.80	-67.1	-65.9	-67.3	-66.6	-65.4
7.83	-66.8	0.75	-67.8	-66.9	-66.2	-66.0	-67.3
7.23	-65.8	0.54	-65.6	-65.7	-65.8	-65.1	-66.6
5.93	-63.2	0.71	-64.1	-62.8	-63.0	-63.8	-62.4
4.07	-60.7	1.94	-61.6	-63.3	-60.9	-58.5	-59.1
3.56	-53.8	1.33	-53.3	-52.7	-53.6	-53.3	-56.1
2.85	-42.7	1.83	-41.6	-43.3	-45.6	-41.4	-41.4

		IMP4	1mg/l		FF30	1mg/l	
pH	Zeta Potential	stdev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	*mV*	*mV*	*mV*	*mV*	*mV*	*mV*
6.00	-25.3	0.6	-25.4	-25.8	-25.5	-24.3	-25.6
6.98	-31.3	0.8	-30.3	-31.2	-32.4	-31.5	-31.2
7.55	-29.8	0.8	-29.6	-28.8	-29.5	-30.6	-30.6
7.89	-32.2	0.6	-32.8	-32.9	-31.5	-31.9	-31.7
9.33	-31.9	1.3	-33.3	-31.9	-32.4	-29.8	-32.0

		IMP4	1mg/l		FF30	50mg/l	
pH	Zeta Potential	stdev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	*mV*	*mV*	*mV*	*mV*	*mV*	*mV*
5.61	-32.0	0.3	-31.7	-32.3	-32.4	-31.7	-31.9
7.09	-34.2	0.6	-34.8	-33.4	-34.3	-34.7	-33.7
7.34	-37.9	0.4	-38.5	-37.5	-38.1	-37.9	-37.5
7.93	-38.3	0.7	-39.5	-38.2	-38.2	-37.8	-37.6
9.02	-38.8	0.5	-38.9	-39.7	-38.5	-38.6	-38.5

		IMP4	1mg/l		FF30	100mg/l	
pH	Zeta Potential	stdev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	*mV*	*mV*	*mV*	*mV*	*mV*	*mV*
5.41	-37.6	0.2	-37.6	-37.9	-37.7	-37.4	-37.3
7.04	-40.8	0.2	-41.1	-40.5	-40.6	-40.7	-40.9
7.34	-41.9	0.6	-42.5	-41.9	-42.6	-41.3	-41.4
8.28	-40.8	0.4	-41.0	-40.1	-40.7	-41.0	-41.0
9.26	-41.3	0.7	-42.0	-41.7	-41.3	-40.2	-41.1

		IMP4	50mg/l		FF30	1mg/l	
pH	Zeta Potential	stdev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	*mV*	*mV*	*mV*	*mV*	*mV*	*mV*
4.46	-12.2	0.8	-11.3	-13.2	-12.8	-12.1	-11.6
6.45	-16.2	0.5	-16.1	-15.9	-17.2	-16.0	-16.0
7.26	-17.4	0.3	-17.8	-16.9	-17.6	-17.2	-17.4
8.40	-18.6	0.5	-18.7	-19.0	-19.1	-17.9	-18.2
9.28	-18.7	0.5	-19.2	-18.5	-18.6	-19.0	-18.0

		IMP4	50mg/l		FF30	50mg/l	
pH	Zeta Potential	stdev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	*mV*	*mV*	*mV*	*mV*	*mV*	*mV*
4.99	-15.4	0.6	-16.0	-15.5	-15.4	-15.7	-14.4
6.59	-19.6	0.4	-19.3	-20.2	-19.6	-19.3	-19.8
7.02	-20.5	0.7	-21.3	-20.8	-20.5	-20.5	-19.3
8.45	-21.5	0.4	-21.9	-21.9	-21.2	-21.4	-21.0
9.20	-23.2	0.3	-23.3	-23.7	-23.2	-23.1	-22.9

