FINDING BASELINE FLOTATION PARAMETERS FOR THE REVERSE FLOTATION BENEFICIATION OF SISHEN LOW GRADE BANDED IRON ORE

By

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ABSTRACT

Anglo American Kumba Iron Ore, a member of the Anglo American plc group, owns high-quality resource bases in both South Africa and Brazil. One of these, Sishen iron ore mine, is a South African mine, where lumpy high-grade hematite ore is treated. As these easily treatable resources depletes, alternative processing methods need to be investigated to ensure sustainability. Low-grade iron ores are commonly beneficiated by a combination of magnetic separation, gravity separation and direct- or reverse flotation.

Fine size iron ore fractions, less than 150 micron, requires flotation to be beneficiated to high-grade saleable iron ore product for pelletizing. Three flotation routes have been developed for iron ores outside of Africa: (i) reverse cationic flotation of quartz; (ii) direct anionic flotation of iron oxides; and (iii) reverse anionic flotation of activated quartz. Although vast ores of increasingly complex nature have been identified in Africa, existing literature does not mention any iron ore flotation practices that are currently employed or investigated on this continent. The aim of this study was to prove that low grade Sishen banded iron ore can be upgraded to a saleable iron product by froth flotation. This was proven by a mineralogical study of banded low grade Sishen iron ore; the evaluation of suitable reagent suites; flotation cell conditions; additional beneficiation circuit stages; evaluation of the developed flotation regime on varied feed compositions and determination of correlations between the mineral liberation analysis and flotation results.

The fundamental mechanism for selective flotation of hematite is attributed to the selective depression of hematite, where quartz particles may be removed from hematite in a narrow pH range. In this pH range, amine collectors form an ion-molecular complex, which induces hydrophobicity on the surface of quartz particles and attain its frothing character. Reverse cationic flotation is the most-common approach for hematite-quartz separation. Amines are used as collecting reagent; two amine variants supplied by Clariant, have been identified to exhibiting superior silica collecting performance. Starch is the most commonly employed hematite depressant.

The ore characterisation of seven clearly identified low grade banded iron formation, BIF, iron ore samples from Sishen iron ore mine, and an equal blend of these seven BIF samples comprises of Chemical composition (by x-ray fluorescence, XRF), mineralogical composition (x-ray diffraction, XRD and mineral liberation analysis, MLA), particle size distribution (sieve tests and laser diffraction) and mineral liberation (by scanning electron microscopy, SEM and MLA).

Baseline flotation parameters for reverse flotation of low grade Sishen iron ore BIF, which included bench-scale laboratory flotation tests were established by the evaluation of the depressant type, depressant dosage and depressant dosing stage, dispersant type and dispersant dosage, collector dosage and mixed collector ratio, grinding size and flotation circuit configuration.

Results from this investigation identify hematite as the main iron bearing mineral in low grade Sishen iron ore and quartz as the main gangue mineral, with limited amounts of annite and kaolinite. The iron content ranges between 25% and 39% for the received individual samples. The particle size distribution, with 80% passing 1.1 mm, was too coarse for flotation. Grinding curves were constructed to produce a fine flotation, medium flotation and coarse flotation particle size range.

Laboratory bench scale flotation tests confirm strong pH dependence for the recovery of hematite, where a natural hydrophobicity is exhibited at pH 7. These tests confirmed that caustisized starch is a suitable depressant for hematite minerals in a low grade Sishen BIF iron ore and that the addition of sodium silicate dispersant may improve the iron product grade. The depressant dosage has a minor effect on the flotation results, and the depressant mechanism is largely dependent on the flotation pulp pH.

Froth stability is greatly influenced by a change in the amine collector dosage, where excessive amounts of fine particles also over stabilise the froth bed and it is not possible to control the froth bed height at collector dosages of larger than 25 g/t/stage.

Alteration of the flotation circuit, from a six stage rougher float to a nine stage rougher float and six stage scavenger float, after additional milling and depressant dosing, yielded the required target of at least 64% Fe and 30% recovery to the tails

(iron product). With no preparation by de-sliming, an iron recovery of 34.7% to the iron product can be achieved by flotation alone. At 66.4% iron, MLA analysis confirmed the iron product to be of a saleable high grade. The MLA analysis also showed the limit of flotation performance to be an excessive entrainment of iron-containing particles after the second scavenger flotation stage.

The use of this reagent suite on individual BIF ores shows that more than 98.5% of the silicate materials can be removed to the froth phase. As with the composite BIF material, an additional scavenger stage is required to reach the target percentage iron recovery of 30%.

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

1.1 World Iron Ore Production

The global output of contained iron from iron ore was estimated at 1.4 Gt in 2011, 8% higher than in 2010, of which China was the largest producer, accounting for approximately 25% of the total production, (Jorgenson, 2012) . World production of iron ore is projected to 1.75 Gt in 2017, although future supply and demand for iron ore is closely linked to the resolution of the sovereign debt crisis and recovery of the European economy, as well as the demand for this commodity in China (Menzie *et al.*, 2013).

1.2 Saleable High-grade Iron Ore Products

Iron is the most widely used of all metals, since it is a key component in steel. The global market for iron ore is thus critically linked to the health of the global steel industry. China, which accounts for approximately 45% of the global steel producing market, is now considered to be the world biggest steel producing country, with steel production reaching record levels in 2011 (Anglo American plc, 2012).

In the production of iron in either the conventional blast furnace or a direct reduction method, it is of great importance to convert the ore to a high-grade iron oxide. The conversion to high-grade iron oxide is beneficial, as neither of these furnaces can be operated properly when high slag volumes need to be tolerated (Zervas *et al.*, 1996). Problems, such as the high cost of energy required to melt extra material, lowered furnace throughput due to minimal gangue minerals present and iron product loss to slag entrainment, may be minimised by making use of a higher grade feed product (Feinmann, 1999).

Keeping the above mentioned in mind, it is common knowledge that iron-rich mineral deposits, from which lump ore can be directly shipped, or a relatively simple beneficiation method can be employed on large particles, are depleting. Ore reserves are becoming increasingly complex, with intricate mineral association of iron bearing minerals and minerals bearing penalty elements. The world standard specifications for iron ore is given in Table 1.1. Flotation concentrate is generally used as pelletizing feed material.

Table 1.1: World standards on iron ore product (Fuerstenau *et al.*, 2007)

Product	**Fe (%)**	**SiO_2 (%)**
Before Pelletizing	67-68	1.6-1.7
Direct Reduction Feed	68-69	0.6-0.7

The inclusion of additional impurities will relate to higher energy input being required in the steelmaking process as well as increased amounts of iron being lost due to slag entrainment. Thus, it is very important to reduce the amount of gangue minerals fed to these processes as much as possible. A saleable high-grade iron ore product may consist of lumpy iron ore, iron ore sinter fines or pelletized iron ore ultrafines. Quality assessment of iron ore product is classified in terms of composition (chemical analysis of the ore). Fines product can be sold from 52% Fe to 65% Fe, with the largest portion of merchantable iron ore product.

1.3 Iron Ore in South Africa

Anglo American Kumba Iron Ore operates three mines in South Africa, namely Sishen and Kolomela in the Northern Cape and Thabazimbi Mine in Limpopo as shown in Figure 1.1. Anglo American Kumba Iron Ore is one of the world's top five iron ore producers, having a high-quality resource base in both South Africa and Brazil. (Anglo American, 2012).

As a leading supplier of seaborne iron ore, Kumba Iron Ore Ltd, a member of the Anglo American plc group, exported over 36.1Mt high-grade iron ore to their customers around the world, including China, Korea, Japan, as well as several Middle Eastern and European countries, as seen in Figure 1.1 (Morgan *et al*., 2011).

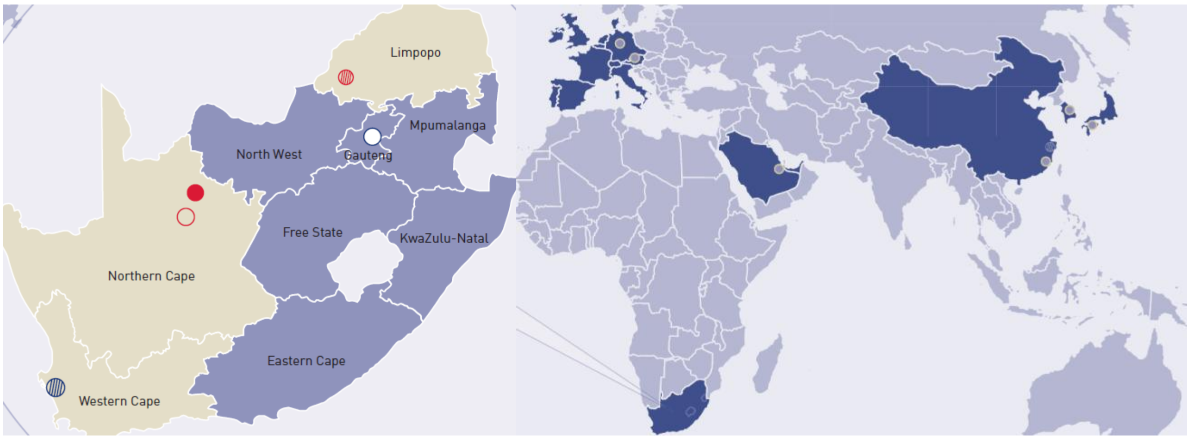

Figure 1.1: Local operations in South Africa for Kumba Iron Ore (left) and customers of Anglo American Kumba Iron Ore Ltd around the globe (right). (Morgan *et al*., 2011)

1.4 Overview of Sishen Operations

According to Astrup *et al.* (1998), the principal iron bearing mineral at the Sishen Mine is hematite, which is primarily present in the banded iron formation. Gangue minerals mainly include quartz, kaolinite, calcite and muscovite. Other weathered forms of these minerals are also present in certain areas of the mine, with varied degrees of the mineral intergrowth. The largest portion of gangue may be classified as silicate minerals, which need to be separated from the iron oxide ore. Continued mining activity depletes this lumpy high-grade ore, which resulted in the need to expand the life of mine by developing processes for the beneficiation of low-grade ores and optimising the current beneficiation process, such as the Sishen expansion project (SEP) (Morgan *et al.,* 2011).

1.5 Options for Beneficiation of Low Grade Iron Ores

The following are some of the beneficiation routes normally employed for the production of high-grade iron ore products from a low-grade iron ore:

- Magnetic separation;
- Gravity separation; and
- Direct- and reverse flotation.

1.5.1 Magnetic Separation

Iron ore, which commonly comprises of various ratios of hematite and magnetite, is commonly beneficiated by magnetic separation, due to the magnetic character of these minerals varying from that of the gangue minerals (usually Goethite, apatite or silicates). The tailings of these magnetically separated materials are then usually beneficiated by froth flotation or in some cases where the iron content of the magnetic concentrate is too low, this is also subjected to flotation (Peres *et al.*, 2007).

Although high-intensity magnetic separators, such as the carousel type SLon, are extensively used for the beneficiation of paramagnetic hematite, some of the drawbacks include a decrease in the magnetics recovery percentage, with a decrease in particle size depending on the liberation characteristics of the ore, (Kelly & Spottiswood, 1989). A general guide of the magnetic attractability ranges of hematite and quartz (relative to iron as 100) is given in Table 1.2. These attractability numbers give an indication of the probability of the mineral to be affected by magnetic attraction, where the probability of hematite being attracted to a magnetic source is larger than what it is for quartz.

Table 1.2: Relative magnetic attractability of hematite and quartz (adapted from Kelly & Spottiswood, 1989)

Mineral	Source of Sample	Relative Attractability
Hematite	Lake Superior District & Iron Mountain, Minnesota	0.531 to 0.769
Quartz	Maine & Unknown	-0.0005 to 0.175

1.5.2 Gravity Separation

Kumba Iron Ore Ltd is the world's sole hematite producer to wholly beneficiate its product, which is currently carried out by dense medium separation and jig technology (Morgan *et al*., 2011). It is also not uncommon to use mineral spirals for upgrading low-grade iron ores. Again, one of the limitations is a decrease in efficiency at smaller particle sizes, due to the increased drag force on the particle overcoming gravitational forces (Kelly & Spottiswood, 1989). The specific gravity of hematite and quartz, which is the mineral property exploited in gravity separation, is shown in Table 1.3.

Table 1.3: Specific gravity of hematite and quartz (adapted from Kelly & Spottiswood, 1989)

Mineral	**Specific Gravity**
Hematite	4.6
Quartz	2.2

1.4.3 Direct- and Reverse Flotation

In the flotation process, appropriately sized and liberated particles are mixed with a flotation medium, usually water, to form a pulp suspension (flotation feed), which is fed to a mixing tank such as the mechanical flotation cell in Figure 1.2.

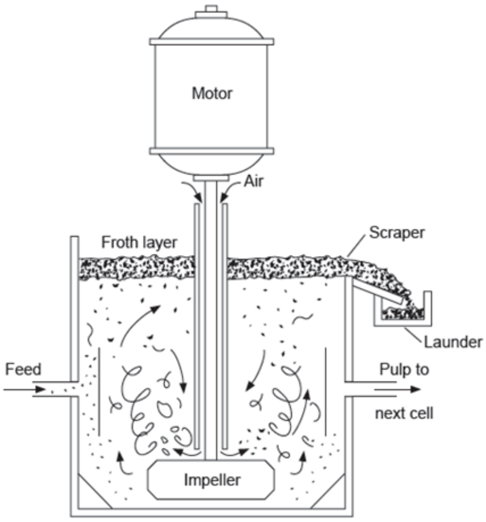

Figure 1.2: Schematic of a mechanical flotation cell (Perry & Green, 1997)

This suspension is then agitated in a mixing tank for conditioning and deposited in a separation vessel (flotation cell), where the slurry is further agitated by means of an impeller in a rotor-stator configuration. Once a secondary fluid is introduced in the system, mineral separation can occur. In the separation by means of froth flotation, where air is introduced as the second fluid phase in the system, mineral separation is achieved when mineral particles with a highly hydrophobic surface are concentrated in this air fluid phase in the froth layer, and collected in the froth launder (with or without the use of mechanical scrapers) (Perry & Green, 1997). In direct flotation, the hydrophobic mineral surfaces are that of the valuable mineral.

In contrast to direct flotation, reverse flotation is a separation system where the gangue minerals are floated and the minerals of value (in this case hematite), reports to that section which is usually labelled as the “tails” of the system. Indirect flotation is usually implemented on high-grade ores, as the amount of reagent required to selectively float the gangue minerals is usually less than the requirement for low-grade ores (Kelly & Spottiswood, 1989).

Iron ore is commonly upgraded by the reverse flotation process due to its inherently high iron-grade and a limited amount of impurities, usually silicates, to be floated and in very rare cases iron ore of very low grades are floated directly (Peres *et al*., 2007). In the industry the normal flotation circuit is made up of rougher, scavenger and cleaner stages, where gangue is floated in each stage, and the concentrate is retained in the flotation cell.

1.6 Iron Ore Flotation Application

1.6.1 Iron Ore Flotation

The most common gangue mineral to be separated from iron ores is quartz. In Brazil, this is achieved in the fine size fraction (<150 micron), by flotation. Three different flotation routes were developed between 1930 and 1940, by Hanna Mining, USBM and Cyanamid (Araujo *et al.*, 2005). These are still the most well-known flotation routes developed today:

- Reverse cationic flotation of quartz;
- Direct anionic flotation of iron oxides; and
- Reverse anionic flotation of activated quartz

1.6.1.1 Reverse Cationic Flotation of Quartz

The most widely employed method for concentration of iron ores by flotation is the reverse cationic flotation of quartz. In this process, quartz is collected to the froth phase with the use of ether amines that have been partially neutralised by acetic acid addition, or a combination of diamines and monoamines (Araujo *et al.*, 2005). Non-modified starches, such as the widely used corn starch, are commonly used to depress iron ore minerals.

1.6.1.2 Direct Anionic Flotation of Iron Oxides

The direct anionic route of flotation prominently represented the former plant practice for flotation of iron oxides. In particular instances, such as the upgrading of low-grade ores, or material stored in tailings ponds, the use of the anionic direct route of flotation of iron oxides, seems attractive. However, this flotation route has difficulty in successfully depressing gangue minerals such as quartz, with the use of sodium silicate as a depressant, and the use of anionic fatty acids or amphoteric collectors does not yield low enough silica content in the concentrate (Araujo *et al.*, 2005).

1.6.1.3 Reverse Anionic Flotation of Activated Quartz

The last of the most well-known iron ore flotation routes is however not commonly employed anymore, as this route of quartz flotation was employed when mineral processors did not have access to amines (Araujo *et al.*, 2005). In general fatty acids were used for this flotation route.

A more recent batch scale study, conducted by Vale Iron Ore, shows encouraging results, where the main advantage of this route, over reverse cationic flotation, was found to be its capacity for selective separation of quartz and hematite ultra-fines (Ma *et al.*, 2011). They also confirmed that the rate of flotation is much slower and that the overall attainable iron grade is lower than that of the reverse cationic flotation route.

1.7 Hypothesis

The main hypothesis for this project is:

Low grade Sishen banded iron ore can be upgraded to a saleable iron product by froth flotation, with a minimum of 30% recovery.*

The aim of this project is firstly to prove that a saleable iron ore product with sufficient iron content can be attained through froth flotation. Many economic factors such as comminution and ore handling, for this specific ore, is not yet defined and its definition lies outside the scope of this investigation. The proof of concept is based on attaining an iron recovery of 30% or more.

**A saleable high-grade iron ore product may range from 62-67% Fe. A target of 64% Fe is set for the project, but blending of lower percentage iron grade concentrates may increase recovery.*

1.8 Objectives

To prove this hypothesis, the following objectives should be achieved:

- A mineralogical study of banded low grade Sishen iron ore samples;
- Evaluate suitable reagent suites, in terms of depressant and dispersant types added to suitable amine collectors, for the reverse flotation of low grade Sishen banded iron ore;
- Determine flotation cell conditions, focused on the flotation pulp pH, which are suited for the upgrading of low grade Sishen banded iron ore by froth flotation
- Investigate additional beneficiation circuit stages to improve froth flotation results of low grade Sishen banded iron ore;
- Evaluate the developed flotation regime on different low grade Sishen banded iron ore samples, with varied feed compositions; and
- Determine possible correlations between the mineral liberation analysis and the flotation results from the developed reagent regime for low grade Sishen banded iron ore.

1.9 Overview

The literature review in Chapter 2 focuses on the basic principles and plant practice for flotation as applicable to the flotation of iron ores. The literature review includes physical-, chemical- and electrical characteristics of iron ore flotation, the influence of water as a flotation medium as well as different flotation surfactants commonly used in iron ore flotation. A review is done on commonly employed flotation machines, as well as laboratory flotation practice.

Chapter 3 describes the test methodology employed to establish the base line flotation parameters for the reverse flotation of iron ore. The test methodology supplied detail on the methods, procedures and equipment used for both the ore characterisation and laboratory flotation tests.

The results and discussion in Chapter 4 gives the interpretation of the results obtained in this study. Chapter 5 concludes the study, highlighting key findings and trends. Future work identified from this study is proposed in Chapter 6.

Chapter 2: Literature Study

2.1 Introduction to Flotation

Froth flotation may be described as the selective separation of specific liberated mineral particles from a liquid-solid suspension, in which both unwanted gangue and valuable mineral particles are present (Gorain *et al*., 2007). Complex and ill-understood principles govern the flotation response, where the “interactive engineering system” of flotation is considered to be made up of three broad groups of different variables (Gorain *et al*., 2007): Chemical, operational and machine.

Chemical variables are the conditions where the property of reagents to render a mineral particle surface selectively as hydrophobic, governs the concentration process (Kelly & Spottiswood, 1989). Plant practice is dominantly covered by operational variables. The physical-mechanical conditions of the flotation process are manipulated by the flotation machine characteristics (Kelly & Spottiswood, 1989).

2.1.1 Iron Ore Flotation Plant Practice for Brazil

Because only minor impurities need to be floated from high-grade iron ore deposits, it is common for reverse flotation to be employed. Alkyl ether amines, which exhibit a natural frothing character, are the most commonly used collectors, which may also be enhanced by the addition of ether monoamines or ether diamines (Peres *et al.*, 2007). Some processing plants do however still make use of certain frothers for froth modification.

Various combinations of flotation machines are used for the flotation of iron ore. The choice of flotation machine depends on the ore lithology and beneficiation mantra of the organisation. A simplified flow sheet from the Conceição concentrator in Brazil, Figure 2.1, shows the use of both mechanical and column flotation cells. It is essential to perform a slimes removal at 10- 20 micron for Brazilian iron ores when cationic reverse flotation is used. The de-slimed feed is then conditioned with a depressant (caustisized starch), at a high pulp density for ten minutes. This is followed by an additional conditioning stage, where the collector is added and conditioned for another five minutes, before the ore is floated at a pH of 8.5-9.0 (Peres *et al.*, 2007).

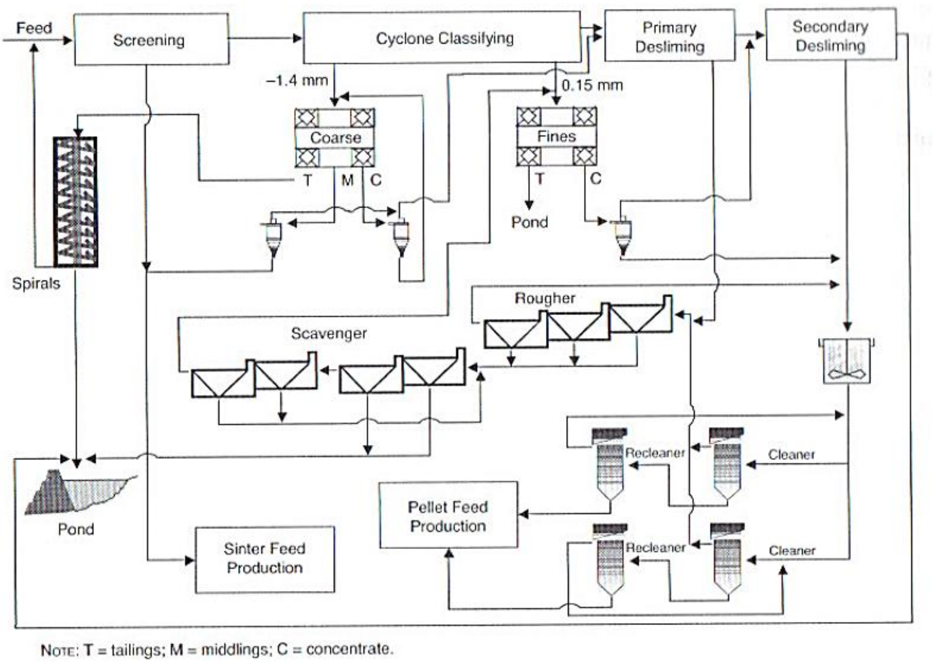

Figure 2.1: Simplified flow sheet of the Conceição Concentrator in Brazil (Peres *et al.*, 2007)

In the rare occasion that the iron ore grade is too low for reverse flotation, a direct flotation route is followed. The implementation of a direct flotation route entails the use of a petroleum sulphonate in combination with a fatty acid being used as collector, with which the pulp is conditioned for ten minutes. The pulp pH is then altered to between pH 4 and pH 5, where after flotation starts (Peres *et al.*, 2007).

2.1.2 International Iron Ore Flotation

The reverse flotation of iron ore is also largely implemented in China, one of the world's largest steel producers. It has been reported that it is not necessary to de-slime the flotation feed on these concentrators (Houot, 1983). Houot (1983) contributed this to the use of anionic flotation collectors, which are considered relatively more tolerating towards ultrafine slimes. This report has yet to be validated by experimental evidence. A detailed study by Ma, Marques & Gontijo (2011) investigated China's iron ore processing practice, and found that the flotation process feed is magnetically separated in numerous stages, which could also result in a de-sliming effect.

2.2 Basic Principles in Flotation

Flotation is a century old separation method, based on the difference in particle surface properties of various minerals.

2.2.1 Preferential Separation based on Hydrophobicity

A difference in either of the main surface parameters, surface energy or excess surface charge, may be exploited for a preferential separation. When the particle is contacted with either two immiscible fluids (such as water and oil, in bulk oil flotation), or two fluids (such as water and gaseous bubbles, in froth flotation), particles exhibiting a hydrophobic (non-wetting) character, are preferentially separated to one of the fluid phases (either into the oil phase or the gaseous froth phase), due to a synergy of the interfacial tension between the particle surface and the fluid phase (Rao, 2004).

The rudimentary principle in a froth flotation system is that for a solid particle to float, the particle must exhibit a hydrophobic character (Fuerstenau, 2007). This character can be indicated by the area of contact (or restriction thereof), when a water droplet is deposited on a flat solid surface of the specific mineral and is exposed to an open air environment (Johnston, Dettre & Brandreth, 1977). A highly rounded water droplet silhouette indicates a hydrophobic solid surface, whereas a flat or more plate-like silhouette indicates a lower hydrophobicity character.

The same hydrophobic tendency can be indicated by the tangential contact angle, measured between a single air bubble and the flat solid interface submerged in a liquid. The contact angle is defined as the angle between the planes tangent to the solid and liquid surfaces at the three phase line of contact, or wetting perimeter (White, 1977).

Solid surfaces with a low surface energy indicate a hydrophobic character and solids with a high surface energy indicate a hydrophilic character. Most minerals have a high surface energy and must thus be treated with collectors to alter the surface to a low-surface energy (Leya & Poling, 1960).

The actual measurement of hydrophobicity, and not just an indication of hydrophobicity, is done by contacting a single air bubble with several submerged mineral particles and counting the number of particles picked up on the bubble surface (Rao, 2004). This method quantifies hydrophobicity, whereas contact angle measurements are only indicative.

2.2.2 Chemical Alteration of Mineral Surface

The versatility of flotation lies in the ease with which the mineral surface characteristics may be altered, either chemically or physically. Chemical alteration involves the use of specific reagents and modifiers, whereas physical alteration can involve mechanical stirring and cell hydrodynamics resulting in liquid film thinning or even the physical attachment of the solid and fluid phases. The hydrophobicity of a particular mineral surface can be altered by the addition of a specific chemical reagent, which will change the surface characteristics, but not the bulk mineral (Rao, 2004). In essence these surfactants consist of a nonpolar hydrocarbon chain, which is orientated towards the air interface, and a polar functional chemical group, which either interacts with the mineral surface or the water. The interfacial surface tension in the three-phase contact system is then altered.

The two core reagents in froth flotation are collectors and frothers. Collectors, which increase the hydrophobicity on a mineral surface, facilitate the selective collecting of specific mineral particles in the froth phase (Wills & Napier-Munn, 2006). The specific functional chemical group used in a collector, is dependent on the nature of the mineral to be collected, as well as the flotation pulp chemistry. A frothing agent is usually added to this system, in which the frothers facilitate the creation of a stable group of air bubbles (Rao, 2004), in which the hydrophobic particles can be captured and separated to the surface of the flotation pulp.

The flotation pulp chemistry can also be altered by the use of modifying agents. Three basic classes of modifying agents exist (Rao, 2004): Activators, depressants and pH regulators. Activators promote the interaction of the mineral surface with a collector, to enhance its chemical nature to interact with the collector. Depressants, on the other hand, impede the ability of the mineral surface to interact with a collector. This results in the selective flotation of a certain mineral, which is in many cases dependent on the pH of flotation. Various acids and bases are used as pH regulators, which enables a controlled pH environment in the flotation pulp.

The final flotation agents that need to be considered are the surfactants associated with the aggregation (flocculation) of flotation tailings. Flocculants enable the formation of a solid aggregate, by the bridging of its hydrocarbon chain with fine particles (Rao, 2004). These bridges are called flocs. Coagulants are responsible for the neutralization of large surface charges in dispersed fine particle, thus lowering the electrostatic repulsion and forming a solid aggregate.

2.2.3 Mineral Liberation Size

Flotation is however limited by two main physical factors: mineral liberation and particle size. Both these factors are interlinked, as the liberation of a specific mineral is dependent on the degree of intergrowth between the different solid mineral phases, which in turn is dependent on the grain size at which the individual particles are constituted of single free minerals (Rao, 2004).

2.2.3.1 Mineral Liberation

The efficiency of any separation technique will be optimal if only mono-mineralic particles are present. Mono-mineralic particles are often obtained by size reduction to free the multiple mineral phases from the composite particle (Perez-Barnuevo, Pirard & Castroviejo, 2012), although this is not always achieved. In Figure 2.2 four typical mineral intergrowths (associations) can be seen. The extent of this mineral intergrowth plays an important role in determining the ability of a mineral to be liberated (Perez-Barnuevo *et al.*, 2012).

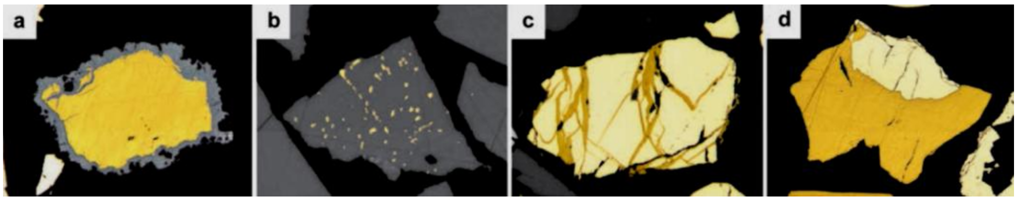

Figure 2.2: Typical mineral intergrowths relevant to flotation from real ore particles, coated (a), emulsion (b), stockwood (c) and simple (d). (Perez-Barnuevo *et al.,* 2012)

One definition of liberation size is the particle size at which the smallest valuable mineral grain is liberated from the host matrix, although many definitions exist (Rabe, 2013). It is, therefore, more applicable to discuss liberation of feed material to a flotation circuit in terms of the degree of liberation; the percentage of particles of a given mineral that exist as free particles (containing only one mineral) (Kelly & Spottiswood, 1989). The recovery of a liberated mineral species may be correlated to the degree of liberation for a well-defined mineral flotation system.

2.2.3.2 Particle Size

The flotation process is largely influenced by the grind size of particles in the flotation feed. Coarse particles exhibit slow flotation kinetics due to their poor liberation and actual size, whilst the flotation kinetics of fine particles is impeded by the poor flotation collision of these particles (Runge *et al.*, 2007). An optimal flotation recovery is often established at an intermediate grind size, as shown in Figure 2.3, which is often depicted by the cost related to grinding to a fine particle size (Runge *et al.*, 2007). The effect of particle size on the kinetics of flotation is discussed in Chapter 2.8.

The adhesion forces between the particle and the bubble/oil surface usually dictate the limit of maximum particle size for flotation, which is dependent on the density of the particles due to gravitational force acting on the particle. For base metals, an upper limit of 70 micron is common, and a lower particle size limit of ten micron, which will still yield high recoveries within an acceptable cell residence time (Jameson *et al.*, 1977*)*. Some flotation systems depict a reduced efficiency in flotation of particles smaller than ten micron, but other systems rely on the readily floatable character of colloidal sized particles.

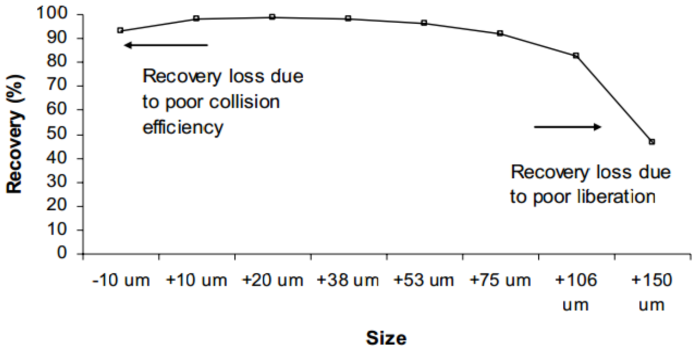

Figure 2.3: Typical flotation recovery as a function of particle size.
(Runge *et al.*, 2007)

2.2.4 Basic Steps in Flotation

The unit process of flotation consists of two main steps namely conditioning and separation (Perry & Green, 1997). Conditioning involves the surface preparation for optimal selectivity between the particle species to be separated, and the separation step introduces the air bubbles which induce the separation of selected mineral particles to the froth phase.

The first requirement for selective froth flotation is usually strict control of the pH of the pulp. All surfactants, acting as a collector, can only do so within a certain pH range. If, in this pH range, the collector adsorbs onto more mineral species than required, a depressant (organic or inorganic ions) needs to be added to suppress the flotation of those mineral phases (Rao, 2004). It is also possible for the surfactant to require reinforcing action from a specific ion. These activators establish a favourable interface between the surfactant and the selected mineral surface.

The collector surfactant alters the mineral surface to a hydrophobic state, in such a way that the surface of the air bubbles, dispersed in the dynamic flotation cell conditions, can successfully attach to the hydrophobic mineral surface. In an extremely short collision contact time between a particle in the agitated pulp and a dispersed bubble, surfactants with frothing characters are responsible for the bubble to particle attachment (Rao, 2004). Air buoyancy will carry the bubbles to the top of the flotation cell, where a mineralized froth is formed. A stable mineralized froth should then be able to overflow into a froth collection launder. The stability of this froth is determined by collector-frother interactions.

2.3 Physical Chemistry of Interfaces

The physio-chemical flotation process requires selective adsorption of reagents on mineral surfaces. Different flotation reagents adsorb onto mineral surfaces with different adsorption characteristics. The adsorption density of flotation reagents on a mineral particle surface will depict the hydrophobic character of the particle.

2.3.1 Characteristics of Adsorption

Adsorption is the main purpose of most flotation reagents. It is denoted by the concentration of a specific chemical species, of any chemical form, at an interfacial region between two phases. Adsorption is also governed by the diffusion mechanism, where the adsorbing chemical species (adsorbate) is transported from a low concentration phase to the interface at the high concentration phase (substrate) (Rao, 2004).

Physical adsorption involves the process where the adsorbate is concentrated on the substrate surface, but does not undergo any alteration in terms of its chemical species or electron transfer (Rao, 2004). Physical adsorption is a fully reversible process, which is usually found in the liquid/gas system, such as the interface between a flotation frother and a gas interface, where no change in the chemical state of the adsorbate or substrate takes place.

Chemisorption involves a transfer of electrons during the process, which is usually an irreversible reaction. Chemisorption is also identified where the adsorbate is present on the substrate surface in only one atom layer thickness (Rao, 2004). The single layer is due to a non-maintainable reaction once the substrate is covered in a layer of the adsorbent. When a multilayer is observed, the process may either be purely physical adsorption or a single layer of chemisorbed adsorbate reaction product and additional layers which are co-adsorbed by physical adsorption. The process may be either physical adsorption or chemical adsorption at the solid/liquid interface or the solid/gas interface.

In iron ore flotation, it is desirable to create a system of a single chemisorbed monolayer of the amine collector reagent on the quartz particle surface. Physical adsorption of starch depressants onto the hematite mineral surface particle is desired for a selective depressant effect.

2.3.2 Adsorption of Reagents and Hydrophobicity

One of the earliest techniques used for fundamental surface chemical forces is the determination of contact angles (Fuerstenau & Pradip, 2005). Direct measurement of the amount of reagent adsorbed at the mineral-water interface permits the analysis of adsorption phenomena relative to the wettability (contact angle). Figure 2.4 shows the correlation of contact angle, surface coverage, flotation recovery, zeta potential and pH when the flotation of quartz conditioned with dodecyl-ammonium acetate is observed.

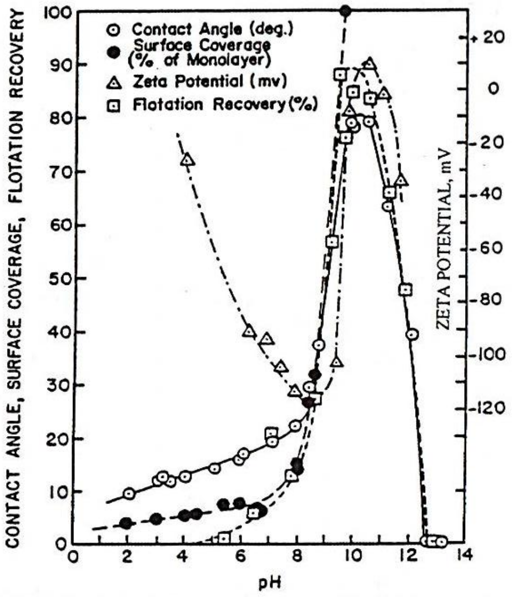

Figure 2.4: Correlation of surface coverage, contact angle, zeta potential and flotation recovery as a function of pH for an amine acetate-quartz system. (Fuerstenau, 1957)

Complex surface phenomena, such as flotation behaviour and wettability at the solid-liquid-gas interface, may be correlated to the measurements taken to reflect the adsorption density and zeta potential at the solid/liquid interface (Fuerstenau & Pradip, 2005).

2.3.3 Alteration of Solid Mineral Surface by Mechanical Forces

Solid materials, inherently containing mineral-mineral interfaces with highly heterogeneous character, are classified as either amorphous or having crystalline structures. Apart from a few exceptions, most minerals have a crystalline structure. These crystal structures are constructed from individual crystal faces, which, although they are ideal planes, contain various ledges, kinks and terraces (Kossel, 1927). The relative immobility of atoms in a solid causes the surface properties of the particles, which are greatly dependent on the immediate history of the particle.

A freshly formed crystal cleavage plane will differ greatly from the surface produced on a mineral by grinding or abrasion. The mechanical force of grinding will induce damaged surface layers, where the continuity of the crystalline lattices are broken, resulting in highly disarrayed material, with the presence of typical locked-in dislocations and imperfections on a molecular level. Additionally, the mechanical forces in a grinding mill will deteriorate the remaining crystallinity on the solid surface, converting this to an amorphous phase (Lin & Somasundaran, 1971).

Further alteration of the physical properties of the mineral particles include a decrease in the specific gravity of the material (Lin & Somasundaran, 1971), which is attributed to the higher quantity of amorphous phase present after grinding. The creation of amorphous surfaces can be inhibited by wet grinding, which is assumed to be facilitated either by a cushioning effect of the liquid, or the disintegration of newly wetted surface layers. A large amount of heat generated during the fracture and abrasion of solid surfaces may have a significant effect on the local temperature of the mineral particles. The additional heat could give rise to additional changes in the physical properties, such as a change in the semiconducting characteristics of fluorite and calcite (Carta *et al.*, 1975).

Finally, the physical wear of the grinding media due to the mechanical forces in a comminution vessel, which results in the deposition of this worn material on the mineral surfaces, also needs to be considered. All of these factors indicate that prolonged grinding, which leads to more severely altered surfaces, could either deteriorate or enhance the possibility of a selective mineral separation.

2.4 Chemical Bonding

2.4.1 Ionic- and Covalent Bonding

The simplest atomic bonding character is the ionic bonds between a negatively charged and a positively charged atom. The ionic bond is a long range force, which attracts counter ions regardless of their position or direction. The character of the bond between two species is dependent on the difference in electronegativity of the atoms. Atoms that are either highly electronegative or highly electropositive will form ionic bonds (Rao, 2004). When the difference in electronegativity is not significant, covalent bonds will form. Most bonds are partially ionic and partially covalent. Whenever a covalent bond in a solid is fractured, the atoms that had been sharing electrons will become ionized. Unless this newly ionized surface is immediately neutralised by its environment, a polar character will be exhibited on the surface, rendering it hydrophilic. This behaviour is common for most sulphide and oxide minerals (Rao, 2004).

The energy of the bond developed between two oppositely charged ions in an isolated pair, can be determined as the sum of the attractive and repulsive contribution of this pair to the overall potential energy (Rao, 2004). The attractive forces in an ionic crystal are depleted when the crystal is submerged into a polar liquid, which will break down the crystal and result in the ions going into solution.

2.4.2 Crystal Structure of Solids and their Chemical Relation

The molecular and atomic structure of a solid, as well as the type of bonding involved, primarily determines its surface features. Any interaction between the environment and a solid structure will modify the surface to a certain extent. If this activity is not too drastic, the surface properties will still reflect the structural features of the solid (Fuerstenau, 1982).

The structure of mineral crystals, give rise to their crystal habit, such as its surface tension, which is related to its crystallisation conditions and the presence of impurities in the crystal (Moffat *et al.*, 1964). An impurity in the crystal can cause a different change in surface tension in different orientations of the crystal.

In an aqueous medium, the formation of an electrical double layer, (which governs the flotation mechanism for quartz from hematite) between the mineral surface and the medium is controlled by the charge arising from the quantity of broken atomic bonds at the surface of the mineral (Fuerstenau & Fuerstenau, 1982).

A routine qualitative analytical technique for mineral identification is x-ray powder diffraction (XRD). XRD is a quick and inexpensive identification method, which records the diffraction intensity of specific atomic planes present in a homogeneously prepared powder sample at an angle of 2ϴ. The obtained diffraction pattern is then compared to a known diffraction pattern from the “powder diffraction file” published by the International Centre for Diffraction Data with the aid of a computer programmed search to identify the minerals present (Klein & Dutrow, 2008).

2.5 Electrical Characteristics at Mineral Surface Interfaces

2.5.1 The Electric Double Layer

The electric double layer is a diffuse region in which the region of electrical inhomogeneity of surface charge on the solid, produced by submerging a mineral into an aqueous solution, balancing the charge with ions of equal, but opposite charge (Fuerstenau, 2007).

The electrical double layer influences flotation in many different ways (Fuerstenau, 1982):

- The adsorption of physically adsorbing surfactants is controlled by the sign and magnitude of the surface charge;

- Chemisorption of chemically adsorbing surfactants can be inhibited by a high surface charge;
- Flocculation and dispersion of mineral suspensions is influenced by the electrical double layer;
- Electrical double layer determines the extent of slime coatings;
- Naturally floating mineral systems are influenced by the effect of double layers on the kinetics of film thinning relates directly to flotation kinetics

The electrical double layer usually controls the adsorption phenomena at mineral-water interfaces. Thus is it important to consider the factors that influence the charge on a solid surface and the additional ions in solution, which adsorb as counter ions to maintain electro-neutrality on the mineral surface. Figure 2.5 shows a schematic representation of the Stern model of the electrical double layer with counter ions in the liquid phase, as well as the potential drop across the double layer at a solid-water interface.

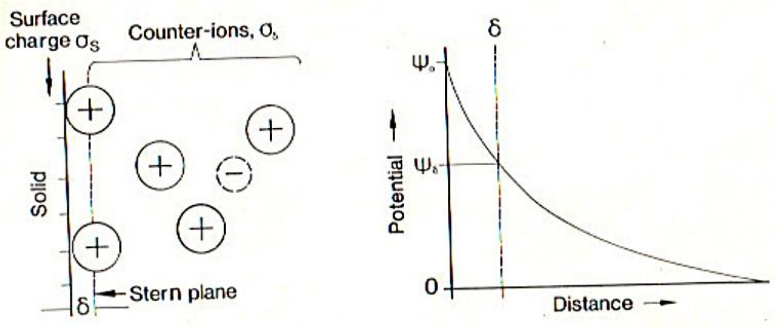

Figure 2.5: Illustration of the electrical double layer and the potential drop across the double layer at a mineral surface-water interface. (Fuerstenau & Raghavan, 1976)

The Stern plane (δ) is described as the closest distance of approach between the centres of the counter ions and the mineral surface. The surface potential (ψ_O) is larger than the potential at the Stern plane (ψ_δ), and the potential drops to zero in the bulk of the solution (Fuerstenau, 1982).

The most important parameter to describe the mineral surface is the condition under which the surface charge (σ_S) is zero. The point of zero charges (PZC) is an activity at which the potential determining ions reaches the stage where the surface charge is zero (Fuerstenau *et al.*, 1972). Thus the surface potential (ψ_O) is zero at the PZC. The importance of the PZC lies therein that the sign of the surface charge on a mineral has a significant effect on the adsorption of all other ions in the aqueous system. This importance is especially true for ions charged opposite to the mineral surface as they function as counter ions to maintain electro-neutrality (Fuerstenau *et al.*, 1972).

The Grahame (1947) model of the electrical double layer is the most used model in surface chemistry. This model, as schematically shown in Figure 2.6, is similar to the Stern model. The Grahame model divides the Stern region, between the Stern layer and the solid surface into an inner Helmholtz plane (IHP) and an outer Helmholtz plane (OHP). The slipping plane, where movement of the liquid relative to the solid starts, is estimated as at a distance, Δ, into the liquid, where the electro kinetic potential exists.

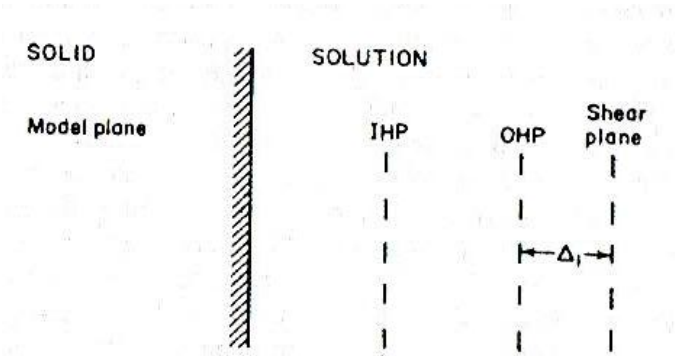

Figure 2.6: The Grahame model of the electrical double layer. (Adapted from Grahame, 1947)

2.5.2 Surface Charge effects

The double layer potential is controlled by the movement of ions across the solid-liquid interface. Preference of one of the lattice ions for a site on the solid surface, as compared to in the aqueous phase, gives rise to the surface charge. These ions moving between the two phases to establish a charge in equilibrium, are termed the potential determining ions (Fuerstenau *et al.*, 1972).

When two solid metallic oxides are submerged in an aqueous system, different electro kinetic behaviour is exhibited, compared to only one solid. Traces of molecules or dissolved ions originating from each of the solids tend to adsorb onto the other solid surface. These adsorbed species change the surface charge of each of the solids and can easily be detected by a change in the PZC. The PZC of each of the solids will shift toward the other solid, which is determined by the quantity of ions or molecules released into the aqueous system by each of the solids (Mackenzie, 1966 & 1971; Mackenzie and O'Brien, 1969; Healy *et al.*, 1968).

2.5.3 Phenomena Arising from Surface Charge

Surface charge effects facilitate one of two phenomena between solid mineral particles. In ideal flotation dispersed particles with similarly charged surfaces repel each other (Rao, 2004). Unfortunately, the presence of metal ion containing electrolytes in a flotation pulp will tend to neutralise the surface charges on mineral surfaces, resulting in coagulation of the solid particles.

2.5.4 Application of Electrical Characteristics in Iron Ore Flotation

The two major minerals present in iron ore flotation are hematite (oxide mineral) and quartz (silicate mineral). An understanding of the flotation mechanisms in iron ore flotation is investigated in terms of the electrostatic (electrical double layer) theory of flotation for oxide minerals and silicate minerals.

2.5.4.1 Oxide Mineral Flotation

For oxides, H^+ and OH^- ions are potential determining and thus the pH is a critical variable to be considered. The PZC (point of zero charge) of a mineral can be determined by electro-kinetic experiments. For an oxide, such as hematite, the ideal surface potential approximated by the Nernst equation, may be postulated as (Fuerstenau & Fuerstenau, 1982):

$$\varphi_O = \frac{RT}{F} ln \frac{(a_{H^+})}{(a_{H^+})_{PZC}} = 0.059(pH_{PZC} - pH)volts \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. Equation\ 2.1$$

Again, ψ_O denotes the value of the surface potential; R is the universal gas constant, F is the Faraday constant and T represents temperature in degrees Kelvin. The activity of the potential- determining cation (Hydrogen) at the PZC, is stated as $(a_{H^+})_{PZC}$. The surface charge of an oxide mineral can be determined by the titration of a suspension of the oxide mineral in water (having both a high ionic strength and making use of an indifferent electrolyte) (Fuerstenau & Fuerstenau, 1982), when the assumption is made that all added potential determining ions (H^+ and OH^-), either change the solution pH or are adsorbed at the mineral surface.

The change in solution condition is the approximated by the following equation (Fuerstenau; 1982):

$$\sigma_S = F(\Gamma_{H^+} - \Gamma_{OH^-}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathit{Equation}\ 2.2$$

The adsorption density of the potential determining cation and -anion are denoted by Γ_{H^+} and Γ_{OH^-}, in mol/cm^2. Thus, the surface area of the solid-liquid interface needs to be determined to quantify the magnitude of the surface charge (Fuerstenau; 1982). The results of such an experiment are shown in Figure 2.7, where the pH at which the adsorption density is zero is shown and thus this intercept will give the pH of the PZC (Parks & de Bruyn, 1962).

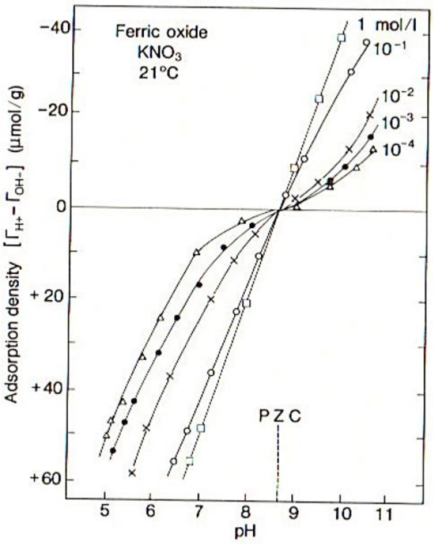

Figure 2.7: The adsorption density of potential determining ions on synthetic hematite as a function of pH and ionic strength (Parks & de Bruyn; 1962)

It is important to measure the PZC of each oxide mineral present individually*, as not only does this affect the flotation behaviour with the collectors used, but also the PZC values for the same mineral from different regions are different and differ from synthesised minerals. This difference is shown in Table 2.1, where the experimental measurement of synthesised hematite and various other hematite minerals are compared.

Table 2.1: Experimental measurement of PZC of hematite (Fuerstenau, 1970)

Material	PZC	Method	Reference
Synth. Hematite	pH 9.0	Titration	Quirk *et al.*
Synth. Hematite	pH 8.4	Titration	Parks & de Bruyn
Synth. Hematite	pH 8.3	Electrophoresis	Troelstra & Kruyt
Hematite (Quebec)	pH 5.4	Titration	Ahmed & Maksimov
Hematite (Quebec)	pH 8.7	Titration	Smith & Salman
Hematite (Brazil)	pH 5.4	Stream. potential	Joy *et al.*
Hematite (Brazil)	pH 5.7	Titration	Joy *et al.*
Hematite (Minn.)	pH 6.7	Electrophoresis	Iwasaki *et al.*
Hematite	pH 6.7	Electrophoresis	Johansen & Buchanan

The separation of oxide minerals by flotation is based on the electrostatic model of flotation, where pulp conditions are created such that the minerals to be floated are oppositely charged to the collector (anionic- or cationic collector), which will then only adsorb onto the desired mineral surface. Within a certain pH range below the PZC of a mineral, flotation response with an anionic collector is possible, inversely, a cationic collector is required when a pH range above the mineral PZC is considered (Fuerstenau, 1970).

** Unfortunately single mineral samples from the origin of the ore used in this study could not be made available for PZC analysis at the time of investigation.*

The schematic illustration in Figure 2.8 shows that at negative zeta potential values (above the PZC), a negatively charged collector (dodecyl-amonium chloride), is required for selective flotation of goethite. Note that chemisorption of collectors on both oxide and silicate mineral surfaces occurs in the pH range where the metal ions present in the mineral have hydrolysed and should thus be present as hydroxyl complexes (Fuerstenau & Fuerstenau, 1982).

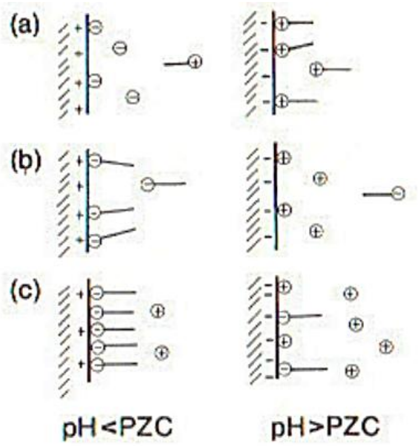

Figure 2.8: Schematic representation of the electrostatic theory of flotation: (a) adsorption of a cationic collector; (b) adsorption of an anionic collector; (c) chemisorption of the anionic collector. (Fuerstenau & Fuerstenau, 1982)

The influence of surface charge on flotation is illustrated in Figure 2.9, where the electro-kinetic and flotation behaviour of two anionic collectors and an additional cationic collector with goethite was experimentally determined. The electro-kinetic experiments yielded a PZC at pH 6.7, and this was confirmed with flotation tests (Iwasaki *et al.*, 1960). The experimental results indicate that a cationic collector must be used when the mineral surface charge is negative, and an anionic collector must be used when the mineral surface is positively charged.

Six different flotation procedures (research and industrial), developed for the separation of hematite and quartz (Fuerstenau & Fuerstenau, 1982), are shown in Table 2.2. This illustrates how different surface charge characteristics can be manipulated to obtain successful flotation of the targeted mineral.

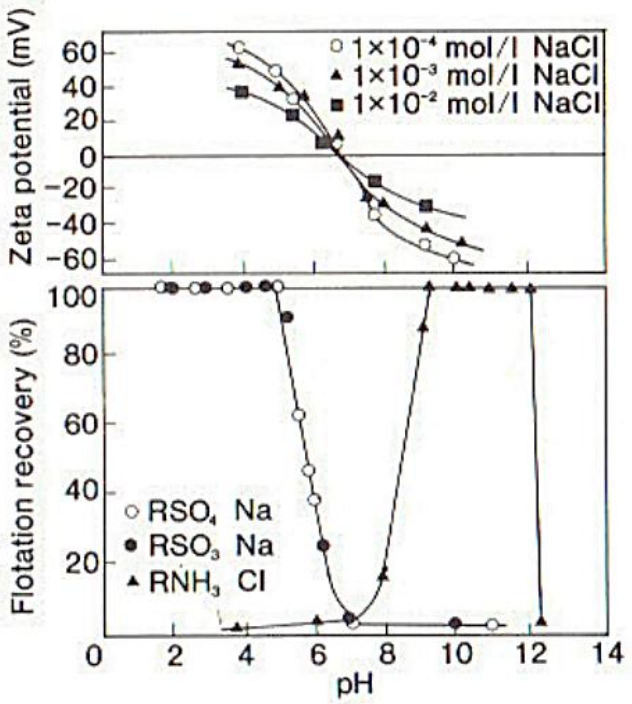

Figure 2.9: Flotation response of goethite as a function of surface charge: (*upper curve*) Zeta potential as a function of pH; (*lower curve*) Flotation recoveries with dodecylamonium chloride. (Iwasaki *et al*., 1960)

Table 2.2: Iron ore flotation procedures.

(adapted from Fuerstenau & Fuerstenau, 1982)

Mineral Floated	Collector	Collector Charge	pH	Additional	Physical Interaction
Hematite	Sulphonate	Anionic	2-4	-	Adsorption
Hematite	Fatty Acid		6-8	-	Chemisorption
Hematite	Amine	Cationic	1.5	Hydrochloric Acid or Sulphuric Acid	
Hematite	Hydroxamate		8.5	Methylisobutylcarbinol Frother	
Quartz	Amine	Cationic	6-7		Adsorption
Quartz	Soap		11-12	Ca ions quartz activation, Starch depressant	Chemisorption

2.5.4.2 Silicate Mineral Flotation

Again focusing on the mineral-water interface at the electrical double-layer, the flotation of silicates may be approached in the same manner as the oxides. A list of experimentally determined PZC values for certain silicates was compiled (Fuerstenau & Fuerstenau, 1982), and extraction of this list is given in Table 2.3.

Table 2.3: PZC values for typical low grade Sishen iron or silicate gangue minerals (adapted from Fuerstenau & Fuerstenau, 1982)

Silicate Class	Mineral	Chemical Formula	PZC
Sheet Silicate	Kaolinite	$Al_4(Si_4O_{10})(OH)_8$	pH 3.4
Sheet Silicate	Muscovite	$K_2Al_4(Al_2Si_6O_{20})(OH,F)$	pH 1.0
Framework Silicate	Quartz	SiO_2	pH 1.8-3.7

The solubility of quartz is extremely limited. Thus, quartz mineral surfaces would only be amenable to flotation in the pH range where the surfaces could be wettened, (in the presence of additional ions added or contained in the system), to hydroxyl complexes (Fuerstenau & Fuerstenau, 1982). An example of this quartz activation being dependant on the additional ions in solution is shown in Figure 2.10, where the flotation recovery of quartz is shown as a function of pH for a fixed concentration of added ions, at various pH levels, with an anionic surfactant.

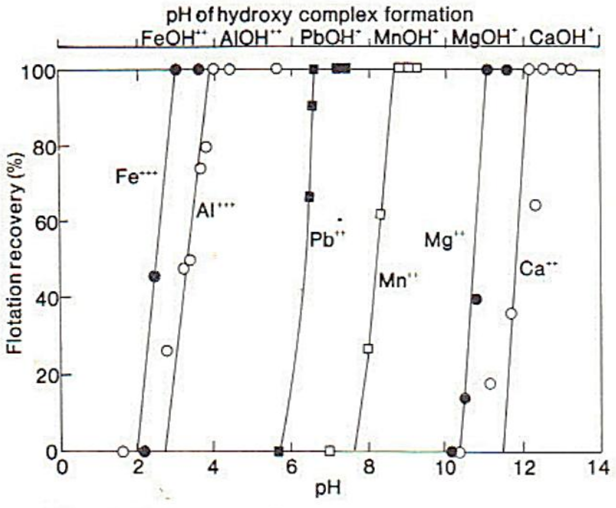

Figure 2.10: Flotation recovery of quartz as a function of pH with constant metal ion concentrations (Fuerstenau & Palmer, 1976)

2.6 Water

Water is the essential separation medium for flotation. The dissolution of minerals and addition of flotation surfactants in the water change the plant-water-composition. The composition of the process water used for flotation will influence the flotation response.

2.6.1 Water Hardness

As the flotation of oxides is based on the electrical double layer interactions at the mineral surface-water interface, the composition of the water used for flotation greatly influences the flotation response (Fuerstenau & Fuerstenau, 1982). Water hardness arises from the dissolution of minerals in water over a certain period. For areas where the water basin level is low, dissolution of minerals results in higher levels of water hardness. Recalling that cationic collectors, such as amines, will attach to negatively charged mineral surfaces, the presence of positively charged ions, such as Mg^{++} and Ca^{++}, will hamper the flotation of negatively charged silicate minerals. The predominance diagrams of Mg^{++} and Ca^{++} are given in Figure 2.11. When an anionic collector is used, these positively charged ions in solution, could act as activators for silicate flotation.

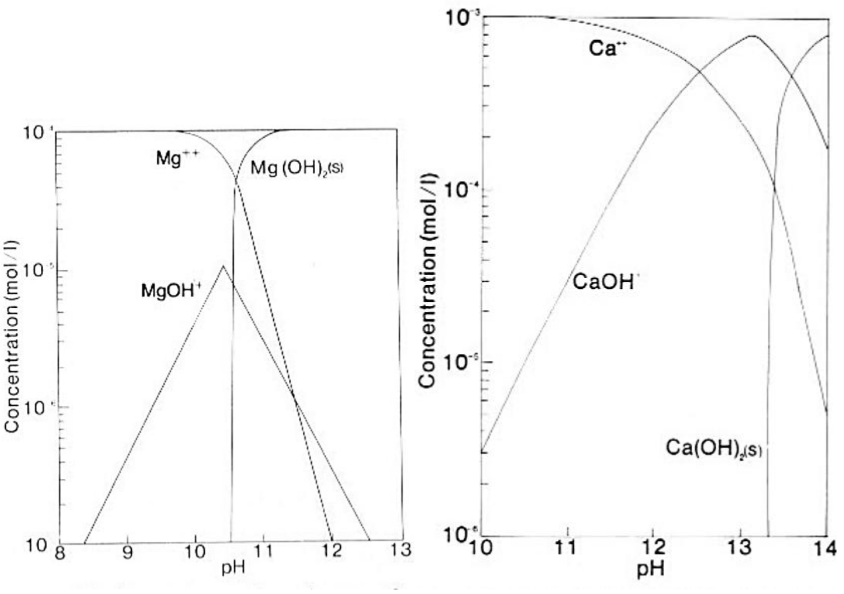

Figure 2.11: Predominance diagrams for Mg++ at 1x10-4mol/l (left) and Ca++at 1x10-3mol/l (right) (Bulter; 1964)

2.7 Flotation Surfactants

The characteristics of the three phase system (liquid, solid and gas) of flotation is controlled by a vast range of organic and inorganic reagents. The phrase surfactant is used exclusively for those reagents exhibiting a dual character (a molecule consisting of both a polar group Z and a non-polar group R) (Rao, 2004). Surfactants are firstly responsible for adsorbing onto a specific liquid/solid interface and inducing a hydrophobic mineral surface, and secondly to influence bubble-mineral attachment kinetics.

2.7.1 Classification of Flotation Surfactants

The most useful classification of surfactants is done according to their specific polar group, which differentiates surfactants based on their characteristics and their action. Surfactants can also be divided into a group of mono-polar and a group of multipolar surfactants before a subdivision by character and action type is made. There are three main classes of mono-polar surfactants (by characteristic behaviour) are (Rao, 2004):

- Thio compounds- Mainly acts as collectors for metallic sulphides, of which the most commonly used are xanthates and di-thio-phosphates.
- Non-thio, ionisable compounds- Reagents could exhibit both a collecting and frothing ability. These include alkyl carboxylate (fatty acids), alkyl sulphates, alkyl sulphites, alkyl phosphates, amines and derivatives of amines.
- Nonionic compounds- Primarily employed as frothers but could also exhibit depressant, flocculent or activator characteristics.

The three main classes of multipolar surfactants are (Rao, 2004):

- Nonionic- Where the polar group of the molecule may consist of either an alcohol, ether, aldehyde or ketone group.
- Anionic- The polar group on these reagents may consist of carboxylic, sulphate, sulfonate, phosphate or a thio-ionized polar group.
- Cationic

For the purpose of this study, only the reagents related to the reverse flotation of iron ore are studied more completely. These reagents are the amines (which belong to the non-thio surfactants) and the starch depressant (which belongs to the non-ionic surfactants).

2.7.2 Non-Thio Flotation Surfactants (Amine Collectors)

The non-thio surfactants substantially lower the interfacial air/water tension, when extremely dilute solutions are added to the flotation cell pulp. Another characteristic of the non-thio surfactants is their proneness to form micelles, (colloidal aggregates), when the concentration of surfactant exceeds a maximum dilution, at a specific concentration (the critical micelle concentration, CMC) (Fuerstenau, 1982). The CMC is also dependent on the solution temperature and this point is reached at a certain minimum temperature, denoted as the Kraft point (Rao, 2004). Additionally non-thio surfactants also have the ability to solubilize hydrocarbons of insoluble nature, as well as other insoluble surfactants, within micelles.

All reagents in the non-thio ionisable surfactant class are prone to dissociation, ionization and hydrolysis. The extent of these reactions is primarily influenced by the pH of the aqueous solution (Rao, 2004). The schematic dissociation curves of amines, substituted trimethyl ammonium ions and alcohols as a function of pH is shown in Figure 2.12. This figure shows that un-substituted amines are fully dissociated acids and neutral pH levels.

When a sodium hydroxide is added to the acid solution, these amine salts undergo a hydrolysis reaction as the solution is made alkaline. This hydrolysis reaction (Rao, 2004) is expected as:

$$RNH_3^+Cl^- + Na^+OH^- \rightarrow RNH_2 + Na^+Cl^- + H_2O \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Equation\ 2.3$$

Ralston *et al.* (1944) has given the dissociation constant for lauryl amine (C_{12}), as 2.4 x 10^{-11}, which indicates that the dissolved amine will be half dissociated at pH 10.6. In contrast to the un-substituted amines, the dissociation of quaternary ammonium salts is not affected by alteration of pH with sodium or potassium hydroxide. Quaternary ammonium salts will remain un-dissociated in both acidic and alkaline conditions. The same is true for alkyl alcohols across the pH range between 0-14 at room temperature.

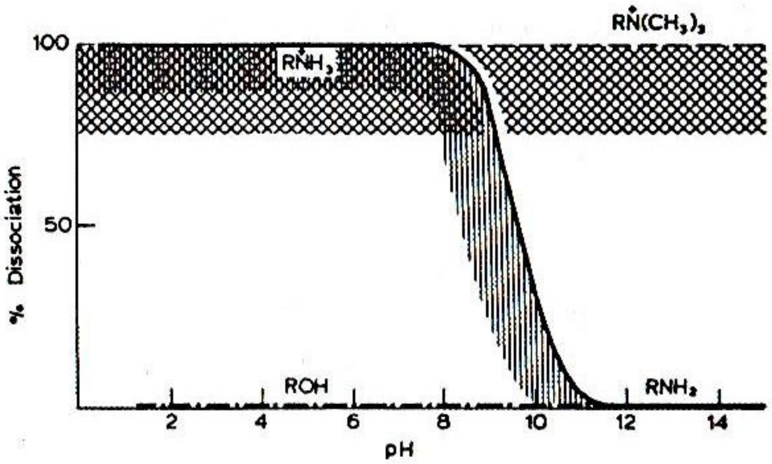

Figure 2.12: Schematic dissociation curves of amines RNH_2-RN+H_3, substituted trimethyl ammonium ions RN+$(CH_3)_3$ and alcohols ROH as a function of pH. (Rao, 2004)

The formation of an intermediate species, expected to contain equal amounts of ionized and unionized ammonia, can be expected when both the CMC and Kraft point are exceeded. This region of half-dissociation coincides with the region where a dual action as both collector and frother are noted. Outside of this S-curve region, the surfactant can act only as either a collector (thus requiring additional frother to be added to establish effective flotation) or as a frother (which will require an additional appropriate collector to attain any floatability) (Rao, 2004).

2.7.2.1 Amine Collector Mechanism

Cationic organic derivatives of ammonium hydroxide are termed amines, which exist in cationic form below certain pH levels, and this is also consequently the basis of their collecting action (Lovell; 1982). In flotation, the application of cationic surfactants has been developed in two groups: quaternary ammonium compounds and un-substituted alkyl amines. Amines have been used extensively in the selective flotation of oxide minerals (such as quartz). Baseline work on cationic flotation agents up to the mid-1950’s was reported by Gaudin (1957). The baseline work was followed by a review of theoretical and practical aspects of cationic surfactants by Agar (1967) and reviews of silicate flotation by Manser (1975) and Smith and Akhtar (1976).

Cationic amines are most frequently employed as salts of hydrochloric acids (un-substituted amines) or acetic acids (substituted amine). These salts are expected to ionize in accordance with the following reactions (at appropriate pH levels):

$$RNH_3Cl \leftrightarrow RN^+H_3 + Cl^- \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. Equation\ 2.4$$

$$RN(CH_3)_3Br \leftrightarrow RN^+(CH_3)_3 + Br^- \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. \ldots . Equation\ 2.5.$$

In alkaline conditions, un-substituted primary amine salts lose an electron, thus becoming unionized by the following reaction:

$$RNH_3^+ + OH^- \leftrightarrow H_2O + RNH_2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Equation\ 2.6$$

Ralston *et al.* (1944) determined the solubilities of the C_{10}, C_{12} and C_{14} un-dissociated amines. This showed a sharp decrease in the solubility of these amines with an increase in their chain length. The number of hydrocarbon radicals bonded to the nitrogen atoms classify the amines as primary (one hydrocarbon group and two hydrogen atoms), secondary, tertiary or quaternary. The configuration of these hydrocarbon chains of amines may also differ and thus amines can then be classified as alkyl, aryl or alkylaryl. Quaternary amines are considered to be completely ionized at all pH levels, whereas the ionization of the other amines is considered to be pH dependent. Thus, the concentration of $(CH_3)_4H^+$ from quaternary amines will remain constant at all pH levels, in contrast to that of the other amines, where the concentration of RNH_3^+, RNH_2(aq) and RNH_2(s) will change and be dependent on the pH. This dependence is highly influenced by the solubility pH of the amines (Fuerstenau, 1982).

In free base form, amines are considered insoluble, but are treated with acids such as acetate or hydrochloric acid to render them water-soluble amine acetates or chlorides (Lovell, 1982). The solubility of amines is also decreased with an increase in the length of the hydrocarbon chain of the amine.

A logarithmic concentration diagram can be used to represent the variation of species' concentration as a function of pH as can be seen in Figure 2.13.

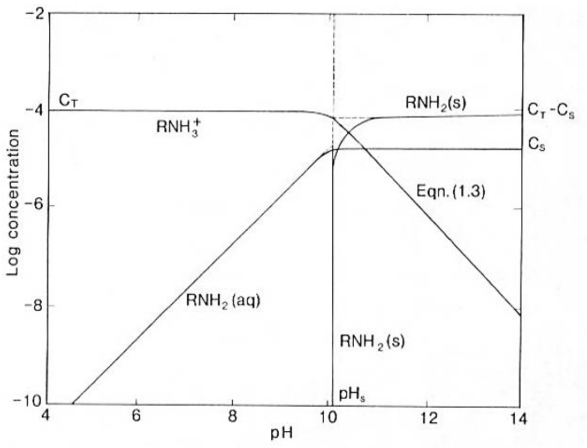

Figure 2.13: Predominance diagram for 1x10-6mol/l total dodecylamine. (Fuerstenau, 1982)

An important characteristic of hydrocarbon chain surfactants is micellization. These micelles are formed by the Van der Waal's bonding between hydrocarbon chains of the collectors and are colloidal sized aggregates of collector ions. The inherent non-polar nature of hydrocarbon chains and their incompatibility with polar water molecules drive the formation of these micelles. A CMC needs to be reached for this phenomenon to occur, and the aggregates to come out of solution, resulting in decreased free energy experienced by the system. Micellization occurs at lower surfactant concentration for longer hydrocarbon chain lengths (Fuerstenau, 1982). Figure 2.14, which shows three distinctly different adsorption processes at the solid surface, also illustrates the surface interaction of such micelles.

