MSc Chemical Engineering Thesis

Considering the Action of Frothers Under Degrading Water Quality

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Synopsis

Froth flotation is a highly water-intensive process which is under scrutiny due to scarce fresh water supplies and increasingly strict environmental regulations with regards to polluted water discharge. This is driving the mining industry to use recycled water for their operations, which is usually sourced from tailings dams and/or concentrator thickeners. This means that the recycled water can contain elevated levels of dissolved solids which consist of various ions and other contaminants such as residual reagents. This presents a problem in the flotation circuit as these dissolved solids tend to affect the water quality and can impact the efficiency and performance of flotation operations.

The stability of the froth is known to strongly affect flotation performance and thus the grade and recovery of the valuable minerals. Literature shows that both frothers and ions reduce bubble coalescence, and stabilise the bubbles that form, resulting in greater froth stability. Considering that the level of ions in process water is on the rise, and both variables act on the froth in a similar manner, it is becoming increasingly important to understand how frothers behave under conditions of increased ionic strength. If it can be determined how these variables interact, then it may be possible to manage frother dosage in operations that recycle process water with the aim of reducing the quantity and frother spend whilst limiting the need for large amounts of fresh water and still maintaining flotation performance.

Therefore, this study was undertaken to investigate how frother dosage and ionic strength, both individually and simultaneously, affect the froth stability and therefore flotation performance. This study was limited to varying the frother type, frother dosage and ionic strength whilst keeping all other experimental conditions constant. Batch flotation tests were carried out involving the bulk flotation of chalcopyrite and pentlandite. Flotation performance was evaluated by examining the water, solids, copper and nickel recoveries, and the grades of both copper and nickel. The ore used for this study was Kevitsa ore from Finland.

Both the individual effects of frother dosage and ionic strength and their simultaneous action were analysed. It was found that increasing the frother dosage stabilised the froth and increased the recovery of water and solids but had no impact on the recovery of copper and only a slightly positive influence on the recovery of nickel. At the same time, the grades of both copper and nickel were found to decrease, likely due to increased gangue recoveries. Increasing the ionic strength also stabilised the froth which increased the recovery of water and solids, but both the recoveries and grades of copper and nickel were not significantly affected.

Examining both variables simultaneously revealed that ionic strength was more influential than frother dosage in the recovery of water with the opposite being true for the solids recoveries. This means that a simultaneous increase in ionic strength and decrease in frother dosage by the same amount will increase the water recoveries and decrease the solids recoveries. It will

also slightly decrease the nickel recoveries while having no effect on the copper recoveries. The grades of both will either increase or remain the same.

Overall, managing the frother dosage under conditions of increased ionic strength, while still maintaining flotation performance, is possible and could result in a decrease in the quantity and frother spend required for flotation. It may also allow the mining industry to recycle more of their water without the need for extensive cleaning which in turn will reduce the amount of fresh water required for flotation and reduce the environmental impact. However, because ionic strength and frother dosage have varying levels of influence and therefore must be monitored, the amount by which the ionic strength of the water is allowed to increase, and the amount by which the frother dosage is decreased, need to be tailored to suit the needs of the plant with regards to water recovery and the recoveries and grades of the valuable minerals.

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List of Abbreviations

BMA	Bulk mineralogy analysis
CMC	Carboxymethylcellulose
EDL	Electrical double layer
ITERAMS	Integrated Mineral Technologies for More Sustainable Raw Material Supply
MIBC	Methyl isobutyl carbinol
NFG	Naturally floating gangue
NRF	National Research Foundation
PGE	Platinum group element
PGM	Platinum group metals
PIBX	Potassium isobutyl xanthate
PMA	Particle mineralogy analysis
QEMSCAN	Quantitative Evaluation of Materials by Scanning Electron Microscopy
SAMMRI	South African Minerals to Metals Research Institute
SIBX	Sodium isobutyl xanthate
SIPX	Sodium isopropyl xanthate
SMS	Specific mineral search
SPW	Synthetic plant water
TDS	Total dissolved solids
XRF	X-ray fluorescence

1. Introduction

1.1 Background to the Project

Froth flotation is considered to be one of the most important processing techniques in the minerals industry because it has enabled the recovery of valuable minerals from low grade ores that would have previously been considered to be uneconomical (Wills & Finch, 2016). Water makes up 80 - 85% of the slurry that is processed in the flotation circuit (Levay, et al., 2001) which means that the mining industry needs large quantities of water in order to carry out their minerals processing operations. However, many challenges are forcing the mining industry to save freshwater resources and to use low-quality or recycled water (Farrokhpay & Zanin, 2012; Muzenda, 2010). Increasingly strict environmental regulations are also forcing minerals processing plants to reduce the amount of polluted water discharged to the environment, or in many cases, to ensure zero-effluent operations (Muzenda, 2010; Manono, et al., 2012; Manono, et al., 2013)

Often mining operations are located in water-scarce regions (Farrokhpay & Zanin, 2012), like South Africa, or the water sources are affected by seasonal changes in the local climate, like Finland, which can impact both the quantity and quality of the usable water (Levay, et al., 2001). Using recycled water results in increased levels of total dissolved solids (TDS) which include various ions and other contaminants. This tends to affect the water quality and can impact the efficiency and performance of flotation operations (Lui, et al., 2013; Farrokhpay & Zanin, 2012; Muzenda, 2010; Manono, et al., 2012; Wiese, et al., 2007; Khraisheh, et al., 2005; Shortridge, 2002; Fuerstenau, et al., 1988).

The stability of the froth is known to strongly influence the efficiency of flotation and thus the grade and recovery of the valuable minerals (Wiese & Harris, 2012; Farrokhpay & Zanin, 2012). A more stable froth is usually desirable to increase the recoveries of the valuable minerals, however a froth that is too stable will recover more gangue and therefore decrease the valuable mineral grades (Triffett & Cilliers, 2004). The type and dosage of the frother used and the ionic strength of the process water are two of the main factors that impact the froth stability. Literature shows that both frothers and ionic strength are known to influence the surface tension, reduce bubble coalescence and stabilise the bubbles that form thus resulting in greater froth stability (Wills & Finch, 2016; Aldrich & Feng, 2000; Bulatovic, 2007; Cho & Laskowski, 2002; Quinn, et al., 2007; Iwasaki, et al., 1980; Viviers, 1979; Hewitt, et al., 1994; Marruci & Nicodemo, 1967; Craig, et al., 1993; Zieminski & Whittemore, 1971; Laskowski, et al., 2003).

Considering that frothers and ions present in the process water both stabilise the froth in similar manners, means that it is important to know how these variables interact. The individual effects of both ionic strength and frother dosage have been investigated (see Sections 2.3.5 and 2.4), however the simultaneous effects of both variables have not been researched. This means that the effects of frothers and their dosages under degrading water quality need to be investigated to determine how these variables work together. If it can be determined how these variables interact, then there is a possibility that the frother dosage can be decreased in the presence of water with elevated ion levels, while still maintaining optimal froth stability. This will hopefully help to reduce frother spend during the flotation process and to optimise the recoveries and grades of the valuable minerals.

1.2 Overall Project Objectives

To investigate how frother dosage and ionic strength, both individually and simultaneously, affect the froth stability and to determine whether a lower frother dosage coupled with a higher ionic strength can maintain flotation performance.

1.3 Scope, Limitations and Key Issues

The flotation parameter triangle adapted by Klimpel (1995) and displayed in Figure 2 shows the operating parameters that are influential in froth flotation. For the purpose of this study, the equipment parameters and operation parameters will be kept constant. From the chemistry parameters, no activator, depressant or pH modifier will be used. The collector type and dosage will be kept constant and only the frother type, dosage and ionic strength will be varied. Therefore this project is limited to the effects of varying frother dosage, frother type and ionic strength on froth stability. The flotation performance will be evaluated by examining the recoveries of water, solids, copper and nickel and the grades of both copper and nickel. The ore used for this study is Kevitsa ore from Finland which is very similar to the Merensky ore in South Africa which means that the results can be applied to the South African mining industry too.

2. Literature Review

2.1 Fundamentals of Flotation

Froth flotation is considered to be one of the most important processing techniques in the minerals industry because it has enabled the recovery of valuable minerals from low grade ores that would have previously been considered to be uneconomical (Wills & Finch, 2016). Froth flotation is a physico-chemical process that uses the differences in the surface properties between the valuable and non-valuable (gangue) minerals in order to separate them (Farrokhpay, 2011). This is done by adding reagents to make the valuable minerals hydrophobic (or water-repelling) and the gangue hydrophilic (water-loving). When the air is turned on, bubbles enter the mineral slurry where the hydrophobic particles attach to them and rise with them to the surface (Farrokhpay, 2011). The impeller provides the turbulence needed to promote collisions between the bubbles and the particles and assists with their transport towards the surface (Wills & Finch, 2016). Two regions exist during flotation namely the pulp phase, which is the mineral slurry consisting of water and solid particles, and the froth phase, which consists of solids, water and air. Figure 1 shows a diagram of a typical flotation cell.

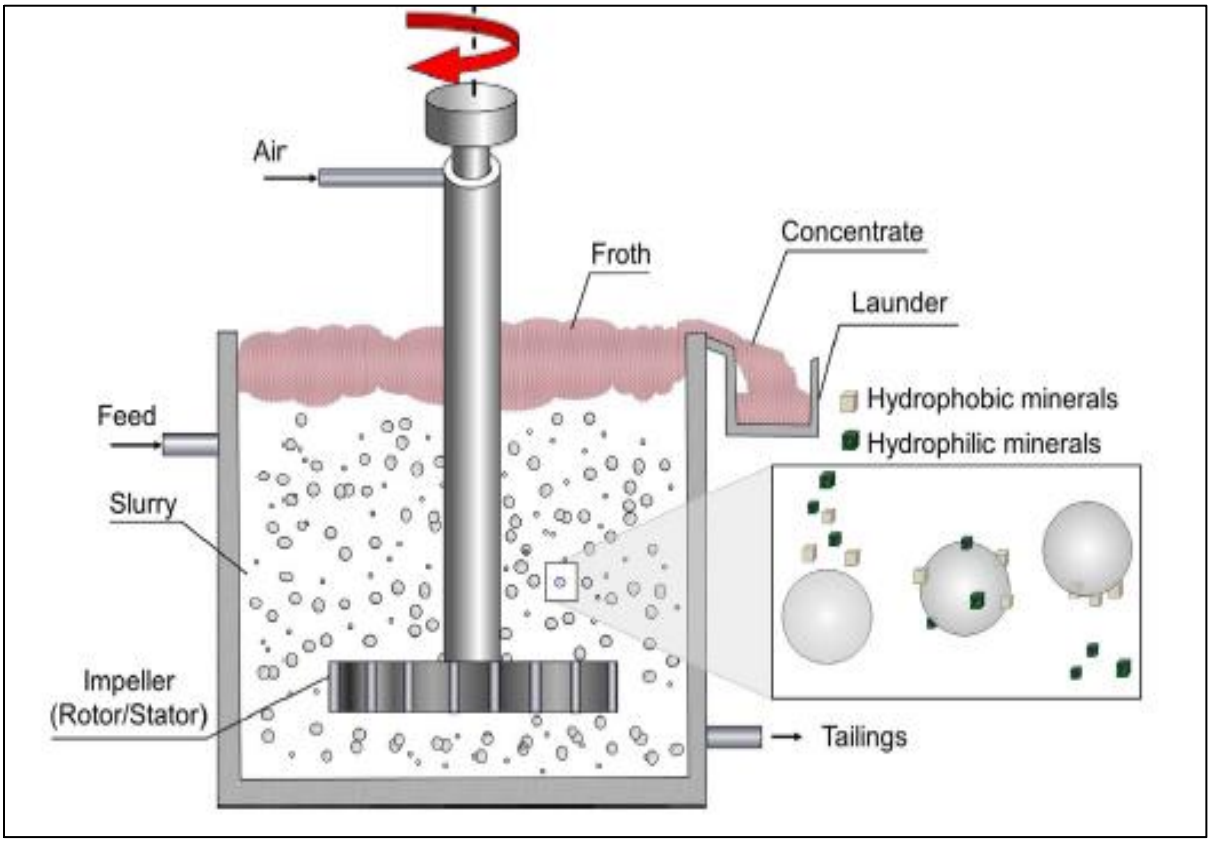

Figure 1 - Diagram of a typical flotation cell (Wills & Finch, 2016)

The recovery of minerals into the froth phase occurs via three distinct mechanisms, namely true flotation, entrainment and entrapment (Wills & Finch, 2016). True flotation involves the selective attachment of the desired minerals to air bubbles and is the dominant mechanism by which minerals report to the froth phase (Wills & Finch, 2016). Entrainment is non-selective and happens when fine particles are carried into the froth with the flow of water, and entrapment occurs when the particles aggregate and trap other particles amongst them thus carrying them into the froth (Smith & Warren, 1989; Yianatos, et al., 1988). The efficiency of froth flotation depends on a variety of things including the conditions under which the cell is operated and the reagents that are added. Figure 2 shows a schematic diagram summarising the many factors that affect froth flotation. Of interest to this study are chemical reagents, frothers in particular, as well as ions present in the process water which will also be referred to as water quality.

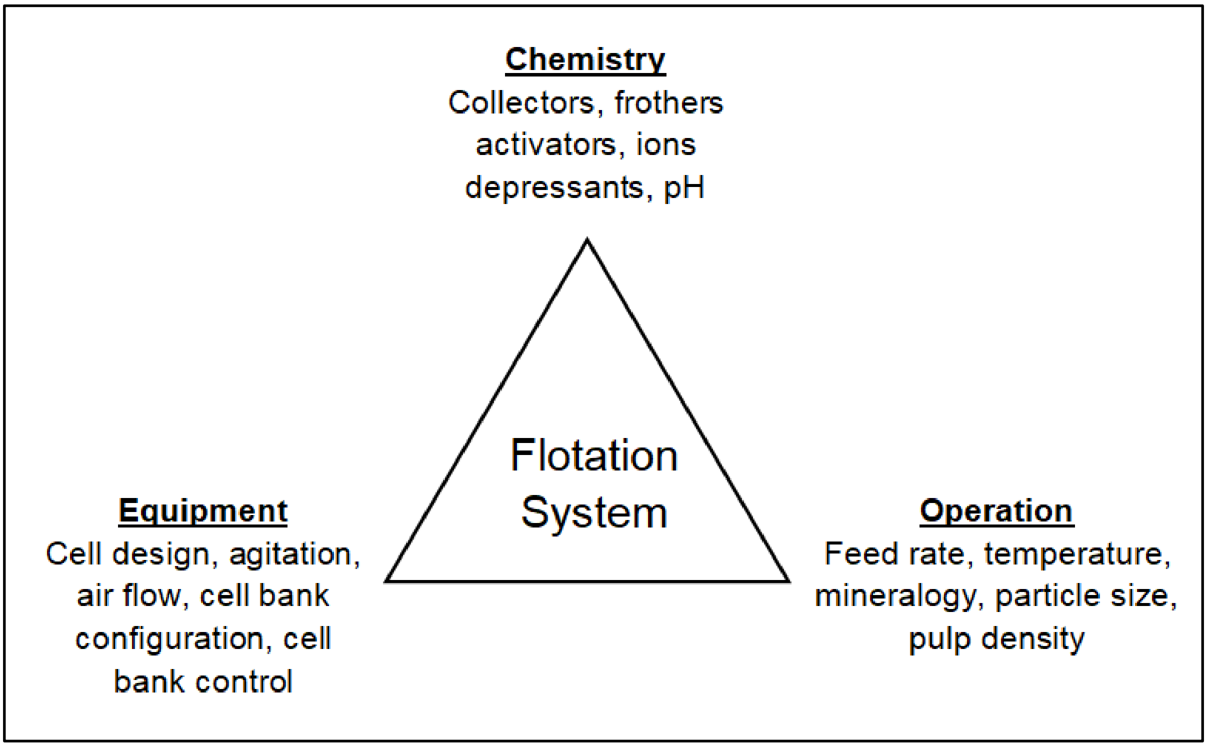

Figure 2 - Summary of the variables in a flotation system (adapted from Klimpel (1995))

2.2 Bubble Theory, Froth Stability and the Electrical Double Layer

Foams are considered to be 2-phase systems consisting of water and air, while froths are considered to be 3-phase systems consisting of water, air and mineral particles (Farrokhpay, 2011). The bubbles that are formed in the pulp phase rise to the surface where they congregate, forming a froth layer on top of the pulp phase, after which they form a polyhedral froth due to distortion from other bubbles (Walstra, 1989). The development of the froth structure can be seen in Figure 3. In order to carry the particles towards the surface, the air bubbles must be large enough to lift the particles up and the particles must be hydrophobic enough to stay attached to the bubbles while they are carried into the froth (Kawatra, 2011). Once the particles reach the surface, they will only stay attached to the bubbles if the froth is stable otherwise the bubbles will burst and drop the particles back into the pulp phase (Kawatra, 2011).

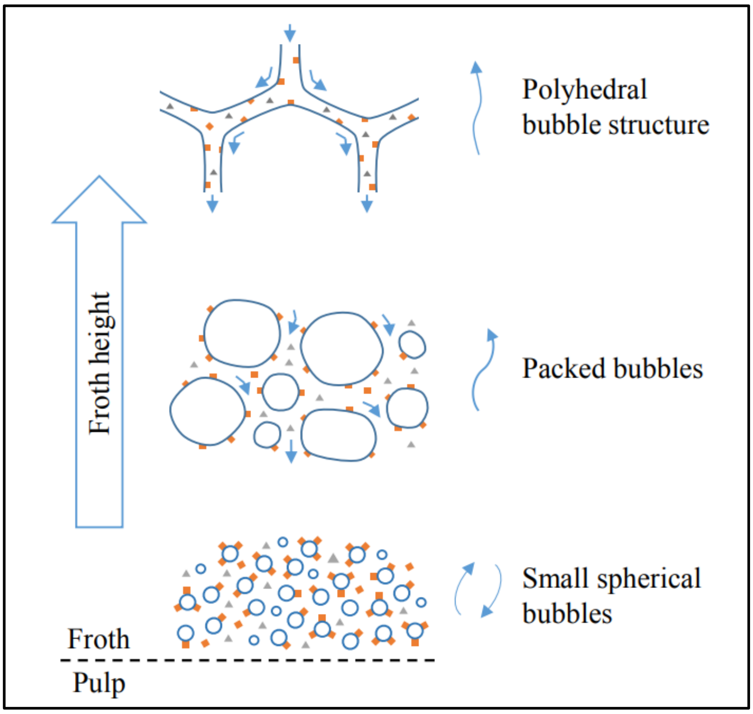

Figure 3 - Diagram of the froth structure at different heights (Hu, 2014)

The bubbles in the froth are separated by thin liquid films called lamellae which join up to create a large network of water channels in which the water and particles can flow (Farrokhpay, 2011) as seen in Figure 4. The water is then able to drain from the lamella back into the pulp phase which causes the lamellae to thin. Film thinning is when the surface tension increases (Bulatovic, 2007) and the lamellae between the bubbles eventually rupture causing the bubbles to burst or coalesce, which means that two or more bubbles fuse together to form one larger bubble, which reduces the surface area (Schramm & Wassmuth, 1994). The intersections between three bubbles are known as Plateau borders and this is where drainage occurs due to lower hydrostatic pressures at these points (Kronberg, et al., 2014).

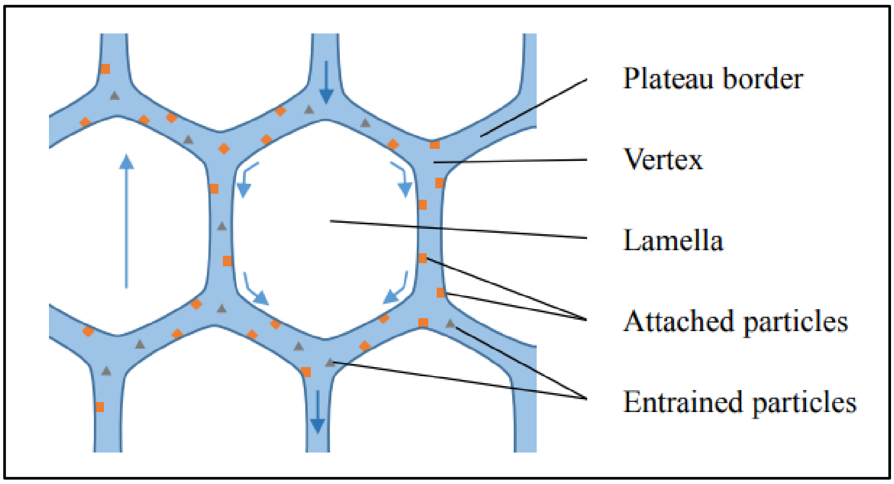

Figure 4 - Cross-section of froth structure near the surface (Hu, 2014)

Foam and/or froth stability refers to the ability of the bubbles to resist bursting (Triffett & Cilliers, 2004). The presence of a surfactant helps to stabilise the foam/froth by adsorbing onto the air-water interface, as seen in Figure 5. Surfactants in flotation are more commonly known as frothers and their properties and effects on flotation are further discussed in Section 2.3.5. Surfactant adsorption helps lower the surface tension which increases the viscosity of the froth and reduces film thinning (Walstra, 1989). This means that bubble coalescence occurs at much thinner films than without a surfactant (Bulatovic, 2007). Fine froths consisting of smaller bubbles also help to reduce water drainage because the bubbles remain more spherical in shape than larger bubbles. Surfactants also increase the hydration layers around the bubbles thus increasing the ability of the bubbles to resist bursting (Bulatovic, 2007).

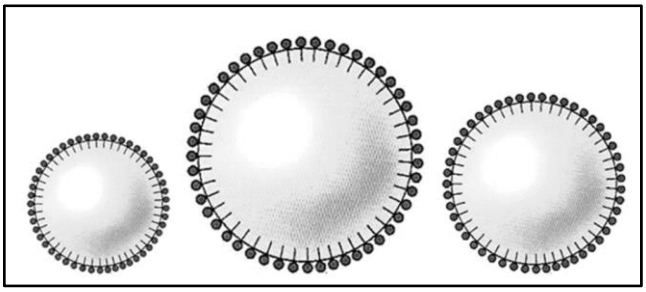

Figure 5 - Surfactant molecules adsorbing at the air-water interface (Khoshdast & Sam, 2011)

In a 3-phase froth, the presence of solids can impact the stability of the froth either negatively or positively (Bulatovic, 2007). If the particles that are carried into the froth are larger than the lamellae thickness or they are more sharply edged as opposed to spherical, they will burst the bubbles and consequently destabilise the froth. Smaller particles flow within the lamellae and can help to stabilise the froth by slowing the drainage from the lamellae (Farrokhpay, 2011; Aktas, et al., 2008). This is because the particles become trapped in the plateau borders and increase the viscosity thus hindering drainage (Kronberg, et al., 2014). This can be seen in Figure 6.

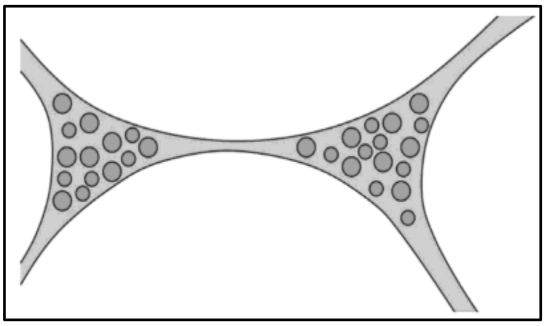

Figure 6 - Particles trapped within the Plateau borders (Kronberg, et al., 2014)

Both the hydrophobicity and size of the particles also play a role in the froth stability and overall flotation performance. Larger particles are more likely to collide with the bubbles however as the bubbles rise, the large particles may be too heavy to be carried upwards and may detach from the bubbles. Fine particles are less likely to collide with the bubbles, however once they are attached to the bubbles then they are easily carried upwards into the froth (Wills & Finch, 2016).

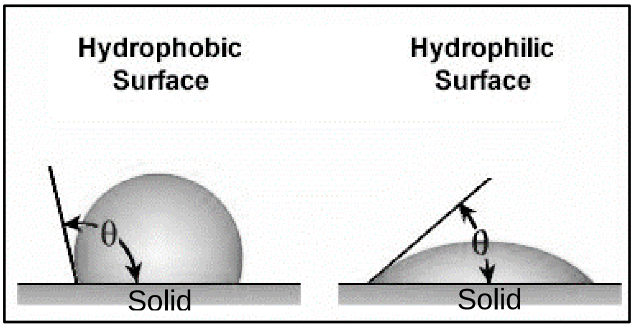

Figure 7 - Contact angle diagram (ramé-hart instrument co., 2019)

Hydrophobicity is dependent on the contact angle that the particle makes with the air bubble surface as seen by theta in Figure 7. The work of adhesion is the force required to break the interface between the particle and the bubble. As the contact angle increases, the work of adhesion increases which increases the hydrophobicity of the particles (Wills & Finch, 2016). Fine, highly hydrophobic particles with contact angles greater than 90^o have a greater chance of rupturing the liquid films between the bubbles because they tend not to move away as the film thins, unlike moderately hydrophobic particles with contact angles of approximately 66^o, that reposition themselves and move away from the thinnest part of the film thus allowing it to rupture naturally (Bulatovic, 2007). Even with moderately hydrophobic particles, a closely packed monolayer of particles is needed to stabilise the froth. Froth stability is therefore partially dependant on the quantity, hydrophobicity and size of the suspended particles (Johansson & Pugh, 1992; Schwarz & Grano, 2005).

The interfaces on either side of the liquid film are equivalent which means that the charge will be equally distributed on either side of the film. Ions from the mineral surfaces, reagents or process water dissociate and cause repulsive forces at the interfaces (Schramm & Wassmuth, 1994). The charged interfaces cause the ions to redistribute themselves within the water whereby oppositely charged ions (counter ions) are attracted to the surface while ions of like charge (co-ions) are repelled. This causes an electrical double layer (EDL) to form which consists of an inner layer of the attracted or adsorbed ions and a diffuse layer where the ions are distributed (Schramm & Wassmuth, 1994). As the lamellae become thinner, repulsion from the EDL becomes important (Scamehorn, 1989).

The zeta potential, which is the potential difference that exists between the surface of the particles or bubbles and the bulk liquid (Lexico, 2019), decreases as the distance from the charged surface increases. A diagram of the EDL and its associated zeta potential can be seen in Figure 8. Repulsion between EDLs helps prevent further thinning of the lamellae thus stabilising the froth (Kronberg, et al., 2014). Compression of the EDL and a reduction in the zeta potential can improve bubble-particle attachment due to the reduced repulsion between the particles and the bubbles (Kurniawan, et al., 2011; Paulson & Pugh, 1996).

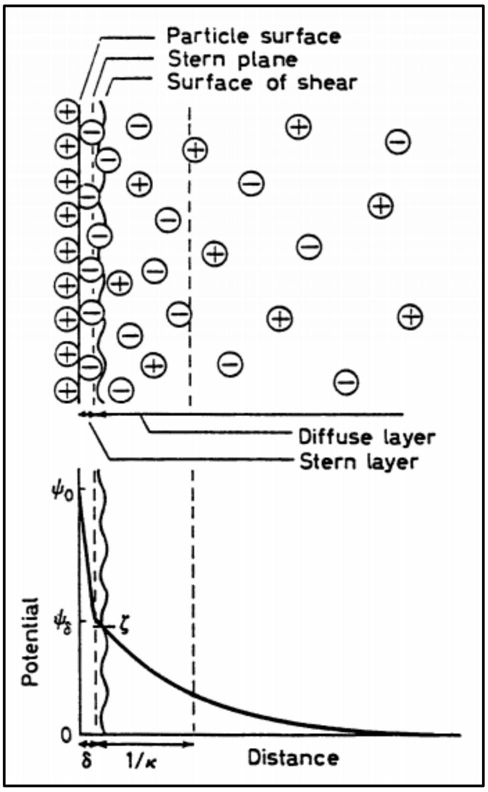

Figure 8 - Surface and zeta potentials for a charged foam lamella surface (Schramm & Wassmuth, 1994)

The stability of the froth, which is dependent upon all the factors already mentioned, is known to strongly influence the efficiency of flotation and thus the grade and recovery of the valuable minerals (Wiese & Harris, 2012; Farrokhpay & Zanin, 2012). An unstable froth will result in lower recoveries of the valuable minerals, however, a froth that is too stable will entrain excess water along with fine particles and gangue material, which may increase the recovery of the valuable minerals, but also decrease the grade due to the unwanted gangue (Triffett & Cilliers, 2004).

2.3 Effect of Reagents on Flotation

During froth flotation, various reagents are added to the pulp phase to strengthen the differences in surface properties between the desired minerals and the gangue in order to improve flotation performance/efficiency. Therefore this section considers the main reagents that influence the froth stability and the flotation process as a whole. Only one collector and three different frothers were used for this study and since the collector type and dosage remained constant, the only reagent variables were the frother type and dosage. Therefore, these will be discussed in detail while the other reagents will be considered briefly.

2.3.1 Collectors

Collectors are one of the most important reagents that are added during froth flotation because they render targeted value-bearing minerals hydrophobic by adsorbing onto the mineral surface and increasing the contact angle (Wills & Finch, 2016). Collectors can be classified as either ionising, which means that the collector will dissociate in water, or non-ionising compounds which are insoluble and instead cover the mineral surface with a thin film that renders it hydrophobic (Wills & Finch, 2016). Ionising compounds are heteropolar meaning that they consist of a polar end that is hydrophilic, and a non-polar hydrocarbon end which is hydrophobic. Collectors adsorb onto the particle surfaces with their non-polar, hydrophobic ends orientated toward the bulk solution, as seen in Figure 9, which causes the particles to become hydrophobic (Wills & Finch, 2016). The concentration of the collector used is important because if too much is administered, it can cause unwanted minerals to float along with the valuable minerals thus reducing the grade, and in extreme cases, it can reduce the hydrophobicity of the valuable minerals due to the formation of multi-layers on the particle surface which reduces recovery. Similarly, if too little collector is used, then only a portion of the valuable minerals will be rendered hydrophobic which also reduces the recovery (Wills & Finch, 2016).

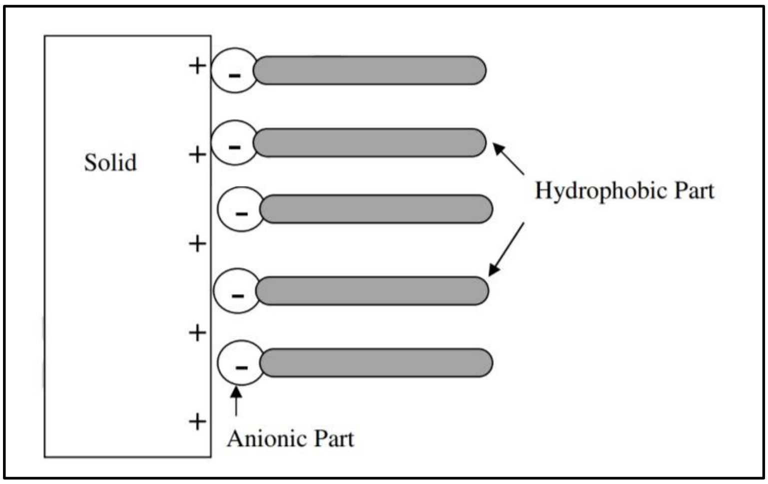

Figure 9 - Adsorption of an anionic collector onto the particle surface (Kawatra, 2011)

Ionising collectors can also be classified as anionic or cationic according to their ionic charge (Kawatra, 2011). Xanthates, a group of anionic collectors, are the most popular choice for flotation particularly in the case of sulphide ores (Lee, 2018). Adeleke, et al. (2014) stated that "*Xanthates are ionising anionic sulfhydryl collectors that are powerful and selective in the flotation of sulphide minerals. They adsorb on to the sulphide mineral surface and form insoluble metal xanthates which are very hydrophobic*". Xanthate adsorption is achieved through the attractive charges between the mineral surface and the collector (Manono, et al., 2018) therefore the presence of charged ions in the process water may affect this process since anionic collectors will preferentially adsorb onto the surface with the strongest positive charge (Kawatra, 2011). Further effects of ions on collector adsorption are discussed in Section 2.4. Typical examples of xanthate collectors include sodium isopropyl xanthate (SIPX), sodium isobutyl xanthate (SIBX) and potassium isobutyl xanthate (PIBX) amongst others (Lee, 2018). SIBX in particular has been found to be quite successful in the flotation of copper ore. The structure of SIBX can be seen in Figure 10.