		IMP4	50mg/l		FF30	100mg/l	
pH	Zeta Potential	stdev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	*mV*	*mV*	*mV*	*mV*	*mV*	*mV*
5.01	-16.1	0.9	-16.8	-16.9	-16.4	-14.7	-15.8
6.86	-21.3	0.3	-21.0	-21.3	-21.9	-21.2	-21.2
7.89	-23.0	0.5	-23.1	-22.4	-22.6	-23.5	-23.6
8.48	-24.2	0.4	-24.4	-24.7	-23.9	-23.6	-24.4
9.23	-25.4	0.5	-26.1	-25.6	-24.6	-25.2	-25.4

		IMP4	100mg/l		FF30	1mg/l	
pH	Zeta Potential	stdev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	*mV*	*mV*	*mV*	*mV*	*mV*	*mV*
4.64	-11.0	0.6	-11.5	-10.5	-11.7	-10.5	-11.0
6.51	-12.9	0.6	-13.0	-12.8	-12.3	-13.8	-12.6
7.07	-14.9	0.7	-15.2	-14.6	-14.4	-14.3	-16.0
8.45	-14.6	0.2	-15.0	-14.3	-14.6	-14.6	-14.6
9.25	-14.9	0.7	-14.7	-15.7	-15.6	-14.4	-14.2

		IMP4	100mg/l		FF30	50mg/l	
pH	Zeta Potential	stdev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	*mV*	*mV*	*mV*	*mV*	*mV*	*mV*
4.89	-9.6	1.3	-11.5	-9.3	-8.7	-10.1	-8.2
7.04	-16.4	0.6	-17.3	-16.5	-16.1	-16.1	-15.8
7.90	-17.4	0.2	-17.2	-17.5	-17.5	-17.4	-17.2
8.52	-19.7	0.5	-18.9	-20.0	-19.7	-20.3	-19.7
9.13	-20.0	0.4	-20.7	-20.0	-20.0	-19.6	-19.9

		IMP4	100mg/l		FF30	100mg/l	
pH	Zeta Potential	stdev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	*mV*	*mV*	*mV*	*mV*	*mV*	*mV*
5.55	-13.5	0.9	-15.0	-13.1	-12.7	-13.1	-13.8
7.07	-18.7	0.6	-18.6	-17.9	-19.1	-19.4	-18.6
7.47	-19.2	0.4	-19.4	-19.7	-19.1	-18.5	-19.2
8.13	-19.7	0.4	-20.0	-19.7	-19.4	-20.3	-19.2
8.75	-20.7	0.5	-20.7	-21.4	-20.8	-20.3	-20.2

FF30 1mg/l NaHMP 1mg/l

pH	Zeta Potential	stdev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	*mV*	*mV*	*mV*	*mV*	*mV*	*mV*
4.77	-32.9	1.3	-34.3	-31.0	-33.1	-32.4	-33.8
5.81	-43.5	1.2	-45.4	-43.0	-42.9	-42.4	-44.0
6.79	-46.2	0.9	-47.3	-46.3	-46.9	-45.5	-45.1
7.28	-44.5	0.7	-44.4	-44.4	-45.2	-43.4	-45.0
9.01	-47.9	1.4	-49.3	-49.2	-46.1	-48.0	-47.1

FF30 1mg/l NaHMP 50mg/l

pH	Zeta Potential	stdev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	*mV*	*mV*	*mV*	*mV*	*mV*	*mV*
4.92	-50.4	0.4	-50.7	-50.8	-50.3	-50.3	-49.9
7.25	-52.8	0.4	-52.6	-52.5	-53.4	-52.8	-52.6
7.44	-52.5	1.0	-53.4	-53.5	-52.4	-51.8	-51.2
8.54	-58.5	1.4	-58.7	-56.9	-60.2	-59.5	-57.2
9.11	-56.5	1.2	-58.7	-55.7	-56.1	-56.0	-55.9