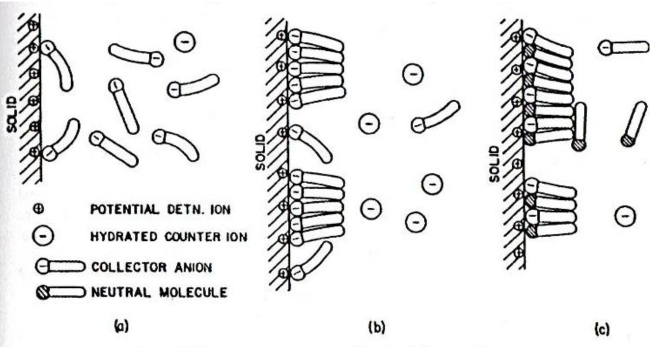

Figure 2.14: Schematic representation of dilute amines in solution (a), hemimicelle formation (b) and co-adsorption of collector ions and neutral molecules (c). (Rao, 2004)

In contrast with sulphydryl collectors, such as xanthates, amines are considered to be stable in aqueous solution and therefore the collector half-life is not dependent on time or pH (Fuerstenau, 1982).

A maximum collector action, between an amine and quartz, was found in a narrow pH range (Fuerstenau, 1957), and is commonly explained by three stages of adsorption. Firstly the initial transfer of collector to the solid surface, which starts the contact angle development. Secondly a region of rapid increases in the adoption of the amine species in association with the pre-adsorbed species. Lastly, there is the final region of less active adsorption.

Amines will attach to mineral surfaces with opposite charge (i.e. negatively charged oxidised surfaces) and are, therefore, very seldom mineral selective in their collecting action. The conditions in the flotation cell thus need to be altered such that the pH, as well as type of ions and concentration thereof, allows only the surfaces of the mineral to be collected, to be positively charged (Fuerstenau & Fuerstenau, 1982). These conditions are however not always possible. Therefore modifiers and depressants need to be used in conjunction with the amines. Some of the major applications of cationic collectors are in rougher flotation of sulphidized zinc carbonates and silicates (Lovell, 1982).

2.7.2.2 Amine Collectors in Reverse Cationic Flotation of Quartz

Cationic amine collectors were developed much later than xanthates or fatty acids. The major use of amines is in the cationic reverse flotation of low-grade iron ores (Papini *et al.*, 2001). Mono ether amines are most commonly used, but diamines are used in Brazilian concentrators when low-silica concentrates are required. Solubility of amines in an aqueous medium is established by neutralisation (between 20 and 75% neutralisation), which is achieved by contact with acetic acid (Papini *et al.*, 2001; Araujo *et al.*, 2005).

To create ether amines, an alcohol must be reacted with acrylonitrile and reduced afterwards, to attain an oxygen atom in the amine chain. The presence of this oxygen atom adds a hydrophilic component to the generally hydrophobic amine chain, which results in higher solubility of the amine. An ether diamine is produced by contacting this ether amine with acrylonitrile a second time. Ether amines exhibit a good frothing character and will not require additional frother for froth stability.

An amine characterization and performance study by Papini *et al.* (2001) showed more selective flotation of quartz from Brazilian itabirite iron ores with two amine acetates, as shown in Table 2.4. Two other ether monoamines (ECAN 04D and Poliad A-3) also performed well but are not as easily available, due to the small size of the manufacturer.

Table 2.4: Characterization of amines under investigation and their collector performance in bench scale flotation experiments. (adapted from Papini *et al*., 2001)

Trade Name	Supplier	Description	Alkyl Groups	Neutralization Degree	%SiO_2 Grade	% Fe Recovery
HOE F2835-B	Clariant	Ether diamine acetate	C12-C13	50%	3.09	90.61
Flotigram EDA-3B	Clariant	Ether amine acetate	C10	50%	2.10	91.46

It is generally accepted that a large portion of non-selectivity in flotation of quartz from hematite is attributed to the amine collectors adsorbing onto both hematite and quartz mineral surfaces. A key component is controlling this, is the selective adsorption of a starch depressant onto the hematite mineral surface (Ma *et al.*, 2011).

2.7.3 Non-ionic Flotation Surfactants (Starch Depressant)

In addition to alcohols and ethers, organic regulating agents (which include cellulose, starch and hydrolysis products of these two substances), are included in the class of non-ionic flotation surfactants. These regulating surfactants aid in the preparation of the solid mineral particles and their environment, to enable a selective flotation process.

Such organic compounds are invariably multipolar, with the distinct characteristic of being able to orientate some of their polar groups toward the aqueous phase once the surfactant has adsorbed onto the mineral surface, thus rendering the particle hydrophilic. The two most widely distributed polysaccharides are cellulose and starch.

2.7.3.1 Starch Depressant Mechanism

Starches and dextrins are polymers of dextrose, which is structurally linked, for linear chains (amylase) through 1-4 glycosidic linkages and for branched points (amylopectin) 1-6 linkages. Dextrin formation causes these chains to fragment and recombine as lower molecular weighted, but highly branched structures (Caeser *et al.*; 1968). Figure 2.15 shows the structural formulae of starch and dextrin.

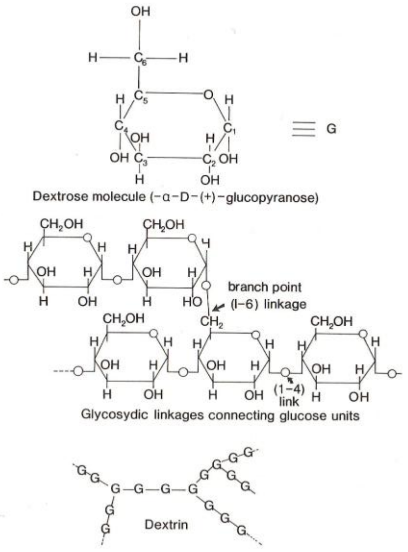

Figure 2.15: Structural formulae for starch and dextrin. (Ceasar *et al.*, 1968)

The polysaccharide depressant, starch is used either in its natural state, typically as maize, potato starch or pearl starch or partially hydrolysed which yields more soluble dextrins.

Starch is the universal depressant used in depressing iron oxides during iron ore flotation (Araujo *et al.*, 2005; Ma, 2008), which has the simultaneous advantage of acting as a ultrafine slimes-flocculent (Iwasaki *et al.*, 1960; Iwasaki, 1989). Starches are commonly used to flocculate hematite, disperse clay slimes, as well as in depressing talc containing minerals and calcite (Lovell, 1982).

It is considered that starches bond strongly to hematite through chemisorption (Fuerstenau & Fuerstenau, 1982), and has a limited adsorption onto quartz, which facilitates a rather selective depressant action required when hematite would also respond to the collector added in a quartz flotation system. From previously published work, it seems that the adsorption of amine collector on hematite and quartz mineral surfaces is limitedly affected by the presence of a modified corn starch and thus any selectivity would arise from the selective adsorption of starch onto the mineral surface (Balajee & Iwasaki, 1969).

2.7.3.2 Starch Depressants in Reverse Cationic Flotation of Quartz

After an initial monopoly supplier of corn starch, marketed as Collamil, claimed that the protein content in certain alternative depressants could be harmful to the flotation performance, Peres and Correa (1996) conducted a study on various corn starches. As seen in Figure 2.16, this study showed high protein starches (such as zein), are as effective in depressing hematite, as conventional corn starch and amylopectin (Araujo *et al.*; 2005).

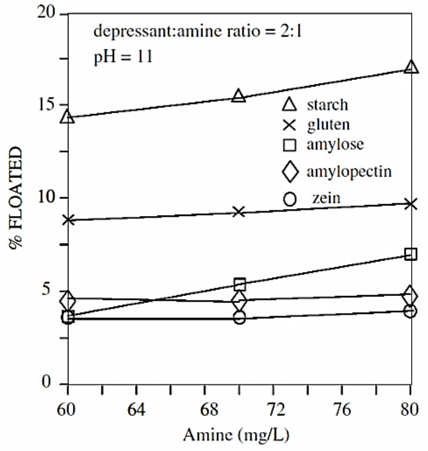

Figure 2.16: Depression action of zein and other depressants on quartz. (Araujo *et al*., 2005)

An additional study by Pinto *et al.* (1992) showed that certain contents in corn starch could however increase its effectiveness of depressing hematite. Figure 2.17 shows such a relation, where amylose and amylopectin (the principal constituents of corn starch) are compared to conventional corn starch. The results show that the amylopectin is the constituent responsible for the central depressing action of hematite. A genetically modified corn species was developed to constitute of 96%

amylopectin, 21% more than regular yellow corn, but this fairly expensive product did not show any industrial benefit (Araujo *et al.*, 2005). One crucial element of these various starches is the oil content. A high oil content (such as the >3% analysed for starches produced from corn that did not have its germ portion removed before grinding), is detrimental to the froth, as explained by theories of the elasticity of films which surround gas bubble (Araujo *et al.*, 2005).

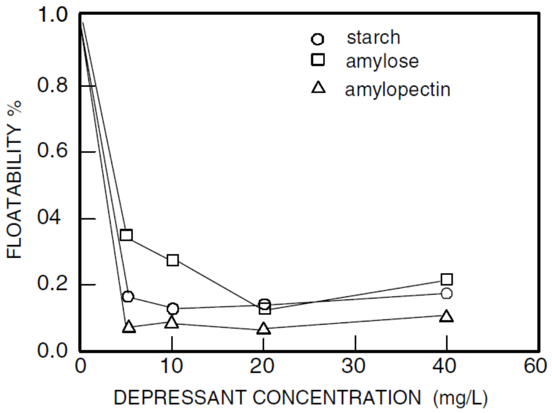

Figure 2.17: Floatability of hematite as a function of depressant concentration. (Araujo *et al*., 2005)

Experiments done on Brazilian iron ores with various depressants show a superior depressing ability with starch, compared to two other polymers: Carboxymethyl-cellulose and Guar Gum, as can be seen from Figure 2.18. Thus, starch, as a depressant, can yield high iron recoveries, as well as low quantities of silica in the final concentrate (Turrer & Peres, 2010).

When a de-sliming step is not implemented before flotation in the reverse cationic flotation of iron ore, it is expected that extremely high starch dosages (exceeding 1000 g/t) would be required for depressing hematite. This particular study showed that it was not possible to attain more than 50.35% Iron recovery, at a 67.86% iron grade (Ma *et al.*, 2011).

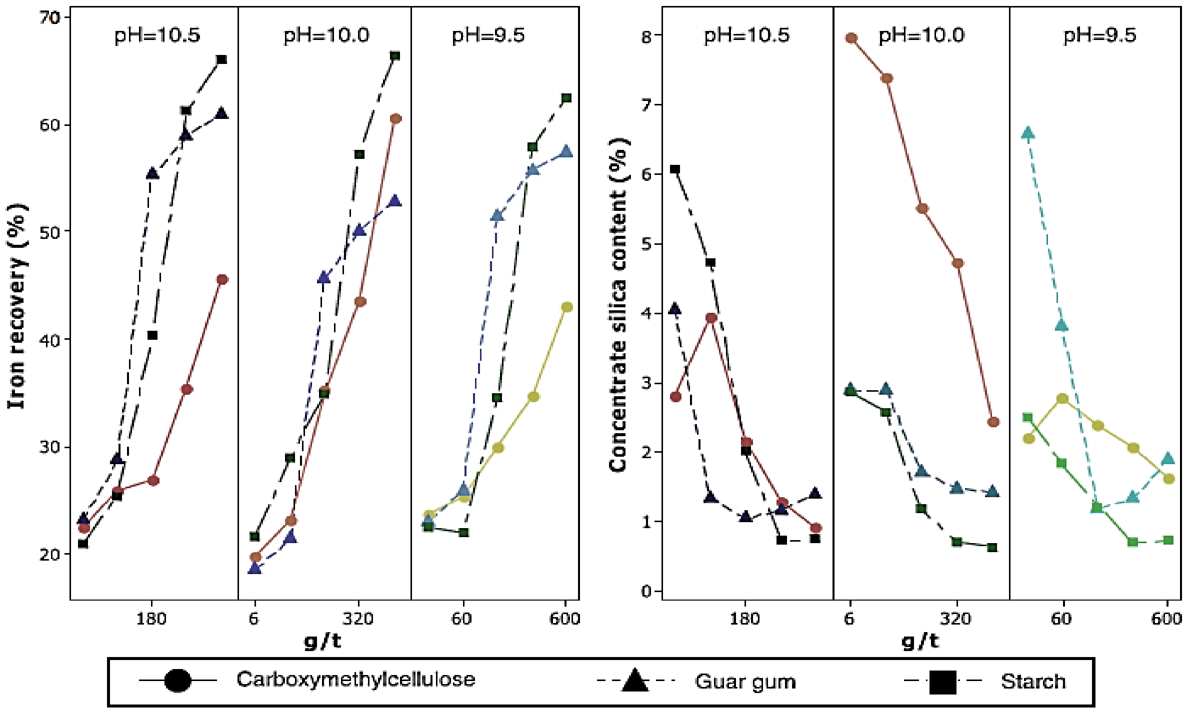

Figure 2.18: The effect of starch and other depressants on flotation performance at specific pH levels. (Turrer & Peres, 2010)

2.7.4 Action Mechanism from Modifying Agents

In essence, modifying agents affect the solution chemistry for flotation by the following cardinal effects (Rao, 2004):

- Alter and control of the pH in the flotation cell environment;
- Control of the speciation degree of competing ionic species;
- Chemical alteration of mineral surface;
- Change of interface charge density;
- Modifying the oxidation state of ions in solution; and
- Control the metallic ion concentration.

Depending on the specific flotation system, a single modifying agent may act either as an activator, regulator or depressant. The action mechanism can also change by changing the concentration of a modifying agent.

2.7.4.1 Control of Charge Density at the Solid/Liquid Interface

Modifying and control of the charge density at the interface between a liquid and solid is established by the addition of ionized additives. These could either be inorganic (sodium silicates, calcium polyphosphates, aluminium salts etc.) or organic (polysaccharides) in nature (Rao, 2004). The control of charge density at the solid/liquid interface is explained in this literature study, by reference of the dispersive- and depressant action of sodium silicate as it is commonly used in iron ore flotation.

2.7.4.2 Dispersant and Depressant Action of Sodium Silicate

In an aqueous system where only one solid is dispersed, the zeta potential curve of this individual solid differs from the curve perceived when more than one solid is in solution. Certain traces of the dissolved molecules of the individual solid components will adsorb onto the surface of the other solid surface, thus altering the surface characteristics. This adsorption will shift the zeta potential curve of each of the different solids towards each other (Reymond & Kolenda, 1999).

Sodium silicate (water glass) is a very common industrial dispersant, employed in the dispersion of slimes, which are generated by the more friable components of the ore during grinding. When sodium silicate is diluted in a supporting electrolyte hydrolysis occurs, resulting in hydroxylated species. These species can range from the uncharged $Si(OH)_4$ to the highly charged $[Si_4O_8(OH)]^{4-}$ (Lagerstrom, 1959; Ingri, 1959). The presence of such species will affect all oppositely charged solid surfaces. The zeta potential on the solid surface is rapidly reversed to a highly negative state. Polymeric species are mainly present in less hydrolysed solutions, which are more concentrated. The kinetics of depolymerisation, such as adding a concentrated sodium silicate liquid to a flotation cell, differ considerably in their effect and are largely dependent on the flotation system.

The mechanism responsible for dispersing two solids in an aqueous medium by sodium silicate addition is explained in Figure 2.19. This figure shows the effect of various electrolyte solutions which contain specifically adsorbing cations or anions (Rao, 2004). One solid possesses a negative zeta potential (N), and the other possesses a positive zeta potential (P). The effect of increased cationic adsorbate M_1 and M_2 and anionic adsorbate (A_1 and A_2) are also schematically shown.

The depressant effect of sodium silicate is highly sensitive to the solution pH and may in some instances only exhibit a depressant effect in a narrow pH range. The ratio of sodium oxide to silica oxide depicts the modulus. A higher modulus will enhance the depressant action of the modifying reagent (Fuerstenau *et al.*, 1969). Commercially more than 29 liquid products are manufactured as sodium silicate (Vail, 1952), with a modulus ranging from 1.6 to 3.75.

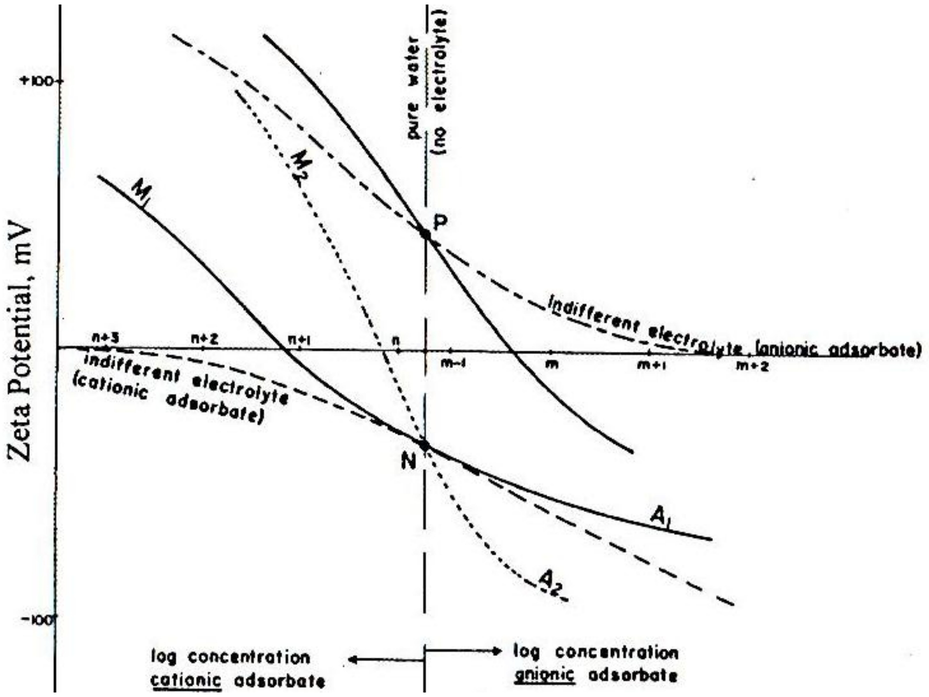

Figure 2.19: Schematic representation of zeta potential changes for two types of solids in electrolyte solutions containing specifically adsorbing cations and anions. (Rao, 2004)

2.7.4.3 Sodium Silicate Dispersant in Reverse Cationic Flotation of Quartz

When sodium silicate is used in flotation, it is important to remember that this regulator has a depressant-, dispersant- and froth modification action (Lovell, 1982). Silicateous slimes are dispersed and depressed, which will tend to result in an embrittled froth.

2.7.5 Frothers and Frothing

Froths and foams are necessary, not only for froth flotation separation of minerals, but also for water purification by adsorptive-bubble separation and many other processes. Bubble coalescence, by which the bubble surface area is reduced to reduce the overall free energy of the system, is detrimental to the mineral froth flotation system. When the individual bubbles coalesce to form larger bubbles, flotation kinetics is disrupted. The addition of frothers can prevent coalescence, when the liquid film between two bubbles is strengthened. When bubbles do not coalesce, their buoyancy will carry them to the surface, where they will aggregate to form a froth (well drained bubble system) or a foam (partially drained liquid-bubble system).

Amine collectors, as used in the reverse flotation of iron ore, exhibit a frothing character (Araujo *et al.*, 2005), which increases with their chain length, resulting in no need for additional frothers to be added to the flotation system. This section will therefor focus on the physical aspects of frothing.

2.7.5.1 Stability of Mineralised Flotation Froths

Once a bubble-particle aggregate reaches the top of the flotation cell, a secondary cleaning process is started. This cleaning process is facilitated by controlling a constant froth height, where misplaced or mechanically entrained particles can be allowed to drain out of the froth and back into the pulp (Rao, 2004). The presence of solid particles significantly changes the stability of the froth.

A stable froth is established when hydrophobic particles strongly adhere to the air/liquid interface, to such an extent that the draining of liquid is restricted. The froth may also become stable against mechanical handling when extensively flocculated particles are floated and then interlock other particles between two air/water interfaces. On the other hand, the presence of extremely hydrophobic particles will easily rupture the liquid film around the bubble surface, leading to a collapse of the froth bed (Dippenaar, 1978).

2.7.5.2 Uncommonly used Frothers in Reverse Cationic Flotation of Quartz

In the USA there exists records of use of frothers (alcohol and polypropylene glycol) in the reverse flotation of iron ores (Houot, 1983), but this is uncommon in plant practice, due to the bimodal amine species usually present at the flotation pH range. This pH range is in the region of half dissociation of the amine into both a cationic and molecular species, and the frothing character is contributed by the molecular species. Laboratory scale flotation tests results in, Figure 2.20, show that the partial replacement of amines by synthetic polyglycol-type frothers can increase both the recovery and selectivity, when approximately 10% of the total amine dosage was replaced with these frothers (Araujo *et al.*, 2005).

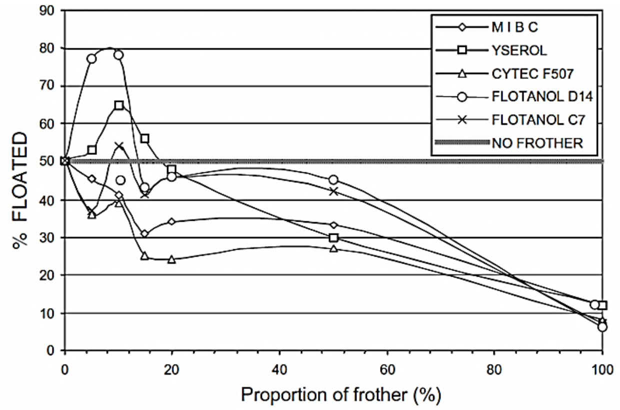

Figure 2.20: Floatability as a function of proportion amine substituted by frother in micro flotation tests. (Araujo *et al*., 2005)

2.8 Probability of Flotation and Flotation as a Rate Process

All physical and chemical processes are rate determined. In flotation this rate is determined by several kinetic factors between the three phases in the system (solid, air and water). The kinetic factors establish a close relation between the probability of a mineral particle to float and flotation as a rate process.

2.8.1 Kinetic Probability of Flotation

In an attempt to relate flotation kinetics to measurable parameters Laskowski (1974, 1986) expressed three criteria underlying the flotation process in terms of a probability P. The product of these criteria yields the overall flotation probability. Laskowski identified the criteria as:

- The probability of collision between the particle and the bubble;
- The probability of attachment, where a thin film between the particle and the bubble must be raptured; and
- The probability of achieving a stable bubble-particle aggregate uninfluenced by the shear forces in the flotation cell.

2.8.2 Flotation Rate Constant and Particle Size Effects

When the variation of flotation rate constant with a change in particle size is observed, as in Figure 2.21 (left), a linear relationship is depicted. Bearing in mind that this is for single mineral flotation (not affected by mineral liberation), it seems that the size of particles alone could also indicate floatability (Jowett, 1980). Figure 2.21 (right) should also be considered as this shows that an upper limit to flotation particle size also exists.

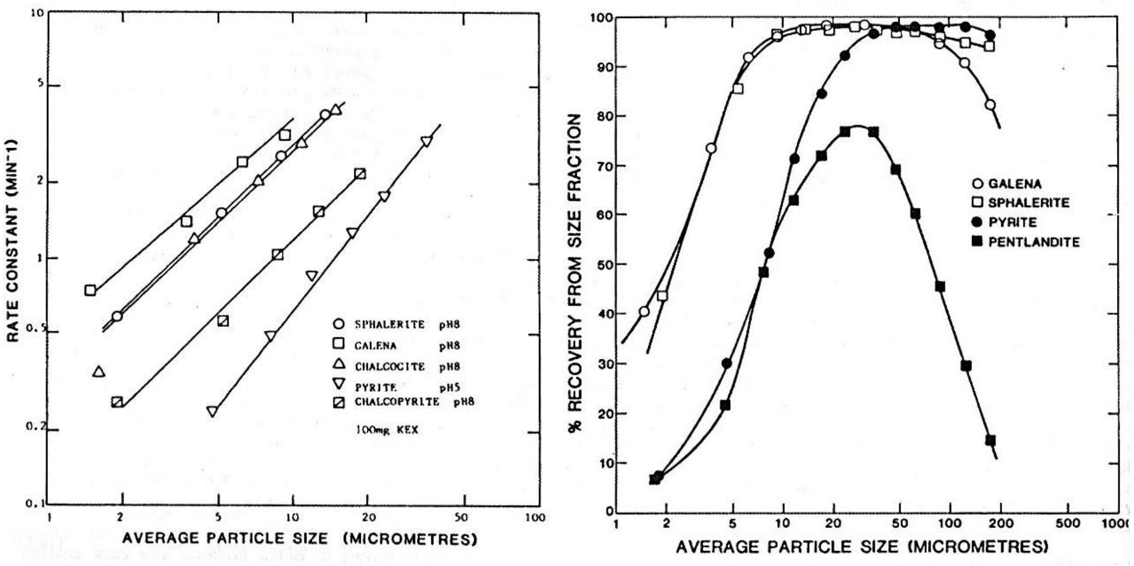

Figure 2.21: Variation of flotation rate constant as a function of particle size in batch flotation of sulphide minerals (left) (Trahar, 1981) and size-by-size recovery of sulphide minerals in batch flotation tests timed for 60 seconds (right) (Jowett, 1980).

The typical laboratory flotation time for iron ore is three to five minutes, in which a scale-up factor of 2.6 is recommended for large scale rougher flotation machines (Nelson *et al.*, 2009). For iron ore, rougher flotation cells are typically operated at 40-50% solids and cleaner cells at 60% of this solids concentration (Nelson *et al.*, 2009). The solids content is also dependent on the characteristics of the ore to be beneficiated.

2.9 Flotation Machines

More than 40 types of industrial flotation machines have been developed over the past century. All of which are based on three principal designs for flotation machines (Rao, 2004). Industrial flotation machines, such as the machines in Figure 2.22, with various features and benefits, are generally supplied by Outotec, Metso and FLSmidt (Nelson *et al.*, 2009).

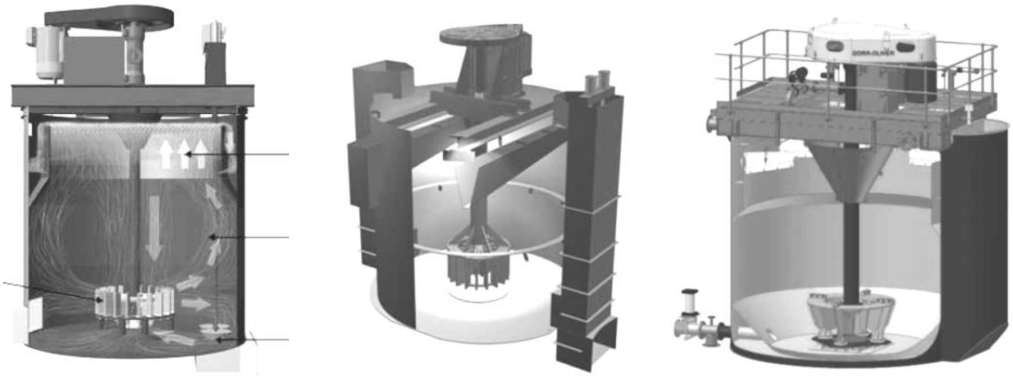

Figure 2.22: Mechanical Flotation Cells OK-cell from Outokumpu (left), RCS-cell from Metso (middle) and Dorr-Oliver-cell from FLSmidt (from Nelson *et al.*, 2009)

The mechanical flotation cell, which consists of a rotor and a stator keeping the mineral mixture in suspension, facilitates flotation when air is dispersed into the pulp from a central pipe along the shaft of the rotor. The pneumatic cell utilises uniformly dispersed air to keep the mineral particles in suspension, before the particles reach a perforated grid, which results in a stable froth bed, where the flotation feed can be top fed. The cyclone cell employs a principle where the pressurised feed material and air are delivered through a cyclone feeder.

The parameters of a kinetic model, such as the Klimpel model (Klimpel, 1980), is calculated from laboratory flotation tests or pilot-plant testing, and used to calculate the required residence time a unit volume slurry would require to be transported through a process or machine (Nelson *et al.*, 2009), in m^3/min. The required cell capacity can then be calculated from the product of the required residence time and the volumetric flow rate of the pulp (Poling, 1980).

2.10 Laboratory Flotation Tests

Batch flotation tests are relatively cheap and simple to perform in a laboratory that is equipped with a suitable laboratory flotation cell and the equipment associated with the processing of flotation products.

2.10.1 Common Laboratory Flotation Practice

There is a clear gap in literature for the standardization of flotation performance testing on the reverse flotation of iron ore. Certain common procedures are usually upheld by researchers, such as the use of amines and starches for reverse flotation, but these are all at different dosing concentrations and sequences. Thus, it would seem that either the test procedure would be ore-dependent or that various approaches may yield similar results.

General research on the standardisation of flotation testing indicates the following recommendations for bench scale flotation tests used in ore characterisation (Runge, 2010):

- Various bench scale flotation cells may be used, whether top-driven (Denver D12) or bottom-driven (Runge Engineering);
- Samples should be floated as soon as possible after collection;
- The weight of the sample is dependent on the required pulp density (which should be low);
- The aeration rate is dependent on the bubble-loading characteristics;

- Water added in the test should simulate the actual plant water; and
- Aeration rate, impeller speed, froth depth and froth scraping interval should be kept constant.

2.10.2 Interpretation of Laboratory Flotation Tests

The ideal graphs to use for the interpretation of batch-scale flotation tests are timed mineral recovery, grade recovery and selectivity curves (Runge, 2010). Mineral release curves, such as the curves in Figure 2.23, indicate the difference in flotation rate between fast-floating minerals and slow-floating minerals. Mineral release curves may also be used for reagent evaluation, where increases in the flotation rate or the overall attainable amount of floatable mineral can be detected. In addition, the flotation performance of a particular reagent suite (or various ores tested with the same reagent suite), may be interpreted from a selectivity analysis, as shown in Figure 2.24.

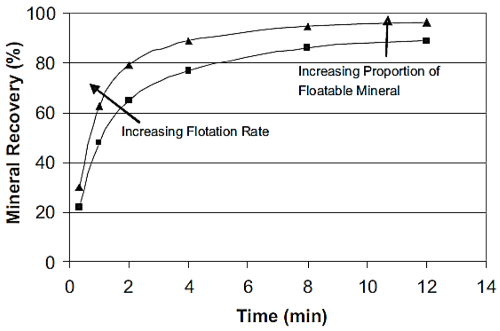

Figure 2.23: Cumulative mineral recovery curve with increased flotation rate and increased proportion of floated material denoted. (Runge, 2010)

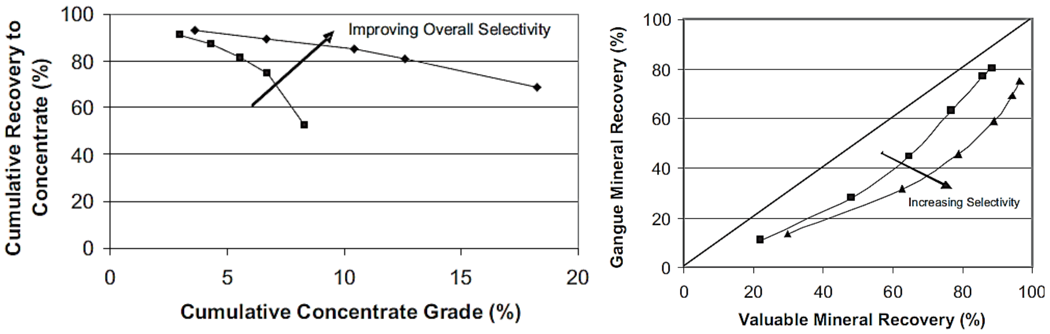

Figure 2.24: Cumulative recovery versus cumulative concentrate grade produced during a batch flotation experiment (left) and Mineral selectivity curve with essential features denoted (right). (Runge, 2010)

2.10.3 Limits of Flotation Test Work in the Laboratory

Batch scale flotation tests may be a good indicator of flotation pulp floatability, but in some instances it is a poor indicator of full-scale froth performance (Runge, 2010). The froth height is significantly less in a batch flotation cell than in a full-scale cell, where a froth height of up to 50 cm is not unusual. The change in bubble character from batch to full-scale flotation may lead reagents to be selected at batch scale, which do not yield the same performances on a flotation plant.

The agitation energies in a batch-scale cell are much higher than in full-scale cells, which will cause loosely deposited surface coatings to be removed in the batch-scale test, but these molecules will remain *in situ* in the full-scale cells (Runge, 2010). Limitations of batch-scale tests cause a need for verifications of tests by full-scale plant trials or large scale pilot plant tests.

2. 11 Summary

This study of the current understanding of iron ore flotation, both from a fundamental perspective and current plant practices, provides background for the flotation of Low grade Sishen iron ore.

The fundamental mechanism for selective flotation is attributed to the selective depression of hematite particles to a hydrophilic state, from which quartz particles can then be separated in a narrow pH range, where amine collectors exhibit the formation of an ion-molecular complex responsible for both the induced hydrophobicity of quartz surfaces and the frothing character, which stabilises air bubbles to facilitate a mineralized froth.

Although vast ores of increasingly complex nature have been identified, existing literature does not mention any iron ore flotation practices currently employed in Africa. From current plant practices in Brazil it can be concluded that:

- Reverse cationic flotation is the most common approach for hematite-quartz separation;
- Amines are used as collector; with two variants from Clariant exhibiting superior performance has been identified; and

- Starch is the most commonly employed hematite depressant, other depressants also show promising results.

Bench scale laboratory flotation tests are deemed appropriate for the evaluation of either a reagent suite or the characterization of an ore by flotation.

Chapter 3: Test Methodology

3.1 Introduction

The results obtained from flotation tests are extremely dependent on the liberation and mineralogical characteristics of the ore. Even a small quantity of gangue minerals can change the outcome of a flotation test completely (Thomas, 2010). The proper characterization of a low-grade iron ore sample from Sishen mine will enable the researcher to identify possible reagent suites as well as additional ore preparation required to investigate possible flotation parameters for the reverse flotation of low grade Sishen iron ore.

The literature study in Chapter 2 shows that use of amines and caustisized starch are appropriate for the reverse flotation of Brazilian ores containing hematite as the main iron bearing mineral and siliceous gangue. The aim of this test work is to determine if these reagents are suited for use on low-grade Sishen banded iron formation (BIF) iron ores and to establish suitable baseline parameters (depressant type, -dosage and dosing stage, dispersant type and –dosage, collector dosage and mixed collector ratio, grinding size and flotation circuit), for future work on reverse flotation of similar iron ores. The evaluation of a reagent suite for flotation is often an iterative process, as most variables affect each other and the pulp chemistry, when changed.

3.2 Ore Characterisation Methodology

3.2.1 Low grade Sishen iron ore sample identification

A low-grade iron ore sample from Sishen mine was used for the investigation. A large drive is under way for the beneficiation of particles smaller than 1mm from the mineral resources at this mine. The bulk of this material is expected to consist of iron minerals with BIF (banded iron formation) morphology at various low-grade iron contents. Samples from seven different BIF stockpiles at the Sishen iron ore mine were collected for this test work. The ore samples were prepared for various projects at Anglo American Technical Solutions Research by jaw crushing each sample to a top size of 2 mm. Reference labelling of the “as received” samples are available in Appendix 1.

3.2.2 Sample Blending and Representative Sampling

Blending and extracting samples, which are representative of the entire bulk sample, are critical for obtaining repeatable results.

3.2.2.1 Sample Blending for Ore Characterization and Flotation Feed

A head sample, consisting of seven BIF sample types were received from Anglo American Technical Solutions Research after the samples were crushed in a jaw crusher to a top size of 2mm. Samples of a weight suitable for flotation tests were required in the ore preparation. Firstly, a composite of equal weight blend from each of the individual BIF types and secondly individual BIF flotation feed samples needed to be produced.

Four sample bags of approximately 10 kg each was collected for each BIF type. The sample, as received was split to 1kg fractions in a rotary splitter, thereafter one 1 kg samples from each of the as received BIF samples was split for use in ore characterization. Thirty-six 1kg samples of each ore type remained for blending and weight reduction for suitable flotation feed.

Half of the samples were kept aside for individual BIF flotation tests, and half of the samples were used for blending a composite ore feed. Each sample was blended (one 1kg from each ore type) to produce 18 x 7 kg composite feed samples. These samples were then divided to 700g fractions, suitable for flotation feed. Seven 1 kg samples from the individual BIF ore types were mixed to produce 18 x 7 kg individual BIF feed samples. These samples were also divided into 700 g flotation feed samples in a rotary splitter. A summary of the sample blending procedure is available in Appendix 1.

3.2.2.2 Representative Sampling

The outcomes of any flotation tests are highly dependent on the homogeneity of the flotation feed samples used for the comparative tests. Samples must be of such a nature that the composition of any single sample must be within a reasonable similarity to the head sample.

To ensure a representative sampling procedure, variation in the ore preparation procedure was evaluated in the sample splitting procedure. This evaluation is done by comparing the average weight of a single sample produced in any splitting procedure to the actual weight of the sample. The standard deviation for each sample split (range) is then calculated to determine the average weight percentage difference between the individual samples. A standard of no more than 5% weight difference is upheld for all splitting procedures.

A final indication of the reproducibility of the flotation tests is the use of a "call factor" to compare the ore composition and recovery of the flotation products to the estimated feed grade, as in Equation 3.1. An XRF analysis (% Fe and % SiO_2), of the froth products and pulp products, together with the dry weight of each sample is used to recalculate the estimated feed of the flotation test. It is ideal for the Call Factor to range between 0.95 and 1.05, but this is influenced by variation in test procedure, sample collection and analysis of XRF and weight parameters.

$$Call\ Factor = \frac{Recalculated\ \%Fe\ in\ Feed}{Head\ Grade\ \%Fe\ in\ Feed\ Sample}\ OR\ \frac{Recalculated\ \%SiO_2\ in\ Feed}{Head\ Grade\ \%SiO_2\ in\ Feed\ Sample} \ldots\ldots eq. 3.1$$

3.2.3 Characterisation of Ore Composition

The chemical composition of low-grade Sishen banded iron ore is determined from the analysis by X-ray fluorescence (XRF), at the University of Pretoria's Metallurgical Engineering department. A Bruker S2-Ranger bench top XRF machine was used for analysis of both the feed ore and flotation products. Calibration standards from Sishen Mine were used to set up the detection limits and detector intensity of the machine for Fe_2O_3, SiO_2, K_2O, Al_2O_3, Na_2O, MgO, P_2O_5, SO_3, MnO, TiO_2 and CaO.

Samples are prepared for XRF analysis, by mixing approximately 28g dry ore sample (which has a maximum particle size of 45 microns), with seven drops of PVA binder. The mixture is homogenised by manual blending and then compressed in aluminium cups, before a curing period of between one and two hours at 90 degrees Celsius is imposed. Once the sample has cooled down, it is stored in an air tight container until being subjected to analysis in the XRF machine.

3.2.4 Characterisation of Ore Mineralogy

The mineralogical analysis for the composite ore, as well as each BIF ore consists of quantitative and qualitative X-ray diffraction analysis (XRD). Samples submitted for XRD analysis were analysed using a PANalytical X'Pert Pro powder diffractometer with X'Celerator detector and variable divergence- and receiving slits with Fe filtered Co-Kα radiation. X'Pert Highscore plus software was used for mineral phase identification. The Rietveld method (implemented in an Autoquan Program) was used to estimate the relative phase amounts (as a % of weight). If amorphous phases were present, they were not taken into consideration in the mineral phase quantification. Both quantitative and qualitative XRD analysis was conducted by the Stoneman analytical laboratory at the University of Pretoria's Geology Department.

3.2.5 Characterisation of Ore Liberation

3.2.5.1 Determining Ore Liberation Size

Scanning Electron Microscopy

Characterisation of the flotation feed "blended BIF" material by scanning electron microscope (SEM), was conducted at the University of Pretoria's physics department surface analysis laboratory. The feed material was split into a representative portion, from which polished sections were prepared for analysis. The energy dispersed from the sample when electrons are excited by an x-ray beam is used to create a backscattered electron image (BEI), from which an interpretation of the particle size and hematite-gangue mineral liberation was done. Single points were targeted to determine the chemical composition of the mineral at that specific point on the image. Additional SEM analysis of some of the flotation products were done to establish the liberation condition of the flotation froth after rougher flotation.

A mineralogical analysis of the bulk modal mineralogy, hematite and gangue mineral liberation, association and grain size distribution was conducted at Anglo American Technical Solutions Research, where a representative portion of the sample is split for characterisation. Characterisation was done by mineral liberation analyser (MLA), and quantitative x-ray diffraction (QXRD) was used to validate the MLA data.

MLA-analysis was conducted on the blended BIF feed ore and the flotation products of three different flotation tests.

3.2.5.2 Particle Size Distribution: "As-received" Sample

To establish the particle size distribution of the "as-received" ore, as well as the particle size distribution of ore fed to the flotation cell after grinding, laboratory sieving tests are required.

The particle size distributions of "as received" ore samples were obtained by physical wet sieving tests. Approximately 200g dry ore sample is added to the top of a laboratory sieve series in the descending order of size: 2360 micron, 1180 micron, 600 micron, 300 micron, 150 micron, 75 micron, 45 micron 25 micron and a non-perforated bottom pan fitted with a water outlet pipe. The wet sieving sieve shaker is started and after 2 minutes, the water inlet is opened to allow a suitable constant flow of water through the sieve series for the next 20 minutes. The samples retained on each of the sieves and in the non-perforated outlet bucket are dried in a laboratory oven for at least 4 hours at 90 degrees Celsius, before the dry retained sample weights are recorded.

3.2.5.3 Particle Size Reduction

The time required for obtaining a desired feed particle size distribution to the flotation cell (as depicted by the mineral liberation and flotation kinetics), was determined by a laboratory grinding curve evaluation. A dry feed ore sample of approximately 700g (similar to the required flotation feed sample size) is added to the laboratory steel rod mill. Synthetic plant water is used to establish 66% solids by weight pulp during a 10 min, 20 min, 30 min and 40 min milling experiment. After each experiment, the pulp is washed from the mill chamber, dried at 90 degrees Celsius and split into ten representative samples each, from which a triplicate particle size distribution can be constructed. Appropriate grinding times are interpolated from the resulting curves.

3.2.5.4 Particle Size Distribution: Flotation Feed

The particle size distribution of the samples fed to the flotation test were monitored (but not controlled), by collection of grab samples from the mill product at random intervals and analysing these samples by laser diffraction in the Malvern Mastersizer 2000. Three samples (of approximately 3g each) from each of the grab samples were analysed in triplicate to determine the top size, 80% passing and 50% passing size of the flotation feed samples. Samples were evaluated against the laser diffraction results from triplicate grab samples collected from the mill after coarse, medium and fine grinding. As a precaution to minimise particle agglomeration during particle size measurement, samples were exposed to ultrasonic waves for 20 seconds before analysis.

3.3 Laboratory Flotation Test Methodology

3.3.1 Experimental Plan

An experimental plan was constructed to find baseline parameters for the reverse flotation of low-grade Sishen iron ore. An overview of this plan is shown in Figure 3.1 where four clearly defined flotation test sections are indicated. The ore characterization is continued in parallel to the flotation tests.

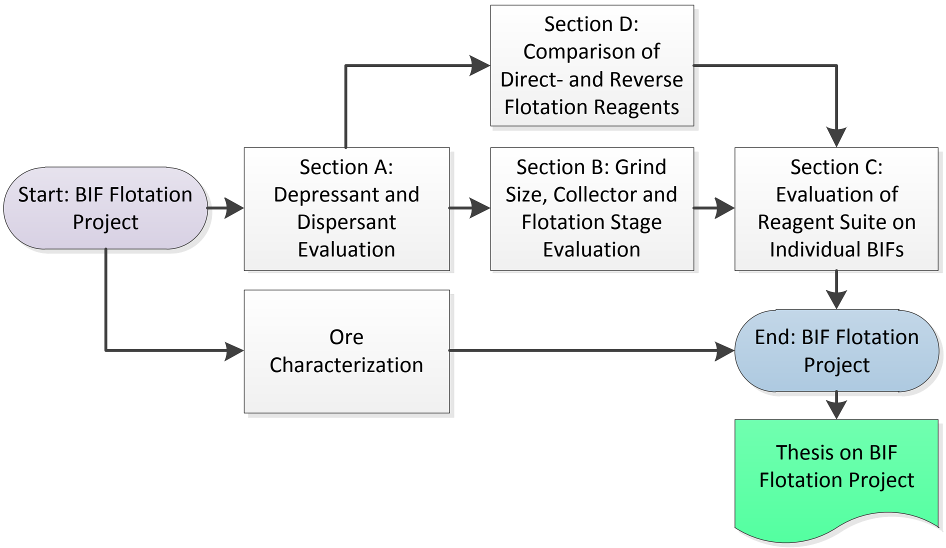

Figure 3.1: Experimental plan for BIF flotation project

A factorial design of experiments was implemented to accommodate the vast amount of experimental variables to be tested: Particle grind size, flotation pH, depressant, dispersant and collector type and –dosage, number of flotation stages and BIF ore type. Section A serves as the start of flotation tests. The aim is to evaluate modifying agents used to enhance the flotation results of quartz from hematite minerals. In section B, the particle size fed to the flotation test is evaluated in terms of a coarse, medium and fine grind size. These results are then used to evaluate the collector dosage required. The number of rougher flotation stages and possibility of employing scavenger flotation stages are also evaluated in this section, as well as additional tests on the influence of a change in the ratio of mixed amine collector. Section C then comprises of the evaluation of these flotation parameters and reagent suite on each of the individual flotation BIF ore samples. Outside of these flotation tests, a comparison of direct and reverse flotation of the low grade Sishen iron ore samples were done in section D.

3.3.2 Reagent Preparation

3.3.2.1 Depressants

Starch is prepared by a causticization process, where a 1M chemical grade NaOH, supplied by Merck Chemicals; solution is added to a solution of 10 g Sigma-Aldrich corn starch and 150 ml distilled water. This solution is stirred at below 300rpm for 30min using an overhead Heidendorph laboratory stirrer, during which time the viscosity of the solution increases. After 30 min, distilled water is added to provide a 500ml solution to produce a 2 wt.% caustisized starch solution. A fresh starch solution is made up at the start of each day of flotation testing. The required dosing volume for each test is removed from the solution with a 0.5-5 ml Mettler Toledo variable pipette.

Dextrin, industrial grade Betamin 3D supplied by BetaChem, is prepared by dissolving 8 g reagents in distilled water to form a 200 ml solution with a 4 wt.% concentration. The solution is stirred for 30min before use in flotation testing, and a fresh solution is made up each day before flotation testing. The required dosing volume for each test is removed from the solution with a 0.5-5 ml Mettler Toledo variable pipette.

3.3.2.2 Collectors

Amine Collectors, industrial grade Flotigram EDA3 and Flotigram 2385-2L supplied by Clariant, are prepared at room temperature by mixing 0.175 g collector with distilled water to form a 300 ml solution with a 0.058 wt.% collector concentration. For most of the designed experiments, a 1:1 amine collector ratio was employed, although an additional investigation evaluates the influence of a change in this ratio. Phosphate collectors, industrial grade Flotinor SM15 supplied by Clariant, are prepared at room temperature by mixing 4.2 g collectors with distilled water to form a 300ml solution with a 1.4 wt.% collector concentration. Fresh collector solutions are made up at the start of each day of flotation testing. The required dosing volume for each test is removed from the solution with a 0.5-5 ml Mettler Toledo variable pipette.

3.3.2.3 Dispersants

Sodium Silicate, industrial grade FloatSil1 and FloatSil2 supplied by PQ Silicates, is prepared by mixing 20 g reagent with distilled water to form a 200 ml solution at 10 wt.% concentration. Fresh dispersant solution is made up at the start of each day of flotation testing. The required dosing volume for each test is removed from the solution with a 0.5-5 ml Mettler Toledo variable pipette.

3.3.2.4 Modifiers

Modifiers for pH adjustment are prepared in advance. Sulphuric acid and Sodium Hydroxide are prepared at 1M concentrations, by dissolving the required amount of reagent in distilled water and storing the solutions in air tight solution bottles.

3.3.2.5 Synthetic plant water

The expected composition of process water for a flotation plant at Sishen iron ore mine may be indicated by the water analysis from the Sishen Expansion Project (SEP) process water dam (Table 3.1, which shows the level of dissolved solids in the process water measured in September 2013, for the constituents present at a level higher than 1 mg/l, by Aquatico Scientific (Pty.) Ltd. Two of the largest contaminants are dissolved calcium and magnesium ions, which can be used for the make-up of synthetic plant water for test work. This level of water hardness could have a negative effect in the flotation of silicate minerals, as stated by Fuerstenau & Fuerstenau (1982).

Table 3.1: Analysis of SEP process water for September 2013 by Aquatico Scientific (Pty.) Ltd.

Variable	Unit	Level
pH		7.98
Chloride (Cl)	mg/l	64.9
Sulphate (SO_4)	mg/l	82.6
Nitrate (NO_3) as N	mg/l	105
Calcium (Ca)	mg/l	121
Magnesium (Mg)	mg/l	54.9
Sodium (Na)	mg/l	48.8
Potassium (K)	mg/l	29.6

Distilled water is used as base liquid before 6.32 g $CaCl_2$ and 5.4 g $MgCl_2$ is added to make up a 20 litre solution. At least 40 litres of synthetic plant water is made in a batch, and the supply is replenished weekly/as needed between flotation tests.

3.3.3 Ore Preparation

The material used for each flotation test was removed from an air tight sample bag, (in accordance with Cytec guidelines (Thomas, 2010)), before it is mixed with synthetic plant water in a laboratory steel rod mill at a pulp density of 66% solids by weight. A cylindrical laboratory mill with inside diameter 240 mm and length 255 mm was used to achieve the desired grinding size. The weight of the rods used was measured as 21.24 kg and consisted of rods with an outside diameter of 20 mm and length 241 mm. The feed ore is milled for a specified amount of time (15 minutes for coarse feed, 25 minutes for medium feed, 45 minutes for fine feed). Synthetic plant water is used to wash the sample out of the mill into a 2.6 litre stainless steel flotation cell (at 50% solids by weight). This sample is then ready for a flotation test.

3.3.4 Flotation Tests

All flotation tests in the experimental design were conducted in a temperature controlled laboratory at an ambient room temperature of 25°Celscius, in a 2.6 litre steel flotation cell, making use of a Denver D12 flotation machine as shown in Figure 3.2. For reagent conditioning, the impeller speed is set at 800 rpm. Depressant reagents are conditioned for five minutes, before additional synthetic plant water is added to result in a pulp density of 30% solids by weight. The pulp pH is measured with a 2-point calibrated Mettler Toledo pH meter and corrected to the desired pH level to be tested (pH 3, pH 5, pH 7, pH 9 or pH 11), before collector reagents are added and conditioned for another 3 minutes.

Figure 3.2: Flotation tests conducted in Denver laboratory flotation machine at the University of Pretoria

The pH is measured again, but not recorded, and altered if necessary, before the impeller speed is increased to 1200 rpm, and the air is opened for the first flotation stage. In each flotation stage froth is removed in 15 second interval and cumulatively collected for 2 minutes before the air supply is closed, and reagent conditioning for the next flotation stage is started. Each reagent conditioning stage, between the 2-minute flotation stages, consists of replenishing the water level with synthetic plant water, measurement and alteration of pH as well as a three-minute collector reagent conditioning. An initial number of rougher flotation stages is started at six stages, which can then be altered during the flotation circuit optimisation.

3.3.5 Flotation Product Handling

Each product from all of the flotation tests were washed into a filtration chamber and filtered in a laboratory pressure filter (with 3 micron filter paper), before being dried overnight in a laboratory oven at 90˚Celscius. Once dry, each of the froth and pulp samples is weighed and recorded, before a representative sample, (coned and quartered), is used for preparation of an XRF powder and the remaining sample is stored in an air tight container. A PVA binder is added to the XRF sample material at less than 5 wt.%. The sample is pressed at 10 tons for two minutes before curing for 30 minutes at 90 ˚Celscius, (in accordance with Cytec guidelines (Thomas, 2010)). XRF samples are cooled down and stored in an airtight container before XRF analysis (Usually within 1-3 days from sample preparation).

3.4 Summary

Ore characterisation of seven clearly identified low grade BIF iron ore samples and a proportionally equal blend of these seven BIF samples, which made up a composite feed sample for flotation tests, could be done by the evaluation of:

- chemical composition (XRF)
- mineralogical composition (XRD and MLA)
- particle size distribution (sieve tests and laser diffraction)
- mineral liberation (SEM and MLA)

An experimental plan was proposed to find the baseline flotation parameters for reverse flotation of low grade Sishen iron ore BIF, which included bench-scale laboratory flotation tests for the evaluation of:

- depressant type, -dosage and dosing stage;
- dispersant type and –dosage;
- collector dosage and mixed collector ratio;
- grinding size; and
- flotation circuit configuration.

Chapter 4: Results and Discussion

4.1 Introduction

By establishing the character of the low grade Sishen iron ore in terms of mineralogy, chemical composition, particle size distribution and mineral association, a flotation regime can be predicted. Laboratory flotation test work will then indicate the suitable reagent suite and flotation parameters required establishing a baseline for flotation work on low grade South African iron ore material.

4.2 Characterisation of low grade Sishen banded iron ore

4.2.1 Ore composition

The ore composition for each of the individual BIF ore type samples was established from the XRF results obtained from 4 different samples from each of the seven BIF ores. After the XRF results had been made available, the labels on the ore types were altered to reflect an indication of the iron content in each ore type (with BIF1 depicting the lowest percentage iron, at 25.6% Fe, and BIF7 depicting the highest percentage iron, at 39.7% Fe). Figure 4.1 shows the XRF results for the major elements present in the ore composition. The percentage silica values range from 59.5% SiO_2 to 39.2% SiO_2. A blend calculation value shows the range of iron- and silica contents one can blend from these seven BIF ores. If equal amounts of each BIF ore type are blended, a 31.0% Fe and 51.3% SiO_2 blend composition may be expected.

An oxide balance of the percentage Fe_2O_3 and percentage SiO_2 present in each of these ore types shows that less than 2% of the ore constitutes of other elements. The presence of these minor elements can however greatly influence the results expected in a flotation experiment, due to the sensitivity of the process to changes in the pulp chemistry or mineral surfaces. Two of the minor elements, K_2O and Al_2O_3, present in the individual BIF ore types are shown in Figure 4.2. As it becomes difficult to detect composition quantities accurately by XRF when the species is present in values lower than 0.5%, other elements (Na_2O, MgO, P_2O_5, SO_3, MnO, TiO_2 and CaO) are not reflected in this comparison.

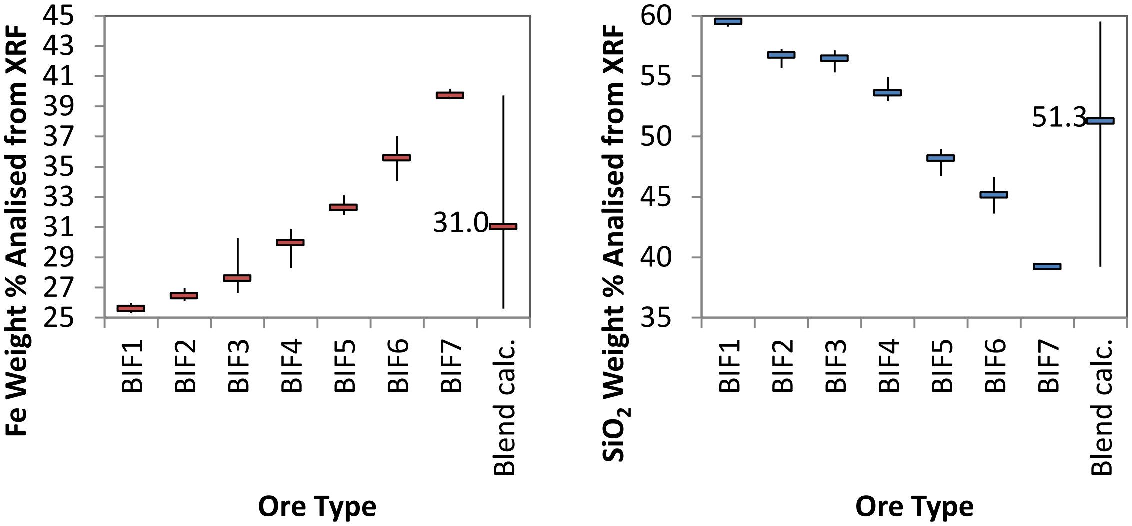

Figure 4.1: XRF analysis of the major elements present in each BIF ore and a calculated equal blend composition.

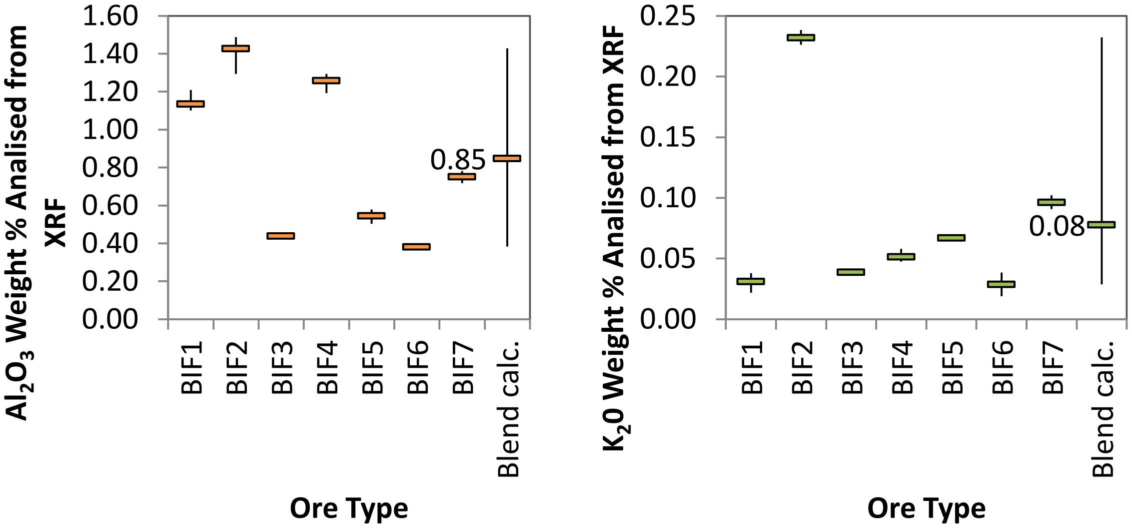

Figure 4.2: XRF analysis of K_2O and Al_2O_3 present as minor gangue minerals in each BIF ore and a calculated equal blend composition.

In an attempt to establish an indication of mineral association, the compositional results for major and minor elements are compared to the percentage iron content. Figure 4.3 shows a very good linear relationship between the percentage iron and percentage silica content (R^2= 0.9878), but no reliable correlation between the percentage iron content and the amount of minor elements present. Identification of this strong correlation enables one to monitor the flotation test performance by evaluating only one element, although confirmation of trends is established by confirming the flotation product sample composition.

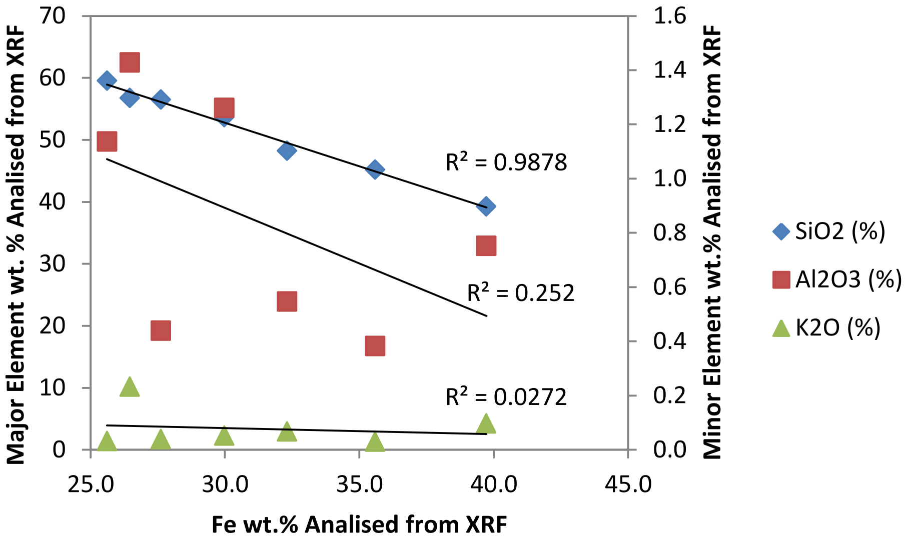

Figure 4.3: Major- and minor element fractions in individual BIF ores as a function of the individual iron content.

Twelve representative blended composite BIF samples were subjected to XRF analysis, to determine the head grade of the composite ore. Figure 4.4 shows the percentage iron and percentage silica analysis of each sample. A target iron content for the project was set at 64% Fe, with as low as possible silica content. All the data for sample characterisation by XRF analysis is available in Appendix 2.

The standard deviation and error percentage on XRF analysis of each constituent for the composite feed is available in Appendix 2. An error value of 0.6% for both percentage iron and silica was obtained. This is the composition used for head grade comparison with the reconstituted flotation feed in determining the call factor.

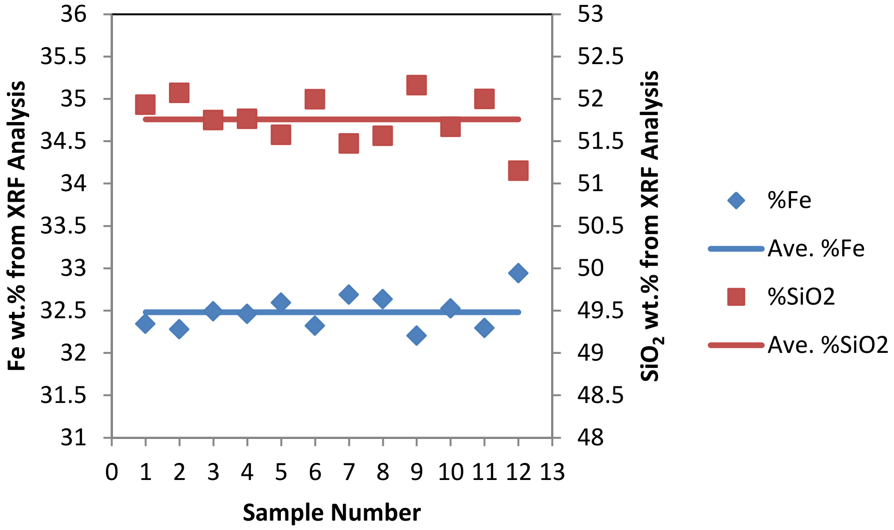

Figure 4.4: XRF analysis of samples used for head grade calculation of composite feed ore.

Again little to no correlation can be made between the K_2O, Al_2O_3 content and the percentage iron in the samples as shown in Figure 4.5. The linear inversely proportional relationship of percentage silica as a function of the percentage iron in the samples is confirmed with an almost perfect line fit (R^2= 0.9938).

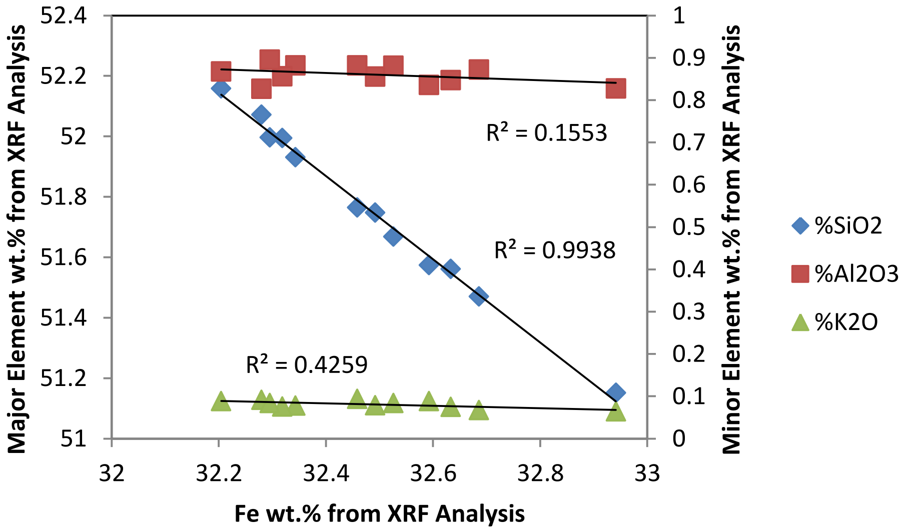

Figure 4.5: Major and minor elemental fractions as a function of iron content of blended composite BIF ore.

4.2.2 Particle Size Distribution and Ore Grinding

In the characterization of the ore sample, a particle size distribution of the composite feed material was established for the ore before being subjected to any grinding or further size reduction. A particle size distribution for three different feed compositions is available in Appendix 3. Figure 4.6 shows the average particle sizes expected from the blended ore.

The average particle size distribution calculated from 10, 20, 30 and 40 minutes of milling composite feed sample with an 80% passing 1100 microns (1.1mm), is shown in Figure 4.7. With less than 10% of the particles smaller than 150 micron, this feed is too coarse for flotation. This graph indicates that 80% of the particles will be smaller than 80 micron after 10 minutes of milling, and 95% of the particles will be smaller than 20 micron after 40 minutes of milling. Initially, the particle size is broken down fast as a substantial shift in the curve is noted between the feed sample and the sample milled for ten minutes. After ten minutes the particle size distribution gradually decreases in size, as the longer mill retention time results in the generation of more fine particles.

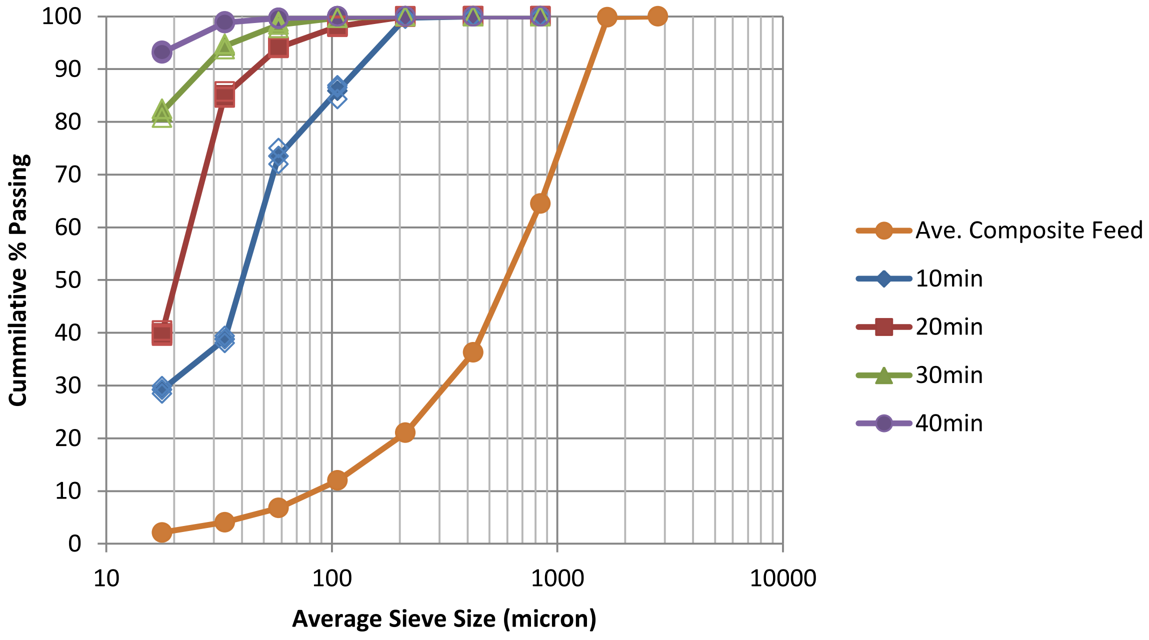

Figure 4.6: Particle Size distribution for composite feed and samples milled for 10, 20, 30 and 40 minutes from Laboratory Sieving

Interpolation of the grinding curve constructed from the sieve analysis at each grinding time interval, as shown in Figure 4.8, shows that 80% of the particles should be smaller than 58 microns after 15 minutes of milling and smaller than 34 microns after 25 minutes. When the curve is extrapolated beyond a milling time of 40 minutes, a particle size distribution of more than 80% passing 18 micron is expected. Laboratory wet sieving is, unfortunately, limited in accurately measuring such fine particle sizes, due to many particles being lost in the sieve section below 25 micron and inter-particle agglomeration.