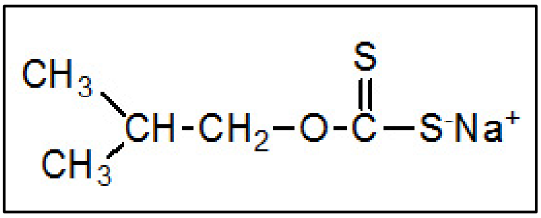

Figure 10 - Structure of SIBX collector (Senmin, n.d.)

2.3.2 Activators

An activator is a reagent that helps change the chemical nature of the particle surface so that it becomes amenable to interaction with the collector. This allows the collector to render the mineral surface hydrophobic when it may not have been possible before (Wills & Finch, 2016). Activators are generally soluble salts which ionise in solution and react with the mineral surface to create a new surface favourable to the collector (Wills & Finch, 2016). A common example of activation is using copper sulphate to activate sphalerite prior to collector addition because sphalerite does not float well using a xanthate collector due to water-soluble products, such as zinc xanthate, being formed which coats the mineral surface making it hydrophilic (Wills & Finch, 2016). The copper sulphate dissociates in solution which allows the copper ions to then react with the xanthate collector to form copper xanthate which is insoluble in water. The copper xanthate then gets deposited on the mineral surface thus creating a thin hydrophobic layer which then allows the mineral to float (Kawatra, 2011; Wills & Finch, 2016).

2.3.3 Depressants

One of the problems of flotation is the presence of unwanted minerals in the form of naturally floating gangue (NFG). NFG is naturally hydrophobic and therefore floats alongside the valuable minerals thus reducing the grade of the recovered minerals. Depressants work in the opposite manner to collectors by adsorbing onto the unwanted mineral surfaces rendering them hydrophilic and preventing them from attaching to the bubbles (Kawatra, 2011). This increases the selectivity of flotation and helps to make the flotation of certain ores, such as platinum and nickel sulphides, more economically viable (Wills & Finch, 2016). However, depressant dosage needs to be carefully monitored because the depression of NFG can lead to destabilisation of the froth (Wiese, et al., 2010). This could be due to a decrease in the quantity of particles reporting to the froth which results in fewer particles being available to form stabilising monolayers around the bubbles (Johansson & Pugh, 1992; Schwarz & Grano, 2005). It could also be due to fewer particles being trapped in the Plateau borders which results in easier drainage (Kronberg, et al., 2014). Depressants are usually long chain polysaccharides with the two most common being guar gum and carboxymethylcellulose (CMC) (Wiese & Harris, 2012).

Depression can also occur naturally in the form of fine particles which form slime coatings on the mineral surface and prevent adsorption of the collector (Parsonage, 1985) therefore some level of desliming is usually done prior to flotation when particles smaller than 20 microns are involved (Wills & Finch, 2016).

2.3.4 pH Regulators

Flotation is usually carried out in an alkaline solution because the majority of collectors that are used are stable at alkaline conditions (Wills & Finch, 2016). Cu-Ni-PGM ores also have a natural alkaline slurry pH of around 9 (Wiese, et al., 2006). The pH of the solution mostly affects the mineral surface by causing it to become positively or negatively charged (Kawatra, 2011). Depending on the surface charge, the attraction of the collector to the mineral surface can be manipulated thus allowing selective mineral separation (Kawatra, 2011). Figure 11 shows how manipulating the pH allows certain minerals to float whilst depressing others. For example, at a pH of 9 and a collector concentration of 50 mg/litre, only chalcopyrite will float while at a pH of 6, both chalcopyrite and galena will float. Increased alkalinity is generally achieved through the addition of lime or soda ash while increased acidity is generally achieved through the addition of sulphuric acid (Wills & Finch, 2016).

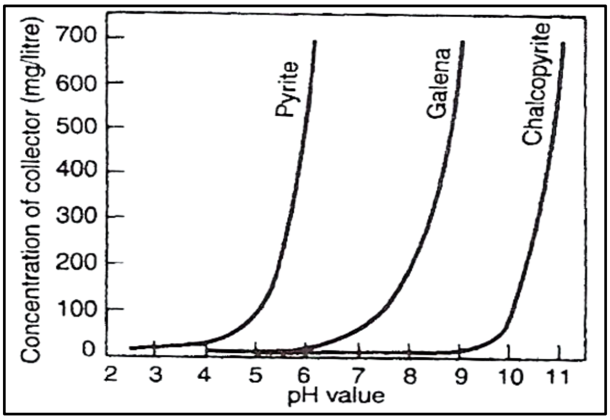

Figure 11 - Relationship between pH and collector concentration (Wills & Finch, 2016)

A study done by Farrokhpay & Zanin (2012) investigated the effect of pH on froth stability and found that lower pH values increased the froth stability because they decreased the zeta potential. A similar study done by Manono, et al. (2017) found that an increase in ionic strength at pH 9 increased the recovery of solids while at pH 11, an increase in ionic strength decreased the solids recovery. The decrease at higher pH is believed to be due to the presence of ions and hydroxo species that hinder collector adsorption onto the mineral surface by reducing the negative surface charge (Ikumapayi, et al., 2012; Bicak, et al., 2012). This agrees with Tadie, et al. (2016) who found that the recovery of galena decreased to a greater extent at a pH of 11.8 compared to a pH of 9.2 thus showing the depressing effect of the hydroxyl ions at higher pH.

2.3.5 Frothers

The role of frothers is to stabilise the bubbles in order to allow for mineral particle attachment and for the attached minerals to be transferred to the froth phase for collection (Wills & Finch, 2016). This is achieved by the frother adsorbing at the air-water interface and reducing the surface tension (Wills & Finch, 2016; Aldrich & Feng, 2000) as well as reducing the degree of bubble coalescence (Bulatovic, 2007; Cho & Laskowski, 2002) which increases the particle-bubble attachment efficiencies (Hewitt, et al., 1994) due to a larger surface area being available for particle attachment. The degree of bubble coalescence decreases with an increase in frother concentration (Cho & Laskowski, 2002; Corin & Wiese, 2014), with bubble coalescence being completely inhibited beyond the critical coalescence concentration (Cho & Laskowski, 2002), which is the minimum concentration of frother needed to completely prevent bubbles joining together (Szyszka, 2018). This agrees with Barbian, et al. (2003) who found that the froth volume tended to increase with an increase in frother dosage thus indicating a more stable froth. The recovery of water and solids is known to give a good indication of the froth stability (Wiese, 2009; Corin, et al., 2011) with greater recoveries indicating more stable froths. For this reason, a more stable froth is usually desirable to increase the recoveries of the valuable minerals however a froth that is too stable will recover more gangue and therefore decrease the valuable mineral grades (Triffett & Cilliers, 2004).

Frothers are usually “heteropolar surface-active organic reagents” (Wills & Finch, 2016). The surface-active ends orientate themselves towards the water while the non-polar hydrocarbon groups orientate themselves towards the air phase. This was shown in Figure 5 and allows adsorption at the air-water interface (Wills & Finch, 2016). Frothers should have negligible collecting power and be mostly soluble in water to facilitate even distribution throughout the pulp phase. The most effective frothers contain either a hydroxyl, carbonyl, carboxyl, amino or sulfo group, however the alcohols, amines and acids are more commonly used since they have much weaker collector properties (Wills & Finch, 2016). Frothers with both strong frothing and collecting abilities make selective flotation difficult (Wills & Finch, 2016). Nowadays a wide range of synthetic frothers have been developed which are based on high molecular weight alcohols since they have been found to be more stable than industrial products such as pine oil and cresol (Wills & Finch, 2016). Methyl isobutyl carbinol (MIBC) is the most commonly used frother in industry since it provides good flotation performance and is relatively cheaper (Tan, et al., 2005). Other synthetic frothers that have been found to be effective have been developed based on polyglycol ethers. Different frother types may also be blended together to suit the needs of the plant (Wills & Finch, 2016).

According to Pugh (2000), the chemical structure of the frother is vital to its performance. Both the maximum particle size that can be recovered and the selectivity of the recovered minerals decreases as the amount of branching in the chemical structure of the frother increases (Klimpel & Hansen, 1988; Klimpel & Isherwood, 1991). This agrees with Bulatovic (2007) who said that the strength and performance of the polyglycol ether frothers are strongly dependent on their carbon chain length and molecular weight, since greater molecular weights increase frothability and lower selectivity.

This was found to be true by Wiese & Harris (2012) who investigated the effects of DOW 200 and DOW 250 on flotation performance. It was found that in the absence of solids, the water recoveries were higher for DOW 250 indicating more stable froths. It was also found that the water recoveries were lower in the three-phase tests than in the two-phase tests, which implies either some degree of destabilisation of the froth by the solids or partial adsorption of the frother onto the solid surface (Lotter, et al., 2003), which leaves less frother available for adsorption onto the bubbles. The water recoveries for both frother types were found to be similar in the presence of solids with greater amounts of solids being recovered using DOW 200 which, according to Wiese & Harris (2012), may be due to the frother's influence on NFG.

Studies done by Wiese, et al. (2010), Wiese & Harris (2012) and Corin & Wiese (2014) investigated how increasing the frother dosage under varying depressant concentrations influenced the flotation performance. Under all depressant conditions, the water and solids recoveries increased with an increase in frother dosage which indicates an increase in froth stability. As mentioned earlier, this is due to the frother adsorbing at the air-water interface and reducing the surface tension thereby stabilising the bubbles and preventing coalescence (Wills & Finch, 2016; Aldrich & Feng, 2000). Both the smaller, spherical bubbles and the particles trapped in the Plateau borders also help reduce water drainage (Bulatovic, 2007; Kronberg, et al., 2014). The more stable bubbles also allow for more particles to remain attached due to increased bubble-particle attachment efficiencies as a result of the larger surface area available (Hewitt, et al., 1994). The increase in frother dosage therefore intensifies these effects.

They also looked at the effects of frother dosage on the recovery and grade of copper and nickel. It was found that for all depressant conditions, both the copper and nickel recoveries increased slightly with an increase in frother dosage. This is expected due to the increased solids recoveries and will occur through the same mechanisms. At the same time, the copper and nickel grades were found to decrease which can be attributed to increased gangue recoveries (Wiese & Harris, 2012) since the recovery of entrained gangue increases with an increase in water recovery (Engelbrecht & Woodburn, 1975; Zheng, et al., 2006a,b; Neethling & Cilliers, 2002). This agrees with Corin & Wiese (2014) who investigated the gangue recoveries and found that an increase in frother dosage increased the recovery of both floating and entrained gangue for all depressant conditions. However, far greater amounts of gangue reported to the concentrate when no depressant was used, with the majority consisting of floating gangue. Depictions of these trends from Wiese, et al. (2010) can be seen in Figures 12, 13 and 14.

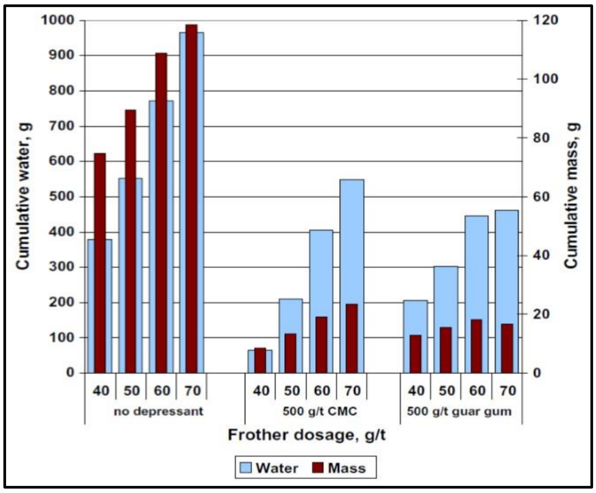

Figure 12 - Effect of increasing frother dosage on water and solids recoveries (Wiese, et al., 2010)

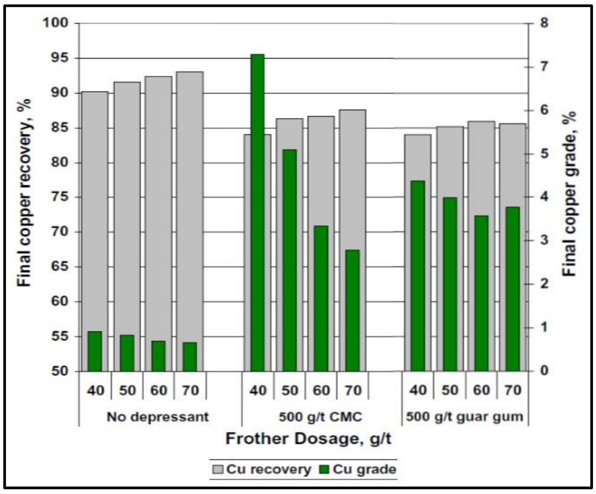

Figure 13 - Effect of increasing frother dosage on copper recovery and grade (Wiese, et al., 2010)

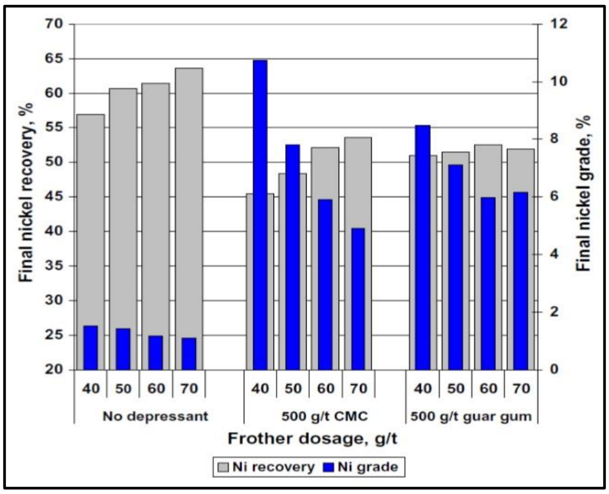

Figure 14 - Effect of increasing frother dosage on nickel recovery and grade (Wiese, et al., 2010)

2.4 Water Quality and the Effect of Ions on Flotation

Water makes up 80 - 85% of the slurry that is processed in the flotation circuit (Levay, et al., 2001). This means that the mining industry needs large quantities of water in order to carry out their minerals processing operations. However, many challenges are forcing the mining industry to save freshwater resources and to use low-quality or recycled water, often from tailings dams, or thickener overflows (Farrokhpay & Zanin, 2012; Muzenda, 2010). The two main challenges are limited freshwater supplies and environmental regulations (Peters & Meybeck, 2000; Ridoutt & Pfister, 2010; Carlson, et al., 2002; Johnson, et al., 2002; Manono, et al., 2013). Often mining operations are located in water-scarce regions (Farrokhpay & Zanin, 2012) or the water sources are affected by seasonal changes in the local climate which can impact both the quantity and quality of the usable water (Levay, et al., 2001). Increasingly strict environmental regulations are also forcing minerals processing plants to reduce the amount of polluted water discharged to the environment, or in many cases, to ensure zero-effluent operations (Muzenda, 2010; Manono, et al., 2012; Manono, et al., 2013).

Recycled water has been shown to contain elevated levels of ions or electrolytes such as Ca^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, Mg^{2+}, NO_3^{-} as well as other contaminants such as thiosalts, base metals and residual reagents (Wiese, et al., 2007; Shortridge, et al., 1999; Khraisheh, et al., 2005; Smith & Hertzog, 1985). Increased levels of total dissolved solids (TDS) tend to affect the water quality and can impact the efficiency and performance of flotation operations (Lui, et al., 2013; Farrokhpay & Zanin, 2012; Muzenda, 2010; Manono, et al., 2012; Wiese, et al., 2007; Khraisheh, et al., 2005; Shortridge, 2002; Fuerstenau, et al., 1988). Metal ions present in the water can also precipitate out of solution and form hydrophilic barriers on the particle surfaces which prevent the collector from adsorbing properly, thus reducing the particle hydrophobicities and compromising the bubble-particle attachment efficiencies (Fornasiero & Ralston, 2006; Senior & Trahar, 1991; Smith & Hertzog, 1985; Schwarz & Grano, 2005). The effects of Ca^{2+} on sulphide ores were investigated by Gaudin & Charles (1953) and Rao, et al. (2016) who found that increasing concentrations of Ca^{2+} present in process water resulted in larger amounts of Ca^{2+} ions adsorbing on the mineral surface thus hindering collector adsorption. However, other literature (Boujounoui, et al., 2015; Corin & Wiese, 2014; Slatter, et al., 2009; Shackleton, et al., 2012; Wang & Peng, 2014) proposes that the presence of Ca^{2+} and thiosulphate ions improves xanthate adsorption onto the sulphide minerals.

Bubble-particle attachment can also be improved with the presence of electrolytes because the zeta potential is reduced which compresses the EDL around the particles and bubbles, thus reducing the electrostatic repulsion between them (Kurniawan, et al., 2011). This was seen by Farrokhpay & Zanin (2012) who found that the zeta potential decreases with an increase in the metal ion concentration. This can be beneficial for the desired minerals, but it may also cause unwanted gangue activation (Chandra & Gerson, 2009; Finkelstein, 1997).

One of the advantages of increased levels of electrolytes is their influence on the surface tension in the froth at the air-water interface (Quinn, et al., 2007; Iwasaki, et al., 1980; Viviers, 1979). The presence of ions increases the froth viscosity and promotes the formation of smaller, more stable bubbles by reducing bubble coalescence (Hewitt, et al., 1994; Marruci & Nicodemo, 1967; Craig, et al., 1993; Zieminski & Whittemore, 1971; Laskowski, et al., 2003). Corin & Wiese (2014) and Manono, et al. (2013) found that the bubble size decreased with an increase in ionic strength. Smaller bubbles help to stabilise the froth and provide a larger surface area for particle attachment which helps to increase the recovery of the solids to the concentrate. Farrokhpay & Zanin (2012) also found that the froth height, and therefore the froth stability, increased with an increase in the concentration of metal ions. The presence of ions also helps to slow inter-bubble drainage which results in more solids being recovered to the concentrate (Manono, et al., 2013). However, the increase in froth stability and therefore the increase in water and solids reporting to the froth, results in an increase in entrained gangue.

Since the primary action of frothers is to increase froth stability by inhibiting bubble coalescence (Manono, et al., 2012; Harris, 1982), it can be said that the ions act in a similar manner to frothers with regard to their froth stabilising abilities. The ability of the frother to decrease surface tension has also been postulated to increase in more electrolytic solutions (Quinn, et al., 2007; Iwasaki, et al., 1980; Craig, et al., 1993; Manono, et al., 2018). This agrees with investigations done by Kurniawan, et al. (2011), Peng & Seaman (2011) and Finch, et al. (2008) who concluded that salts such as NaCl and Na_2SO_4 could be compared to MIBC and polyglycol frothers in their ability to inhibit bubble coalescence and reduce bubble size.

Considering that ions present in recycled water appear to act on the froth in a manner that is similar to the action of frothers, it is important to investigate the impact of ionic strength on flotation performance. Wiese, et al. (2005) developed a recipe for standard synthetic plant water (SPW) with a TDS of 1023 mg/l which mimicked the water quality of typical South African Platinum Group mineral concentrators. However, in the time since this standard recipe was created, it has become apparent that there has been a steady increase in the amount of dissolved ions present in the process water, owing to recycled water on site, and therefore a TDS of 1023 mg/l is no longer typical of most PGE concentrators (Corin, et al., 2011).

In order to account for this, a collection of studies was done at the Centre for Minerals Research at the University of Cape Town (Corin, et al., 2011; Manono, et al., 2012; Manono, et al., 2013; Corin & Wiese, 2014; Manono, et al., 2018) which investigated the effects of increasing the ionic strength of synthetic plant water on flotation performance under various depressant conditions of CMC and guar. This was achieved by multiplying the concentration of dissolved ions in the standard recipe 2-, 3-, 5- and 10-fold to achieve 2 SPW, 3 SPW, 5 SPW and 10 SPW respectively.

The studies done by Corin, et al. (2011), Manono, et al. (2012), Corin & Wiese (2014) and Manono, et al. (2018) were 3-phase studies which found that increasing the ionic strength increased both the water and solids recoveries as well as the entrained gangue under all depressant conditions. The gangue recovered per unit water was also found to decrease by Corin, et al. (2011) and Manono, et al. (2012) which is a counterintuitive phenomenon since entrainment is known to follow the water recovery (Engelbrecht & Woodburn, 1975; Neethling & Cilliers, 2002; Zheng, et al., 2006a,b) however, owing to the large increases in water recovered, the overall entrained gangue increased. The increase in water and solids recoveries shows that increasing the ionic strength stabilised the froth by increasing the froth viscosity thus hindering drainage, stabilising the bubbles and compressing the EDL which increases bubble-particle attachment efficiencies.

The recoveries of copper and nickel were generally unaffected by a change in ionic strength, but Corin & Wiese (2014) found that the recovery of nickel increased slightly. The grades of copper and nickel generally decreased with an increase in ionic strength which is due to increased gangue recoveries, however Manono, et al. (2012) found that the nickel grade remained the same. The slightly increased nickel recoveries and constant nickel grades experienced by Corin & Wiese (2014) and Manono, et al. (2012) respectively could be due to the presence of ions increasing the floatability of the nickel-gangue composites (Chandra & Gerson, 2009; Finkelstein, 1997; Lui, et al., 2013) since some of the nickel is contained in non-liberated pentlandite.

The 2-phase studies done by Corin, et al. (2011) and Manono, et al. (2013) showed that increasing the ionic strength increases the recovery of water. The increase in froth stability in the 3-phase tests can be directly related to the increase in foam stability in the 2-phase tests which implies that the increased ionic strength helped to stabilise the froth as opposed to any changes in the hydrophobicity of the solids (Corin, et al., 2011; Dippenaar, 1982). Manono, et al. (2013) also found that the foam height and foam collapse time decreased with an increase in ionic strength which also implies an increase in stability which agrees with Manono, et al. (2018) who found that the froth exhibited the same trends.

2.5 The South African and Finnish Context

As part of a large collaborative project, the recycling of water and its quality is being considered within the mineral process industry with a comparison being made between mining operations located in water-scarce regions and those in which there is plenty of water. Fresh water is freely available in Finland, but this water is pristine and incredibly strict environmental regulations aim to keep it this way by limiting the amount and quality of discharge from mining and other operations. The source of freshwater for the Kevitsa mine is the Vajukoski Pond however most of the process water is made up of water from the tailings pond. Due to the heavy water usage requirements and strict environmental regulations about the release of used water, 90 - 95% of the concentrator water is recycled (Schreithofer & Muzinda, 2017).

However, this causes the dissolved species to build up which negatively impacts the flotation circuit. In addition, due to vast seasonal changes, the tailings dam freezes over which reduces both the quantity of usable water and the residence time that the water spends in the dam, both of which increase the ionic strength of the water thus reducing its quality (Schreithofer & Muzinda, 2017).

The needs of South Africa and Finland are similar but different in that the mining industries both suffer with water quality problems but at different ends of the spectrum. Kevitsa has a lot of low-quality water due to recycling and seasonal changes, while South African mining operations are generally located in water scarce regions and thus do not have easy access to fresh water. This is why it is becoming increasingly important to use alternative water sources for mining operations, but the quality is often sub-par. Kevitsa ore is also very similar to the Merensky ore in South Africa which means that the results can be applied to the South African mining industry too.

Based on the results of investigations into the effects of ionic strength on flotation, it is obvious that ionic strength plays an important role in the stability of the froth and the performance of the flotation circuit. Since the water used in the circuit is being sourced from recycled or low-quality water, it is important to examine these changes. However, simply examining each variable on its own, as has been done previously, will not give a true representation of how ionic strength influences the flotation circuit because a frother is also present. This means that the effects of frothers and their dosages under degrading water quality need to be investigated to determine how these variables work together. If it can be determined how these variables interact, then there is a possibility that the frother dosage can be decreased in the presence of water with elevated ion levels while still maintaining optimal froth stability. This will hopefully help to reduce frother costs during the flotation process and to optimise the recoveries and grades of the valuable minerals. In order to do this, the effects on flotation performance due to a simultaneous change in frother dosage and ionic strength need to be investigated.

2.6 Summary and the Gap in Knowledge

In summary, investigations into the effects of ionic strength on flotation performance appear to agree that the presence of elevated ion levels increases the froth stability which increases the water and solids recoveries. This is due to ions influencing the surface tension, increasing the froth viscosity thus hindering drainage, stabilising the bubbles and compressing the EDL which increases bubble-particle attachment efficiencies. Increasing the ionic strength does not appear to affect the copper and nickel recoveries, but it does decrease their grades due to increased gangue recoveries. The increased gangue recoveries are due to the increased water recoveries but can also be attributed to ion-induced gangue activation due to increased bubble-particle attachment efficiencies from compression of the EDL. Therefore, it is important to monitor water quality due to its influential effects on flotation performance.

At the same time, investigations into the effects of frother dosage revealed that increasing the frother dosage appears to increase froth stability thus resulting in higher recoveries of water, solids, copper and nickel, with a simultaneous decrease in the grade of both copper and nickel due to increased gangue recovery. This is due to the frother adsorbing at the air-water interface, reducing bubble coalescence, and lowering the surface tension thus stabilising the froth.

The closest study done on both frother dosage and ionic strength is by Corin, et al. (2011) but it consists of two individual studies, one that varies ionic strength under constant frother dosage and one that varies frother dosage under constant ionic strength. The simultaneous effects of both these variables have not yet been investigated. Based on the fact that ionic strength plays a similar role to frother dosage in the effects that it has on flotation, it is important to investigate the simultaneous effects of these two variables on flotation performance. This is in the hope that frother dosage can be decreased under conditions of increased ionic strength while maintaining flotation performance. If this is possible, it will result in a decrease in the quantity of frothers required for flotation as well as allow the mining industry to recycle more of their water without the need for extensive cleaning which in turn will reduce the amount of fresh water required for flotation.

In order to fill this gap in the knowledge, the simultaneous effects of ionic strength and frother dosage on flotation performance will be investigated.

3. Research Objectives

3.1 Overall Project Objectives

To investigate how a simultaneous change in frother dosage and ionic strength affects the froth stability and to determine whether a lower frother dosage coupled with a higher ionic strength can maintain flotation performance.

3.2 Key Questions

- How does changing the frother dosage influence the water, solids, copper and nickel recoveries and the copper and nickel grades?
- How does changing the ionic strength influence the water, solids, copper and nickel recoveries and the copper and nickel grades?
- How does the frother type influence the water, solids, copper and nickel recoveries and the copper and nickel grades?
- How does a simultaneous change in both frother dosage and ionic strength influence the water, solids, copper and nickel recoveries and the copper and nickel grades?
- Can the frother dosage be lowered at higher ionic strengths while still maintaining flotation performance?

3.3 Hypotheses

Hypothesis 1:
The combination of a high frother dosage and high ionic strength will result in a very stable froth because both frother dosage and ionic strength individually stabilise the froth and therefore their simultaneous action should intensify this effect.

Hypothesis 2:
The frother dosage can be decreased if plant water is recycled while still maintaining flotation performance due to the fact that recycled plant water has a higher ionic strength and ionic strength and frother dosage both act on the bubble surface and produce similar effects on flotation.

3.4 Sustainability Development Goals

Sustainability goals 6 and 12 are being addressed through the investigation of using recycled water for the flotation circuit which will reduce the amount of clean water being used in the mining industry as well as reduce the amount of contaminated water discharged to the environment. Sustainability goal 12 is also being addressed through investigation into decreasing the amount of chemical frothers needed for flotation and therefore reducing the production and consumption of these chemicals. Sustainability goals 13, 14 and 15 are being indirectly addressed through goals 6 and 12 because reducing the amount of clean water being used and the amount of contaminated water being discharged to the environment helps slow down climate change and preserve life below water and on land.

Figure 15 - Sustainability Development Goals (United Nations, n.d.)

4. Experimental Method

4.1 Synthetic Plant Water

Synthetic plant water (SPW) represents water typically found on a South African Platinum Group Metals (PGM) concentrator (Wiese, et al., 2005). The concentration of ions present in synthetic plant water can be seen in Table 1 and synthetic plant water can be made up using the recipe in Table 2. To simulate ion build up during water recycling, the quantities of each salt have been multiplied to achieve different ionic strengths. Synthetic plant water was used for all milling and flotation procedures at strengths of 3 SPW, 5 SPW and 10 SPW which equates to 3, 5 and 10 times the TDS per litre respectively.

Table 1 - Concentration of ions in standard synthetic plant water (Wiese, et al., 2005)

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

Table 2 - Synthetic plant water recipe for standard plant water

Type of Salt	Concentration (g/L)
Magnesium Sulphate [$MgSO_4.7H_2O$]	0.615
Magnesium Nitrate [$Mg(NO_3)_2.6H_2O$]	0.107
Calcium Nitrate [$Ca(NO_3)_2.6H_2O$]	0.236
Calcium Chloride Dihydrate [$CaCl_2.2H_2O$]	0.15
Sodium Chloride [NaCl]	0.356
Sodium Carbonate [Na_2CO_3]	0.03

The synthetic plant water was made up in a 20 L bucket which was stirred with an impellor for 20 min, 40 min and 60 min for 3, 5 and 10 SPW respectively to ensure the salts were properly dissolved. The water was stirred again briefly before use if it had been standing overnight.

4.2 Ore Mineralogy

4.2.1 Kevitsa Igneous Complex

The Kevitsa igneous complex in Northern Finland (Figure 16) is composed of nickel, copper and platinum group elements (Ni-Cu-PGE) and was discovered in 1987. The deposit is located in the Central Lapland Greenstone Belt and is unique to other global deposits because the sulphide mineralization is mostly disseminated with the ore being more heavily enriched in Cu relative to Ni. The deposit is fairly low grade with sulphides consisting of less than 5% of the total mineralogy. The main Cu minerals are chalcopyrite and cubanite while the main Ni minerals are pentlandite and millerite. 20% of the nickel and 10% of the copper in the feed is contained within non-sulphide minerals (Musuku, et al., 2016; Schreithofer & Muzinda, 2017). Other ore minerals include chromite, magnetite and pyrrhotite, which is a sulphide gangue mineral, with pyroxene group metals making up the major non-sulphide gangue minerals (Musuku, et al., 2016; Schreithofer & Muzinda, 2017). The mine is currently producing 18 000 tops of copper, 9 500 tons of nickel, 12 500 ounces of gold, 23 000 ounces of platinum and 23 000 ounces of palladium per year and is expected to have a lifespan of 20 years.