FF30 1mg/l NaHMP 100mg/l

pH	Zeta Potential	stdev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	*mV*	*mV*	*mV*	*mV*	*mV*	*mV*
4.72	-54.9	0.9	-55.6	-55.5	-55.2	-54.8	-53.3
6.72	-60.4	2.7	-61.7	-60.4	-58.4	-57.4	-64.2
7.54	-62.4	1.3	-64.4	-61.0	-61.9	-63.0	-61.6
8.48	-61.4	0.7	-62.5	-60.9	-61.1	-60.7	-61.6
9.00	-60.7	2.3	-58.6	-58.4	-63.8	-62.0	-60.8

FF30 50mg/l NaHMP 1mg/l

pH	Zeta Potential	stdev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	*mV*	*mV*	*mV*	*mV*	*mV*	*mV*
5.10	-39.9	0.3	-39.7	-39.8	-39.6	-40.3	-40.1
6.83	-47.9	0.7	-48.3	-48.6	-47.1	-47.1	-48.2
7.38	-48.8	0.3	-48.6	-49.0	-48.8	-49.1	-48.5
8.54	-47.3	0.4	-47.1	-47.0	-46.9	-47.4	-47.9
9.23	-49.5	0.3	-49.8	-49.2	-49.8	-49.5	-49.2

FF30 50mg/l NaHMP 50mg/l

pH	Zeta Potential	stdev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	*mV*	*mV*	*mV*	*mV*	*mV*	*mV*
5.13	-50.7	0.6	-51.1	-51.5	-50.0	-50.2	-50.5
6.92	-54.1	0.7	-55.2	-53.9	-54.3	-53.4	-53.8
7.45	-54.2	0.6	-53.4	-54.9	-54.6	-53.7	-54.4
8.02	-54.4	0.8	-53.9	-55.0	-55.4	-54.3	-53.5
9.35	-54.2	0.3	-53.7	-54.4	-54.2	-54.3	-54.6

FF30 50mg/l NaHMP 100mg/l

pH	Zeta Potential	stdev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	*mV*	*mV*	*mV*	*mV*	*mV*	*mV*
5.07	-54.4	0.8	-55.7	-54.5	-53.9	-53.5	-54.3
6.91	-55.7	0.9	-56.8	-56.3	-55.4	-55.6	-54.4
7.58	-55.0	0.3	-55.2	-55.2	-55.1	-54.6	-54.7
7.96	-56.1	0.9	-56.0	-57.4	-56.3	-55.6	-55.0
9.00	-55.9	0.5	-56.6	-56.0	-56.0	-55.4	-55.4

FF30 100mg/l NaHMP 1mg/l

pH	Zeta Potential	stdev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	*mV*	*mV*	*mV*	*mV*	*mV*	*mV*
4.31	-33.9	0.4	-34.7	-33.8	-33.6	-33.7	-33.8
6.18	-49.4	0.6	-50.3	-49.0	-49.7	-48.9	-49.3
7.04	-51.6	0.7	-51.5	-50.9	-52.8	-51.7	-51.3
7.96	-52.0	0.3	-51.7	-52.3	-51.8	-52.4	-51.9
9.55	-52.3	0.5	-52.7	-52.8	-52.2	-52.1	-51.6

FF30 100mg/l NaHMP 50mg/l

pH	Zeta Potential	stdev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	*mV*	*mV*	*mV*	*mV*	*mV*	*mV*
4.86	-47.6	0.7	-47.9	-48.6	-47.1	-47.5	-46.7
6.38	-53.9	0.7	-53.8	-53.0	-53.8	-54.9	-54.2
7.39	-54.1	0.4	-53.7	-54.5	-54.1	-53.9	-54.5
8.25	-52.9	0.2	-52.8	-52.9	-53.0	-53.1	-52.6
9.73	-53.8	0.3	-53.6	-53.7	-53.9	-54.4	-53.6