Table 4.1 shows the grinding results from both laboratory sieve analysis and laser diffractive analysis. The particle size distribution obtained from laser diffraction analysis is available in Appendix 3.

Table 4.1: Sieve and lased diffraction analysis size of 80% material passing for 10, 20, 30 and 40 minutes mill retention time

Mill Retention Time	Sieve Analysis	Laser Diffraction
10 minutes	80 micron	180 micron
20 minutes	31 micron	55 micron
30 minutes	18 micron	23 micron
40 minutes	Not quantified	17 micron

After consultation with Vratislav Malysiak from Anglo American Technical Solutions Research, a grinding time of 25 minutes was agreed upon as the medium grind size to be evaluated during flotation test work. This was deemed to achieve a grind size of approximately 80% passing 25 micron. A coarse grind of 80% passing 55 micron would be achieved after milling for 15 minutes and a very fine grind below 15 microns was expected after 45 minutes of milling.

4.2.3 Mineralogy

Mineralogical analysis indicated the presence of hematite and quartz as the major minerals in the ore composition. This corresponds with the previously published information on deposits from Sishen iron ore mine (Astrup *et al.*, 1998)). Although the detection limit of analysis by XRD does not permit accurate quantitative analysis for minor elements (present in less than 1%), the presence of kaolinite and annite were confirmed for BIF1 and BIF2, the two samples with the lowest hematite content, as can be seen in Figure 4.7. For a blend of equal amounts of each of the BIF ore types, an average composite 47.3 %hematite and 52.4 %quartz can be expected. The difference in expected composition between Figure 4.4 and Figure 4.7 can be attributed to different calibration standards for XRF and XRD respectively.

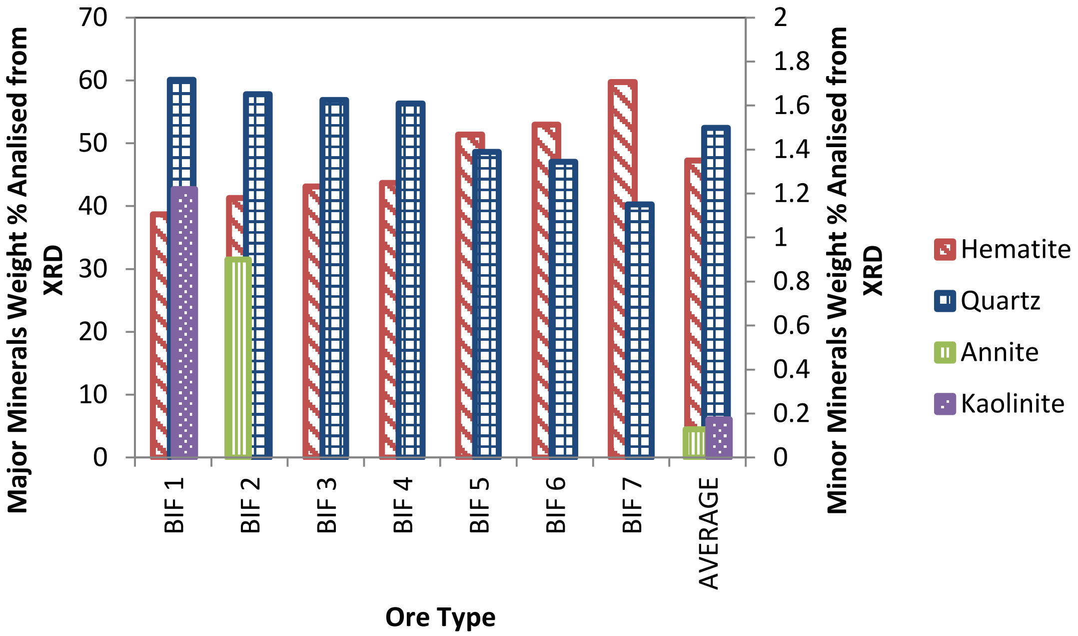

Figure 4.7: Mineralogical analysis of each BIF ore sample and an expected average mineralogical composition of an equal blend composite

The difference in mineralogical composition is best illustrated by a comparison between the x-ray diffractive peaks used for identification of mineral phases. Figure 4.8 shows the matching diffractive peaks of annite and Figure 4.9 shows the matching diffractive peaks of kaolinite. This explains the higher Al_2O_3 and K_20 values depicted in BIF1, where kaolinite is responsible for the Al_2O_3 content, and BIF2, where annite is responsible for the K_2O content, by XRF analysis. All other XRD graphs for the remaining samples are available in Appendix 4.

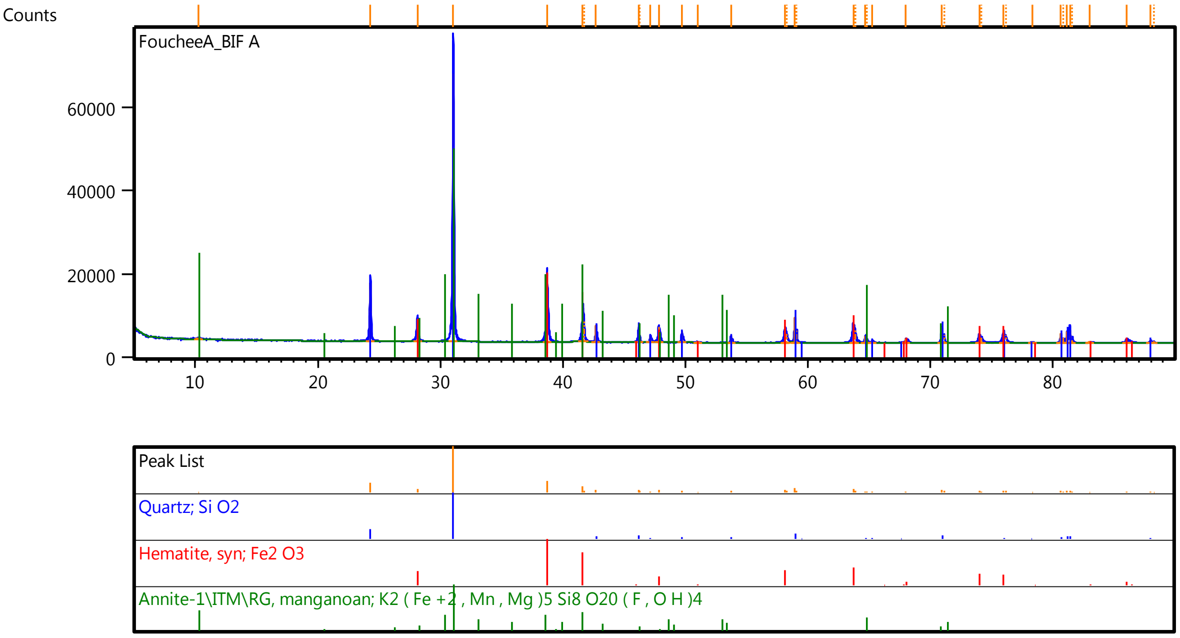

Figure 4.8: Qualitative mineralogical analysis of BIF sample containing annite.

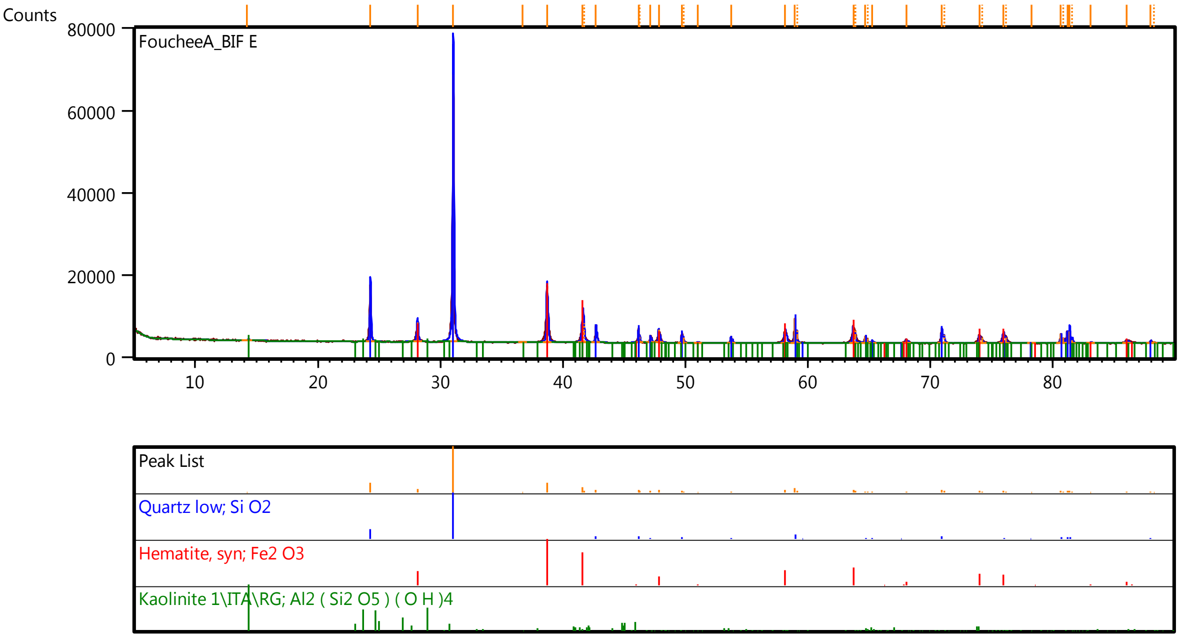

Figure 4.9: Qualitative mineralogical analysis of BIF sample containing kaolinite.

Four random samples from the composite blend (of equal quantities of each BIF ore type), indicated the presence of only hematite and quartz mineral phases, for which QXRD results are available in Appendix 4. It is assumed that the presence of other mineral phases, such as kaolinite and annite identified in the individual BIF ore types, is at a level below the detection limit of XRD analysis. The average relative amount of hematite and quartz mineral phases in the composite ore corresponds well with the expected composition as calculated from the individual BIF ore types.

Hematite was expected to contribute 47.3%wt. and was measured at 47.6%wt. quartz was expected to contribute 52.4%wt. and was measured at 52.5%wt. This is an indication of well-represented sampling as well as a good blending procedure.

4.2.4 Mineral Liberation

Mineral liberation of the feed material is established by two methods. A first indication is obtained from SEM micrographs and secondly the quantification of mineral liberation by MLA. A range of SEM micrographs are available in Appendix 5.

4.2.4.1 SEM

SEM images from the un-milled as-received composite sample show a range of liberation levels for various particle sizes. Figure 4.10 shows a 200 micron particle containing more than 95% free hematite, but also similarly sized particles in which hematite is occluded by quartz.

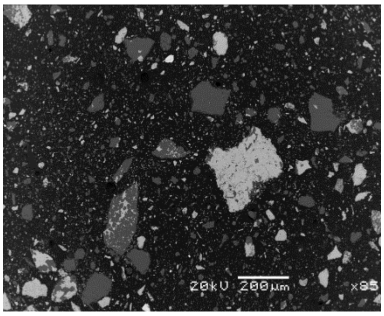

Figure 4.10: BSE SEM image of as-received composite BIF material with a 200 micron scale indication

At a higher magnification, such as in Figure 4.11, it is possible to see that even at a particle size of 20 micron, certain hematite containing particles are not liberated. In Figure 4.11*a*, a hematite matrix particle with occluded quartz mineral phases are present. Such particles are difficult to float selectively, as a very fine particle size distribution is required for liberation of the hematite. Frame *b* shows a particle with hematite phases which should be liberated at a particle size distribution of 80% passing 20 micron. Frame *c* in Figure 4.11 shows hematite phases smaller than 5 micron concentrated in a single quartz matrix particle. Grinding to such a fine grain size might deplete selectivity by establishing an excessively stable froth phase, which will not be able to drain sufficiently.

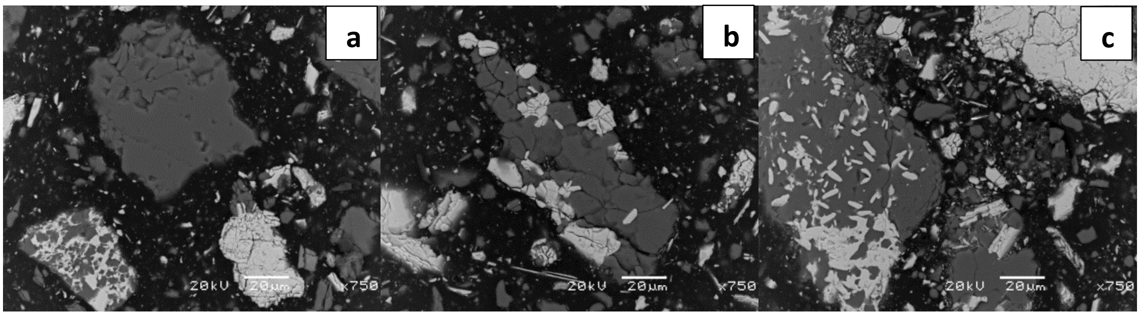

Figure 4.11: BSE SEM images of as-received composite BIF material with a 20 micron scale indication

SEM images from the composite sample milled for 45 minutes indicate more homogenous levels of liberation, as shown in Figure 4.12. All three frames indicate that the bulk of the particles are smaller than 20 micron and liberated in excess of 90%. Thus, beneficiation by magnetic separation could prove difficult as a decrease in the particle size for liberated mineral phases will result in a decrease of the recovery of magnetics for certain iron ores (Kelly & Spottiswood, 1989). The efficiency of gravity separation is also limited by the small particle size (Kelly & Spottiswood, 1989).

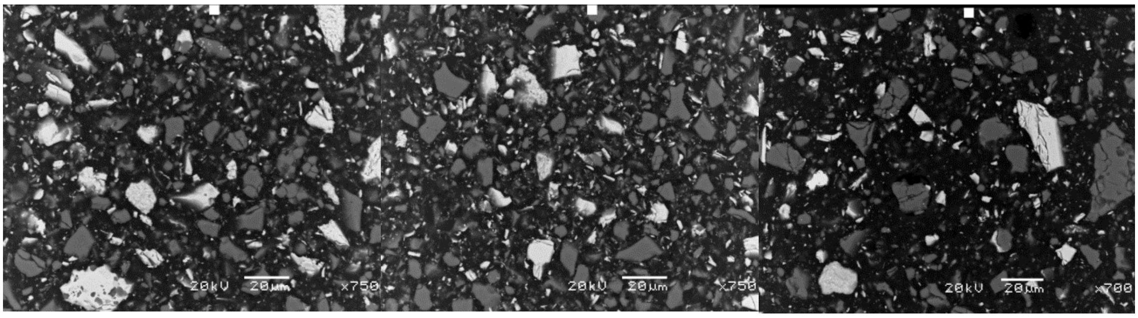

Figure 4.12: BSE SEM images of composite BIF material milled for 45 minutes with a 20 micron scale indication

4.2.4.2 MLA

The mineralogical investigation conducted at Anglo American Technical Solutions Research firstly confirmed the mineralogical composition of the low grade Sishen iron ore used in this study to consist of hematite (Fe_2O_3), quartz (SiO_2), muscovite ($KAl_2(Si_3Al)O_{10}(OH)_2$), kaolinite ($Al_2Si_2O_5(OH)_4$), as well as other minor silicate phases. The bulk mineralogy of a composite blend BIF feed sample (milled for 45 minutes, achieving more than 50% passing 10 micron), was identified as hematite (43.3%), quartz (54.0%), mica (1.1%) and kaolinite (1,6%). In this sample 82% of hematite grains were liberated more than 95%, and the mean hematite grain size (d50) was determined as 11 micron. Of the 18% hematite grains reporting less than 95% liberation, 93.0% of the grains consist of hematite associated with quartz, 3.3% hematite associated with clay, 2.7% hematite associated with mica and 1.0% hematite associated with two or more minerals. This indicates that 16.7% of the feed material may still potentially be misplaced due to insufficient liberation when the quartz is targeted by an amine collector.

The sample also showed 95% or more liberation for 89.0% of the silicate grains in the composite BIF flotation feed material at a mean silicate grain size of 12 micron. This indicates that a sample milled for 45 minutes will yield well liberated flotation feed material and it can be expected that up to 89% of the 52% quartz in the feed material could potentially be recovered by flotation. The MLA results also show that all particles (both hematite and silicate) are liberated 80% and more in the particle size group 20-40 micron, as can be seen in Figure 4.13.

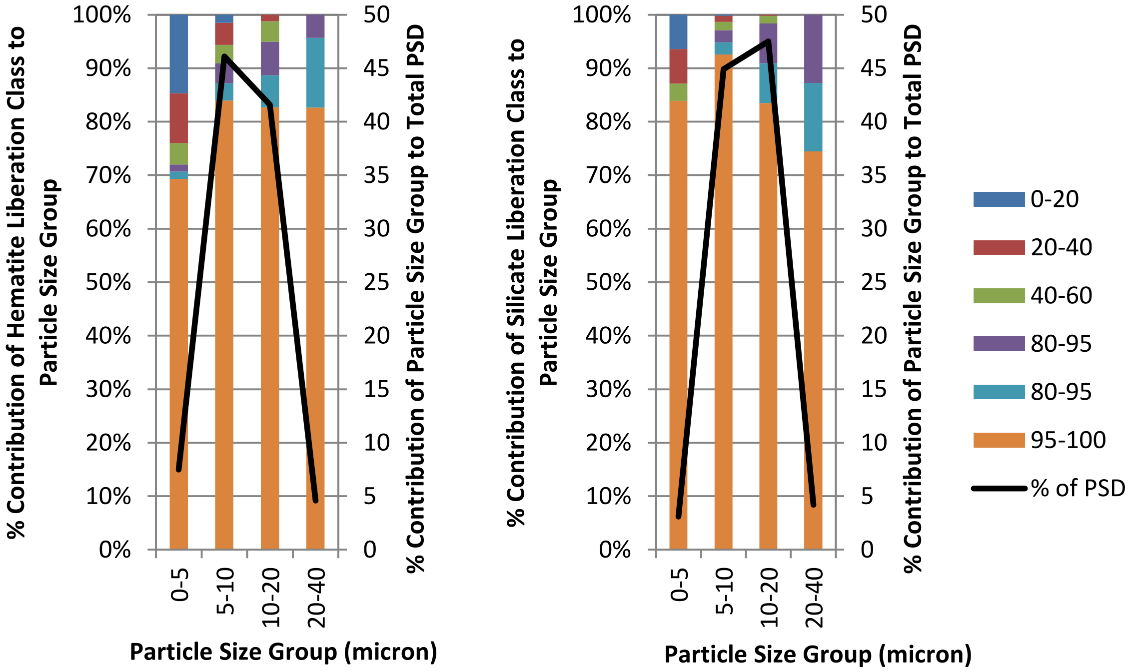

Figure 4.13: Liberation class and PSD percentage contribution to each particle size group for 45 minutes milled low-grade composite BIF

In the 0-5 micron particle size group for hematite particles, 30.7% of the particles are less than 95% liberated, rendering their particles extremely susceptible to misplacement due to both entrainment and insufficient liberation. The same is true for the hematite particles in the particle size group 5 to 10 micron, although one would expect the selectivity of the collector and depressant used in the flotation test to counter these effects. Entrainment of silica particles is advantageous. Thus, the high percentage of silica particles in size classes below 10 micron is beneficial.

4.2.5 Variation from Sample preparation

Variation in the sample feed originates from the variance in the sample weight used for each test and variation in the composition of each sample. The error arising from the sample weight is due to inherent inefficiencies during sample splitting. The standard deviation and percentage error for each of the bulk primary sample splits are shown in Appendix 6. This indicates a sample weight error of less than 5%, which is the accepted standard for baseline investigative test work.

The largest and smallest variation in percentage error in sample weights from individual BIF ore samples split by a second stage rotary splitter are shown in Figure 4.14, where each colour depicts one of the bulk material bags. This also indicates an error of less than 5% for the samples used for blending the composite BIF material.

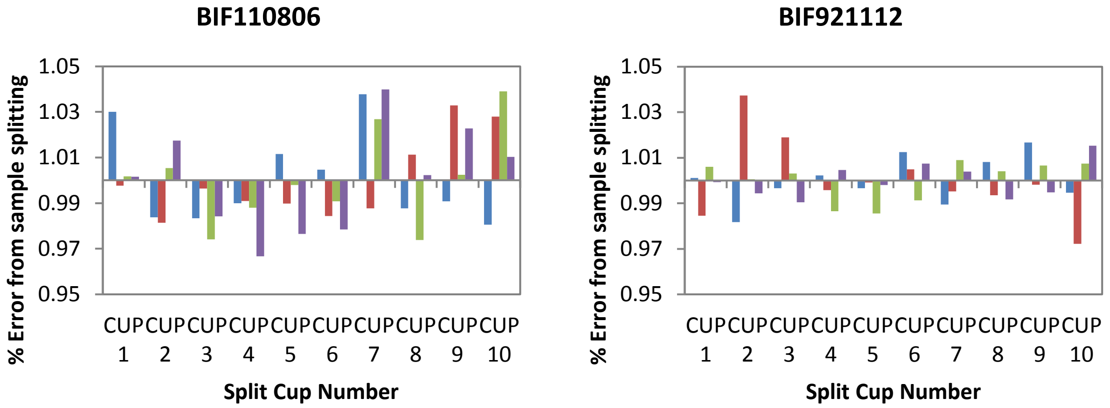

Figure 4.14: Variation in sample weights from split individual BIF ores with the highest and lowest error percentage

4.3 Flotation Tests Evaluation of a reagent suite for the reverse flotation of low grade Sishen BIF iron ore

The results for all flotation tests conducted are evaluated on four basic parameters: percentage iron grade, percentage silica grade, percentage iron recovery and percentage silica recovery. All results will be discussed in terms of a SiO_2 Flotation cell, where the SiO_2 concentrate is the froth phase carried over the flotation cell lip, and the SiO_2 tails are the pulp remaining in the flotation cell. Table 4.2 shows on what basis the four parameters are evaluated for each of the flotation products and the reasoning behind it.

4.3.1 Depressant Type Evaluation

An opening baseline condition was established for the reverse flotation of low grade BIF iron ore by amine collectors, where no depressant was added in tests at pH levels 3, 5 and 9, by conducting laboratory flotation tests on a bench-scale. This was then compared to tests at the same pH levels, when either caustisized starch or dextrin, (both non-ionic surfactants recommended to depress hematite in the reverse flotation of iron ore (Rao, 2004; Fuerstenau & Fuerstenau, 1982)), were added as a hematite depressant. The results in Figure 4.15 and Figure 4.16 showed a decrease in the iron grade and an increase in the percentage SiO_2 grade reported in the SiO_2 rougher concentrate, as the basicity of the flotation pulp was increased. The inverse was true for the SiO_2 rougher tails.

Table 4.2: Desired Results for Flotation Parameters

Parameter	**SiO_2 Concentrate**	**SiO_2 Tails**	**Reasoning**
% Fe Grade	Low	High (>62%)	The SiO_2 Tails is to be sold as an iron product
% Fe Recovery	Low	High (>30%)	Project Feasibility is dependent on achievable throughput
% SiO_2 Grade	High	Low (<6%)	Penalties are inferred for high %SiO_2 in %SiO_2 Tails (sold as iron product)
% SiO_2 Recovery	High	Low (minimum)	Bulk of silica minerals must be removed in the froth

The recovery of Fe to the concentrate seemed to reach a minimum at pH 3 and the recovery of SiO_2 reached a maximum at pH 9. In the tails, a maximum iron recovery is reached at pH 3 and a minimum SiO_2 recovery at pH 9. To determine a defined trend, additional flotation tests were conducted at pH levels 7 and 11, only using starch and the baseline of no depressant. This resulted in a minimum percentage iron grade and recovery being identified at pH 11 in the concentrate, where most of the un-substituted amines are expected to be dissociated (Ralston *et al.,*1944; Rao, 2004*).* The highest percentage silica grade in the concentrate was also at pH 11, but the highest silica recovery was identified at pH 7.

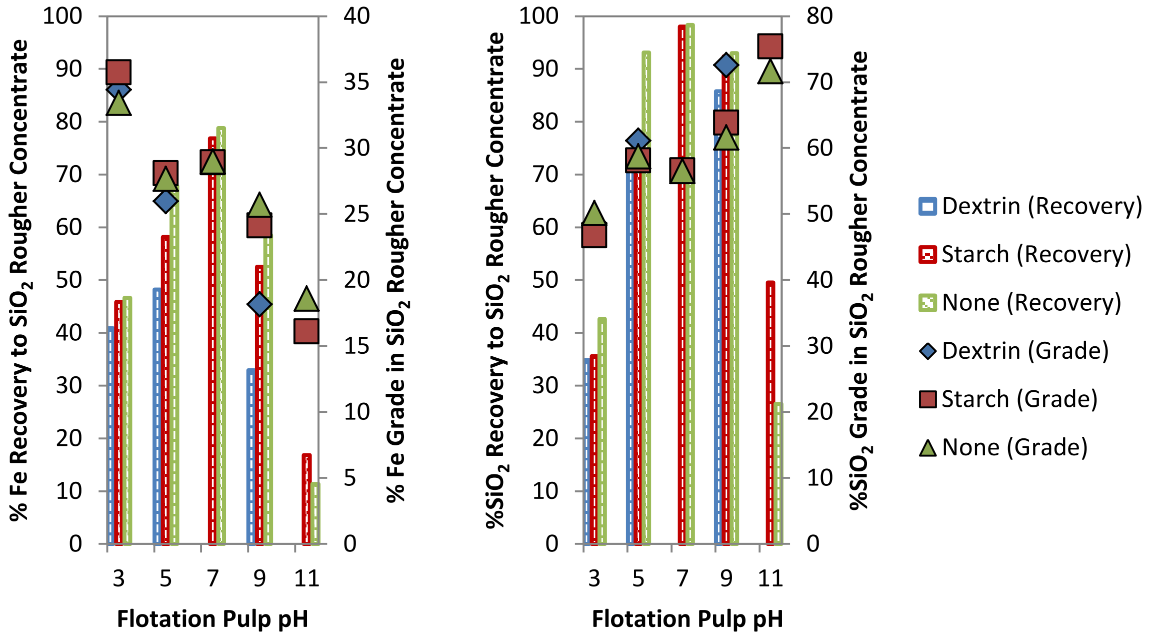

Figure 4.15: Grade and recovery to SiO_2 rougher concentrate results for dextrin, starch and no depressant at various pH levels for % Fe (left) and % SiO_2 (right)

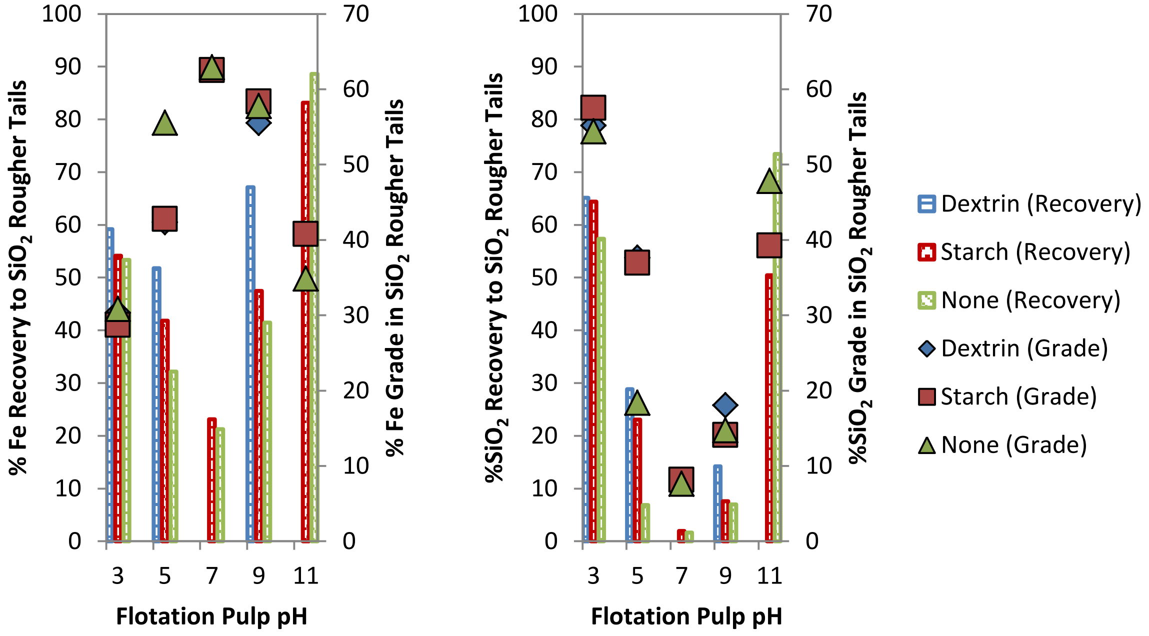

Figure 4.16: Grade and recovery to SiO_2 rougher tails results for dextrin, starch and no depressant at various pH levels for % Fe (left) and % SiO_2 (right)

The same trade-off between grade and recovery is noticed for a maximum percentage Fe grade at pH 7 and maximum recovery at pH 11 in the tails. A localised minimum percentage SiO_2 grade and recovery are noted at pH 7 in the tails. As the focus of the study is to produce a high grade iron product at an economically acceptable recovery, the sharp decrease of iron recovery between pH 9 and pH 7, as well as the sharp increase of percentage SiO_2 grade and recovery between pH 9 and pH 11, indicates that pH 9 could be a suitable parameter for reverse flotation of the BIF iron ore.

Mineral release curves in Figure 4.17 show the recovery of SiO_2 and Fe to the SiO_2 rougher concentrate as a function of flotation time, for each of the three depressant conditions at pH 9. A maximum percentage silica recovery in the concentrate is required for a low percentage SiO_2 grade in the tails (iron product). The lowest recovery for both Fe and SiO_2 is noted when dextrin is used as depressant. During this flotation test, the froth bed started to become demineralised, which would restrict the amount of additional flotation stages one may add to improve the percentage silica recovery. When no depressant is used, the percentage iron recovery to the concentrate is slightly higher compared to when starch is used. This indicates a certain portion of natural floatability for hematite at pH 9, where true flotation of hematite particles occurs. It may also indicate the amount of entrainment of fine well-liberated particles being misplaced to the froth phase. This indicates the existence of a relation between the type of depressant used and the floatability of the iron ore and also confirms starch as being one of the key components in controlling the selective adsorption of amines on the quartz mineral phases (Ma, 2011).

The mineral release curves in Figure 4.18 indicate true flotation of SiO_2 at pH 7 and 9, and complex flotation at pH 3, 5 and 11. This also indicates that the amine collectors are more effective in the range of above pH 5 and below pH 11. This corresponds with defined collector mechanisms as stated in the literature study. The recovery of Fe in Figure 4.18 indicates a hydrophobic tendency for hematite at pH 7, which indicates true flotation, although at a much slower rate than SiO_2.

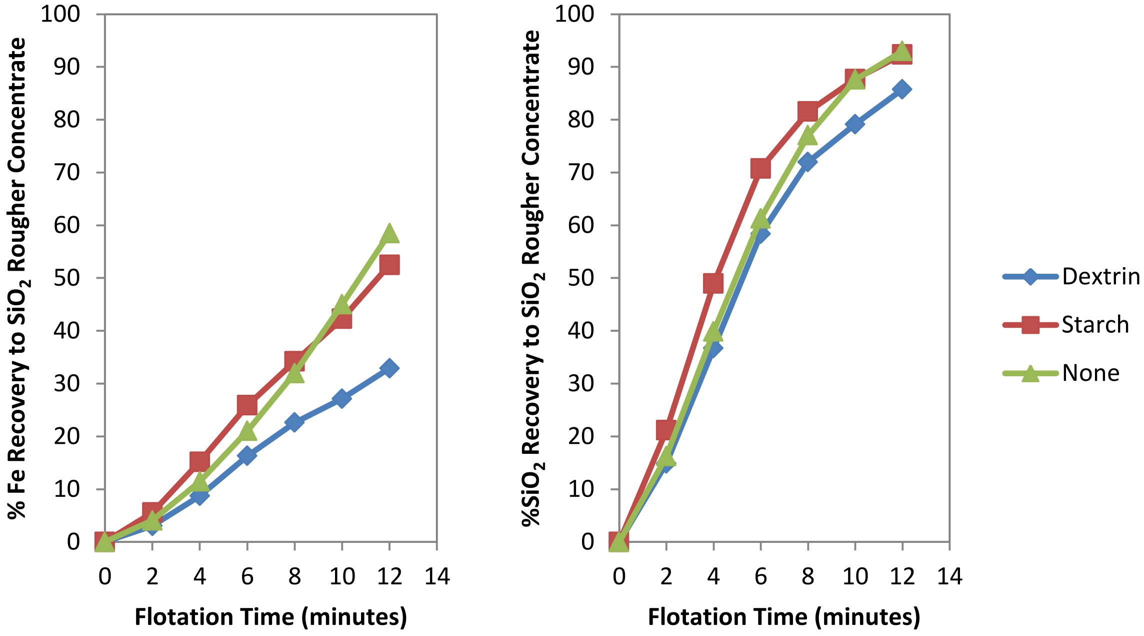

Figure 4.17: Mineral release curves for Fe (left) and SiO_2 (right) in flotation tests using Dextrin, Starch and No Depressant at pH 9

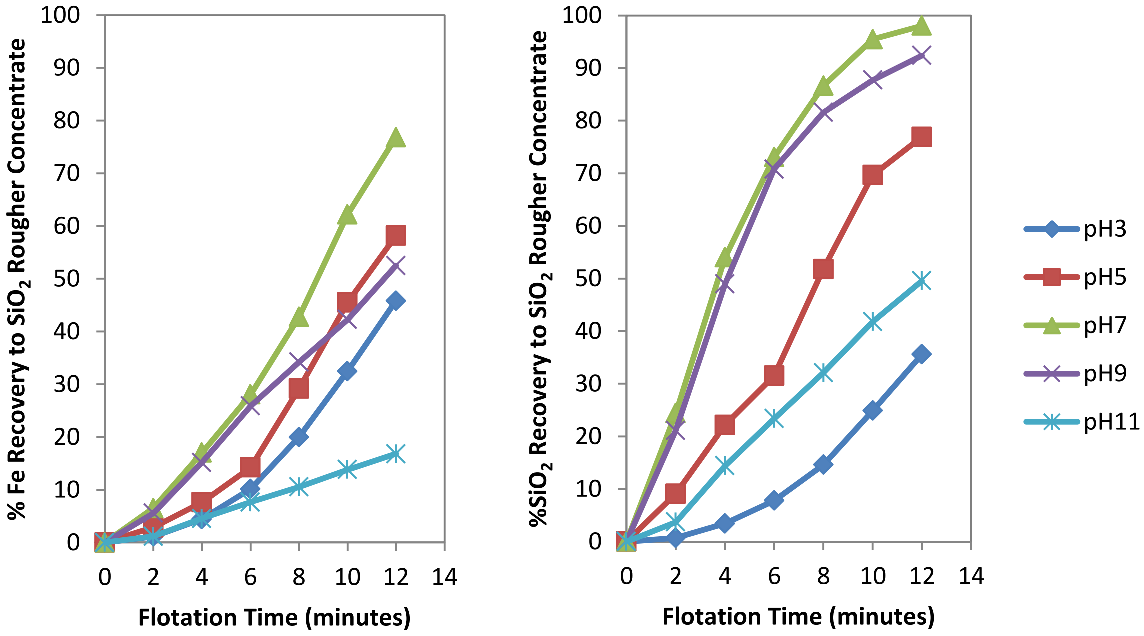

Figure 4.18: Mineral release curves for Fe (left) and SiO_2 (right) in flotation tests using starch as depressant at pH levels 3, 5, 7, 9 and 11

The final silica recovery to the SiO_2 rougher concentrate can still be increased by increasing the amount of rougher flotation stages, as indicated in Figure 4.19. This slower increase in SiO_2 recovery between flotation stage 6 and stage 9, is, unfortunately, demolished by the steady increase in the percentage iron recovery. The increase in iron recovery may be attributed to the selection of partially liberated silica-hematite particles with increasing amounts of exposed hematite surface, being collected to the froth phase as the total amount of high silica particles depleted in the pulp, which would have to be proven by MLA analysis.

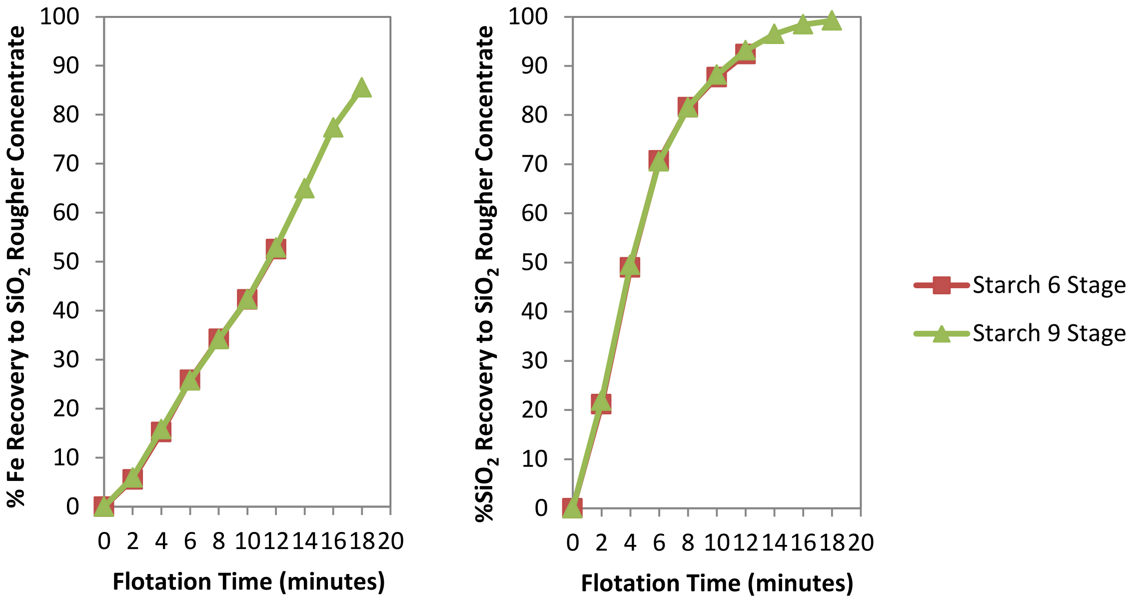

Figure 4.19: Mineral release curves for Fe (left) and SiO_2 (right) in flotation tests using starch as depressant at pH 9 for a 6- and 9 stage rougher flotation

The final percentage iron and percentage silica grade in each of the flotation products in Table 4.3 indicates that it is possible to produce a high grade iron product (64.1% Fe) using reverse flotation, when 9 flotation stages are used. The 3 additional stages allow a decrease in the final percentage SiO_2 grade from 14.1% to 5.6%, as well as the increase in percentage Fe from 58.4% to 64.1%.

Further test work in the experimental design was conducted using only caustisized starch as a depressant. The use of pH 9 for flotation shows a good compromise between the best possible percentage iron grade and recovery, as well as low percentage silica grade and recoveries in the SiO_2 rougher tails (iron product).

Table 4.3: Final % Fe and % SiO_2 grade in SiO_2 rougher concentrate and - tails for 6 stage- and 9 stage flotation tests

	% Fe Grade		% SiO_2 Grade		% Fe Recovery		% SiO_2 Recovery	
Stages	6	9	6	9	6	9	6	9
Final SiO_2 Rougher Concentrate	24.12	30.13	63.84	54.81	52.51	85.54	92.38	99.19
Final SiO_2 Rougher Tails	58.37	64.09	14.09	5.62	47.49	14.46	7.62	0.81

4.3.2 Dispersant Type Evaluation

The use of sodium silicate as a dispersant for quartz and hematite slimes is evaluated in terms of the percentage iron and percentage silica grade and recoveries to each of the flotation products. In Figure 4.20 a baseline comparison of the minerals floated with and without a dispersant is made in terms of mineral release curves. Figure 4.20 indicates that the floatability of iron minerals (hematite) is increased, with increased recoveries from 52.5% to 65.2% are reported. A slight increase in percentage silica recovery, from 92.3% to 95.1% shows the possibility that silicate minerals are better dispersed with the use of sodium silicate as a dispersant.

The use of sodium silicate in a flotation test may lead to a change in surface chemistry, which will warrant the iterative re-evaluation of the depressant type used. Before the evaluation of pH on the flotation results with the use of a dispersant was conducted, an additional preliminary depressant dosage evaluation was done. Figure 4.21 shows the use of a FloatSil1 dispersant at 80 g/t will negatively affect the percentage iron recovery to the SiO_2 rougher tails and –concentrate. This negative effect is less prominent at lower starch dosages. The percentage iron grade attainable is increased from 58% when no depressant is used to 61% when FloatSil1 is used.

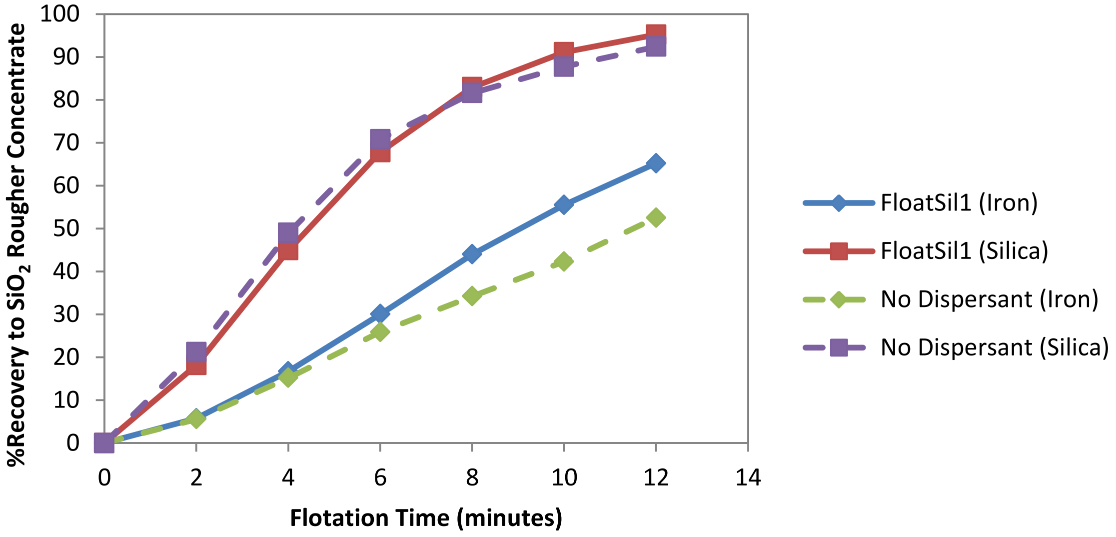

Figure 4.20: Mineral release curves of iron and silica minerals for flotation tests with and without a dispersant at pH 9 and 400 g/t starch dosage

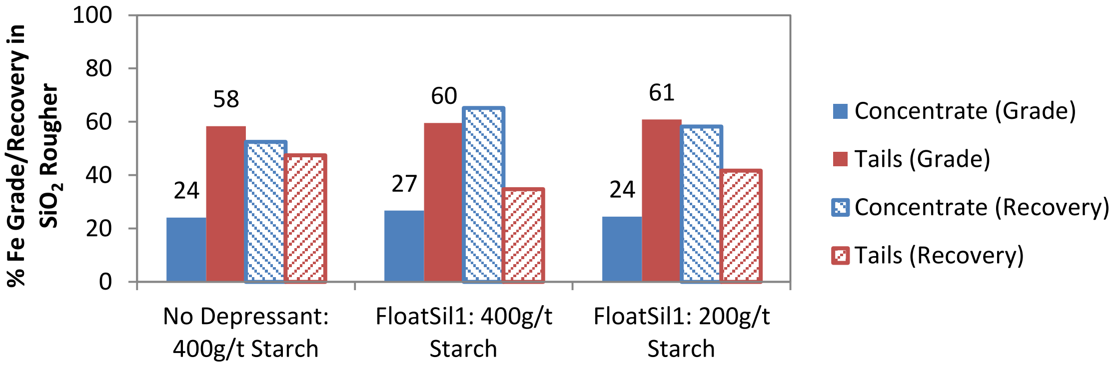

Figure 4.21: Percentage iron grade and percentage iron recovery to SiO_2 rougher for FloatSil1 and no dispersant, at 200 g/t and 400 g/t starch dosage and pH 9

Figure 4.22 indicates a maximum iron grade in the tails where FloatSil1 is used at 80 g/t (with higher percentage iron recovery to tails, 41.7% vs. 34.8%, at 200 g/t starch dosage). An increase in the dispersant dosage had a negative effect on both the percentage iron recovery and grade in the tails.

FloatSil2 reported a similar percentage iron recovery to the tails (42.4%), but a lower percentage iron grade. The percentage silica grade and recovery is the lowest for the 80 g/t FloatSil1 with a 200 g/t starch dosage. These results indicate that the use of FloatSil1 will be beneficial for the reverse flotation of iron ore, as the percentage iron grade in the iron product can be improved without significant loss in the percentage iron recovery, if a lower starch dosage is used.

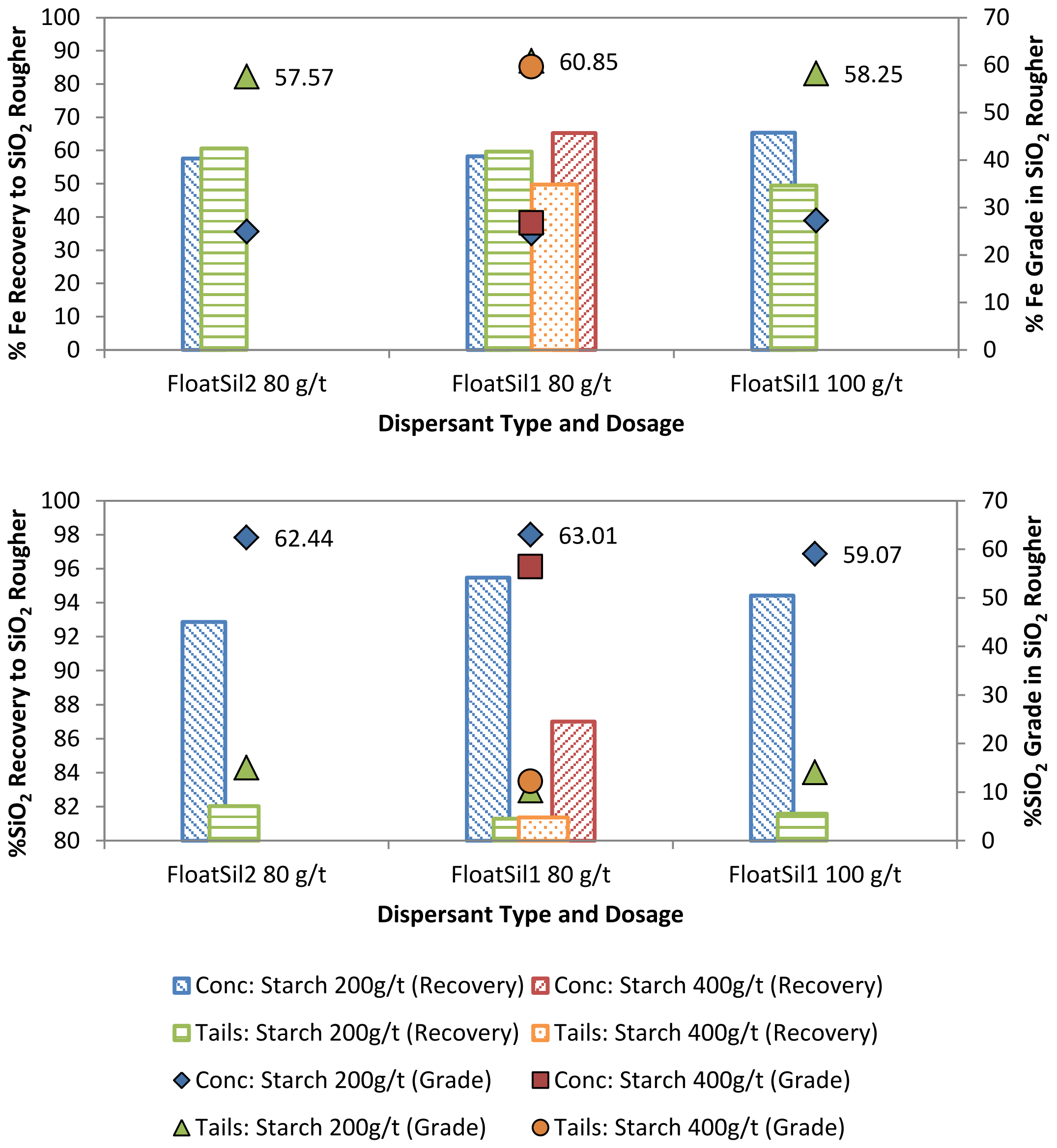

Figure 4.22: Grade and recovery results of percentage iron (top) and percentage silica (bottom) for FloatSil1 (80 g/t and 100 g/t) and FloatSil2 (80 g/t) at 200 g/t and 400 g/t starch dosage at pH 9

The use of two sodium silicate dispersants, FloatSil1 and FloatSil2, were evaluated at pH 3, 5 and 9, with a dispersant dosage of 80 g/t and starch dosage of 200 g/t. This is to determine additional pH effects. Figure 4.23 again shows a steady decrease in percentage iron grade in the concentrate as the pH is increased, with a sharp increase in percentage iron grade in the tails.

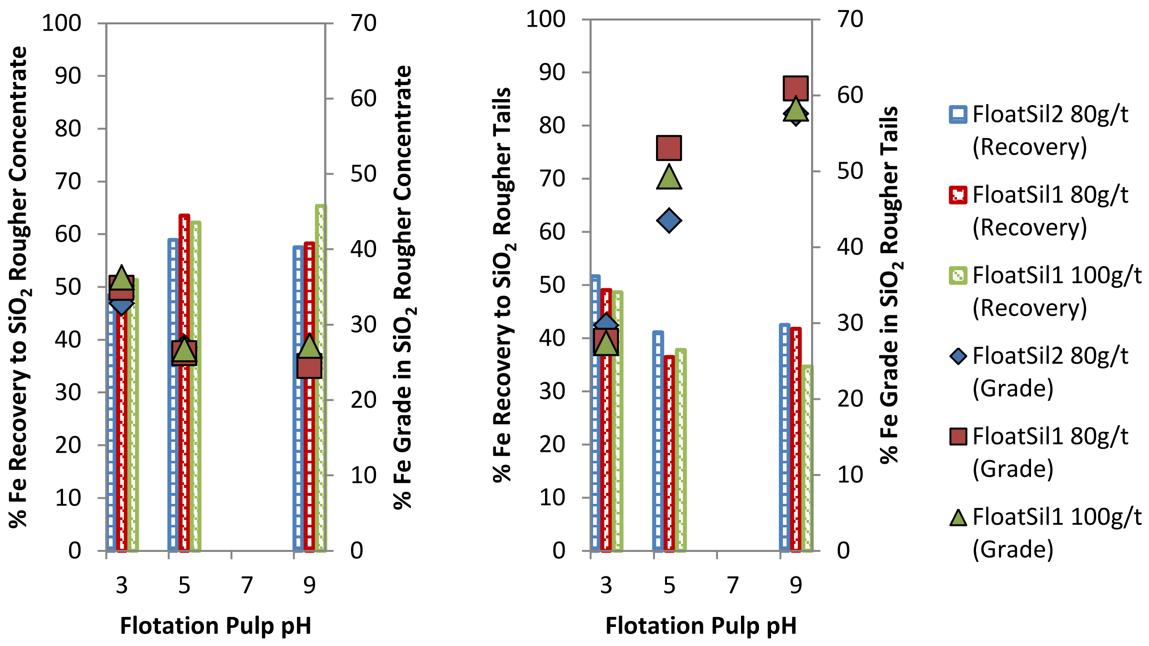

Figure 4.23: Grade and recovery to SiO_2 rougher concentrate (left) and tails (right) results for FloatSil1 (80 g/t), Floatsil2 (80 g/t) and FloatSil1 (100 g/t) at various pH levels for percentage iron

Figure 4.24 shows that the percentage silica grade again follows the same trend, with a slightly higher percentage silica grade in the concentrate, which results in a lower percentage silica grade in the tails (at pH 5 and 9). The limited change in the percentage silica grade indicates that no chemical phase change on the surface of the quartz minerals resulted after the addition of FloatSil. This indicates the dispersive action to be an atomic force between the ions from the sodium silicate dissolved in water and the charged surface on the mineral particles, thus flotation by means of chemisorption as stated by Fuerstenau & Fuerstenau, (1982).

The limited change in recovery to the froth phase with the increase of amine dosage confirms the trend indicated by Araujo *et al.* (2005), which states the type of depressant used as a more dominant factor in the reverse flotation of iron ore.

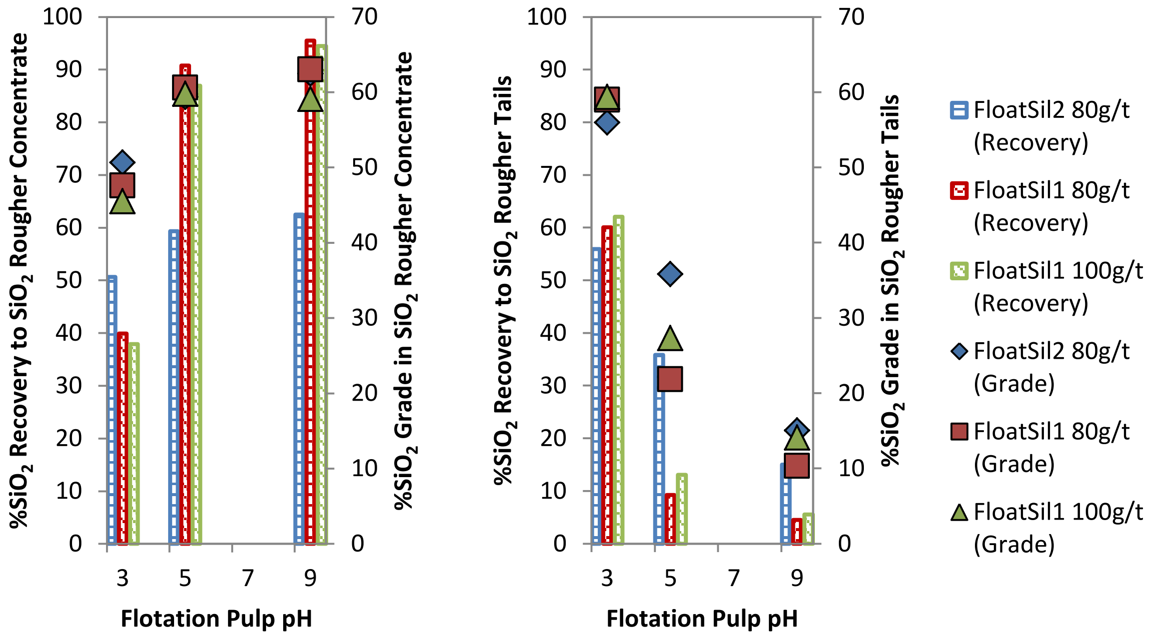

Figure 4.24: Grade and recovery to SiO_2 rougher concentrate (left) and tails (right) results for FloatSil1 (80 g/t), Floatsil2 (80 g/t) and FloatSil1 (100 g/t) at various pH levels for percentage silica

4.3.3 Depressant Dosage Evaluation

In general one would expect to observe a decrease in the percentage iron recovery to the SiO_2 rougher concentrate when the hematite depressant dosage is increased, as was the case for test work done by Turrer & Peres (2010). Figure 4.25 shows this is not the case for low grade Sishen BIF material, where a decrease in iron recovery to the concentrate is noted at pH 3 for an increase in depressant dosage.

The combined lowest percentage iron grade and recovery to the concentrate is noted at pH 9 for a 200 g/t starch dosage. Figure 4.25 also shows a pronounced increase in the silica recovery to the concentrate at pH 3 for a starch dosage of 600 g/t. This is however lower than the percentage silica grade attained at pH 9 for a

200 g/t starch dosage, which additionally also reports the highest recovery to the froth phase.

The use of a minimum and maximum level of depressant (100 g/t and 800 g/t), does not change the percentage iron and percentage silica grades or recoveries to the concentrate significantly. This is similar to results obtained by Araujo *et al.* (2005), where the floatability of hematite stayed below 40%, but did not decrease to less than 15% when starch was used as a depressant.

High silica grades and recoveries to the tails are noted at pH 3 in Figure 4.26, which decreased with an increase in pH level. A percentage silica grade below 12.4% and percentage silica recovery below 6% are attained for all starch dosages at pH 9. A general increase in the percentage iron grade attained in the tails is noted for an increase in the flotation pulp pH.

All three investigated starch dosages yielded similar percentage iron grades above 59.9% and a slightly higher iron recovery to the tails for the 200 g/t starch dosage at pH 9. Again no significant changes in the flotation results were reported for a maximum and minimum starch dosage. This indicates that the hematite depressant mechanism of starch is rather influenced by the solution pH, than by the actual starch dosage. It may also be true that the threshold for starch to act as a dispersant is reached at a 100 g/t dosage.

Mineral release curves in Figure 4.27 show similar results in the floatability of silicate minerals for either pH 7 or pH 9 at starch dosages of 200 g/t or 400 g/t. The high iron recovery to the froth phase at pH 7 and a starch dosage of 200 g/t could again indicate the natural floatability of hematite at this pH level.

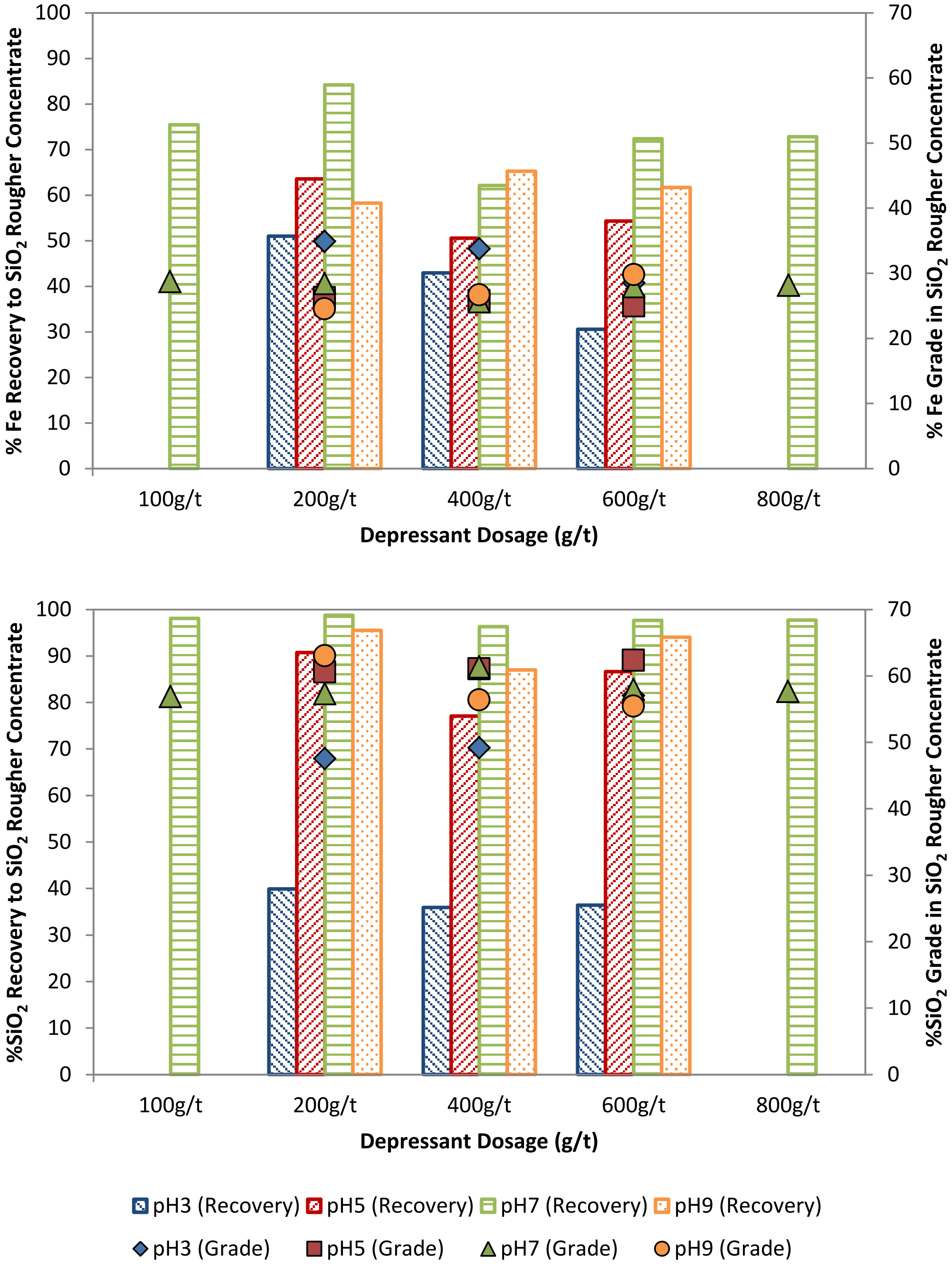

Figure 4.25: Grade and recovery to SiO_2 rougher concentrate results as a function of starch dosages at various pH levels for percentage iron (top) and percentage silica (bottom)

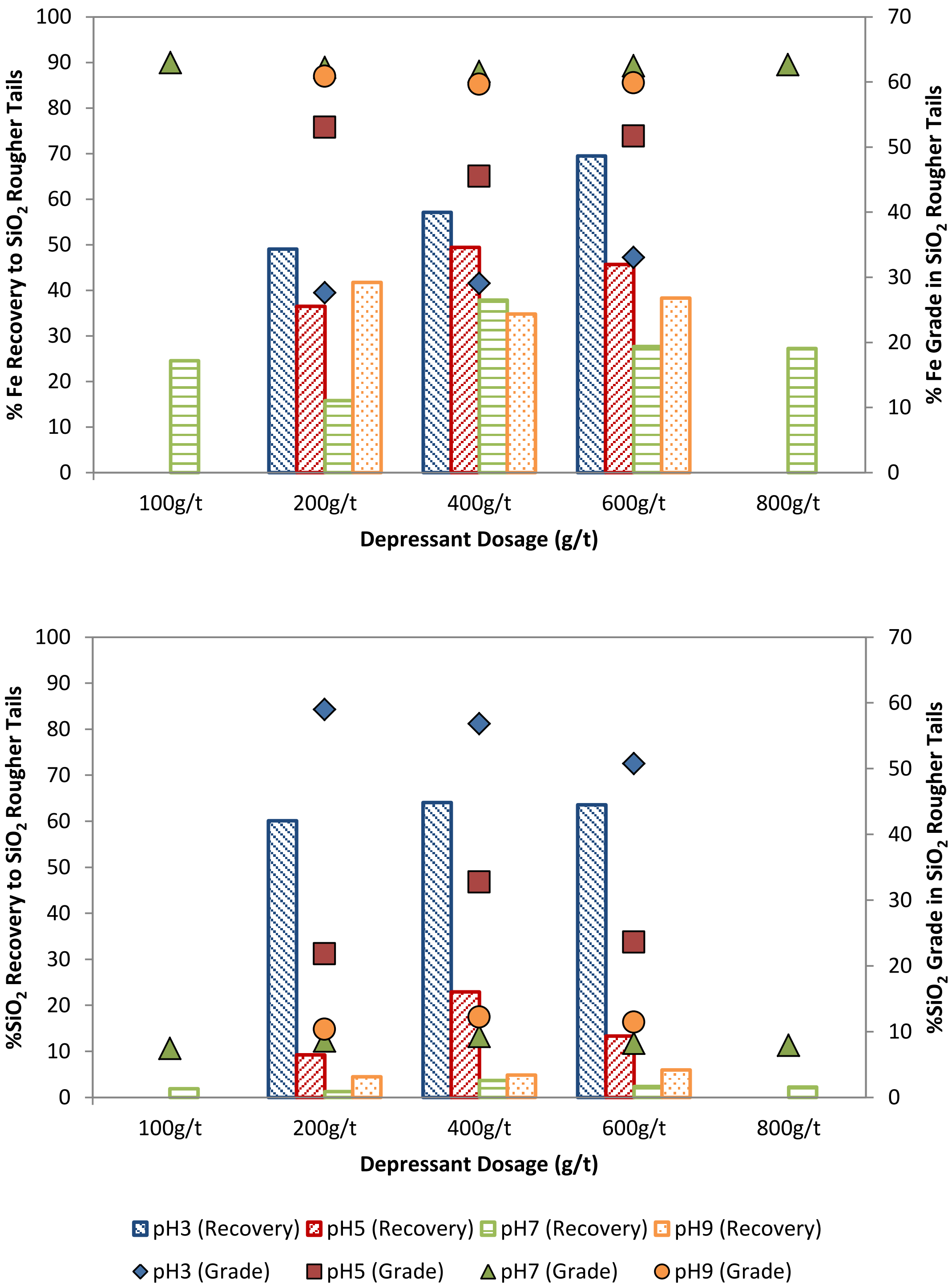

Figure 4.26: Grade and recovery to SiO_2 rougher tails results as a function of starch dosages at various pH levels for percentage iron (top) and percentage silica (bottom)

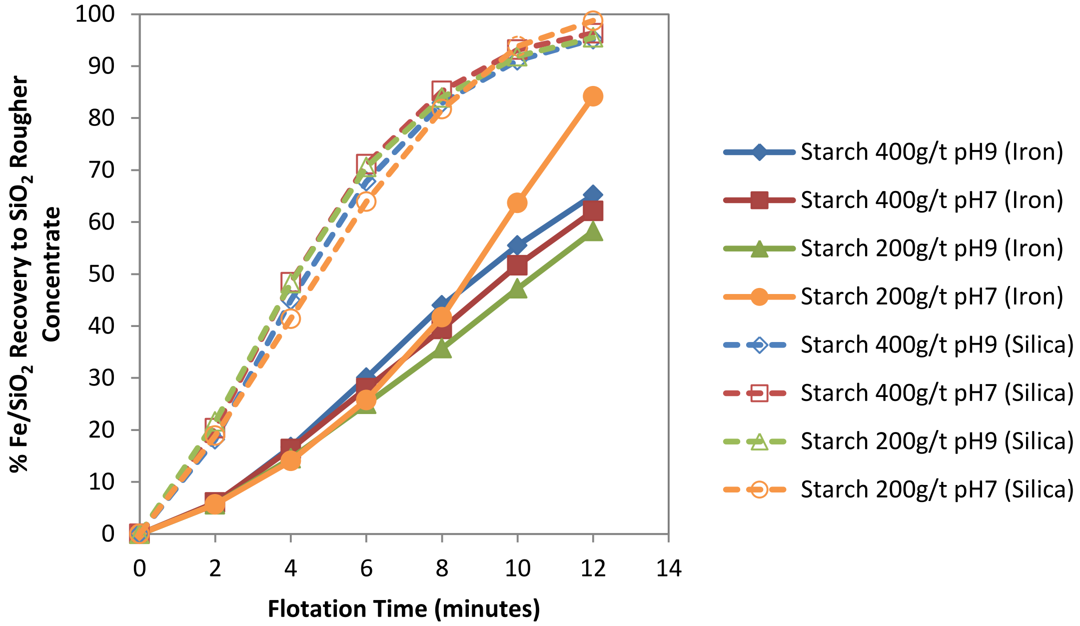

Figure 4.27: Mineral release curves for iron and silica minerals at pH 7 and pH 9 for a starch dosage of 200 g/t and 400 g/t in a six stage rougher flotation

4.3.4 Multi Staged Depressant Dosing

In an attempt to increase the iron recovery to the SiO_2 rougher tails, an investigation into a multi-staged depressant dosing sequence was done. Alternatively, the iron recovery to the froth phase may be decreased by increasing the hematite particle size. The use of a two-staged depressant dosing system did not affect the recovery rate of a feed sample with a coarse particle size as seen in the mineral release curves in Figure 4.28. It did however increase the recovery rate of iron bearing minerals to the froth phase for a medium sized feed sample. A larger particle size decreased the flotation rate of silicate minerals, which was not affected by the additional starch dosing stage. The overall attained percentage iron and the percentage silica grade in these rougher cells also seem to be more affected by the feed size in the flotation cell (which depicts the extent to which the minerals are liberated), than the additional depressant dosing stage. Table 4.4 shows higher iron grades in the silica rougher tails for the finer material, which confirms that hematite minerals in the coarser material are not liberated sufficiently.