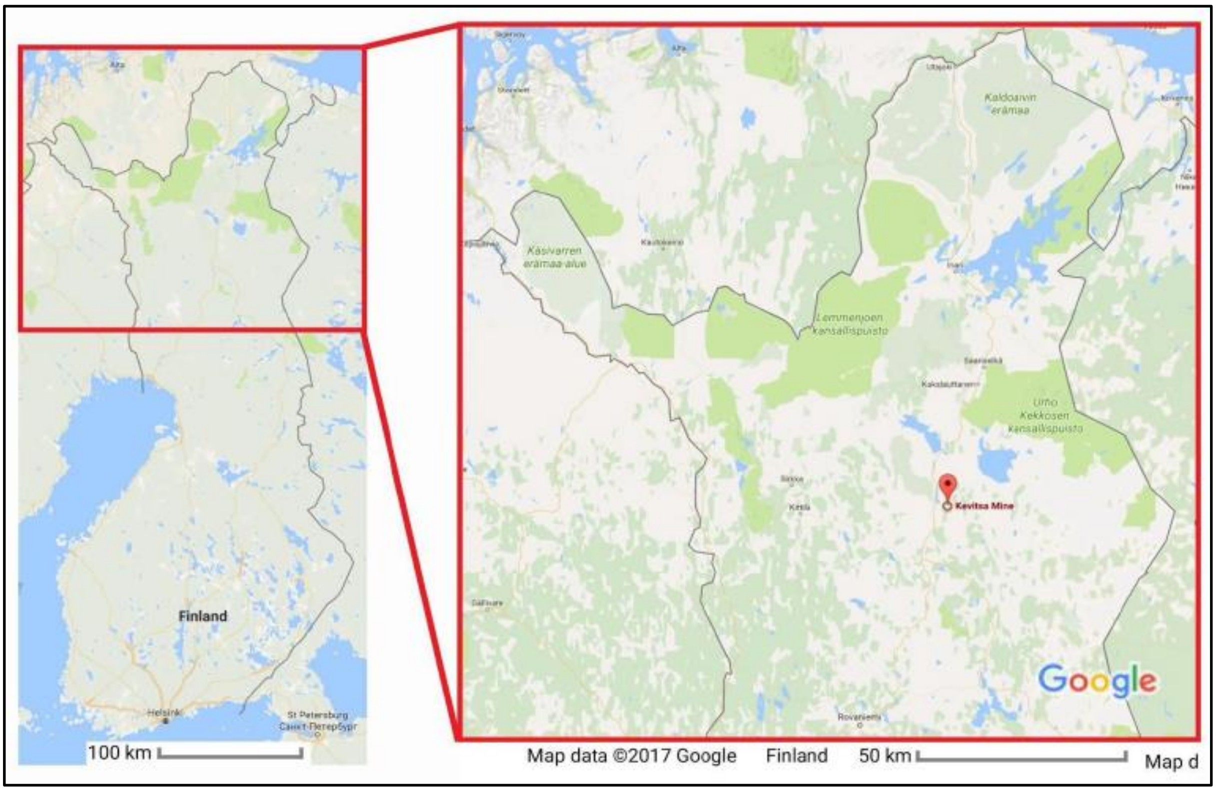

Figure 16 - Boliden Kevitsa mine location (Schreithofer & Muzinda, 2017)

4.2.2 QEMSCAN Analysis

Quantitative Evaluation of Materials by Scanning Electron Microscopy (QEMSCAN) was used to analyse the bulk mineralogy composition and sulphide liberation of the samples. A portion of the feed sample was split into 1 g samples using a quantachrome microriffler while the other portion of the feed was first screened to produce samples of different size fractions and then also split into 1 g samples using the quantachrome microriffler. Each sample was used to make an analysis block by mixing the sample with graphite and resin and then curing them. The blocks were quality checked using an optical microscope after which they were polished and carbon coated. The blocks were then placed in a vacuum and analysed using QEMSCAN 650F. The analyses that were done consisted of a bulk mineralogy analysis (BMA), a particle mineralogy analysis (PMA) and a specific mineral search (SMS) to obtain detailed particle information on the minerals of interest.

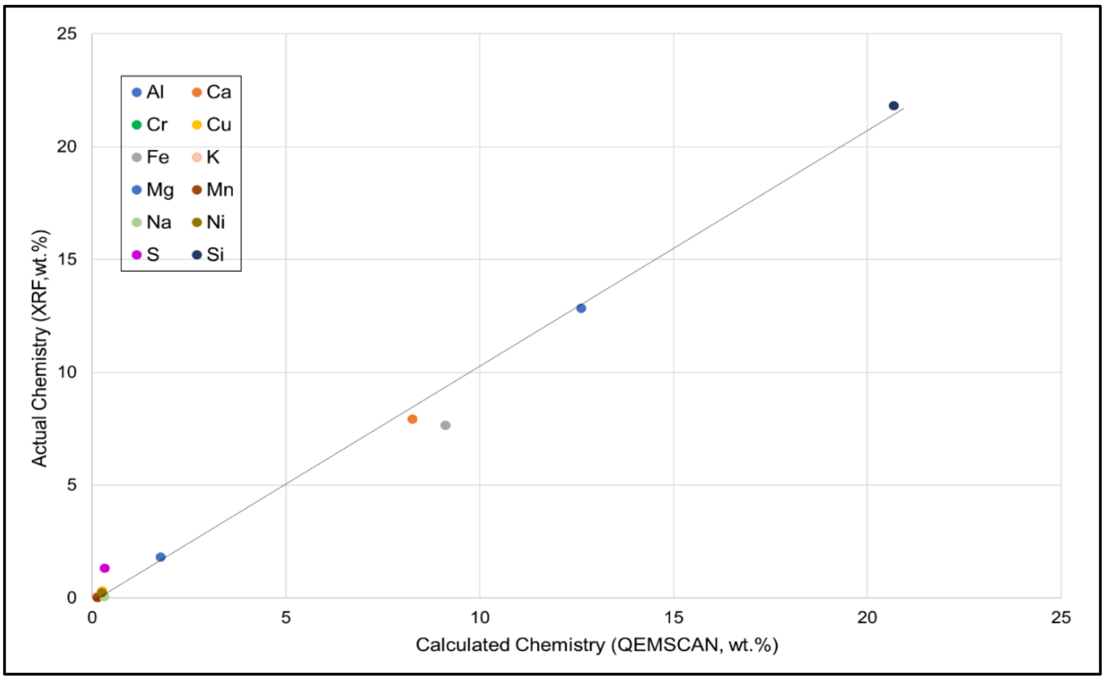

Figure 17 - QEMSCAN vs XRF bulk mineralogy analysis graph

Figure 17 shows the bulk mineralogy analysis of the feed sample using QEMSCAN and XRF. According to the graph, both methods agree with each other and therefore the data obtained is validated.

Table 3 - Percentage of minerals by mass in the bulk feed sample

Cu-sulfides	1.14
Ni-sulfides	0.76
Pyrrhotite	1.97
Olivine	7.74
Enstatite (OPX)	7.78
Augite (CPX)	28.08
Tremolite	33.76
Serpentine	1.52
Talc	0.23
Chlorite	6.79
Biotite/Phlogopite	0.77
Plagioclase Feldspar	2.38
K-Feldspar	0.05
Quartz	0.26

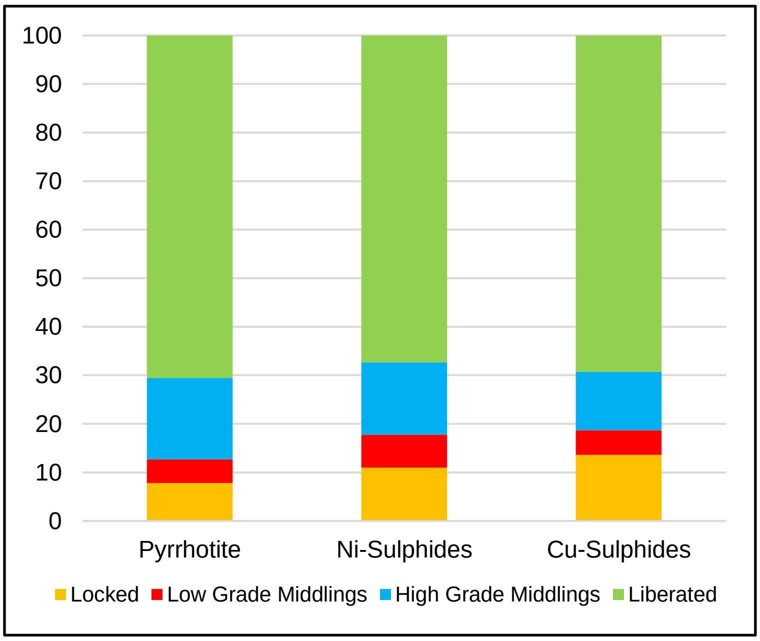

Figure 18 - Bar graph showing the extent of liberation of base metal sulphides

Table 3 shows the mass percentage of the various minerals in the bulk feed sample. Figure 18 shows the extent of liberation of the feed sample with respect to pyrrhotite, nickel sulphides and copper sulphides. The majority of the particles are liberated with the remainder being mostly high grade middlings and locked.

4.3 Ore Preparation

A typical sample of Kevitsa ore was obtained. The bulk sample was crushed in a Terminator JLT1AL jaw crusher, until a top size of -1mm was achieved. The sample was blended, riffled and split using a rotary splitter into 1 kg samples which were stored in airtight bags. Before each flotation test, the 1 kg sample was milled in a 1 kg stainless-steel rod mill along with 500ml of the specified synthetic plant water which equates to a slurry density of 66%. The specifications of the rod mill can be seen in Table 4. To determine the required milling time, four samples were milled for 6, 7, 9 and 11 minutes respectively and then wet screened to create the milling curve shown in Figure 19. The target grind was 70% passing 75 µm which resulted in a final milling time of 10 min which was taken from the curve. This grind was confirmed and used for all further experimental work.

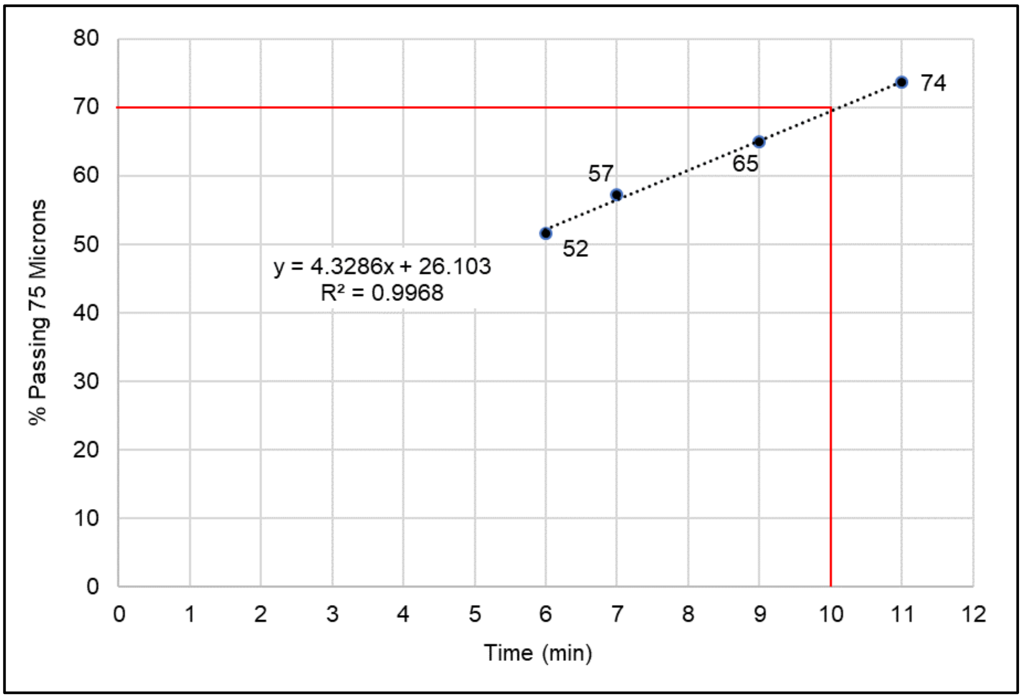

Figure 19 - Kevitsa milling curve

Table 4 - 1 kg stainless steel laboratory scale rod mill specifications

Mill	**Internal Diameter**	**Internal Length**	
	210 mm	295 mm	
Rods	**Diameter**	**Length**	**Number of rods**
	25 mm	285 mm	6
	20 mm	285 mm	8
	16 mm	285 mm	6

4.4 Reagents

Only four reagents were used for this work - three frother types and a collector. The collector used was SIBX of 90% purity which was supplied by Senmin in powder form and mixed to form a 1% (w/v) solution using distilled water. Three industrial frother mixtures trading under the names Senfroth 200, Senfroth 516 and Senfroth 580 were supplied in liquid form by Senmin and used as supplied. They are composed of varying amounts of alcohol, polyethylene glycols and ethylene glycols. Due to confidentiality reasons the exact compositions are not known.

4.5 Factorial Experimental Design

In order to account for all possible combinations of the variables being considered, a factorial experimental design was created. A factorial experimental design consists of two or more factors of different levels and considers all possible combinations of the factors and levels. For example, a 2^3 factorial design would signify that there are 3 factors consisting of two levels each which results in 8 experiments (Wikipedia, 2019).

For this design, three frother dosages, SPW concentrations and frother types were tested. This can be denoted by a 3^3 factorial design which equates to 27 experiments which are outlined in Table 5. Each experiment was done in duplicate to ensure reproducibility. All other variables were kept constant. Figure 20 shows two runs done at the same experimental conditions which shows that the experimental work is reproducible.

Table 5 - Factorial experimental design for each frother type

Factor	Low level	Medium level	High level
Water strength	3 SPW	5 SPW	10 SPW
Frother Dosage	50 g/ton	60 g/ton	70 g/ton
Frother Type	Senfroth 200	Senfroth 516	Senfroth 580

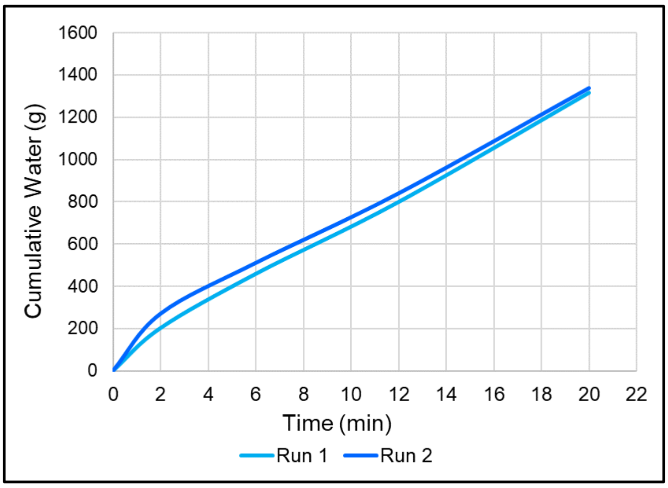

Figure 20 - Graph showing cumulative water recovery vs time for duplicate runs to show reproducibility

4.6 Batch Flotation Procedure

4.6.1 Apparatus

The apparatus used for the batch floats was a 3L Barker flotation cell with a top driven impellor and a Wilkerson ¼ inch 0-8 bar air flow regulator. The float cell has a marked line on the side denoting the 3L volume with another marked line denoting the 2cm froth height. Four collection pans were used to collect the concentrates and each concentrate had its own dedicated wash bottle and top up bottle in order to measure and control the additional water per concentrate. An image of the apparatus can be seen in Figure 21.

Figure 21 - Images of the 3L modified Leeds flotation cell and accompanying bottles

4.6.2 Procedure

The milled slurry was transferred to the flotation cell and topped up to the 3L mark. The impeller was turned on at a speed of 1200 rpm and left to agitate the slurry for one minute after which a 50 ml syringe was used to collect a feed sample. The wash bottles and top-up bottles were filled with the required SPW for that test and weighed. 5 ml of the 1% (w/v) collector solution was then added to the slurry and allowed to condition for 2 minutes after which the frother was added at the required dosage and allowed to condition for a further 1 minute. The air was then turned on and maintained at a flow rate of 7 L/min.

The froth was scraped into the collection pan every 15 seconds and the scraping tool was rinsed with wash water after each scrape. Concentrates 1 through 4 were collected for 2, 4, 6 and 8 min respectively. The pulp phase was topped up every minute to maintain a froth height of 2 cm. Once concentrate 4 had been collected, the air was turned off and two 50 ml syringes were used to collect representative samples of the tails. The impeller was then turned off and the tails were decanted into a bucket for filtering. The wash bottles, top-up bottles and wet concentrates were weighed to mass balance the amount of water used. The concentrates and tails were then each filtered and dried in the oven overnight and were reweighed once they were dry.

4.7 Analysis

4.7.1 X-ray Fluorescence Machine

The solid samples were analysed at Axis House using a Thermo Scientific Niton XL3t X-ray Fluorescence (XRF) analyser to determine the percentage of copper and nickel in the feed, tails and concentrates. The percentages obtained were used to determine how much of the collected solids consisted of copper and nickel. Equations 1 – 3 were used to calculate the grade and recovery of copper. The grade and recovery of nickel were calculated in the same way.

$$\text{Grade} = \frac{\text{cumulative mass of Cu}}{\text{cumulative solids mass}}$$

Equation 1

$$\text{Total possible Cu} = \text{total mass of Cu collected} + \text{remaining Cu mass in tails}$$

Equation 2

$$\text{Recovery} = \frac{\text{cumulative Cu mass}}{\text{total possible Cu}}$$

Equation 3

This data was used to plot various graphs to visualise how each variable affects the water and solids recovery as well as the recovery and grade of copper and nickel.

4.7.2 Statistical Modelling Using Design Expert 8

To better understand how the three factors interact and influence the flotation outcomes, the statistical program Design Expert 8 (Anderson & Whitcomb, 2000) was used to generate a series of plots and accompanying models to visualise the effects. Frother type was entered as a categoric factor since there are three distinct types whereas ionic strength and frother dosage were entered as nominal factors. The responses chosen were water recovery, solids recovery, copper recovery, nickel recovery, copper grade and nickel grade. The average value from each duplicate experiment was used for each response. The program then assigned terms A, B and C to frother type, frother dosage and ionic strength respectively and then completed the model hierarchy to consider the interactive effects; AB, AC, BC and ABC.

All terms were initially chosen for graphical modelling. Anova assigned each term a Prob > F value, also known as a p-value, which is used to determine the significance of the results (Rumsey, 2019). For a 95% confidence interval, a p-value of less than 0.05 indicates that the term is significant. Each term was then described as significant or not significant and any non-significant terms were removed along with their hierarchical components.

3D graphs were used to display the results for which both frother dosage and ionic strength were significant while 2D graphs were used where only one of the above was significant. This is because a 3D graph requires two nominal factors to be acceptable. Models where all three terms were significant resulted in three different 3D graphs while models that contained only the two nominal factors resulted in one 3D graph however the different frother types could be displayed which resulted in the same 3D graph but with different points showing how that factor’s specific results differed from the overall model.

5. Results

For all of the following graphs, the condition for each line or bar is written as SPW_Dosage which describes both the ionic strength and the frother dosage. This is shown by two examples, 3_50 and 3 SPW_50, both of which mean an ionic strength of 3 SPW and a frother dosage of 50 g/ton. This convention will be used throughout the results both in the figures and accompanying text.

5.1 Senfroth 200

5.1.1 Cumulative Water Recoveries vs Time

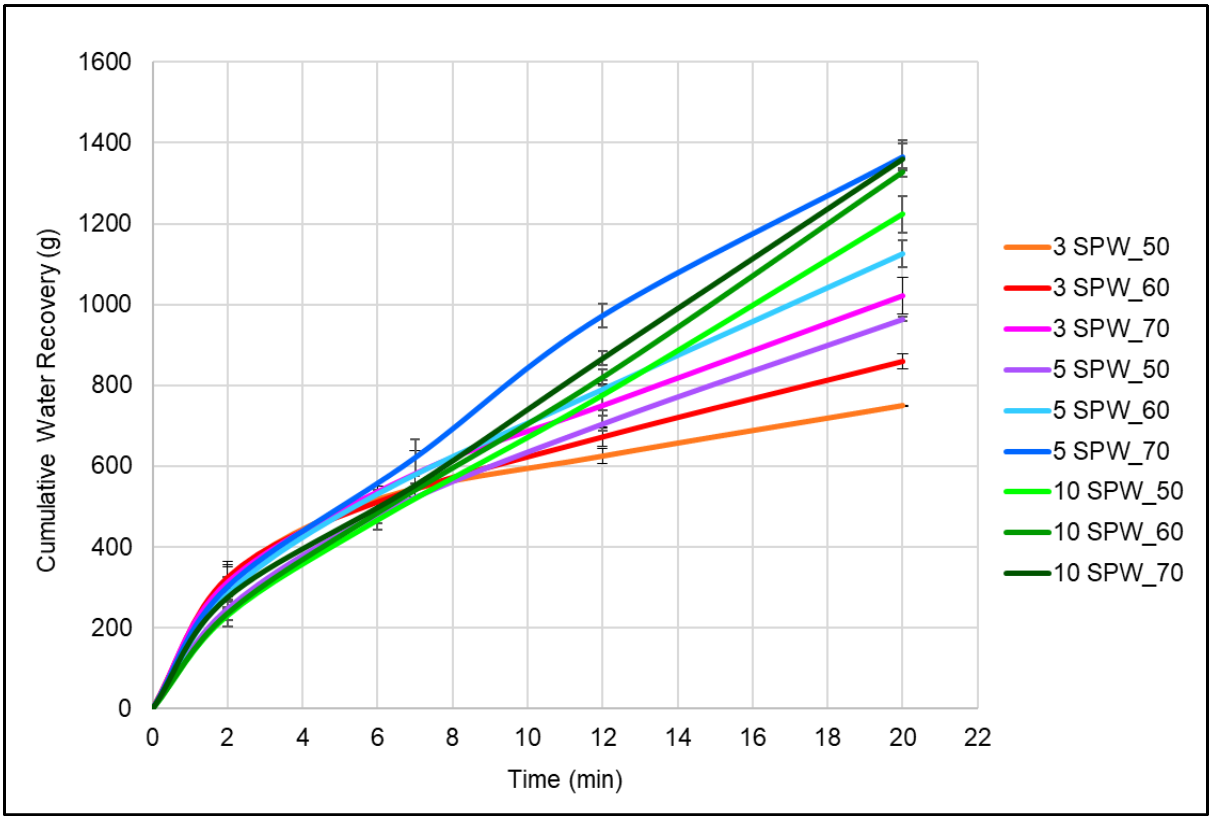

Figure 22 - Graph showing the cumulative water recoveries vs time for three frother dosages and three ionic strengths using Senfroth 200

Figure 22 shows the cumulative water recoveries versus time for three frother dosages and three ionic strengths using Senfroth 200. From 0 - 8 minutes, the rates at which water is recovered are very similar however after 8 minutes they become more distinguishable. When this happens, it can be seen that the rate at which water is recovered appears to increase with an increase in either ionic strength or frother dosage. 3_50 results in the slowest rate while 5_70 results in the fastest rate. However, the rate at which water is recovered at 5_70 appears to slow down near the end of the collection period resulting in a final water recovery that appears to be almost the same as 10_60 or 10_70. The highest total water recoveries are obtained at 5_70 and 10_70 while the lowest total water recovery is obtained at 3_50.

5.1.2 Cumulative Solids Recoveries vs Time

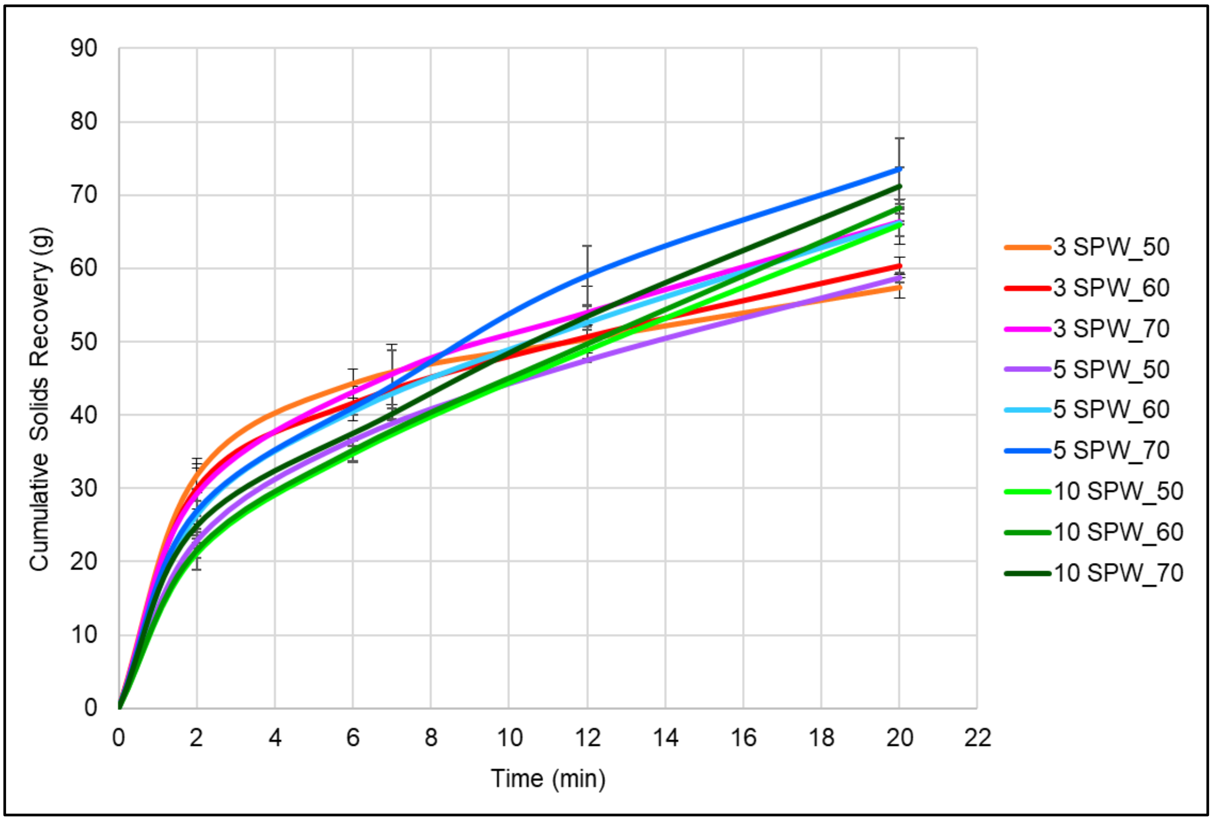

Figure 23 - Graph showing the cumulative solids recoveries vs time for three ionic strengths and three frother dosages using Senfroth 200

Figure 23 shows the cumulative solids recoveries versus time for three frother dosages and three ionic strengths using Senfroth 200. At 6 minutes there are two distinct sets of rates after which they become indistinct. At 3 SPW, increasing the frother dosage results in slower initial rates but higher total solids recoveries while at 5 SPW and 10 SPW, increasing the frother dosage increases both the initial rates and the total solids recoveries. Increasing the ionic strength results in slower initial rates but increases the total solids recoveries. Overall it appears that higher initial rates obtained at lower ionic strengths tend to slow down and result in lower total solids recoveries while slower initial rates obtained at higher ionic strengths tend to remain consistent and result in higher total solids recoveries except for 5_70 which appears to be an outlier which matches the higher water recovery in Figure 22. The highest total solids recoveries are obtained at 5_70 and 10_70 while the lowest total solids recoveries are obtained at 3_50 and 5_50.

5.1.3 Cumulative Solids Recoveries vs Cumulative Water Recoveries

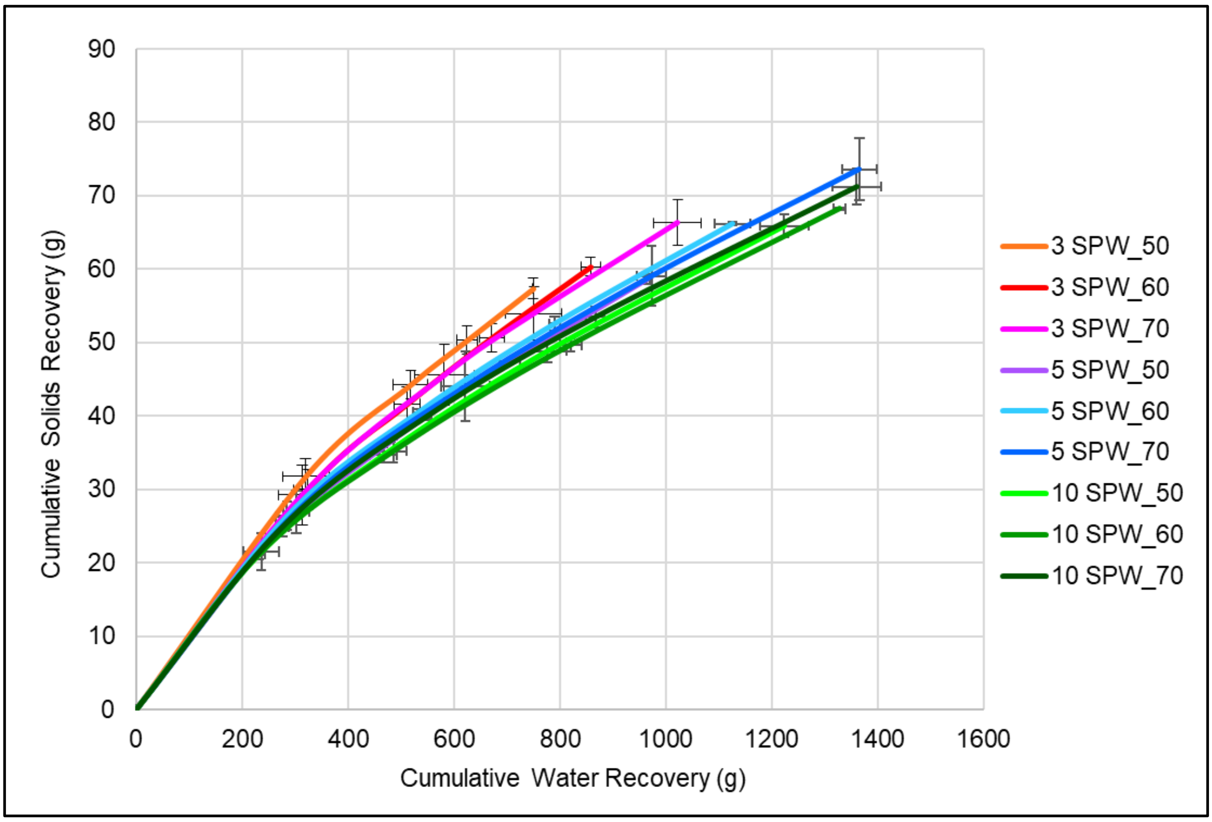

Figure 24 - Graph showing the cumulative solids recoveries vs the cumulative water recoveries for three ionic strengths and three frother dosages using Senfroth 200

Figure 24 shows the cumulative solids recoveries versus the cumulative water recoveries for three frother dosages and three ionic strengths using Senfroth 200. There appear to be three regions defined by ionic strength where a low ionic strength results in more solids per unit water while a high ionic strength results in less solids per unit water. The effects of changing frother dosage are most visible at a low ionic strength of 3 SPW where an increase in frother dosage increases both the solids and water recoveries while decreasing the solids per unit water. However, at higher ionic strengths of 5 SPW and 10 SPW, the effects of changing frother dosage are not as noticeable.

When looking at the total cumulative solids and water recovered, it can be seen that 3_70, 5_60 and 10_50 appear to recover approximately the same total solids but as the ionic strength increases and frother dosage decreases, the total water recovery increases. Thus, operating at a lower ionic strength and higher frother dosage results in higher solids per unit water than at a higher ionic strength and lower frother dosage.

5.1.4 Total Cumulative Water Recoveries and Total Cumulative Solids Recoveries

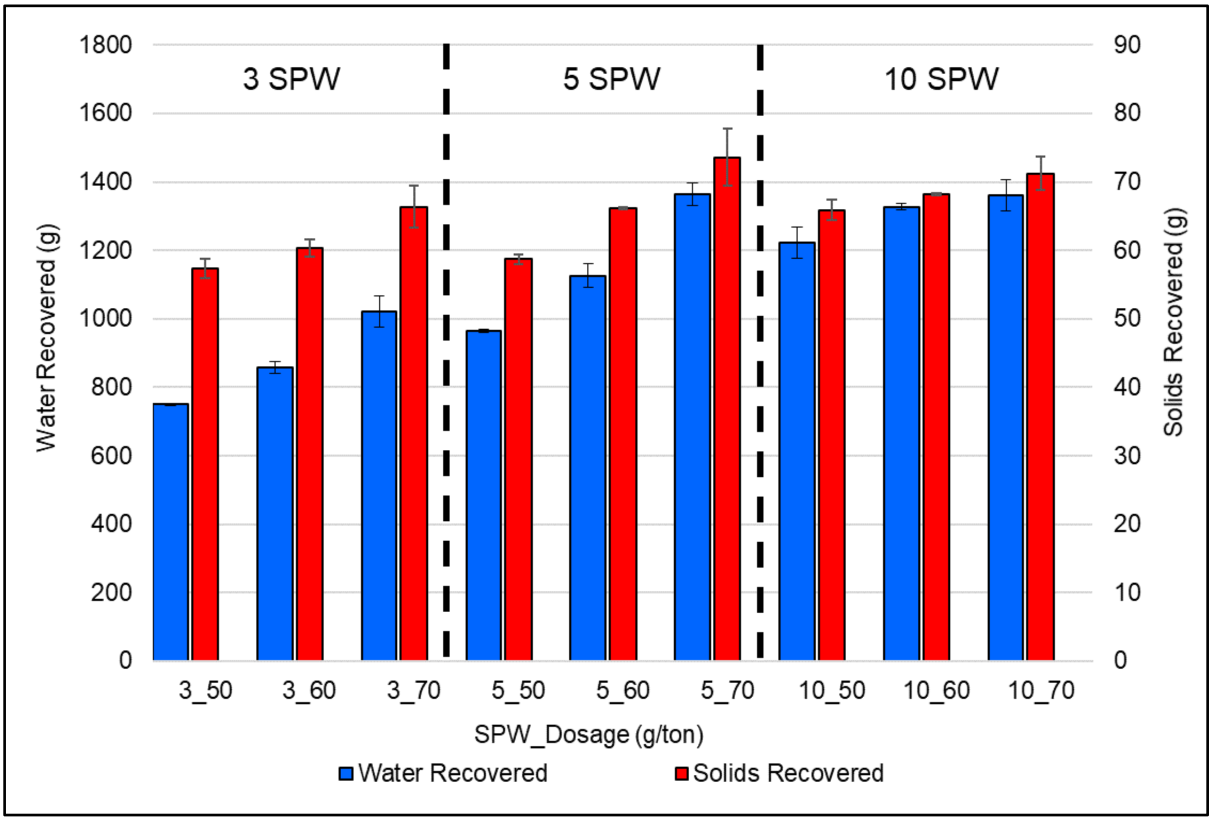

Figure 25 - Graph showing the total solids recoveries and total water recoveries for three frother dosages and three ionic strengths using Senfroth 200

Figure 25 shows the total cumulative solids recoveries and total cumulative water recoveries for three frother dosages and three ionic strengths using Senfroth 200. The blue bars represent the total water recoveries on the left axis while the red bars represent the total solids recoveries on the right axis.