FF30 100mg/l NaHMP 100mg/l

pH	Zeta Potential	stdev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	*mV*	*mV*	*mV*	*mV*	*mV*	*mV*
4.61	-48.0	0.6	-48.7	-48.1	-47.6	-47.3	-48.4
6.62	-53.1	0.3	-53.2	-53.1	-52.5	-53.3	-53.3
7.49	-53.8	0.4	-54.0	-53.2	-54.1	-53.7	-54.0
7.94	-54.0	0.7	-54.2	-54.9	-54.3	-53.1	-53.6
9.55	-54.2	0.9	-53.1	-55.4	-54.1	-53.8	-54.5

		IMP4 1mg/l			NaHMP 1mg/l		
pH	Zeta Potential	stdev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	*mV*	*mV*	*mV*	*mV*	*mV*	*mV*
2.91	-13.8	0.5	-13.4	-13.5	-13.9	-14.6	-13.6
3.29	-18.8	0.3	-18.4	-19.2	-18.6	-18.9	-18.8
3.55	-20.4	0.3	-20.6	-20.2	-20.9	-20.1	-20.3
4.50	-29.9	1.0	-29.0	-30.8	-30.4	-30.6	-28.7
7.04	-34.8	0.4	-35.5	-34.6	-34.5	-34.8	-34.5
8.77	-35.9	0.3	-36.3	-35.9	-36.1	-35.7	-35.5
10.32	-36.2	0.4	-36.9	-36.2	-36.1	-36.0	-35.9
10.84	-36.2	0.7	-36.8	-36.3	-36.0	-36.7	-35.0

		IMP4 1mg/l			NaHMP 50mg/l		
pH	Zeta Potential	stdev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	*mV*	*mV*	*mV*	*mV*	*mV*	*mV*
2.79	-21.0	0.7	-22.1	-20.9	-20.5	-21.1	-20.5
3.47	-28.3	1.0	-28.7	-28.5	-29.7	-27.7	-27.0
3.97	-34.4	1.5	-34.3	-36.8	-34.5	-33.3	-33.2
6.27	-40.7	0.7	-40.7	-40.7	-41.8	-40.3	-39.8
7.09	-41.6	1.1	-41.3	-41.1	-43.0	-42.4	-40.3
8.03	-41.7	0.9	-42.4	-41.3	-42.0	-40.4	-42.4
9.14	-42.4	1.5	-43.2	-42.3	-44.1	-42.1	-40.1
10.72	-44.3	0.7	-45.2	-43.7	-43.5	-44.3	-44.6

		IMP4 1mg/l			NaHMP 100mg/l		
pH	Zeta Potential	stdev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	*mV*	*mV*	*mV*	*mV*	*mV*	*mV*
5.05	-47.8	0.7	-47.1	-48.6	-48.3	-47.2	-47.6
6.57	-48.9	0.9	-47.5	-49.8	-49.6	-49.2	-48.4
7.43	-48.3	0.6	-47.8	-48.6	-49.1	-48.0	-47.8
8.05	-47.7	0.9	-47.9	-49.1	-47.2	-46.7	-47.6
9.08	-49.5	0.9	-49.6	-49.6	-50.9	-48.7	-48.6

		IMP4 50mg/l			NaHMP 1mg/l		
pH	Zeta Potential	stdev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	*mV*	*mV*	*mV*	*mV*	*mV*	*mV*
4.73	-11.0	0.3	-11.3	-11.2	-11.1	-10.6	-11.0
6.33	-18.6	0.5	-18.6	-19.5	-18.5	-18.2	-18.4
7.01	-21.1	0.7	-20.6	-20.6	-20.6	-21.3	-22.3
8.58	-24.6	0.8	-25.5	-24.5	-24.7	-23.4	-24.7
9.18	-22.8	0.4	-22.8	-22.5	-23.6	-22.6	-22.7