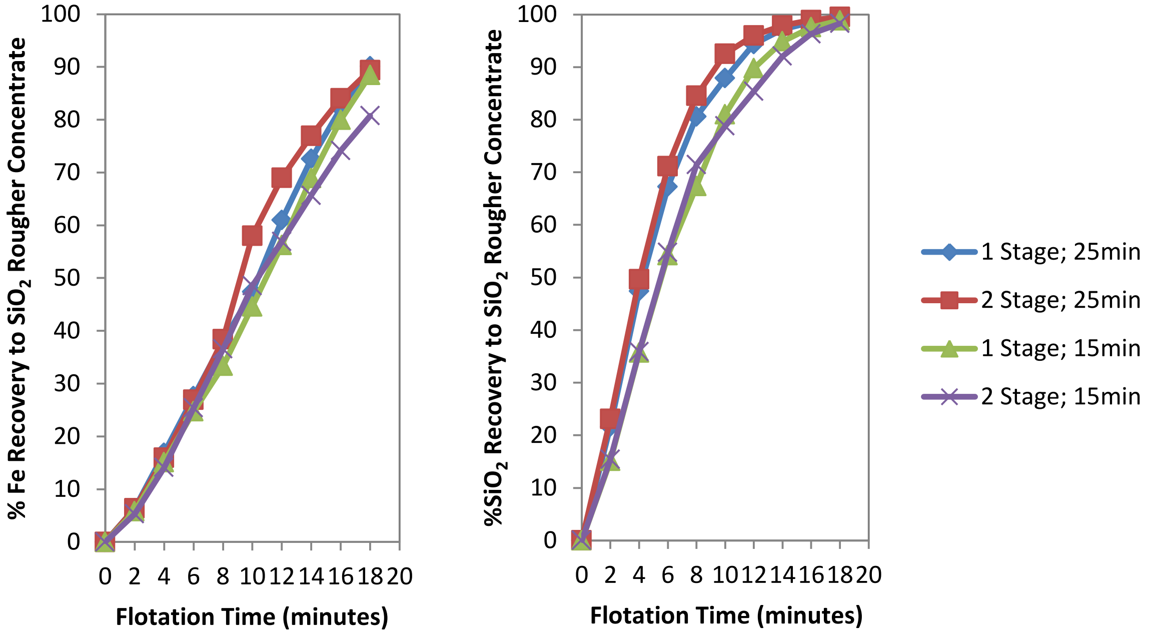

Figure 4.28: Mineral release curves for iron minerals (left) and silicate minerals (right) for a single and double staged depressant dosing in a nine stage flotation rougher

Table 4.4: Percentage iron and percentage silica grade of final SiO$_2$ rougher concentrate and -tails for single- and multi-staged depressant dosing

	% Fe Grade				**%SiO$_2$ Grade**			
	1 Stage Dosing		2 Stage Dosing		1 Stage Dosing		2 Stage Dosing	
	15 min	25 min	15 min	25 min	15 min	25 min	15 min	25 min
Final SiO$_2$ Rougher Conc.	31.19	31.28	30.19	31.01	53.18	53.09	54.61	53.49
Final SiO$_2$ Rougher Tails	61.54	63.55	62.49	64.66	9.22	6.27	8.27	4.87

The increase in the iron grade (64.7% Fe) to the product stream when a multi-staged depressant dosage system is used indicates the possibility that a change in the flotation circuit could be beneficial.

4.3.5 Collector Dosage Evaluation

The dosage required for flotation of silica from hematite in the medium grind size at pH 9 was investigated, and the results of these tests are shown in Figure 4.29, for a six stage rougher flotation. An increase in the collector dosage per flotation stage increases the iron grade in the silica rougher tails to 60.9% Fe at a 37.5 g/t/stage, before the iron grade decreases again. The iron recovery to the tails is at a trade off with the iron grade, where a sharp decrease (from 61.3% at 37.5 g/t to 2.8% at 50 g/t) is noted with an increase in the collector dosage.

The silica recovery to the concentrate increases with an increase in collector dosage as more quartz particles containing larger fractions of hematite mineral phases are also floated. A sharp increase in the percentage silica grade in the tails (from 10.1% at 37.5 g/t to 23.1% at 50 g/t) indicates possible overdosing of collector, where the surface charge of silica particles are presumed to be overruled by an additional charge plane, which will again render the particle hydrophobic.

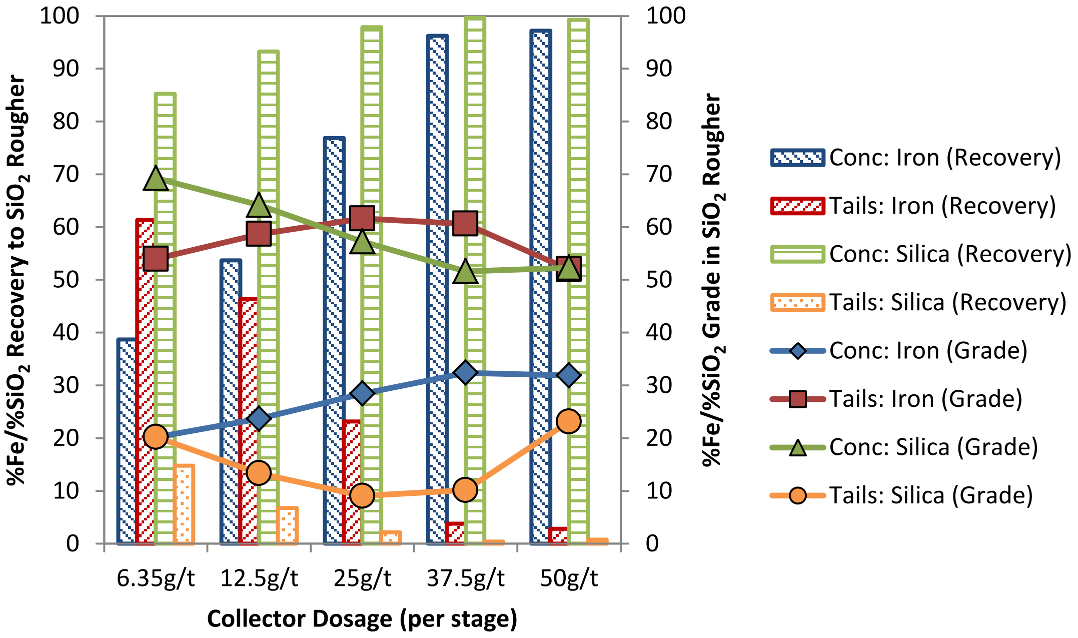

Figure 4.29: Percentage iron- and percentage silica grade and recovery in rougher flotation as a function of the collector dosage at pH 9

A change in the feed particle size will change the particle surface area. Smaller particles will generate a larger surface area, which should require higher collector dosages. Mineral release curves, in Figure 4.30 indicate a very predictable trend, where the flotation rate of each mineral is increased with an increase in collector dosage. It is clear that a collector dosage higher than 25 g/t/stage does not float the quartz particle selectively. A trade-off between the percentage iron recovery and the percentage silica recovery is made, and it seems that a collector dosage of 12.5 g/t/stage will yield a high recovery of silicate minerals (93.3%) without increasing the percentage iron recovery excessively (53.7%).

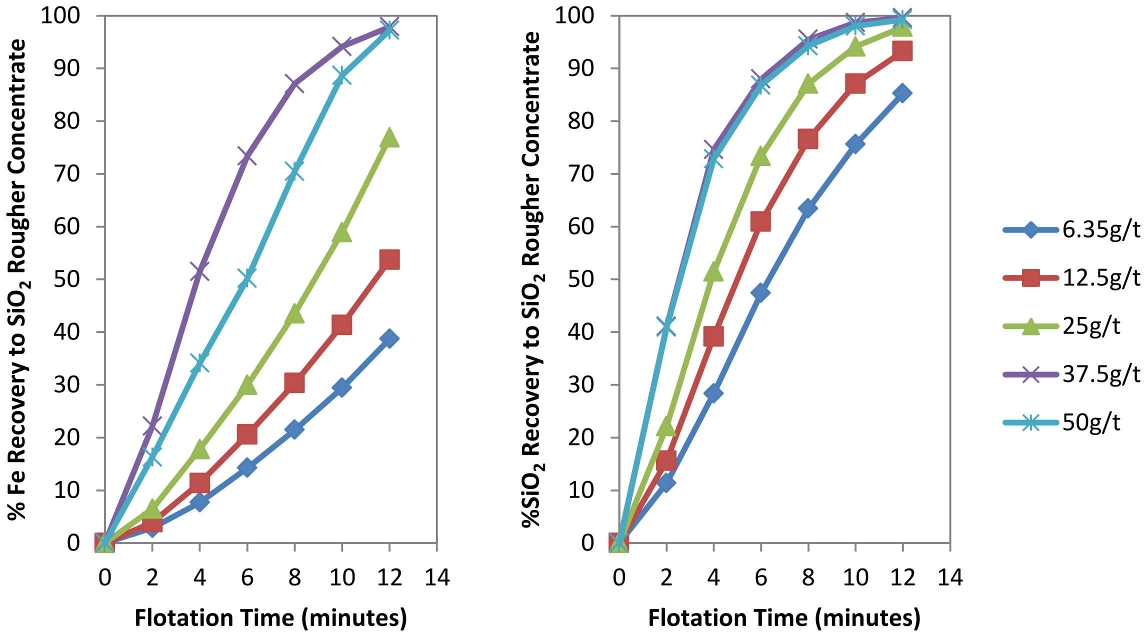

Figure 4.30: Mineral release curves for iron minerals (left) and silicate minerals (right) for various collector dosages at pH 9

4.3.6 Grinding Size Evaluation

The inherent floatability characteristics of an ore can be altered by modification in the grind size, as was indicated by Runge *et al.* (2007). Larger particles will in general not float easily, due to either an issue of non-liberation of minerals, or gravitational forces being larger than the electrostatic bubble/particle attachment. Particles that are milled too fine, will easily entrain in the water layer around a bubble and thus report in the froth phase via a mechanism not included in true flotation. An additional factor in the flotation of very fine particles is the creation of a very stable froth bed by these fine particles.

The actual grinding size fed to the flotation tests were determined for each of the mill retention times by triplicate laser diffractive analysis of various random grab samples taken from the mill before flotation. Figure 4.31 shows an average 80% passing of 140 micron for coarse-, 28 micron for medium-, and 13 micron for fine particles.

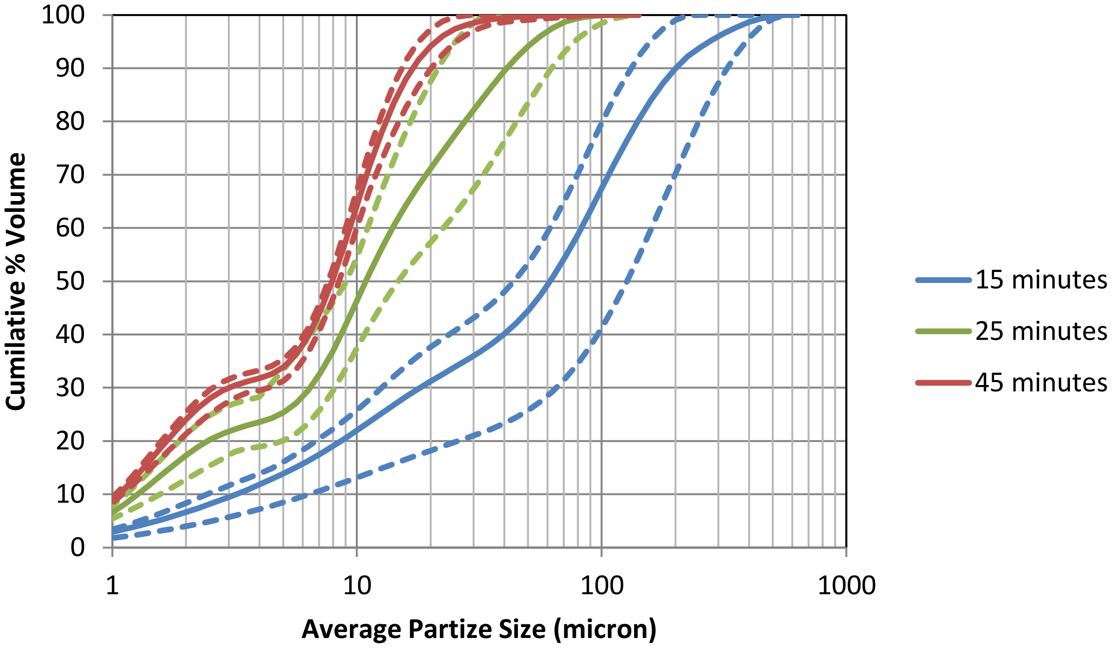

Figure 4.31: Particle size distribution of coarse (15 minutes), medium (25 minutes) and fine (15 minutes) grind from laser diffraction analysis

In Figure 4.32 the influence of the grind size on the percentage iron grade and recovery for various collector dosages are depicted. Only three tests were conducted at the fine grind, as the froth generation and stability was not controllable at collector dosages above 25 g/t/stage. It seems that both a higher percentage iron grade and recovery in the concentrate is attained at a coarse grind. A percentage iron grade of 61.6% was attainable in the tails for fine grind material. Neither the coarsely ground, nor the medium grind material could be upgraded successfully in a 6 Stage rougher flotation.

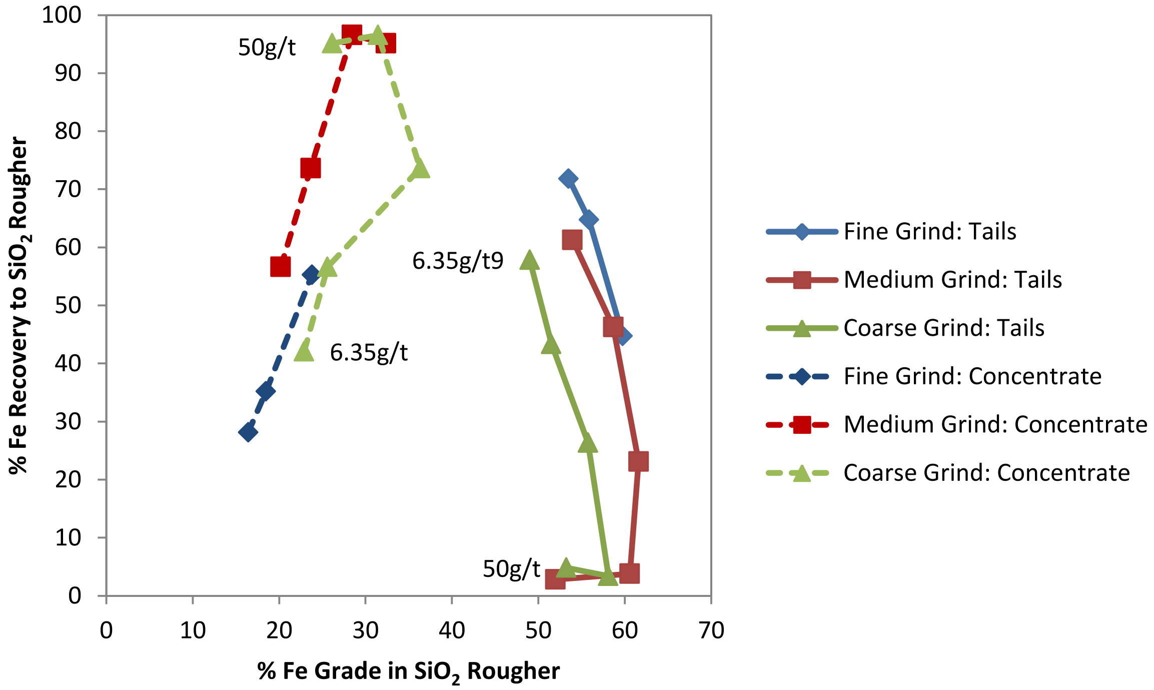

Figure 4.32: Percentage iron recovery as a function of percentage iron grade in SiO_2 rougher tails and concentrate for a fine-, medium- and coarse grind

The percentage silica grade and recovery for each of the fine, medium and coarse grind sizes Figure 4.33, shows that the highest percentage silica grade reports to the tails (iron product) for coarsely ground material. This may support the theory that coarse quartz particles are difficult to float, but also confirms that the quartz particles are not liberated from hematite inclusions.

An MLA analysis was done on the flotation products from a 15 minute milled composite low grade BIF material fed to a six stage rougher flotation circuit, as shown in Figure 4.34. This figure shows a decrease in the amount of 95% liberated particles reporting to the froth phase from one stage to the next for both the hematite and silicate particles,

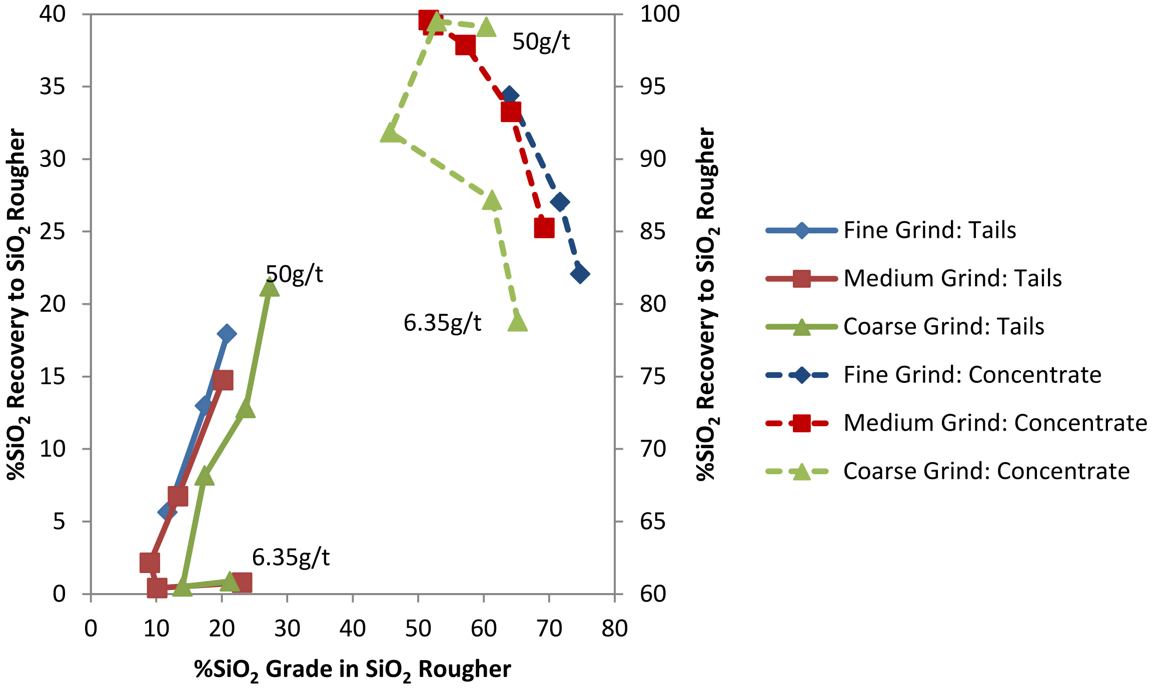

Figure 4.33: Percentage silica recovery as a function of percentage silica grade in SiO_2 rougher tails and concentrate for a fine-, medium- and coarse grind size

The sharp increase in the 50% passing particle size up to rougher stage 6 may indicate that additional collector was required to sufficiently float larger silicate particles. Neither the hematite, nor the quartz content in the silica rougher tails from the coarse grind float conforms to the product specifications required for this project (a saleable high grade iron ore product with an average of 64% Fe.).

It is reasonable to assume that a change in the grind size, will also affect the required starch dosage. Figure 4.35 shows a higher percentage iron recovery to the tails at a fine grind and 200 g/t starch dosage than at a medium grind or higher 400 g/t starch dosage. This again indicates a liberation issue, requiring material which is milled extremely fine to achieve selective flotation. It also suggests that fine hematite particles only become entrained at higher depressant dosages. Very little change in the flotation performance of silicatious mineral particles is noted, except an increased percentage silica grade reported in the rougher concentrate.

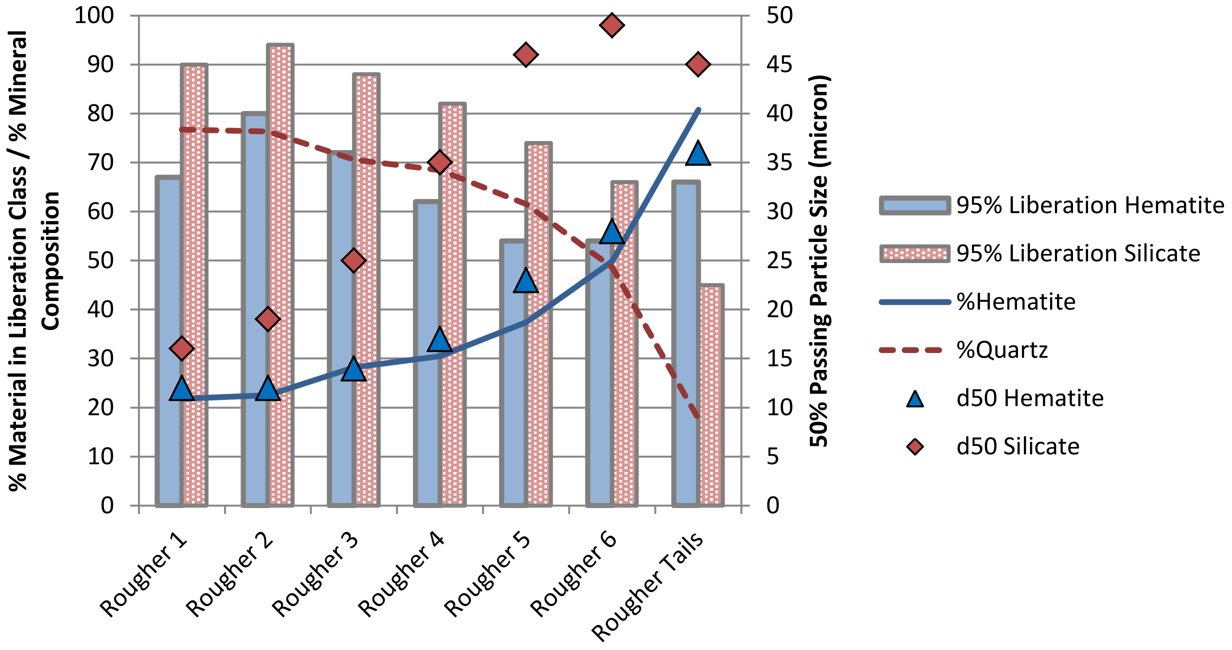

Figure 4.34: MLA analysis of a 15 minute milled low grade composite BIF six stage rougher flotation test

The possibility of a change in the required collector dosage for more than six stages of rougher flotation for finer feed sample was investigated and the results are shown in Figure 4.36. The result from a six stage rougher flotation test is used as baseline condition and is compared to three nine stage rougher flotation tests at increasing collector dosages. The increased collector dosages again show an increase in recoveries to the froth phase, with a decrease in selectivity. An acceptable compromise can be reached at the 12.5 g/t/stage collector dosage, where a 64.5 percentage iron grade is reported at a 17.1% recovery to the tails and 99.1% of the silicate minerals are floated. The high percentage iron grade attained may accommodate a scavenger stage where an iron product of slightly lower iron content can be blended with this initial product to attain acceptable percentage iron recoveries.

A final iterative reagent evaluation was done to determine if a change in the depressant dosage, which had already been evaluated for a six stage rougher flotation circuit, would improve the final nine stage rougher flotation results for a fine grind feed sample particle size and a 6.35 g/t/stage collector dosage. Table 4.5 indicates a very low percentage iron recovery to the tails, 7.4%, for a higher starch dosage. The improvement in percentage iron grade in the tails is not significant enough to substantiate such a high loss in recovery.

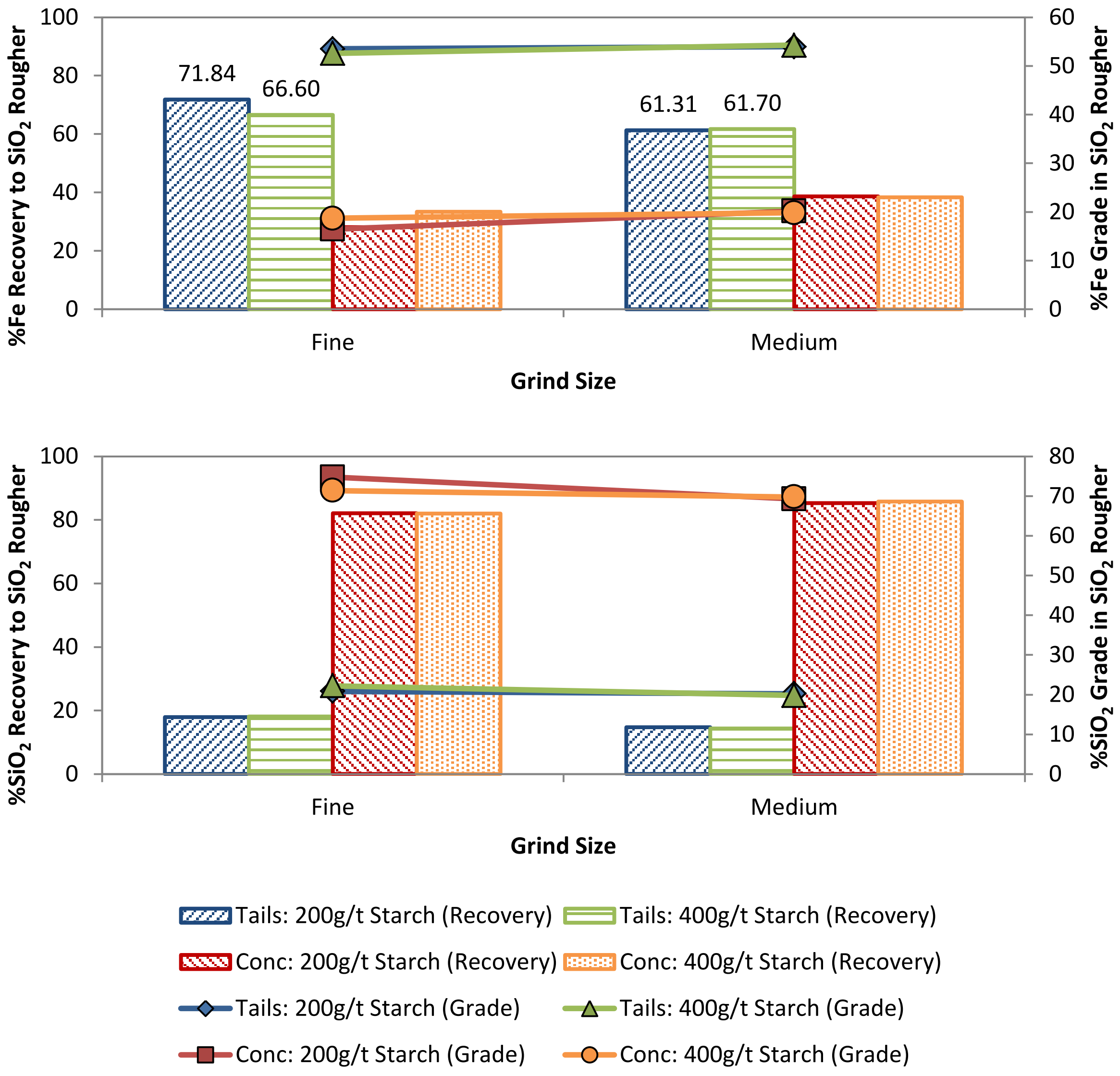

Figure 4.35: Grade and recovery percentage iron (top) and percentage silica (bottom) results from fine and medium grind feed size with 200 g/t and 400 g/t starch dosage flotation tests at pH 9 for 6 stage rougher flotation

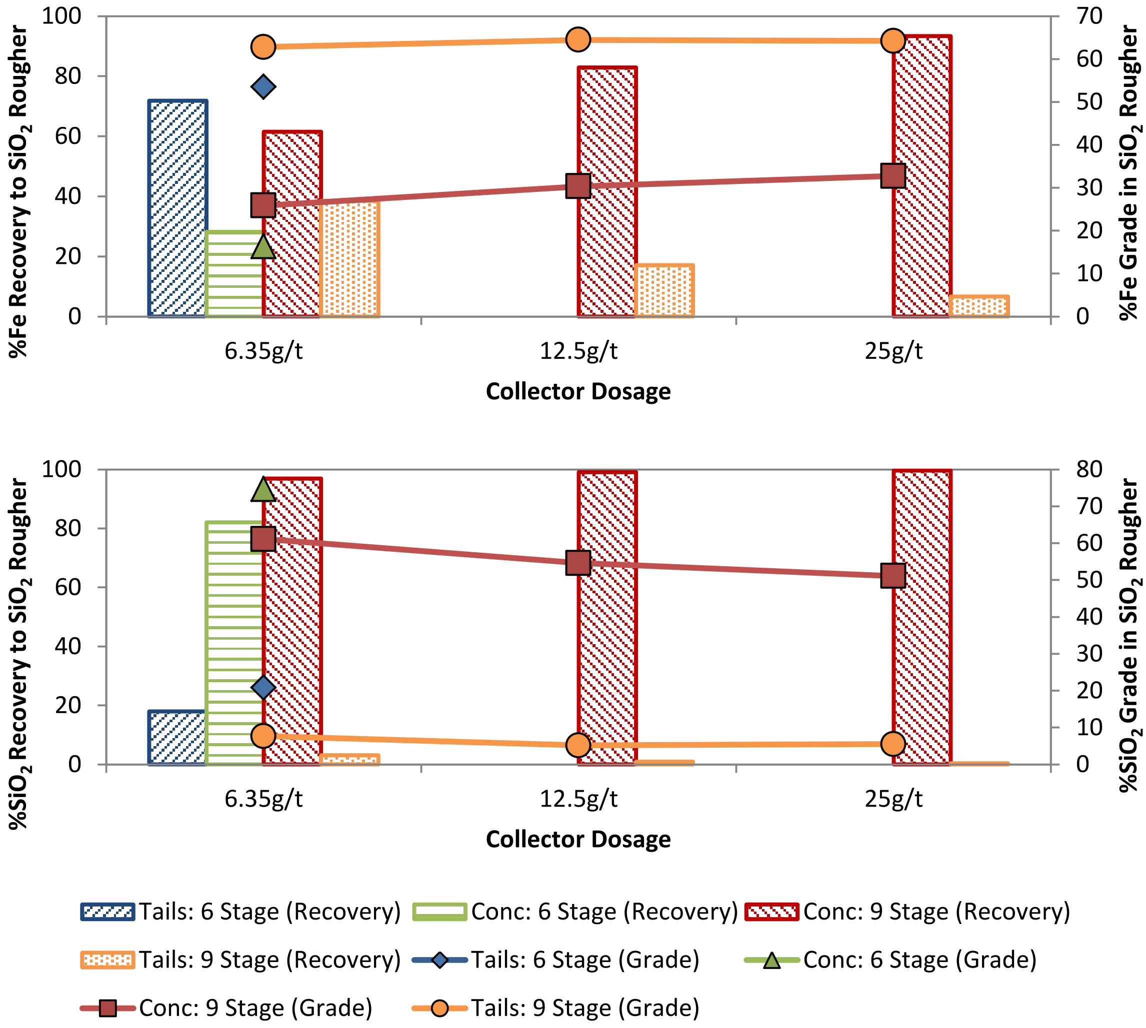

Figure 4.36: Grade and recovery percentage iron (top) and percentage silica (bottom) results from a fine grind feed size with 200 g/t starch dosage flotation tests at pH 9 for 6 and 9 stage rougher flotation at increased collector dosages

Table 4.5: Percentage iron and percentage silica grade and recovery results for 200 g/t and 400 g/t starch dosage 9 stage rougher flotation tests at pH 9

	SiO_2 Rougher Tails		**SiO_2 Rougher Concentrate**	
Starch dosage (g/t)	200	400	200	400
% Fe	62.79	63.54	16.44	31.87
% SiO_2	7.64	6.2	74.75	52.86
% Fe Recovery	38.53	7.44	28.16	92.56
% SiO_2 Recovery	3.12	0.5	82.07	99.53

4.3.7 Characterisation of Rougher-Scavenger Flotation Circuit

In order to gain a better understanding of the process in the reverse flotation cell, back scattered electron (BSE) images produced on a scanning electron microscope were created of the first froth sample, sixth froth sample and final SiO_2 Rougher tails of a general flotation test conducted with the current reagent suite and flotation regime. Lighter particles are associated with a higher atomic weight, and are thus expected to contain a high iron value.

4.3.7.1 Silica Concentrate Froth 1

The first silica concentrate froth collected generally has a low percentage iron grade and a high percentage silica grade. Figure 4.37 a, b and c, shows very small particles (<5 micron), which seem to be fully liberated, but which are reporting to the silica concentrate froth phase. Particles in the range of 20 micron which indicate non-liberated association of hematite with quartz are also reporting to the silica concentrate froth phase. In general the bulk amount of particles in the concentrate, are fully liberated quartz minerals.

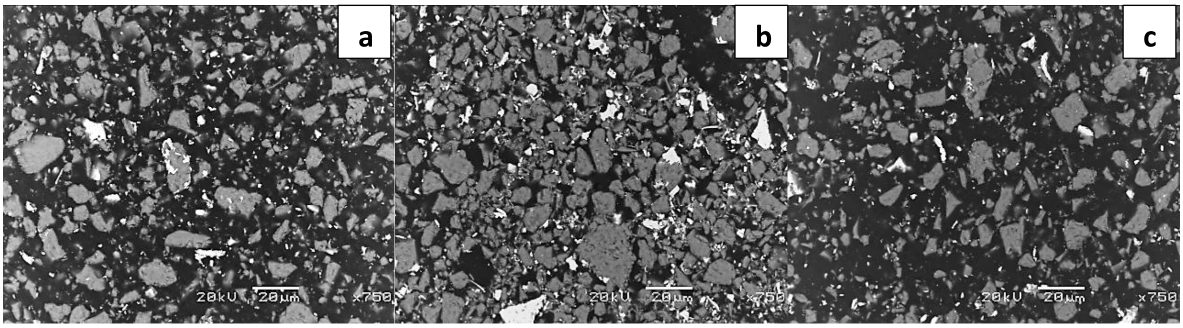

Figure 4.37: BSE SEM images of silica concentrate froth 1 from the rougher flotation cell with a 20 micron scale indication

A very bright particle was also noted in the first silica concentrate froth, as shown in Figure 4.38a. Upon closer inspection, frame b, the approximately 50 micron particle seems to consist of a iron mineral matrix containing occluded chrome bearing mineral phases. This indicates that the chrome-steel grinding media wears off during the particle size reduction in the mill. It also indicates that the worn grinding media will be selected fast by the amine collecter and removed to the first rougher flotation cell silica concentrate froth.

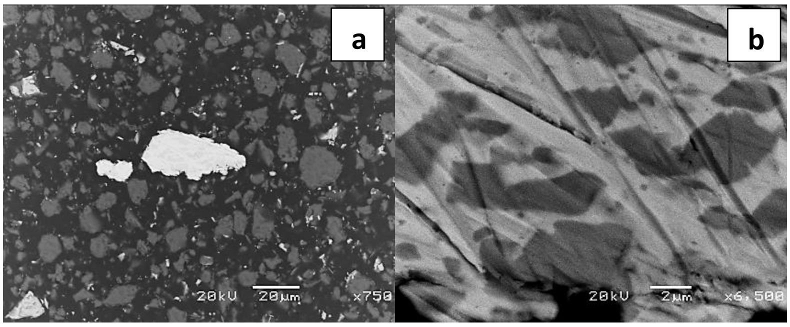

Figure 4.38: BSE SEM images of Cr-containing particle in silica concentrate froth 1 from the rougher flotation cell with a 20 micron scale (a) and a 2 micron scale (b) indication

4.3.7.2 Silica Concentrate Froth 6

In the sixth flotation stage, shown in Figure 4.39, it is clear that a much larger amount of hematite bearing particles are reporting to the silica concentrate froth phase. This indicates that the selectivity of the collector has decreased, or that the depressant can no longer be effective. Very large well liberated quartz particles are still reporting to the silica concentrate froth phase, but also hematite particles of approximately 25 micron.

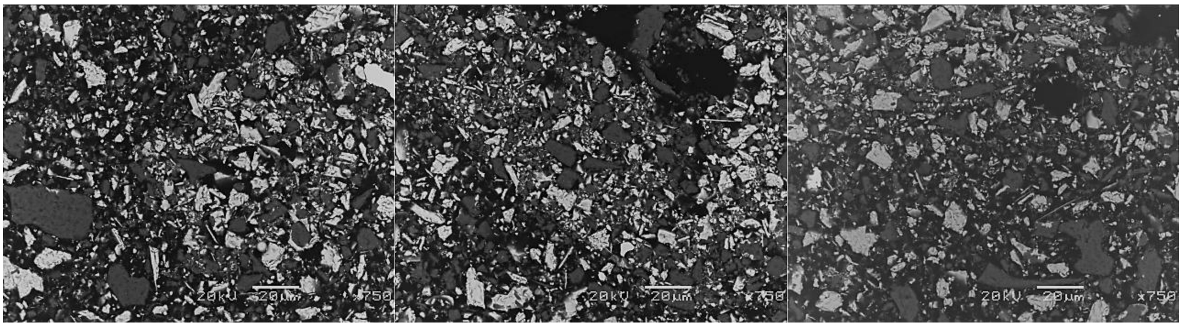

Figure 4.39: BSE SEM images of silica concentrate froth 6 from the rougher flotation cell with a 20 micron scale indication

Figure 4.40 shows non-liberated quartz/hematite particles, which indicates that liberation may be the cause of the sudden increase in percentage iron grade reported in the sixth silica concentrate froth phase. Hematite particles of approximately 15 micron are reporting to the silica concentrate froth phase, although the particle seems to be liberated. This indicates either misplacement of the particle in the silica concentrate froth phase due to bubble-particle entrapment, or the presence of surface effects hindering the successful depression of hematite by a starch depressant.

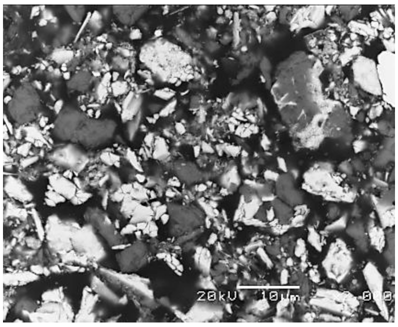

Figure 4.40: BSE SEM image of silica concentrate froth 6 from the rougher flotation cell with a 10 micron scale indication

Surface effects of flotation reagents added in the rougher flotation circuit may be minimised by a scrubbing or grinding phase, before an additional scavenger float is done on the collected silica concentrate froth. The use of grinding to clean the particle surface will have an additional advantage of increasing particle liberation.

4.3.7.3 Silica Rougher Tails

The silica rougher tails images in Figure 4.41 indicate the bulk portion of the tails (iron product) to contain hematite minerals. These are in the size ranges between 2 micron and 60 micron. Some quartz particles of approximately 20 micron are also noted in the tails, where these particles contain associated hematite mineral phases.

A very large hematite particle of approximately 100 micron size also reported to the silica rougher tails, as indicated in Figure 4.42. An additional 15 micron particle, containing less than 10% hematite phase has shown also to report to the silica rougher tails. This may be an indication that the froth carrying capacity of the cell is still over loaded after six rougher flotation stages and that additional stages could be required to allow simmilar particles to be collected and recovered from the silica concentrate froth phase.

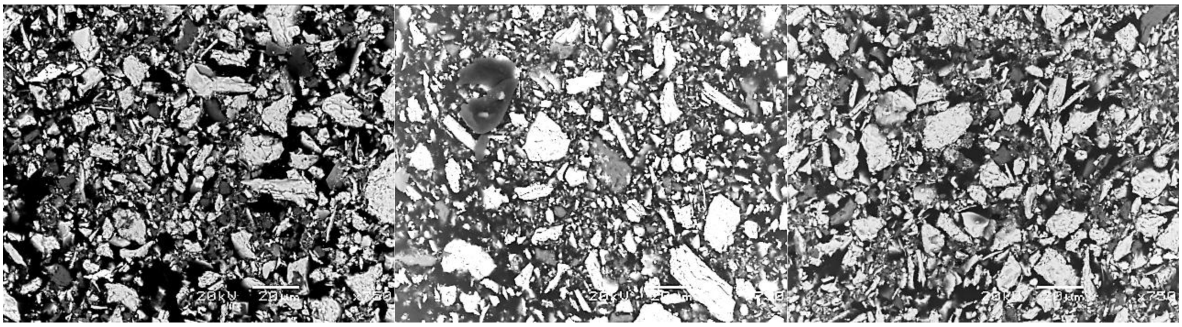

Figure 4.41: BSE SEM images of SiO_2 rougher tails from the rougher flotation cell with a 20 micron scale indication

From the information obtained with the SEM BSE images three flotation circuits were proposed:

- Nine two-minute stages of rougher float of particles milled for 45 minutes;
- Nine two-minute stage floats of particles milled for 45 minutes, where froth six to nine are collected and re-floated in a six stage two minute scavenger flotation after an additional depressant dosing at 200 g/t;
- Nine two-minute stage floats of particles milled for 45 minutes, where froth six to nine are collected and re-floated in a six stage two minute scavenger flotation after an additional 15 minute milling and depressant dosing 200 g/t

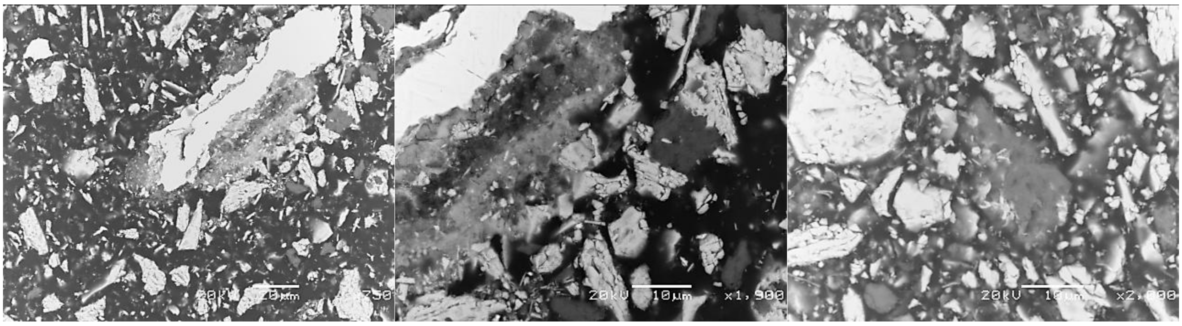

Figure 4.42: BSE SEM images of SiO_2 rougher tails from the rougher flotation cell with a 20 micron scale (left) and 10 micron scale (right) indication

These proposed flotation circuits were tested in a batch flotation process and the results are shown in Figure 4.43. The use of a nine stage rougher float increases the overall attained recovery of both iron minerals and hematite minerals.

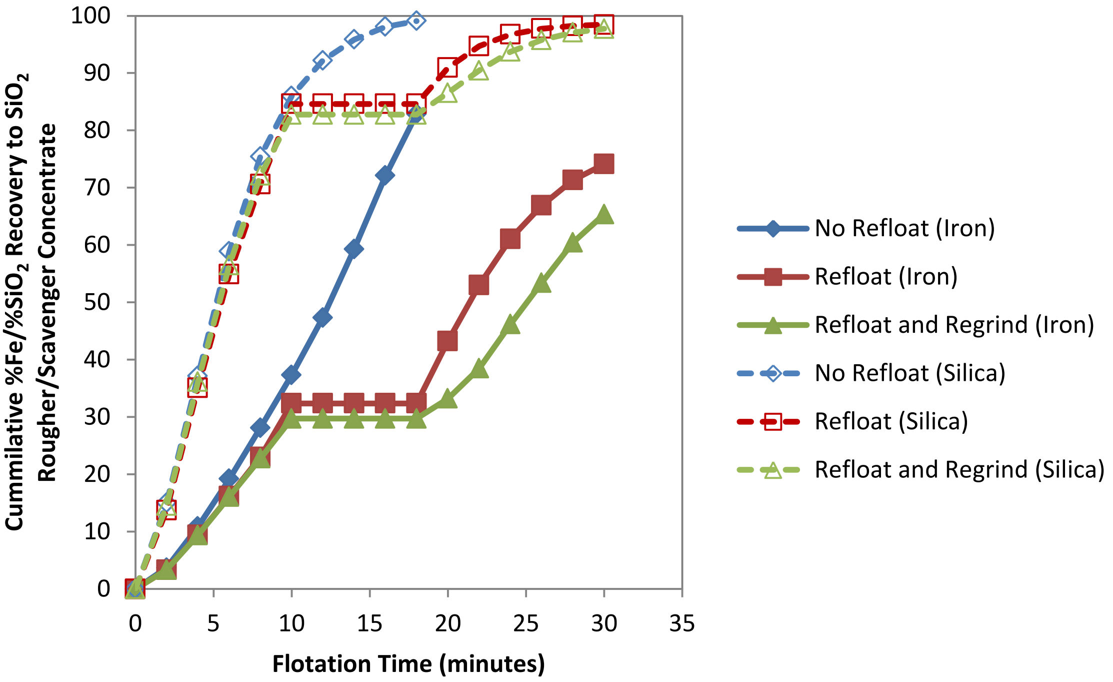

Figure 4.43: Mineral liberation curves for extended rougher flotation and rougher-scavenger flotation circuits with and without additional milling

A change in the flotation rate is evident after the fifth rougher flotation stage, where the rate of silicatious mineral recovery slows down drastically. The rate of flotation of iron bearing minerals does however not slow down after the fifth stage of flotation. Physical constraints, where the froth bed is no longer stable after more than nine rougher flotation stages hinders any additional upgrading in the rougher stage alone.

By implementing an additional scavenger stage, the percentage silica recovery to the concentrate is maximised, with beneficial decrease in the percentage iron recovery to the froth phase (from 82.9% to below 74.1%). The additional regrinding of rougher froths 6 to 9 shows that the rate of hematite mineral flotation is decreased again to yield a final percentage iron recovery of 65.3% to the froth phase. This is an acceptable amount of recovery of iron the froth phase, as the study by Ma *et al.* (2011) indicated that it was not possible to yield more than 50.4% Iron recovery to the iron product (SiO_2 Rougher Tails), when no de-sliming step is implemented.

The decrease in flotation rate of silicate minerals with this re-grind indicates that either the additional depressant dosing retards flotation on fresh mineral surfaces, or that the flotation rate is now limited kinetically by the attachment time of finer particles to the bubble-water interface. The change in particle size to each flotation section is shown in Figure 4.44.

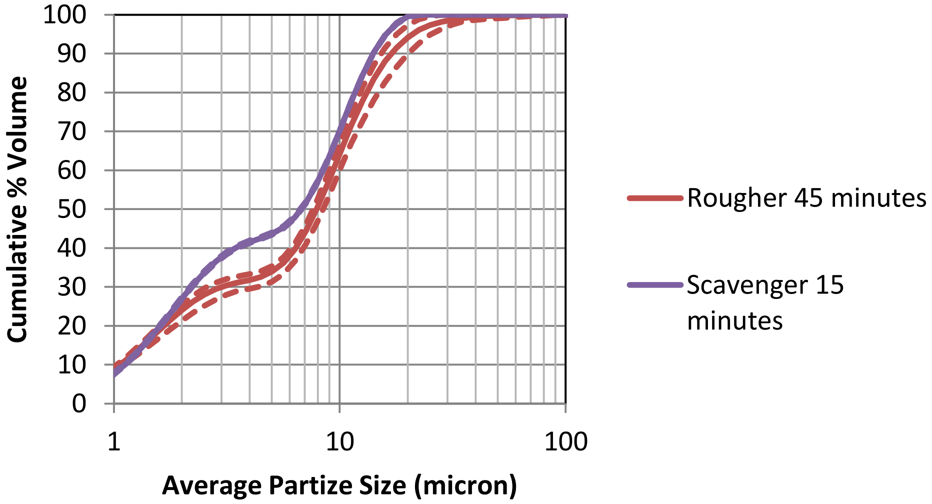

Figure 4.44: Cumulative particle feed size to rougher- and scavenger flotation sections

A further investigation of two of the proposed flotation circuits was done by interpretation of MLA results of the silica flotation concentrate and –tails from one test where no re-float was done and one test where a 15 minute regrind and a re-float was done. Figure 4.45 shows the liberation characteristics of the froth phases for an 8 stage rougher flotation circuit.

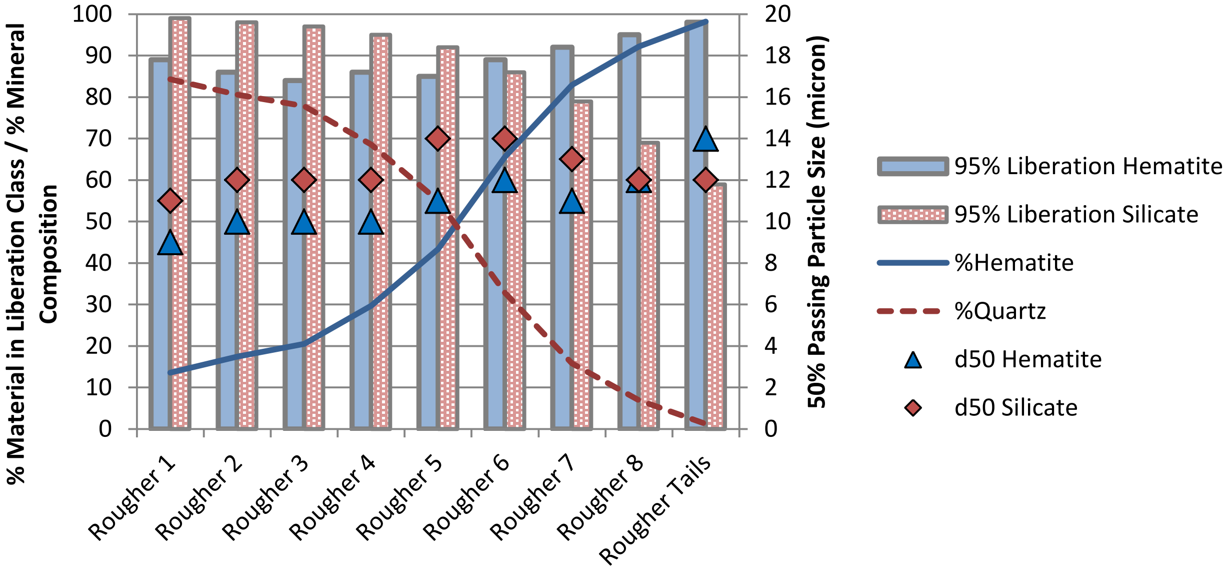

Figure 4.45: MLA analysis of a 45 minute milled low grade composite BIF eight stage rougher flotation test

One can see an increase in the amount of 95% liberated hematite particles reporting to the froth phase from one stage to the next. A decrease in the amount of 95% liberated silicate particles reporting to the froth phase are noted down the flotation bank. This is due to fewer highly liberated silicate particles (which have a high probability of flotation), left in the flotation pulp after each stage. An optimum level of silicate enrichment is achieved between rougher stage five and rougher stage six, where the percentage hematite in the froth starts to exceed the percentage quartz. This supports the postulation that a decrease in the flotation performance is noted after rougher stage six, due to insufficient liberation of silicate particles. The 50% passing particle size of quartz particles is larger than that of the hematite particles for each of the froths up to rougher stage eight. This results in a coarser 50% passing size for hematite particles than for silicate particles in the rougher tails.

The MLA results from a flotation test where the composite feed was milled for 45 minutes before a nine stage rougher float, where the last 4 froths were reground for 15 minutes and followed by a six stage scavenger float, is shown in Figure 4.46. This shows that by regrinding the four last froth products from the rougher stages, an additional two scavenger flotation stages where the quartz content exceeds the hematite content in the froth phase, may be added. After the second scavenger stage, the amount of 95% liberated hematite particles again starts to exceed the amount of 95% liberated silicate particles and the hematite content in the froth silica rougher concentrate increases steadily.

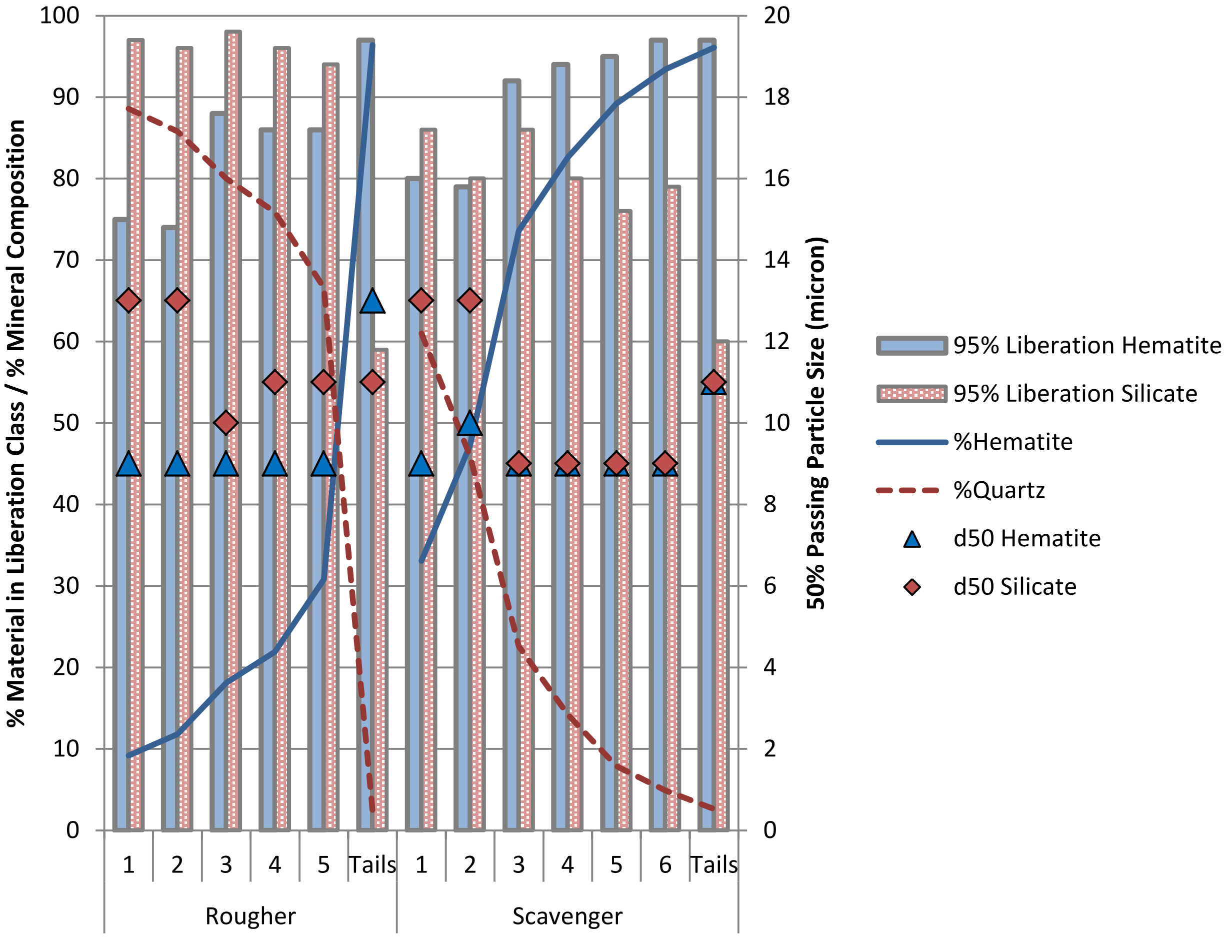

Figure 4.46: MLA analysis of a 45 minute milled low grade composite BIF nine stage rougher flotation test, with 15 minute regrind and six stage scavenger flotation

4.3.8 Collector Ratio Evaluation

Additional flotation tests were conducted to determine the effect of various amine ratios on the flotation performance. Collectors with longer chain lengths are expected to exhibit a more prominent frothing character (Araujo *et al.*, 2005), thus one would expect a more stable froth to be constructed when the portion of quaternary amine is increased. The results of three nine stage tests with diamine to quaternary amine ratios of 1:1, 1:3 and 3:1 are shown in Figure 4.47 as mineral release curves. The collector dosage for each stage was kept constant at 12.5 g/t dry feed. This figure indicates that the overall selectivity of the collector can be increased when the portion of quaternary amine is increased, as a decrease in the flotation rate of iron bearing minerals (hematite) is shown for a 1:3 EDA3 ratio, as well as a decrease in the final percentage iron recovered to the froth phase.

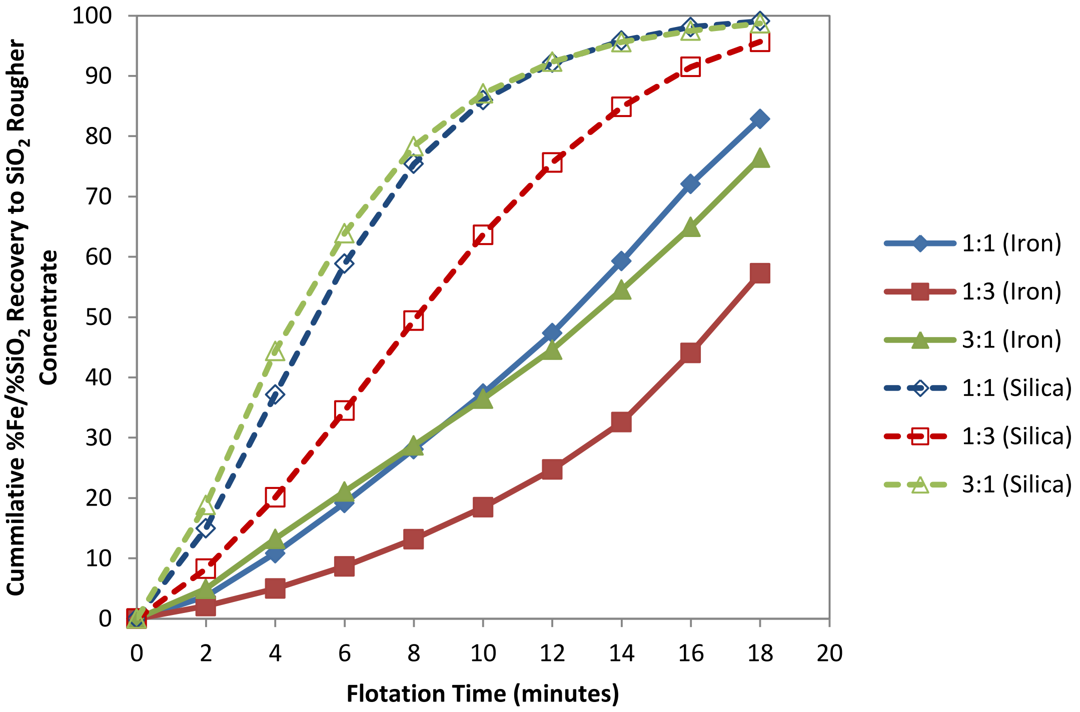

Figure 4.47: Mineral release curves for iron and silica minerals at collector ratios of 1:1, 1:3 and 3:1 of EDA3 to Flotigram 2385-2L, in 9 stage flotation tests with 200 g/t starch and 80 g/t FloatSil1 at pH 9

This ratio unfortunately also show a decreased rate of flotation for silicatious minerals and a decreased overall percentage silica recovery compared to the amine ratio of 1:1, (95.7% vs 99.1%), used for all other test work. Using a 3:1 EDA3 ratio slightly increases the flotation rate of silicatious minerals and results in percentage silica recovery similar to the 1:1 ratio. The rate of flotation of iron bearing minerals is also similar, with the exception of a lower final percentage iron recovery (76.4% vs. 82.8%).

Figure 4.48 shows the highest percentage iron grade in the SiO_2 rougher tails with the use of EDA3 to Flotigram 2385-2L in a ratio of 3:1, which is similar to the grade attained at a 1:1 ratio. The highest percentage iron recovery to the tails is at a ratio of 1:3, but the lowest percentage iron grade of 61.5% Fe and highest percentage silica grade in the tails. It is only in the 1:3 ratio test condition where a slight increase in the percentage silica recovery is noted.

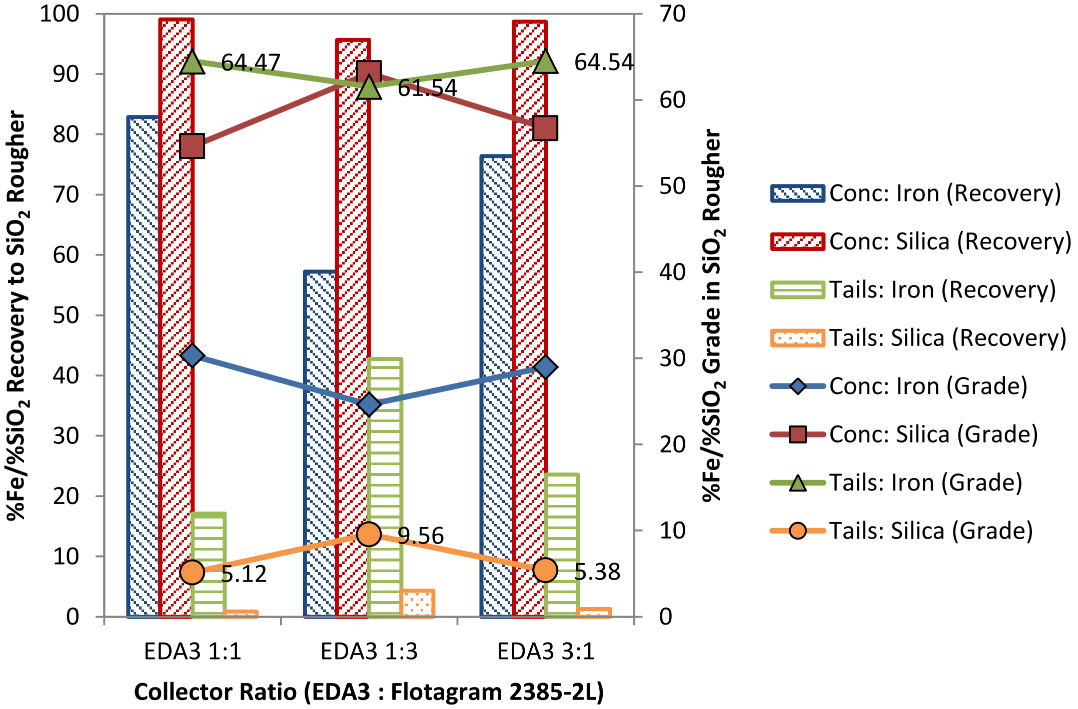

Figure 4.48: Grade and recovery results for percentage iron and percentage silica at collector ratios of 1:1, 1:3 and 3:1 of EDA3 to Flotigram 2385-2L, in 9 stage flotation tests with 200 g/t starch and 80 g/t FloatSil1 at pH 9

This indicates that the bulk of silicate minerals are selectively collected with EDA3 constituting 50% or more of the collector blend. Further optimisation of the reagent suite may include an investigation into a cleaning circuit with the use of a low EDA3 fraction in the rougher stage and 1:1 ratio in the cleaning stage.

4.3.9 Reagent Suite Evaluation of Individual BIF ores

The reagent suite developed in the experimental design results in a reverse flotation circuit where the feed material is milled for 45 minutes before a single stage dispersant, FloatSil1 80 g/t, and then depressant, 200 g/t caustisized starch, conditioning is done. Collector conditioning of a 1:1 EDA3 to Flotigram 2385-2L at 12.5 g/t feed material per flotation stage is done for 9 stages, during which the last four froths are collected and milled for an additional 15 minutes. The scavenged froth is then conditioned again with 200 g/t starch at low pulp density before conditioned with the same collector mix before each of the six scavenging flotation stages.

Figure 4.49 shows the mineral release curves for each of the individual BIF feed ores (marked BIF1 to BIF7 by increasing percentage iron content). In general, it seems that a steady incline in the flotation recovery of iron bearing minerals is to be expected, with the range in flotation rates increasing with flotation time. The lowest rate of iron mineral flotation is noted for BIF4 and the highest rate, for BIF2. The recovery of silicate minerals is above 98.5% (BIF4) for all of the feed ores after a 9 Stage rougher float.

4.4 Test Work Validation

4.4.1 Repeatability of Flotation Test work

The repeatability of the flotation test work done in this investigation is quantified by the flotation Call Factor (equation 3.1 from Chapter 3). In Table 4.6, the calculated call factors of triplicate tests performed under the same conditions for a coarse feed grind and a medium feed grind is given. All of these values were within a range of between 0.95-1.05.

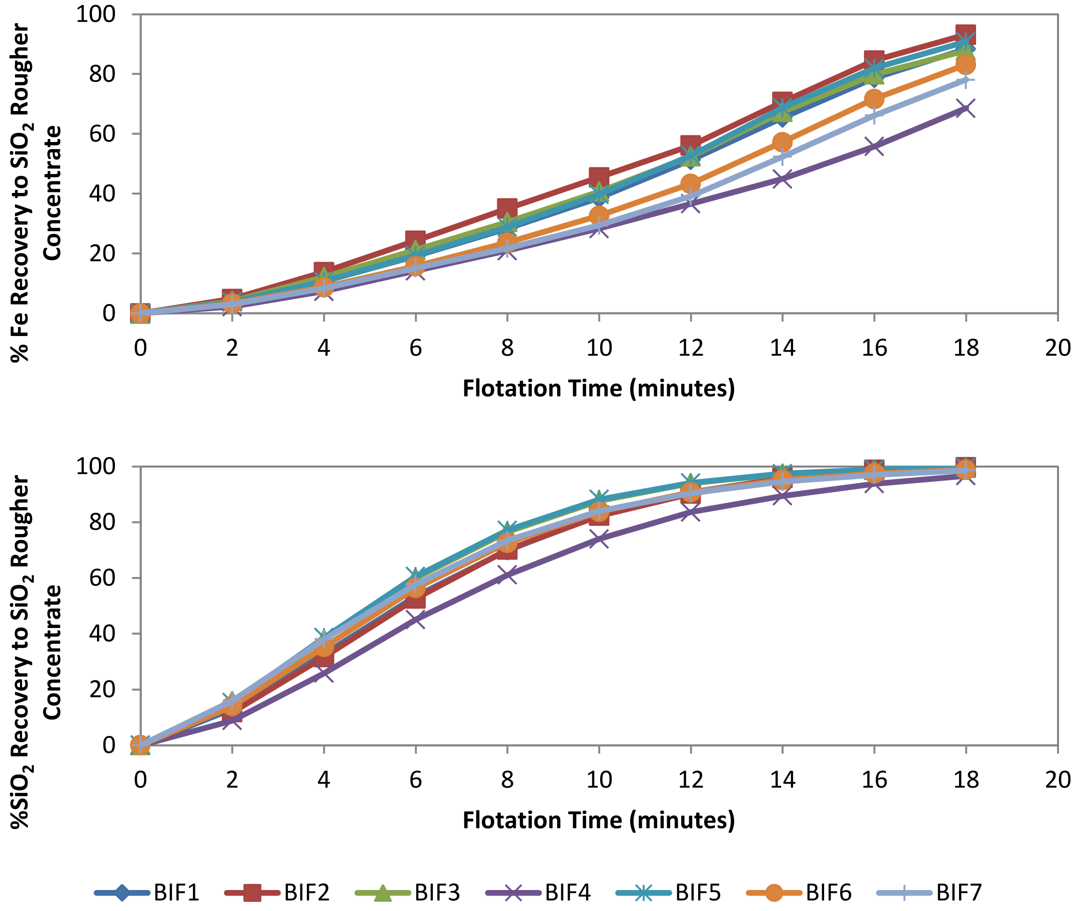

Figure 4.49: Mineral release curves iron minerals (top) and silicate minerals (bottom) for each of the individual BIF ores at the developed reagent suite conditions for SiO_2 rougher flotation

Table 4.6: Call factor on triplicate repeated tests for coarse- and medium grind

		Call Factor on % Fe		
Grind	Test A	Test B	Test C	Average
Coarse (55 micron)	0.98	1.04	1.05	1.02
Medium (25 micron)	1.00	0.95	1.03	0.99
		Call Factor on % SiO_2		
Grind	Test A	Test B	Test C	Average
Coarse (55 micron)	1.01	0.97	0.95	0.97
Medium (25 micron)	0.99	1.05	0.97	1.00

4.4.2 Validation of Flotation Test Work Trends by MLA

Two sample sets were sent to Anglo Technical Solutions Research for MLA analysis. The results from these analyses in confidential Anglo American Report MPR/13/226 were used to validate the grade-recovery trends found in the flotation test work. Figure 4.50 shows that the grade-recovery curves from Test A (A rougher-scavenger flotation setup with feed milled for 45 minutes and a re-grind of the last six froths from the rougher for 15 minutes before the material was fed to the scavenger cell) as calculated from XRF analysis done at the University of Pretoria and from MLA done at Anglo Technical Solutions Research. Both iron and SiO_2 grade-recovery curves follow the same trend. The same can be observed in Figure 4.51, where Test B (a coarse grind, 6 stage rougher float) yielded similar trends for the grade-recovery curves calculated for this test.

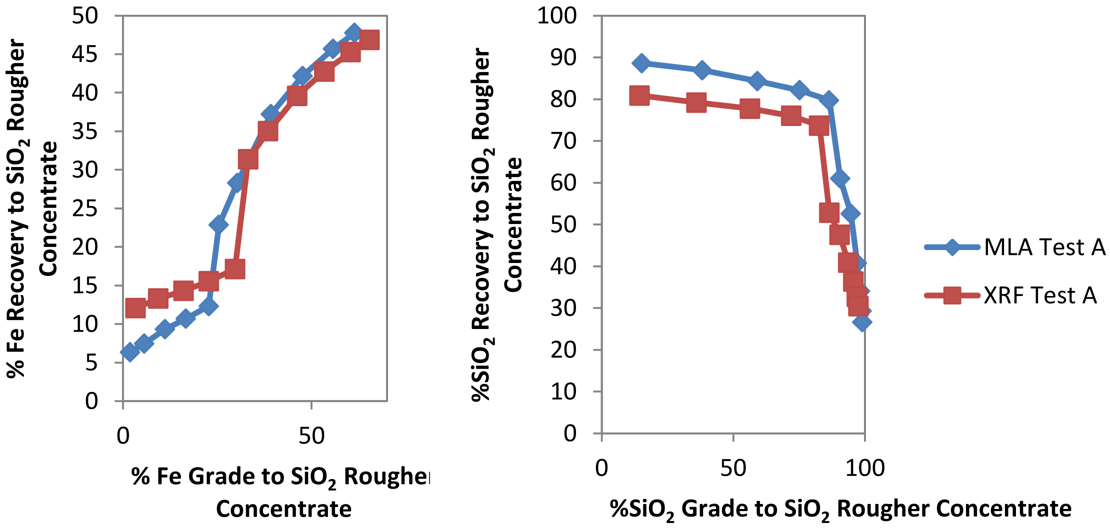

Figure 4.50: Grade and recovery results calculated from XRF and MLA analysis for percentage iron and percentage silica in a rougher-scavenger flotation configuration

Table 4.9 shows that the percentage iron in the final SiO_2 flotation tails, (the iron product), in both Test A and Test B's MLA analysis exceeds that of the XRF analysis. This could indicate that the actual iron content of the final iron product from the flotation parameters and reagent regime could exceed 66% Fe. The inverse is also true where both tests show lower percentage silica values from the MLA results than from the XRF results.