Increasing the frother dosage at constant ionic strength increases the total recovery of both water and solids except at 10 SPW where the total water recovery increases from 50 g/ton to 60 g/ton but remains the same from 60 g/ton to 70 g/ton. Increasing the ionic strength at a frother dosage of 50 g/ton or 60 g/ton causes the total water recovery to increase but at 70 g/ton, it increases from 3 SPW to 5 SPW but remains the same from 5 SPW to 10 SPW. Increasing the ionic strength at a frother dosage of 50 g/ton causes the total solids recovery to remain the same from 3 SPW to 5 SPW but increase from 5 SPW to 10 SPW. At a frother dosage of 60 g/ton, increasing the ionic strength causes the total solids recovery to increase while at 70 g/ton the total solids recovery is unaffected. The solids per unit water appears to decrease with an increase in ionic strength which agrees with Figure 24.

When considering a simultaneous increase in ionic strength and decrease in frother dosage, Figure 25 shows that the total amount of water recovered increases from 3_60 to 5_50 and from 3_70 to 5_60 to 10_50 however changing from 5_70 to 10_60 appears to not affect the total water recovery. The same change in ionic strength and frother dosage from 3_60 to 5_50 and from 3_70 to 5_60 to 10_50 appears to not affect the total solids recovery but a change from 5_70 to 10_60 decreases the total solids recovery. Comparing 3_70 versus 5_50 results in higher total water and solids recoveries at 3_70 while comparing 5_70 versus 10_50 results in higher total water and solids recoveries at 5_70.

The highest total solids recoveries are obtained at a frother dosage of 70 g/ton regardless of the ionic strength while the lowest total solids recoveries are obtained at 3_50 and 5_50. The highest total water recoveries are obtained at 5_70, 10_60 and 10_70 while the lowest total water recovery is obtained at 3_50.

5.1.5 Cumulative Copper Recoveries vs Time

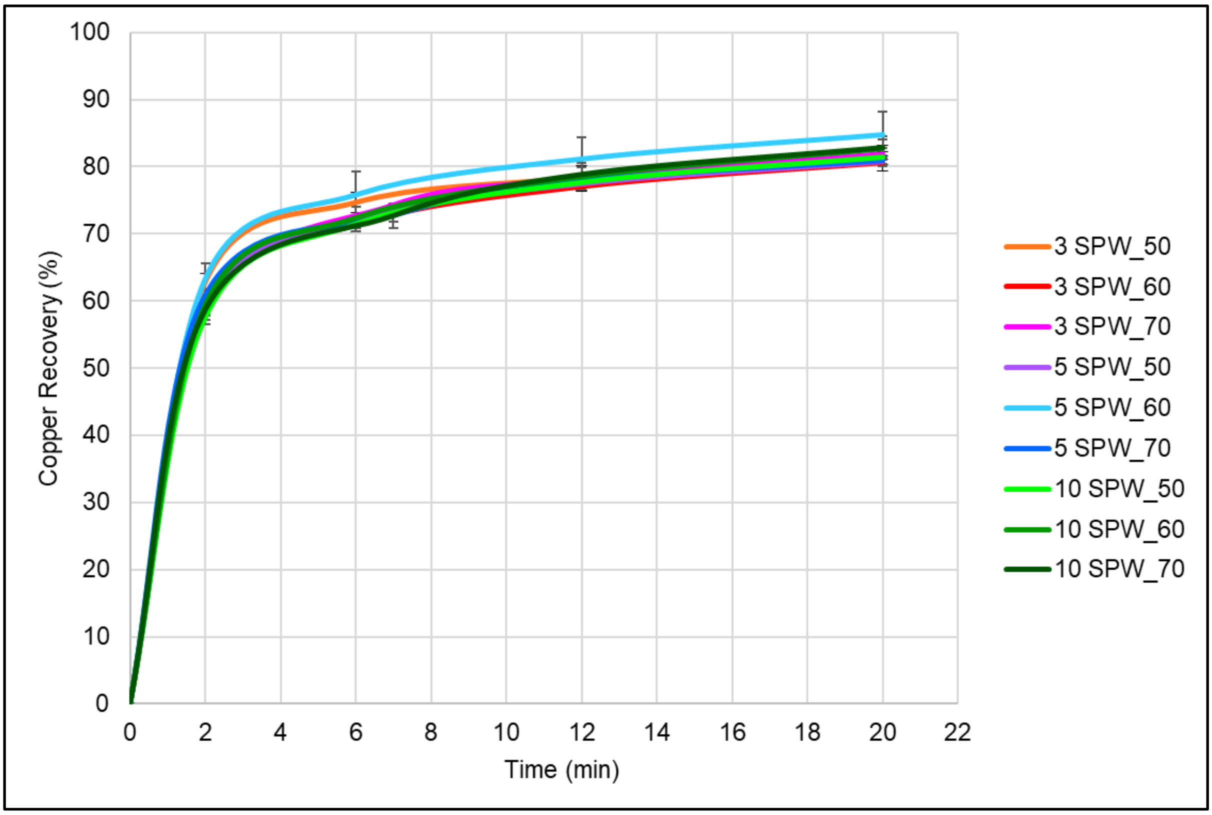

Figure 26 - Graph showing the cumulative copper recoveries vs time for three frother dosages and three ionic strengths using Senfroth 200

Figure 26 shows the cumulative copper recoveries versus time for three frother dosages and three ionic strengths using Senfroth 200. Copper recovery appears to be unaffected by a change in either frother dosage or ionic strength. Most of the copper seems to be collected within the first 4 minutes with the final copper recoveries varying between 80 - 85%.

5.1.6 Cumulative Copper Recoveries vs Cumulative Water Recoveries

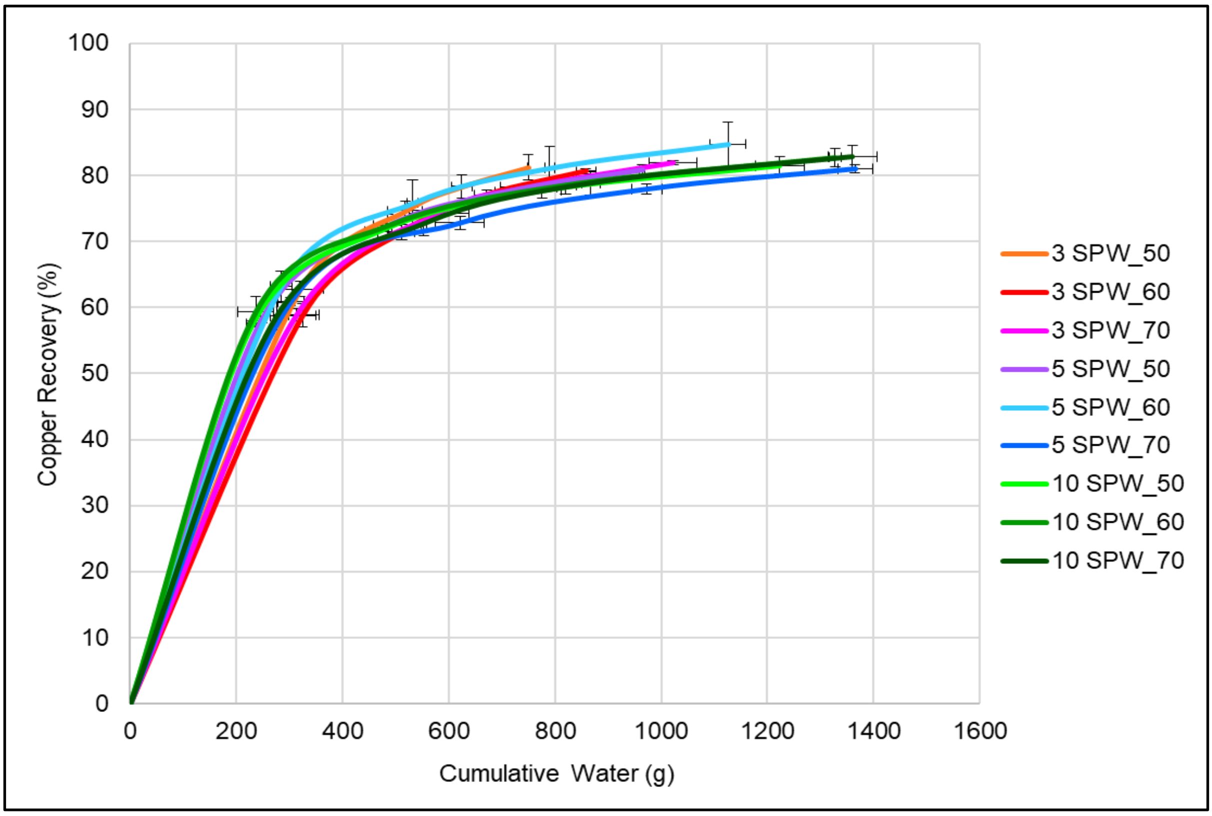

Figure 27 - Graph showing the cumulative copper recoveries vs the cumulative water recoveries for three frother dosages and three ionic strengths using Senfroth 200

Figure 27 shows the cumulative copper recoveries versus the cumulative water recoveries for three frother dosages and three ionic strengths using Senfroth 200. It appears that higher ionic strengths and higher frother dosages recover more water while recovering the same or similar amount of copper as lower ionic strengths and lower frother dosages.

5.1.7 Total Cumulative Water Recoveries and Total Cumulative Copper Recoveries

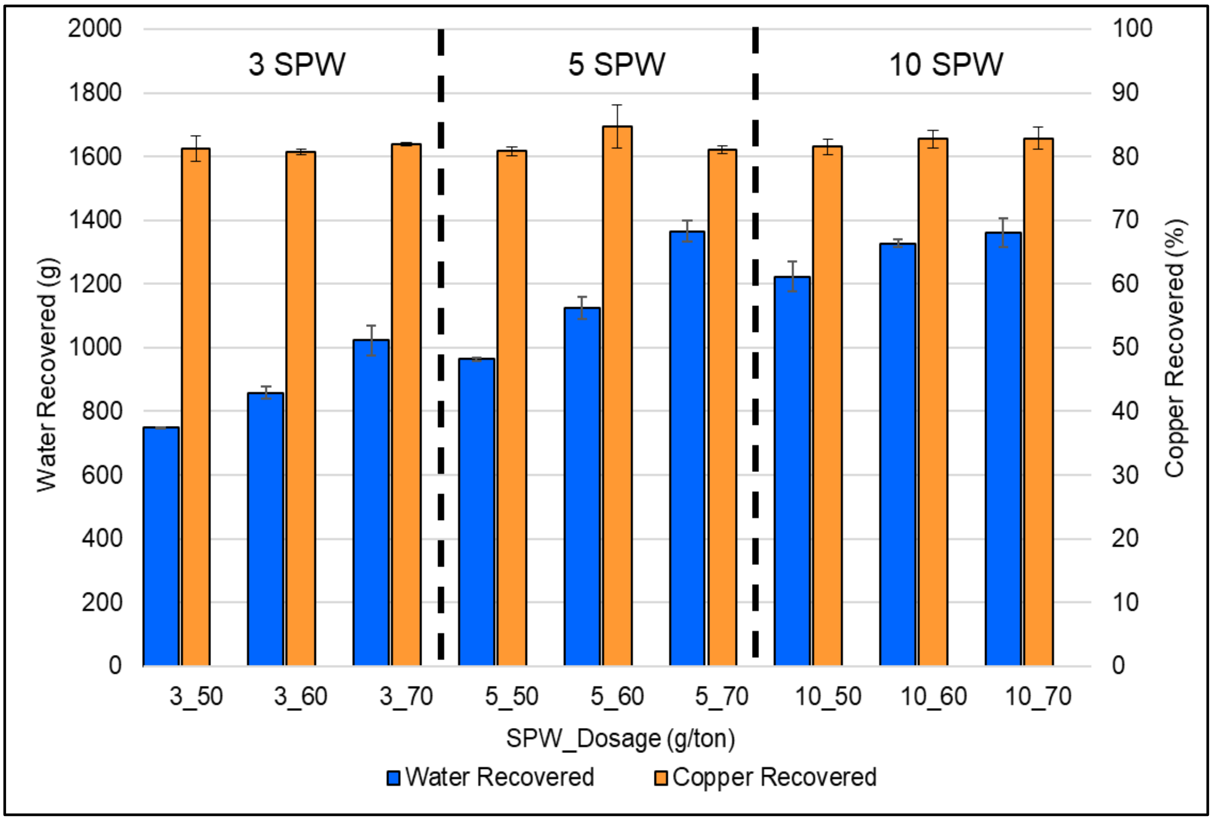

Figure 28 - Graph showing the total copper recoveries and total water recoveries for three frother dosages and three ionic strengths using Senfroth 200

Figure 28 shows the total cumulative copper recoveries and total cumulative water recoveries for three frother dosages and three ionic strengths using Senfroth 200. The blue bars represent the total water recoveries in grams on the left axis while the orange bars represent the total copper recoveries in percentages on the right axis.

The effects of frother dosage and ionic strength on the recovery of water have been discussed in Figure 25. While both frother dosage and ionic strength influence the total water recovery, neither variable seems to affect the total copper recovery as the total copper recoveries are all very similar with a range of 80 - 85%. Since the total copper recovery remains constant, the copper recovery per unit water follows the same trends as the water recovery whereby an increase in water recovery decreases the copper recovery per unit water.

When considering a simultaneous increase in ionic strength and decrease in frother dosage, Figure 28 shows that the total copper recovery is unaffected and therefore increasing the ionic strength and decreasing the frother dosage only affects the total water recovery.

5.1.8 Cumulative Copper Grades vs Cumulative Copper Recoveries

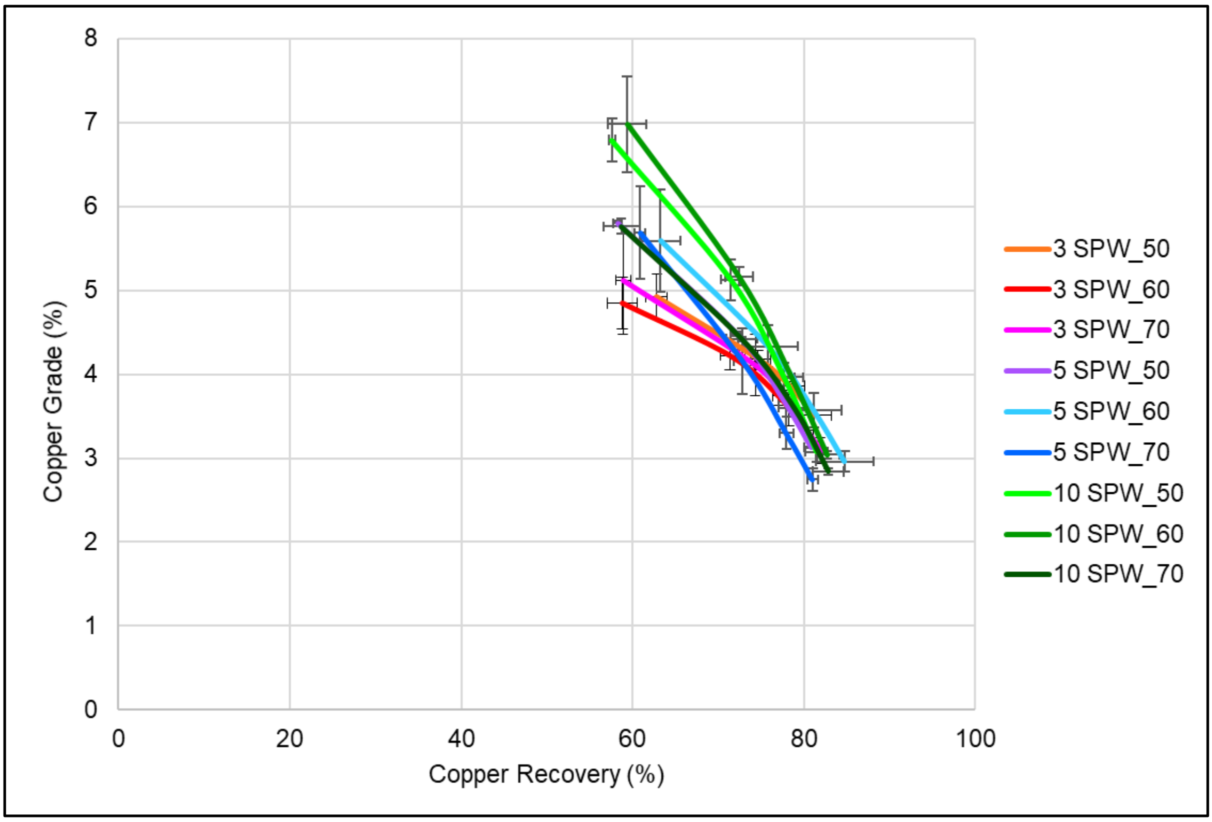

Figure 29 - Graph showing the cumulative copper grades vs the cumulative copper recoveries for three frother dosages and three ionic strengths using Senfroth 200

Figure 29 shows the cumulative copper grades versus the cumulative copper recoveries for three frother dosages and three ionic strengths using Senfroth 200. As the recovery increases, the grade decreases. An increase in ionic strength also appears to increase the extent to which the grade decreases as the recovery increases.

5.1.9 Total Cumulative Copper Recoveries and Final Cumulative Copper Grades

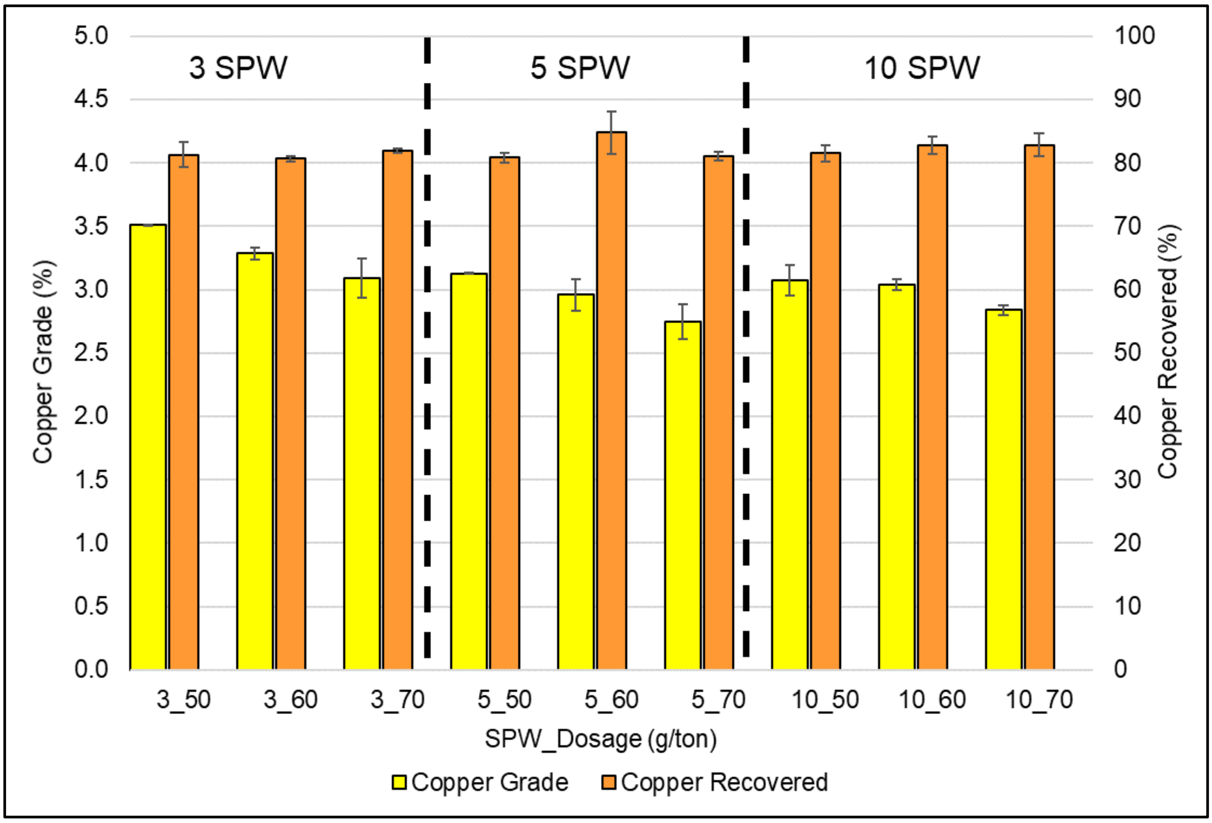

Figure 30 - Graph showing the total copper recoveries and final copper grades for three frother dosages and three ionic strengths using Senfroth 200

Figure 30 shows the total cumulative copper recoveries and final cumulative copper grades for three frother dosages and three ionic strengths using Senfroth 200. The orange bars represent the total copper recoveries on the right axis while the yellow bars represent the final copper grades on the left axis.

The effects of frother dosage and ionic strength on the total recovery of copper have been discussed in Figure 28. At 3 SPW and 5 SPW, increasing the frother dosage from 50 g/ton to 60 g/ton decreases the final grade but from 60 g/ton to 70 g/ton the final grade remains the same. At 10 SPW, increasing the frother dosage from 50 g/ton to 60 g/ton does not affect the final grade but increasing the frother dosage from 60 g/ton to 70 g/ton decreases the final grade. Increasing the ionic strength from 3 SPW to 5 SPW decreases the final grade but from 5 SPW to 10 SPW the grade is unaffected for all frother dosages. The highest total recovery and final grade are obtained at 3_50.

When considering a simultaneous increase in ionic strength and decrease in frother dosage, the final grade decreases from 3_60 to 5_50, increases from 5_70 to 10_60 but remains unaffected by a change from 3_70 to 5_60 to 10_50. Comparing 3_70 versus 5_50 results in the same final grade while comparing 5_70 versus 10_50 results in 10_50 having a higher final grade.

5.1.10 Cumulative Nickel Recoveries vs Time

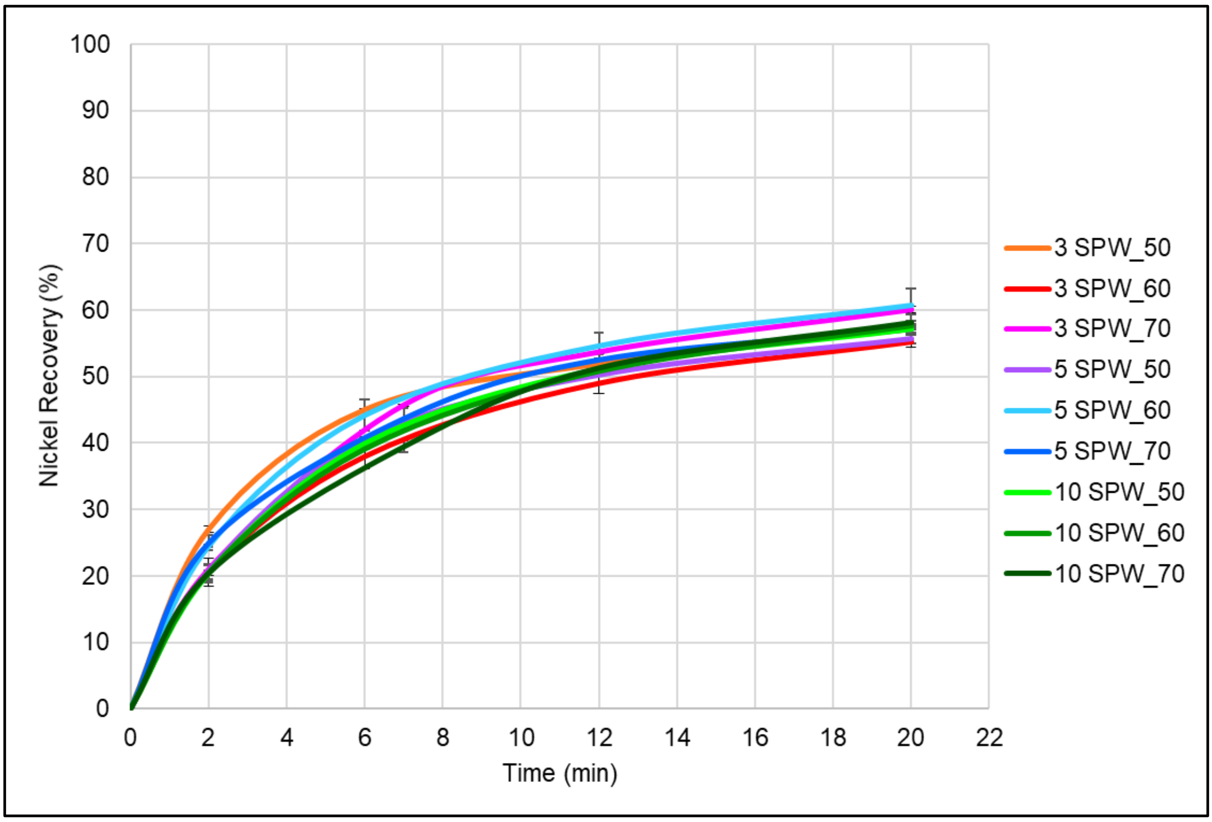

Figure 31 - Graph showing the cumulative nickel recoveries vs time for three frother dosages and three ionic strengths using Senfroth 200

Figure 31 shows the cumulative nickel recoveries versus time for three frother dosages and three ionic strengths using Senfroth 200. At 2 minutes there are two distinct sets of rates after which they become indistinct which implies that changing the frother dosage or ionic strength has negligible effects on the rate at which nickel is recovered. The final recoveries vary from 55 - 60%.

5.1.11 Cumulative Nickel Recoveries vs Cumulative Water Recoveries

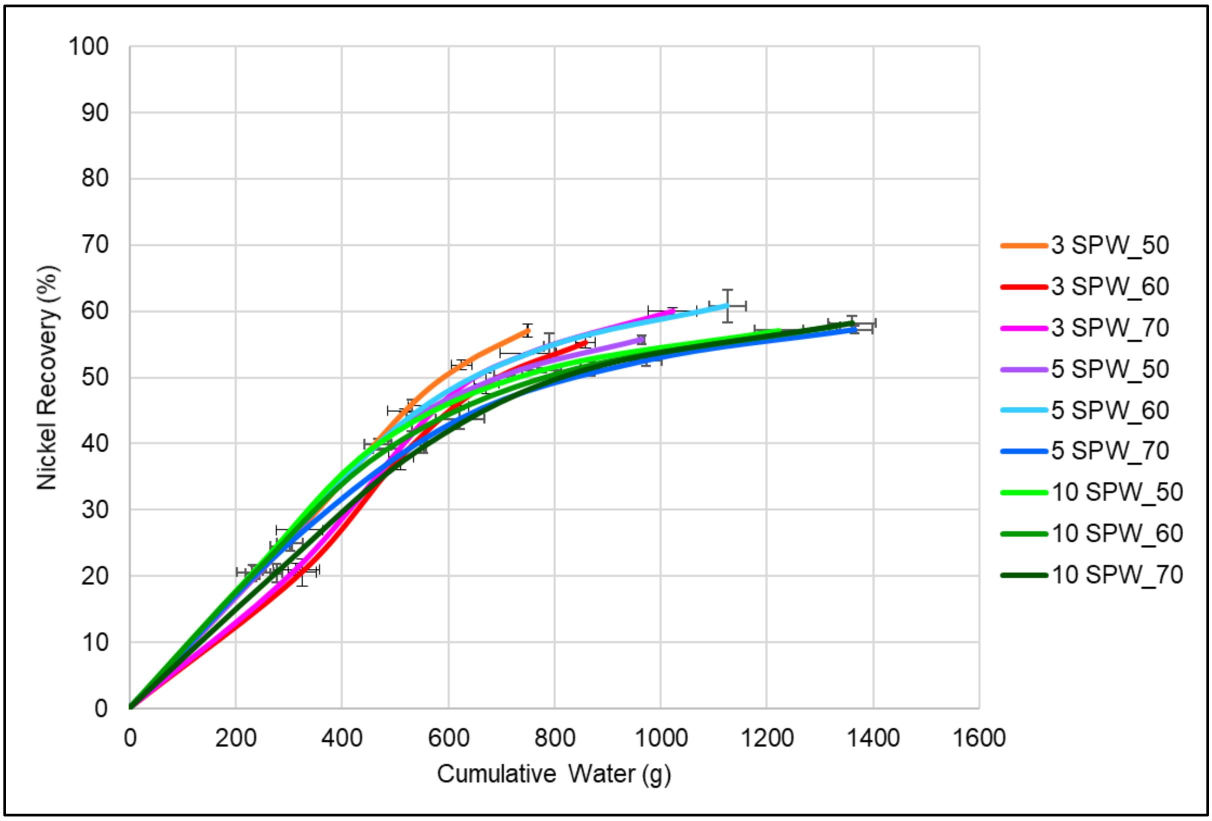

Figure 32 - Graph showing the cumulative nickel recoveries vs the cumulative water recoveries for three frother dosages and three ionic strengths using Senfroth 200

Figure 32 shows the cumulative nickel recoveries versus the cumulative water recoveries for three frother dosages and three ionic strengths using Senfroth 200. Higher ionic strengths and higher frother dosages appear to recover more water while recovering similar amounts of nickel as lower ionic strengths and lower frother dosages.