		IMP4 50mg/l			NaHMP 50mg/l		
pH	Zeta Potential	stdev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	*mV*	*mV*	*mV*	*mV*	*mV*	*mV*
4.68	-21.7	0.9	-23.0	-21.1	-22.3	-21.4	-20.7
6.51	-27.2	1.6	-26.3	-25.7	-26.6	-27.7	-29.7
7.17	-27.6	1.0	-26.3	-28.8	-27.1	-27.4	-28.2
8.00	-28.6	0.7	-27.7	-28.9	-28.0	-29.3	-29.2
9.08	-27.9	0.5	-27.5	-28.0	-28.7	-27.9	-27.6

		IMP4 50mg/l			NaHMP 100mg/l		
pH	Zeta Potential	stdev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	*mV*	*mV*	*mV*	*mV*	*mV*	*mV*
4.36	-22.8	0.7	-22.1	-23.8	-22.7	-22.3	-23.1
7.00	-25.4	0.7	-24.9	-26.1	-24.5	-25.3	-26.1
7.39	-26.5	1.7	-24.8	-29.1	-27.0	-25.5	-26.1
8.30	-27.5	0.6	-27.2	-28.5	-27.1	-27.4	-27.4
9.30	-28.9	0.8	-28.7	-29.3	-30.0	-28.0	-28.4

		IMP4 100mg/l			NaHMP 1mg/l		
pH	Zeta Potential	stdev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	*mV*	*mV*	*mV*	*mV*	*mV*	*mV*
2.83	-2.8	0.3	-2.3	-2.8	-3.0	-2.9	-2.8
3.35	-3.9	0.2	-4.2	-3.8	-3.8	-3.8	-3.8
3.68	-5.1	0.2	-4.9	-4.9	-5.3	-5.1	-5.3
5.29	-11.0	1.2	-12.2	-10.2	-9.4	-11.9	-11.2
7.02	-13.3	0.9	-13.6	-14.0	-13.5	-11.8	-13.7
8.91	-14.5	0.4	-14.6	-14.4	-14.9	-13.8	-14.8
10.12	-14.3	0.6	-14.9	-13.8	-14.5	-13.5	-14.9
10.75	-18.1	0.5	-18.2	-18.7	-17.8	-18.5	-17.5

		IMP4 100mg/l			NaHMP 50mg/l		
pH	Zeta Potential	stdev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	*mV*	*mV*	*mV*	*mV*	*mV*	*mV*
2.73	-4.7	0.3	-5.0	-4.5	-4.5	-4.4	-5.1
3.39	-7.5	0.5	-7.4	-7.3	-7.1	-8.4	-7.4
4.05	-11.1	0.7	-10.8	-11.7	-11.7	-11.1	-10.1
6.08	-18.5	1.0	-18.6	-18.2	-17.7	-17.7	-20.1
7.05	-18.9	0.6	-18.9	-18.3	-20.0	-18.8	-18.7
8.14	-19.3	0.5	-19.1	-19.3	-18.7	-19.8	-19.8
9.22	-19.7	0.6	-20.8	-19.6	-19.3	-19.4	-19.3
10.73	-23.0	0.7	-23.3	-23.8	-22.5	-23.3	-22.2

		IMP4 100mg/l			NaHMP 100mg/l		
pH	Zeta Potential	stdev	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
	mV	*mV*	*mV*	*mV*	*mV*	*mV*	*mV*
4.41	-19.0	0.0	-19.0	-19.0	-19.0	-19.0	-19.1
6.72	-19.9	1.2	-21.5	-20.6	-19.5	-19.4	-18.3
7.28	-22.3	0.9	-21.5	-22.0	-23.8	-22.1	-22.1
8.13	-20.9	0.8	-20.8	-22.0	-19.8	-21.0	-20.8
9.08	-22.9	0.7	-22.0	-22.6	-22.5	-23.9	-23.3