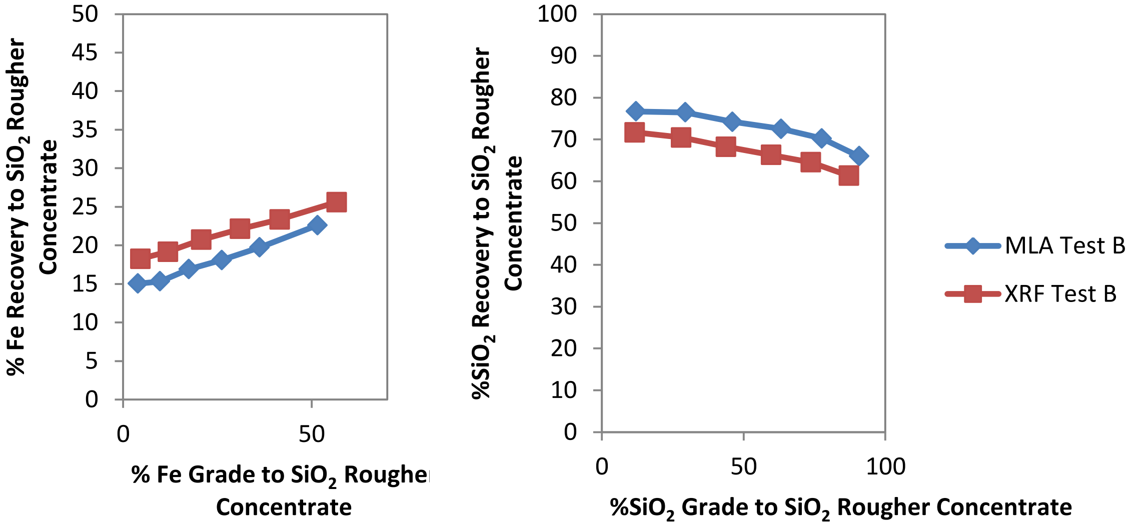

Figure 4.51: Grade and recovery results calculated from XRF and MLA analysis for percentage iron and percentage silica in a 6 stage rougher float from a coarse feed material

Table 4.7: Validation of iron product results from XRF and MLA analysis of percentage iron and percentage silica grade and recovery calculations

	% Fe Grade		**% Fe Recovery**		**% SiO_2 Grade**		**% SiO_2 Recovery**	
	MLA	XRF	MLA	XRF	MLA	XRF	MLA	XRF
Test A	66.44	63.52	38.56	34.63	2.47	2.27	0.84	2.27
Test B	55.75	51.50	48.41	43.37	17.70	23.68	9.27	12.82

4.5 Proposed Flotation Circuit from Test Work

The proposed flotation circuit suitable for upgrading Sishen low grade BIF iron ore is illustrated in Figure 4.52. This shows the rougher float, which consists of five primary rougher stages of two minutes each at laboratory scale, and four secondary rougher flotation stages of two minutes each at laboratory scale. This secondary rougher stage is followed by 15 minute milling and an additional six stages scavenger flotation of two minutes each at laboratory scale. All flotation product collection points are indicated. It is expected to produce a high percentage iron grade tails in the rougher section, and recover additional iron minerals in the scavenger tails.

The pulp pH is maintained at pH 9 throughout the entire circuit. A depressant dosage of 200 g/t is dosed at the start of the primary rougher stage, where the pulp is conditioned for three minutes before the addition of 80 g/t FloatSil1 for the first stage. The amine collector addition of 37.5 g/t EDA3 and Flotigram 2L each is added at the start of each stage and conditioned for one minute.

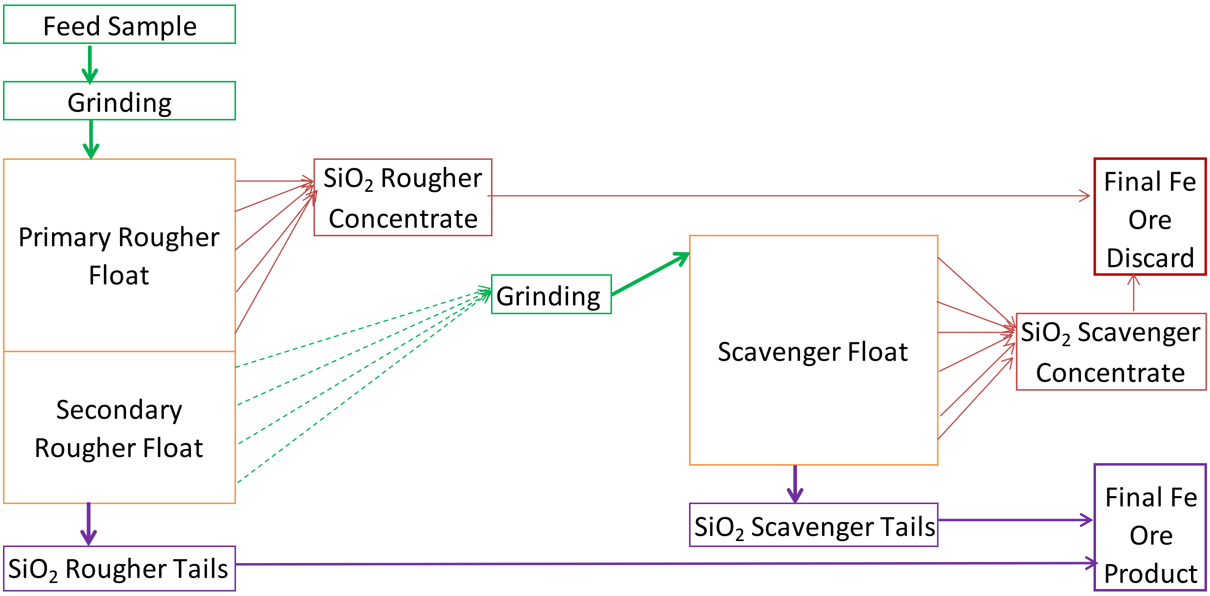

Figure 4.52: Proposed flow sheet for reverse flotation of low grade BIF Sishen iron ore

4.6 Summary

The main iron bearing mineral in the low grade Sishen iron ore BIF was identified as hematite, and no other iron bearing minerals were identified. The main gangue mineral was identified by XRD as quartz, with additional minor gangue minerals annite and kaolinite.

The composition (as analysed by XRF) of the individual BIF samples range from 25-39% Fe and 59-39.2% SiO_2 and the composition of the composite blend material as 32.48% Fe and 51.75% SiO_2. A strong correlation between the percentage iron and percentage silica content of both the individual samples and the composite blend sample was established. No correlation could be found between the percentage iron content and the minor elements present.

The received sample had an 80% passing particle size of 1.1 mm, which is too large for flotation. A grinding curve experiment showed that milling of 15 minutes would be sufficient for a feed particle size suitable for flotation and 25 minutes of milling would produce a sample with particle sizes below 34 micron. Variation in sample sizes was evaluated to a level below 5% error in split samples.

In bench-scale laboratory flotation tests conducted with a Denver D12 flotation machine, strong pH dependence is confirmed for the recovery rate of hematite mineral particles in flotation, where a natural hydrophobicity is exhibited at pH 7. These tests also confirmed that caustisized starch is a suitable depressant for hematite minerals in a low grade Sishen iron ore BIF and that the addition of a sodium silicate dispersant may improve the iron product grade.

An increase in the depressant dosage has a minor effect on the flotation results and it seems that the depressant mechanism is largely dependent on the flotation pulp pH. Froth stability is greatly influenced by a change in the amine collector dosage, where fine particles over stabilise the froth bed and it is not possible to control the froth bed height at high collector dosages (larger than 25 g/t/stage).

Alteration of the flotation circuit from a six stage rougher float to a nine stage rougher float and six stage scavenger float after additional milling and depressant dosing, yielded the required target of at least 64% Fe and a 30% recovery to the tails (iron product).

The use of this reagent suite on individual BIF ores shows that more than 98.5% of the silicate materials can be removed to the froth phase. An additional scavenger stage will be required to reach the target percentage iron recovery of 30%.

Chapter 5: Conclusion

Low grade BIF Sishen iron ore sample was characterized in terms of its mineralogy, composition, particle size distribution and grinding characteristics. The characterisation study showed that this ore sample, which consists mainly of hematite and quartz (as well as minor amounts of clay minerals such as kaolinite, muscovite and annite), has an iron content of 25-39% Fe and a blended composite was made up to consist of 32.48% Fe and 51.75% SiO_2. A strong correlation between the %Fe and %SiO_2 content of both the individual samples and the composite blend sample was established. No correlation could be found between the %Fe content and the minor elements present. MLA analysis showed sufficient 95% liberation of both silicate- and hematite particles, (89% and 82% respectively), at a liberation size (d50) of 11 micron for hematite particles and 12 micron for silica particles.

A suitable reagent suit for the reverse flotation of low grade Sishen banded iron ore was evaluated and it may be concluded that the use of an amine collector in conjunction with caustisized starch depressant and sodium silicate dispersant are sufficient to upgrade a low grade Sishen iron ore to 64% Fe. The use of this reagent suite on individual BIF ores shows that more than 98.5% of the silicate materials can be removed to the froth phase. An additional scavenger stage will be required to reach the target %Fe recovery of 30%.

Laboratory flotation experiments showed that in the narrow pH range, where amine collectors exhibit the formation of an ion-molecular complex responsible for both the induced hydrophobicity of quartz surfaces and the frothing character, which stabilises air bubbles, a superior flotation performance between pH 7 and pH 9. Strong pH dependence is confirmed for the recovery rate of hematite mineral particles in flotation when no depressant was used in the flotation test. The use of caustisized starch sufficiently depressed hematite particles in a low grade Sishen iron ore and the addition of a sodium silicate dispersant induced an improvement of the iron product grade. The depressant dosage showed minor effect on the flotation results, thus rendering the flotation pulp pH as the largest influencing factor on the selective depressing of hematite.

It is also concluded that the flotation circuit proposed from the laboratory test work in this study (consisting of a 9 stage 2 minute rougher float, 15 minute regrinding and a six stage two minute scavenger float), The developed flotation regime was deemed duitable for different low grade Sishen banded iron ore samples, with 98.5% of silicate minerals being removed to the froth after a 9 stage rougher flotation test.

MLA results indicated a degree of residual collector was required to successfully float larger quartz particles, and flotation tests indicated that a maximum level of collector dosage can be reached when the froth is over stabilised by excessive amounts of fine particles are present in the froth bed. Alteration of the flotation circuit from a six stage rougher float to a nine stage rougher float and six stage scavenger float after additional milling and depressant dosing, yielded the required target of at least 64%Fe and a 30% recovery to the tails (iron product). MLA results also indicated that an optimum flotation of 95% liberated quartz particles are reached between stage five and stage six.

Chapter 6: Future Work

The development of a reverse flotation reagent suite and flotation regime is still in its initial development stages, where vast opportunities for the optimisation of the baseline parameters identified still exist. The following aspects may also be considered in future work:

- Feasibility study into the economic viability of froth flotation as a beneficiation means for low grade Sishen iron ore
- Flocculation and surface phenomena characterisation to identify adsorption mechanisms
- Development of a suitable reagent suite for the flotation of other iron ore samples, such as low grade concentrate or tailings material from magnetic separation processes.
- The use of newly developed reagents not stated in this study to improve flotation results.
- Further alteration and modification of flotation circuit targeting specific size fractions.
- Further optimization of reagent dosing locations in stages before, during and after milling, and dosing quantity optimization per flotation stage.
- Locked cycle- and pilot scale tests for determination of up-scale parameters to a full plant scale.
- Characterization of the surface chemistry of Sishen iron ore in reverse flotation by Atomic Force Microscopy or ToFSims and Zeta potential measurements.
- PZC analysis of single mineral samples from the origin of the ore

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Appendix 1: Reference Ore Labelling and Ore Preparation

Kumba Iron Ore Sample identification labels for individual BIF ores from a South African Iron Ore Mine

Mine Sample Identification Label	UP Sample Identification Label
BIF571407	BIF1
BIF020911	BIF2
BIF921112	BIF3
BIF621206	BIF4
BIF110806	BIF5
BIF381007	BIF6
BIF260634	BIF7

Sample Splitting procedure for "As received" BIF samples

	BIF 020 911	BIF 110 806	BIF 621 206	BIF 571 407	BIF 381 007	BIF 921 112	BIF 260 634	Total (kg)	Used (kg)
As Received (kg)	4x10	4x10	4x10	4x10	4x10	4x10	4x10	280	
Split (kg)	40x1	40x1	40x1	40x1	40x1	40x1	40x1	280	
XRD/XRF Split (g)	40 x100	40 x100	40 x100	40 x100	40 x100	40 x100	40 x100		28
Blend Samples (kg)	36x1	36x1	36x1	36x1	36x1	36x1	36x1	252	

Sample Splitting procedure for composite blend samples and individual BIF samples required in flotation tests and characterization samples

	Individual BIF	Composite	TOTAL (kg)	Used (kg)
Blend	18 x 7kg	18x7kg	252	
Split	180 x 700g	180x700g	252	
Samples for Characterization		40 x 70g		2.8
Samples for Grinding Curve		7 x 700g		4.9
Available for Flotation Feed Samples	180x700g	169 x 700g	244.3	

Appendix 2: Ore Composition XRF

Individual BIF Samples (XRF)

UP Label	Fe_2O_3 (%)	SiO_2 (%)	K_2O (%)	Al_2O_3 (%)	Na_2O (%)	MgO (%)	P_2O_5 (%)	SO_3 (%)	MnO (%)	TiO_2 (%)	CaO (%)	Calc.Fe (%)
BIF6	55.75	43.62	0.02	0.36	0.00	0.03	0.03	0.02	0.04	0.03	0.09	37.03
	54.98	44.35	0.04	0.38	0.02	0.04	0.03	0.02	0.04	0.03	0.09	36.36
	53.25	46.07	0.02	0.40	0.01	0.04	0.03	0.02	0.04	0.02	0.09	34.91
	52.68	46.64	0.04	0.39	0.00	0.04	0.03	0.02	0.03	0.03	0.10	34.05
	54.17	**45.17**	**0.03**	**0.38**	**0.01**	**0.04**	**0.03**	**0.02**	**0.04**	**0.03**	**0.09**	**35.59**
BIF3	42.36	57.02	0.04	0.45	0.02	0.02	0.02	0.01	0.03	0.02	0.02	26.63
	42.26	57.12	0.04	0.44	0.02	0.03	0.02	0.01	0.03	0.02	0.01	26.74
	44.11	55.29	0.04	0.43	0.00	0.03	0.02	0.01	0.03	0.02	0.01	30.28
	42.86	56.53	0.04	0.43	0.02	0.03	0.02	0.01	0.03	0.02	0.02	26.84
	42.90	**56.49**	**0.04**	**0.44**	**0.01**	**0.03**	**0.02**	**0.01**	**0.03**	**0.02**	**0.02**	**27.62**
BIF4	45.23	53.20	0.05	1.19	0.02	0.03	0.05	0.08	0.03	0.06	0.06	30.85
	44.90	53.45	0.06	1.27	0.01	0.03	0.05	0.08	0.04	0.06	0.06	30.02
	45.41	52.95	0.05	1.28	0.01	0.03	0.05	0.08	0.03	0.06	0.05	30.77
	43.44	54.91	0.05	1.29	0.00	0.03	0.05	0.08	0.03	0.06	0.05	28.29
	44.74	**53.63**	**0.05**	**1.26**	**0.01**	**0.03**	**0.05**	**0.08**	**0.04**	**0.06**	**0.06**	**29.98**
BIF1	39.13	59.53	0.03	1.10	0.00	0.03	0.04	0.04	0.03	0.03	0.04	25.34
	39.57	59.10	0.02	1.11	0.00	0.03	0.04	0.04	0.03	0.04	0.03	25.96
	38.89	59.64	0.04	1.21	0.01	0.03	0.04	0.05	0.03	0.04	0.04	25.53
	38.84	59.80	0.03	1.12	0.00	0.02	0.04	0.04	0.03	0.04	0.04	25.62
	39.11	**59.52**	**0.03**	**1.14**	**0.00**	**0.03**	**0.04**	**0.04**	**0.03**	**0.04**	**0.04**	**25.61**
BIF7	59.90	38.94	0.09	0.75	0.00	0.03	0.05	0.10	0.04	0.06	0.04	40.16
	59.46	39.35	0.10	0.78	0.01	0.03	0.05	0.10	0.04	0.06	0.02	39.46
	59.43	39.46	0.10	0.72	0.00	0.02	0.05	0.09	0.04	0.06	0.03	39.46
	59.68	39.16	0.09	0.76	0.00	0.03	0.05	0.10	0.04	0.06	0.03	39.81
	59.62	**39.23**	**0.10**	**0.75**	**0.01**	**0.03**	**0.05**	**0.09**	**0.04**	**0.06**	**0.03**	**39.73**
BIF5	50.84	48.33	0.07	0.58	0.02	0.03	0.04	0.02	0.03	0.02	0.02	32.44
	52.54	46.74	0.07	0.50	0.00	0.02	0.04	0.01	0.03	0.02	0.02	33.11
	50.23	48.95	0.07	0.58	0.02	0.03	0.04	0.02	0.03	0.02	0.02	31.78
	50.43	48.83	0.07	0.53	0.00	0.02	0.03	0.01	0.03	0.02	0.02	31.93
	51.01	**48.21**	**0.07**	**0.55**	**0.01**	**0.03**	**0.04**	**0.02**	**0.03**	**0.02**	**0.02**	**32.32**
BIF2	40.96	57.13	0.23	1.47	0.02	0.03	0.04	0.04	0.03	0.04	0.02	26.43
	42.62	55.64	0.23	1.29	0.00	0.03	0.05	0.04	0.03	0.04	0.03	26.99
	40.80	57.26	0.24	1.49	0.01	0.03	0.05	0.04	0.03	0.03	0.02	26.10
	41.14	56.96	0.23	1.47	0.00	0.03	0.05	0.04	0.03	0.03	0.02	26.36
	41.38	**56.75**	**0.23**	**1.43**	**0.01**	**0.03**	**0.05**	**0.04**	**0.03**	**0.03**	**0.02**	**26.47**
Calc. Ave.	47.56	51.46	0.08	0.85	0.01	0.03	0.04	0.04	0.03	0.04	0.04	**31.07**

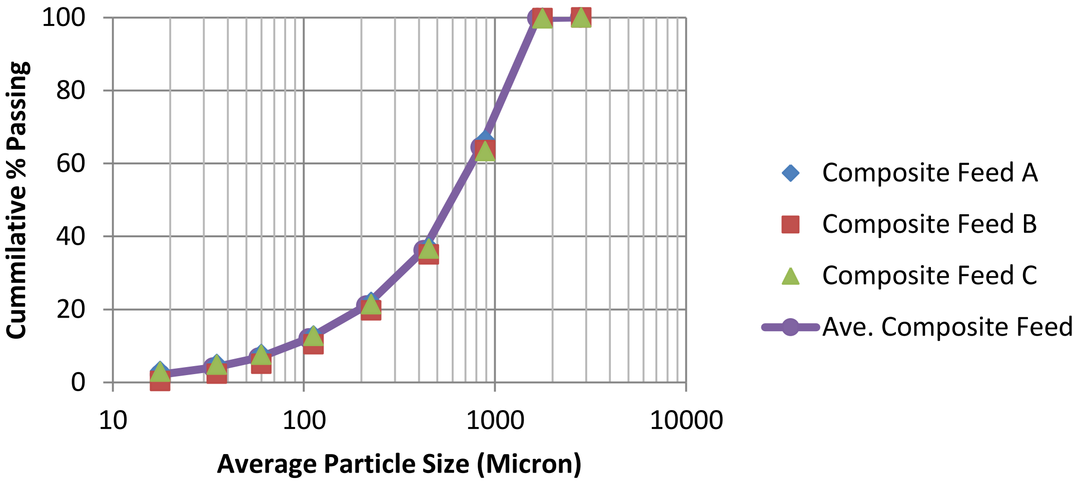
Blended Composite BIF Samples (XRF)

UP Label	Fe2O3 (%)	SiO2 (%)	K2O (%)	Al2O3 (%)	Na2O (%)	MgO (%)	P2O5 (%)	SO3 (%)	MnO (%)	TiO2 (%)	CaO (%)	Calc. Fe (%)
Blend 1	46.87	51.93	0.08	0.88	0.01	0.03	0.04	0.04	0.03	0.03	0.04	32.34
Blend 2	46.78	52.07	0.09	0.83	0.02	0.03	0.04	0.04	0.03	0.04	0.04	32.28
Blend 3	47.09	51.75	0.08	0.86	0.00	0.03	0.04	0.05	0.03	0.04	0.04	32.49
Blend 4	47.04	51.76	0.09	0.88	0.00	0.03	0.04	0.05	0.03	0.04	0.04	32.46
Blend 5	47.24	51.57	0.09	0.84	0.02	0.03	0.04	0.04	0.03	0.04	0.06	32.59
Blend 6	46.84	51.99	0.08	0.86	0.02	0.03	0.04	0.04	0.03	0.04	0.03	32.32
Blend 7	47.37	51.47	0.07	0.87	0.00	0.03	0.04	0.04	0.03	0.04	0.03	32.69
Blend 8	47.29	51.56	0.07	0.85	0.00	0.03	0.04	0.05	0.03	0.04	0.04	32.63
Blend 9	46.67	52.16	0.09	0.87	0.00	0.03	0.04	0.04	0.03	0.04	0.04	32.20
Blend 10	47.14	51.67	0.08	0.88	0.00	0.03	0.04	0.05	0.03	0.04	0.04	32.53
Blend 11	46.80	52.00	0.08	0.90	0.00	0.03	0.04	0.05	0.03	0.04	0.04	32.30
Blend 12	47.74	51.15	0.06	0.83	0.00	0.03	0.04	0.04	0.03	0.04	0.04	32.94
Ave.	**47.07**	**51.76**	**0.08**	**0.86**	**0.01**	**0.03**	**0.04**	**0.04**	**0.03**	**0.04**	**0.04**	**32.48**
Std.Dev.	**0.31**	**0.29**	**0.01**	**0.02**	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.01**	**0.21**

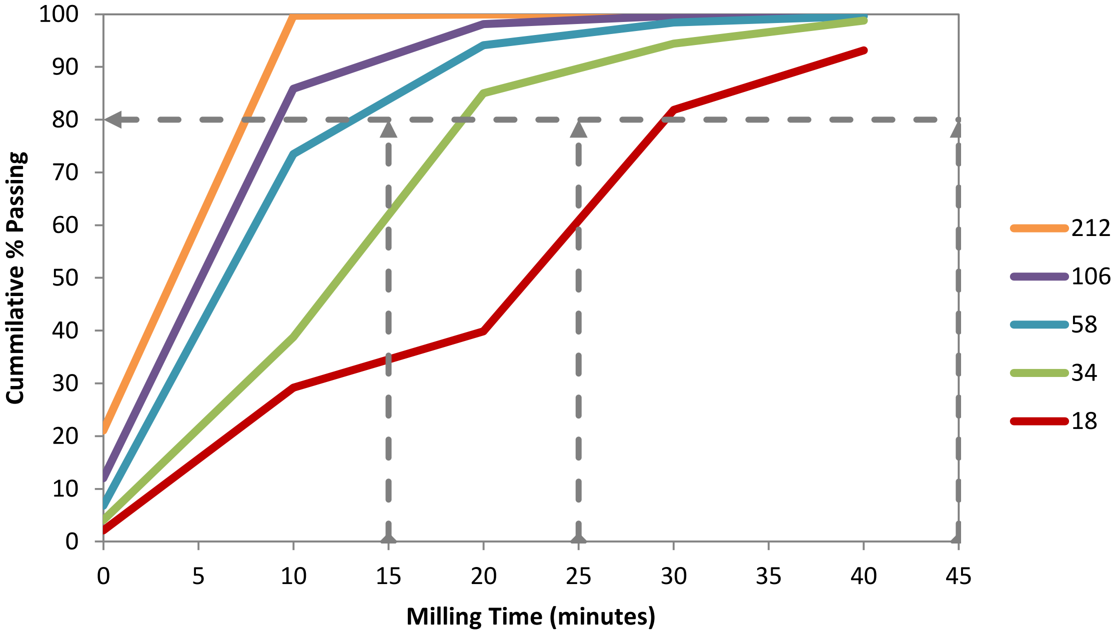
Standard deviation and error percentage for each compositional constituent.

Constituent	Average wt. %	Standard deviation	Error %
Fe	32.48	0.21	0.6
SiO_2	51.76	0.29	0.6
K_2O	0.08	0.01	11.5
Al_2O_3	0.86	0.02	2.7
Na_2O	0.01	0.01	129.8
MgO	0.03	<0.01	6.7
P_2O_5	0.04	<0.01	5.2
SO_3	0.04	<0.01	3.9
MnO	0.03	<0.01	2.8
TiO_2	0.04	<0.01	4.1
CaO	0.04	0.01	19.3

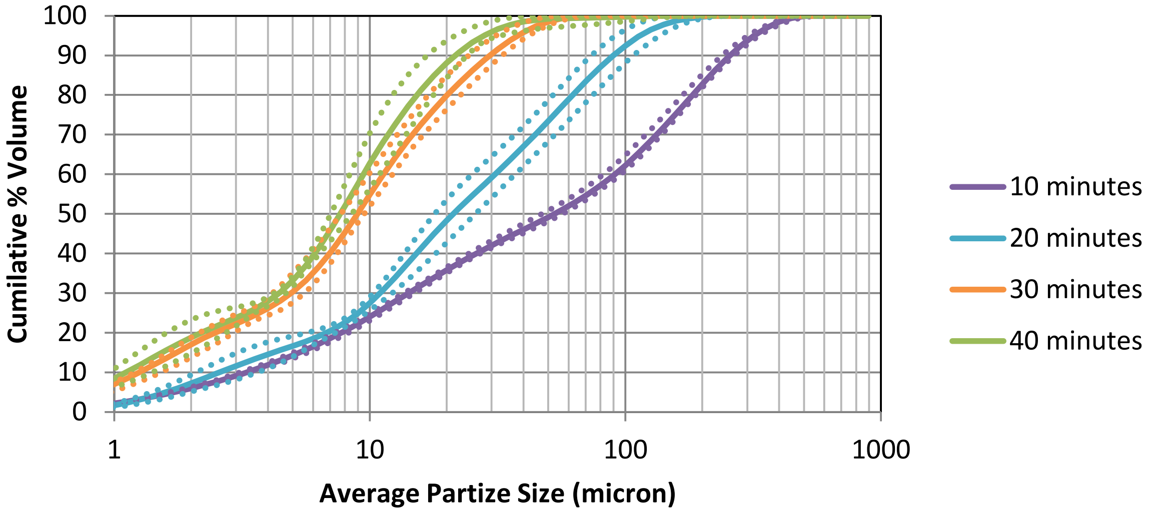
Appendix34: Grinding Curve Calibration



Average Feed Particle Size Distribution for composite ore blend



Grinding curve for composite BIF sample



Particle Size Distribution for composite Feed Samples milled 10, 20, 30 and 40 minutes from Laser Diffraction Analysis

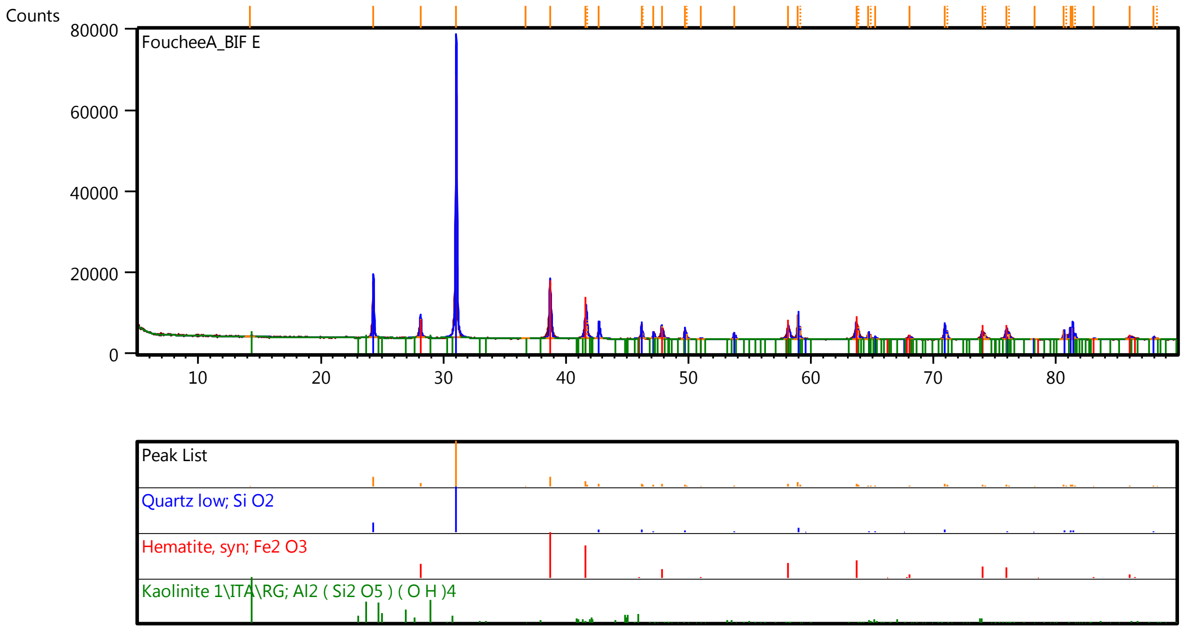
Appendix 4: Ore Composition XRD

Individual BIF Samples (Quantitative XRD)

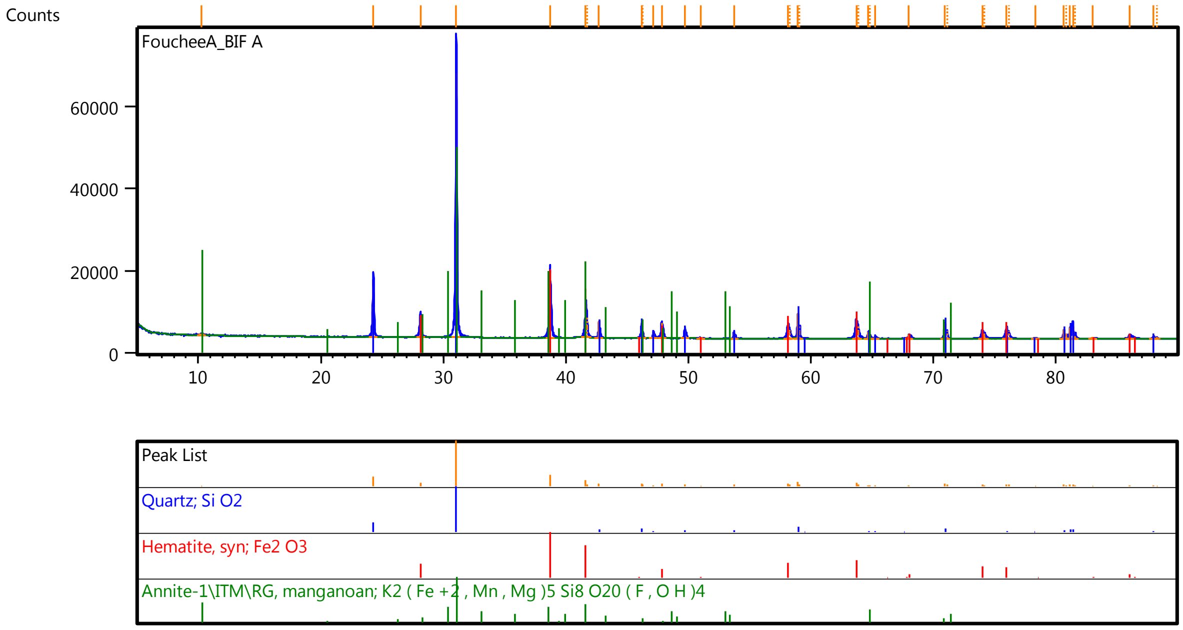
Mineral	**Hematite**		**Quartz**		**Annite**		**Kaolinite**	
Ore Type	weight%	3 σ error	weight%	3 σ error	weight%	3 σ error	weight%	3 σ error
BIF 1	38.69	0.42	60.09	0.48	0	0	1.22	0.57
BIF 2	41.27	0.42	57.82	0.45	0.9	0.51	0	0
BIF 3	43.11	0.36	56.89	0.36	0	0	0	0
BIF 4	43.68	0.39	56.32	0.39	0	0	0	0
BIF 5	51.36	0.42	48.64	0.42	0	0	0	0
BIF 6	52.97	0.42	47.03	0.42	0	0	0	0
BIF 7	59.72	0.42	40.28	0.42	0	0	0	0
AVERAGE	47.26		52.44		0.13		0.17	

Individual BIF Samples (Qualitative XRD)

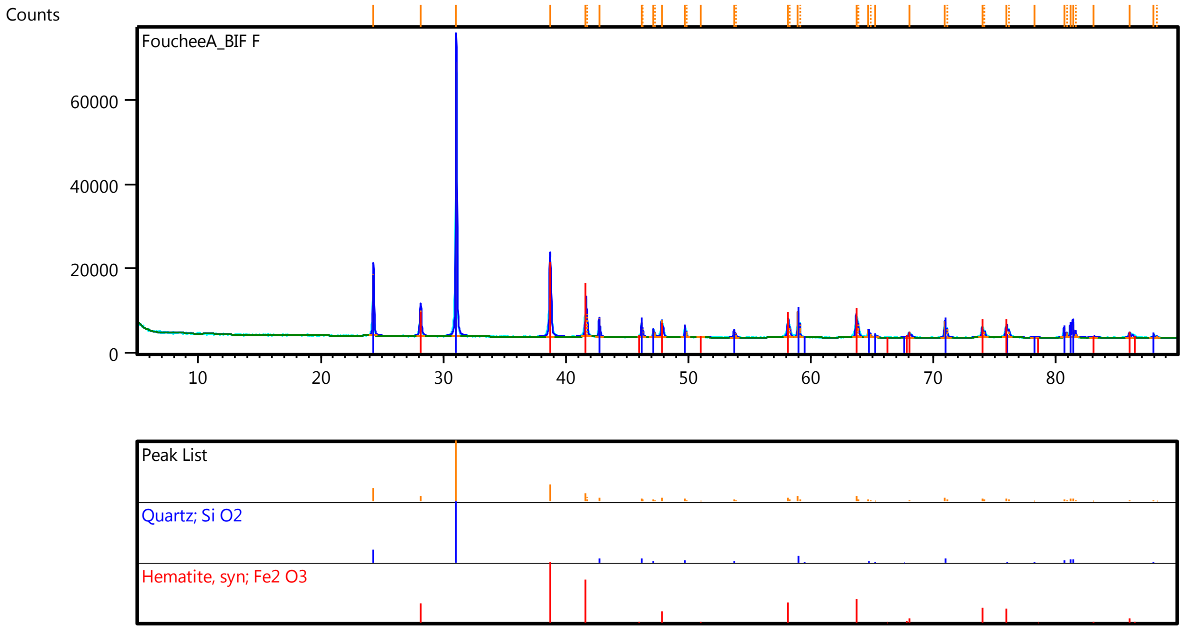
BIF1



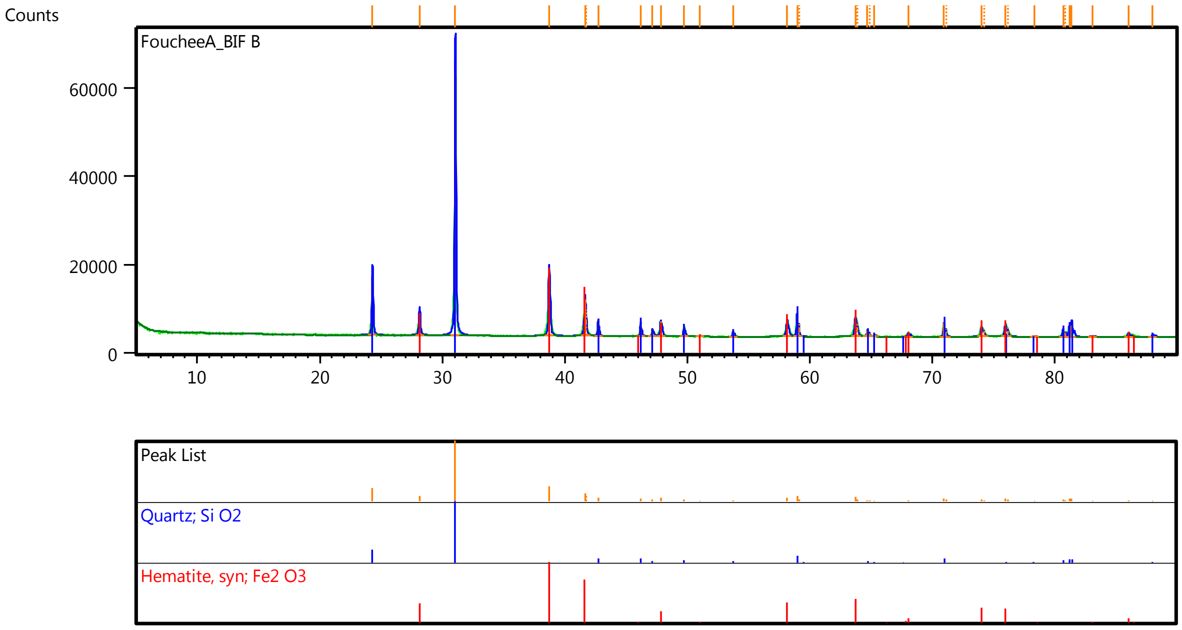
BIF2


Counts
FoucheeA_BIF A
60000
40000
20000
0
10
20
30
40
50
60
70
80
Peak List
Quartz; Si O2
Hematite, syn; Fe2 O3
Annite-1\ITM\RG, manganoan; K2 (Fe +2 , Mn , Mg)5 Si8 O20 (F , O H)4

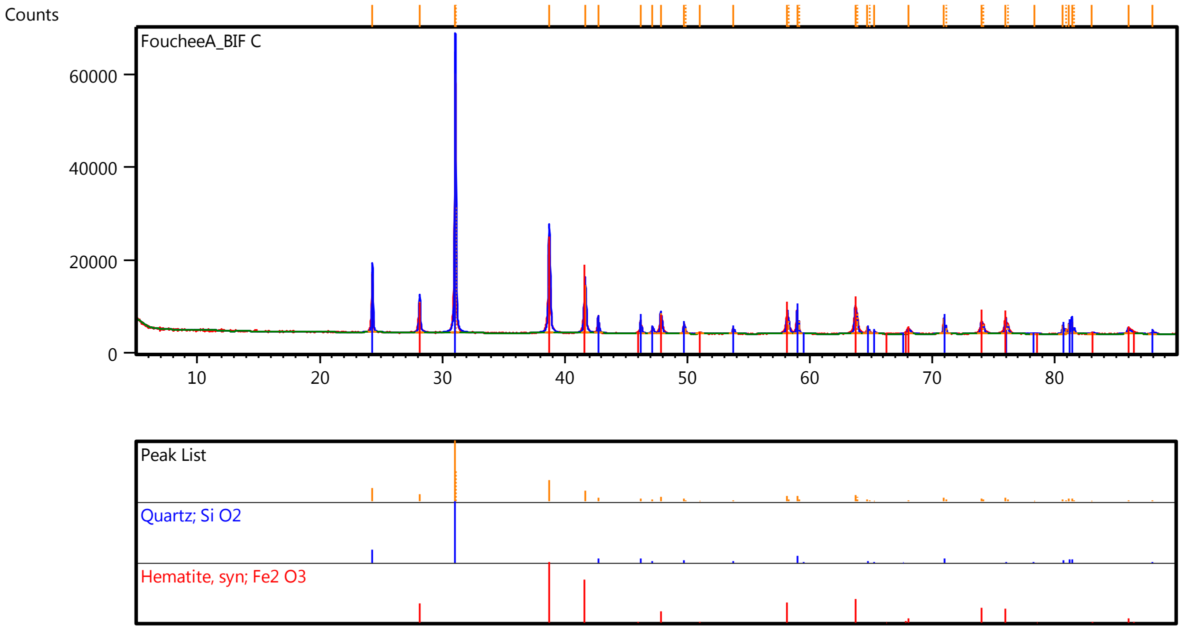
BIF3


Counts
FoucheeA_BIF F
60000
40000
20000
0
10
20
30
40
50
60
70
80
Peak List
Quartz; Si O2
Hematite, syn; Fe2 O3

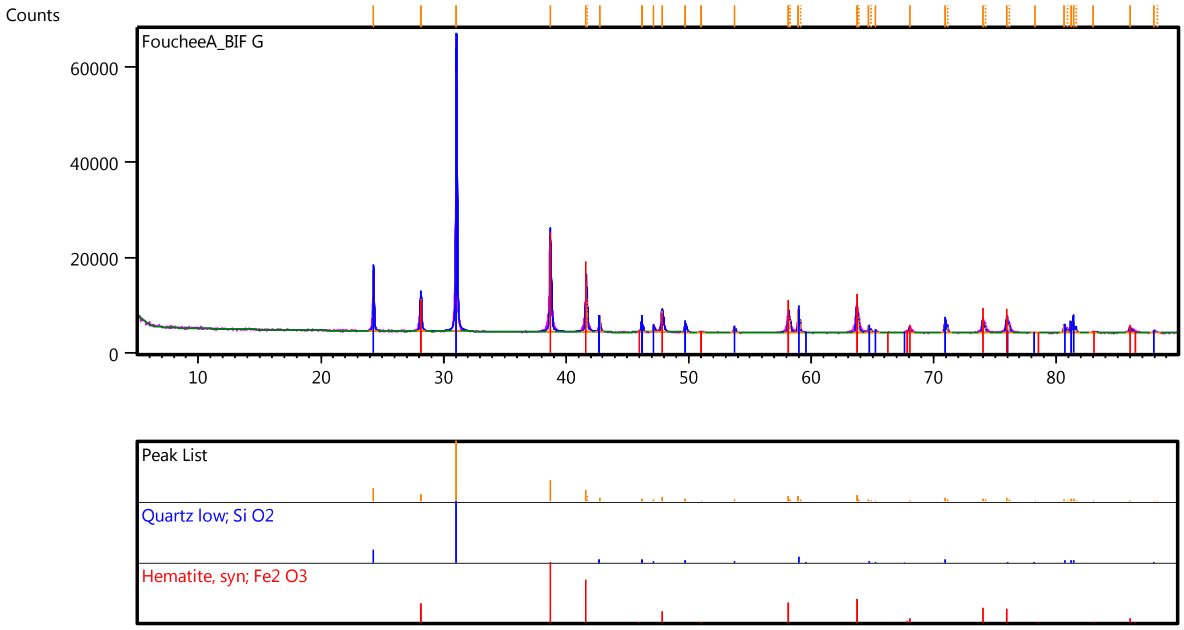
BIF4


Counts
FoucheeA_BIF B
60000
40000
20000
0
10
20
30
40
50
60
70
80
Peak List
Quartz; Si O2
Hematite, syn; Fe2 O3

BIF5


Counts
FoucheeA_BIF C
60000
40000
20000
0
10
20
30
40
50
60
70
80
Peak List
Quartz; Si O2
Hematite, syn; Fe2 O3

BIF6


Counts
FoucheeA_BIF G
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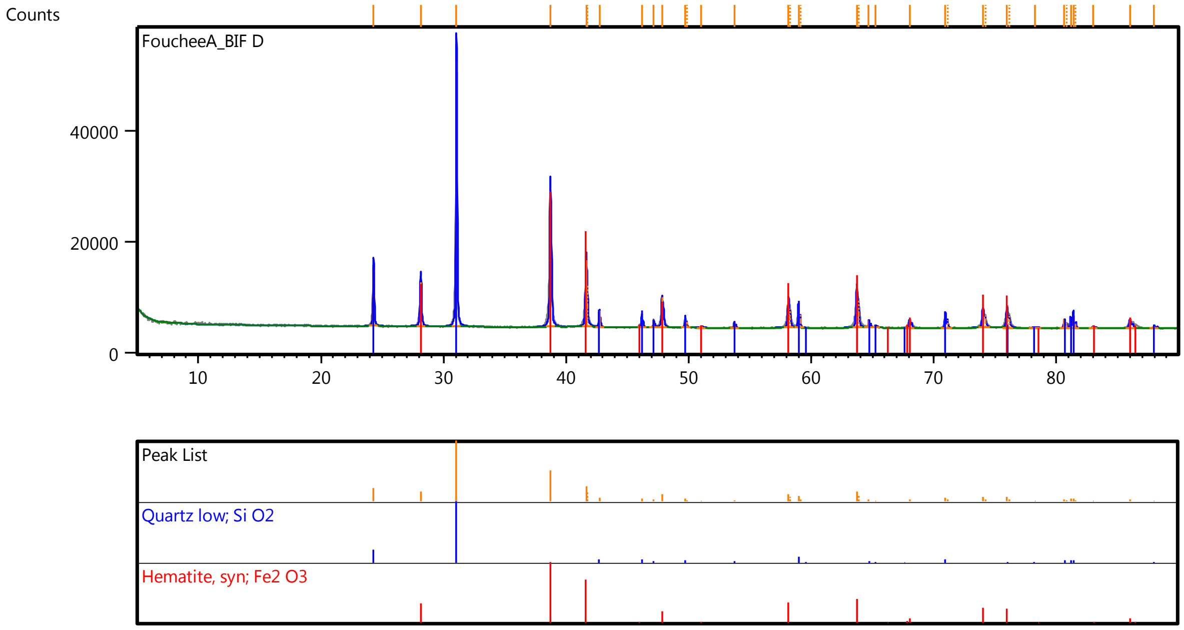
40000
20000
0
10
20
30
40
50
60
70
80
Peak List
Quartz low; Si O2
Hematite, syn; Fe2 O3

BIF7

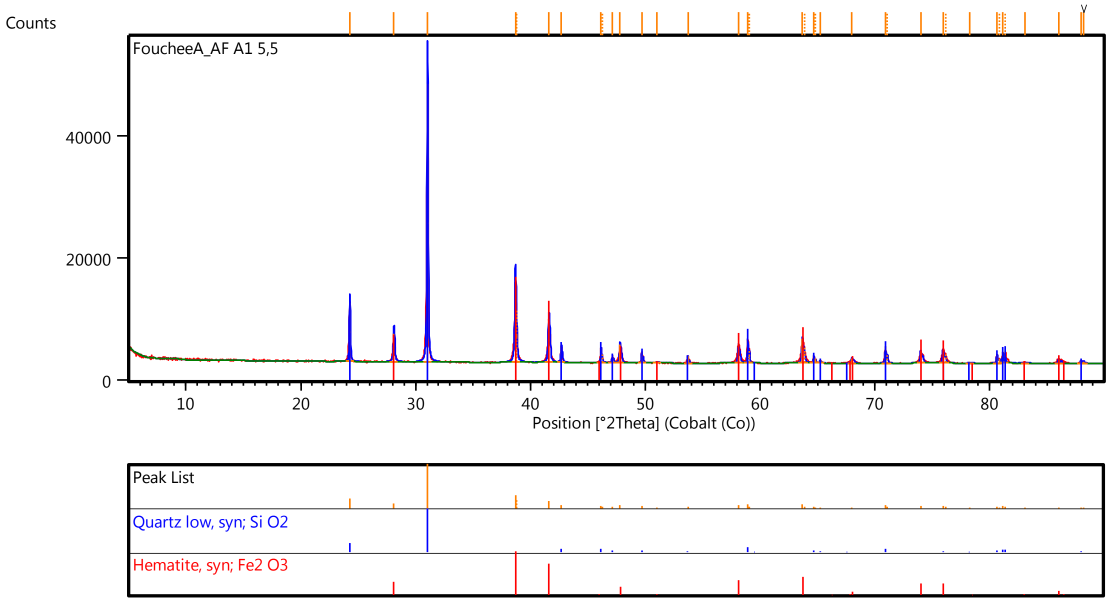

Counts
FoucheeA_BIF D
40000
20000
0
10
20
30
40
50
60
70
80
Peak List
Quartz low; Si O2
Hematite, syn; Fe2 O3

Blended Composite BIF Samples (Quantitative XRD)

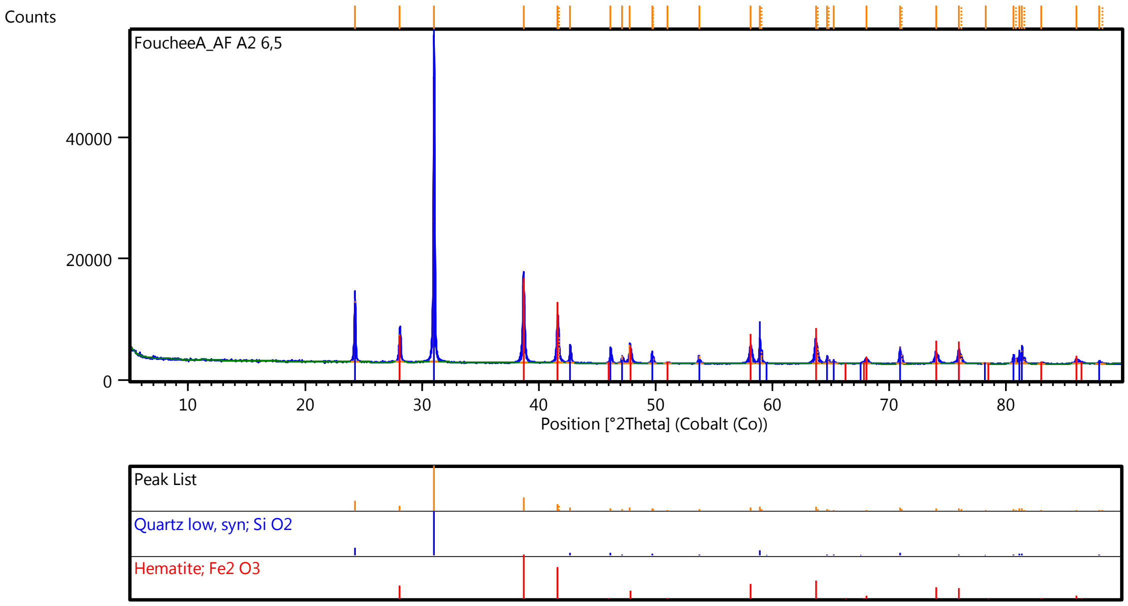
	Composite 1	Composite 2	Composite 3	Composite 4	**Average**	3 σ error
Hematite wt. %	48.06	46.81	47.26	48.06	47.54	0.42
Quartz wt.%	51.94	53.19	52.74	51.94	52.45	0.42

Blended Composite BIF Samples (Qualitative XRD)

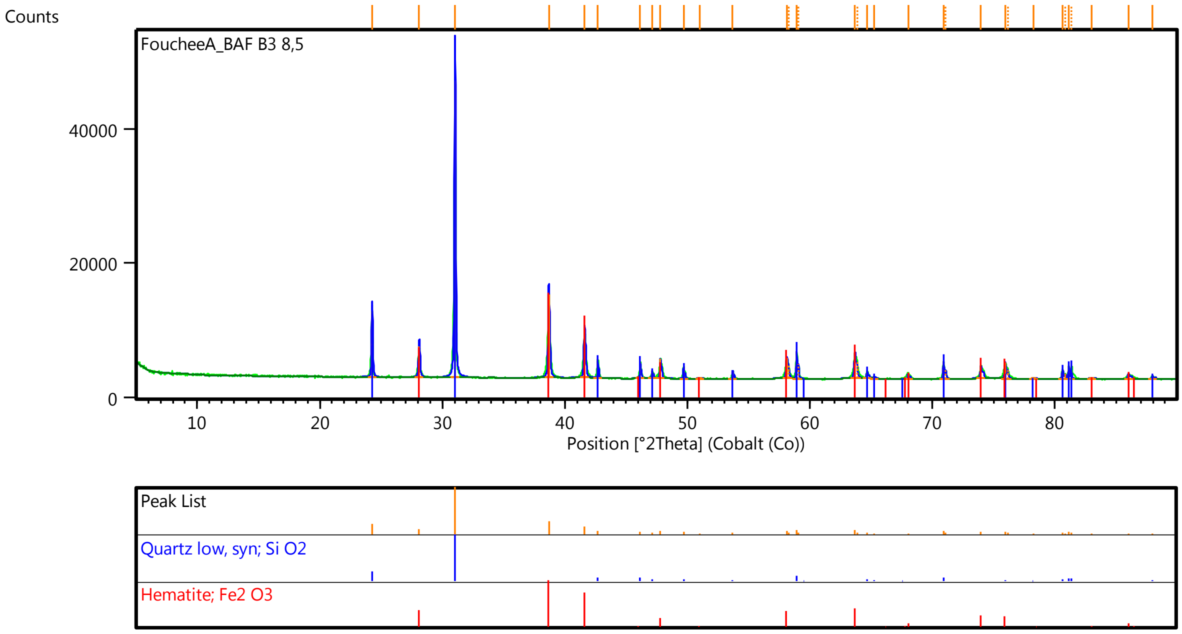
Composite 1



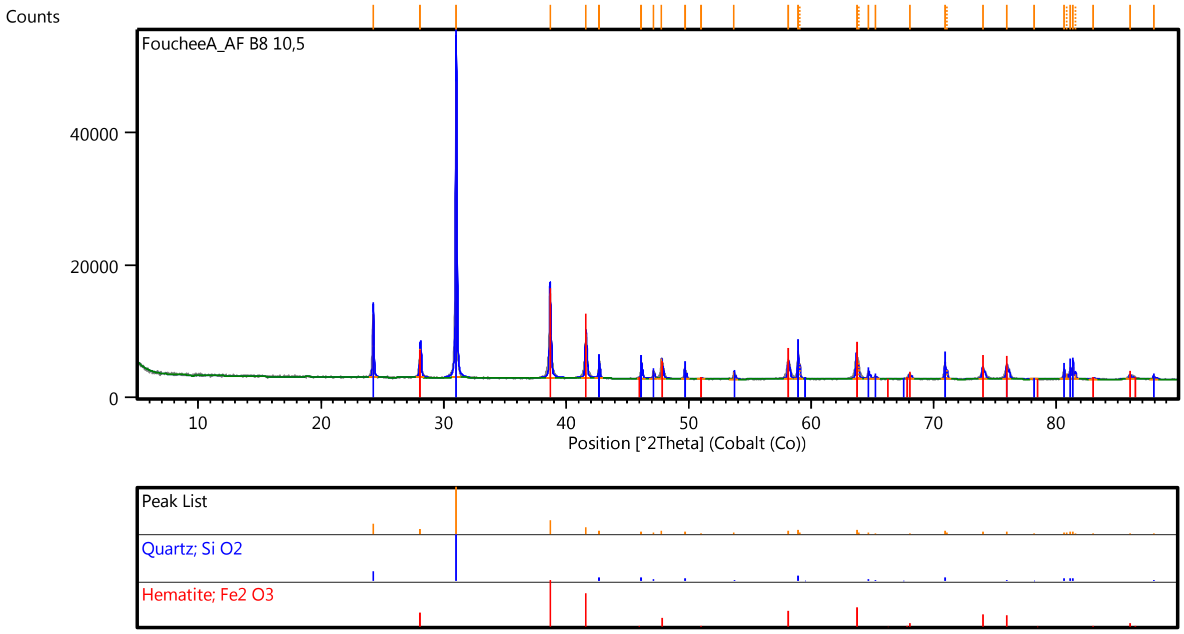
Composite 2



Composite 3



Composite 4

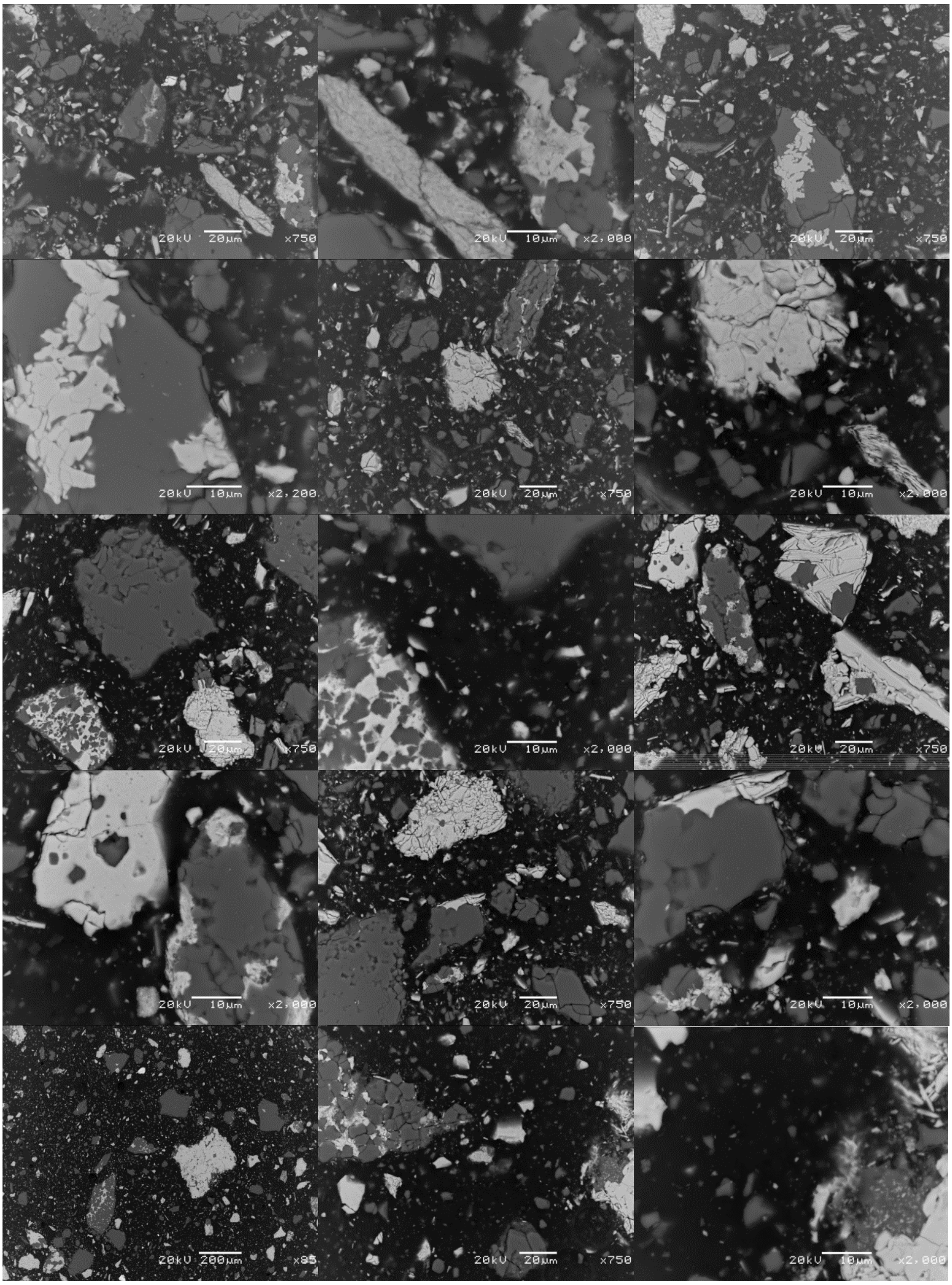


Quantitative Mineralogical analysis results for blended composite BIF ore

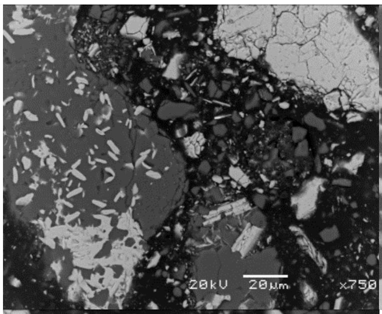
	Composite 1	Composite 2	Composite 3	Composite 4	Ave. wt.%	Var.
Hematite wt.%	48.06	46.81	47.26	48.06	47.55	0.384
Quartz wt.%	51.94	53.19	52.74	51.94	52.45	0.384

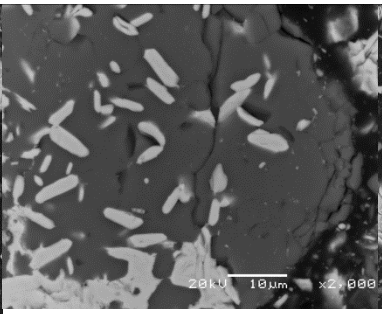
Appendix 5: SEM

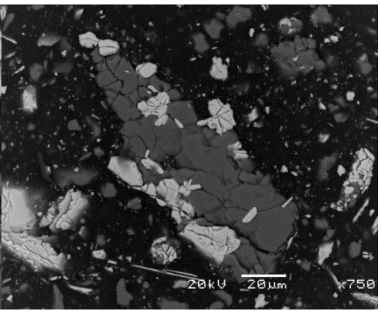
Feed

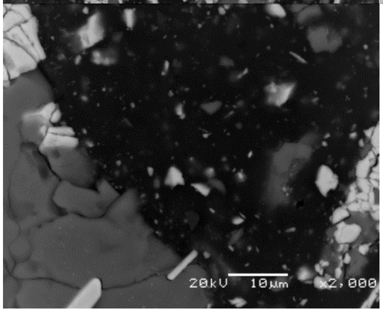


Feed (Continued)

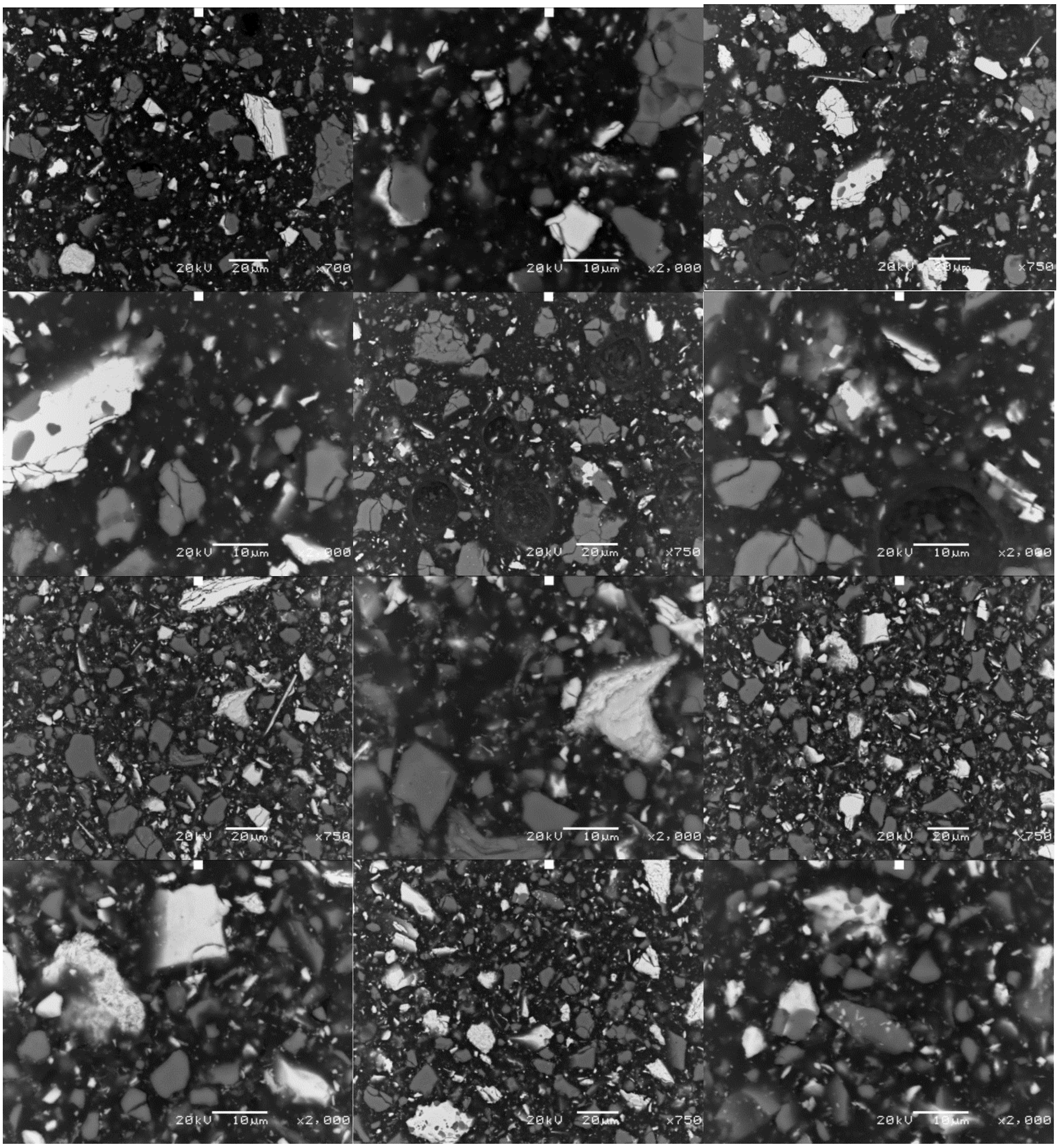




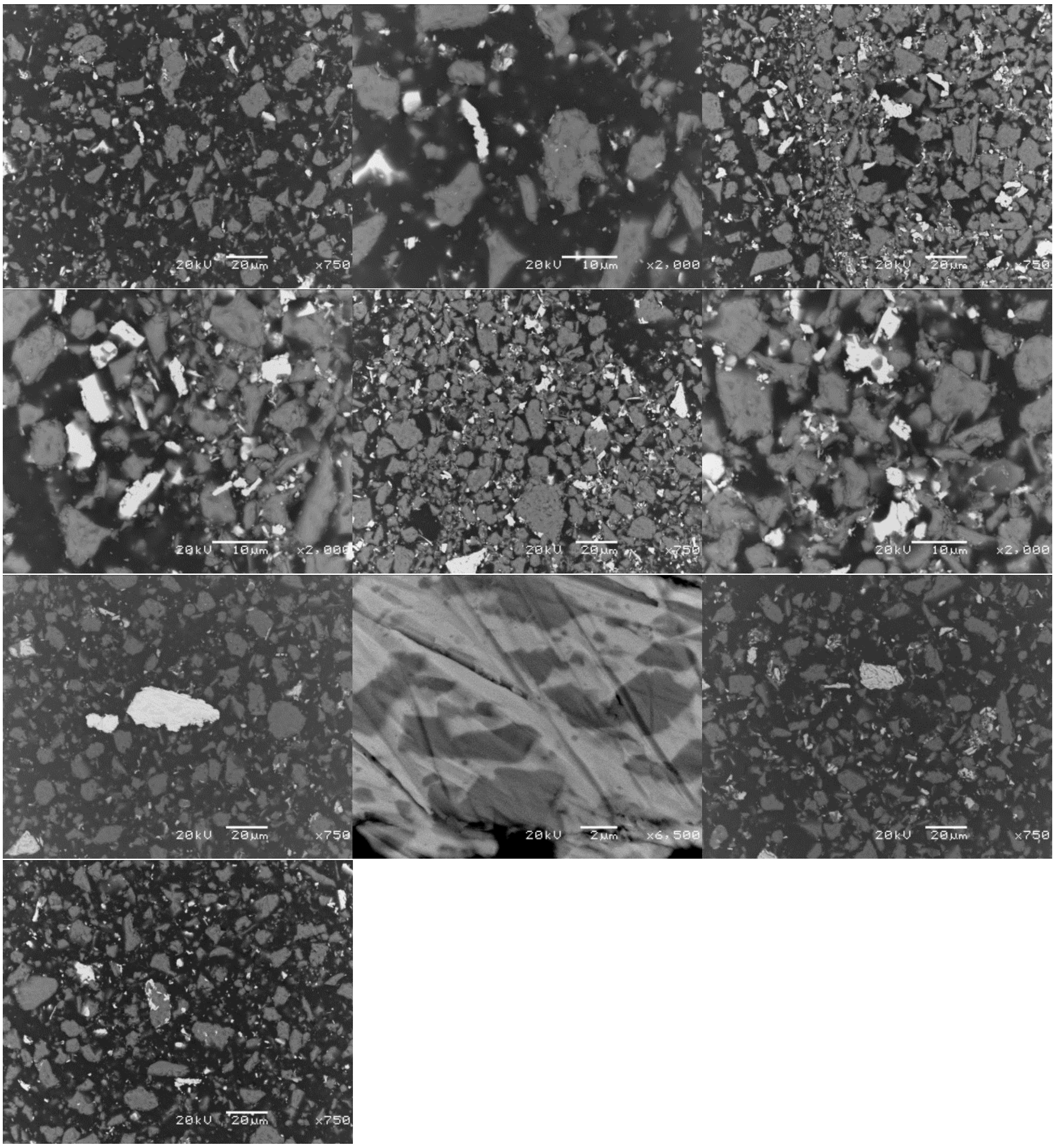




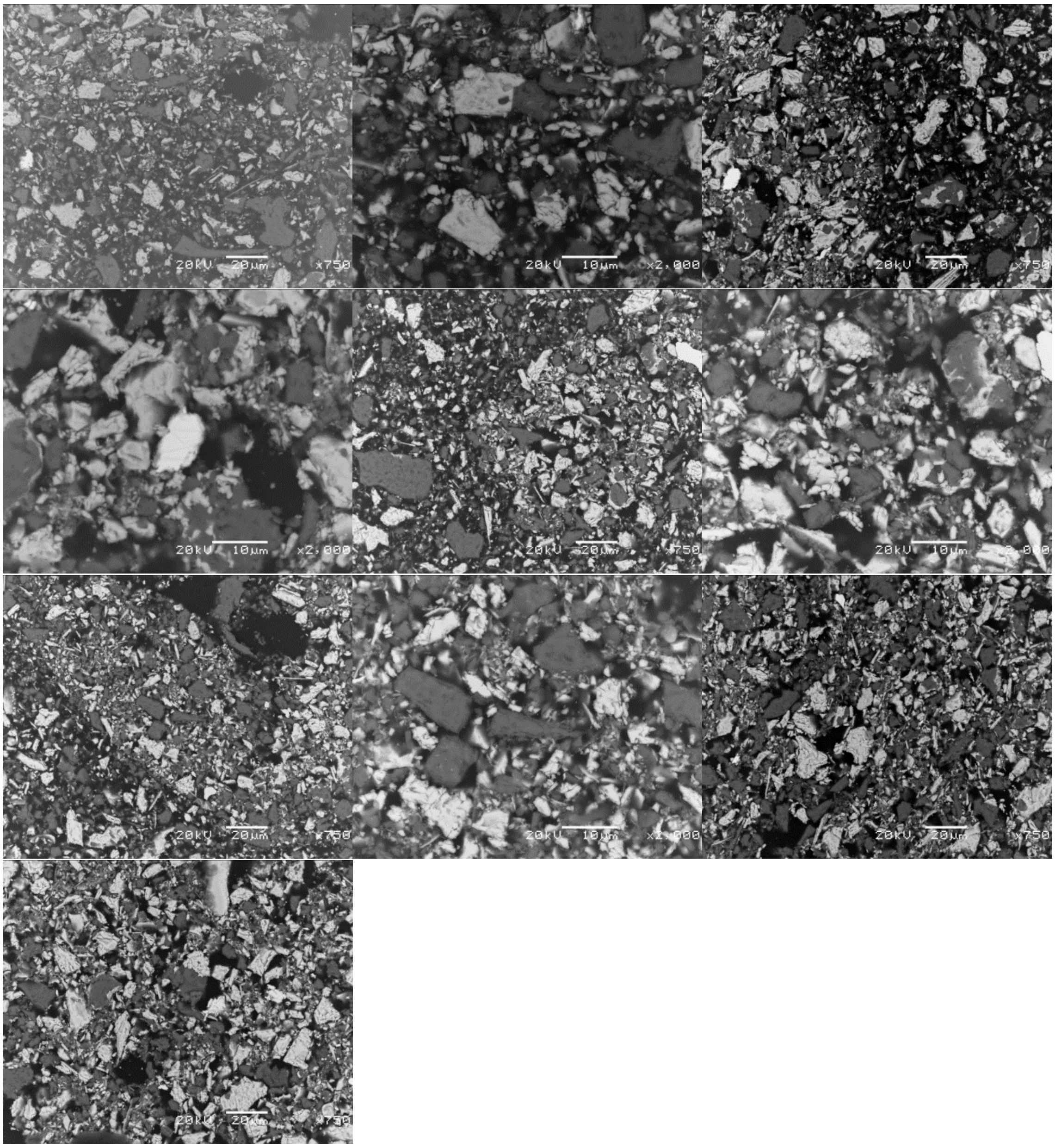
Milled Feed


20kV 20µm x700
20kV 10µm x2,000
20kV 20µm x750
20kV 10µm 000
20kV 20µm x750
20kV 10µm x2,000
20kV 20µm x750
20kV 10µm x2,000
20kV 20µm x750
20kV 10µm x2,000
20kV 20µm x750
20kV 10µm x2,000