5.1.12 Total Cumulative Water Recoveries and Total Cumulative Nickel Recoveries

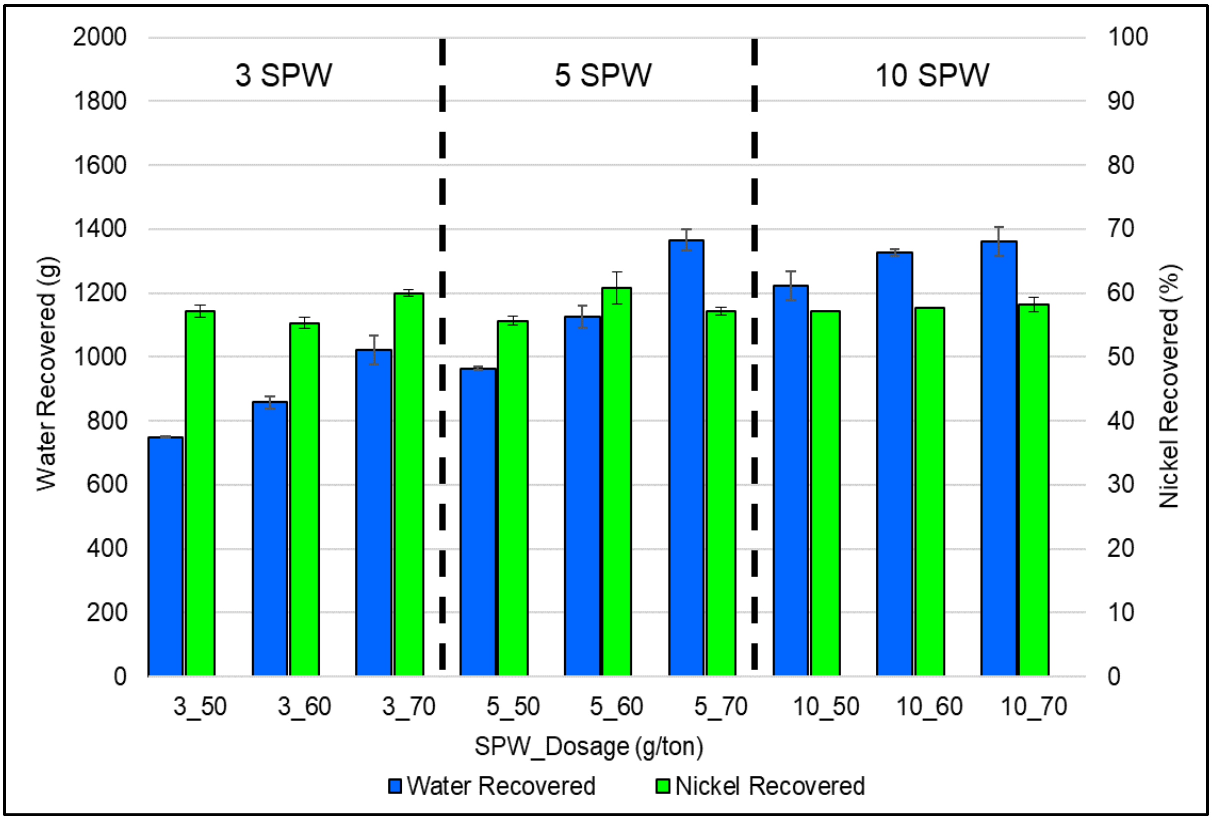

Figure 33 - Graph showing the total nickel recoveries and total water recoveries for three frother dosages and three ionic strengths using Senfroth 200

Figure 33 shows the total cumulative nickel recovery and total cumulative water recovery for three frother dosages and three ionic strengths using Senfroth 200. The blue bars represent the total water recoveries in grams on the left axis while the green bars represent the total nickel recoveries in percentages on the right axis.

The effects of frother dosage and ionic strength on the total recovery of water have been discussed in Figure 25. Increasing the frother dosage at 3 SPW results in a minimum total nickel recovery at 60 g/ton and a maximum at 70 g/ton, at 5 SPW the total nickel recovery has a maximum at 60 g/ton, and at 10 SPW, the total nickel recovery is unaffected. Increasing the ionic strength at 50 g/ton does not affect the total nickel recovery, at 60 g/ton there is a maximum total nickel recovery at 5 SPW with 10 SPW recovering more total nickel than 3 SPW, and at 70 g/ton the total nickel recovery decreases from 3 SPW to 5 SPW and then remains the same from 5 SPW to 10 SPW. The total nickel recoveries appear to vary between 55 - 60% with the highest recoveries being obtained at 5_60 and 3_70.

The nickel recovery per unit water appears to decrease with an increase in dosage or an increase in ionic strength except at 70 g/ton where the nickel recovery per unit water decreases from 3 SPW to 5 SPW and then remains the same from 5 SPW to 10 SPW.

When considering a simultaneous increase in ionic strength and decrease in frother dosage, Figure 33 shows that the total nickel recovery in unaffected when changing from 3_60 to 5_50, from 3_70 to 5_60 or from 5_70 to 10_60. However changing from 5_60 to 10_50 results in a decrease in the total nickel recovery. Comparing 3_70 versus 5_50 results in a lower total nickel recovery for 5_50 while comparing 5_70 versus 10_50 results in the same total nickel recovery.

5.1.13 Cumulative Nickel Grades vs Cumulative Nickel Recoveries

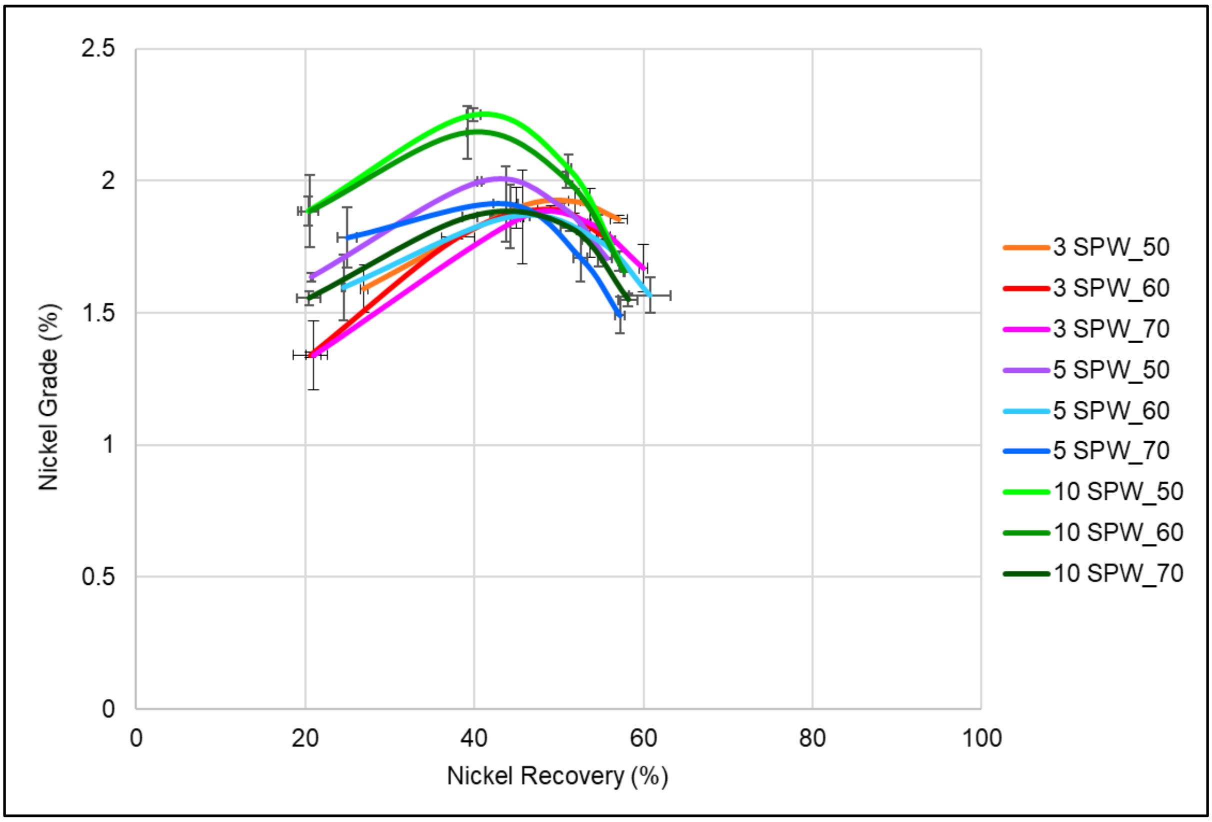

Figure 34 - Graph showing the cumulative nickel grades vs the cumulative nickel recoveries for three frother dosages and three ionic strengths using Senfroth 200

Figure 34 shows the cumulative nickel grades versus the cumulative nickel recoveries for three frother dosages and three ionic strengths using Senfroth 200. The grade first increases and then decreases with an increase in recovery resulting in a maximum grade between 40 - 50% recovery. The final grades vary between 1.5 and 1.85% while the final recoveries vary between 55 - 60%.

5.1.14 Total Cumulative Nickel Recoveries and Final Cumulative Nickel Grades

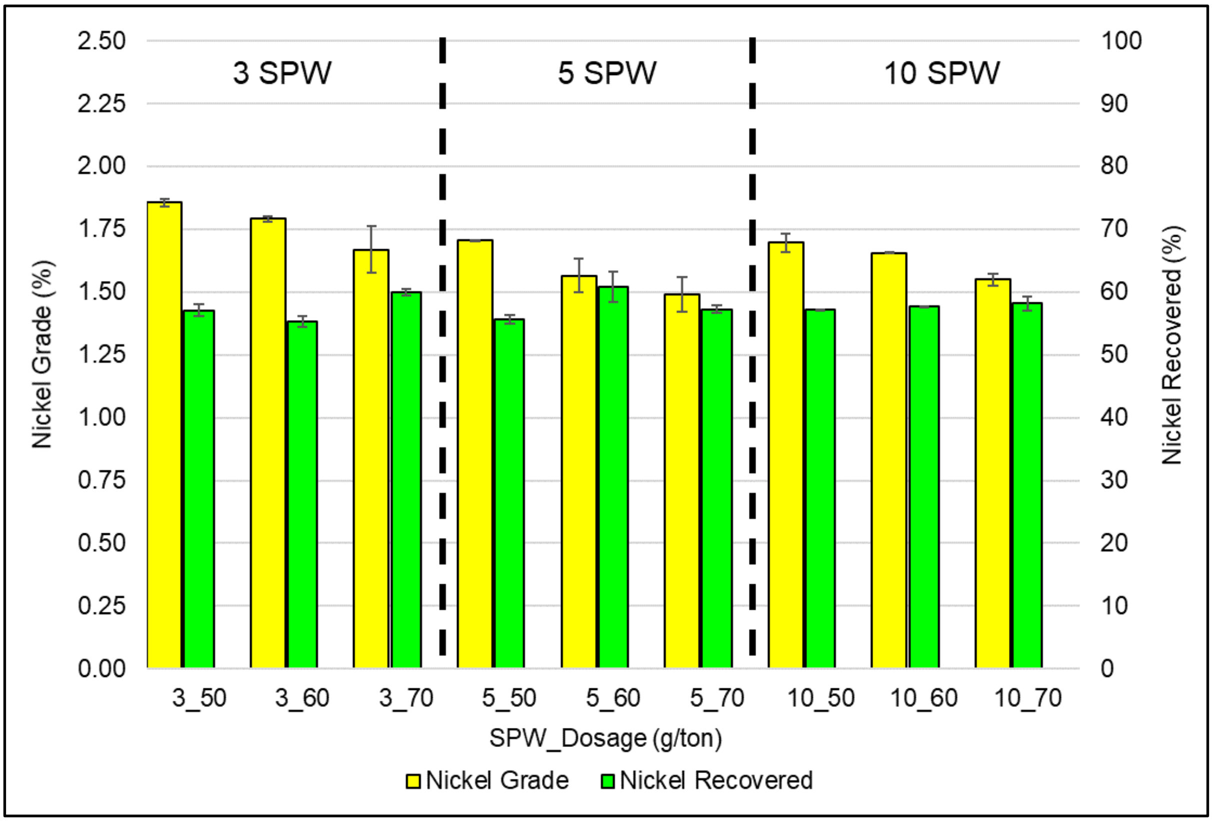

Figure 35 - Graph showing the total nickel recoveries and final nickel grades for three frother dosages and three ionic strengths using Senfroth 200

Figure 35 shows the total cumulative nickel recoveries and final cumulative nickel grades for three frother dosages and three ionic strengths using Senfroth 200. The green bars represent the total nickel recoveries on the right axis while the yellow bars represent the final nickel grades on the left axis.

The effects of frother dosage and ionic strength on the total recovery of nickel have been discussed in Figure 33. Increasing the frother dosage at either 3 SPW or 10 SPW decreases the final grade but at 5 SPW the final grade decreases from 50 g/ton to 60 g/ton but remains constant from 60 g/ton to 70 g/ton. Increasing the ionic strength at 50 g/ton or 70 g/ton causes the final grade to decrease from 3 SPW to 5 SPW and then remain the same from 5 SPW to 10 SPW however at 60 g/ton there is a minimum final grade at 5 SPW with 3 SPW having a higher final grade than 10 SPW. The highest final grade is obtained at 3_50.

When considering a simultaneous increase in ionic strength and decrease in frother dosage, Figure 33 shows that changing from 3_60 to 5_50 decreases the final grade while changing from 5_70 to 10_60 increases the final grade. Changing from 3_70 to 5_60 does not affect the final grade but changing from 5_60 to 10_50 increases the final grade. Comparing 3_70 versus 5_50 results in the same final grade while comparing 5_70 versus 10_50 results in 10_50 having a higher final grade.

5.2 Senfroth 516

5.2.1 Cumulative Water Recoveries vs Time

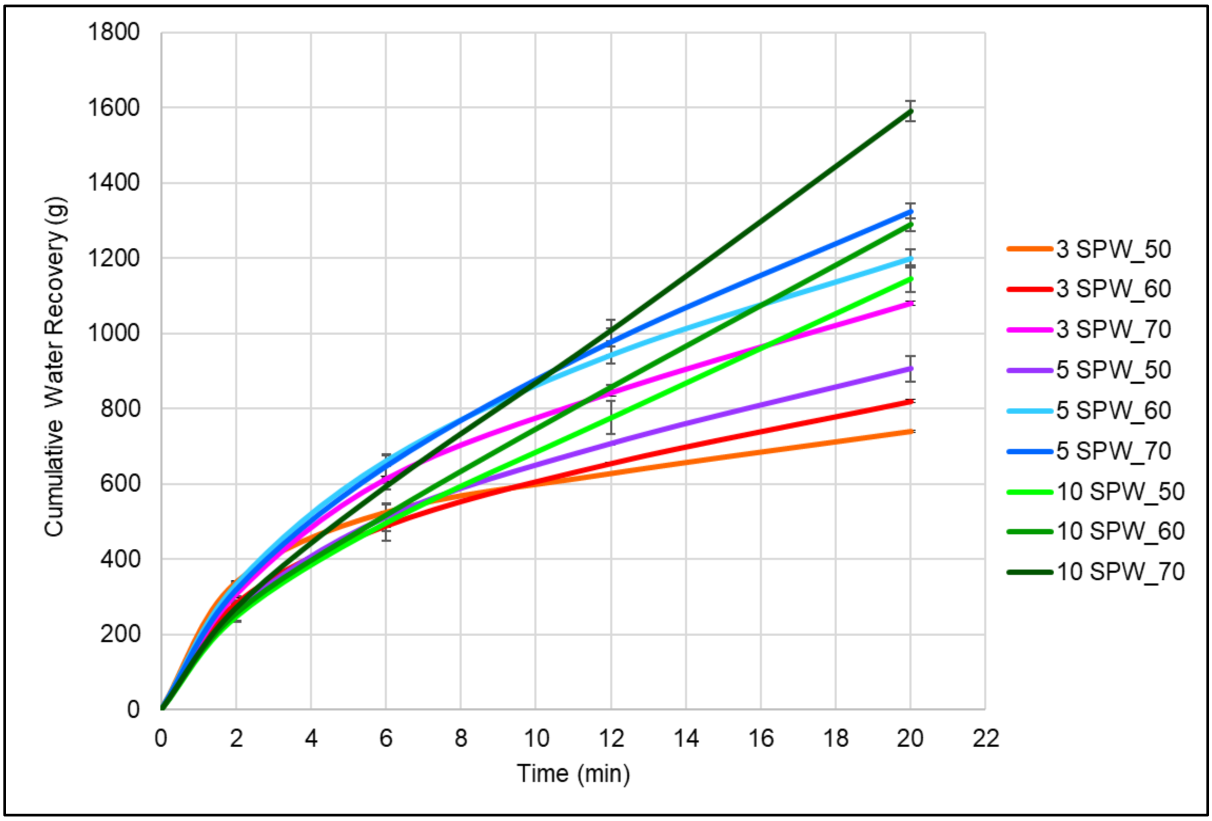

Figure 36 - Graph showing the cumulative water recoveries vs time for three frother dosages and three ionic strengths using Senfroth 516

Figure 36 shows the cumulative water recoveries versus time for three frother dosages and three ionic strengths using Senfroth 516. At 6 minutes there appears to be two distinct sets of rates. Increasing the frother dosage or ionic strength appears to increase the rate at which water is recovered with the slowest rate occurring at 3_50 and the fastest rate occurring at 10_70. This agrees with the apparent trend that low dosages and low ionic strengths result in slower rates while high dosages and high ionic strengths result in faster rates. The highest total water recovery is obtained at 10_70 while the lowest total water recovery is obtained at 3_50.

5.2.2 Cumulative Solids Recoveries vs Time

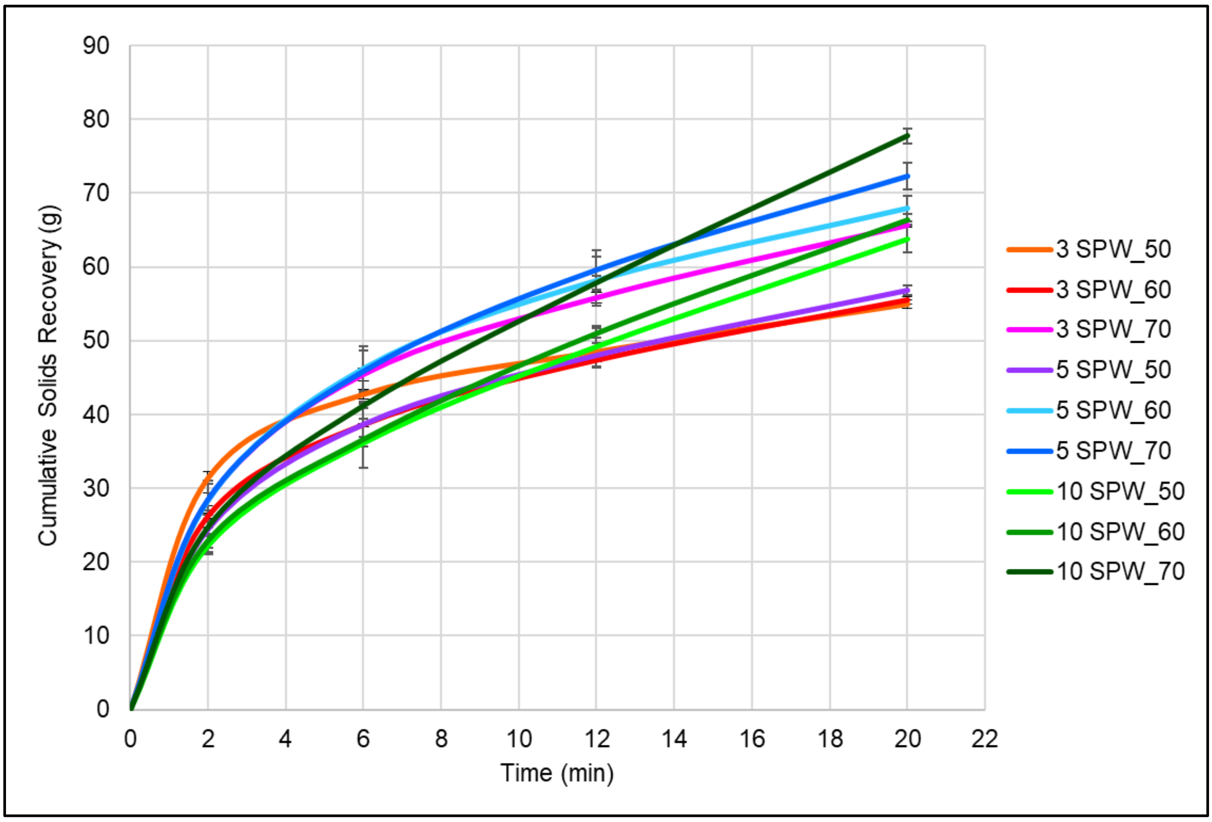

Figure 37 - Graph showing the cumulative solids recoveries vs time for three ionic strengths and three frother dosages using Senfroth 516

Figure 37 shows the cumulative solids recoveries versus time for three ionic strengths and three frother dosages using Senfroth 516. At 4 minutes there appear to be two sets of rates while at 12 minutes there appear to be two different sets of rates after which the rates become more distinct. Increasing the frother dosage or the ionic strength increases the solids recovery except at 60 g/ton where an increase in ionic strength results in an increase in rate from 3 SPW to 5 SPW but a decrease in rate from 5 SPW to 10 SPW. 3_50, 5_60 and 5_70 have high initial rates but while 5_60 and 5_70 remain high, 3_50 slows down to give a low total solids recovery. The highest total solids recovery is obtained at 10_70 while the lowest is obtained at 3_50 and 3_60.

5.2.3 Cumulative Solids Recoveries vs Cumulative Water Recoveries

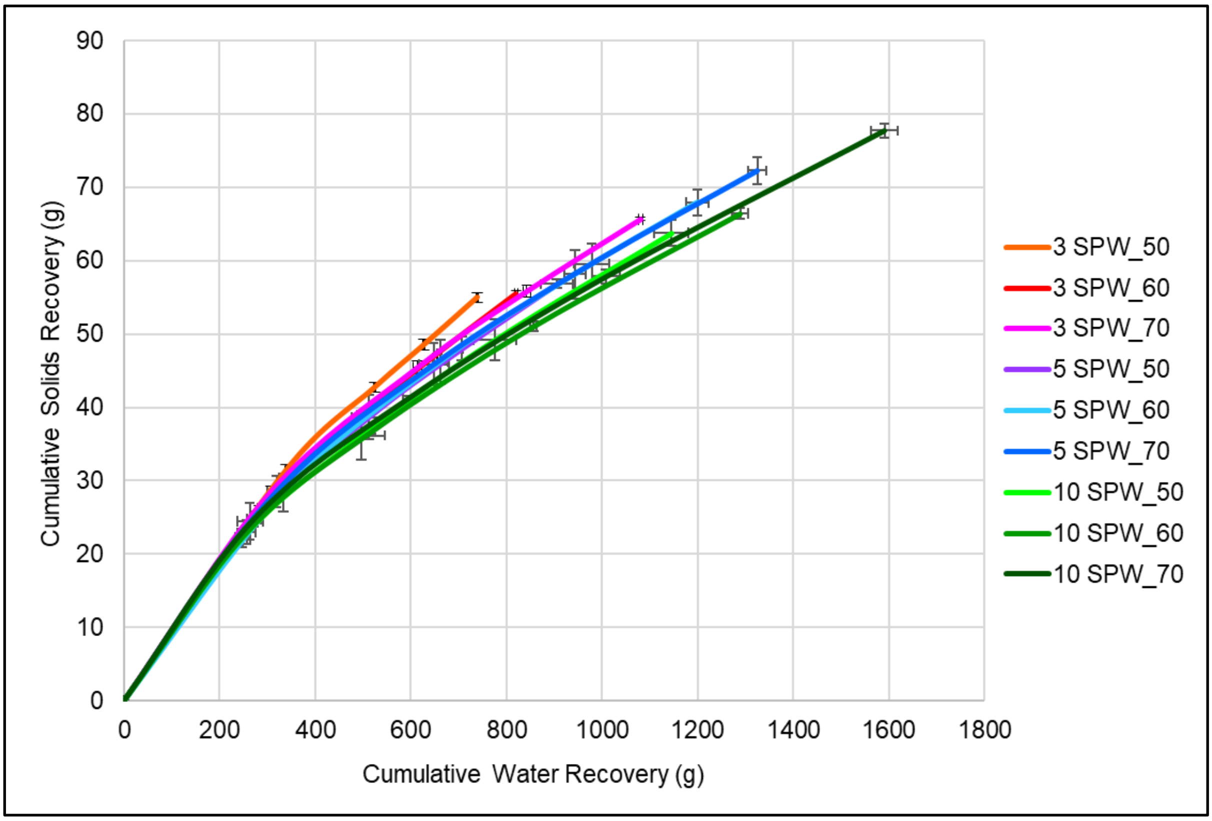

Figure 38 - Graph showing the cumulative solids recoveries vs cumulative water recoveries for three frother dosages and three ionic strengths using Senfroth 516

Figure 38 shows the cumulative solids recoveries versus the cumulative water recoveries for three frother dosages and three ionic strengths using Senfroth 516. When looking at the total solids and water recovered, it can be seen that 3_70 and 5_60 appear to recover the same total solids but 5_60 recovers more water. The highest total solids recovery and the highest total water recovery are obtained at 10_70 while the lowest total solids recovery and lowest total water recovery are obtained at 3_50. There appear to be three regions defined by ionic strength where a low ionic strength results in more solids per unit water while a high ionic strength results in less solids per unit water.

5.2.4 Total Cumulative Water Recoveries and Total Cumulative Solids Recoveries

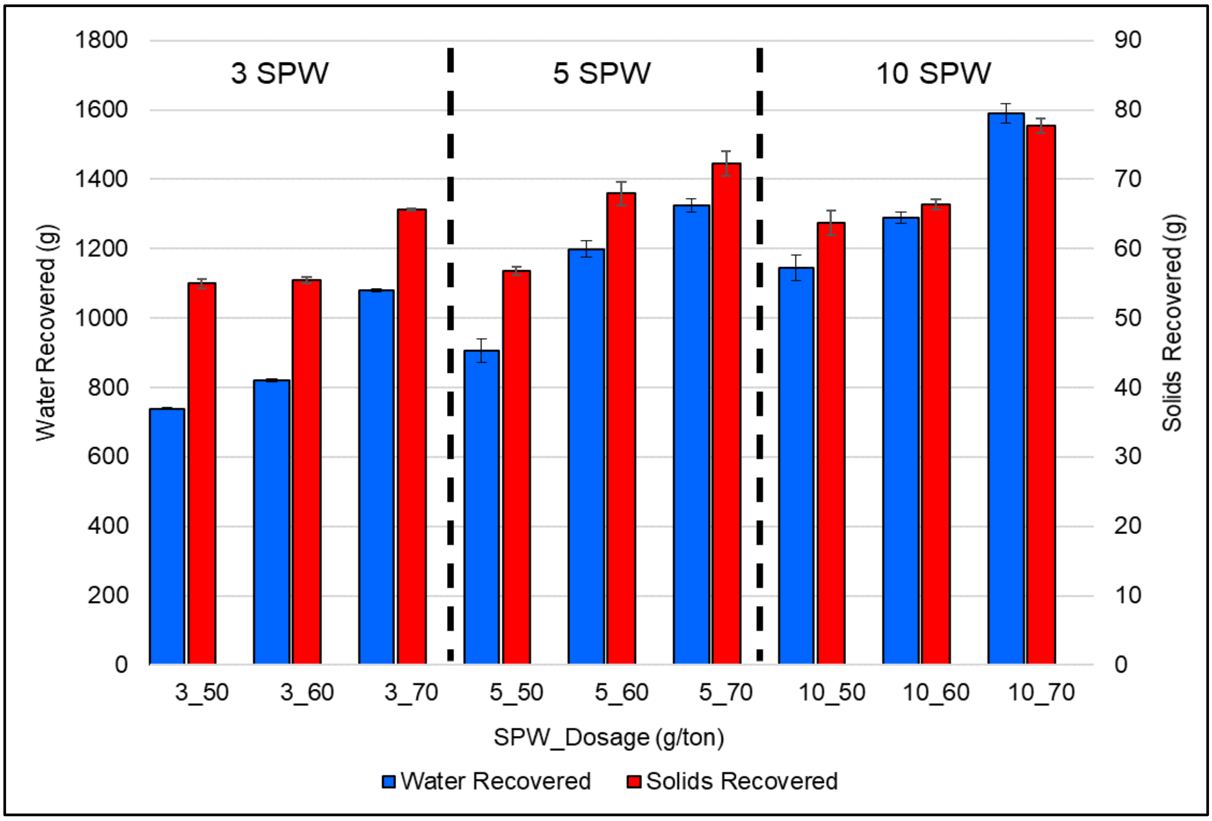

Figure 39 - Graph showing the total solids recoveries and total water recoveries for three frother dosages and three ionic strengths using Senfroth 516

Figure 39 shows the total cumulative solids recoveries and total cumulative water recoveries for three frother dosages and three ionic strengths using Senfroth 516. The blue bars represent the total water recoveries on the left axis while the red bars represent the total solids recoveries on the right axis.

Increasing the frother dosage at constant ionic strength increases the total recovery of both water and solids except at 3 SPW where the total solids recovery remains the same from 50 g/ton to 60 g/ton and then increases from 60 g/ton to 70 g/ton. Increasing the ionic strength at constant frother dosage also increases the total recovery of both solids and water except at a frother dosage of 60 g/ton where the total solids recovery increases from 3 SPW to 5 SPW and then remains the same from 5 SPW to 10 SPW. The solids per unit water appears to decrease with an increase in ionic strength which agrees with the trend displayed in Figure 38. The highest total water recovery is obtained at 10_70 while the lowest total water recovery is obtained at 3_50. The highest total solids recovery is obtained at 10_70 while the lowest total solids recoveries are obtained at 3_50 and 3_60.

When considering a simultaneous increase in ionic strength and decrease in frother dosage, Figure 39 shows that the total water recovery increases from 3_60 to 5_50 but remains the same from 5_70 to 10_60. The total water recovery increases from 3_70 to 5_60 and remains the same from 5_60 to 10_50. The total solids recovery decreases from 5_70 to 10_60 but remains the same from 3_60 to 5_50 and 3_70 to 5_60 to 10_50. When comparing 3_70 to 5_50 and 5_70 to 10_50, both the total water recoveries and total solids recoveries decrease as the ionic strength increases.

5.2.5 Cumulative Copper Recoveries vs Time

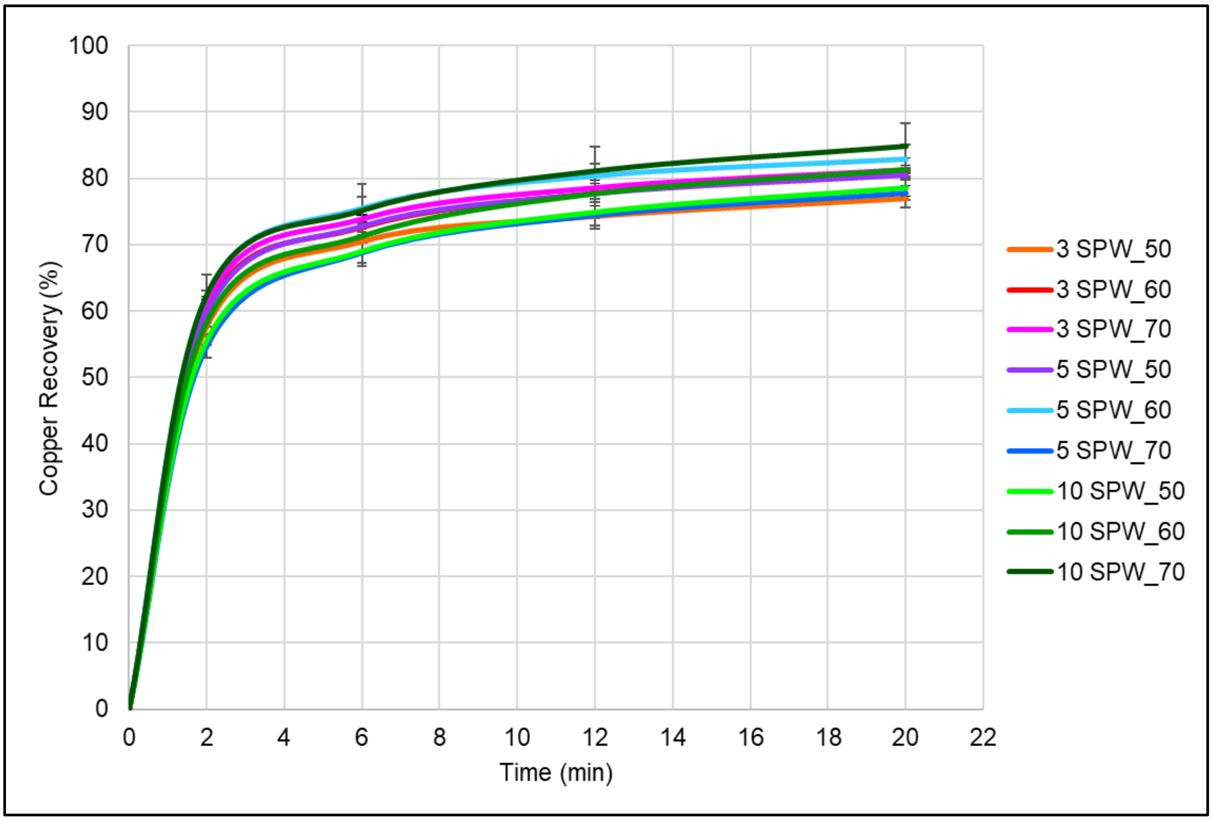

Figure 40 - Graph showing the cumulative copper recoveries vs time for three frother dosages and three ionic strengths using Senfroth 516

Figure 40 shows the cumulative copper recoveries versus time for three frother dosages and three ionic strengths using Senfroth 516. The rate at which copper is recovered appears to be only slightly affected by a change in frother dosage or ionic strength as the rates are fairly similar. Most of the copper has been recovered by 4 minutes with the final recoveries ranging from approximately 77 - 85%.

5.2.6 Cumulative Copper Recoveries vs Cumulative Water Recoveries

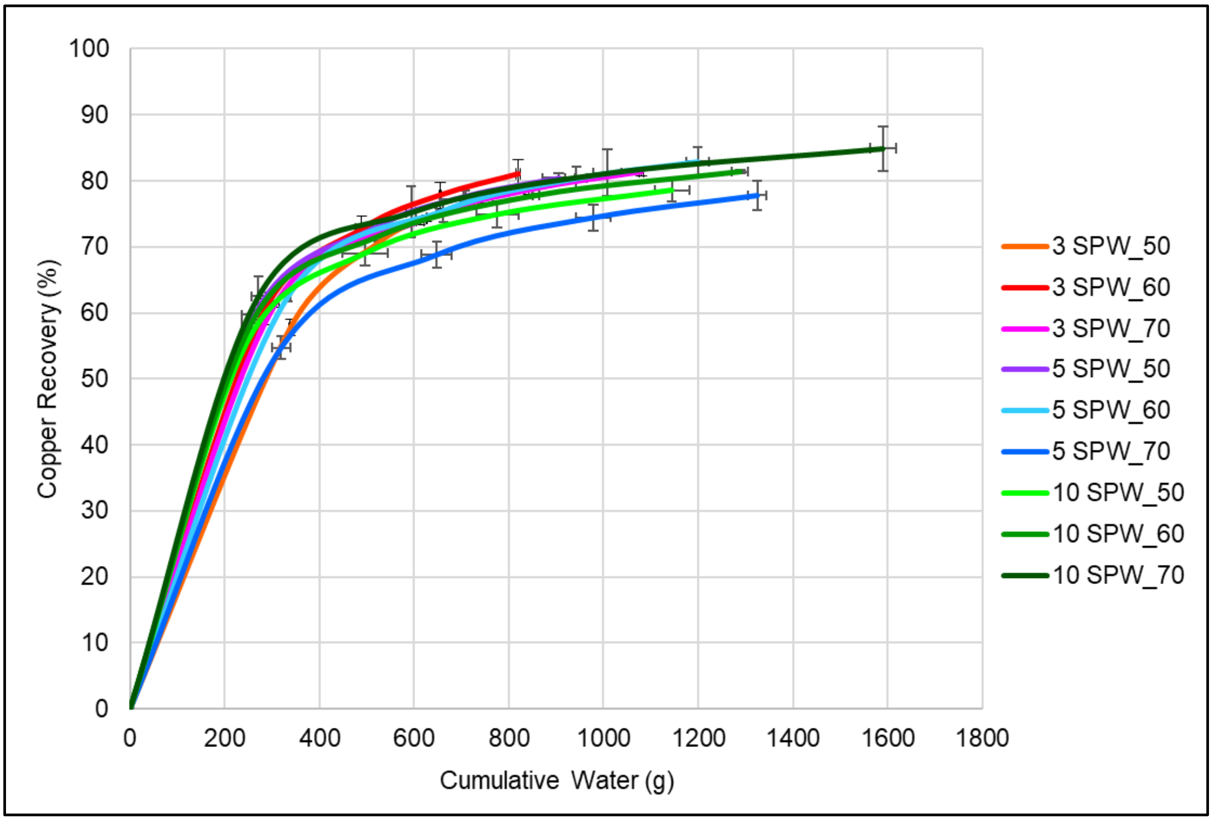

Figure 41 - Graph showing the cumulative copper recoveries vs the cumulative water recoveries for three frother dosages and three ionic strengths using Senfroth 516

Figure 41 shows the cumulative copper recoveries versus the cumulative water recoveries for three frother dosages and three ionic strengths using Senfroth 516. High ionic strengths and high frother dosages appear to recover more water while recovering the same or similar amounts of copper as low ionic strengths and low frother dosages. The final copper recoveries vary between 77 - 85%.

5.2.7 Total Cumulative Water Recoveries and Total Cumulative Copper Recoveries

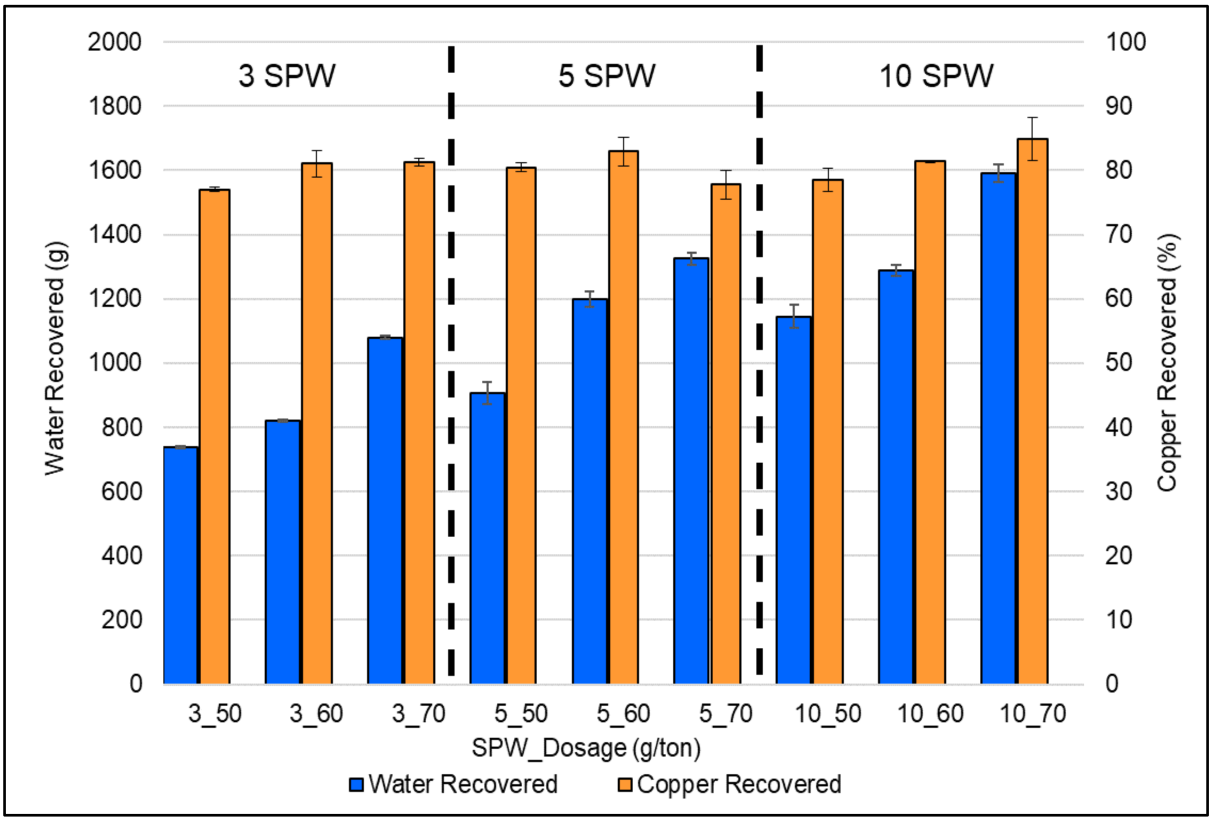

Figure 42 - Graph showing the total copper recoveries and total water recoveries for three frother dosages and three ionic strengths using Senfroth 516

Figure 42 shows the total copper recoveries and total water recoveries for three frother dosages and three ionic strengths using Senfroth 516. The blue bars represent the total water recoveries in grams on the left axis while the orange bars represent the total copper recoveries in percentages on the right axis.

The effects of frother dosage and ionic strength on the total recovery of water have been discussed in Figure 39. Increasing the frother dosage increases the total copper recovery from 50 g/ton to 60 g/ton but has no effect on the total copper recovery from 60 g/ton to 70 g/ton, except for 5 SPW where the latter change causes a decrease in the copper recovery. Increasing the ionic strength at a frother dosage of 50 g/ton or 60 g/ton has little to no effect on the total copper recovery while at 70 g/ton the copper recovery has a minimum at 5 SPW. However, despite these slight changes, the total copper recoveries are fairly similar ranging from 77 - 85%. The copper recovery per unit water appears to decrease with an increase in ionic strength or an increase in frother dosage.

When considering a simultaneous increase in ionic strength and decrease in frother dosage, Figure 42 shows that 3_60, 3_70, 5_50, 5_60, 10_60 and 10_70 have statistically similar total copper recoveries. Changing from 3_70 to 5_60 to 10_50 as well as from 3_70 to 5_50 or from 5_70 to 10_50 also results in the same total copper recoveries. Therefore there appears to be no change when increasing the ionic strength and decreasing the frother dosage.

5.2.8 Cumulative Copper Grades vs Cumulative Copper Recoveries

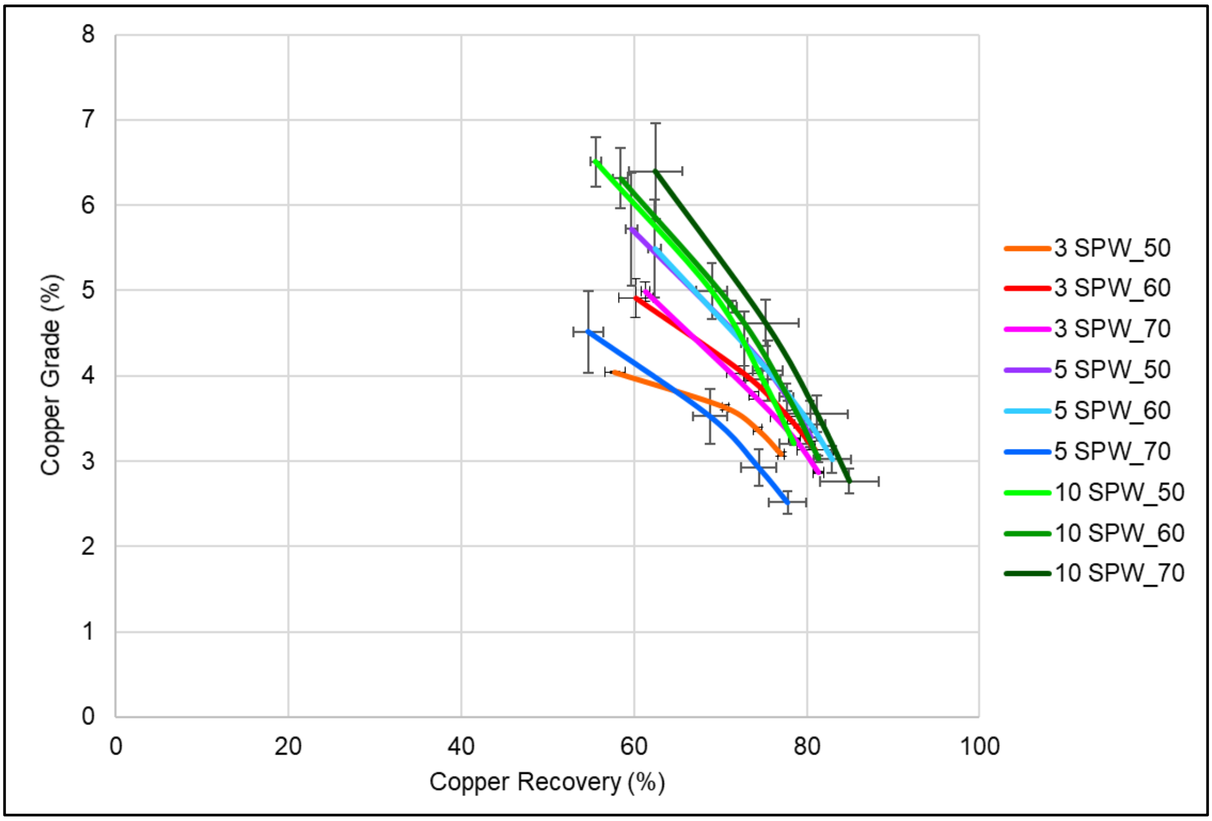

Figure 43 - Graph showing the cumulative copper grades vs the cumulative copper recoveries for three frother dosages and three ionic strengths using Senfroth 516

Figure 43 shows the cumulative copper grades versus the cumulative copper recoveries for three frother dosages and three ionic strengths using Senfroth 516. As the recovery increases, the grade decreases. An increase in ionic strength also appears to increase the extent to which the copper grade decreases as the recovery increases, as higher ionic strengths have higher initial grades but similar final grades as lower ionic strengths.

5.2.9 Total Cumulative Copper Recoveries and Final Cumulative Copper Grades

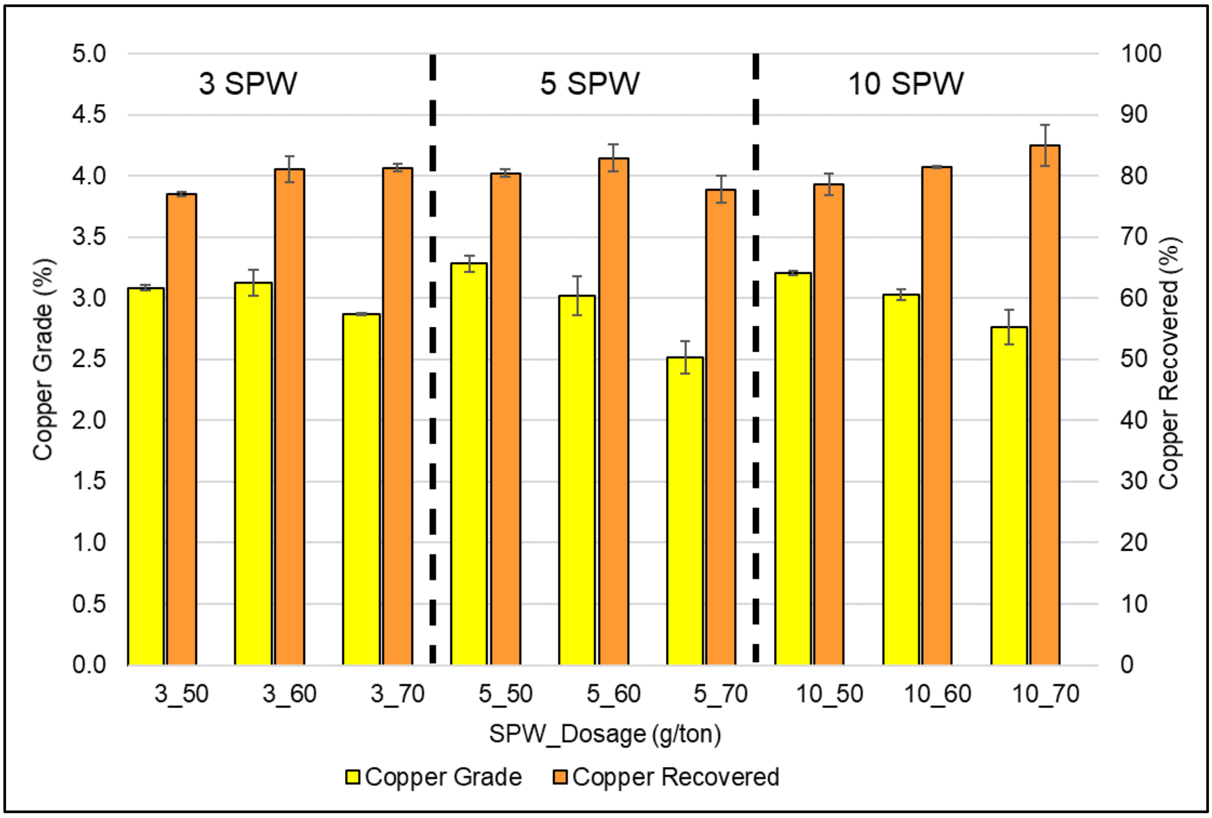

Figure 44 - Graph showing the total copper recoveries and final copper grades for three frother dosages and three ionic strengths using Senfroth 516

Figure 44 shows the total cumulative copper recoveries and final cumulative copper grades for three frother types and three ionic strengths using Senfroth 516. The orange bars represent the total copper recoveries on the right axis while the yellow bars represent the final copper grades on the left axis.

The effects of changing either frother dosage or ionic strength on the total recovery of copper have been discussed in Figure 42. Increasing the frother dosage at 5 SPW and 10 SPW decreases the final copper grade while at 3 SPW the final grade remains constant from 50 g/ton to 60 g/ton and then decreases from 60 g/ton to 70 g/ton. Increasing the ionic strength at 50 g/ton increases the final grade from 3 SPW to 5 SPW but has no effect from 5 SPW to 10 SPW. At 60 g/ton, the final grade is unaffected by a change in ionic strength and at 70 g/ton increasing the ionic strength results in a minimum at 5 SPW with a maximum at 10 SPW.

When considering a simultaneous increase in ionic strength and decrease in frother dosage, the final grade stays constant from 3_70 to 5_60 but increases from 5_60 to 10_50. 3_60 and 5_50 have the same final grades while 5_70 has a lower final grade than 10_60. When comparing 3_70 versus 5_50 and 5_70 versus 10_50, the final grade increases as the ionic strength increases.

5.2.10 Cumulative Nickel Recoveries vs Time

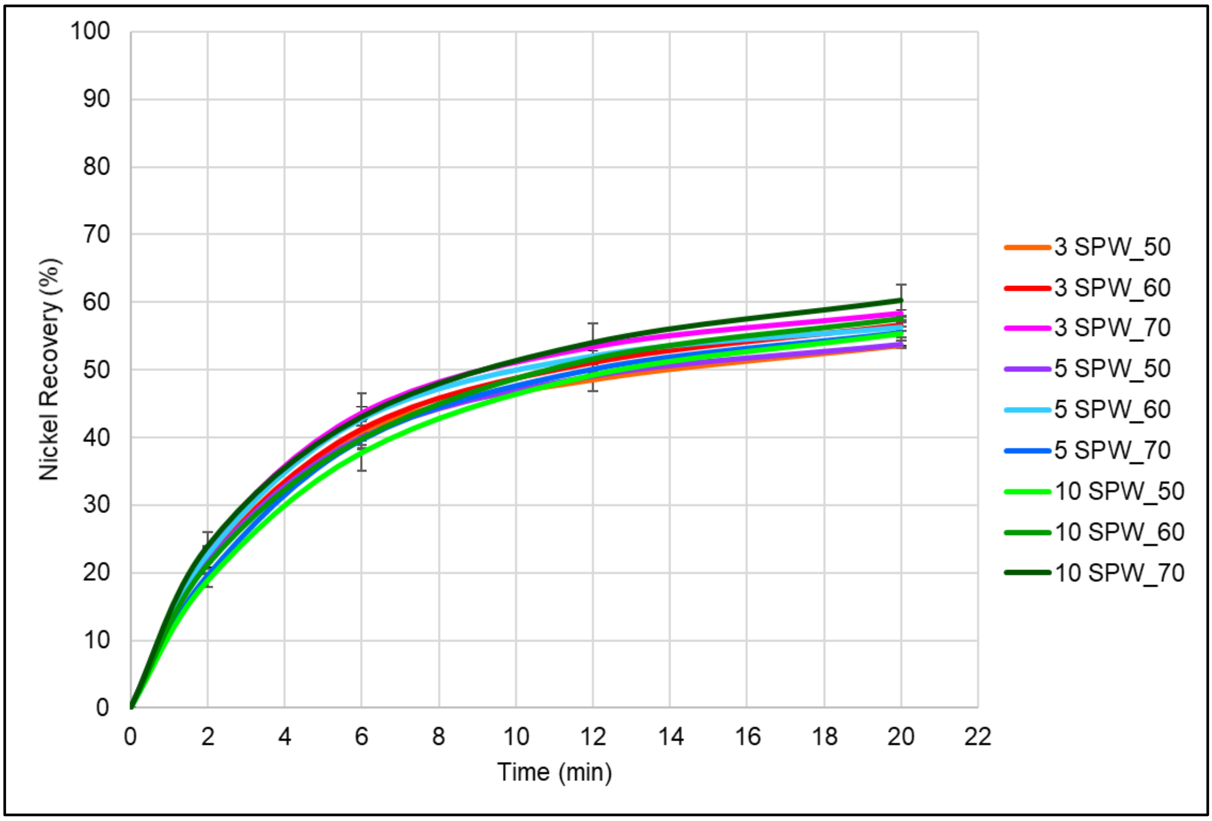

Figure 45 - Graph showing the cumulative nickel recoveries vs time for three frother dosages and three ionic strengths using Senfroth 516

Figure 45 shows the cumulative nickel recoveries versus time for three frother dosages and three ionic strengths using Senfroth 516. There are no clear distinctions between the various rates and therefore changing the frother dosage or ionic strength appears to not significantly affect the rate at which nickel is recovered. The final recoveries range from 54 - 60% with the lowest recoveries being obtained at 3_50 and 5_50 and the highest recovery being obtained at 10_70.

5.2.11 Cumulative Nickel Recoveries vs Cumulative Water Recoveries

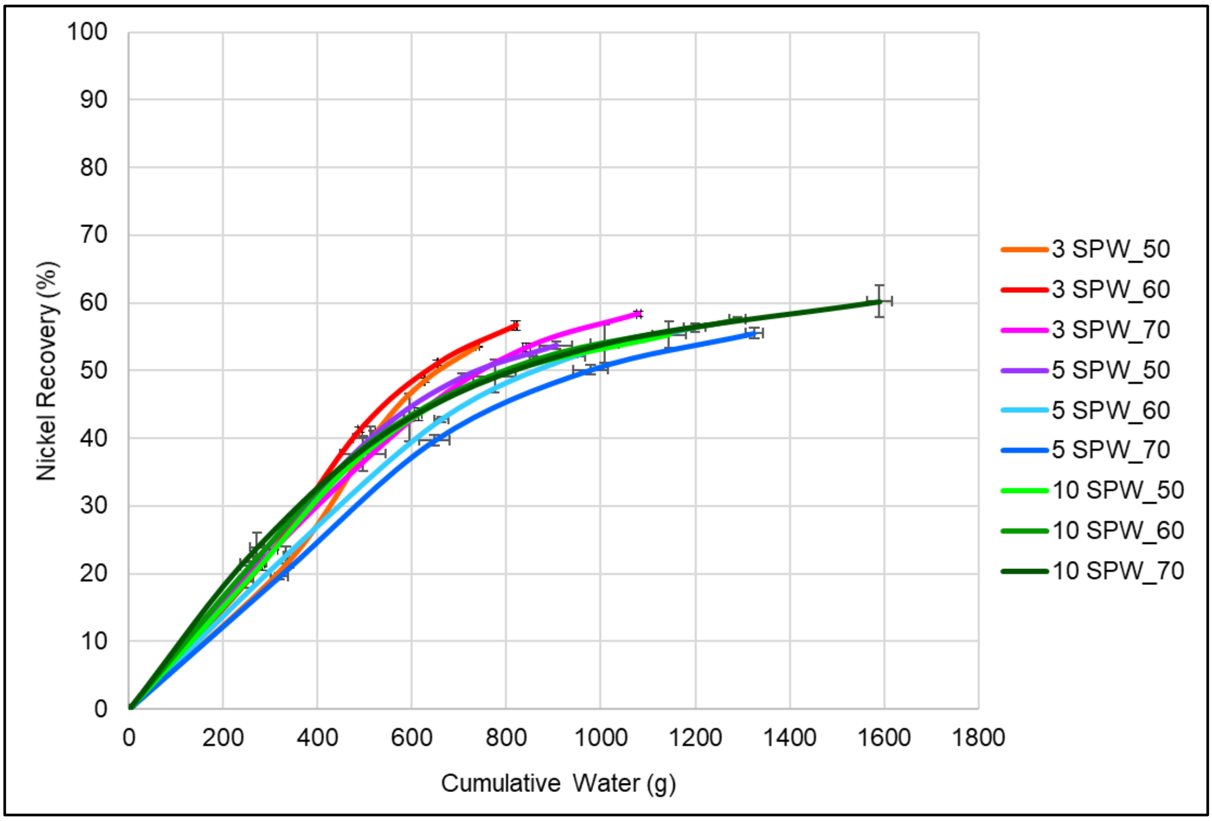

Figure 46 - Graph showing the cumulative nickel recoveries vs the cumulative water recoveries for three frother dosages and three ionic strengths using Senfroth 516

Figure 46 shows the cumulative nickel recoveries versus the cumulative water recoveries for three frother dosages and three ionic strengths using Senfroth 516. Higher ionic strengths and higher frother dosages appear to recover more water while recovering a similar amount of nickel as that achieved at lower ionic strengths and lower frother dosages. The highest final nickel and water recoveries are obtained at 10_70.

5.2.12 Total Cumulative Water Recoveries and Total Cumulative Nickel Recoveries

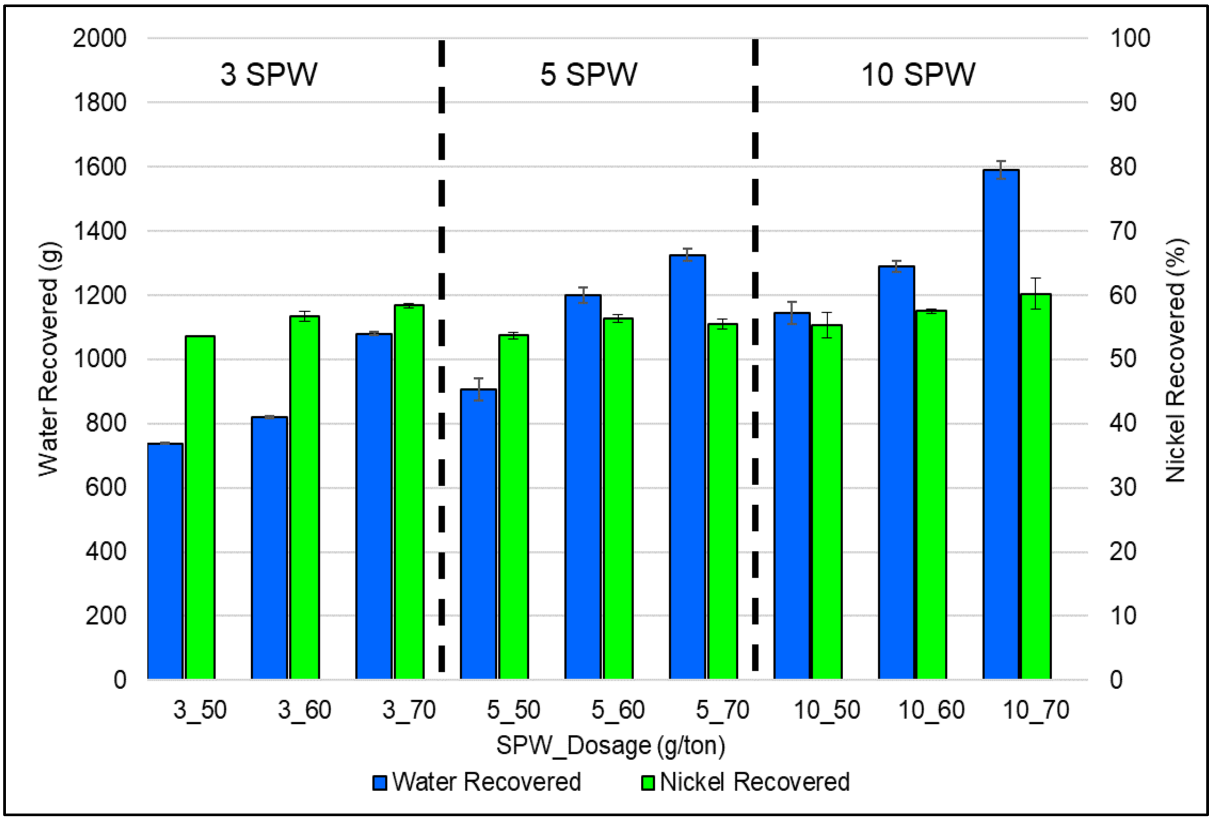

Figure 47 - Graph showing the total nickel recoveries and total water recoveries for three frother dosages and three ionic strengths using Senfroth 516

Figure 47 shows the total nickel recoveries and total water recoveries for three frother dosages and three ionic strengths using Senfroth 516. The blue bars represent the total water recoveries in grams on the left axis while the green bars represent the total nickel recoveries in percentages on the right axis.

The effects of frother dosage and ionic strength on the total recovery of water have been discussed in Figure 39. Increasing the frother dosage at 3 SPW and 10 SPW increases the total nickel recovery while at 5 SPW the total nickel recovery increases from 50 g/ton to 60 g/ton and then remains constant from 60 g/ton to 70 g/ton. Increasing the ionic strength at 50 g/ton and 60 g/ton appears to not affect the total nickel recovery but at 70 g/ton the total nickel recovery has a minimum at 5 SPW. The total nickel recoveries appear to vary between 54 - 60% with the highest total nickel recovery being obtained at 10_70 and the lowest at 50 g/ton regardless of the ionic strength. The nickel recovery per unit water decreases with an increase in either frother dosage or ionic strength.

When considering a simultaneous increase in ionic strength and decrease in frother dosage, Figure 47 shows that the total nickel recovery decreases from 3_70 to 5_60 but remains the same from 5_60 to 10_50. The total nickel recovery decreases from 3_60 to 5_50 but increases from 5_70 to 10_60. When comparing 3_70 versus 5_50, the total nickel recovery decreases as the ionic strength increases but comparing 5_70 versus 10_50 shows no effect on the total nickel recovery. Therefore increasing the ionic strength and decreasing the frother dosage appears to have an overall decreasing effect on the nickel recovery.

5.2.13 Cumulative Nickel Grades vs Cumulative Nickel Recoveries

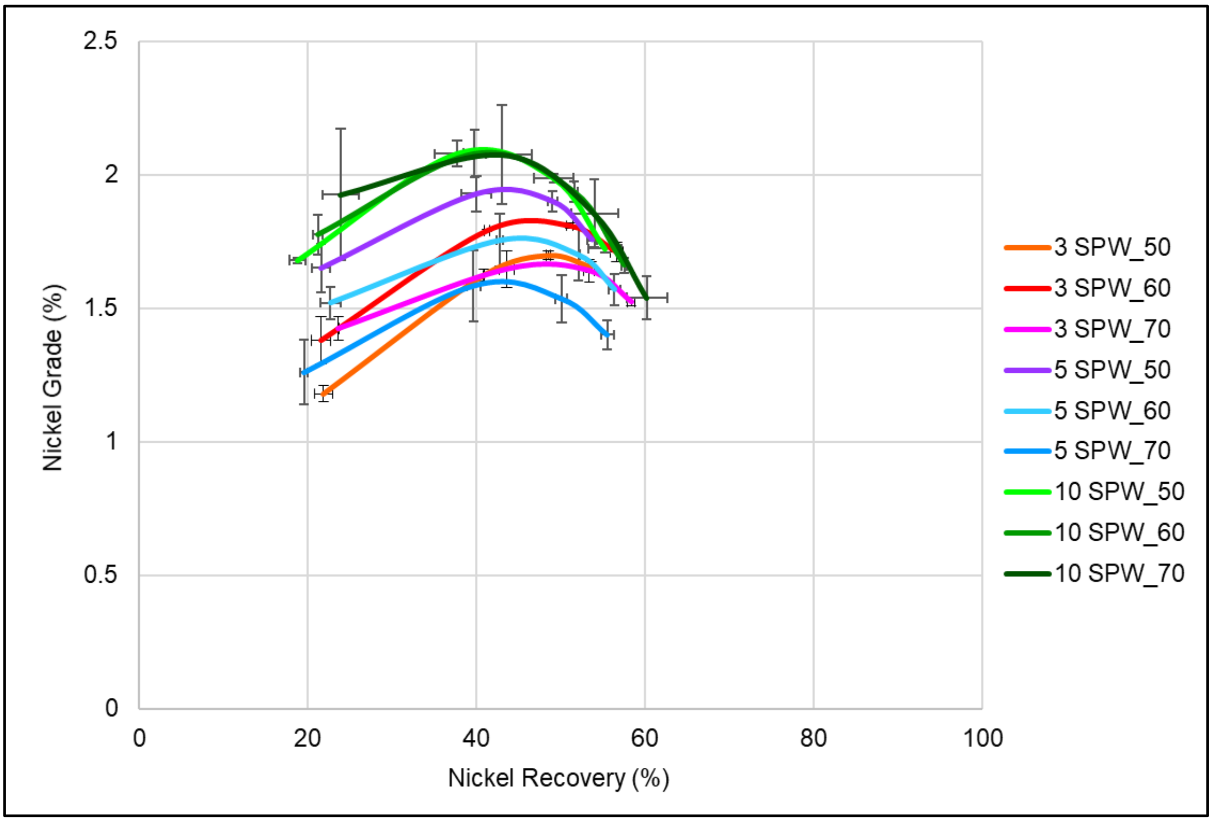

Figure 48 - Graph showing the cumulative nickel grades vs the cumulative nickel recoveries for three frother dosages and three ionic strengths using Senfroth 516

Figure 48 shows the cumulative nickel grades versus the cumulative nickel recoveries for three frother dosages and three ionic strengths using Senfroth 516. The grade initially increases as the recovery increases until it reaches a maximum value at a recovery of approximately 45% and then decreases again. The final grades vary between 1.4 - 1.8%.