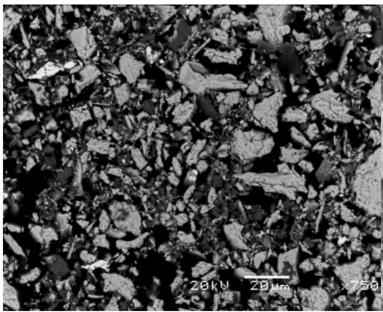
Overflow 1

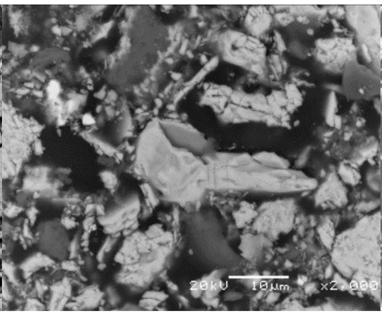

20kV 20µm x750
20kV 10µm x2,000
20kV 20µm x750
20kV 10µm x2,000
20kV 20µm x750
20kV 10µm x2,000
20kV 20µm x750
20kV 2µm x6,500
20kV 20µm x750
20kV 20µm x750

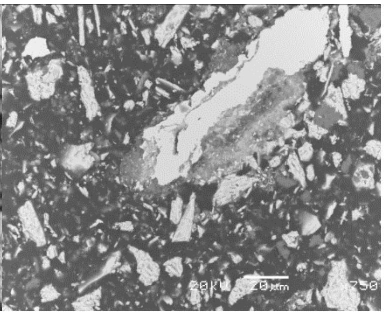
Overflow 6

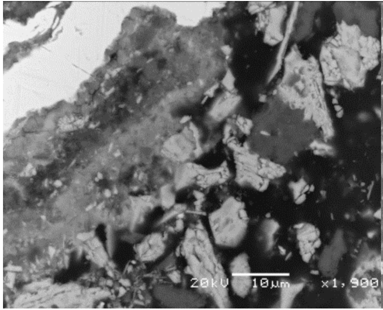

20kV 20µm x750
20kV 10µm x2,000
20kV 20µm x750
20kV 10µm x2,000
20kV 20µm x750
20kV 10µm x2,000
20kV 20µm x750
20kV 10µm x2,000
20kV 20µm x750
20kV 20µm x750

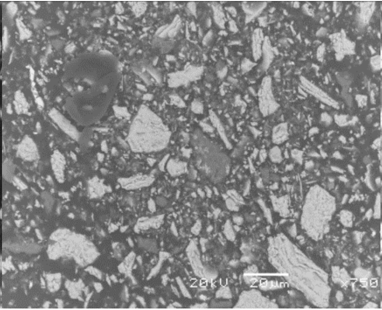
Iron Concentrate

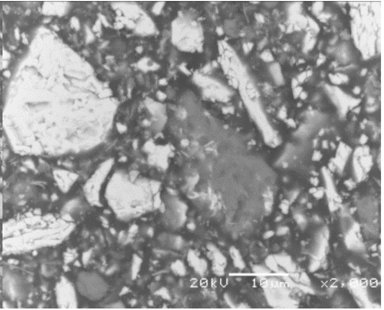


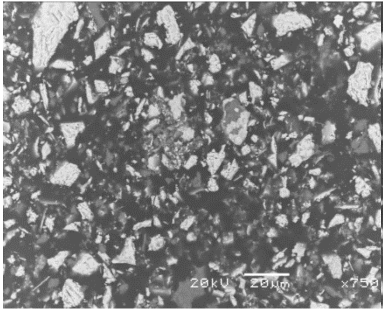


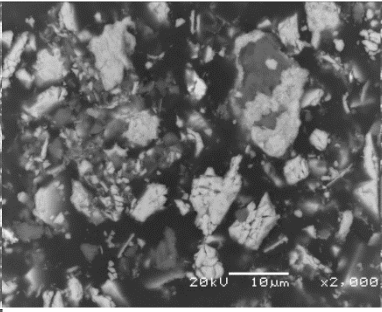


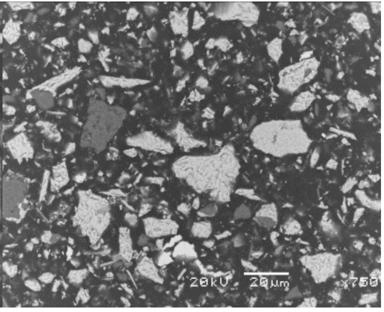


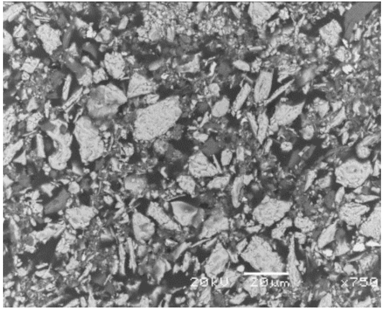












Appendix 6: Variation in Sample Weight from Ore Preparation

Variation in Sample Weight of initial bulk BIF sample split

BIF Ore Type	Ave Split sample weight (g)	Std dev	% Error on Sample Weight
AF BIF 020911.4	1000.52	15.66	1.57
AF BIF 020911.2	1006.89	8.54	0.85
AF BIF 020911.1	1020.62	19.26	1.89
AF BIF 020911.3	1015.80	22.80	2.24
AF BIF 110806.3	1037.55	17.78	1.71
AF BIF 110806.6	1035.53	20.38	1.97
AF BIF 110806.9	1044.40	20.20	1.93
AF BIF 110806.10	1042.31	23.06	2.21
AF BIF 621206.10	1032.22	7.97	0.77
AF BIF 621206.1	1040.40	16.33	1.57
AF BIF 621206.7	1036.82	16.97	1.64
AF BIF 621206.8	1010.62	24.92	2.47
AF BIF 571407.5	1030.75	9.01	0.87
AF BIF 571407.6	1002.63	19.96	1.99
AF BIF 571407.2	1040.40	21.53	2.07
AF BIF 571407.3	1033.81	9.54	0.92
AF BIF 381007.9	937.77	10.53	1.12
AF BIF 381007.5	973.97	6.16	0.63
AF BIF 381007.8	1036.17	20.75	2.00
AF BIF 381007.10	1001.57	17.49	1.75
AF BIF 921112.1	1000.54	7.39	0.74
AF BIF 921112.5	1017.31	8.56	0.84
AF BIF 921112.3	996.74	16.89	1.69
AF BIF 921112.7	1026.73	10.27	1.00
AF BIF 260634.1	1077.00	10.45	0.97
AF BIF 260634.9	1067.65	9.89	0.93
AF BIF 260634.3	1082.15	10.17	0.94
AF BIF 260634.4	1100.47	7.13	0.65

Appendix 7: Flotation Test Data

Depressant Type Evaluation

Cationic Reverse Fe Flotation **Test A1.1** NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 75 g/t, Flotigram 2L 75 g/t, Dextrin 400g/t
Grind:	80% -45µm
Water Type:	Sishen (Synthetic)
Cell pH:	3

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative M	Grade		Recovery	
			Fe	SiO$_2$	Fe	SiO$_2$							Fe	SiO$_2$	Fe	SiO$_2$
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	31.88	52.67	100	100
SiO$_2$ Rougher Conc 1	10.59	1.47	20.47	66.68	0.94	1.86	0.94	20.47	1.86	66.68	Recalc Tai	98.53	32.05	52.46	99.06	98.14
SiO$_2$ Rougher Conc 2	13.94	1.94	28.28	55.54	1.72	2.04	2.66	24.91	3.90	60.35	Recalc Tai	96.59	32.12	52.40	97.34	96.10
SiO$_2$ Rougher Conc 3	43.57	6.05	30.23	54.20	5.73	6.22	8.40	28.31	10.13	56.42	Recalc Tai	90.55	32.25	52.28	91.60	89.87
SiO$_2$ Rougher Conc 4	63.00	8.75	34.37	48.71	9.43	8.09	17.82	31.22	18.21	52.71	Recalc Tai	81.80	32.02	52.66	82.18	81.79
SiO$_2$ Rougher Conc 5	69.33	9.62	36.54	45.83	11.03	8.37	28.86	33.06	26.59	50.33	Recalc Tai	72.18	31.42	53.58	71.14	73.41
SiO$_2$ Rougher Conc 6	72.07	10.00	38.18	43.69	11.98	8.30	40.84	34.41	34.88	48.58	Recalc Tai	62.17	30.33	55.17	59.16	65.12
SiO$_2$ Rougher Concentrate	272.50	37.83	**34.41**	**48.58**	40.84	34.88	40.84	34.41	34.88	48.58						
SiO$_2$ Rougher Tailings	447.89	62.17	30.33	55.17	59.16	65.12	59.16	30.33	65.12	55.17						
Total	720.39	100.00	31.88	52.67	100.00	100.00	100.00		100.00							
Call Factor			0.98	1.02												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.03	0.60	0.00	0.03	0.03	0.04	0.08	0.04	0.03
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A1.2** NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 75 g/t, Flotigram 2L 75 g/t, Dextrin 400g/t
Grind:	80% -45µm
Water Type:	Sishen (Synthetic)
Cell pH:	5

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative M	Grade		Recovery	
			Fe	SiO$_2$	Fe	SiO$_2$							Fe	SiO$_2$	Fe	SiO$_2$
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	32.46	51.79	100	100
SiO$_2$ Rougher Conc 1	10.58	1.51	17.00	72.46	0.79	2.12	0.79	17.00	2.12	72.46	Recalc Tai	98.49	32.70	51.47	99.21	97.88
SiO$_2$ Rougher Conc 2	42.07	6.02	14.99	76.45	2.78	8.89	3.57	15.40	11.00	75.65	Recalc Tai	92.47	33.85	49.84	96.43	89.00
SiO$_2$ Rougher Conc 3	104.14	14.90	18.53	71.95	8.51	20.70	12.08	17.48	31.70	73.19	Recalc Tai	77.57	36.79	45.60	87.92	68.30
SiO$_2$ Rougher Conc 4	104.17	14.90	26.57	60.31	12.20	17.36	24.28	21.11	49.06	68.05	Recalc Tai	62.67	39.23	42.10	75.72	50.94
SiO$_2$ Rougher Conc 5	98.33	14.07	29.44	56.23	12.76	15.27	37.03	23.39	64.33	64.81	Recalc Tai	48.60	42.06	38.00	62.97	35.67
SiO$_2$ Rougher Conc 6	62.16	8.89	40.82	39.76	11.18	6.83	48.21	25.96	71.16	61.12	Recalc Tai	39.71	42.34	37.61	51.79	28.84
SiO$_2$ Rougher Concentrate	421.45	60.29	**25.96**	**61.12**	48.21	71.16	48.21	25.96	71.16	61.12						
SiO$_2$ Rougher Tailings	277.54	39.71	42.34	37.61	51.79	28.84	51.79	42.34	28.84	37.61						
Total	698.99	100.00	32.46	51.79	100.00	100.00	100.00		100.00							
Call Factor			1.00	1.00												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.06	0.63	0.00	0.03	0.04	0.04	0.12	0.05	0.06
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A1.3** NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 75 g/t, Flotigram 2L 75 g/t, Dextrin 400g/t
Grind:	80% -45µm
Water Type:	Sishen (Synthetic)
Cell pH:	9

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative M	Grade		Recovery	
			Fe	SiO$_2$	Fe	SiO$_2$							Fe	SiO$_2$	Fe	SiO$_2$
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	33.10	50.75	100	100
SiO$_2$ Rougher Conc 1	66.69	9.13	11.06	82.74	3.05	14.88	3.05	11.06	14.88	82.74	Recalc Tai	90.87	35.31	47.54	96.95	85.12
SiO$_2$ Rougher Conc 2	101.96	13.95	13.41	79.44	5.65	21.84	8.71	12.48	36.72	80.74	Recalc Tai	76.92	39.29	41.76	91.29	63.28
SiO$_2$ Rougher Conc 3	108.03	14.78	16.98	74.31	7.58	21.65	16.29	14.24	58.36	78.23	Recalc Tai	62.13	44.60	34.01	83.71	41.64
SiO$_2$ Rougher Conc 4	73.51	10.06	20.80	68.71	6.32	13.62	22.61	15.61	71.98	76.23	Recalc Tai	52.07	49.19	27.31	77.39	28.02
SiO$_2$ Rougher Conc 5	42.95	5.88	25.46	61.89	4.52	7.17	27.13	16.69	79.15	74.66	Recalc Tai	46.20	52.21	22.91	72.87	20.85
SiO$_2$ Rougher Conc 6	45.25	6.19	30.76	54.19	5.76	6.61	32.88	18.14	85.76	72.55	Recalc Tai	40.00	55.53	18.06	67.12	14.24
SiO$_2$ Rougher Concentrate	438.39	60.00	**18.14**	**72.55**	32.88	85.76	32.88	18.14	85.76	72.55						
SiO$_2$ Rougher Tailings	292.30	40.00	55.53	18.06	67.12	14.24	67.12	55.53	14.24	18.06						
Total	730.69	100.00	33.10	50.75	100.00	100.00	100.00		100.00							
Call Factor			1.02	0.98												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.08	0.83	0.01	0.04	0.07	0.07	0.16	0.09	0.10
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A1.4**

NORMALISED DATA

Ore Type: BIF Composite — BIF Composite
Reagent Suite: — EDA3 75 g/t, Flotigram 2L 75 g/t, Starch 400g/t
Grind: — 80% -45µm
Water Type: — Sishen (Synthetic)
Cell pH: — 3

Stream	**Mass**	**Mass**	**Grade**		**Recovery**		**um Reco**	**Cum Gra**	**Cum Reco**	**Cum Grade**	**Cummilative I**		**Grade**		**Recovery**	
			Fe	**SiO$_2$**	**Fe**	**SiO$_2$**							**Fe**	**SiO$_2$**	**Fe**	**SiO$_2$**
	(g)	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**		**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
Head Sample			32.48	51.76							Recalc Fe	100	31.56	53.15	100	100
SiO$_2$ Rougher Conc 1	6.77	0.93	38.78	38.98	1.14	0.68	1.14	38.78	0.68	38.98	Recalc Tai	99.07	31.49	53.28	98.86	99.32
SiO$_2$ Rougher Conc 2	22.45	3.07	33.99	47.54	3.31	2.75	4.45	35.10	3.43	45.56	Recalc Tai	96.00	31.41	53.46	95.55	96.57
SiO$_2$ Rougher Conc 3	36.59	5.01	35.76	45.98	5.68	4.33	10.13	35.47	7.76	45.79	Recalc Tai	90.99	31.17	53.87	89.87	92.24
SiO$_2$ Rougher Conc 4	60.22	8.25	37.66	43.97	9.84	6.82	19.97	36.52	14.59	44.92	Recalc Tai	82.74	30.53	54.86	80.03	85.41
SiO$_2$ Rougher Conc 5	82.57	11.31	34.90	48.30	12.50	10.28	32.47	35.88	24.86	46.26	Recalc Tai	71.44	29.84	55.90	67.53	75.14
SiO$_2$ Rougher Conc 6	87.02	11.92	35.36	47.83	13.35	10.72	45.82	35.73	35.59	46.72	Recalc Tai	59.52	28.73	57.51	54.18	64.41
SiO$_2$ Rougher Concentrate	295.62	40.48	**35.73**	**46.72**	45.82	35.59	45.82	35.73	35.59	46.72						
SiO$_2$ Rougher Tailings	434.70	59.52	28.73	57.51	54.18	64.41	54.18	28.73	64.41	57.51						
Total	730.32	100.00	31.56	53.15	100.00	100.00	100.00		100.00							
Call Factor			0.97	1.03												

	K2O	**Al2O3**	**Na2O**	**MgO**	**P2O5**	**SO3**	**MnO**	**TiO2**	**CaO**
	(%)	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
Fe Concentrate	0.04	0.59	0.00	0.03	0.02	0.04	0.08	0.03	0.03
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A1.5**

NORMALISED DATA

Ore Type: BIF Composite — BIF Composite
Reagent Suite: — EDA3 75 g/t, Flotigram 2L 75 g/t, Starch 400g/t
Grind: — 80% -45µm
Water Type: — Sishen (Synthetic)
Cell pH: — 5

Stream	**Mass**	**Mass**	**Grade**		**Recovery**		**um Reco**	**Cum Gra**	**Cum Reco**	**Cum Grade**	**Cummilative I**		**Grade**		**Recovery**	
			Fe	**SiO$_2$**	**Fe**	**SiO$_2$**							**Fe**	**SiO$_2$**	**Fe**	**SiO$_2$**
	(g)	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**		**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
Head Sample			32.48	51.76							Recalc Fe	100	32.79	51.31	100	100
SiO$_2$ Rougher Conc 1	46.03	6.14	15.23	76.07	2.85	9.10	2.85	15.23	9.10	76.07	Recalc Tai	93.86	33.94	49.70	97.15	90.90
SiO$_2$ Rougher Conc 2	68.26	9.10	17.15	73.71	4.76	13.07	7.61	16.38	22.17	74.66	Recalc Tai	84.76	35.74	47.12	92.39	77.83
SiO$_2$ Rougher Conc 3	60.46	8.06	27.01	59.31	6.64	9.32	14.25	20.05	31.49	69.35	Recalc Tai	76.70	36.66	45.84	85.75	68.51
SiO$_2$ Rougher Conc 4	132.68	17.69	27.63	58.87	14.90	20.29	29.15	23.32	51.78	64.83	Recalc Tai	59.01	39.37	41.93	70.85	48.22
SiO$_2$ Rougher Conc 5	128.43	17.12	31.37	53.54	16.38	17.86	45.53	25.70	69.64	61.50	Recalc Tai	41.89	42.64	37.18	54.47	30.36
SiO$_2$ Rougher Conc 6	73.77	9.83	42.16	37.90	12.64	7.26	58.18	28.08	76.91	58.09	Recalc Tai	32.06	42.79	36.96	41.82	23.09
SiO$_2$ Rougher Concentrate	509.63	67.94	**28.08**	**58.09**	58.18	76.91	58.18	28.08	76.91	58.09						
SiO$_2$ Rougher Tailings	240.45	32.06	42.79	36.96	41.82	23.09	41.82	42.79	23.09	36.96						
Total	750.08	100.00	32.79	51.31	100.00	100.00	100.00		100.00							
Call Factor			1.01	0.99												

	K2O	**Al2O3**	**Na2O**	**MgO**	**P2O5**	**SO3**	**MnO**	**TiO2**	**CaO**
	(%)	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
Fe Concentrate	0.07	0.61	0.01	0.03	0.04	0.04	0.12	0.05	0.06
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A1.6**

NORMALISED DATA

Ore Type: BIF Composite — BIF Composite
Reagent Suite: — EDA3 75 g/t, Flotigram 2L 75 g/t,Starch 400g/t
Grind: — 80% -45µm
Water Type: — Sishen (Synthetic)
Cell pH: — 9

Stream	**Mass**	**Mass**	**Grade**		**Recovery**		**um Reco**	**Cum Gra**	**Cum Reco**	**Cum Grade**	**Cummilative I**		**Grade**		**Recovery**	
			Fe	**SiO$_2$**	**Fe**	**SiO$_2$**							**Fe**	**SiO$_2$**	**Fe**	**SiO$_2$**
	(g)	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**		**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
Head Sample			32.48	51.76							Recalc Fe	100	33.43	50.30	100	100
SiO$_2$ Rougher Conc 1	87.13	13.49	13.75	78.85	5.55	21.14	5.55	13.75	21.14	78.85	Recalc Tai	86.51	36.50	45.85	94.45	78.86
SiO$_2$ Rougher Conc 2	121.94	18.88	17.08	74.10	9.64	27.81	15.19	15.69	48.95	76.08	Recalc Tai	67.64	41.92	37.97	84.81	51.05
SiO$_2$ Rougher Conc 3	105.61	16.35	21.87	67.15	10.69	21.82	25.88	17.76	70.77	73.09	Recalc Tai	51.29	48.32	28.67	74.12	29.23
SiO$_2$ Rougher Conc 4	61.85	9.57	29.06	56.63	8.32	10.78	34.20	19.62	81.55	70.38	Recalc Tai	41.71	52.74	22.25	65.80	18.45
SiO$_2$ Rougher Conc 5	45.89	7.10	38.03	43.53	8.08	6.15	42.28	21.62	87.70	67.47	Recalc Tai	34.61	55.76	17.88	57.72	12.30
SiO$_2$ Rougher Conc 6	47.85	7.41	46.17	31.78	10.23	4.68	52.51	24.12	92.38	63.84	Recalc Tai	27.20	58.37	14.09	47.49	7.62
SiO$_2$ Rougher Concentrate	470.27	72.80	**24.12**	**63.84**	52.51	92.38	52.51	24.12	92.38	63.84						
SiO$_2$ Rougher Tailings	175.73	27.20	58.37	14.09	47.49	7.62	47.49	58.37	7.62	14.09						
Total	646.00	100.00	33.43	50.30	100.00	100.00	100.00		100.00							
Call Factor			1.03	0.97												

	K2O	**Al2O3**	**Na2O**	**MgO**	**P2O5**	**SO3**	**MnO**	**TiO2**	**CaO**
	(%)	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
Fe Concentrate	0.06	0.69	0.00	0.04	0.07	0.08	0.17	0.10	0.12
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

NORMALISED DATA

Cationic Reverse Fe Flotation **Test A1.7**

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 75 g/t, Flotigram 2L 75 g/t
Grind:	80% -45µm
Water Type:	Sishen (Synthetic)
Cell pH:	3

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative M	Grade		Recovery	
			Fe	SiO_2	Fe	SiO_2							Fe	SiO_2	Fe	SiO_2
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	31.98	52.50	100	100
SiO_2 Rougher Conc 1	12.98	1.89	28.38	55.71	1.68	2.01	1.68	28.38	2.01	55.71	Recalc Tai	98.11	32.05	52.44	98.32	97.99
SiO_2 Rougher Conc 2	29.16	4.25	27.57	57.82	3.66	4.68	5.34	27.82	6.69	57.17	Recalc Tai	93.86	32.26	52.19	94.66	93.31
SiO_2 Rougher Conc 3	44.47	6.48	32.15	51.70	6.51	6.38	11.86	30.04	13.07	54.36	Recalc Tai	87.38	32.26	52.23	88.14	86.93
SiO_2 Rougher Conc 4	63.53	9.26	31.50	53.02	9.12	9.35	20.97	30.66	22.42	53.79	Recalc Tai	78.12	32.35	52.14	79.03	77.58
SiO_2 Rougher Conc 5	73.22	10.67	34.84	48.36	11.62	9.83	32.60	32.03	32.25	52.01	Recalc Tai	67.45	31.96	52.73	67.40	67.75
SiO_2 Rougher Conc 6	82.74	12.06	37.18	45.09	14.02	10.36	46.61	33.42	42.61	50.14	Recalc Tai	55.39	30.83	54.40	53.39	57.39
SiO_2 Rougher Concentrate	306.10	44.61	**33.42**	**50.14**	46.61	42.61	46.61	33.42	42.61	50.14						
SiO_2 Rougher Tailings	380.07	55.39	30.83	54.40	53.39	57.39	53.39	30.83	57.39	54.40						
Total	686.17	100.00	31.98	52.50	100.00	100.00	100.00		100.00							
Call Factor			0.98	1.01												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.06	0.62	0.00	0.03	0.03	0.03	0.08	0.04	0.04
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

NORMALISED DATA

Cationic Reverse Fe Flotation **Test A1.8**

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 75 g/t, Flotigram 2L 75 g/t
Grind:	80% -45µm
Water Type:	Sishen (Synthetic)
Cell pH:	5

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative M	Grade		Recovery	
			Fe	SiO_2	Fe	SiO_2							Fe	SiO_2	Fe	SiO_2
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	33.00	51.02	100	100
SiO_2 Rougher Conc 1	42.60	6.33	12.23	80.72	2.34	10.01	2.34	12.23	10.01	80.72	Recalc Tai	93.67	34.40	49.01	97.66	89.99
SiO_2 Rougher Conc 2	96.47	14.33	16.26	75.16	7.06	21.11	9.40	15.02	31.12	76.86	Recalc Tai	79.35	37.68	44.29	90.60	68.88
SiO_2 Rougher Conc 3	132.31	19.65	21.12	68.20	12.58	26.27	21.98	18.00	57.39	72.64	Recalc Tai	59.69	43.13	36.42	78.02	42.61
SiO_2 Rougher Conc 4	137.71	20.45	29.44	56.24	18.25	22.54	40.23	21.85	79.93	67.12	Recalc Tai	39.24	50.26	26.09	59.77	20.07
SiO_2 Rougher Conc 5	91.28	13.56	39.40	41.84	16.19	11.12	56.42	25.05	91.05	62.51	Recalc Tai	25.69	55.99	17.78	43.58	8.95
SiO_2 Rougher Conc 6	44.27	6.57	57.23	16.03	11.40	2.07	67.82	27.67	93.12	58.73	Recalc Tai	19.11	55.56	18.38	32.18	6.88
SiO_2 Rougher Concentrate	544.64	80.89	**27.67**	**58.73**	67.82	93.12	67.82	27.67	93.12	58.73						
SiO_2 Rougher Tailings	128.67	19.11	55.56	18.38	32.18	6.88	32.18	55.56	6.88	18.38						
Total	673.31	100.00	33.00	51.02	100.00	100.00	100.00		100.00							
Call Factor			1.02	0.99												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.06	0.61	0.00	0.03	0.05	0.06	0.17	0.07	0.06
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

NORMALISED DATA

Cationic Reverse Fe Flotation **Test A1.9**

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 75 g/t, Flotigram 2L 75 g/t
Grind:	80% -45µm
Water Type:	Sishen (Synthetic)
Cell pH:	9

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative M	Grade		Recovery	
			Fe	SiO_2	Fe	SiO_2							Fe	SiO_2	Fe	SiO_2
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	33.39	50.36	100	100
SiO_2 Rougher Conc 1	70.30	10.28	13.22	79.66	4.07	16.25	4.07	13.22	16.25	79.66	Recalc Tai	89.72	35.70	47.01	95.93	83.75
SiO_2 Rougher Conc 2	106.95	15.63	15.75	76.07	7.37	23.61	11.44	14.75	39.87	77.49	Recalc Tai	74.09	39.91	40.87	88.56	60.13
SiO_2 Rougher Conc 3	106.74	15.60	20.51	69.14	9.58	21.42	21.03	16.91	61.29	74.36	Recalc Tai	58.49	45.08	33.33	78.97	38.71
SiO_2 Rougher Conc 4	91.67	13.40	27.35	59.22	10.97	15.76	32.00	19.46	77.04	70.66	Recalc Tai	45.09	50.35	25.64	68.00	22.96
SiO_2 Rougher Conc 5	80.44	11.76	36.93	45.28	13.01	10.57	45.01	22.54	87.61	66.18	Recalc Tai	33.33	55.08	18.71	54.99	12.39
SiO_2 Rougher Conc 6	64.05	9.36	48.17	28.94	13.51	5.38	58.51	25.70	92.99	61.60	Recalc Tai	23.97	57.78	14.72	41.49	7.01
SiO_2 Rougher Concentrate	520.15	76.03	**25.70**	**61.60**	58.51	92.99	58.51	25.70	92.99	61.60						
SiO_2 Rougher Tailings	164.00	23.97	57.78	14.72	41.49	7.01	41.49	57.78	7.01	14.72						
Total	684.15	100.00	33.39	50.36	100.00	100.00	100.00		100.00							
Call Factor			1.03	0.97												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.09	0.83	0.01	0.04	0.08	0.09	0.18	0.11	0.12
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A1.a**

NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 75 g/t, Flotigram 2L 75 g/t, Starch 400g/t
Grind:	80% -45µm
Water Type:	Sishen (Synthetic)
Cell pH:	9

Stream	Mass	Mass	Grade		Recovery		Fe Cum Recovery	Fe Cum Grade	SiO_2 Cum Recovery	SiO_2 Cum Grade		Cum Mass	Grade		Recovery	
			Fe	SiO_2	Fe	SiO_2							Fe	SiO_2	Fe	SiO_2
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Feed	100	32.63	51.19	100	100
SiO_2 Rougher Conc 1	95.37	14.24	13.59	78.74	5.93	21.90	5.93	13.59	21.90	78.74	Recalc Tailings 1	85.76	35.79	46.62	94.07	78.10
SiO_2 Rougher Conc 2	127.67	19.06	16.85	74.10	9.84	27.59	15.77	15.46	49.48	76.09	Recalc Tailings 2	66.71	41.20	38.76	84.23	50.52
SiO_2 Rougher Conc 3	105.32	15.72	20.73	68.54	9.99	21.05	25.76	17.15	70.53	73.67	Recalc Tailings 3	50.99	47.51	29.58	74.24	29.47
SiO_2 Rougher Conc 4	65.45	9.77	28.02	57.91	8.39	11.05	34.15	18.96	81.58	71.05	Recalc Tailings 4	41.22	52.13	22.87	65.85	18.42
SiO_2 Rougher Conc 5	49.48	7.39	36.27	45.80	8.21	6.61	42.36	20.89	88.19	68.23	Recalc Tailings 5	33.83	55.59	17.87	57.64	11.81
SiO_2 Rougher Conc 6	51.20	7.64	44.92	33.16	10.52	4.95	52.88	23.38	93.14	64.60	Recalc Tailings 6	26.19	58.71	13.40	47.12	6.86
SiO_2 Rougher Conc 7	50.48	7.53	52.27	22.64	12.07	3.33	64.95	26.05	96.48	60.71	Recalc Tailings 7	18.66	61.31	9.67	35.05	3.52
SiO_2 Rougher Conc 8	46.75	6.98	58.13	14.27	12.43	1.94	77.38	28.59	98.42	57.04	Recalc Tailings 8	11.68	63.21	6.93	22.62	1.58
SiO_2 Rougher Conc 9	28.90	4.31	61.72	9.16	8.16	0.77	85.54	30.13	99.19	54.81	Recalc Tailings 9	7.36	64.09	5.62	14.46	0.81
SiO_2 Rougher Concentrate	620.62	92.64	**30.13**	**54.81**	85.54	99.19	85.54	30.13	99.19	54.81						
SiO_2 Rougher Tailings	49.34	7.36	64.09	5.62	14.46	0.81	14.46	64.09	0.81	5.62						
Total	669.96	100.00	32.63	51.19	100.00	100.00	100.00		100.00							
Call Factor			1.00	0.99												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.04	0.51	0.00	0.03	0.10	0.13	0.35	0.16	0.18
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A1.b**

NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 75 g/t, Flotigram 2L 75 g/t, Starch 400g/t
Grind:	80% -45µm
Water Type:	Sishen (Synthetic)
Cell pH:	7

Stream	Mass	Mass	Grade		Recovery		um Reco	Cum Gra	Cum Reco	$_2$ Cum Grade	Cummilative		Grade		Recovery	
			Fe	SiO_2	Fe	SiO_2							Fe	SiO_2	Fe	SiO_2
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	33.02	50.66	100	100
SiO_2 Rougher Conc 1	108.89	15.73	13.65	78.48	6.50	24.37	6.50	13.65	24.37	78.48	Recalc Tai	84.27	36.64	45.47	93.50	75.63
SiO_2 Rougher Conc 2	140.85	20.35	17.07	73.79	10.52	29.64	17.02	15.58	54.01	75.83	Recalc Tai	63.92	42.87	36.45	82.98	45.99
SiO_2 Rougher Conc 3	104.92	15.16	24.11	63.63	11.07	19.04	28.09	18.10	73.05	72.22	Recalc Tai	48.76	48.70	28.00	71.91	26.95
SiO_2 Rougher Conc 4	97.63	14.11	34.35	48.72	14.67	13.56	42.76	21.61	86.61	67.15	Recalc Tai	34.65	54.55	19.57	57.24	13.39
SiO_2 Rougher Conc 5	96.92	14.00	45.88	31.93	19.46	8.83	62.22	25.89	95.44	60.93	Recalc Tai	20.65	60.42	11.19	37.78	4.56
SiO_2 Rougher Conc 6	58.30	8.42	57.36	15.60	14.63	2.59	76.85	28.91	98.03	56.58	Recalc Tai	12.23	62.53	8.15	23.15	1.97
SiO_2 Rougher Concentrate	607.51	87.77	**28.91**	**56.58**	76.85	98.03	76.85	28.91	98.03	56.58						
SiO_2 Rougher Tailings	84.62	12.23	62.53	8.15	23.15	1.97	23.15	62.53	1.97	8.15						
Total	692.13	100.00	33.02	50.66	100.00	100.00	100.00		100.00							
Call Factor			1.02	0.98												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.05	0.48	0.00	0.03	0.07	0.08	0.28	0.11	0.12
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A1.c**

NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 75 g/t, Flotigram 2L 75 g/t, Starch 400g/t
Grind:	80% -45µm
Water Type:	Sishen (Synthetic)
Cell pH:	11

Stream	Mass	Mass	Grade		Recovery		um Reco	Cum Gra	Cum Reco	$_2$ Cum Grade	Cummilative		Grade		Recovery	
			Fe	SiO_2	Fe	SiO_2							Fe	SiO_2	Fe	SiO_2
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	32.41	51.48	100	100
SiO_2 Rougher Conc 1	17.51	2.49	15.21	76.47	1.17	3.70	1.17	15.21	3.70	76.47	Recalc Tai	97.51	32.85	50.84	98.83	96.30
SiO_2 Rougher Conc 2	50.78	7.21	15.29	76.50	3.40	10.72	4.57	15.27	14.41	76.49	Recalc Tai	90.30	34.25	48.79	95.43	85.59
SiO_2 Rougher Conc 3	43.09	6.12	16.29	75.05	3.08	8.92	7.65	15.67	23.34	75.93	Recalc Tai	84.18	35.55	46.88	92.35	76.66
SiO_2 Rougher Conc 4	41.72	5.93	15.74	75.93	2.88	8.74	10.53	15.69	32.08	75.93	Recalc Tai	78.25	37.06	44.68	89.47	67.92
SiO_2 Rougher Conc 5	46.51	6.61	16.08	75.48	3.28	9.69	13.80	15.78	41.77	75.83	Recalc Tai	71.65	38.99	41.84	86.20	58.23
SiO_2 Rougher Conc 6	38.68	5.49	17.72	73.04	3.00	7.80	16.81	16.09	49.56	75.37	Recalc Tai	66.15	40.76	39.25	83.19	50.44
SiO_2 Rougher Concentrate	238.29	33.85	**16.09**	**75.37**	16.81	49.56	16.81	16.09	49.56	75.37						
SiO_2 Rougher Tailings	465.68	66.15	40.76	39.25	83.19	50.44	83.19	40.76	50.44	39.25						
Total	703.97	100.00	32.41	51.48	100.00	100.00	100.00		100.00							
Call Factor			1.00	0.99												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.14	1.02	0.00	0.04	0.06	0.05	0.14	0.08	0.15
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A1.d**

NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 75 g/t, Flotigram 2L 75 g/t
Grind:	80% -45µm
Water Type:	Sishen (Synthetic)
Cell pH:	7

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO_2	Fe	SiO_2							Fe	SiO_2	Fe	SiO_2
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	32.73	51.09	100	100
SiO_2 Rougher Conc 1	55.22	7.84	13.97	77.79	3.35	11.94	3.35	13.97	11.94	77.79	Recalc Tai	92.16	34.33	48.81	96.65	88.06
SiO_2 Rougher Conc 2	134.04	19.03	18.96	70.92	11.02	26.42	14.37	17.50	38.36	72.92	Recalc Tai	73.13	38.33	43.06	85.63	61.64
SiO_2 Rougher Conc 3	150.64	21.39	22.70	65.62	14.83	27.47	29.20	19.80	65.83	69.69	Recalc Tai	51.74	44.79	33.74	70.80	34.17
SiO_2 Rougher Conc 4	138.16	19.61	31.71	52.61	19.00	20.20	48.20	23.24	86.03	64.75	Recalc Tai	32.13	52.77	22.22	51.80	13.97
SiO_2 Rougher Conc 5	98.43	13.97	43.60	35.41	18.62	9.69	66.82	26.72	95.71	59.74	Recalc Tai	18.16	59.83	12.06	33.18	4.29
SiO_2 Rougher Conc 6	50.05	7.11	55.04	18.93	11.95	2.63	78.77	28.98	98.35	56.48	Recalc Tai	11.05	62.90	7.64	21.23	1.65
SiO_2 Rougher Concentrate	626.54	88.95	**28.98**	**56.48**	78.77	98.35	78.77	28.98	98.35	56.48						
SiO_2 Rougher Tailings	77.83	11.05	62.90	7.64	21.23	1.65	21.23	62.90	1.65	7.64						
Total	704.37	100.00	32.73	51.09	100.00	100.00	100.00		100.00							
Call Factor			1.01	0.99												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.05	0.44	0.01	0.03	0.07	0.08	0.29	0.11	0.13
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A1.e**

NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 75 g/t, Flotigram 2L 75 g/t
Grind:	80% -45µm
Water Type:	Sishen (Synthetic)
Cell pH:	11

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO_2	Fe	SiO_2							Fe	SiO_2	Fe	SiO_2
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	31.72	52.44	100	100
SiO_2 Rougher Conc 1	4.07	0.57	26.11	60.23	0.47	0.66	0.47	26.11	0.66	60.23	Recalc Tai	99.43	31.75	52.40	99.53	99.34
SiO_2 Rougher Conc 2	23.88	3.36	18.44	71.85	1.96	4.61	2.43	19.56	5.27	70.16	Recalc Tai	96.06	32.22	51.71	97.57	94.73
SiO_2 Rougher Conc 3	19.31	2.72	21.67	67.05	1.86	3.48	4.29	20.42	8.75	68.89	Recalc Tai	93.34	32.53	51.27	95.71	91.25
SiO_2 Rougher Conc 4	28.02	3.95	17.43	73.37	2.17	5.52	6.46	19.31	14.27	70.55	Recalc Tai	89.39	33.19	50.29	93.54	85.73
SiO_2 Rougher Conc 5	31.02	4.37	17.55	73.23	2.42	6.10	8.87	18.80	20.37	71.34	Recalc Tai	85.02	34.00	49.11	91.13	79.63
SiO_2 Rougher Conc 6	31.44	4.43	17.87	72.79	2.50	6.15	11.37	18.58	26.52	71.67	Recalc Tai	80.59	34.88	47.81	88.63	73.48
SiO_2 Rougher Concentrate	137.74	19.41	**18.58**	**71.67**	11.37	26.52	11.37	18.58	26.52	71.67						
SiO_2 Rougher Tailings	572.02	80.59	34.88	47.81	88.63	73.48	88.63	34.88	73.48	47.81						
Total	709.76	100.00	31.72	52.44	100.00	100.00	100.00		100.00							
Call Factor			0.98	1.01												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.12	1.04	0.01	0.03	0.05	0.04	0.13	0.07	0.13
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Dispersant Type Evaluation

Cationic Reverse Fe Flotation **Test A2.10** NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 75 g/t, Flotigram 2L 75 g/t,Starch 200g/t
Grind:	80% -45µm
Water Type:	Sishen (Synthetic)
Cell pH:	3

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO$_2$	Fe	SiO$_2$							Fe	SiO$_2$	Fe	SiO$_2$
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	30.89	53.83	100	100
SiO$_2$ Rougher Conc 1	9.66	1.39	32.68	47.36	1.47	1.22	1.47	32.68	1.22	47.36	Recalc Tai	98.61	30.86	53.93	98.53	98.78
SiO$_2$ Rougher Conc 2	18.87	2.72	38.27	40.29	3.37	2.03	4.84	36.38	3.26	42.69	Recalc Tai	95.89	30.65	54.31	95.16	96.74
SiO$_2$ Rougher Conc 3	45.99	6.62	35.50	46.01	7.61	5.66	12.45	35.84	8.92	44.74	Recalc Tai	89.27	30.29	54.93	87.55	91.08
SiO$_2$ Rougher Conc 4	74.09	10.67	36.00	46.13	12.43	9.14	24.88	35.92	18.06	45.43	Recalc Tai	78.60	29.52	56.12	75.12	81.94
SiO$_2$ Rougher Conc 5	82.38	11.86	35.23	47.44	13.53	10.45	38.41	35.67	28.51	46.15	Recalc Tai	66.74	28.50	57.66	61.59	71.49
SiO$_2$ Rougher Conc 6	82.64	11.90	32.61	51.50	12.56	11.38	50.98	34.87	39.89	47.56	Recalc Tai	54.84	27.61	59.00	49.02	60.11
SiO$_2$ Rougher Concentrate	313.63	45.16	**34.87**	**47.56**	50.98	39.89	50.98	34.87	39.89	47.56						
SiO$_2$ Rougher Tailings	380.90	54.84	27.61	59.00	49.02	60.11	49.02	27.61	60.11	59.00						
Total	694.53	100.00	30.89	53.83	100.00	100.00	100.00		100.00							
Call Factor			0.95	1.04												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.03	0.66	0.01	0.04	0.03	0.03	0.10	0.04	0.04
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A2.11** NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 75 g/t, Flotigram 2L 75 g/t,Starch 200g/t, Floatsil1 80g/t
Grind:	80% -45µm
Water Type:	Sishen (Synthetic)
Cell pH:	5

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO$_2$	Fe	SiO$_2$							Fe	SiO$_2$	Fe	SiO$_2$
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	32.13	52.00	100	100
SiO$_2$ Rougher Conc 1	32.03	4.53	15.35	75.23	2.16	6.55	2.16	15.35	6.55	75.23	Recalc Tai	95.47	32.92	50.90	97.84	93.45
SiO$_2$ Rougher Conc 2	73.18	10.34	15.61	75.66	5.03	15.05	7.19	15.53	21.60	75.53	Recalc Tai	85.13	35.03	47.89	92.81	78.40
SiO$_2$ Rougher Conc 3	104.54	14.78	20.31	69.10	9.34	19.64	16.53	17.91	41.24	72.33	Recalc Tai	70.35	38.12	43.44	83.47	58.76
SiO$_2$ Rougher Conc 4	127.79	18.06	27.42	58.83	15.42	20.44	31.95	21.51	61.67	67.22	Recalc Tai	52.29	41.81	38.12	68.05	38.33
SiO$_2$ Rougher Conc 5	127.16	17.97	31.29	53.41	17.51	18.46	49.46	24.19	80.13	63.44	Recalc Tai	34.31	47.32	30.11	50.54	19.87
SiO$_2$ Rougher Conc 6	86.42	12.22	37.02	45.07	14.08	10.59	63.53	26.20	90.72	60.56	Recalc Tai	22.10	53.02	21.84	36.47	9.28
SiO$_2$ Rougher Concentrate	551.12	77.90	**26.20**	**60.56**	63.53	90.72	63.53	26.20	90.72	60.56						
SiO$_2$ Rougher Tailings	156.33	22.10	53.02	21.84	36.47	9.28	36.47	53.02	9.28	21.84						
Total	707.45	100.00	32.13	52.00	100.00	100.00	100.00		100.00							
Call Factor			0.99	1.00												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.09	0.65	0.01	0.03	0.06	0.08	0.22	0.10	0.09
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A2.12** NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 75 g/t, Flotigram 2L 75 g/t,Starch 200g/t, Floatsil1 80g/t
Grind:	80% -45µm
Water Type:	Sishen (Synthetic)
Cell pH:	9

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO$_2$	Fe	SiO$_2$							Fe	SiO$_2$	Fe	SiO$_2$
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	32.63	51.21	100	100
SiO$_2$ Rougher Conc 1	93.48	13.96	13.26	79.29	5.67	21.62	5.67	13.26	21.62	79.29	Recalc Tai	86.04	35.78	46.66	94.33	78.38
SiO$_2$ Rougher Conc 2	120.96	18.07	15.98	75.43	8.84	26.61	14.52	14.79	48.23	77.11	Recalc Tai	67.97	41.04	39.01	85.48	51.77
SiO$_2$ Rougher Conc 3	111.36	16.63	20.54	68.80	10.47	22.34	24.99	16.76	70.57	74.27	Recalc Tai	51.34	47.68	29.36	75.01	29.43
SiO$_2$ Rougher Conc 4	80.98	12.09	28.88	56.64	10.70	13.38	35.69	19.17	83.94	70.76	Recalc Tai	39.24	53.48	20.95	64.31	16.06
SiO$_2$ Rougher Conc 5	64.81	9.68	38.88	41.98	11.53	7.94	47.22	21.88	91.88	66.81	Recalc Tai	29.57	58.25	14.07	52.78	8.12
SiO$_2$ Rougher Conc 6	48.02	7.17	50.15	25.70	11.02	3.60	58.24	24.49	95.48	63.01	Recalc Tai	22.39	60.85	10.34	41.76	4.52
SiO$_2$ Rougher Concentrate	519.61	77.61	**24.49**	**63.01**	58.24	95.48	58.24	24.49	95.48	63.01						
SiO$_2$ Rougher Tailings	149.93	22.39	60.85	10.34	41.76	4.52	41.76	60.85	4.52	10.34						
Total	669.54	100.00	32.63	51.21	100.00	100.00	100.00		100.00							
Call Factor			1.00	0.99												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.07	0.67	0.00	0.03	0.08	0.09	0.26	0.13	0.14
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A2.13**

NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 75 g/t, Flotigram 2L 75 g/t,Starch 200g/t, Floatsil2 80g/t
Grind:	80% -45µm
Water Type:	Sishen (Synthetic)
Cell pH:	3

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO$_2$	Fe	SiO$_2$							Fe	SiO$_2$	Fe	SiO$_2$
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	31.10	53.52	100	100
SiO$_2$ Rougher Conc 1	13.19	1.90	23.17	62.57	1.41	2.22	1.41	23.17	2.22	62.57	Recalc Tai	98.10	31.25	53.35	98.59	97.78
SiO$_2$ Rougher Conc 2	21.79	3.14	26.58	57.92	2.68	3.39	4.10	25.29	5.62	59.67	Recalc Tai	94.96	31.41	53.20	95.90	94.38
SiO$_2$ Rougher Conc 3	42.43	6.11	32.11	50.92	6.31	5.81	10.40	29.03	11.43	54.88	Recalc Tai	88.85	31.36	53.35	89.60	88.57
SiO$_2$ Rougher Conc 4	78.12	11.25	31.60	52.58	11.43	11.05	21.83	30.32	22.48	53.72	Recalc Tai	77.61	31.32	53.47	78.17	77.52
SiO$_2$ Rougher Conc 5	82.02	11.81	34.52	48.56	13.11	10.71	34.94	31.77	33.19	51.94	Recalc Tai	65.80	30.75	54.35	65.06	66.81
SiO$_2$ Rougher Conc 6	80.86	11.64	35.81	46.79	13.41	10.18	48.34	32.79	43.37	50.63	Recalc Tai	54.15	29.67	55.97	51.66	56.63
SiO$_2$ Rougher Concentrate	318.41	45.85	**32.79**	**50.63**	48.34	43.37	48.34	32.79	43.37	50.63						
SiO$_2$ Rougher Tailings	376.12	54.15	29.67	55.97	51.66	56.63	51.66	29.67	56.63	55.97						
Total	694.53	100.00	31.10	53.52	100.00	100.00	100.00		100.00							
Call Factor			0.96	1.03												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.05	0.67	0.00	0.03	0.03	0.04	0.11	0.05	0.06
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A2.14**

NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 75 g/t, Flotigram 2L 75 g/t,Starch 200g/t, Floatsil2 80g/t
Grind:	80% -45µm
Water Type:	Sishen (Synthetic)
Cell pH:	5

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO$_2$	Fe	SiO$_2$							Fe	SiO$_2$	Fe	SiO$_2$
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	31.96	52.23	100	100
SiO$_2$ Rougher Conc 1	32.91	4.82	14.91	75.86	2.25	7.00	2.25	14.91	7.00	75.86	Recalc Tai	95.18	32.82	51.03	97.75	93.00
SiO$_2$ Rougher Conc 2	75.07	11.00	15.11	76.37	5.20	16.09	7.45	15.05	23.09	76.21	Recalc Tai	84.18	35.13	47.72	92.55	76.91
SiO$_2$ Rougher Conc 3	97.80	14.33	23.30	64.61	10.45	17.73	17.90	18.97	40.82	70.70	Recalc Tai	69.84	37.56	44.25	82.10	59.18
SiO$_2$ Rougher Conc 4	110.48	16.19	29.76	55.41	15.08	17.18	32.98	22.74	58.00	65.36	Recalc Tai	53.65	39.92	40.88	67.02	42.00
SiO$_2$ Rougher Conc 5	80.38	11.78	36.28	45.95	13.37	10.36	46.36	25.49	68.36	61.42	Recalc Tai	41.87	40.94	39.46	53.64	31.64
SiO$_2$ Rougher Conc 6	79.64	11.67	34.43	48.83	12.57	10.91	58.93	26.98	79.28	59.32	Recalc Tai	30.20	43.45	35.83	41.07	20.72
SiO$_2$ Rougher Concentrate	476.28	69.80	**26.98**	**59.32**	58.93	79.28	58.93	26.98	79.28	59.32						
SiO$_2$ Rougher Tailings	206.10	30.20	43.45	35.83	41.07	20.72	41.07	43.45	20.72	35.83						
Total	682.38	100.00	31.96	52.23	100.00	100.00	100.00		100.00							
Call Factor			0.98	1.01												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.10	0.64	0.00	0.03	0.04	0.05	0.17	0.07	0.08
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A2.15**

NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 75 g/t, Flotigram 2L 75 g/t,Starch 200g/t, Floatsil2 80g/t
Grind:	80% -45µm
Water Type:	Sishen (Synthetic)
Cell pH:	9

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO$_2$	Fe	SiO$_2$							Fe	SiO$_2$	Fe	SiO$_2$
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	32.79	50.98	100	100
SiO$_2$ Rougher Conc 1	94.06	13.57	13.98	78.18	5.78	20.81	5.78	13.98	20.81	78.18	Recalc Tai	86.43	35.75	46.71	94.22	79.19
SiO$_2$ Rougher Conc 2	127.05	18.33	17.16	73.67	9.59	26.49	15.37	15.80	47.29	75.59	Recalc Tai	68.10	40.75	39.45	84.63	52.71
SiO$_2$ Rougher Conc 3	118.03	17.03	23.25	64.95	12.07	21.69	27.44	18.39	68.99	71.89	Recalc Tai	51.08	46.59	30.95	72.56	31.01
SiO$_2$ Rougher Conc 4	79.40	11.45	29.22	56.11	10.21	12.61	37.65	20.45	81.59	68.89	Recalc Tai	39.62	51.61	23.68	62.35	18.41
SiO$_2$ Rougher Conc 5	46.42	6.70	38.88	42.16	7.94	5.54	45.59	22.29	87.13	66.23	Recalc Tai	32.93	54.20	19.92	54.41	12.87
SiO$_2$ Rougher Conc 6	60.61	8.74	44.85	33.43	11.96	5.73	57.55	24.89	92.87	62.44	Recalc Tai	24.18	57.57	15.04	42.45	7.13
SiO$_2$ Rougher Concentrate	525.57	75.82	**24.89**	**62.44**	57.55	92.87	57.55	24.89	92.87	62.44						
SiO$_2$ Rougher Tailings	167.63	24.18	57.57	15.04	42.45	7.13	42.45	57.57	7.13	15.04						
Total	693.20	100.00	32.79	50.98	100.00	100.00	100.00		100.00							
Call Factor			1.01	0.98												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.07	0.75	0.01	0.03	0.08	0.09	0.23	0.13	0.14
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A2.16**

NORMALISED DATA

Ore Type: BIF Composite — BIF Composite
Reagent Suite: EDA3 75 g/t, Flotigram 2L 75 g/t,Starch 200g/t, Floatsil1 100g/t
Grind: 80% -45µm
Water Type: Sishen (Synthetic)
Cell pH: 3

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO$_2$	Fe	SiO$_2$							Fe	SiO$_2$	Fe	SiO$_2$
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	31.28	53.22	100	100
SiO$_2$ Rougher Conc 1	6.82	0.97	40.08	35.92	1.24	0.65	1.24	40.08	0.65	35.92	Recalc Tai	99.03	31.20	53.39	98.76	99.35
SiO$_2$ Rougher Conc 2	17.05	2.42	35.94	43.63	2.78	1.99	4.02	37.12	2.64	41.43	Recalc Tai	96.61	31.08	53.63	95.98	97.36
SiO$_2$ Rougher Conc 3	41.89	5.95	36.48	44.42	6.94	4.97	10.96	36.71	7.60	43.34	Recalc Tai	90.66	30.72	54.23	89.04	92.40
SiO$_2$ Rougher Conc 4	81.01	11.50	36.20	45.67	13.31	9.87	24.27	36.43	17.48	44.62	Recalc Tai	79.16	29.93	55.48	75.73	82.52
SiO$_2$ Rougher Conc 5	93.80	13.32	35.90	46.43	15.29	11.62	39.56	36.22	29.10	45.33	Recalc Tai	65.84	28.72	57.31	60.44	70.90
SiO$_2$ Rougher Conc 6	71.61	10.17	36.28	46.10	11.79	8.81	51.36	36.24	37.91	45.51	Recalc Tai	55.67	27.34	59.36	48.64	62.09
SiO$_2$ Rougher Concentrate	312.18	44.33	**36.24**	**45.51**	51.36	37.91	51.36	36.24	37.91	45.51						
SiO$_2$ Rougher Tailings	391.99	55.67	27.34	59.36	48.64	62.09	48.64	27.34	62.09	59.36						
Total	704.17	100.00	31.28	53.22	100.00	100.00	100.00		100.00							
Call Factor			0.96	1.03												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.05	0.68	0.01	0.03	0.03	0.04	0.10	0.04	0.04
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A2.17**

NORMALISED DATA

Ore Type: BIF Composite — BIF Composite
Reagent Suite: EDA3 75 g/t, Flotigram 2L 75 g/t,Starch 200g/t, Floatsil1 100g/t
Grind: 80% -45µm
Water Type: Sishen (Synthetic)
Cell pH: 5

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO$_2$	Fe	SiO$_2$							Fe	SiO$_2$	Fe	SiO$_2$
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	32.31	51.74	100	100
SiO$_2$ Rougher Conc 1	35.77	5.16	14.07	77.22	2.25	7.69	2.25	14.07	7.69	77.22	Recalc Tai	94.84	33.31	50.36	97.75	92.31
SiO$_2$ Rougher Conc 2	56.75	8.18	16.64	73.99	4.21	11.70	6.46	15.65	19.39	75.24	Recalc Tai	86.66	34.88	48.13	93.54	80.61
SiO$_2$ Rougher Conc 3	102.89	14.83	21.37	67.55	9.81	19.36	16.26	18.66	38.75	71.19	Recalc Tai	71.83	37.67	44.12	83.74	61.25
SiO$_2$ Rougher Conc 4	131.02	18.89	27.59	58.64	16.12	21.40	32.39	22.24	60.15	66.15	Recalc Tai	52.95	41.27	38.94	67.61	39.85
SiO$_2$ Rougher Conc 5	110.81	15.97	32.28	51.91	15.96	16.02	48.34	24.79	76.18	62.54	Recalc Tai	36.97	45.15	33.34	51.66	23.82
SiO$_2$ Rougher Conc 6	84.74	12.21	36.75	45.55	13.89	10.75	62.23	26.73	86.93	59.78	Recalc Tai	24.76	49.29	27.31	37.77	13.07
SiO$_2$ Rougher Concentrate	521.98	75.24	**26.73**	**59.78**	62.23	86.93	62.23	26.73	86.93	59.78						
SiO$_2$ Rougher Tailings	171.77	24.76	49.29	27.31	37.77	13.07	37.77	49.29	13.07	27.31						
Total	693.75	100.00	32.31	51.74	100.00	100.00	100.00		100.00							
Call Factor			0.99	1.00												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.09	0.62	0.00	0.03	0.05	0.07	0.20	0.08	0.10
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

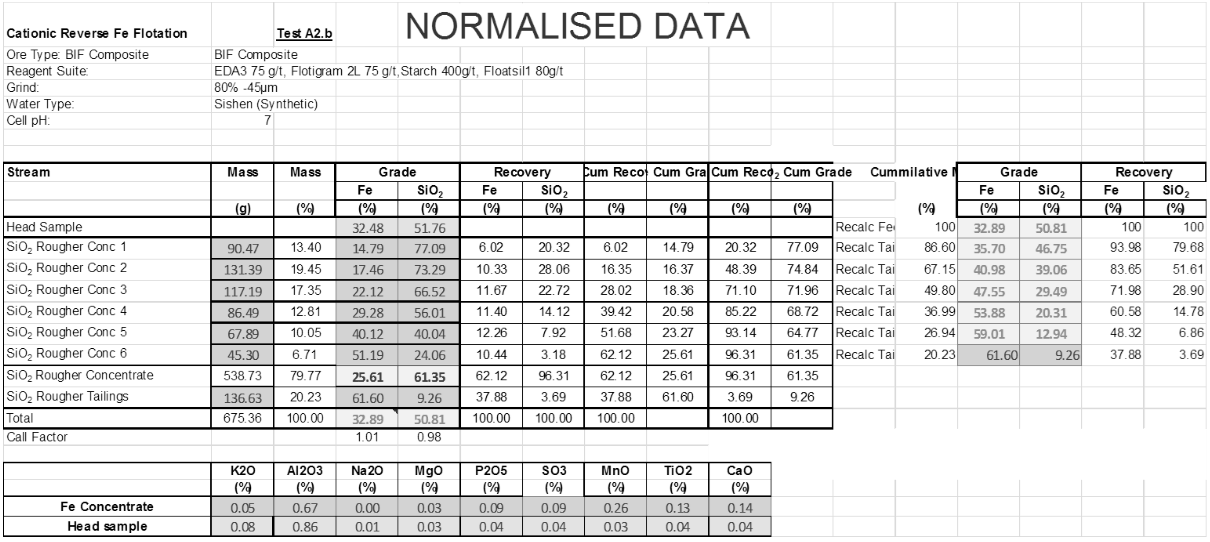
Cationic Reverse Fe Flotation **Test A2.18**

NORMALISED DATA

Ore Type: BIF Composite — BIF Composite
Reagent Suite: EDA3 75 g/t, Flotigram 2L 75 g/t,Starch 200g/t, Floatsil1 100g/t
Grind: 80% -45µm
Water Type: Sishen (Synthetic)
Cell pH: 9

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO$_2$	Fe	SiO$_2$							Fe	SiO$_2$	Fe	SiO$_2$
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	33.38	50.14	100	100
SiO$_2$ Rougher Conc 1	93.61	12.21	15.74	75.51	5.76	18.39	5.76	15.74	18.39	75.51	Recalc Tai	87.79	35.83	46.61	94.24	81.61
SiO$_2$ Rougher Conc 2	142.77	18.62	18.72	71.38	10.44	26.51	16.20	17.54	44.90	73.01	Recalc Tai	69.16	40.44	39.95	83.80	55.10
SiO$_2$ Rougher Conc 3	124.29	16.21	23.38	64.70	11.36	20.92	27.56	19.55	65.82	70.15	Recalc Tai	52.95	45.67	32.37	72.44	34.18
SiO$_2$ Rougher Conc 4	93.33	12.17	30.49	54.41	11.12	13.21	38.68	21.80	79.03	66.91	Recalc Tai	40.78	50.20	25.79	61.32	20.97
SiO$_2$ Rougher Conc 5	77.62	10.13	37.74	43.80	11.45	8.84	50.13	24.13	87.88	63.54	Recalc Tai	30.65	54.31	19.84	49.87	12.12
SiO$_2$ Rougher Conc 6	82.79	10.80	47.08	30.39	15.23	6.55	65.36	27.22	94.42	59.07	Recalc Tai	19.85	58.25	14.09	34.64	5.58
SiO$_2$ Rougher Concentrate	614.41	80.15	**27.22**	**59.07**	65.36	94.42	65.36	27.22	94.42	59.07						
SiO$_2$ Rougher Tailings	152.18	19.85	58.25	14.09	34.64	5.58	34.64	58.25	5.58	14.09						
Total	766.59	100.00	33.38	50.14	100.00	100.00	100.00		100.00							
Call Factor			1.03	0.97												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.05	0.72	0.01	0.03	0.09	0.09	0.23	0.13	0.14
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04



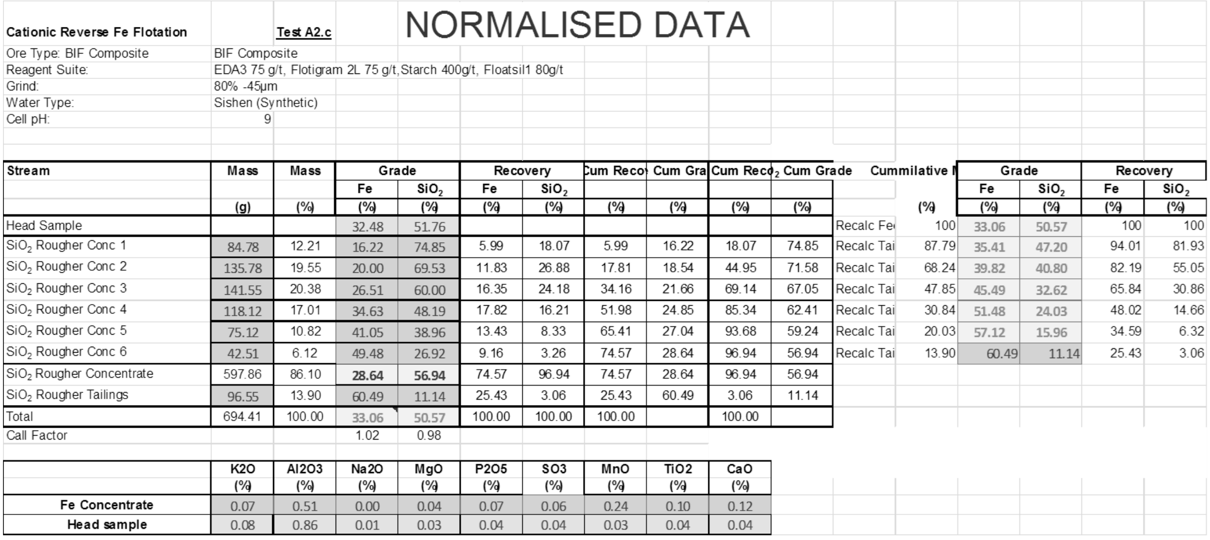
Cationic Reverse Fe Flotation **Test A2.b**

NORMALISED DATA

Ore Type: BIF Composite — BIF Composite
Reagent Suite: EDA3 75 g/t, Flotigram 2L 75 g/t,Starch 400g/t, Floatsil1 80g/t
Grind: 80% -45µm
Water Type: Sishen (Synthetic)
Cell pH: 7

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco	Cum Grade		Cummilative M	Grade		Recovery	
			Fe	SiO_2	Fe	SiO_2							Fe	SiO_2	Fe	SiO_2
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	32.89	50.81	100	100
SiO_2 Rougher Conc 1	90.47	13.40	14.79	77.09	6.02	20.32	6.02	14.79	20.32	77.09	Recalc Tai	86.60	35.70	46.75	93.98	79.68
SiO_2 Rougher Conc 2	131.39	19.45	17.46	73.29	10.33	28.06	16.35	16.37	48.39	74.84	Recalc Tai	67.15	40.98	39.06	83.65	51.61
SiO_2 Rougher Conc 3	117.19	17.35	22.12	66.52	11.67	22.72	28.02	18.36	71.10	71.96	Recalc Tai	49.80	47.55	29.49	71.98	28.90
SiO_2 Rougher Conc 4	86.49	12.81	29.28	56.01	11.40	14.12	39.42	20.58	85.22	68.72	Recalc Tai	36.99	53.88	20.31	60.58	14.78
SiO_2 Rougher Conc 5	67.89	10.05	40.12	40.04	12.26	7.92	51.68	23.27	93.14	64.77	Recalc Tai	26.94	59.01	12.94	48.32	6.86
SiO_2 Rougher Conc 6	45.30	6.71	51.19	24.06	10.44	3.18	62.12	25.61	96.31	61.35	Recalc Tai	20.23	61.60	9.26	37.88	3.69
SiO_2 Rougher Concentrate	538.73	79.77	**25.61**	**61.35**	62.12	96.31	62.12	25.61	96.31	61.35						
SiO_2 Rougher Tailings	136.63	20.23	61.60	9.26	37.88	3.69	37.88	61.60	3.69	9.26						
Total	675.36	100.00	32.89	50.81	100.00	100.00	100.00		100.00							
Call Factor			1.01	0.98												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.05	0.67	0.00	0.03	0.09	0.09	0.26	0.13	0.14
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04



Cationic Reverse Fe Flotation **Test A2.c**

NORMALISED DATA

Ore Type: BIF Composite — BIF Composite
Reagent Suite: EDA3 75 g/t, Flotigram 2L 75 g/t,Starch 400g/t, Floatsil1 80g/t
Grind: 80% -45µm
Water Type: Sishen (Synthetic)
Cell pH: 9

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco	Cum Grade		Cummilative M	Grade		Recovery	
			Fe	SiO_2	Fe	SiO_2							Fe	SiO_2	Fe	SiO_2
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	33.06	50.57	100	100
SiO_2 Rougher Conc 1	84.78	12.21	16.22	74.85	5.99	18.07	5.99	16.22	18.07	74.85	Recalc Tai	87.79	35.41	47.20	94.01	81.93
SiO_2 Rougher Conc 2	135.78	19.55	20.00	69.53	11.83	26.88	17.81	18.54	44.95	71.58	Recalc Tai	68.24	39.82	40.80	82.19	55.05
SiO_2 Rougher Conc 3	141.55	20.38	26.51	60.00	16.35	24.18	34.16	21.66	69.14	67.05	Recalc Tai	47.85	45.49	32.62	65.84	30.86
SiO_2 Rougher Conc 4	118.12	17.01	34.63	48.19	17.82	16.21	51.98	24.85	85.34	62.41	Recalc Tai	30.84	51.48	24.03	48.02	14.66
SiO_2 Rougher Conc 5	75.12	10.82	41.05	38.96	13.43	8.33	65.41	27.04	93.68	59.24	Recalc Tai	20.03	57.12	15.96	34.59	6.32
SiO_2 Rougher Conc 6	42.51	6.12	49.48	26.92	9.16	3.26	74.57	28.64	96.94	56.94	Recalc Tai	13.90	60.49	11.14	25.43	3.06
SiO_2 Rougher Concentrate	597.86	86.10	**28.64**	**56.94**	74.57	96.94	74.57	28.64	96.94	56.94						
SiO_2 Rougher Tailings	96.55	13.90	60.49	11.14	25.43	3.06	25.43	60.49	3.06	11.14						
Total	694.41	100.00	33.06	50.57	100.00	100.00	100.00		100.00							
Call Factor			1.02	0.98												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.07	0.51	0.00	0.04	0.07	0.06	0.24	0.10	0.12
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Depressant Dosage Evaluation

Cationic Reverse Fe Flotation **Test A3.19** NORMALISED DATA

Ore Type: BIF Composite | BIF Composite
Reagent Suite: EDA3 75 g/t, Flotigram 2L 75 g/t, Starch 400g/t, Floatsil1 80g/t
Grind: 80% -45µm
Water Type: Sishen (Synthetic)
Cell pH: 3

Stream	**Mass**	**Mass**	**Grade**		**Recovery**		**Cum Reco**	**Cum Gra**	**Cum Reco$_2$**	**Cum Grade**		**Cummilative M**	**Grade**		**Recovery**	
			Fe	**SiO$_2$**	**Fe**	**SiO$_2$**							**Fe**	**SiO$_2$**	**Fe**	**SiO$_2$**
	(g)	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**		**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
Head Sample			32.48	51.76							Recalc Fe	100	30.89	53.82	100	100
SiO$_2$ Rougher Conc 1	6.65	0.91	33.20	49.62	0.97	0.83	0.97	33.20	0.83	49.62	Recalc Tai	99.09	30.86	53.86	99.03	99.17
SiO$_2$ Rougher Conc 2	14.70	2.00	36.14	43.25	2.34	1.61	3.31	35.22	2.44	45.24	Recalc Tai	97.09	30.76	54.08	96.69	97.56
SiO$_2$ Rougher Conc 3	42.18	5.74	32.13	50.71	5.97	5.41	9.29	33.17	7.85	48.87	Recalc Tai	91.35	30.67	54.29	90.71	92.15
SiO$_2$ Rougher Conc 4	70.73	9.63	33.31	49.79	10.38	8.91	19.67	33.24	16.76	49.35	Recalc Tai	81.72	30.36	54.82	80.33	83.24
SiO$_2$ Rougher Conc 5	79.17	10.78	34.28	48.71	11.96	9.75	31.64	33.63	26.51	49.11	Recalc Tai	70.94	29.76	55.75	68.36	73.49
SiO$_2$ Rougher Conc 6	75.14	10.23	33.98	49.40	11.25	9.39	42.89	33.72	35.90	49.19	Recalc Tai	60.72	29.05	56.82	57.11	64.10
SiO$_2$ Rougher Concentrate	288.57	39.28	**33.72**	**49.19**	42.89	35.90	42.89	33.72	35.90	49.19						
SiO$_2$ Rougher Tailings	446.00	60.72	29.05	56.82	57.11	64.10	57.11	29.05	64.10	56.82						
Total	734.57	100.00	30.89	53.82	100.00	100.00	100.00		100.00							
Call Factor			0.95	1.04												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.07	0.70	0.00	0.03	0.03	0.04	0.11	0.05	0.05
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A3.20** NORMALISED DATA

Ore Type: BIF Composite | BIF Composite
Reagent Suite: EDA3 75 g/t, Flotigram 2L 75 g/t, Starch 400g/t, Floatsil1 80g/t
Grind: 80% -45µm
Water Type: Sishen (Synthetic)
Cell pH: 5

Stream	**Mass**	**Mass**	**Grade**		**Recovery**		**Cum Reco**	**Cum Gra**	**Cum Reco$_2$**	**Cum Grade**		**Cummilative M**	**Grade**		**Recovery**	
			Fe	**SiO$_2$**	**Fe**	**SiO$_2$**							**Fe**	**SiO$_2$**	**Fe**	**SiO$_2$**
	(g)	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**		**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
Head Sample			32.48	51.76							Recalc Fe	100	32.82	50.97	100	100
SiO$_2$ Rougher Conc 1	32.78	4.69	16.69	73.44	2.39	6.76	2.39	16.69	6.76	73.44	Recalc Tai	95.31	33.61	49.87	97.61	93.24
SiO$_2$ Rougher Conc 2	52.37	7.49	16.90	73.64	3.86	10.83	6.24	16.82	17.59	73.56	Recalc Tai	87.81	35.04	47.84	93.76	82.41
SiO$_2$ Rougher Conc 3	92.60	13.25	22.23	66.29	8.97	17.23	15.22	19.64	34.82	69.77	Recalc Tai	74.56	37.32	44.56	84.78	65.18
SiO$_2$ Rougher Conc 4	111.86	16.01	27.25	58.95	13.29	18.51	28.51	22.58	53.33	65.59	Recalc Tai	58.56	40.07	40.62	71.49	46.67
SiO$_2$ Rougher Conc 5	105.14	15.05	28.20	57.80	12.93	17.06	41.43	24.07	70.39	63.52	Recalc Tai	43.51	44.18	34.68	58.57	29.61
SiO$_2$ Rougher Conc 6	55.00	7.87	38.10	43.36	9.14	6.70	50.57	25.79	77.09	61.05	Recalc Tai	35.64	45.52	32.77	49.43	22.91
SiO$_2$ Rougher Concentrate	449.75	64.36	**25.79**	**61.05**	50.57	77.09	50.57	25.79	77.09	61.05						
SiO$_2$ Rougher Tailings	249.06	35.64	45.52	32.77	49.43	22.91	49.43	45.52	22.91	32.77						
Total	698.81	100.00	32.82	50.97	100.00	100.00	100.00		100.00							
Call Factor			1.01	0.98												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.12	0.69	0.01	0.03	0.05	0.04	0.16	0.08	0.09
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A3.21** NORMALISED DATA

Ore Type: BIF Composite | BIF Composite
Reagent Suite: EDA3 75 g/t, Flotigram 2L 75 g/t, Starch 400g/t, Floatsil1 80g/t
Grind: 80% -45µm
Water Type: Sishen (Synthetic)
Cell pH: 9

Stream	**Mass**	**Mass**	**Grade**		**Recovery**		**Cum Reco**	**Cum Gra**	**Cum Reco$_2$**	**Cum Grade**		**Cummilative M**	**Grade**		**Recovery**	
			Fe	**SiO$_2$**	**Fe**	**SiO$_2$**							**Fe**	**SiO$_2$**	**Fe**	**SiO$_2$**
	(g)	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**		**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
Head Sample			32.48	51.76							Recalc Fe	100	33.21	50.33	100	100
SiO$_2$ Rougher Conc 1	84.13	12.03	15.24	76.34	5.52	18.24	5.52	15.24	18.24	76.34	Recalc Tai	87.97	35.67	46.78	94.48	81.76
SiO$_2$ Rougher Conc 2	129.71	18.55	18.03	72.42	10.07	26.68	15.59	16.93	44.93	73.96	Recalc Tai	69.42	40.38	39.93	84.41	55.07
SiO$_2$ Rougher Conc 3	112.12	16.03	21.37	67.60	10.32	21.53	25.90	18.46	66.46	71.78	Recalc Tai	53.39	46.09	31.62	74.10	33.54
SiO$_2$ Rougher Conc 4	84.44	12.07	27.65	58.38	10.05	14.00	35.96	20.35	80.46	69.02	Recalc Tai	41.32	51.47	23.80	64.04	19.54
SiO$_2$ Rougher Conc 5	61.79	8.83	36.28	45.75	9.65	8.03	45.61	22.43	88.49	65.97	Recalc Tai	32.49	55.61	17.83	54.39	11.51
SiO$_2$ Rougher Conc 6	52.60	7.52	45.18	32.77	10.23	4.90	55.84	24.71	93.39	62.65	Recalc Tai	24.96	58.75	13.33	44.16	6.61
SiO$_2$ Rougher Concentrate	524.79	75.04	**24.71**	**62.65**	55.84	93.39	55.84	24.71	93.39	62.65						
SiO$_2$ Rougher Tailings	174.60	24.96	58.75	13.33	44.16	6.61	44.16	58.75	6.61	13.33						
Total	699.39	100.00	33.21	50.33	100.00	100.00	100.00		100.00							
Call Factor			1.02	0.97												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.08	0.77	0.00	0.04	0.09	0.09	0.22	0.12	0.13
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A3.22**

NORMALISED DATA

Ore Type: BIF Composite | BIF Composite
Reagent Suite: EDA3 75 g/t, Flotigram 2L 75 g/t,Starch 600g/t, Floatsil1 80g/t
Grind: 80% -45µm
Water Type: Sishen (Synthetic)
Cell pH: 3

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO$_2$	Fe	SiO$_2$							Fe	SiO$_2$	Fe	SiO$_2$
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	31.50	52.88	100	100
SiO$_2$ Rougher Conc 1	9.60	1.41	27.66	57.65	1.24	1.54	1.24	27.66	1.54	57.65	Recalc Tai	98.59	31.55	52.81	98.76	98.46
SiO$_2$ Rougher Conc 2	33.60	4.93	22.91	64.83	3.59	6.04	4.82	23.97	7.58	63.24	Recalc Tai	93.66	32.01	52.18	95.18	92.42
SiO$_2$ Rougher Conc 3	43.84	6.43	27.55	58.10	5.63	7.07	10.45	25.77	14.65	60.65	Recalc Tai	87.23	32.34	51.74	89.55	85.35
SiO$_2$ Rougher Conc 4	49.71	7.29	25.29	61.84	5.86	8.53	16.30	25.59	23.18	61.08	Recalc Tai	79.94	32.98	50.82	83.70	76.82
SiO$_2$ Rougher Conc 5	46.16	6.77	31.51	52.80	6.78	6.76	23.08	27.09	29.94	58.99	Recalc Tai	73.16	33.12	50.64	76.92	70.06
SiO$_2$ Rougher Conc 6	47.18	6.92	33.85	49.38	7.44	6.46	30.52	28.47	36.40	57.02	Recalc Tai	66.24	33.04	50.77	69.48	63.60
SiO$_2$ Rougher Concentrate	230.09	33.76	**28.47**	**57.02**	30.52	36.40	30.52	28.47	36.40	57.02						
SiO$_2$ Rougher Tailings	451.48	66.24	33.04	50.77	69.48	63.60	69.48	33.04	63.60	50.77						
Total	681.57	100.00	31.50	52.88	100.00	100.00	100.00		100.00							
Call Factor			0.97	1.02												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.12	0.88	0.01	0.04	0.03	0.05	0.11	0.06	0.04
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A3.23**

NORMALISED DATA

Ore Type: BIF Composite | BIF Composite
Reagent Suite: EDA3 75 g/t, Flotigram 2L 75 g/t,Starch 600g/t, Floatsil1 80g/t
Grind: 80% -45µm
Water Type: Sishen (Synthetic)
Cell pH: 5

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO$_2$	Fe	SiO$_2$							Fe	SiO$_2$	Fe	SiO$_2$
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	32.68	51.13	100	100
SiO$_2$ Rougher Conc 1	52.70	7.46	16.31	74.72	3.72	10.91	3.72	16.31	10.91	74.72	Recalc Tai	92.54	34.00	49.23	96.28	89.09
SiO$_2$ Rougher Conc 2	117.37	16.62	19.41	70.43	9.87	22.89	13.59	18.45	33.80	71.76	Recalc Tai	75.92	37.20	44.59	86.41	66.20
SiO$_2$ Rougher Conc 3	125.69	17.80	23.80	64.03	12.96	22.29	26.56	20.72	56.09	68.47	Recalc Tai	58.12	41.30	38.64	73.44	43.91
SiO$_2$ Rougher Conc 4	103.32	14.63	27.25	59.03	12.20	16.89	38.76	22.41	72.98	66.03	Recalc Tai	43.49	46.03	31.78	61.24	27.02
SiO$_2$ Rougher Conc 5	63.20	8.95	32.43	51.43	8.88	9.00	47.63	23.78	81.98	64.03	Recalc Tai	34.54	49.56	26.68	52.37	18.02
SiO$_2$ Rougher Conc 6	39.87	5.65	38.71	42.31	6.69	4.67	54.32	24.97	86.65	62.31	Recalc Tai	28.89	51.68	23.63	45.68	13.35
SiO$_2$ Rougher Concentrate	502.15	71.11	**24.97**	**62.31**	54.32	86.65	54.32	24.97	86.65	62.31						
SiO$_2$ Rougher Tailings	204.00	28.89	51.68	23.63	45.68	13.35	45.68	51.68	13.35	23.63						
Total	706.15	100.00	32.68	51.13	100.00	100.00	100.00		100.00							
Call Factor			1.01	0.99												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.10	0.89	0.00	0.04	0.05	0.06	0.18	0.09	0.07
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A3.24**

NORMALISED DATA

Ore Type: BIF Composite | BIF Composite
Reagent Suite: EDA3 75 g/t, Flotigram 2L 75 g/t,Starch 600g/t, Floatsil1 80g/t
Grind: 80% -45µm
Water Type: Sishen (Synthetic)
Cell pH: 9

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO$_2$	Fe	SiO$_2$							Fe	SiO$_2$	Fe	SiO$_2$
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	36.85	45.04	100	100
SiO$_2$ Rougher Conc 1	55.49	7.90	14.11	78.13	3.03	13.71	3.03	14.11	13.71	78.13	Recalc Tai	92.10	38.80	42.20	96.97	86.29
SiO$_2$ Rougher Conc 2	134.77	19.19	17.83	72.76	9.28	31.01	12.31	16.74	44.71	74.33	Recalc Tai	72.91	44.33	34.16	87.69	55.29
SiO$_2$ Rougher Conc 3	117.67	16.76	24.29	63.39	11.04	23.58	23.36	19.63	68.30	70.15	Recalc Tai	56.15	50.31	25.43	76.64	31.70
SiO$_2$ Rougher Conc 4	98.86	14.08	34.30	48.77	13.10	15.24	36.46	23.19	83.54	64.95	Recalc Tai	42.07	55.66	17.62	63.54	16.46
SiO$_2$ Rougher Conc 5	71.89	10.24	46.57	30.97	12.94	7.04	49.39	26.70	90.58	59.85	Recalc Tai	31.83	58.59	13.33	50.61	9.42
SiO$_2$ Rougher Conc 6	57.87	8.24	54.98	18.73	12.29	3.43	61.69	29.75	94.01	55.41	Recalc Tai	23.59	59.85	11.44	38.31	5.99
SiO$_2$ Rougher Concentrate	536.55	76.41	**29.75**	**55.41**	61.69	94.01	61.69	29.75	94.01	55.41						
SiO$_2$ Rougher Tailings	165.66	23.59	59.85	11.44	38.31	5.99	38.31	59.85	5.99	11.44						
Total	702.21	100.00	36.85	45.04	100.00	100.00	100.00		100.00							
Call Factor			1.13	0.87												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.14	0.99	0.00	0.03	0.08	0.08	0.24	0.13	0.13
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A3.b** NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 75 g/t, Flotigram 2L 75 g/t,Starch 100g/t, Floatsil1 80g/t
Grind:	80% -45µm
Water Type:	Sishen (Synthetic)
Cell pH:	9

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO_2	Fe	SiO_2							Fe	SiO_2	Fe	SiO_2
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	32.75	51.03	100	100
SiO_2 Rougher Conc 1	109.01	15.63	14.11	78.13	6.74	23.93	6.74	14.11	23.93	78.13	Recalc Tai	84.37	36.20	46.02	93.26	76.07
SiO_2 Rougher Conc 2	138.71	19.89	17.83	72.76	10.83	28.36	17.57	16.19	52.29	75.12	Recalc Tai	64.47	41.87	37.76	82.43	47.71
SiO_2 Rougher Conc 3	125.48	17.99	24.29	63.39	13.35	22.35	30.91	18.92	74.64	71.18	Recalc Tai	46.48	48.68	27.84	69.09	25.36
SiO_2 Rougher Conc 4	92.56	13.27	34.30	48.77	13.90	12.69	44.81	21.97	87.33	66.73	Recalc Tai	33.21	54.43	19.47	55.19	12.67
SiO_2 Rougher Conc 5	78.33	11.23	46.57	30.97	15.97	6.82	60.79	25.51	94.15	61.58	Recalc Tai	21.97	58.45	13.59	39.21	5.85
SiO_2 Rougher Conc 6	64.90	9.31	54.98	18.73	15.62	3.42	76.41	28.65	97.56	57.01	Recalc Tai	12.67	60.99	9.82	23.59	2.44
SiO_2 Rougher Concentrate	608.99	87.33	**28.65**	**57.01**	76.41	97.56	76.41	28.65	97.56	57.01						
SiO_2 Rougher Tailings	88.32	12.67	60.99	9.82	23.59	2.44	23.59	60.99	2.44	9.82						
Total	697.31	100.00	32.75	51.03	100.00	100.00	100.00		100.00							
Call Factor			1.01	0.99												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.09	0.76	0.01	0.04	0.10	0.14	0.29	0.17	0.17
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A3.c** NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 75 g/t, Flotigram 2L 75 g/t,Starch 800g/t, Floatsil1 80g/t
Grind:	80% -45µm
Water Type:	Sishen (Synthetic)
Cell pH:	9

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO_2	Fe	SiO_2							Fe	SiO_2	Fe	SiO_2
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	32.86	50.83	100	100
SiO_2 Rougher Conc 1	85.58	12.28	14.24	78.30	5.32	18.92	5.32	14.24	18.92	78.30	Recalc Tai	87.72	35.47	46.99	94.68	81.08
SiO_2 Rougher Conc 2	126.69	18.18	16.57	74.87	9.17	26.78	14.49	15.63	45.70	76.26	Recalc Tai	69.53	40.41	39.70	85.51	54.30
SiO_2 Rougher Conc 3	134.54	19.31	23.04	65.33	13.54	24.82	28.03	18.51	70.52	72.02	Recalc Tai	50.22	47.08	29.84	71.97	29.48
SiO_2 Rougher Conc 4	102.44	14.70	31.99	52.08	14.32	15.06	42.35	21.58	85.58	67.47	Recalc Tai	35.52	53.33	20.63	57.65	14.42
SiO_2 Rougher Conc 5	68.93	9.89	42.19	36.90	12.70	7.18	55.05	24.32	92.77	63.41	Recalc Tai	25.62	57.63	14.35	44.95	7.23
SiO_2 Rougher Conc 6	42.26	6.07	48.55	27.35	8.96	3.26	64.02	26.15	96.03	60.69	Recalc Tai	19.56	60.45	10.32	35.98	3.97
SiO_2 Rougher Concentrate	560.44	80.44	**26.15**	**60.69**	64.02	96.03	64.02	26.15	96.03	60.69						
SiO_2 Rougher Tailings	136.27	19.56	60.45	10.32	35.98	3.97	35.98	60.45	3.97	10.32						
Total	696.71	100.00	32.86	50.83	100.00	100.00	100.00		100.00							
Call Factor			1.01	0.98												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.19	1.16	0.00	0.03	0.08	0.09	0.24	0.14	0.14
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A3.d** NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 75 g/t, Flotigram 2L 75 g/t,Starch 100g/t, Floatsil1 80g/t
Grind:	80% -45µm
Water Type:	Sishen (Synthetic)
Cell pH:	7

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO_2	Fe	SiO_2							Fe	SiO_2	Fe	SiO_2
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	33.13	50.50	100	100
SiO_2 Rougher Conc 1	76.22	11.48	12.68	79.94	4.39	18.17	4.39	12.68	18.17	79.94	Recalc Tai	88.52	35.78	46.68	95.61	81.83
SiO_2 Rougher Conc 2	115.82	17.44	15.61	75.90	8.22	26.21	12.61	14.45	44.38	77.50	Recalc Tai	71.08	40.73	39.51	87.39	55.62
SiO_2 Rougher Conc 3	112.42	16.93	21.01	68.12	10.74	22.84	23.35	16.87	67.22	74.04	Recalc Tai	54.15	46.90	30.57	76.65	32.78
SiO_2 Rougher Conc 4	95.57	14.39	30.00	54.97	13.03	15.66	36.38	20.01	82.88	69.48	Recalc Tai	39.76	53.01	21.74	63.62	17.12
SiO_2 Rougher Conc 5	96.27	14.50	43.41	35.63	19.00	10.23	55.38	24.55	93.11	62.92	Recalc Tai	25.26	58.52	13.77	44.62	6.89
SiO_2 Rougher Conc 6	81.90	12.33	53.87	20.41	20.06	4.98	75.43	28.70	98.10	56.90	Recalc Tai	12.93	62.95	7.44	24.57	1.90
SiO_2 Rougher Concentrate	578.20	87.07	**28.70**	**56.90**	75.43	98.10	75.43	28.70	98.10	56.90						
SiO_2 Rougher Tailings	85.87	12.93	62.95	7.44	24.57	1.90	24.57	62.95	1.90	7.44						
Total	664.07	100.00	33.13	50.50	100.00	100.00	100.00		100.00							
Call Factor			1.02	0.98												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.05	0.50	0.00	0.02	0.06	0.10	0.31	0.13	0.15
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A3.e**

NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 75 g/t, Flotigram 2L 75 g/t,Starch 200g/t, Floatsil1 80g/t
Grind:	80% -45µm
Water Type:	Sishen (Synthetic)
Cell pH:	7

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative M	Grade		Recovery	
			Fe	SiO_2	Fe	SiO_2							Fe	SiO_2	Fe	SiO_2
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	31.07	53.46	100	100
SiO_2 Rougher Conc 1	85.83	12.91	13.69	78.23	5.69	18.89	5.69	13.69	18.89	78.23	Recalc Tai	87.09	33.65	49.79	94.31	81.11
SiO_2 Rougher Conc 2	106.70	16.05	16.17	75.01	8.35	22.52	14.04	15.07	41.41	76.45	Recalc Tai	71.04	37.60	44.09	85.96	58.59
SiO_2 Rougher Conc 3	116.65	17.55	20.76	68.49	11.72	22.48	25.77	17.21	63.89	73.45	Recalc Tai	53.49	43.12	36.08	74.23	36.11
SiO_2 Rougher Conc 4	112.59	16.94	29.24	56.22	15.94	17.81	41.70	20.42	81.70	68.85	Recalc Tai	36.56	49.55	26.76	58.30	18.30
SiO_2 Rougher Conc 5	110.61	16.64	41.05	38.98	21.98	12.13	63.68	24.71	93.83	62.64	Recalc Tai	19.92	56.65	16.55	36.32	6.17
SiO_2 Rougher Conc 6	79.85	12.01	53.00	21.79	20.49	4.90	84.17	28.40	98.73	57.31	Recalc Tai	7.91	62.19	8.59	15.83	1.27
SiO_2 Rougher Concentrate	612.23	92.09	**28.40**	**57.31**	84.17	98.73	84.17	28.40	98.73	57.31						
SiO_2 Rougher Tailings	52.58	7.91	62.19	8.59	15.83	1.27	15.83	62.19	1.27	8.59						
Total	664.81	100.00	31.07	53.46	100.00	100.00	100.00		100.00							
Call Factor			0.96	1.03												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.03	0.50	0.00	0.03	0.07	0.09	0.29	0.12	0.13
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A3.f**

NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 75 g/t, Flotigram 2L 75 g/t,Starch 600g/t, Floatsil1 80g/t
Grind:	80% -45µm
Water Type:	Sishen (Synthetic)
Cell pH:	7

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative M	Grade		Recovery	
			Fe	SiO_2	Fe	SiO_2							Fe	SiO_2	Fe	SiO_2
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	32.96	50.72	100	100
SiO_2 Rougher Conc 1	82.06	11.72	13.27	79.06	4.72	18.26	4.72	13.27	18.26	79.06	Recalc Tai	88.28	35.57	46.96	95.28	81.74
SiO_2 Rougher Conc 2	134.70	19.23	17.04	73.74	9.94	27.96	14.66	15.61	46.22	75.75	Recalc Tai	69.05	40.73	39.50	85.34	53.78
SiO_2 Rougher Conc 3	124.35	17.75	22.05	66.58	11.88	23.30	26.54	17.96	69.52	72.41	Recalc Tai	51.30	47.19	30.13	73.46	30.48
SiO_2 Rougher Conc 4	91.16	13.01	43.80	34.85	17.30	8.94	43.84	23.41	78.47	64.49	Recalc Tai	38.29	48.34	28.53	56.16	21.53
SiO_2 Rougher Conc 5	103.42	14.77	31.21	53.19	13.98	15.49	57.83	24.92	93.95	62.31	Recalc Tai	23.52	59.09	13.04	42.17	6.05
SiO_2 Rougher Conc 6	62.62	8.94	53.56	20.89	14.53	3.68	72.36	27.92	97.63	57.97	Recalc Tai	14.58	62.48	8.23	27.64	2.37
SiO_2 Rougher Concentrate	598.31	85.42	**27.92**	**57.97**	72.36	97.63	72.36	27.92	97.63	57.97						
SiO_2 Rougher Tailings	102.13	14.58	62.48	8.23	27.64	2.37	27.64	62.48	2.37	8.23						
Total	700.44	100.00	32.96	50.72	100.00	100.00	100.00		100.00							
Call Factor			1.01	0.98												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.05	0.50	0.00	0.04	0.07	0.08	0.27	0.11	0.11
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test A3.g**

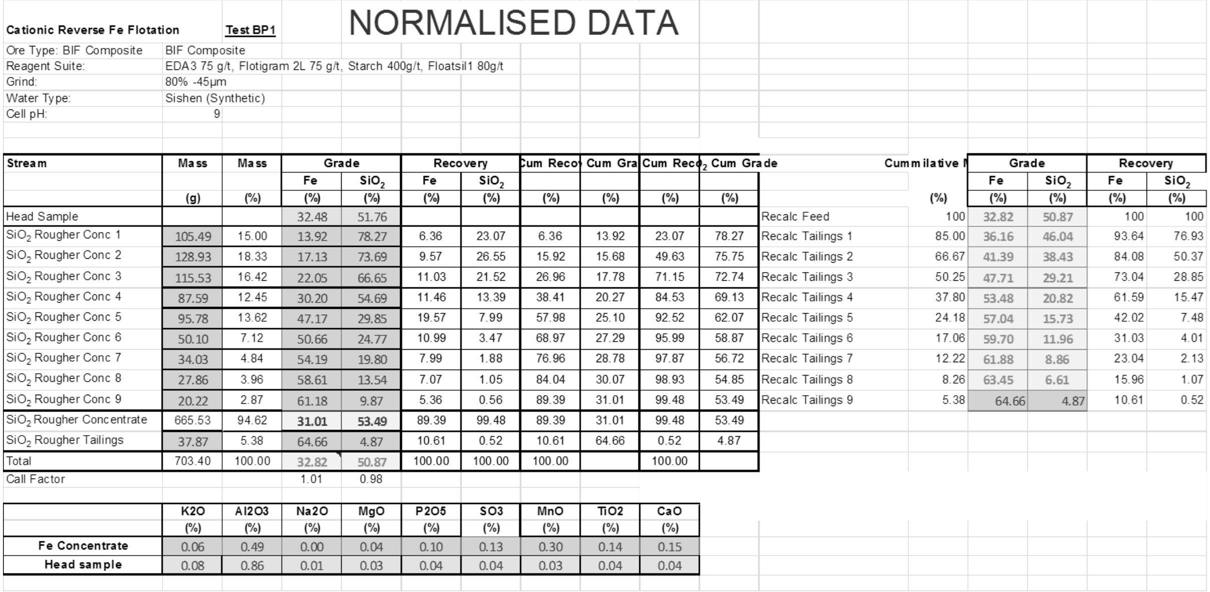
NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 75 g/t, Flotigram 2L 75 g/t,Starch 800g/t, Floatsil1 80g/t
Grind:	80% -45µm
Water Type:	Sishen (Synthetic)
Cell pH:	7

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative M	Grade		Recovery	
			Fe	SiO_2	Fe	SiO_2							Fe	SiO_2	Fe	SiO_2
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	33.12	50.48	100	100
SiO_2 Rougher Conc 1	83.53	11.70	14.88	76.89	5.26	17.82	5.26	14.88	17.82	76.89	Recalc Tai	88.30	35.53	46.98	94.74	82.18
SiO_2 Rougher Conc 2	141.39	19.81	18.80	71.34	11.24	27.99	16.50	17.34	45.82	73.40	Recalc Tai	68.49	40.37	39.94	83.50	54.18
SiO_2 Rougher Conc 3	134.87	18.90	23.43	64.54	13.37	24.16	29.87	19.62	69.97	70.08	Recalc Tai	49.59	46.83	30.57	70.13	30.03
SiO_2 Rougher Conc 4	115.34	16.16	32.69	50.97	15.95	16.31	45.82	22.80	86.29	65.44	Recalc Tai	33.43	53.67	20.70	54.18	13.71
SiO_2 Rougher Conc 5	86.47	12.11	43.84	34.67	16.04	8.32	61.86	26.04	94.61	60.70	Recalc Tai	21.32	59.25	12.77	38.14	5.39
SiO_2 Rougher Conc 6	49.43	6.93	52.17	22.80	10.91	3.13	72.77	28.15	97.74	57.64	Recalc Tai	14.39	62.66	7.94	27.23	2.26
SiO_2 Rougher Concentrate	611.03	85.61	**28.15**	**57.64**	72.77	97.74	72.77	28.15	97.74	57.64						
SiO_2 Rougher Tailings	102.73	14.39	62.66	7.94	27.23	2.26	27.23	62.66	2.26	7.94						
Total	713.76	100.00	33.12	50.48	100.00	100.00	100.00		100.00							
Call Factor			1.02	0.98												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.06	0.54	0.00	0.03	0.07	0.06	0.26	0.11	0.10
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Multi Staged Depressant Dosing



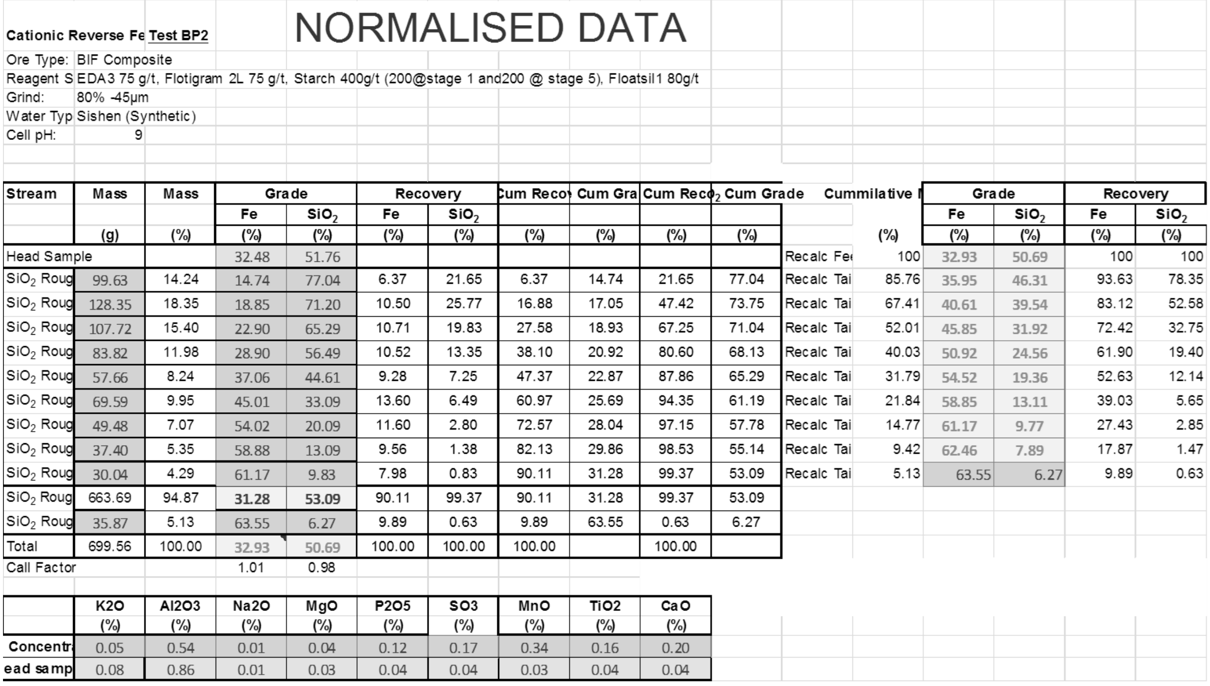
Cationic Reverse Fe Flotation **Test BP1**

NORMALISED DATA

Ore Type: BIF Composite BIF Composite
Reagent Suite: EDA3 75 g/t, Flotigram 2L 75 g/t, Starch 400g/t, Floatsil1 80g/t
Grind: 80% -45µm
Water Type: Sishen (Synthetic)
Cell pH: 9

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO$_2$	Fe	SiO$_2$							Fe	SiO$_2$	Fe	SiO$_2$
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Feed	100	32.82	50.87	100	100
SiO$_2$ Rougher Conc 1	105.49	15.00	13.92	78.27	6.36	23.07	6.36	13.92	23.07	78.27	Recalc Tailings 1	85.00	36.16	46.04	93.64	76.93
SiO$_2$ Rougher Conc 2	128.93	18.33	17.13	73.69	9.57	26.55	15.92	15.68	49.63	75.75	Recalc Tailings 2	66.67	41.39	38.43	84.08	50.37
SiO$_2$ Rougher Conc 3	115.53	16.42	22.05	66.65	11.03	21.52	26.96	17.78	71.15	72.74	Recalc Tailings 3	50.25	47.71	29.21	73.04	28.85
SiO$_2$ Rougher Conc 4	87.59	12.45	30.20	54.69	11.46	13.39	38.41	20.27	84.53	69.13	Recalc Tailings 4	37.80	53.48	20.82	61.59	15.47
SiO$_2$ Rougher Conc 5	95.78	13.62	47.17	29.85	19.57	7.99	57.98	25.10	92.52	62.07	Recalc Tailings 5	24.18	57.04	15.73	42.02	7.48
SiO$_2$ Rougher Conc 6	50.10	7.12	50.66	24.77	10.99	3.47	68.97	27.29	95.99	58.87	Recalc Tailings 6	17.06	59.70	11.96	31.03	4.01
SiO$_2$ Rougher Conc 7	34.03	4.84	54.19	19.80	7.99	1.88	76.96	28.78	97.87	56.72	Recalc Tailings 7	12.22	61.88	8.86	23.04	2.13
SiO$_2$ Rougher Conc 8	27.86	3.96	58.61	13.54	7.07	1.05	84.04	30.07	98.93	54.85	Recalc Tailings 8	8.26	63.45	6.61	15.96	1.07
SiO$_2$ Rougher Conc 9	20.22	2.87	61.18	9.87	5.36	0.56	89.39	31.01	99.48	53.49	Recalc Tailings 9	5.38	64.66	4.87	10.61	0.52
SiO$_2$ Rougher Concentrate	665.53	94.62	**31.01**	**53.49**	89.39	99.48	89.39	31.01	99.48	53.49						
SiO$_2$ Rougher Tailings	37.87	5.38	64.66	4.87	10.61	0.52	10.61	64.66	0.52	4.87						
Total	703.40	100.00	32.82	50.87	100.00	100.00	100.00		100.00							
Call Factor			1.01	0.98												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.06	0.49	0.00	0.04	0.10	0.13	0.30	0.14	0.15
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04



Cationic Reverse Fe **Test BP2**

NORMALISED DATA

Ore Type: BIF Composite
Reagent S EDA3 75 g/t, Flotigram 2L 75 g/t, Starch 400g/t (200@stage 1 and200 @ stage 5), Floatsil1 80g/t
Grind: 80% -45µm
Water Typ Sishen (Synthetic)
Cell pH: 9

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO$_2$	Fe	SiO$_2$							Fe	SiO$_2$	Fe	SiO$_2$
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	32.93	50.69	100	100
SiO$_2$ Roug	99.63	14.24	14.74	77.04	6.37	21.65	6.37	14.74	21.65	77.04	Recalc Tai	85.76	35.95	46.31	93.63	78.35
SiO$_2$ Roug	128.35	18.35	18.85	71.20	10.50	25.77	16.88	17.05	47.42	73.75	Recalc Tai	67.41	40.61	39.54	83.12	52.58
SiO$_2$ Roug	107.72	15.40	22.90	65.29	10.71	19.83	27.58	18.93	67.25	71.04	Recalc Tai	52.01	45.85	31.92	72.42	32.75
SiO$_2$ Roug	83.82	11.98	28.90	56.49	10.52	13.35	38.10	20.92	80.60	68.13	Recalc Tai	40.03	50.92	24.56	61.90	19.40
SiO$_2$ Roug	57.66	8.24	37.06	44.61	9.28	7.25	47.37	22.87	87.86	65.29	Recalc Tai	31.79	54.52	19.36	52.63	12.14
SiO$_2$ Roug	69.59	9.95	45.01	33.09	13.60	6.49	60.97	25.69	94.35	61.19	Recalc Tai	21.84	58.85	13.11	39.03	5.65
SiO$_2$ Roug	49.48	7.07	54.02	20.09	11.60	2.80	72.57	28.04	97.15	57.78	Recalc Tai	14.77	61.17	9.77	27.43	2.85
SiO$_2$ Roug	37.40	5.35	58.88	13.09	9.56	1.38	82.13	29.86	98.53	55.14	Recalc Tai	9.42	62.46	7.89	17.87	1.47
SiO$_2$ Roug	30.04	4.29	61.17	9.83	7.98	0.83	90.11	31.28	99.37	53.09	Recalc Tai	5.13	63.55	6.27	9.89	0.63
SiO$_2$ Roug	663.69	94.87	**31.28**	**53.09**	90.11	99.37	90.11	31.28	99.37	53.09						
SiO$_2$ Roug	35.87	5.13	63.55	6.27	9.89	0.63	9.89	63.55	0.63	6.27						
Total	699.56	100.00	32.93	50.69	100.00	100.00	100.00		100.00							
Call Factor			1.01	0.98												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Concentr	0.05	0.54	0.01	0.04	0.12	0.17	0.34	0.16	0.20
ead samp	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe **Test BP3**

NORMALISED DATA

Ore Type: BIF Composite
Reagent S EDA3 75 g/t, Flotigram 2L 75 g/t, Starch 400g/t, Floatsil1 80g/t
Grind: 80% -75µm
Water Typ Sishen (Synthetic)
Cell pH: 9

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	iO$_2$ Cum Recover	$_2$ Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO$_2$	Fe	SiO$_2$							Fe	SiO$_2$	Fe	SiO$_2$
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	33.53	49.82	100	100
SiO$_2$ Roug	72.19	10.47	17.03	73.41	5.32	15.43	5.32	17.03	15.43	73.41	Recalc Tai	89.53	35.46	47.06	94.68	84.57
SiO$_2$ Roug	101.38	14.71	20.05	69.31	8.79	20.46	14.11	18.79	35.88	71.01	Recalc Tai	74.82	38.49	42.69	85.89	64.12
SiO$_2$ Roug	104.26	15.12	25.07	62.17	11.31	18.87	25.42	21.15	54.75	67.69	Recalc Tai	59.70	41.89	37.76	74.58	45.25
SiO$_2$ Roug	96.09	13.94	26.81	59.64	11.14	16.68	36.56	22.60	71.44	65.62	Recalc Tai	45.76	46.48	31.10	63.44	28.56
SiO$_2$ Roug	66.53	9.65	41.55	37.95	11.96	7.35	48.52	25.46	78.79	61.44	Recalc Tai	36.11	47.79	29.27	51.48	21.21
SiO$_2$ Roug	51.64	7.49	37.55	43.87	8.39	6.60	56.91	26.73	85.38	59.60	Recalc Tai	28.62	50.47	25.44	43.09	14.62
SiO$_2$ Roug	53.19	7.72	38.08	43.19	8.76	6.69	65.68	27.84	92.07	58.00	Recalc Tai	20.91	55.05	18.89	34.32	7.93
SiO$_2$ Roug	43.50	6.31	44.92	33.31	8.45	4.22	74.13	29.10	96.29	56.18	Recalc Tai	14.60	59.43	12.66	25.87	3.71
SiO$_2$ Roug	29.38	4.26	51.99	23.32	6.61	1.99	80.74	30.19	98.29	54.61	Recalc Tai	10.33	62.49	8.27	19.26	1.71
SiO$_2$ Roug	618.16	89.67	**30.19**	**54.61**	80.74	98.29	80.74	30.19	98.29	54.61						
SiO$_2$ Roug	71.25	10.33	62.49	8.27	19.26	1.71	19.26	62.49	1.71	8.27						
Total	689.41	100.00	33.53	49.82	100.00	100.00	100.00		100.00							
Call Factor			1.03	0.96												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Concentr	0.05	0.42	0.01	0.02	0.07	0.09	0.23	0.13	0.15
ead samp	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test BP4**

NORMALISED DATA

Ore Type: BIF Composite BIF Composite
Reagent Suite: EDA3 75 g/t, Flotigram 2L 75 g/t, Starch 400g/t (200@stage 1 and200 @ stage 5), Floatsil1 80g/t
Grind: 80% -75µm
Water Type: Sishen (Synthetic)
Cell pH: 9

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco	$_2$ Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO$_2$	Fe	SiO$_2$							Fe	SiO$_2$	Fe	SiO$_2$
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	33.07	50.46	100	100
SiO$_2$ Rougher Conc 1	73.88	10.60	18.06	71.96	5.79	15.12	5.79	18.06	15.12	71.96	Recalc Tai	89.40	34.85	47.91	94.21	84.88
SiO$_2$ Rougher Conc 2	105.14	15.09	20.44	68.76	9.33	20.56	15.12	19.46	35.68	70.08	Recalc Tai	74.31	37.77	43.68	84.88	64.32
SiO$_2$ Rougher Conc 3	98.98	14.20	22.41	65.96	9.63	18.57	24.75	20.51	54.24	68.61	Recalc Tai	60.10	41.40	38.42	75.25	45.76
SiO$_2$ Rougher Conc 4	76.09	10.92	26.07	60.63	8.61	13.12	33.35	21.70	67.36	66.90	Recalc Tai	49.18	44.81	33.49	66.65	32.64
SiO$_2$ Rougher Conc 5	86.92	12.47	29.80	55.22	11.24	13.65	44.60	23.30	81.01	64.60	Recalc Tai	36.71	49.90	26.10	55.40	18.99
SiO$_2$ Rougher Conc 6	70.81	10.16	37.90	43.45	11.65	8.75	56.24	25.32	89.76	61.67	Recalc Tai	26.55	54.50	19.46	43.76	10.24
SiO$_2$ Rougher Conc 7	61.34	8.80	47.67	29.30	12.69	5.11	68.93	27.71	94.87	58.21	Recalc Tai	17.74	57.89	14.58	31.07	5.13
SiO$_2$ Rougher Conc 8	46.89	6.73	54.12	20.07	11.01	2.68	79.95	29.71	97.55	55.32	Recalc Tai	11.01	60.20	11.22	20.05	2.45
SiO$_2$ Rougher Conc 9	33.70	4.84	58.48	13.78	8.55	1.32	88.50	31.19	98.87	53.18	Recalc Tai	6.18	61.54	9.22	11.50	1.13
SiO$_2$ Rougher Concentrate	653.75	93.82	**31.19**	**53.18**	88.50	98.87	88.50	31.19	98.87	53.18						
SiO$_2$ Rougher Tailings	43.05	6.18	61.54	9.22	11.50	1.13	11.50	61.54	1.13	9.22						
Total	696.80	100.00	33.07	50.46	100.00	100.00	100.00		100.00							
Call Factor			1.02	0.98												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.06	0.58	0.00	0.04	0.11	0.17	0.26	0.16	0.21
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Collector Dosage Evaluation and Grinding Size Evaluation

Cationic Reverse Fe Flotation **Test B1.25** NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 18.75 g/t, Flotigram 2L 18.75 g/t, Starch 200g/t, Floatsil1 80g/t
Grind:	80% -25µm
Water Type:	Sishen (Synthetic)
Cell pH:	9

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO$_2$	Fe	SiO$_2$							Fe	SiO$_2$	Fe	SiO$_2$
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	32.73	51.07	100	100
SiO$_2$ Rougher Conc 1	46.10	6.67	11.17	82.33	2.28	10.75	2.28	11.17	10.75	82.33	Recalc Tai	93.33	34.27	48.83	97.72	89.25
SiO$_2$ Rougher Conc 2	65.58	9.48	12.86	79.84	3.73	14.83	6.00	12.16	25.58	80.87	Recalc Tai	83.85	36.69	45.32	94.00	74.42
SiO$_2$ Rougher Conc 3	82.04	11.86	16.51	74.67	5.98	17.35	11.99	14.00	42.93	78.25	Recalc Tai	71.98	40.02	40.49	88.01	57.07
SiO$_2$ Rougher Conc 4	76.16	11.01	14.02	78.28	4.72	16.88	16.71	14.01	59.81	78.25	Recalc Tai	60.97	44.71	33.66	83.29	40.19
SiO$_2$ Rougher Conc 5	64.52	9.33	19.73	70.05	5.63	12.80	22.33	15.11	72.61	76.67	Recalc Tai	51.64	49.23	27.08	77.67	27.39
SiO$_2$ Rougher Conc 6	53.26	7.70	24.75	62.67	5.83	9.45	28.16	16.44	82.07	74.75	Recalc Tai	43.94	53.52	20.85	71.84	17.93
SiO$_2$ Rougher Concentrate	387.66	56.06	**16.44**	**74.75**	28.16	82.07	28.16	16.44	82.07	74.75						
SiO$_2$ Rougher Tailings	303.79	43.94	53.52	20.85	71.84	17.93	71.84	53.52	17.93	20.85						
Total	691.45	100.00	32.73	51.07	100.00	100.00	100.00		100.00							
Call Factor			1.01	0.99												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.10	0.85	0.00	0.04	0.08	0.08	0.22	0.11	0.11
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test B1.26** NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 37.5 g/t, Flotigram 2L 37.5 g/t, Starch 200g/t, Floatsil1 80g/t
Grind:	80% -25µm
Water Type:	Sishen (Synthetic)
Cell pH:	9

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO$_2$	Fe	SiO$_2$							Fe	SiO$_2$	Fe	SiO$_2$
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	32.62	51.19	100	100
SiO$_2$ Rougher Conc 1	54.88	7.83	11.44	81.84	2.75	12.52	2.75	11.44	12.52	81.84	Recalc Tai	92.17	34.42	48.58	97.25	87.48
SiO$_2$ Rougher Conc 2	88.59	12.65	13.24	79.35	5.13	19.60	7.88	12.55	32.12	80.30	Recalc Tai	79.52	37.78	43.69	92.12	67.88
SiO$_2$ Rougher Conc 3	91.83	13.11	15.29	76.41	6.14	19.57	14.02	13.62	51.69	78.78	Recalc Tai	66.41	42.22	37.24	85.98	48.31
SiO$_2$ Rougher Conc 4	83.22	11.88	18.39	71.90	6.70	16.69	20.72	14.86	68.38	76.98	Recalc Tai	54.53	47.41	29.68	79.28	31.62
SiO$_2$ Rougher Conc 5	64.20	9.16	24.39	63.09	6.85	11.29	27.57	16.46	79.67	74.65	Recalc Tai	45.37	52.06	22.94	72.43	20.33
SiO$_2$ Rougher Conc 6	52.62	7.51	33.17	50.17	7.64	7.36	35.21	18.48	87.03	71.69	Recalc Tai	37.86	55.81	17.53	64.79	12.97
SiO$_2$ Rougher Concentrate	435.34	62.14	**18.48**	**71.69**	35.21	87.03	35.21	18.48	87.03	71.69						
SiO$_2$ Rougher Tailings	265.24	37.86	55.81	17.53	64.79	12.97	64.79	55.81	12.97	17.53						
Total	700.58	100.00	32.62	51.19	100.00	100.00	100.00		100.00							
Call Factor			1.00	0.99												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.08	0.81	0.00	0.04	0.08	0.09	0.24	0.12	0.12
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test B1.27** NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 75 g/t, Flotigram 2L 75 g/t, Starch 200g/t, Floatsil1 80g/t
Grind:	80% -25µm
Water Type:	Sishen (Synthetic)
Cell pH:	9

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO$_2$	Fe	SiO$_2$							Fe	SiO$_2$	Fe	SiO$_2$
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Feed	100	32.56	51.23	100	100
SiO$_2$ Rougher Conc 1	86.99	12.28	13.05	79.56	4.92	19.07	4.92	13.05	19.07	79.56	Recalc Tailings 1	87.72	35.29	47.26	95.08	80.93
SiO$_2$ Rougher Conc 2	128.90	18.19	16.13	75.17	9.01	26.70	13.93	14.89	45.77	76.94	Recalc Tailings 2	69.53	40.30	39.96	86.07	54.23
SiO$_2$ Rougher Conc 3	110.91	15.65	19.47	70.31	9.36	21.49	23.29	16.44	67.25	74.69	Recalc Tailings 3	53.87	46.36	31.14	76.71	32.75
SiO$_2$ Rougher Conc 4	82.43	11.63	25.61	61.29	9.15	13.92	32.45	18.29	81.17	71.99	Recalc Tailings 4	42.24	52.07	22.83	67.55	18.83
SiO$_2$ Rougher Conc 5	65.40	9.23	36.15	45.90	10.25	8.27	42.70	20.75	89.44	68.39	Recalc Tailings 5	33.01	56.52	16.38	57.30	10.56
SiO$_2$ Rougher Conc 6	60.96	8.60	47.53	29.36	12.56	4.93	55.26	23.80	94.38	63.95	Recalc Tailings 6	24.40	59.70	11.81	44.74	5.62
SiO$_2$ Rougher Concentrate	535.59	75.60	**23.80**	**63.95**	55.26	94.38	55.26	23.80	94.38	63.95						
SiO$_2$ Rougher Tailings	172.88	24.40	59.70	11.81	44.74	5.62	44.74	59.70	5.62	11.81						
Total	708.47	100.00	32.56	51.23	100.00	100.00	100.00		100.00							
Call Factor			1.00	0.99												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.10	0.77	0.01	0.04	0.09	0.10	0.27	0.13	0.15
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test B1.30**

NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 18.75 g/t, Flotigram 2L 18.75 g/t, Starch 400g/t, Floatsil1 80g/t
Grind:	80% -25µm
Water Type:	Sishen (Synthetic)
Cell pH:	9

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade
			Fe	SiO_2	Fe	SiO_2				
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76						
SiO_2 Rougher Conc 1	47.33	6.50	12.06	80.82	2.39	10.30	2.39	12.06	10.30	80.82
SiO_2 Rougher Conc 2	79.83	10.97	14.40	77.57	4.82	16.68	7.22	13.53	26.99	78.78
SiO_2 Rougher Conc 3	88.74	12.19	16.75	74.25	6.24	17.75	13.45	14.85	44.73	76.92
SiO_2 Rougher Conc 4	82.46	11.33	19.07	70.89	6.60	15.75	20.05	16.02	60.48	75.25
SiO_2 Rougher Conc 5	69.53	9.55	22.20	66.33	6.48	12.42	26.53	17.19	72.90	73.57
SiO_2 Rougher Conc 6	58.22	8.00	28.15	57.53	6.88	9.02	33.40	18.68	81.93	71.37
SiO_2 Rougher Concentrate	426.11	58.54	**18.68**	**71.37**	33.40	81.93	33.40	18.68	81.93	71.37
SiO_2 Rougher Tailings	301.80	41.46	52.60	22.23	66.60	18.07	66.60	52.60	18.07	22.23
Total	727.91	100.00	32.74	51.00	100.00	100.00	100.00		100.00	
Call Factor			1.01	0.99						

	Cummilative M	Grade		Recovery	
		Fe	SiO_2	Fe	SiO_2
	(%)	(%)	(%)	(%)	(%)
Recalc Fe	100	32.74	51.00	100	100
Recalc Tai	93.50	34.18	48.93	97.61	89.70
Recalc Tai	82.53	36.81	45.12	92.78	73.01
Recalc Tai	70.34	40.29	40.07	86.55	55.27
Recalc Tai	59.01	44.36	34.15	79.95	39.52
Recalc Tai	49.46	48.64	27.94	73.47	27.10
Recalc Tai	41.46	52.60	22.23	66.60	18.07

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.09	0.81	0.00	0.04	0.07	0.08	0.23	0.11	0.11
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test B1.31**

NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 75 g/t, Flotigram 2L 75 g/t, Starch 400g/t, Floatsil1 80g/t
Grind:	80% -25µm
Water Type:	Sishen (Synthetic)
Cell pH:	9

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade
			Fe	SiO_2	Fe	SiO_2				
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76						
SiO_2 Rougher Conc 1	88.11	12.83	14.95	76.93	5.67	19.95	5.67	14.95	19.95	76.93
SiO_2 Rougher Conc 2	134.00	19.51	20.81	68.44	12.00	26.99	17.67	18.49	46.94	71.81
SiO_2 Rougher Conc 3	117.85	17.16	22.06	66.62	11.18	23.11	28.85	19.73	70.04	70.01
SiO_2 Rougher Conc 4	82.51	12.01	29.87	55.15	10.60	13.39	39.46	21.71	83.43	67.11
SiO_2 Rougher Conc 5	65.46	9.53	40.91	39.10	11.52	7.53	50.98	24.28	90.96	63.35
SiO_2 Rougher Conc 6	59.28	8.63	50.88	24.63	12.98	4.30	63.96	27.16	95.26	59.16
SiO_2 Rougher Conc 7	53.78	7.83	57.21	15.55	13.24	2.46	77.20	29.85	97.72	55.25
SiO_2 Rougher Conc 8	37.59	5.47	59.89	11.74	9.69	1.30	86.88	31.62	99.02	52.69
SiO_2 Rougher Conc 9	24.13	3.51	62.31	8.31	6.47	0.59	93.35	32.74	99.61	51.08
SiO_2 Rougher Concentrate	662.71	96.50	**32.74**	**51.08**	93.35	99.61	93.35	32.74	99.61	51.08
SiO_2 Rougher Tailings	24.07	3.50	64.19	5.49	6.65	0.39	6.65	64.19	0.39	5.49
Total	686.78	100.00	33.84	49.48	100.00	100.00	100.00		100.00	
Call Factor			1.04	0.96						

	Cummilative M	Grade		Recovery	
		Fe	SiO_2	Fe	SiO_2
	(%)	(%)	(%)	(%)	(%)
Recalc Feed	100	33.84	49.48	100	100
Recalc Tailings 1	87.17	36.62	45.44	94.33	80.05
Recalc Tailings 2	67.66	41.18	38.81	82.33	53.06
Recalc Tailings 3	50.50	47.68	29.35	71.15	29.96
Recalc Tailings 4	38.49	53.24	21.30	60.54	16.57
Recalc Tailings 5	28.95	57.30	15.44	49.02	9.04
Recalc Tailings 6	20.32	60.02	11.54	36.04	4.74
Recalc Tailings 7	12.49	61.78	9.02	22.80	2.28
Recalc Tailings 8	7.02	63.25	6.90	13.12	0.98
Recalc Tailings 9	3.50	64.19	5.49	6.65	0.39

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.05	0.49	0.00	0.03	0.08	0.11	0.39	0.15	0.19
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test B1.32**

NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 37.5 g/t, Flotigram 2L 37.5 g/t, Starch 200g/t, Floatsil1 80g/t
Grind:	80% -25µm
Water Type:	Sishen (Synthetic)
Cell pH:	9

Stream	Mass	Mass	Grade		Recovery		Fe Cum Recovery	Fe Cum Grade	SiO_2 Cum Recovery	SiO_2 Cum Grade
			Fe	SiO_2	Fe	SiO_2				
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76						
SiO_2 Rougher Conc 1	66.89	9.45	12.96	79.72	3.67	15.00	3.67	12.96	15.00	79.72
SiO_2 Rougher Conc 2	104.82	14.81	16.16	75.14	7.18	22.15	10.85	14.92	37.14	76.92
SiO_2 Rougher Conc 3	107.11	15.13	18.38	72.04	8.34	21.70	19.19	16.25	58.85	75.05
SiO_2 Rougher Conc 4	90.68	12.81	23.21	64.99	8.92	16.57	28.10	17.96	75.42	72.58
SiO_2 Rougher Conc 5	70.14	9.91	31.01	53.57	9.21	10.57	37.32	20.04	85.99	69.55
SiO_2 Rougher Conc 6	57.26	8.09	41.28	38.50	10.01	6.20	47.33	22.49	92.19	65.97
SiO_2 Rougher Conc 7	54.77	7.74	51.54	23.79	11.96	3.66	59.29	25.37	95.85	61.78
SiO_2 Rougher Conc 8	52.62	7.43	57.45	15.17	12.81	2.25	72.10	28.16	98.09	57.72
SiO_2 Rougher Conc 9	40.97	5.79	62.04	8.69	10.77	1.00	82.86	30.32	99.10	54.61
SiO_2 Rougher Concentrate	645.26	91.14	**30.32**	**54.61**	82.86	99.10	82.86	30.32	99.10	54.61
SiO_2 Rougher Tailings	62.74	8.86	64.48	5.13	17.14	0.90	17.14	64.48	0.90	5.13
Total	708.00	100.00	33.34	50.22	100.00	100.00	100.00		100.00	
Call Factor			1.03	0.97						

	Cum Mass	Grade		Recovery	
		Fe	SiO_2	Fe	SiO_2
	(%)	(%)	(%)	(%)	(%)
Recalc Feed	100	33.34	50.22	100	100
Recalc Tailings 1	90.55	35.47	47.15	96.33	85.00
Recalc Tailings 2	75.75	39.24	41.68	89.15	62.86
Recalc Tailings 3	60.62	44.45	34.10	80.81	41.15
Recalc Tailings 4	47.81	50.14	25.82	71.90	24.58
Recalc Tailings 5	37.90	55.14	18.57	62.68	14.01
Recalc Tailings 6	29.82	58.90	13.16	52.67	7.81
Recalc Tailings 7	22.08	61.47	9.44	40.71	4.15
Recalc Tailings 8	14.65	63.52	6.53	27.90	1.91
Recalc Tailings 9	8.86	64.48	5.13	17.14	0.90

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.06	0.50	0.00	0.03	0.09	0.11	0.32	0.15	0.16
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test B1.33**

NORMALISED DATA

Ore Type: BIF Composite BIF Composite
Reagent Suite: EDA3 18.75 g/t, Flotigram 2L 18.75 g/t, Starch 400g/t, Floatsil1 80g/t
Grind: 80% -25μm
Water Type: Sishen (Synthetic)
Cell pH: 9

Stream	Mass	Mass	Grade		Recovery		e Cum Recover	Cum Gra	Cum Reco	$_2$ Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO_2	Fe	SiO_2							Fe	SiO_2	Fe	SiO_2
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Feed	100	33.42	50.13	100	100
SiO_2 Rougher Conc 1	46.43	6.77	11.44	81.97	2.32	11.07	2.32	11.44	11.07	81.97	Recalc Tailings 1	93.23	35.01	47.82	97.68	88.93
SiO_2 Rougher Conc 2	74.15	10.81	14.16	77.99	4.58	16.82	6.90	13.12	27.89	79.53	Recalc Tailings 2	82.42	37.75	43.86	93.10	72.11
SiO_2 Rougher Conc 3	83.70	12.20	15.71	75.84	5.74	18.46	12.64	14.18	46.35	78.02	Recalc Tailings 3	70.22	41.58	38.30	87.36	53.65
SiO_2 Rougher Conc 4	76.85	11.20	18.52	71.82	6.21	16.05	18.85	15.37	62.40	76.32	Recalc Tailings 4	59.02	45.95	31.94	81.15	37.60
SiO_2 Rougher Conc 5	66.61	9.71	22.93	65.35	6.66	12.66	25.51	16.82	75.06	74.22	Recalc Tailings 5	49.30	50.49	25.36	74.49	24.94
SiO_2 Rougher Conc 6	56.63	8.26	29.51	55.75	7.29	9.18	32.80	18.59	84.24	71.64	Recalc Tailings 6	41.05	54.71	19.25	67.20	15.76
SiO_2 Rougher Conc 7	47.30	6.90	38.43	42.71	7.93	5.87	40.73	20.67	90.11	68.61	Recalc Tailings 7	34.15	57.99	14.51	59.27	9.89
SiO_2 Rougher Conc 8	44.79	6.53	46.70	30.69	9.13	4.00	49.86	23.02	94.11	65.19	Recalc Tailings 8	27.62	60.66	10.69	50.14	5.89
SiO_2 Rougher Conc 9	48.82	7.12	54.51	19.47	11.61	2.76	61.47	25.84	96.88	61.09	Recalc Tailings 9	20.51	62.79	7.64	38.53	3.12
SiO_2 Rougher Concentrate	545.28	79.49	**25.84**	**61.09**	61.47	96.88	61.47	25.84	96.88	61.09						
SiO_2 Rougher Tailings	140.66	20.51	62.79	7.64	38.53	3.12	38.53	62.79	3.12	7.64						
Total	685.94	100.00	33.42	50.13	100.00	100.00	100.00		100.00							
Call Factor			1.03	0.97												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.06	0.54	0.01	0.04	0.07	0.08	0.28	0.14	0.13
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test B1.b**

NORMALISED DATA

Ore Type: BIF Composite BIF Composite
Reagent Suite: EDA3 18.75 g/t, Flotigram 2L 18.75 g/t, Starch 200g/t, Floatsil1 80g/t
Grind: 80% -25μm
Water Type: Sishen (Synthetic)
Cell pH: 9

Stream	Mass	Mass	Grade		Recovery		Cum Recov	Cum Gra	Cum Reco	$_2$ Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO_2	Fe	SiO_2							Fe	SiO_2	Fe	SiO_2
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Feed	100	33.10	51.05	100	100
SiO_2 Rougher Conc 1	86.33	12.58	15.79	75.65	6.00	18.64	6.00	15.79	18.64	75.65	Recalc Tailings 1	87.42	35.59	47.51	94.00	81.36
SiO_2 Rougher Conc 2	119.86	17.47	16.11	75.33	8.50	25.78	14.51	15.98	44.42	75.46	Recalc Tailings 2	69.95	40.45	40.56	85.49	55.58
SiO_2 Rougher Conc 3	111.15	16.20	19.64	70.14	9.61	22.26	24.12	17.26	66.68	73.60	Recalc Tailings 3	53.75	46.72	31.65	75.88	33.32
SiO_2 Rougher Conc 4	82.02	11.95	26.67	59.88	9.63	14.02	33.75	19.19	80.70	70.78	Recalc Tailings 4	41.80	52.46	23.58	66.25	19.30
SiO_2 Rougher Conc 5	64.50	9.40	37.94	43.42	10.78	8.00	44.53	21.80	88.69	66.98	Recalc Tailings 5	32.39	56.67	17.82	55.47	11.31
SiO_2 Rougher Conc 6	59.83	8.72	48.61	27.94	12.81	4.77	57.33	24.86	93.47	62.52	Recalc Tailings 6	23.67	59.65	14.09	42.67	6.53
SiO_2 Rougher Conc 7	63.07	9.19	56.03	17.27	15.56	3.11	72.90	28.21	96.58	57.65	Recalc Tailings 7	14.48	61.94	12.07	27.10	3.42
SiO_2 Rougher Conc 8	44.60	6.50	60.43	10.89	11.87	1.39	84.76	30.49	97.96	54.35	Recalc Tailings 8	7.98	63.18	13.03	15.24	2.04
SiO_2 Rougher Conc 9	28.19	4.11	62.83	19.47	7.80	1.57	92.56	31.87	99.53	52.86	Recalc Tailings 9	3.87	63.54	6.20	7.44	0.47
SiO_2 Rougher Concentrate	659.55	96.13	**31.87**	**52.86**	92.56	99.53	92.56	31.87	99.53	52.86						
SiO_2 Rougher Tailings	26.58	3.87	63.54	6.20	7.44	0.47	7.44	63.54	0.47	6.20						
Total	686.13	100.00	33.10	51.05	100.00	100.00	100.00		100.00							
Call Factor			1.02	0.99												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.06	0.58	0.00	0.04	0.10	0.16	0.39	0.19	0.20
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test B2.34**

NORMALISED DATA

Ore Type: BIF Composite BIF Composite
Reagent Suite: EDA3 18.75 g/t, Flotigram 2L 18.75 g/t, Starch 200g/t, Floatsil1 80g/t
Grind: 80% -45μm
Water Type: Sishen (Synthetic)
Cell pH: 9

Stream	Mass	Mass	Grade		Recovery		Cum Recov	Cum Gra	Cum Reco	$_2$ Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO_2	Fe	SiO_2							Fe	SiO_2	Fe	SiO_2
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	32.76	51.01	100	100
SiO_2 Rougher Conc 1	49.82	7.28	12.92	79.60	2.87	11.35	2.87	12.92	11.35	79.60	Recalc Tai	92.72	34.31	48.77	97.13	88.65
SiO_2 Rougher Conc 2	76.29	11.14	14.18	77.87	4.82	17.01	7.69	13.68	28.36	78.55	Recalc Tai	81.58	37.06	44.79	92.31	71.64
SiO_2 Rougher Conc 3	88.96	12.99	16.54	74.61	6.56	19.00	14.25	14.86	47.36	76.92	Recalc Tai	68.59	40.95	39.15	85.75	52.64
SiO_2 Rougher Conc 4	80.55	11.76	20.05	69.55	7.20	16.04	21.45	16.28	63.40	74.92	Recalc Tai	56.83	45.27	32.85	78.55	36.60
SiO_2 Rougher Conc 5	69.45	10.14	25.74	61.25	7.97	12.18	29.42	18.08	75.58	72.32	Recalc Tai	46.69	49.52	26.68	70.58	24.42
SiO_2 Rougher Conc 6	64.85	9.47	32.05	52.09	9.27	9.67	38.69	20.18	85.25	69.26	Recalc Tai	37.22	53.96	20.22	61.31	14.75
SiO_2 Rougher Concentrate	429.92	62.78	**20.18**	**69.26**	38.69	85.25	38.69	20.18	85.25	69.26						
SiO_2 Rougher Tailings	254.83	37.22	53.96	20.22	61.31	14.75	61.31	53.96	14.75	20.22						
Total	684.75	100.00	32.76	51.01	100.00	100.00	100.00		100.00							
Call Factor			1.01	0.99												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.08	0.85	0.00	0.03	0.08	0.09	0.21	0.12	0.12
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test B2.35**

NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 37.5 g/t, Flotigram 2L 37.5 g/t, Starch 200g/t, Floatsil1 80g/t
Grind:	80% -45µm
Water Type:	Sishen (Synthetic)
Cell pH:	9

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO_2	Fe	SiO_2							Fe	SiO_2	Fe	SiO_2
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	32.69	51.07	100	100
SiO_2 Rougher Conc 1	69.48	9.99	12.84	79.77	3.92	15.61	3.92	12.84	15.61	79.77	Recalc Tai	90.01	34.90	47.88	96.08	84.39
SiO_2 Rougher Conc 2	109.75	15.78	15.38	76.22	7.42	23.55	11.35	14.40	39.16	77.59	Recalc Tai	74.23	39.05	41.86	88.65	60.84
SiO_2 Rougher Conc 3	109.10	15.69	19.17	70.80	9.20	21.75	20.55	16.20	60.91	75.02	Recalc Tai	58.54	44.38	34.10	79.45	39.09
SiO_2 Rougher Conc 4	89.16	12.82	24.88	62.49	9.76	15.69	30.31	18.25	76.60	72.06	Recalc Tai	45.71	49.85	26.14	69.69	23.40
SiO_2 Rougher Conc 5	74.78	10.75	33.57	49.77	11.04	10.48	41.35	20.78	87.08	68.38	Recalc Tai	34.96	54.85	18.87	58.65	12.92
SiO_2 Rougher Conc 6	63.67	9.16	44.09	34.46	12.35	6.18	53.70	23.66	93.26	64.19	Recalc Tai	25.80	58.67	13.34	46.30	6.74
SiO_2 Rougher Concentrate	515.94	74.20	**23.66**	**64.19**	53.70	93.26	53.70	23.66	93.26	64.19						
SiO_2 Rougher Tailings	179.43	25.80	58.67	13.34	46.30	6.74	46.30	58.67	6.74	13.34						
Total	695.37	100.00	32.69	51.07	100.00	100.00	100.00		100.00							
Call Factor			1.01	0.99												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.09	0.80	0.00	0.04	0.09	0.10	0.24	0.13	0.13
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test B2.36**

NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 75 g/t, Flotigram 2L 75 g/t, Starch 200g/t, Floatsil1 80g/t
Grind:	80% -45µm
Water Type:	Sishen (Synthetic)
Cell pH:	9

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO_2	Fe	SiO_2							Fe	SiO_2	Fe	SiO_2
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	32.49	51.39	100	100
SiO_2 Rougher Conc 1	104.49	14.63	14.35	77.67	6.46	22.11	6.46	14.35	22.11	77.67	Recalc Tai	85.37	35.60	46.89	93.54	77.89
SiO_2 Rougher Conc 2	147.83	20.70	17.77	72.80	11.32	29.32	17.78	16.35	51.44	74.82	Recalc Tai	64.67	41.30	38.59	82.22	48.56
SiO_2 Rougher Conc 3	123.20	17.25	22.93	65.39	12.17	21.95	29.96	18.51	73.39	71.73	Recalc Tai	47.42	47.99	28.84	70.04	26.61
SiO_2 Rougher Conc 4	97.35	13.63	32.29	51.70	13.55	13.71	43.51	21.35	87.10	67.60	Recalc Tai	33.79	54.32	19.63	56.49	12.90
SiO_2 Rougher Conc 5	78.92	11.05	45.31	32.67	15.41	7.03	58.92	24.78	94.12	62.61	Recalc Tai	22.74	58.70	13.28	41.08	5.88
SiO_2 Rougher Conc 6	75.22	10.53	55.33	18.19	17.94	3.73	76.86	28.44	97.85	57.28	Recalc Tai	12.21	61.60	9.05	23.14	2.15
SiO_2 Rougher Concentrate	627.01	87.79	**28.44**	**57.28**	76.86	97.85	76.86	28.44	97.85	57.28						
SiO_2 Rougher Tailings	87.17	12.21	61.60	9.05	23.14	2.15	23.14	61.60	2.15	9.05						
Total	714.18	100.00	32.49	51.39	100.00	100.00	100.00		100.00							
Call Factor			1.00	0.99												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.07	0.69	0.01	0.04	0.11	0.14	0.29	0.16	0.17
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test B2.37**

NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 112.5 g/t, Flotigram 2L 112.5 g/t, Starch 200g/t, Floatsil1 80g/t
Grind:	80% -45µm
Water Type:	Sishen (Synthetic)
Cell pH:	9

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO_2	Fe	SiO_2							Fe	SiO_2	Fe	SiO_2
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	32.96	50.76	100	100
SiO_2 Rougher Conc 1	205.88	28.98	18.36	71.99	16.14	41.10	71.99	18.36	41.10	71.99	Recalc Tai	71.02	38.92	42.10	83.86	58.90
SiO_2 Rougher Conc 2	183.41	25.81	22.60	65.85	17.70	33.49	137.84	20.36	74.59	69.10	Recalc Tai	45.21	48.24	28.53	66.17	25.41
SiO_2 Rougher Conc 3	102.56	14.43	35.47	47.05	15.53	13.38	184.89	23.51	87.97	64.50	Recalc Tai	30.78	54.24	19.85	50.64	12.03
SiO_2 Rougher Conc 4	102.16	14.38	49.64	26.60	21.65	7.53	211.49	28.00	95.50	57.98	Recalc Tai	16.40	58.26	13.93	28.98	4.50
SiO_2 Rougher Conc 5	73.11	10.29	57.12	15.69	17.83	3.18	227.17	31.19	98.68	53.35	Recalc Tai	6.11	60.19	10.97	11.16	1.32
SiO_2 Rougher Conc 6	28.69	4.04	59.99	11.40	7.35	0.91	238.57	32.38	99.59	51.62	Recalc Tai	2.07	60.59	10.14	3.81	0.41
SiO_2 Rougher Concentrate	695.81	97.93	**32.38**	**51.62**	96.19	99.59	238.57	32.38	99.59	51.62						
SiO_2 Rougher Tailings	14.72	2.07	60.59	10.14	3.81	0.41	3.81	60.59	0.41	10.14						
Total	710.53	100.00	32.96	50.76	100.00	100.00	242.38		100.00							
Call Factor			1.01	0.98												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.11	0.72	0.01	0.04	0.14	0.17	0.39	0.18	0.29
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test B2.38**

NORMALISED DATA

Ore Type: BIF Composite BIF Composite
Reagent Suite: EDA3 150 g/t, Flotigram 2L 150 g/t, Starch 200g/t, Floatsil1 80g/t
Grind: 80% -45µm
Water Type: Sishen (Synthetic)
Cell pH: 9

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative M	Grade		Recovery	
			Fe	SiO_2	Fe	SiO_2							Fe	SiO_2	Fe	SiO_2
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	32.23	51.79	100	100
SiO_2 Rougher Conc 1	216.80	29.21	17.96	72.55	16.27	40.92	16.27	17.96	40.92	72.55	Recalc Tai	70.79	38.12	43.22	83.73	59.08
SiO_2 Rougher Conc 2	186.92	25.18	22.77	65.62	17.79	31.91	34.07	20.18	72.83	69.34	Recalc Tai	45.61	46.59	30.85	65.93	27.17
SiO_2 Rougher Conc 3	111.13	14.97	34.63	48.25	16.09	13.95	50.16	23.30	86.78	64.79	Recalc Tai	30.63	52.44	22.35	49.84	13.22
SiO_2 Rougher Conc 4	100.72	13.57	48.23	28.50	20.31	7.47	70.46	27.38	94.25	58.85	Recalc Tai	17.06	55.79	17.46	29.54	5.75
SiO_2 Rougher Conc 5	79.00	10.64	55.13	18.40	18.21	3.78	88.67	30.54	98.03	54.25	Recalc Tai	6.42	56.87	15.90	11.33	1.97
SiO_2 Rougher Conc 6	34.69	4.67	58.70	13.20	8.51	1.19	97.18	31.88	99.22	52.30	Recalc Tai	1.75	51.98	23.14	2.82	0.78
SiO_2 Rougher Concentrate	729.26	98.25	**31.88**	**52.30**	97.18	99.22	97.18	31.88	99.22	52.30						
SiO_2 Rougher Tailings	12.96	1.75	51.98	23.14	2.82	0.78	2.82	51.98	0.78	23.14						
Total	742.22	100.00	32.23	51.79	100.00	100.00	100.00		100.00							
Call Factor			0.99	1.00												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.11	0.83	0.00	0.03	0.07	0.07	0.20	0.11	0.11
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test B2.39**

NORMALISED DATA

Ore Type: BIF Composite BIF Composite
Reagent Suite: EDA3 18.75 g/t, Flotigram 2L 18.75 g/t, Starch 400g/t, Floatsil1 80g/t
Grind: 80% -45µm
Water Type: Sishen (Synthetic)
Cell pH: 9

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative M	Grade		Recovery	
			Fe	SiO_2	Fe	SiO_2							Fe	SiO_2	Fe	SiO_2
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	32.58	51.26	100	100
SiO_2 Rougher Conc 1	50.41	6.92	13.57	78.64	2.88	10.62	2.88	13.57	10.62	78.64	Recalc Tai	93.08	33.99	49.23	97.12	89.38
SiO_2 Rougher Conc 2	83.35	11.45	14.43	77.57	5.07	17.32	7.95	14.11	27.94	77.97	Recalc Tai	81.63	36.73	45.25	92.05	72.06
SiO_2 Rougher Conc 3	92.06	12.64	16.49	74.64	6.40	18.41	14.36	15.08	46.35	76.62	Recalc Tai	68.99	40.44	39.86	85.64	53.65
SiO_2 Rougher Conc 4	86.67	11.90	19.32	70.56	7.06	16.38	21.42	16.26	62.74	74.94	Recalc Tai	57.08	44.85	33.46	78.58	37.26
SiO_2 Rougher Conc 5	74.50	10.23	24.23	63.41	7.61	12.66	29.03	17.79	75.39	72.72	Recalc Tai	46.85	49.35	26.92	70.97	24.61
SiO_2 Rougher Conc 6	71.48	9.82	30.78	53.82	9.28	10.31	38.30	19.82	85.70	69.77	Recalc Tai	37.04	54.27	19.79	61.70	14.30
SiO_2 Rougher Concentrate	458.47	62.96	**19.82**	**69.77**	38.30	85.70	38.30	19.82	85.70	69.77						
SiO_2 Rougher Tailings	269.68	37.04	54.27	19.79	61.70	14.30	61.70	54.27	14.30	19.79						
Total	728.15	100.00	32.58	51.26	100.00	100.00	100.00		100.00							
Call Factor			1.00	0.99												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.09	0.84	0.00	0.04	0.08	0.08	0.20	0.11	0.11
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test B3.43**

NORMALISED DATA

Ore Type: BIF Composite BIF Composite
Reagent Suite: EDA3 18.75 g/t, Flotigram 2L 18.75 g/t, Starch 200g/t, Floatsil1 80g/t
Grind: 80% -75µm
Water Type: Sishen (Synthetic)
Cell pH: 9

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative M	Grade		Recovery	
			Fe	SiO_2	Fe	SiO_2							Fe	SiO_2	Fe	SiO_2
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	33.11	50.41	100	100
SiO_2 Rougher Conc 1	42.62	6.18	17.23	73.11	3.22	8.97	3.22	17.23	8.97	73.11	Recalc Tai	93.82	34.15	48.92	96.78	91.03
SiO_2 Rougher Conc 2	67.19	9.75	17.30	73.26	5.09	14.16	8.31	17.27	23.13	73.21	Recalc Tai	84.07	36.11	46.10	91.69	76.87
SiO_2 Rougher Conc 3	71.77	10.41	19.93	69.53	6.27	14.36	14.58	18.32	37.49	71.75	Recalc Tai	73.66	38.39	42.78	85.42	62.51
SiO_2 Rougher Conc 4	74.00	10.73	22.94	65.24	7.44	13.89	22.02	19.66	51.38	69.87	Recalc Tai	62.92	41.03	38.95	77.98	48.62
SiO_2 Rougher Conc 5	81.67	11.85	26.23	60.50	9.39	14.22	31.41	21.25	65.60	67.60	Recalc Tai	51.08	44.46	33.95	68.59	34.40
SiO_2 Rougher Conc 6	82.51	11.97	29.61	55.56	10.71	13.19	42.11	22.90	78.79	65.23	Recalc Tai	39.11	49.01	27.34	57.89	21.21
SiO_2 Rougher Concentrate	419.76	60.89	**22.90**	**65.23**	42.11	78.79	42.11	22.90	78.79	65.23						
SiO_2 Rougher Tailings	269.58	39.11	49.01	27.34	57.89	21.21	57.89	49.01	21.21	27.34						
Total	689.34	100.00	33.11	50.41	100.00	100.00	100.00		100.00							
Call Factor			1.02	0.97												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.08	0.95	0.01	0.04	0.09	0.09	0.16	0.11	0.12
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test B3.44**

NORMALISED DATA

Ore Type: BIF Composite — BIF Composite
Reagent Suite: EDA3 37.5 g/t, Flotigram 2L 37.5 g/t, Starch 200g/t, Floatsil1 80g/t
Grind: 80% -75µm
Water Type: Sishen (Synthetic)
Cell pH: 9

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO$_2$	Fe	SiO$_2$							Fe	SiO$_2$	Fe	SiO$_2$
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	32.74	50.95	100	100
SiO$_2$ Rougher Conc 1	55.60	8.27	18.25	71.70	4.61	11.63	4.61	18.25	11.63	71.70	Recalc Tai	91.73	34.05	49.08	95.39	88.37
SiO$_2$ Rougher Conc 2	80.67	11.99	19.81	69.60	7.26	16.38	11.86	19.17	28.02	70.46	Recalc Tai	79.74	36.19	45.99	88.14	71.98
SiO$_2$ Rougher Conc 3	83.61	12.43	23.28	64.66	8.84	15.78	20.70	20.73	43.80	68.25	Recalc Tai	67.31	38.57	42.55	79.30	56.20
SiO$_2$ Rougher Conc 4	88.96	13.23	25.58	61.44	10.34	15.95	31.04	22.13	59.75	66.29	Recalc Tai	54.08	41.75	37.92	68.96	40.25
SiO$_2$ Rougher Conc 5	82.57	12.28	27.98	58.01	10.49	13.98	41.53	23.36	73.72	64.54	Recalc Tai	41.80	45.79	32.03	58.47	26.28
SiO$_2$ Rougher Conc 6	95.70	14.23	34.72	48.19	15.09	13.46	56.63	25.60	87.18	61.33	Recalc Tai	27.57	51.50	23.68	43.37	12.82
SiO$_2$ Rougher Concentrate	487.11	72.43	**25.60**	**61.33**	56.63	87.18	56.63	25.60	87.18	61.33						
SiO$_2$ Rougher Tailings	185.43	27.57	51.50	23.68	43.37	12.82	43.37	51.50	12.82	23.68						
Total	672.54	100.00	32.74	50.95	100.00	100.00	100.00		100.00							
Call Factor			1.01	0.98												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.08	0.96	0.02	0.04	0.09	0.09	0.17	0.11	0.12
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test B3.45**

NORMALISED DATA

Ore Type: BIF Composite — BIF Composite
Reagent Suite: EDA3 75 g/t, Flotigram 2L 75 g/t, Starch 200g/t, Floatsil1 80g/t
Grind: 80% -75µm
Water Type: Sishen (Synthetic)
Cell pH: 9

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO$_2$	Fe	SiO$_2$							Fe	SiO$_2$	Fe	SiO$_2$
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	40.01	40.35	100	100
SiO$_2$ Rougher Conc 1	71.69	10.02	20.88	68.07	5.23	16.91	5.23	20.88	16.91	68.07	Recalc Tai	89.98	42.15	37.26	94.77	83.09
SiO$_2$ Rougher Conc 2	98.71	13.80	24.26	63.34	8.36	21.66	13.59	22.84	38.57	65.33	Recalc Tai	76.18	45.38	32.53	86.41	61.43
SiO$_2$ Rougher Conc 3	115.08	16.08	32.37	51.53	13.01	20.54	26.60	26.68	59.11	59.77	Recalc Tai	60.10	48.87	27.45	73.40	40.89
SiO$_2$ Rougher Conc 4	116.41	16.27	39.61	40.93	16.11	16.51	42.71	30.43	75.62	54.31	Recalc Tai	43.83	52.30	22.45	57.29	24.38
SiO$_2$ Rougher Conc 5	94.08	13.15	47.78	29.10	15.70	9.48	58.41	33.72	85.10	49.53	Recalc Tai	30.68	54.24	19.59	41.59	14.90
SiO$_2$ Rougher Conc 6	84.03	11.74	51.83	23.15	15.21	6.74	73.62	36.34	91.84	45.71	Recalc Tai	18.93	55.74	17.39	26.38	8.16
SiO$_2$ Rougher Concentrate	580.00	81.07	**36.34**	**45.71**	73.62	91.84	73.62	36.34	91.84	45.71						
SiO$_2$ Rougher Tailings	135.47	18.93	55.74	17.39	26.38	8.16	26.38	55.74	8.16	17.39						
Total	715.47	100.00	40.01	40.35	100.00	100.00	100.00		100.00							
Call Factor			1.23	0.78												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.10	0.80	0.02	0.04	0.11	0.14	0.24	0.15	0.23
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test B3.46**

NORMALISED DATA

Ore Type: BIF Composite — BIF Composite
Reagent Suite: EDA3 112.5 g/t, Flotigram 2L 112.5 g/t, Starch 200g/t, Floatsil1 80g/t
Grind: 80% -75µm
Water Type: Sishen (Synthetic)
Cell pH: 9

Stream	Mass	Mass	Grade		Recovery		Cum Reco	Cum Gra	Cum Reco$_2$	Cum Grade		Cummilative	Grade		Recovery	
			Fe	SiO$_2$	Fe	SiO$_2$							Fe	SiO$_2$	Fe	SiO$_2$
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Head Sample			32.48	51.76							Recalc Fe	100	31.96	52.10	100	100
SiO$_2$ Rougher Conc 1	170.79	25.84	20.24	69.07	16.37	34.26	16.37	20.24	34.26	69.07	Recalc Tai	74.16	36.04	46.19	83.63	65.74
SiO$_2$ Rougher Conc 2	160.57	24.30	23.84	63.90	18.13	29.80	34.50	21.99	64.05	66.57	Recalc Tai	49.86	41.98	37.56	65.50	35.95
SiO$_2$ Rougher Conc 3	124.47	18.83	32.80	50.94	19.33	18.41	53.83	24.94	82.47	62.30	Recalc Tai	31.03	47.55	29.44	46.17	17.53
SiO$_2$ Rougher Conc 4	103.83	15.71	42.50	36.80	20.89	11.10	74.72	28.20	93.56	57.57	Recalc Tai	15.32	52.73	21.89	25.28	6.44
SiO$_2$ Rougher Conc 5	58.13	8.80	49.94	25.94	13.75	4.38	88.47	30.25	97.94	54.59	Recalc Tai	6.52	56.49	16.43	11.53	2.06
SiO$_2$ Rougher Conc 6	30.67	4.64	55.83	17.41	8.11	1.55	96.58	31.46	99.49	52.84	Recalc Tai	1.88	58.10	14.01	3.42	0.51
SiO$_2$ Rougher Concentrate	648.46	98.12	**31.46**	**52.84**	96.58	99.49	96.58	31.46	99.49	52.84						
SiO$_2$ Rougher Tailings	12.45	1.88	58.10	14.01	3.42	0.51	3.42	58.10	0.51	14.01						
Total	660.91	100.00	31.96	52.10	100.00	100.00	100.00		100.00							
Call Factor			0.98	1.01												

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.07	0.76	0.00	0.04	0.11	0.13	0.29	0.15	0.24
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Cationic Reverse Fe Flotation **Test B3.47**

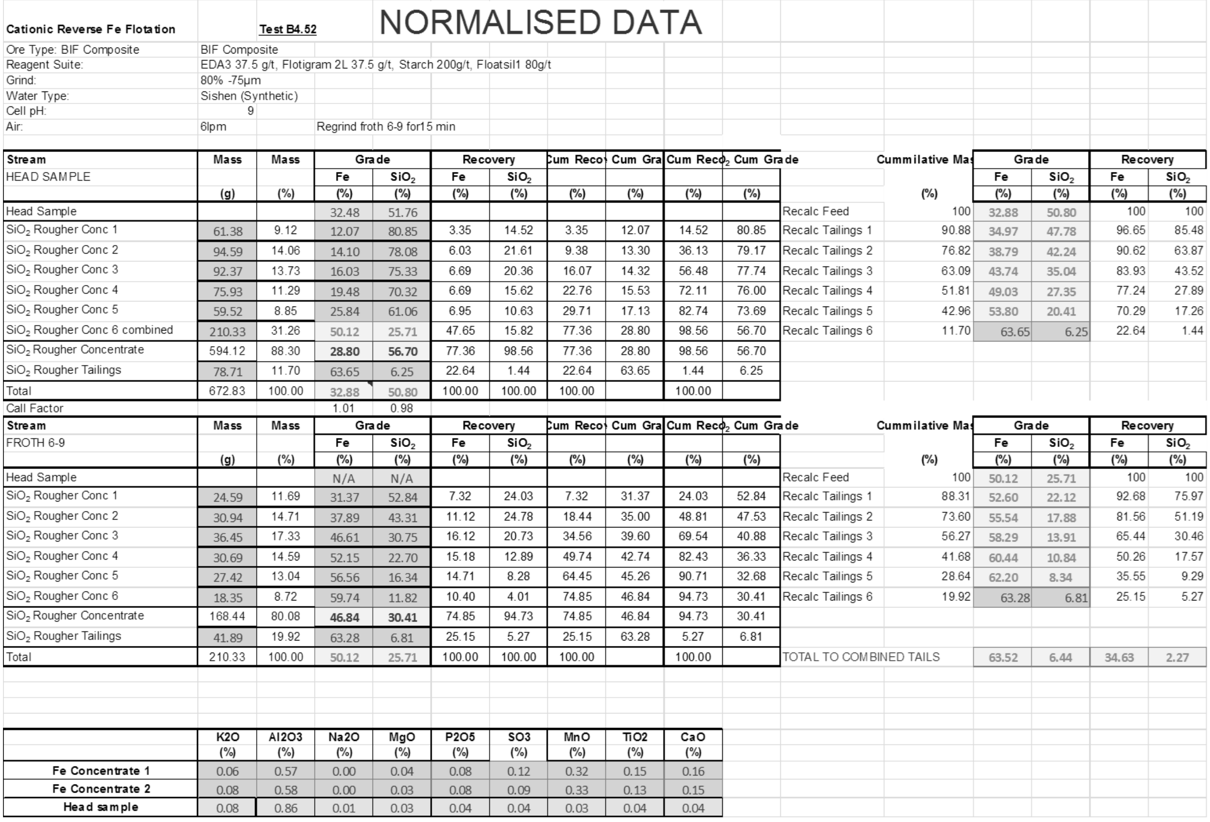
NORMALISED DATA

Ore Type: BIF Composite	BIF Composite
Reagent Suite:	EDA3 150 g/t, Flotigram 2L 150 g/t, Starch 200g/t, Floatsil1 80g/t
Grind:	80% -75µm
Water Type:	Sishen (Synthetic)
Cell pH:	9

Stream	**Mass**	**Mass**	**Grade**		**Recovery**		**Cum Reco**	**Cum Gra**	**Cum Reco$_2$**	**Cum Grade**	**Cummilative M**		**Grade**		**Recovery**	
			Fe	**SiO_2**	**Fe**	**SiO_2**							**Fe**	**SiO_2**	**Fe**	**SiO_2**
	(g)	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**		**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
Head Sample			32.48	51.76							Recalc Fe	100	26.80	59.49	100	100
SiO_2 Rougher Conc 1	168.33	23.67	20.07	68.99	17.73	27.46	17.73	20.07	27.46	68.99	Recalc Tai	76.33	28.89	56.54	82.27	72.54
SiO_2 Rougher Conc 2	169.81	23.88	23.31	64.49	20.77	25.89	38.49	21.70	53.34	66.73	Recalc Tai	52.44	31.44	52.93	61.51	46.66
SiO_2 Rougher Conc 3	141.60	19.92	25.77	61.05	19.15	20.44	57.64	22.90	73.78	65.05	Recalc Tai	32.53	34.91	47.95	42.36	26.22
SiO_2 Rougher Conc 4	97.97	13.78	27.59	58.56	14.18	13.56	71.82	23.69	87.34	63.95	Recalc Tai	18.75	40.28	40.16	28.18	12.66
SiO_2 Rougher Conc 5	72.75	10.23	33.76	49.59	12.89	8.53	84.71	24.82	95.87	62.35	Recalc Tai	8.52	48.12	28.83	15.29	4.13
SiO_2 Rougher Conc 6	43.17	6.07	46.06	31.86	10.43	3.25	95.14	26.14	99.12	60.45	Recalc Tai	2.45	53.24	21.29	4.86	0.88
SiO_2 Rougher Concentrate	693.63	97.55	**26.14**	**60.45**	95.14	99.12	95.14	26.14	99.12	60.45						
SiO_2 Rougher Tailings	17.39	2.45	53.24	21.29	4.86	0.88	4.86	53.24	0.88	21.29						
Total	711.02	100.00	26.80	59.49	100.00	100.00	100.00		100.00							
Call Factor			0.83	1.15												

	K2O	**Al2O3**	**Na2O**	**MgO**	**P2O5**	**SO3**	**MnO**	**TiO2**	**CaO**
	(%)	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
Fe Concentrate	0.08	0.79	0.01	0.03	0.09	0.12	0.18	0.12	0.14
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04

Grinding Stage (Rougher-Scavenger Circuit) Evaluation



Cationic Reverse Fe Flotation **Test B4.52** NORMALISED DATA

Ore Type: BIF Composite BIF Composite
Reagent Suite: EDA3 37.5 g/t, Flotigram 2L 37.5 g/t, Starch 200g/t, Floatsil1 80g/t
Grind: 80% -75µm
Water Type: Sishen (Synthetic)
Cell pH: 9
Air: 6lpm Regrind froth 6-9 for15 min

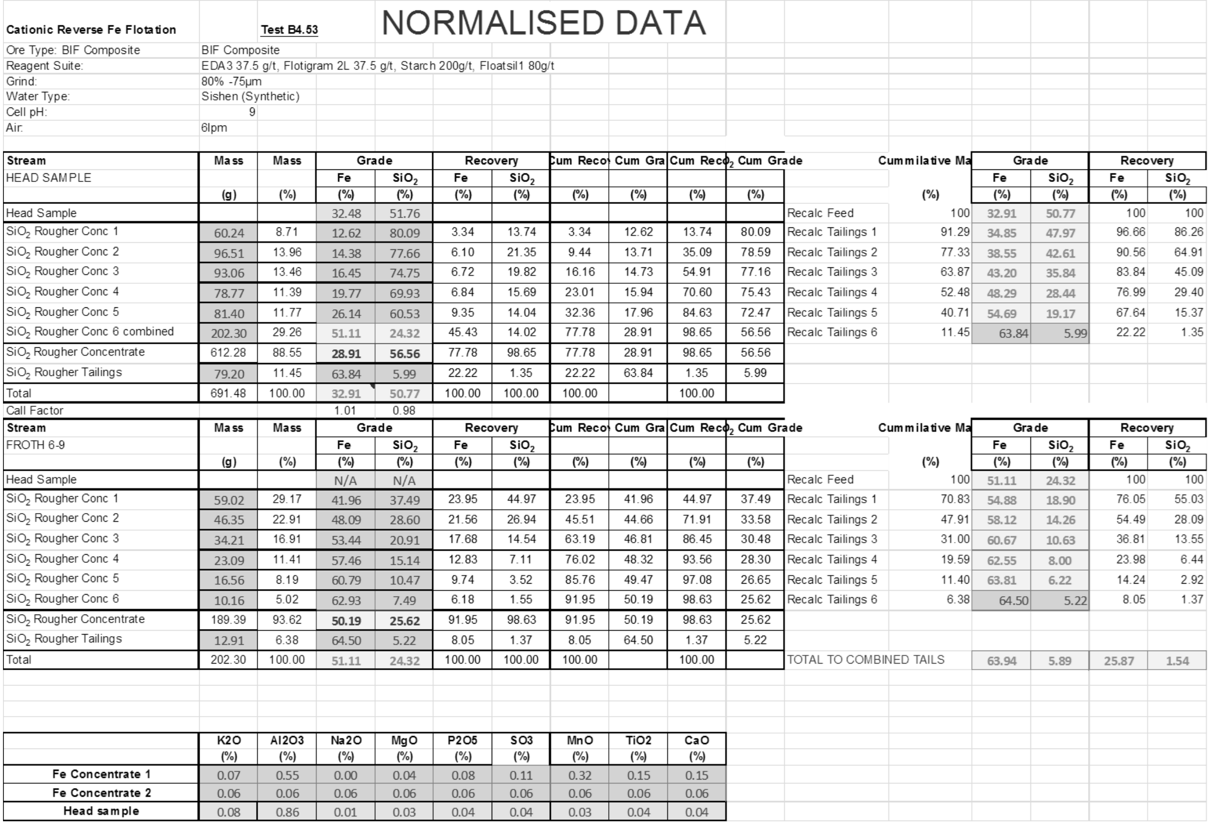
Stream	**Mass**	**Mass**	**Grade**		**Recovery**		**Cum Reco**	**Cum Gra**	**Cum Reco$_2$**	**Cum Grade**
HEAD SAMPLE			**Fe**	**SiO_2**	**Fe**	**SiO_2**				
	(g)	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
Head Sample			32.48	51.76						
SiO_2 Rougher Conc 1	61.38	9.12	12.07	80.85	3.35	14.52	3.35	12.07	14.52	80.85
SiO_2 Rougher Conc 2	94.59	14.06	14.10	78.08	6.03	21.61	9.38	13.30	36.13	79.17
SiO_2 Rougher Conc 3	92.37	13.73	16.03	75.33	6.69	20.36	16.07	14.32	56.48	77.74
SiO_2 Rougher Conc 4	75.93	11.29	19.48	70.32	6.69	15.62	22.76	15.53	72.11	76.00
SiO_2 Rougher Conc 5	59.52	8.85	25.84	61.06	6.95	10.63	29.71	17.13	82.74	73.69
SiO_2 Rougher Conc 6 combined	210.33	31.26	50.12	25.71	47.65	15.82	77.36	28.80	98.56	56.70
SiO_2 Rougher Concentrate	594.12	88.30	**28.80**	**56.70**	77.36	98.56	77.36	28.80	98.56	56.70
SiO_2 Rougher Tailings	78.71	11.70	63.65	6.25	22.64	1.44	22.64	63.65	1.44	6.25
Total	672.83	100.00	32.88	50.80	100.00	100.00	100.00		100.00	
Call Factor			1.01	0.98						

	Cummilative Mas	**Grade**		**Recovery**	
		Fe	**SiO_2**	**Fe**	**SiO_2**
	(%)	**(%)**	**(%)**	**(%)**	**(%)**
Recalc Feed	100	32.88	50.80	100	100
Recalc Tailings 1	90.88	34.97	47.78	96.65	85.48
Recalc Tailings 2	76.82	38.79	42.24	90.62	63.87
Recalc Tailings 3	63.09	43.74	35.04	83.93	43.52
Recalc Tailings 4	51.81	49.03	27.35	77.24	27.89
Recalc Tailings 5	42.96	53.80	20.41	70.29	17.26
Recalc Tailings 6	11.70	63.65	6.25	22.64	1.44

Stream	**Mass**	**Mass**	**Grade**		**Recovery**		**Cum Reco**	**Cum Gra**	**Cum Reco$_2$**	**Cum Grade**
FROTH 6-9			**Fe**	**SiO_2**	**Fe**	**SiO_2**				
	(g)	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
Head Sample			N/A	N/A						
SiO_2 Rougher Conc 1	24.59	11.69	31.37	52.84	7.32	24.03	7.32	31.37	24.03	52.84
SiO_2 Rougher Conc 2	30.94	14.71	37.89	43.31	11.12	24.78	18.44	35.00	48.81	47.53
SiO_2 Rougher Conc 3	36.45	17.33	46.61	30.75	16.12	20.73	34.56	39.60	69.54	40.88
SiO_2 Rougher Conc 4	30.69	14.59	52.15	22.70	15.18	12.89	49.74	42.74	82.43	36.33
SiO_2 Rougher Conc 5	27.42	13.04	56.56	16.34	14.71	8.28	64.45	45.26	90.71	32.68
SiO_2 Rougher Conc 6	18.35	8.72	59.74	11.82	10.40	4.01	74.85	46.84	94.73	30.41
SiO_2 Rougher Concentrate	168.44	80.08	**46.84**	**30.41**	74.85	94.73	74.85	46.84	94.73	30.41
SiO_2 Rougher Tailings	41.89	19.92	63.28	6.81	25.15	5.27	25.15	63.28	5.27	6.81
Total	210.33	100.00	50.12	25.71	100.00	100.00	100.00		100.00	

	Cummilative Mas	**Grade**		**Recovery**	
		Fe	**SiO_2**	**Fe**	**SiO_2**
	(%)	**(%)**	**(%)**	**(%)**	**(%)**
Recalc Feed	100	50.12	25.71	100	100
Recalc Tailings 1	88.31	52.60	22.12	92.68	75.97
Recalc Tailings 2	73.60	55.54	17.88	81.56	51.19
Recalc Tailings 3	56.27	58.29	13.91	65.44	30.46
Recalc Tailings 4	41.68	60.44	10.84	50.26	17.57
Recalc Tailings 5	28.64	62.20	8.34	35.55	9.29
Recalc Tailings 6	19.92	63.28	6.81	25.15	5.27
TOTAL TO COMBINED TAILS		63.52	6.44	34.63	2.27

	K2O	**Al2O3**	**Na2O**	**MgO**	**P2O5**	**SO3**	**MnO**	**TiO2**	**CaO**
	(%)	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
Fe Concentrate 1	0.06	0.57	0.00	0.04	0.08	0.12	0.32	0.15	0.16
Fe Concentrate 2	0.08	0.58	0.00	0.03	0.08	0.09	0.33	0.13	0.15
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04



Cationic Reverse Fe Flotation **Test B4.53** NORMALISED DATA

Ore Type: BIF Composite BIF Composite
Reagent Suite: EDA3 37.5 g/t, Flotigram 2L 37.5 g/t, Starch 200g/t, Floatsil1 80g/t
Grind: 80% -75µm
Water Type: Sishen (Synthetic)
Cell pH: 9
Air: 6lpm

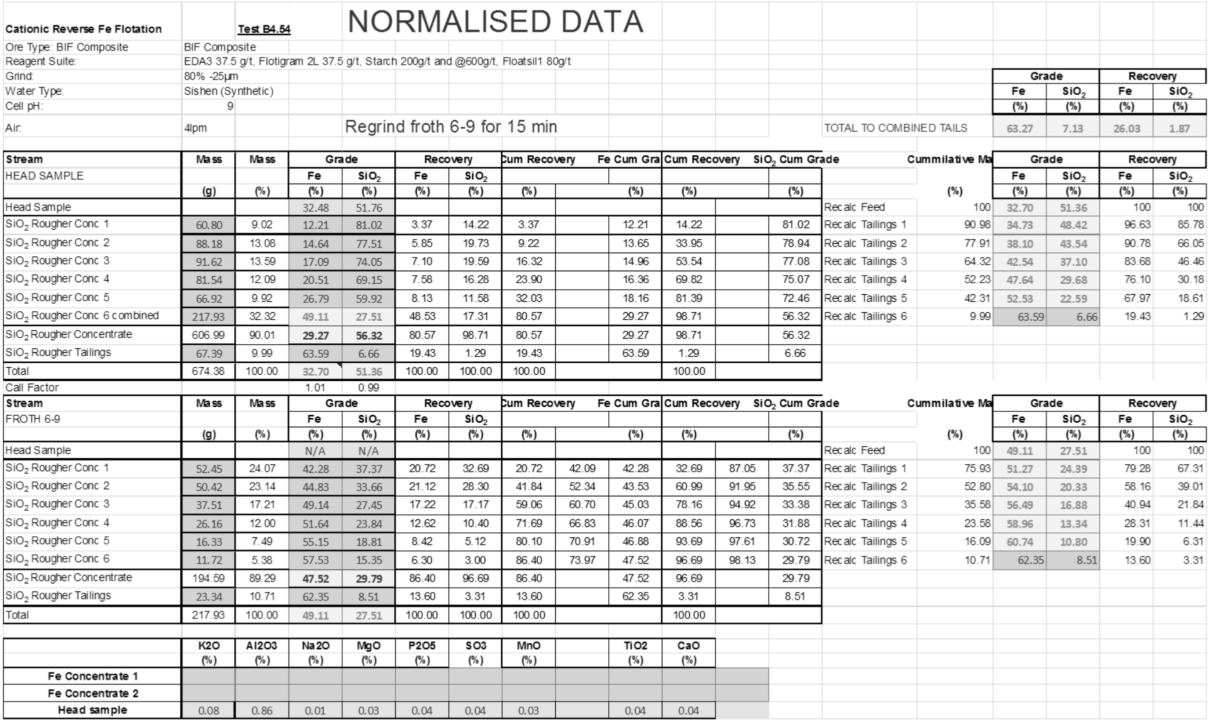
Stream	**Mass**	**Mass**	**Grade**		**Recovery**		**Cum Reco**	**Cum Gra**	**Cum Reco$_2$**	**Cum Grade**
HEAD SAMPLE			**Fe**	**SiO_2**	**Fe**	**SiO_2**				
	(g)	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
Head Sample			32.48	51.76						
SiO_2 Rougher Conc 1	60.24	8.71	12.62	80.09	3.34	13.74	3.34	12.62	13.74	80.09
SiO_2 Rougher Conc 2	96.51	13.96	14.38	77.66	6.10	21.35	9.44	13.71	35.09	78.59
SiO_2 Rougher Conc 3	93.06	13.46	16.45	74.75	6.72	19.82	16.16	14.73	54.91	77.16
SiO_2 Rougher Conc 4	78.77	11.39	19.77	69.93	6.84	15.69	23.01	15.94	70.60	75.43
SiO_2 Rougher Conc 5	81.40	11.77	26.14	60.53	9.35	14.04	32.36	17.96	84.63	72.47
SiO_2 Rougher Conc 6 combined	202.30	29.26	51.11	24.32	45.43	14.02	77.78	28.91	98.65	56.56
SiO_2 Rougher Concentrate	612.28	88.55	**28.91**	**56.56**	77.78	98.65	77.78	28.91	98.65	56.56
SiO_2 Rougher Tailings	79.20	11.45	63.84	5.99	22.22	1.35	22.22	63.84	1.35	5.99
Total	691.48	100.00	32.91	50.77	100.00	100.00	100.00		100.00	
Call Factor			1.01	0.98						

	Cummilative Ma	**Grade**		**Recovery**	
		Fe	**SiO_2**	**Fe**	**SiO_2**
	(%)	**(%)**	**(%)**	**(%)**	**(%)**
Recalc Feed	100	32.91	50.77	100	100
Recalc Tailings 1	91.29	34.85	47.97	96.66	86.26
Recalc Tailings 2	77.33	38.55	42.61	90.56	64.91
Recalc Tailings 3	63.87	43.20	35.84	83.84	45.09
Recalc Tailings 4	52.48	48.29	28.44	76.99	29.40
Recalc Tailings 5	40.71	54.69	19.17	67.64	15.37
Recalc Tailings 6	11.45	63.84	5.99	22.22	1.35

Stream	**Mass**	**Mass**	**Grade**		**Recovery**		**Cum Reco**	**Cum Gra**	**Cum Reco$_2$**	**Cum Grade**
FROTH 6-9			**Fe**	**SiO_2**	**Fe**	**SiO_2**				
	(g)	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
Head Sample			N/A	N/A						
SiO_2 Rougher Conc 1	59.02	29.17	41.96	37.49	23.95	44.97	23.95	41.96	44.97	37.49
SiO_2 Rougher Conc 2	46.35	22.91	48.09	28.60	21.56	26.94	45.51	44.66	71.91	33.58
SiO_2 Rougher Conc 3	34.21	16.91	53.44	20.91	17.68	14.54	63.19	46.81	86.45	30.48
SiO_2 Rougher Conc 4	23.09	11.41	57.46	15.14	12.83	7.11	76.02	48.32	93.56	28.30
SiO_2 Rougher Conc 5	16.56	8.19	60.79	10.47	9.74	3.52	85.76	49.47	97.08	26.65
SiO_2 Rougher Conc 6	10.16	5.02	62.93	7.49	6.18	1.55	91.95	50.19	98.63	25.62
SiO_2 Rougher Concentrate	189.39	93.62	**50.19**	**25.62**	91.95	98.63	91.95	50.19	98.63	25.62
SiO_2 Rougher Tailings	12.91	6.38	64.50	5.22	8.05	1.37	8.05	64.50	1.37	5.22
Total	202.30	100.00	51.11	24.32	100.00	100.00	100.00		100.00	

	Cummilative Ma	**Grade**		**Recovery**	
		Fe	**SiO_2**	**Fe**	**SiO_2**
	(%)	**(%)**	**(%)**	**(%)**	**(%)**
Recalc Feed	100	51.11	24.32	100	100
Recalc Tailings 1	70.83	54.88	18.90	76.05	55.03
Recalc Tailings 2	47.91	58.12	14.26	54.49	28.09
Recalc Tailings 3	31.00	60.67	10.63	36.81	13.55
Recalc Tailings 4	19.59	62.55	8.00	23.98	6.44
Recalc Tailings 5	11.40	63.81	6.22	14.24	2.92
Recalc Tailings 6	6.38	64.50	5.22	8.05	1.37
TOTAL TO COMBINED TAILS		63.94	5.89	25.87	1.54

	K2O	**Al2O3**	**Na2O**	**MgO**	**P2O5**	**SO3**	**MnO**	**TiO2**	**CaO**
	(%)	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
Fe Concentrate 1	0.07	0.55	0.00	0.04	0.08	0.11	0.32	0.15	0.15
Fe Concentrate 2	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03	0.04	0.04



Cationic Reverse Fe Flotation **Test B4.54** NORMALISED DATA

Ore Type: BIF Composite — BIF Composite
Reagent Suite: EDA3 37.5 g/t, Flotigram 2L 37.5 g/t, Starch 200g/t and @600g/t, Floatsil1 80g/t
Grind: 80% -25µm
Water Type: Sishen (Synthetic)
Cell pH: 9
Air: 4lpm

Regrind froth 6-9 for 15 min

	Grade Fe (%)	Grade SiO₂ (%)	Recovery Fe (%)	Recovery SiO₂ (%)
TOTAL TO COMBINED TAILS	63.27	7.13	26.03	1.87

Stream	Mass	Mass	Grade		Recovery		Cum Recovery		Fe Cum Gra	Cum Recovery		SiO₂ Cum Grade
HEAD SAMPLE			Fe	SiO₂	Fe	SiO₂						
	(g)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)		(%)
Head Sample			32.48	51.76								
SiO₂ Rougher Conc 1	60.80	9.02	12.21	81.02	3.37	14.22	3.37		12.21	14.22		81.02
SiO₂ Rougher Conc 2	88.18	13.08	14.64	77.51	5.85	19.73	9.22		13.65	33.95		78.94
SiO₂ Rougher Conc 3	91.62	13.59	17.09	74.05	7.10	19.59	16.32		14.96	53.54		77.08
SiO₂ Rougher Conc 4	81.54	12.09	20.51	69.15	7.58	16.28	23.90		16.36	69.82		75.07
SiO₂ Rougher Conc 5	66.92	9.92	26.79	59.92	8.13	11.58	32.03		18.16	81.39		72.46
SiO₂ Rougher Conc 6 combined	217.93	32.32	49.11	27.51	48.53	17.31	80.57		29.27	98.71		56.32
SiO₂ Rougher Concentrate	606.99	90.01	**29.27**	**56.32**	80.57	98.71	80.57		29.27	98.71		56.32
SiO₂ Rougher Tailings	67.39	9.99	63.59	6.66	19.43	1.29	19.43		63.59	1.29		6.66
Total	674.38	100.00	32.70	51.36	100.00	100.00	100.00			100.00		
Call Factor			1.01	0.99								

Cummilative Ma		Grade		Recovery	
		Fe	SiO₂	Fe	SiO₂
	(%)	(%)	(%)	(%)	(%)
Recalc Feed	100	32.70	51.36	100	100
Recalc Tailings 1	90.98	34.73	48.42	96.63	85.78
Recalc Tailings 2	77.91	38.10	43.54	90.78	66.05
Recalc Tailings 3	64.32	42.54	37.10	83.68	46.46
Recalc Tailings 4	52.23	47.64	29.68	76.10	30.18
Recalc Tailings 5	42.31	52.53	22.59	67.97	18.61
Recalc Tailings 6	9.99	63.59	6.66	19.43	1.29

Stream	Mass	Mass	Grade		Recovery		Cum Recovery		Fe Cum Gra	Cum Recovery		SiO₂ Cum Grade
FROTH 6-9			Fe	SiO₂	Fe	SiO₂						
	(g)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)		(%)
Head Sample			N/A	N/A								
SiO₂ Rougher Conc 1	52.45	24.07	42.28	37.37	20.72	32.69	20.72	42.09	42.28	32.69	87.05	37.37
SiO₂ Rougher Conc 2	50.42	23.14	44.83	33.66	21.12	28.30	41.84	52.34	43.53	60.99	91.95	35.55
SiO₂ Rougher Conc 3	37.51	17.21	49.14	27.45	17.22	17.17	59.06	60.70	45.03	78.16	94.92	33.38
SiO₂ Rougher Conc 4	26.16	12.00	51.64	23.84	12.62	10.40	71.69	66.83	46.07	88.56	96.73	31.88
SiO₂ Rougher Conc 5	16.33	7.49	55.15	18.81	8.42	5.12	80.10	70.91	46.88	93.69	97.61	30.72
SiO₂ Rougher Conc 6	11.72	5.38	57.53	15.35	6.30	3.00	86.40	73.97	47.52	96.69	98.13	29.79
SiO₂ Rougher Concentrate	194.59	89.29	**47.52**	**29.79**	86.40	96.69	86.40		47.52	96.69		29.79
SiO₂ Rougher Tailings	23.34	10.71	62.35	8.51	13.60	3.31	13.60		62.35	3.31		8.51
Total	217.93	100.00	49.11	27.51	100.00	100.00	100.00			100.00		

Cummilative Ma		Grade		Recovery	
		Fe	SiO₂	Fe	SiO₂
	(%)	(%)	(%)	(%)	(%)
Recalc Feed	100	49.11	27.51	100	100
Recalc Tailings 1	75.93	51.27	24.39	79.28	67.31
Recalc Tailings 2	52.80	54.10	20.33	58.16	39.01
Recalc Tailings 3	35.58	56.49	16.88	40.94	21.84
Recalc Tailings 4	23.58	58.96	13.34	28.31	11.44
Recalc Tailings 5	16.09	60.74	10.80	19.90	6.31
Recalc Tailings 6	10.71	62.35	8.51	13.60	3.31

	K2O (%)	Al2O3 (%)	Na2O (%)	MgO (%)	P2O5 (%)	SO3 (%)	MnO (%)		TiO2 (%)	CaO (%)
Fe Concentrate 1										
Fe Concentrate 2										
Head sample	0.08	0.86	0.01	0.03	0.04	0.04	0.03		0.04	0.04

Test ID	Scavenger	Regrind	200g/t Starch	200g/t + 600g/t Starch	Grade Fe (%)	Grade SiO2 (%)	Recovery Fe (%)	Recovery SiO2 (%)
B4.52	Yes	Yes	Yes	No	**63.52**	**6.44**	**34.63**	**2.27**
B4.53	Yes	No	Yes	No	**63.94**	**5.89**	**25.87**	**1.54**
B4.54	Yes	Yes	No	Yes	**63.27**	**7.13**	**26.03**	**1.87**
B1.32	No	No	Yes	No	**64.48**	**5.13**	**17.14**	**0.90**

Reagent Suite Evaluation for Individual BIF ores

Cationic Reverse Fe Flotation **Test C1.55** NORMALISED DATA

Ore Type: BIF Composite BIF A
Reagent Suite: EDA3 37.5 g/t, Flotigram 2L 37.5 g/t, Starch 200g/t, Floatsil1 80g/t
Grind: 80% -25µm
Water Type: Sishen (Synthetic)
Cell pH: 9

Stream	Mass	Mass	Grade		Recovery		Fe Cum Recovery	Fe Cum Grade	SiO_2 Cum Recovery	SiO_2 Cum Grade
			Fe	SiO_2	Fe	SiO_2				
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Head Sample			26.47	39.11						
SiO_2 Rougher Conc 1	64.98	9.61	10.76	82.16	4.78	11.84	4.78	10.76	11.84	82.16
SiO_2 Rougher Conc 2	110.61	16.36	11.95	80.54	9.03	19.76	13.81	11.51	31.61	81.14
SiO_2 Rougher Conc 3	119.38	17.66	12.84	79.41	10.47	21.03	24.28	12.05	52.64	80.44
SiO_2 Rougher Conc 4	103.47	15.31	15.17	76.23	10.72	17.50	35.00	12.86	70.14	79.35
SiO_2 Rougher Conc 5	78.37	11.59	19.57	69.80	10.48	12.14	45.48	13.96	82.27	77.78
SiO_2 Rougher Conc 6	59.65	8.82	26.12	60.22	10.64	7.97	56.12	15.31	90.24	75.82
SiO_2 Rougher Conc 7	57.42	8.49	37.05	44.37	14.53	5.65	70.65	17.42	95.90	72.78
SiO_2 Rougher Conc 8	42.91	6.35	47.20	29.80	13.83	2.84	84.49	19.42	98.73	69.89
SiO_2 Rougher Conc 9	23.21	3.43	54.97	18.84	8.72	0.97	93.20	20.67	99.70	68.09
SiO_2 Rougher Concentrate	660.00	97.64	**20.67**	**68.09**	93.20	99.70	93.20	20.67	99.70	68.09
SiO_2 Rougher Tailings	15.97	2.36	62.31	8.39	6.80	0.30	6.80	62.31	0.30	8.39
Total	675.97	100.00	21.66	66.68	100.00	100.00	100.00		100.00	
Call Factor			0.82	1.71						

	Cum Mass	Grade		Recovery	
		Fe	SiO_2	Fe	SiO_2
	(%)	(%)	(%)	(%)	(%)
Recalc Feed	100	21.66	66.68	100	100
Recalc Tailings 1	90.39	22.81	65.03	95.22	88.16
Recalc Tailings 2	74.02	25.22	61.61	86.19	68.39
Recalc Tailings 3	56.36	29.09	56.03	75.72	47.36
Recalc Tailings 4	41.06	34.29	48.50	65.00	29.86
Recalc Tailings 5	29.46	40.08	40.12	54.52	17.73
Recalc Tailings 6	20.64	46.04	31.52	43.88	9.76
Recalc Tailings 7	12.14	52.33	22.54	29.35	4.10
Recalc Tailings 8	5.80	57.96	14.58	15.51	1.27
Recalc Tailings 9	2.36	62.31	8.39	6.80	0.30

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.09	0.63	0.00	0.06	0.08	0.07	0.18	0.14	0.07
Head sample	59.52	0.03	1.14	0.00	0.03	0.04	0.04	0.03	0.04

Cationic Reverse Fe Flotation **Test C1.56** NORMALISED DATA

Ore Type: BIF Composite BIF B
Reagent Suite: EDA3 37.5 g/t, Flotigram 2L 37.5 g/t, Starch 200g/t, Floatsil1 80g/t
Grind: 80% -25µm
Water Type: Sishen (Synthetic)
Cell pH: 9

Stream	Mass	Mass	Grade		Recovery		Fe Cum Recovery	Fe Cum Grade	SiO_2 Cum Recovery	SiO_2 Cum Grade
			Fe	SiO_2	Fe	SiO_2				
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Head Sample			29.98	41.38						
SiO_2 Rougher Conc 1	40.25	5.77	12.16	81.08	2.23	8.87	2.23	12.16	8.87	81.08
SiO_2 Rougher Conc 2	79.76	11.44	14.15	78.24	5.14	16.95	7.37	13.48	25.82	79.19
SiO_2 Rougher Conc 3	93.75	13.45	15.97	75.60	6.82	19.25	14.20	14.57	45.07	77.62
SiO_2 Rougher Conc 4	81.47	11.69	18.25	72.19	6.77	15.98	20.97	15.59	61.05	76.12
SiO_2 Rougher Conc 5	71.97	10.33	22.50	66.03	7.38	12.91	28.35	16.94	73.96	74.14
SiO_2 Rougher Conc 6	62.83	9.01	28.86	56.61	8.26	9.66	36.61	18.68	83.62	71.58
SiO_2 Rougher Conc 7	48.56	6.97	37.46	43.94	8.29	5.80	44.90	20.59	89.42	68.78
SiO_2 Rougher Conc 8	51.73	7.42	46.25	31.05	10.90	4.36	55.80	23.09	93.78	65.10
SiO_2 Rougher Conc 9	52.24	7.49	53.67	20.20	12.78	2.87	68.58	25.83	96.65	61.07
SiO_2 Rougher Concentrate	582.56	83.58	**25.83**	**61.07**	68.58	96.65	68.58	25.83	96.65	61.07
SiO_2 Rougher Tailings	114.48	16.42	60.23	10.78	31.42	3.35	31.42	60.23	3.35	10.78
Total	697.04	100.00	31.48	52.81	100.00	100.00	100.00		100.00	
Call Factor			1.05	1.28						

	Cum Mass	Grade		Recovery	
		Fe	SiO_2	Fe	SiO_2
	(%)	(%)	(%)	(%)	(%)
Recalc Feed	100	31.48	52.81	100	100
Recalc Tailings 1	94.23	32.67	51.08	97.77	91.13
Recalc Tailings 2	82.78	35.23	47.32	92.63	74.18
Recalc Tailings 3	69.33	38.96	41.84	85.80	54.93
Recalc Tailings 4	57.65	43.16	35.68	79.03	38.95
Recalc Tailings 5	47.32	47.67	29.06	71.65	26.04
Recalc Tailings 6	38.31	52.10	22.58	63.39	16.38
Recalc Tailings 7	31.34	55.35	17.83	55.10	10.58
Recalc Tailings 8	23.92	58.18	13.73	44.20	6.22
Recalc Tailings 9	16.42	60.23	10.78	31.42	3.35

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.03	1.11	0.01	0.05	0.08	0.13	0.18	0.23	0.10
Head sample	56.75	0.23	1.43	0.01	0.03	0.05	0.04	0.03	0.03

Cationic Reverse Fe Flotation **Test C1.57**

NORMALISED DATA

Ore Type: BIF Composite	BIF C
Reagent Suite:	EDA3 37.5 g/t, Flotigram 2L 37.5 g/t, Starch 200g/t, Floatsil1 80g/t
Grind:	80% -25µm
Water Type:	Sishen (Synthetic)
Cell pH:	9

Stream	Mass	Mass	Grade		Recovery		Fe Cum Recovery	Fe Cum Grade	SiO_2 Cum Recovery	SiO_2 Cum Grade
			Fe	SiO_2	Fe	SiO_2				
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Head Sample			32.32	42.90						
SiO_2 Rougher Conc 1	65.53	9.37	14.28	78.28	3.78	15.33	3.78	14.28	15.33	78.28
SiO_2 Rougher Conc 2	103.59	14.81	16.50	75.11	6.91	23.25	10.69	15.64	38.58	76.34
SiO_2 Rougher Conc 3	105.59	15.10	20.30	69.68	8.66	21.99	19.34	17.43	60.57	73.78
SiO_2 Rougher Conc 4	89.90	12.85	26.04	61.37	9.46	16.49	28.80	19.55	77.06	70.72
SiO_2 Rougher Conc 5	77.09	11.02	35.18	48.09	10.96	11.08	39.76	22.28	88.14	66.77
SiO_2 Rougher Conc 6	67.04	9.58	48.09	29.48	13.02	5.91	52.78	25.68	94.05	61.86
SiO_2 Rougher Conc 7	69.04	9.87	57.28	16.21	15.97	3.34	68.76	29.46	97.39	56.40
SiO_2 Rougher Conc 8	52.63	7.52	61.98	9.48	13.18	1.49	81.93	32.17	98.88	52.48
SiO_2 Rougher Conc 9	34.37	4.91	64.01	6.53	8.89	0.67	90.82	33.82	99.55	50.11
SiO_2 Rougher Concentrate	664.78	95.04	**33.82**	**50.11**	90.82	99.55	90.82	33.82	99.55	50.11
SiO_2 Rougher Tailings	34.68	4.96	65.52	4.31	9.18	0.45	9.18	65.52	0.45	4.31
Total	699.46	100.00	35.39	47.84	100.00	100.00	100.00		100.00	
Call Factor			1.10	1.12						

	Cum Mass	Grade		Recovery	
		Fe	SiO_2	Fe	SiO_2
	(%)	(%)	(%)	(%)	(%)
Recalc Feed	100	35.39	47.84	100	100
Recalc Tailings 1	90.63	37.57	44.69	96.22	84.67
Recalc Tailings 2	75.82	41.69	38.75	89.31	61.42
Recalc Tailings 3	60.73	47.01	31.06	80.66	39.43
Recalc Tailings 4	47.87	52.64	22.92	71.20	22.94
Recalc Tailings 5	36.85	57.86	15.39	60.24	11.86
Recalc Tailings 6	27.27	61.29	10.44	47.22	5.95
Recalc Tailings 7	17.40	63.57	7.17	31.24	2.61
Recalc Tailings 8	9.87	64.77	5.42	18.07	1.12
Recalc Tailings 9	4.96	65.52	4.31	9.18	0.45

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.03	0.21	0.00	0.05	0.06	0.03	0.19	0.09	0.07
Head sample	56.49	0.04	0.44	0.01	0.03	0.02	0.01	0.03	0.02

Cationic Reverse Fe Flotation **Test C1.58**

NORMALISED DATA

Ore Type: BIF Composite	BIF D
Reagent Suite:	EDA3 37.5 g/t, Flotigram 2L 37.5 g/t, Starch 200g/t, Floatsil1 80g/t
Grind:	80% -25µm
Water Type:	Sishen (Synthetic)
Cell pH:	9

Stream	Mass	Mass	Grade		Recovery		Fe Cum Recovery	Fe Cum Grade	SiO_2 Cum Recovery	SiO_2 Cum Grade
			Fe	SiO_2	Fe	SiO_2				
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Head Sample			39.73	44.74						
SiO_2 Rougher Conc 1	56.41	8.01	15.39	76.38	2.96	15.96	2.96	15.39	15.96	76.38
SiO_2 Rougher Conc 2	83.29	11.83	18.90	71.32	5.36	22.01	8.32	17.48	37.97	73.36
SiO_2 Rougher Conc 3	83.26	11.83	24.00	64.03	6.81	19.75	15.12	19.92	57.73	69.88
SiO_2 Rougher Conc 4	71.24	10.12	27.14	59.45	6.59	15.69	21.71	21.67	73.42	67.35
SiO_2 Rougher Conc 5	62.19	8.83	36.41	45.91	7.71	10.58	29.42	24.24	84.00	63.61
SiO_2 Rougher Conc 6	59.45	8.45	48.25	28.89	9.77	6.36	39.19	27.67	90.36	58.65
SiO_2 Rougher Conc 7	68.23	9.69	56.74	16.53	13.19	4.18	52.38	31.77	94.54	52.71
SiO_2 Rougher Conc 8	66.10	9.39	61.34	9.96	13.81	2.44	66.19	35.32	96.98	47.58
SiO_2 Rougher Conc 9	55.64	7.90	62.95	7.70	11.93	1.59	78.12	37.86	98.57	43.91
SiO_2 Rougher Concentrate	605.81	86.06	**37.86**	**43.91**	78.12	98.57	78.12	37.86	98.57	43.91
SiO_2 Rougher Tailings	98.14	13.94	65.47	3.93	21.88	1.43	21.88	65.47	1.43	3.93
Total	703.95	100.00	41.71	38.34	100.00	100.00	100.00		100.00	
Call Factor			1.05	0.86						

	Cum Mass	Grade		Recovery	
		Fe	SiO_2	Fe	SiO_2
	(%)	(%)	(%)	(%)	(%)
Recalc Feed	100	41.71	38.34	100	100
Recalc Tailings 1	91.99	44.00	35.03	97.04	84.04
Recalc Tailings 2	80.15	47.71	29.67	91.68	62.03
Recalc Tailings 3	68.33	51.81	23.72	84.88	42.27
Recalc Tailings 4	58.21	56.10	17.51	78.29	26.58
Recalc Tailings 5	49.37	59.62	12.43	70.58	16.00
Recalc Tailings 6	40.93	61.97	9.03	60.81	9.64
Recalc Tailings 7	31.24	63.59	6.70	47.62	5.46
Recalc Tailings 8	21.85	64.56	5.30	33.81	3.02
Recalc Tailings 9	13.94	65.47	3.93	21.88	1.43

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.05	0.40	0.02	0.07	0.07	0.14	0.16	0.21	0.07
Head sample	53.63	0.05	1.26	0.01	0.03	0.05	0.08	0.04	0.06

Cationic Reverse Fe Flotation **Test C1.59**

NORMALISED DATA

Ore Type: BIF Composite	BIF E
Reagent Suite:	EDA3 37.5 g/t, Flotigram 2L 37.5 g/t, Starch 200g/t, Floatsil1 80g/t
Grind:	80% -25µm
Water Type:	Sishen (Synthetic)
Cell pH:	9

Stream	Mass	Mass	Grade		Recovery		Fe Cum Recovery	Fe Cum Grade	SiO_2 Cum Recovery	SiO_2 Cum Grade
			Fe	SiO_2	Fe	SiO_2				
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Head Sample			25.61	51.01						
SiO_2 Rougher Conc 1	65.86	9.31	12.34	80.93	4.10	12.96	4.10	12.34	12.96	80.93
SiO_2 Rougher Conc 2	101.11	14.29	12.90	80.16	6.59	19.70	10.69	12.68	32.66	80.47
SiO_2 Rougher Conc 3	110.96	15.68	15.05	77.00	8.44	20.77	19.13	13.63	53.43	79.08
SiO_2 Rougher Conc 4	95.56	13.50	19.13	71.02	9.23	16.50	28.36	15.03	69.93	77.02
SiO_2 Rougher Conc 5	82.57	11.67	24.54	63.12	10.23	12.67	38.59	16.76	82.60	74.50
SiO_2 Rougher Conc 6	71.15	10.05	35.36	47.27	12.71	8.18	51.30	19.27	90.78	70.83
SiO_2 Rougher Conc 7	61.59	8.70	45.35	32.62	14.11	4.88	65.40	22.00	95.66	66.83
SiO_2 Rougher Conc 8	48.61	6.87	54.11	20.03	13.28	2.37	78.69	24.44	98.03	63.26
SiO_2 Rougher Conc 9	33.47	4.73	57.58	15.14	9.73	1.23	88.42	26.10	99.26	60.86
SiO_2 Rougher Concentrate	670.88	94.80	26.10	60.86	88.42	99.26	88.42	26.10	99.26	60.86
SiO_2 Rougher Tailings	36.80	5.20	62.31	8.28	11.58	0.74	11.58	62.31	0.74	8.28
Total	707.68	100.00	27.98	58.13	100.00	100.00	100.00		100.00	
Call Factor			1.09	1.14						

	Cum Mass	Grade		Recovery	
		Fe	SiO_2	Fe	SiO_2
	(%)	(%)	(%)	(%)	(%)
Recalc Feed	100	27.98	58.13	100	100
Recalc Tailings 1	90.69	29.58	55.79	95.90	87.04
Recalc Tailings 2	76.41	32.71	51.23	89.31	67.34
Recalc Tailings 3	60.73	37.26	44.57	80.87	46.57
Recalc Tailings 4	47.22	42.45	37.01	71.64	30.07
Recalc Tailings 5	35.56	48.32	28.44	61.41	17.40
Recalc Tailings 6	25.50	53.43	21.02	48.70	9.22
Recalc Tailings 7	16.80	57.62	15.02	34.60	4.34
Recalc Tailings 8	9.93	60.05	11.54	21.31	1.97
Recalc Tailings 9	5.20	62.31	8.28	11.58	0.74

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.03	0.61	0.00	0.06	0.07	0.12	0.22	0.21	0.10
Head sample	48.21	0.07	0.55	0.01	0.03	0.04	0.02	0.03	0.02

Cationic Reverse Fe Flotation **Test C1.60**

NORMALISED DATA

Ore Type: BIF Composite	BIF F
Reagent Suite:	EDA3 37.5 g/t, Flotigram 2L 37.5 g/t, Starch 200g/t, Floatsil1 80g/t
Grind:	80% -25µm
Water Type:	Sishen (Synthetic)
Cell pH:	9

Stream	Mass	Mass	Grade		Recovery		Fe Cum Recovery	Fe Cum Grade	SiO_2 Cum Recovery	SiO_2 Cum Grade
			Fe	SiO_2	Fe	SiO_2				
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Head Sample			27.62	54.17						
SiO_2 Rougher Conc 1	71.54	10.52	11.89	81.99	4.08	15.74	4.08	11.89	15.74	81.99
SiO_2 Rougher Conc 2	107.71	15.84	15.57	76.65	8.04	22.15	12.12	14.10	37.89	78.78
SiO_2 Rougher Conc 3	110.43	16.24	17.06	74.56	9.03	22.09	21.15	15.23	59.98	77.17
SiO_2 Rougher Conc 4	90.90	13.37	21.52	68.11	9.38	16.61	30.53	16.73	76.59	75.01
SiO_2 Rougher Conc 5	72.64	10.69	29.19	56.97	10.17	11.10	40.70	18.73	87.69	72.12
SiO_2 Rougher Conc 6	59.32	8.73	41.42	39.22	11.78	6.24	52.48	21.36	93.93	68.31
SiO_2 Rougher Conc 7	57.83	8.51	53.52	21.79	14.84	3.38	67.32	24.62	97.31	63.59
SiO_2 Rougher Conc 8	43.71	6.43	59.72	12.84	12.52	1.51	79.83	27.12	98.82	59.98
SiO_2 Rougher Conc 9	26.63	3.92	62.85	8.39	8.02	0.60	87.86	28.60	99.42	57.84
SiO_2 Rougher Concentrate	640.71	94.25	28.60	57.84	87.86	99.42	87.86	28.60	99.42	57.84
SiO_2 Rougher Tailings	39.11	5.75	64.77	5.54	12.14	0.58	12.14	64.77	0.58	5.54
Total	679.82	100.00	30.68	54.83	100.00	100.00	100.00		100.00	
Call Factor			1.11	1.01						

	Cum Mass	Grade		Recovery	
		Fe	SiO_2	Fe	SiO_2
	(%)	(%)	(%)	(%)	(%)
Recalc Feed	100	30.68	54.83	100	100
Recalc Tailings 1	89.48	32.89	51.63	95.92	84.26
Recalc Tailings 2	73.63	36.62	46.25	87.88	62.11
Recalc Tailings 3	57.39	42.15	38.24	78.85	40.02
Recalc Tailings 4	44.02	48.42	29.16	69.47	23.41
Recalc Tailings 5	33.33	54.59	20.25	59.30	12.31
Recalc Tailings 6	24.61	59.25	13.52	47.52	6.07
Recalc Tailings 7	16.10	62.29	9.15	32.68	2.69
Recalc Tailings 8	9.67	63.99	6.69	20.17	1.18
Recalc Tailings 9	5.75	64.77	5.54	12.14	0.58

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.02	0.14	0.00	0.04	0.03	0.02	0.21	0.07	0.06
Head sample	39.23	0.10	0.75	0.01	0.03	0.05	0.09	0.04	0.06

Cationic Reverse Fe Flotation **Test C1.61**

NORMALISED DATA

Ore Type: BIF Composite	BIF G
Reagent Suite:	EDA3 37.5 g/t, Flotigram 2L 37.5 g/t, Starch 200g/t, Floatsil1 80g/t
Grind:	80% -25µm
Water Type:	Sishen (Synthetic)
Cell pH:	9

Stream	Mass	Mass	Grade		Recovery		Fe Cum Recovery	Fe Cum Grade	SiO_2 Cum Recovery	SiO_2 Cum Grade
			Fe	SiO_2	Fe	SiO_2				
	(g)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Head Sample			35.59	59.62						
SiO_2 Rougher Conc 1	53.28	8.10	14.89	77.64	3.22	13.99	3.22	14.89	13.99	77.64
SiO_2 Rougher Conc 2	83.20	12.65	16.43	75.43	5.55	21.23	8.78	15.83	35.22	76.29
SiO_2 Rougher Conc 3	88.20	13.41	19.56	70.90	7.01	21.15	15.78	17.29	56.37	74.17
SiO_2 Rougher Conc 4	76.45	11.62	25.25	62.70	7.84	16.21	23.62	19.31	72.58	71.26
SiO_2 Rougher Conc 5	65.55	9.97	33.67	50.38	8.97	11.17	32.59	21.88	83.75	67.53
SiO_2 Rougher Conc 6	59.48	9.04	44.42	34.81	10.73	7.00	43.32	25.02	90.75	62.96
SiO_2 Rougher Conc 7	62.85	9.56	54.36	20.38	13.88	4.33	57.20	28.79	95.09	57.49
SiO_2 Rougher Conc 8	59.11	8.99	60.27	11.84	14.47	2.37	71.67	32.19	97.45	52.57
SiO_2 Rougher Conc 9	45.03	6.85	62.57	8.53	11.44	1.30	83.12	34.49	98.75	49.22
SiO_2 Rougher Concentrate	593.15	90.19	**34.49**	**49.22**	83.12	98.75	83.12	34.49	98.75	49.22
SiO_2 Rougher Tailings	64.52	9.81	64.42	5.72	16.88	1.25	16.88	64.42	1.25	5.72
Total	657.67	100.00	37.43	44.96	100.00	100.00	100.00		100.00	
Call Factor			1.05	0.75						

	Cum Mass	Grade		Recovery	
		Fe	SiO_2	Fe	SiO_2
	(%)	(%)	(%)	(%)	(%)
Recalc Feed	100	37.43	44.96	100	100
Recalc Tailings 1	91.90	39.42	42.07	96.78	86.01
Recalc Tailings 2	79.25	43.09	36.75	91.22	64.78
Recalc Tailings 3	65.84	47.88	29.79	84.22	43.63
Recalc Tailings 4	54.21	52.73	22.74	76.38	27.42
Recalc Tailings 5	44.25	57.03	16.51	67.41	16.25
Recalc Tailings 6	35.20	60.27	11.81	56.68	9.25
Recalc Tailings 7	25.65	62.47	8.62	42.80	4.91
Recalc Tailings 8	16.66	63.66	6.87	28.33	2.55
Recalc Tailings 9	9.81	64.42	5.72	16.88	1.25

	K2O	Al2O3	Na2O	MgO	P2O5	SO3	MnO	TiO2	CaO
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fe Concentrate	0.04	0.20	0.01	0.08	0.05	0.04	0.18	0.09	0.24
Head sample	39.23	0.10	0.75	0.01	0.03	0.05	0.09	0.04	0.06