5.2.14 Total Cumulative Nickel Recoveries and Final Cumulative Nickel Grades

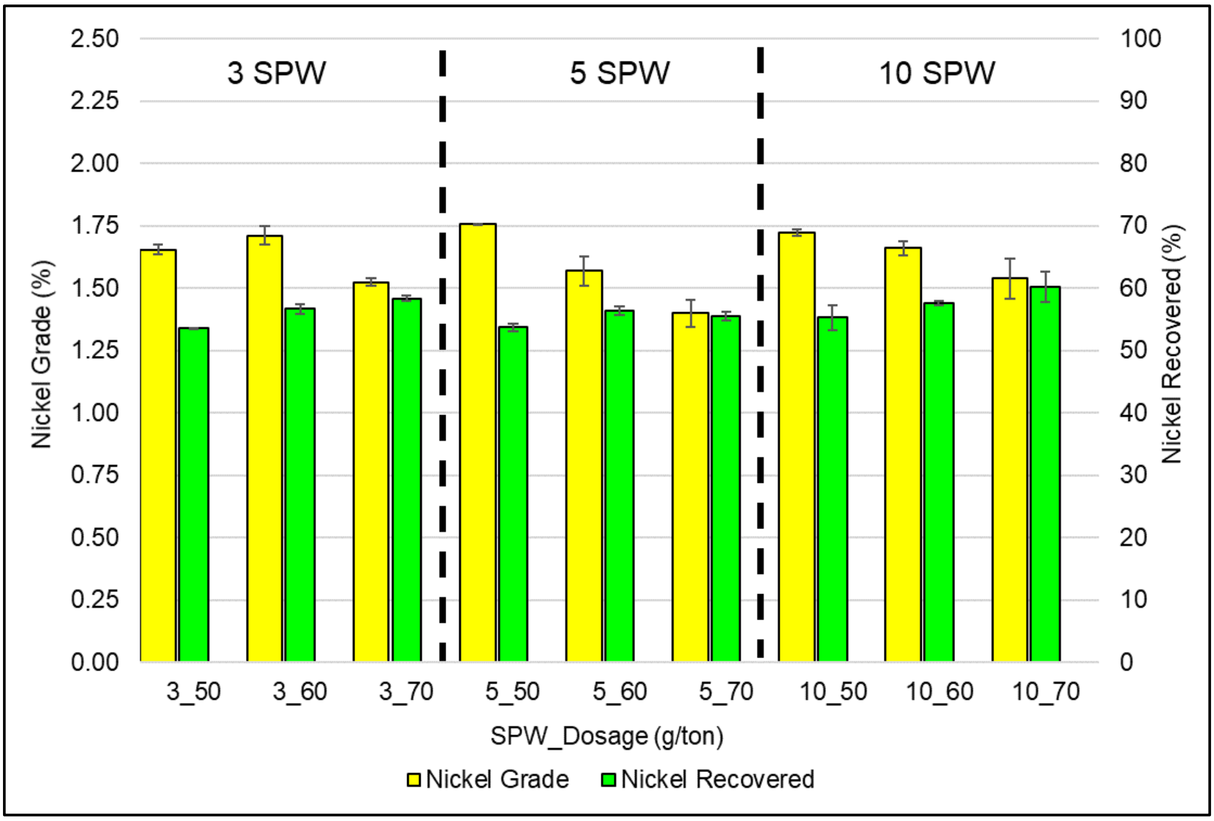

Figure 49 - Graph showing the total nickel recoveries and final nickel grades for three frother dosages and three ionic strengths using Senfroth 516

Figure 49 shows the total cumulative nickel recoveries and final cumulative nickel grades for three frother dosages and three ionic strengths using Senfroth 516. The green bars represent the total nickel recoveries on the right axis while the yellow bars represent the final nickel grades on the left axis.

The effects of frother dosage and ionic strength on the recovery of nickel have been discussed in Figure 47. Increasing the frother dosage at 5 SPW and 10 SPW decreases the final grade while at 3 SPW the final grade remains the same from 50 g/ton to 60 g/ton but decreases from 60 g/ton to 70 g/ton. Increasing the ionic strength at 50 g/ton results in a maximum final grade at 5 SPW with 10 SPW being higher than 3 SPW but at 60 g/ton and 70 g/ton, increasing the ionic strength results in a minimum final grade at 5 SPW with 3 SPW and 10 SPW giving approximately the same results. The highest and lowest final grades are obtained at 5_50 and 5_70 respectively.

When considering a simultaneous increase in ionic strength and decrease in frother dosage, Figure 49 shows that the final grade is unaffected when changing from 3_70 to 5_60 but increases from 5_60 to 10_50. The final grade also increases when changing from 3_60 to 5_50 or from 5_70 to 10_60. Comparing 3_70 versus 5_50 and 5_70 versus 10_50 results in a significant increase in the final grade for both comparisons. Overall, increasing the ionic strength and decreasing the frother dosage increases the final grade.

5.3 Senfroth 580

5.3.1 Cumulative Water Recoveries vs Time

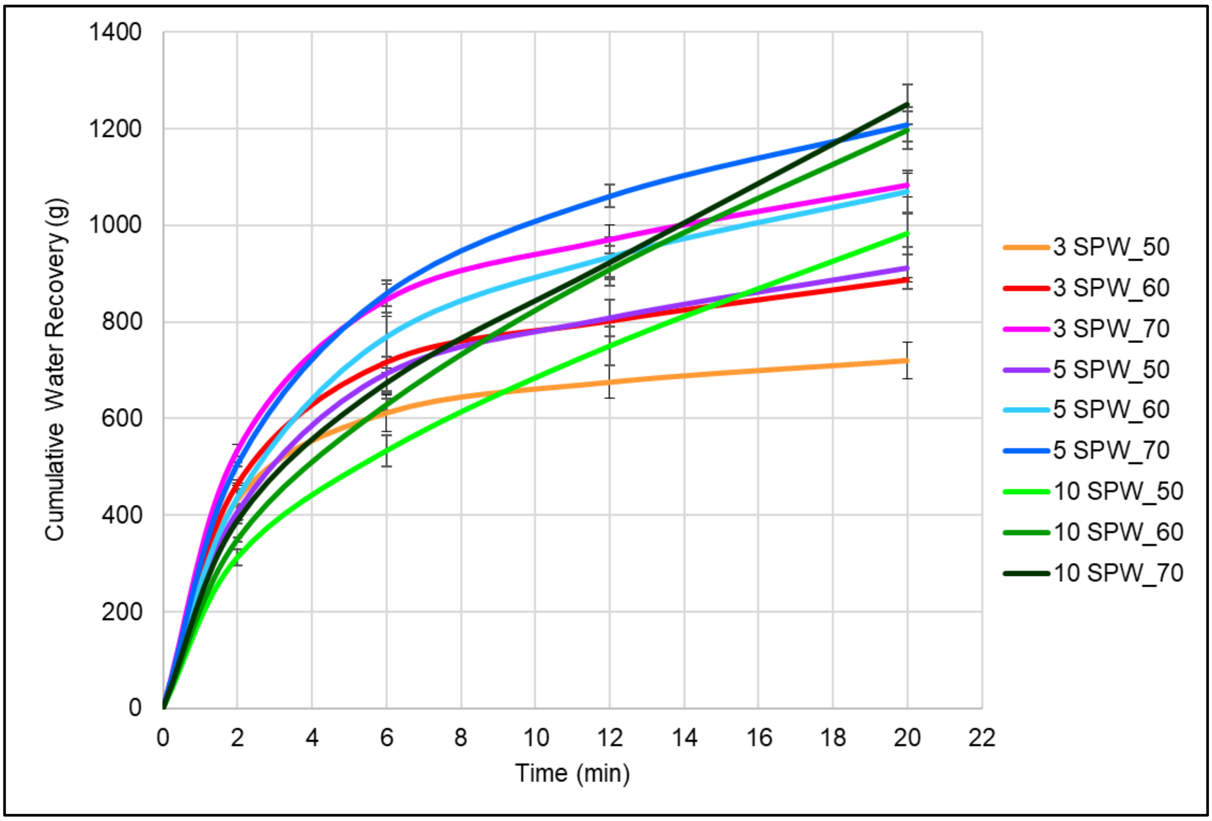

Figure 50 - Graph showing cumulative water recoveries vs time for three frother dosages and three ionic strengths using Senfroth 580

Figure 50 shows the cumulative water recoveries versus time for three frother dosages and three ionic strengths using Senfroth 580. Increasing either the frother dosage or the ionic strength appears to increase the rate at which water is recovered. 3 SPW and 5 SPW appear to have faster initial rates compared to 10 SPW however the rate at which water is recovered for 3 SPW slows down significantly while 5 SPW only slows down slightly and 10 SPW remains consistently high therefore resulting in higher total water recoveries. The highest total water recoveries are obtained at 10_70, 10_60 and 5_70 while the lowest total water recovery is obtained at 3_50.

5.3.2 Cumulative Solids Recoveries vs Time

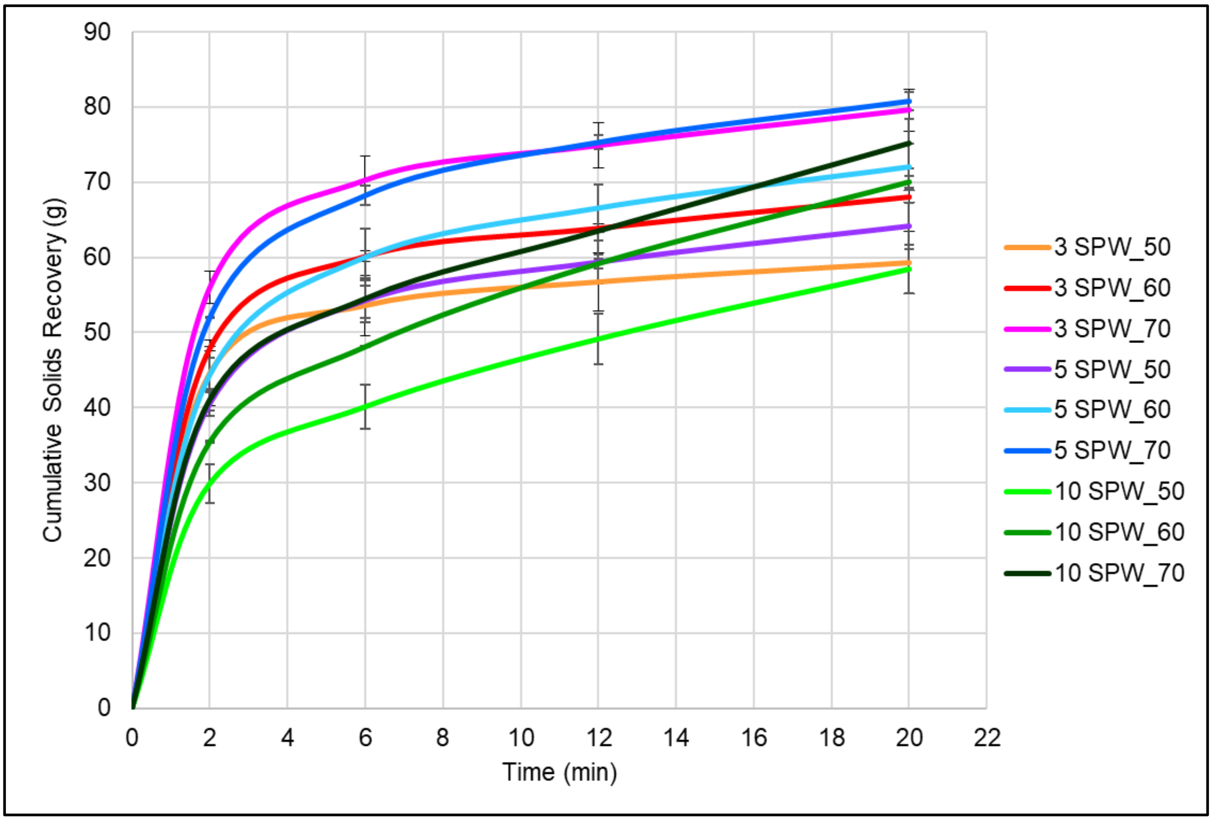

Figure 51 - Graph showing cumulative solids recoveries vs time for three ionic strengths and three frother dosages using Senfroth 580

Figure 51 shows the cumulative solids recoveries versus time for three ionic strengths and three frother dosages using Senfroth 580. Increasing the frother dosage increases the rate at which the solids are recovered. Increasing the ionic strength results in an increase in rate from 3 SPW to 5 SPW but a decrease in rate from 5 SPW to 10 SPW. The rates are initially fast but slow down after 4 minutes. A combination of high ionic strength and low frother dosage gives the slowest initial rates while a combination of low ionic strength and high frother dosage gives the fastest initial rates. The lowest total solids recoveries are obtained at 3_50 and 10_50 with the next lowest at 5_50 while the highest total solids recoveries are obtained at 3_70 and 5_70 with the next highest at 10_70.

5.3.3 Cumulative Solids Recoveries vs Cumulative Water Recoveries

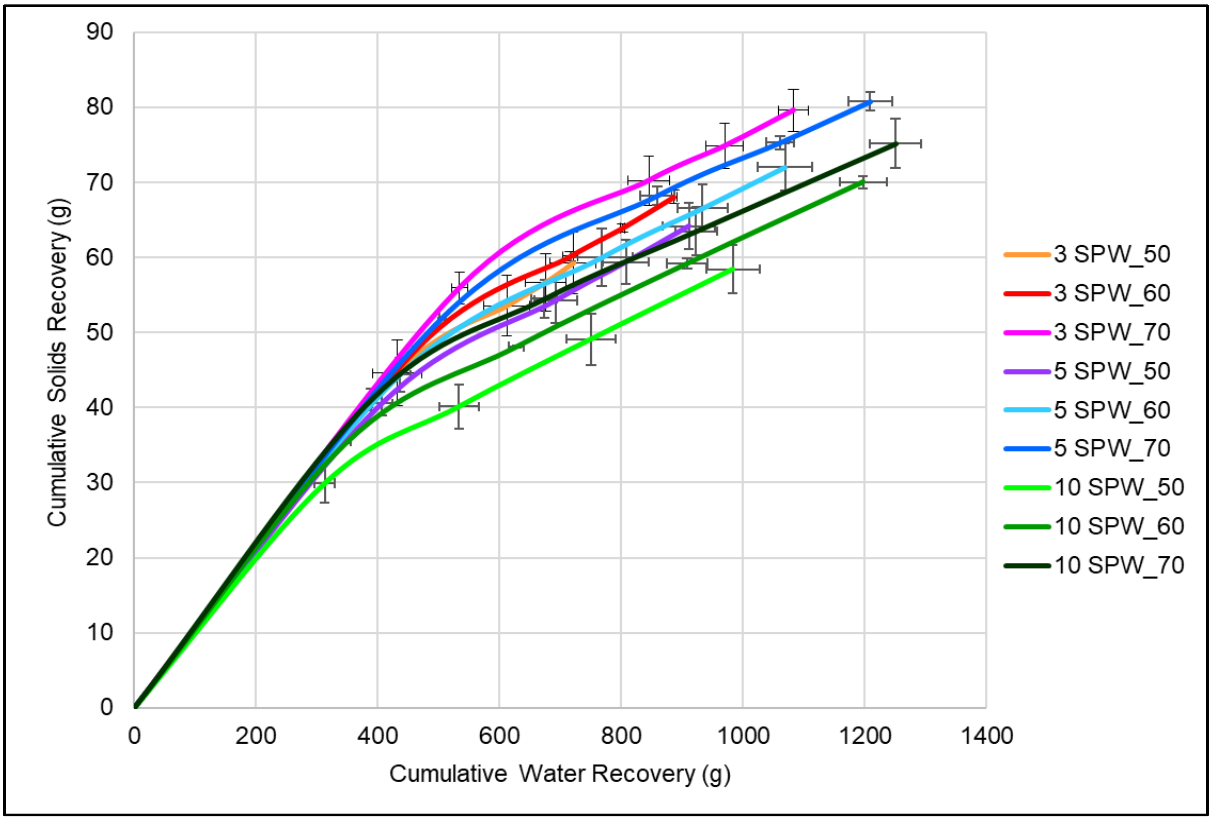

Figure 52 - Graph showing the cumulative solids recoveries vs cumulative water recoveries for three frother dosages and three ionic strengths using Senfroth 580

Figure 52 shows the cumulative solids recoveries versus the cumulative water recoveries for three frother dosages and three ionic strengths using Senfroth 580. Increasing the frother dosage increases the solids per unit water while increasing the ionic strength decreases the solids per unit water. 3_70 and 5_70 appear to have the same solids recovery but 5_70 recovers more water. 3_60 and 10_60 also appear to recover the same amount of solids but 10_60 recovers more water. There appear to be three regions defined by ionic strength where a low ionic strength results in more solids per unit water while a high ionic strength results in less solids per unit water.

5.3.4 Total Cumulative Water Recoveries and Total Cumulative Solids Recoveries

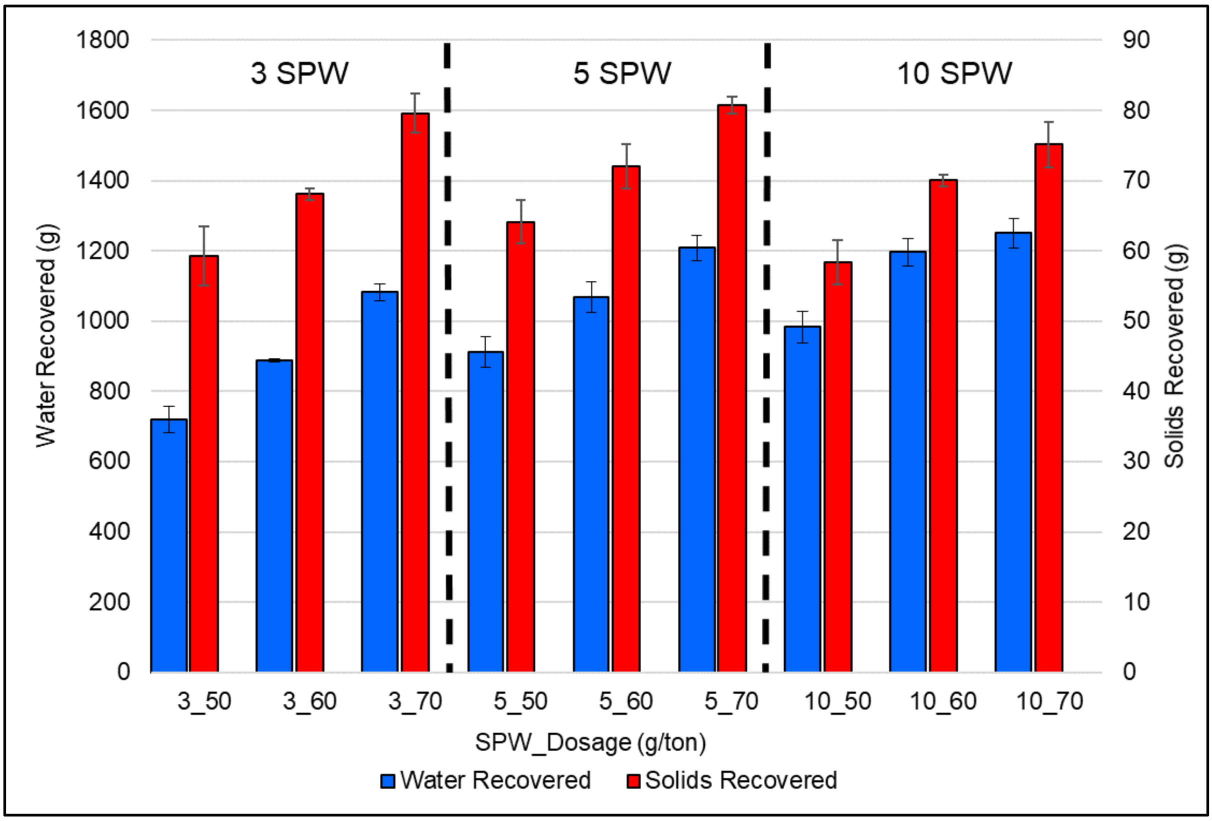

Figure 53 - Graph showing the total solids recoveries and total water recoveries for three frother dosages and three ionic strengths using Senfroth 580

Figure 53 shows the total cumulative solids recoveries and total cumulative water recoveries for three frother dosages and three ionic strengths using Senfroth 580. The blue bars represent the total water recoveries on the left axis while the red bars represent the total solids recoveries on the right axis.

Increasing the frother dosage at constant ionic strength increases the total water recovery except at 10 SPW where the total water recovery increases from 50 g/ton to 60 g/ton and then remains constant from 60 g/ton to 70 g/ton. Increasing the ionic strength at 60 g/ton increases the total water recovery but at 50 g/ton or 70 g/ton, the total water recovery increases from 3 SPW to 5 SPW but is unaffected from 5 SPW to 10 SPW. Increasing the frother dosage at constant ionic strength increases the total solids recovery but increasing the ionic strength at constant frother dosage does not affect the total solids recovery. The highest total water recoveries are obtained at 5_70, 10_60 and 10_70 while the lowest is obtained at 3_50. The highest total solids recoveries are obtained at 3_70 and 5_70 while the lowest are obtained at 3_50, 5_50 and 10_50. The solids recovery per unit water appears to decrease with an increase in ionic strength.

When considering a simultaneous increase in ionic strength and decrease in frother dosage, Figure 53 shows that the total water recovery remains constant from 3_70 to 5_60 but decreases from 5_60 to 10_50. The total water recovery also stays constant from 3_60 to

5_50 and from 5_70 to 10_60. When comparing 3_70 to 5_50 and 5_70 to 10_50, the total water recovery decreases significantly as the ionic strength increases. The total solids recovery decreases from 3_70 to 5_60 to 10_50 as well as from 3_60 to 5_50 and from 5_70 to 10_60. Comparing 3_70 to 5_50 and 5_70 to 10_50 also results in a decrease in the total solids recovery as the ionic strength increases.

5.3.5 Cumulative Copper Recoveries vs Time

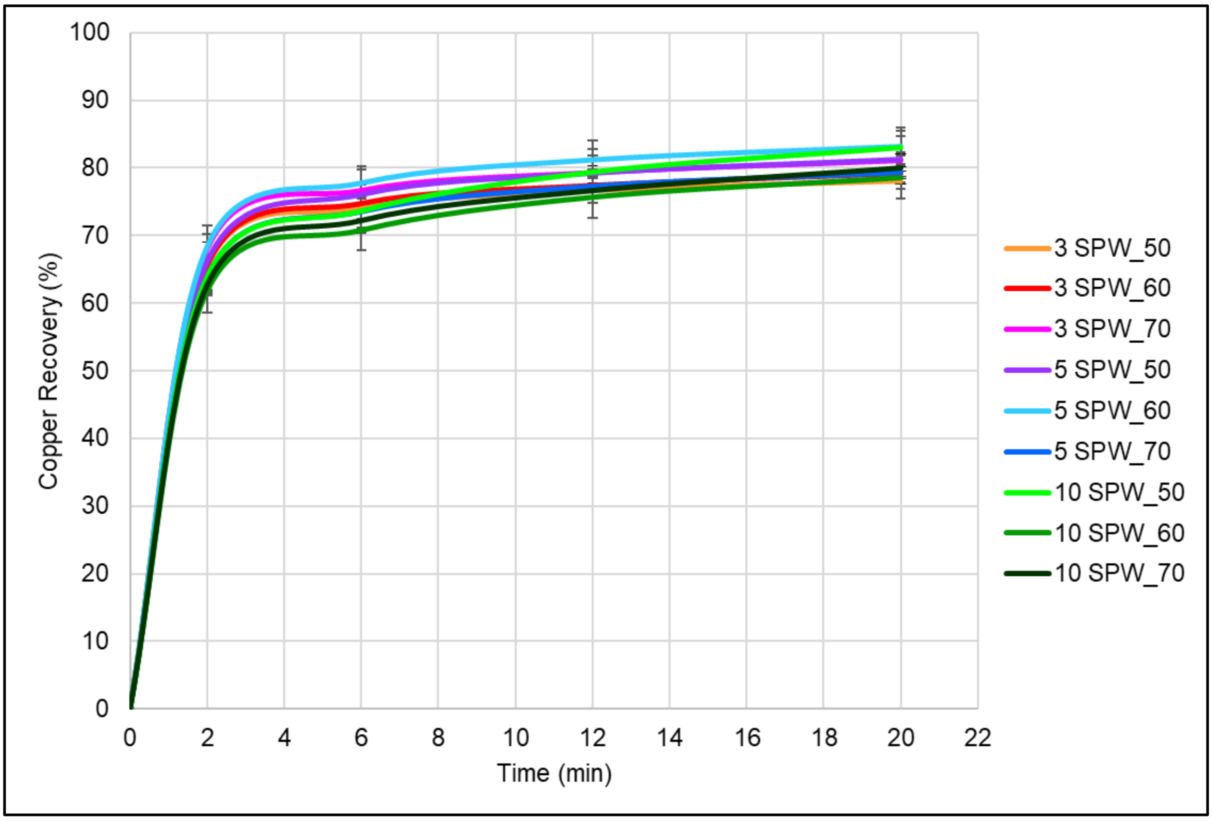

Figure 54 - Graph showing the cumulative copper recoveries vs time for three frother dosages and three ionic strengths using Senfroth 580

Figure 54 shows the cumulative copper recoveries versus time for three frother dosages and three ionic strengths using Senfroth 580. The rates are very similar which implies that the rate at which copper is recovered is not affected by frother dosage or ionic strength. Most of the copper is recovered by 4 minutes with the final recoveries varying from 77 - 84%.

5.3.6 Cumulative Copper Recoveries vs Cumulative Water Recoveries

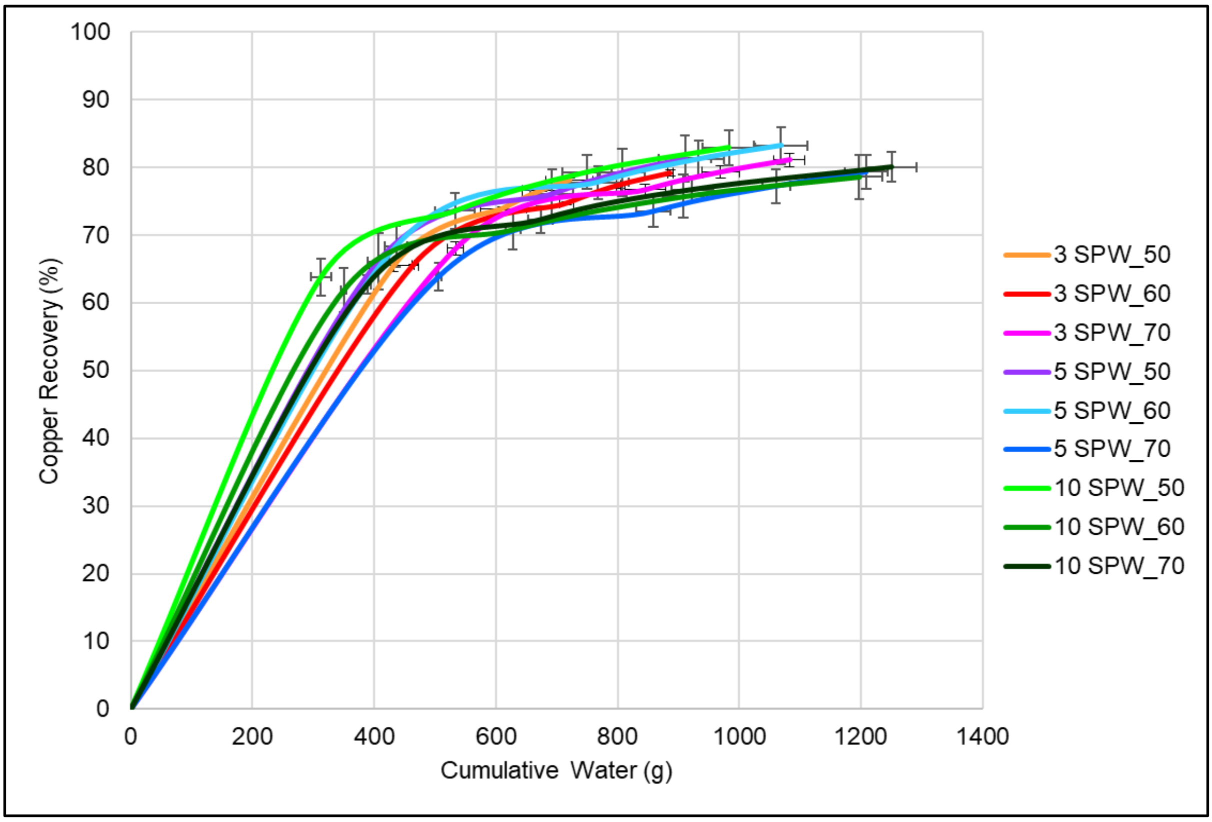

Figure 55 - Graph showing the cumulative copper recoveries vs the cumulative water recoveries for three frother dosages and three ionic strengths using Senfroth 580

Figure 55 shows the cumulative copper recoveries versus the cumulative water recoveries for three frother dosages and three ionic strengths using Senfroth 580. An increase in frother dosage appears to result in more water being recovered for the same copper recovery.

5.3.7 Total Cumulative Water Recoveries and Total Cumulative Copper Recoveries

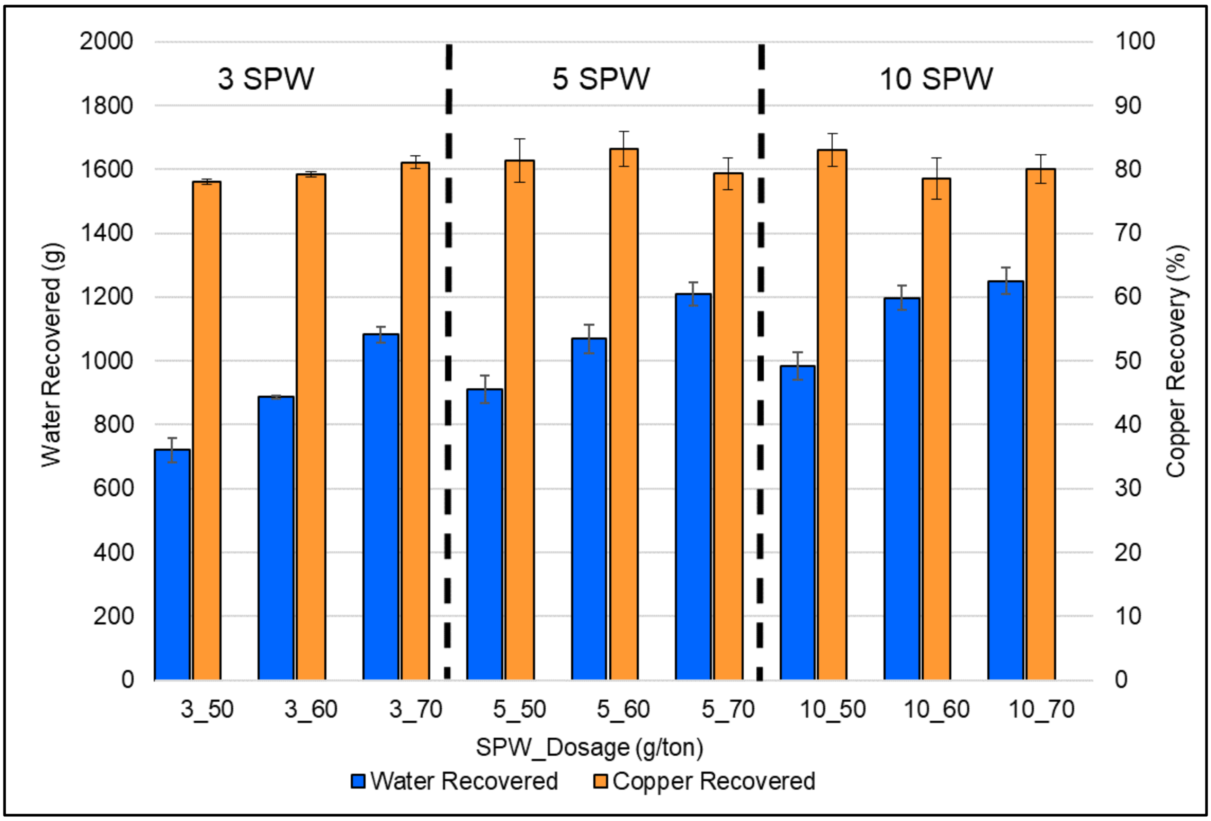

Figure 56 - Graph showing the total copper recoveries and total water recoveries for three frother dosages and three ionic strengths using Senfroth 580

Figure 56 shows the total copper recoveries and total water recoveries for three frother dosages and three ionic strengths using Senfroth 580. The blue bars represent the total water recoveries in grams on the left axis while the orange bars represent the total copper recoveries in percentages on the right axis.

The effects of frother dosage and ionic strength on the recovery of water have been discussed in Figure 53. Increasing the frother dosage at constant ionic strength increases the total copper recovery at 3 SPW but does not affect it at 5 SPW and 10 SPW. Increasing the ionic strength at constant frother dosage does not appear to affect the total copper recovery. The copper recovery per unit water follows the same trends as the total water recovery.

When considering a simultaneous increase in ionic strength and decrease in frother dosage, the total copper recovery remains constant therefore increasing the ionic strength and decreasing the frother dosage only affects the total water recovery.

5.3.8 Cumulative Copper Grades vs Cumulative Copper Recoveries

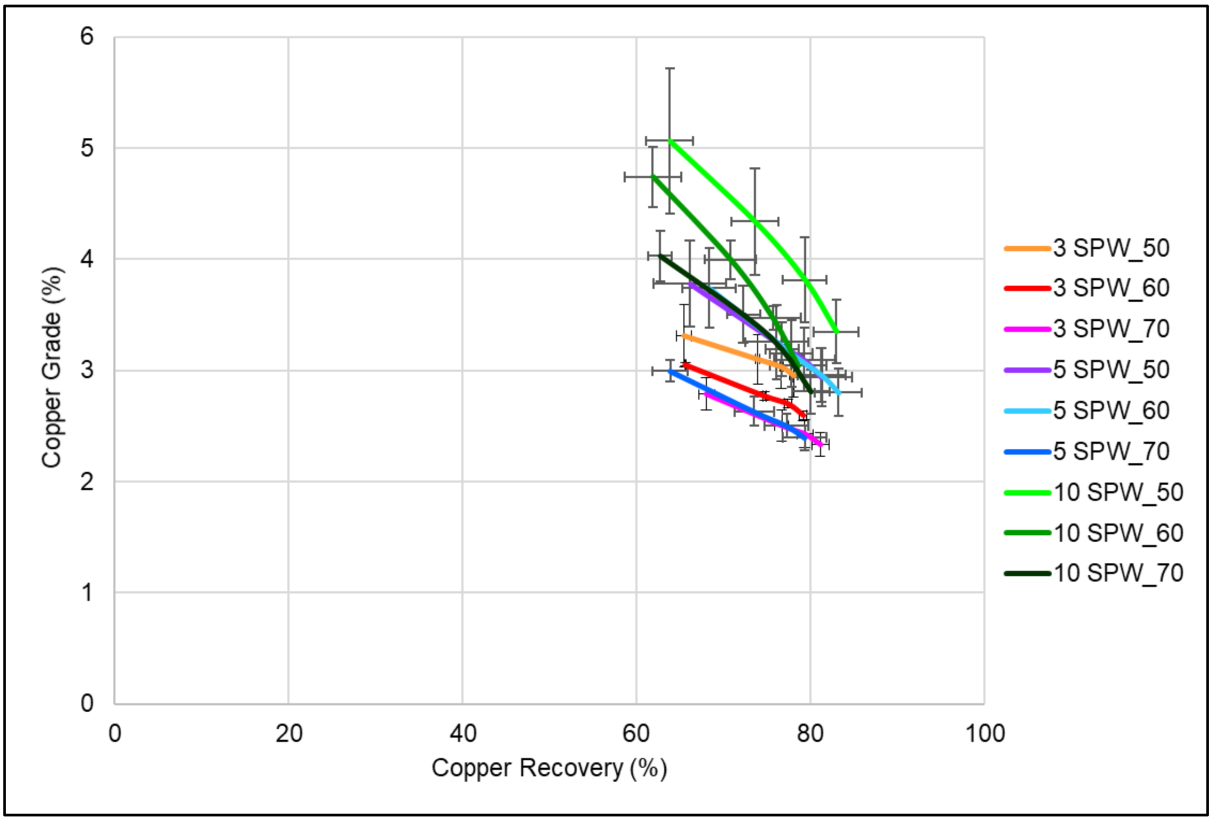

Figure 57 - Graph showing the cumulative copper grades vs the cumulative copper recoveries for three frother dosages and three ionic strengths using Senfroth 580

Figure 57 shows the cumulative copper grades versus the cumulative copper recoveries for three frother dosages and three ionic strengths using Senfroth 580. As the recovery increases, the grade decreases. An increase in ionic strength appears to increase the extent to which the copper grade decreases as the recovery increases while an increase in frother dosage appears to decrease the extent to which the copper grade decreases as the recovery increases.

5.3.9 Total Cumulative Copper Recoveries and Final Cumulative Copper Grades

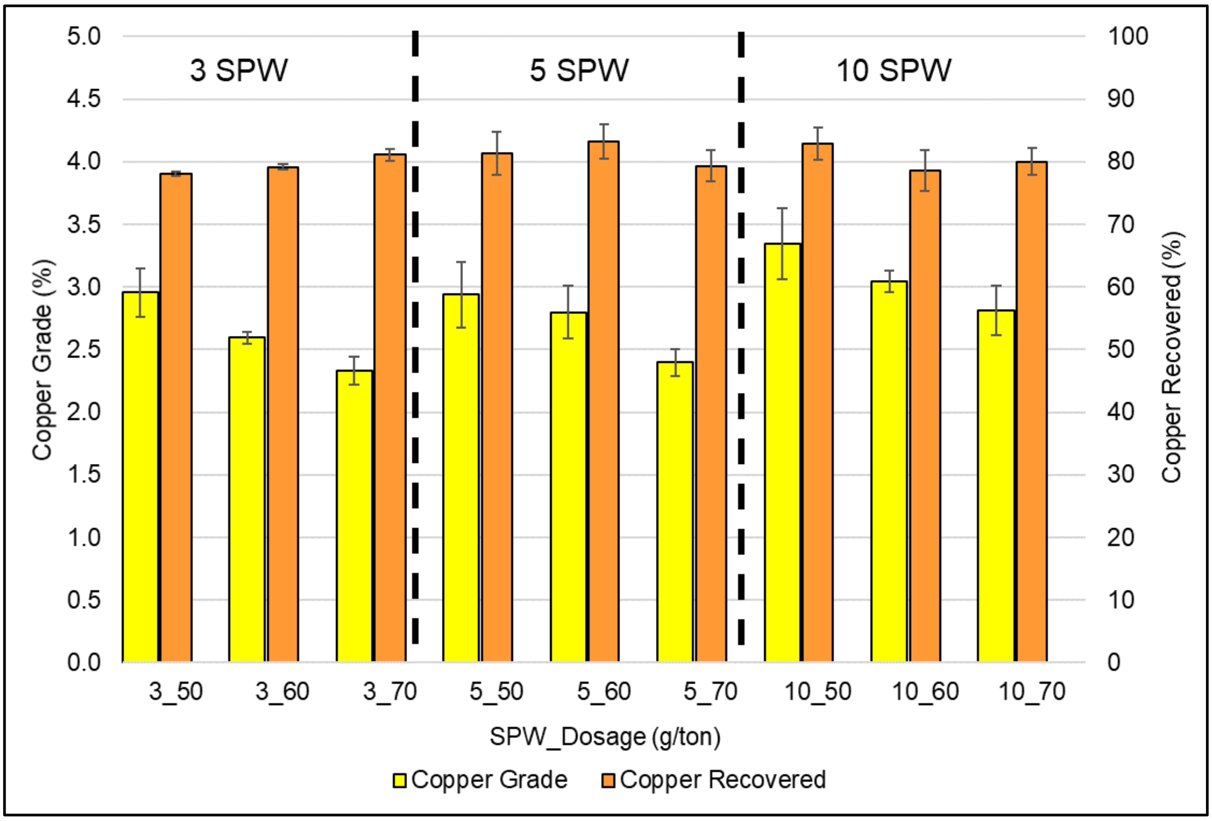

Figure 58 - Graph showing the total copper recoveries and final copper grades for three frother dosages and three ionic strengths using Senfroth 580

Figure 58 shows the total cumulative copper recoveries and final cumulative copper grades for three frother types and three ionic strengths using Senfroth 580. The orange bars represent the total copper recoveries on the right axis while the yellow bars represent the final copper grades on the left axis.

The effects of changing either frother dosage or ionic strength on the recovery of copper have been discussed in Figure 56. Increasing the frother dosage at 3 SPW decreases the final grade while at 10 SPW the final grade is unaffected. At 5 SPW, increasing the frother dosage does not affect the final grade from 50 g/ton to 60 g/ton but decreases the final grade from 60 g/ton to 70 g/ton. Increasing the ionic strength at 50 g/ton has no effect on the final grade, at 60 g/ton it increases the final grade and at 70 g/ton the grade remains constant from 3 SPW to 5 SPW but increases from 5 SPW to 10 SPW. The lowest grades are obtained at 3_70 and 5_70.

When considering a simultaneous increase in ionic strength and decrease in frother dosage, the final grade increases from 3_70 to 5_60 to 10_50. The final grade also increases from 3_60 to 5_50 and from 5_70 to 10_60. There is also a substantial increase in the final grade from 3_70 to 5_50 and from 5_70 to 10_50.

5.3.10 Cumulative Nickel Recoveries vs Time

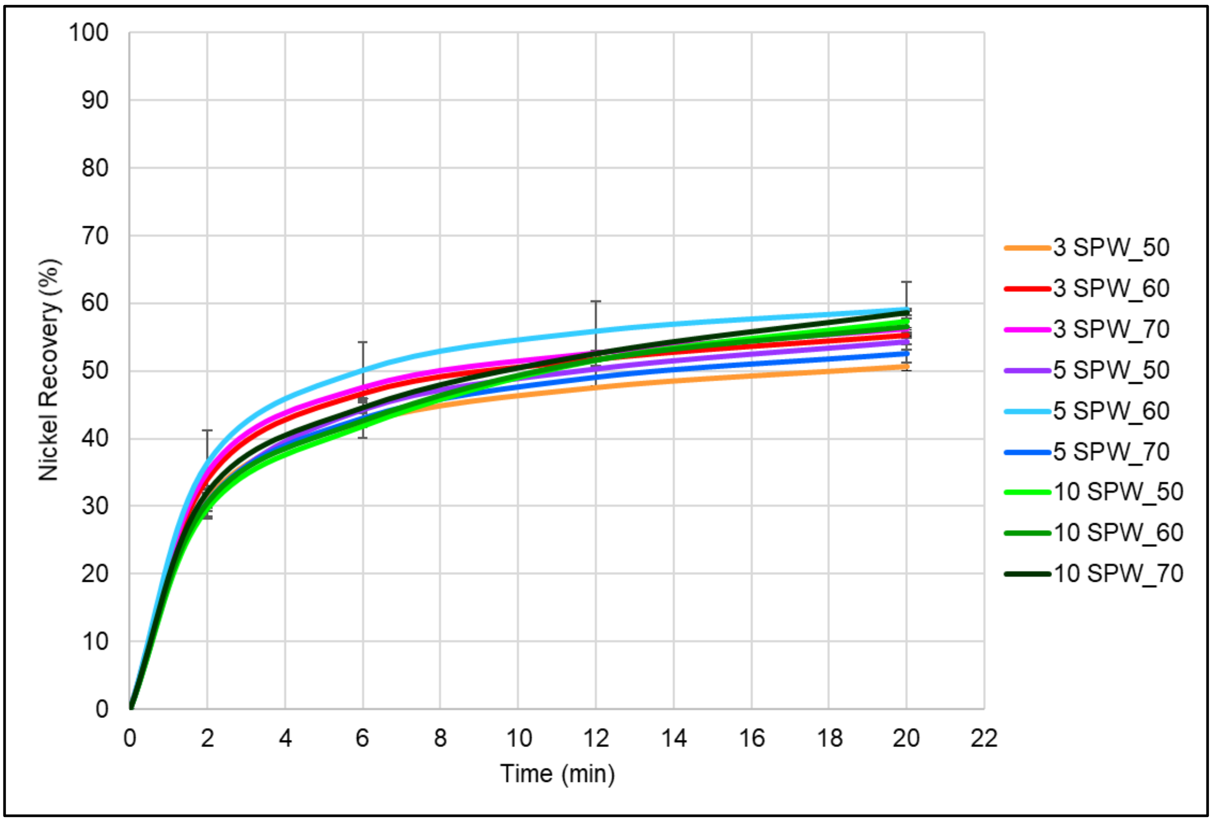

Figure 59 - Graph showing the cumulative nickel recoveries vs time for three frother dosages and three ionic strengths using Senfroth 580

Figure 59 shows the cumulative nickel recoveries versus time for three frother dosages and three ionic strengths using Senfroth 580. There appear to be two different groups of rates between 2 - 6 minutes however the rates are very similar. Lower ionic strengths appear to have faster initial rates that slow down while higher ionic strengths appear to have slow initial rates that stay consistent thus resulting in higher total recoveries. The total recoveries range between 50 - 60% with the lowest total recovery being obtained at 3_50.

5.3.11 Cumulative Nickel Recoveries vs Cumulative Water Recoveries

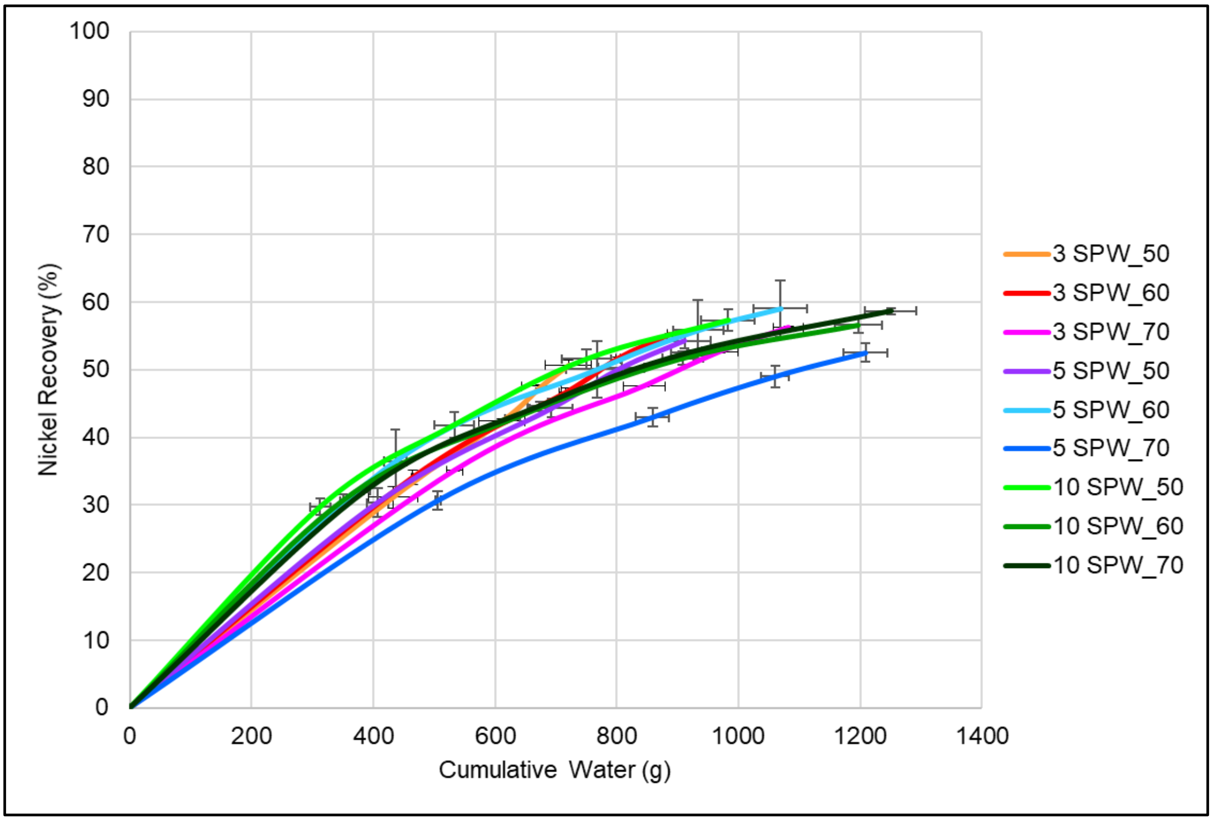

Figure 60 - Graph showing the cumulative nickel recoveries vs the cumulative water recoveries for three frother dosages and three ionic strengths using Senfroth 580

Figure 60 shows the cumulative nickel recoveries versus the cumulative water recoveries for three frother dosages and three ionic strengths using Senfroth 580. Higher ionic strengths and higher frother dosages appear to recover more water while recovering a similar amount of nickel as lower ionic strengths and lower frother dosages. 5_70 appears to be an outlier as it has the lowest nickel recovery per unit water. The total nickel recoveries vary from 50 - 60%.

5.3.12 Total Cumulative Water Recoveries and Total Cumulative Nickel Recoveries

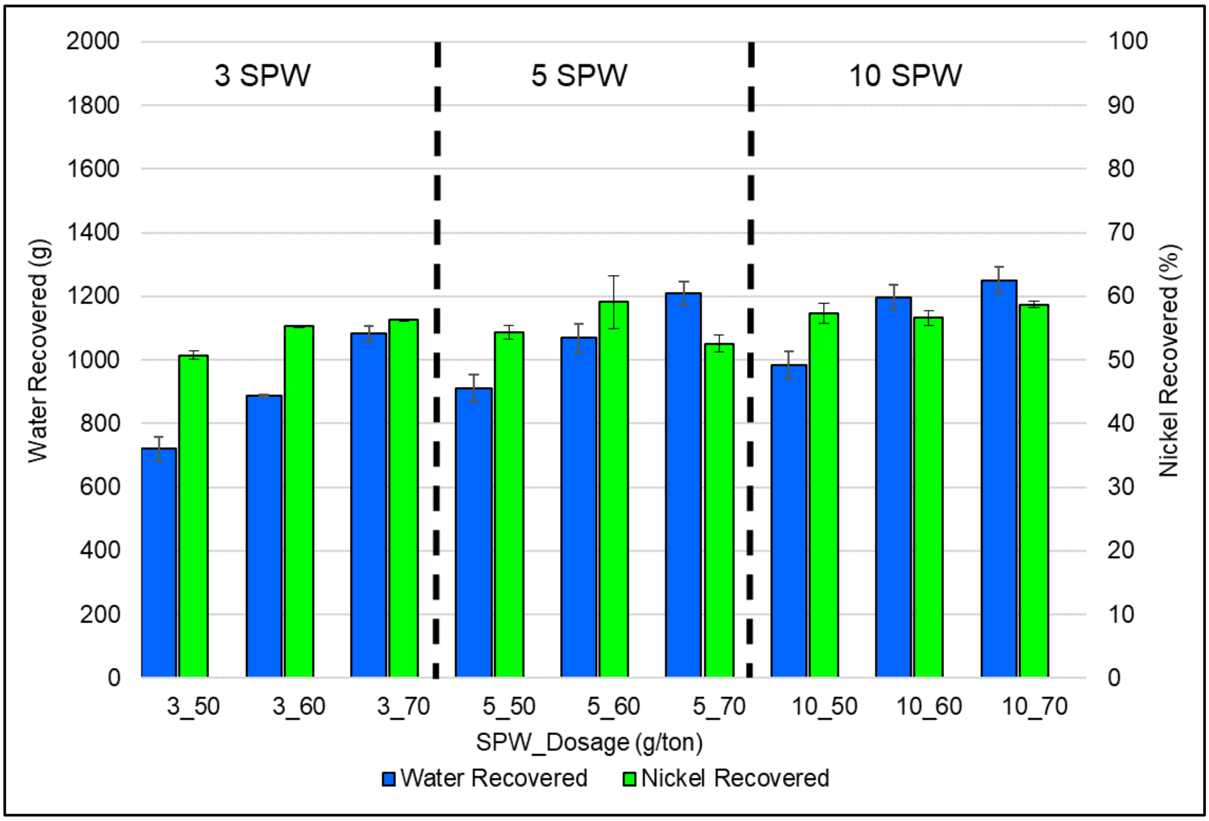

Figure 61 - Graph showing the total nickel recoveries and total water recoveries for three frother dosages and three ionic strengths using Senfroth 580

Figure 61 shows the total nickel recoveries and total water recoveries for three frother dosages and three ionic strengths using Senfroth 580. The blue bars represent the total water recoveries in grams on the left axis while the green bars represent the total nickel recoveries in percentages on the right axis.

The effects of frother dosage and ionic strength on water recovery have been discussed in Figure 53. Increasing the frother dosage at 3 SPW increases the total nickel recovery, at 5 SPW there is a maximum at 60 g/ton and at 10 SPW the frother dosage appears to not influence the total recovery of nickel. Increasing the ionic strength at 50 g/ton results in an increase in the total nickel recovery, at 60 g/ton it has no effect on the total nickel recovery and at 70 g/ton, the total nickel recovery has a minimum at 5 SPW with 10 SPW being higher than 3 SPW. The total nickel recoveries vary between 50 - 60% with the highest nickel recovery being obtained at 5_60 and the lowest at 3_50. The nickel recovery per unit water appears to decrease with an increase in either ionic strength or frother dosage.

When considering a simultaneous increase in ionic strength and decrease in frother dosage, Figure 61 shows that the total nickel recovery is unaffected when changing from 3_70 to 5_60 to 10_50 and from 3_60 to 5_50. There is a slight decrease in the total nickel recovery when changing from 3_70 to 5_50 and a slight increase when changing from 5_70 to 10_50 or from 5_70 to 10_60.

5.3.13 Cumulative Nickel Grades vs Cumulative Nickel Recoveries

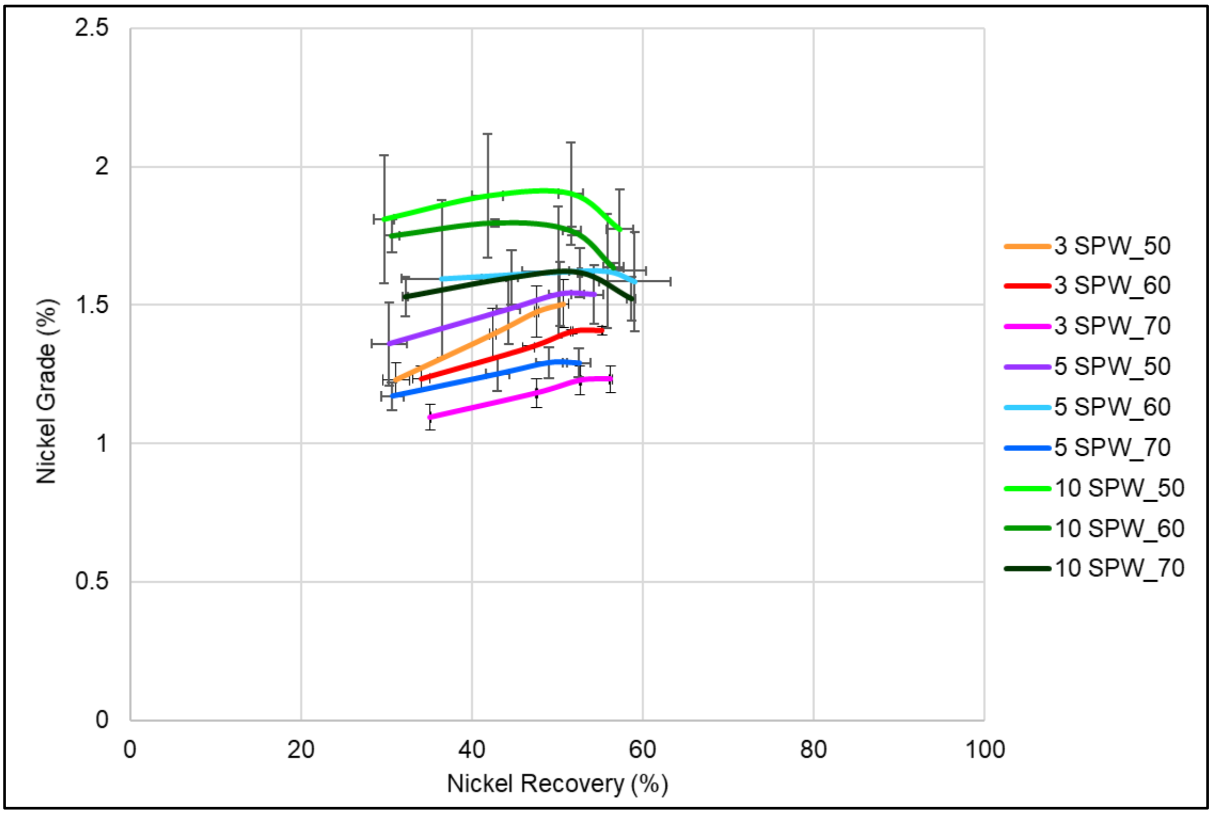

Figure 62 - Graph showing the cumulative nickel grades vs the cumulative nickel recoveries for three frother dosages and three ionic strengths using Senfroth 580

Figure 62 shows the cumulative nickel grades versus the cumulative nickel recoveries for three frother dosages and three ionic strengths using Senfroth 580. The grade appears to have a maximum at a recovery of approximately 53%. An increase in frother dosage appears to decrease the grade while an increase in ionic strength appears to increase the grade. The final grades vary between 1.2 - 1.8%.

5.3.14 Total Cumulative Nickel Recoveries and Final Cumulative Nickel Grades

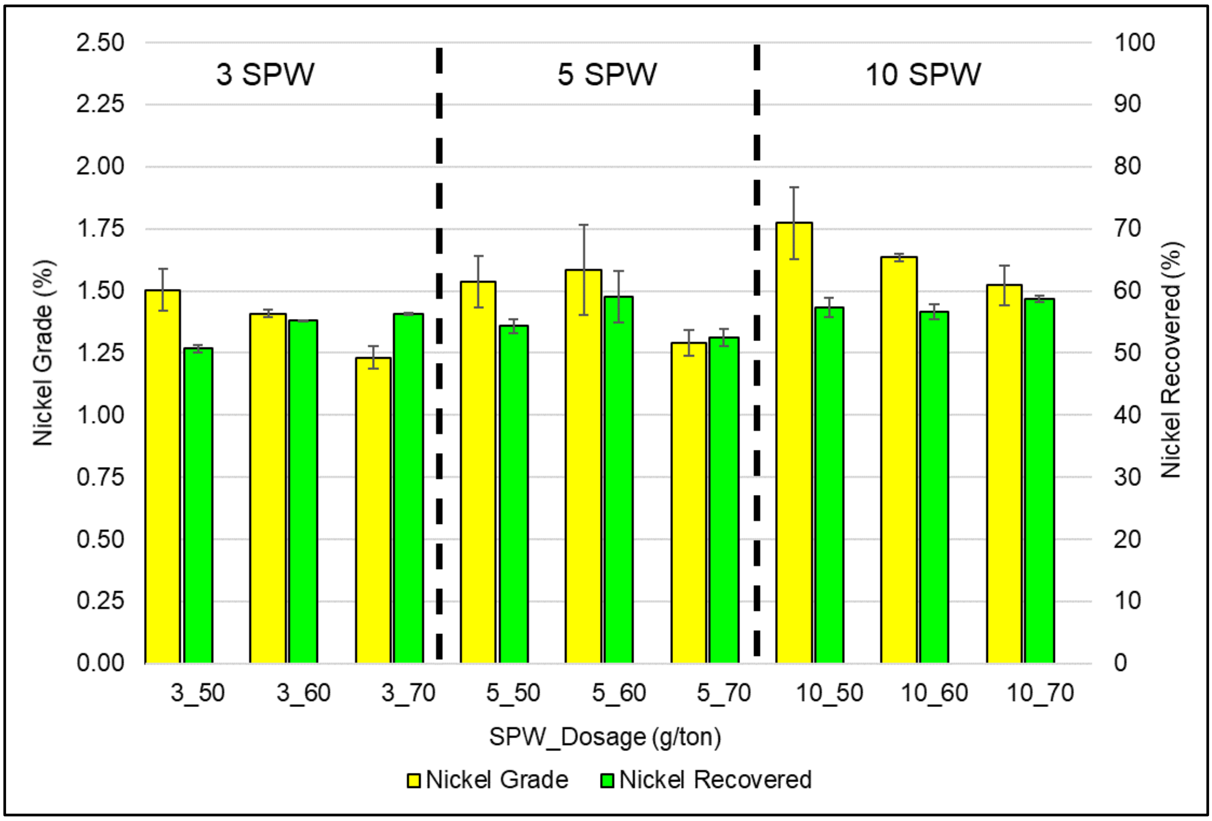

Figure 63 - Graph showing the total nickel recoveries and final nickel grades for three frother dosages and three ionic strengths using Senfroth 580

Figure 63 shows the total cumulative nickel recoveries and total cumulative nickel grades for three frother dosages and three ionic strengths using Senfroth 580. The green bars represent the total nickel recoveries on the right axis while the yellow bars represent the final nickel grades on the left axis.

The effects of frother dosage and ionic strength on the recovery of nickel have been discussed in Figure 61. Increasing the frother dosage at constant ionic strength does not affect the final grade from 50 g/ton to 60 g/ton but decreases the final grade from 60 g/ton to 70 g/ton. Increasing the ionic strength at 50 g/ton or 70 g/ton causes the final grade to remain the same from 3 SPW to 5 SPW but increase from 60 g/ton to 70 g/ton while at 60 g/ton, increasing the ionic strength increases the final grade from 3 SPW to 5 SPW but does not affect the final grade from 5 SPW to 10 SPW. The highest final grades are obtained at 10_50 and 5_60 and the lowest at 3_70 and 5_70 with the final grades varying from 1.2 - 1.8%.

When considering a simultaneous increase in ionic strength and decrease in frother dosage, the final grade increases from 3_70 to 5_60 and then remains constant from 5_60 to 10_50. The final grade also increases from 3_60 to 5_50 but stays the same from 5_70 to 10_60. Comparing 3_70 versus 5_50 and 5_70 versus 10_50 results in a substantial increase in the final grade as the ionic strength increases.

5.4 Statistical Modelling

As explained earlier, all the terms were initially chosen for graphical modelling. Anova assigned each term a p-value which was then described as significant or not significant. For a 95% confidence interval, if the p-value was less than 0.05 then it indicated that the model term was significant. The p-values were not recorded in the following sections, but the significant terms were noted. Any non-significant terms were removed along with their hierarchical components. For each response, the significant factors have been listed along with the final model equation/s given by Anova and the accompanying model graphs. Frother type, frother dosage and ionic strength are referred to as **FT**, **FD** and **IS** in the models.

5.4.1 Water Recovery

Significant factors: **FD** and **IS**
Terms used in the model: **FD**, **IS** and **FD*****IS**

Resulting model

Water recovery = - 336.35 + 18.83***FD** + 73.97***IS** - 0.41***FD*****IS**

The 3D surface graphs can be seen in Figures 64, 65 and 66 below. The model is the same for each graph but changing the frother type shows which actual data points lie outside the model. Figures 64, 65 and 66 all show that an increase in ionic strength and/or an increase in frother dosage increases the amount of water recovered. The combined effect of increasing both ionic strength and frother dosage gives a higher water recovery than that of each factor on its own. The highest amount of water is recovered when both ionic strength and frother dosage are high while the lowest amount of water is recovered when they are both low.

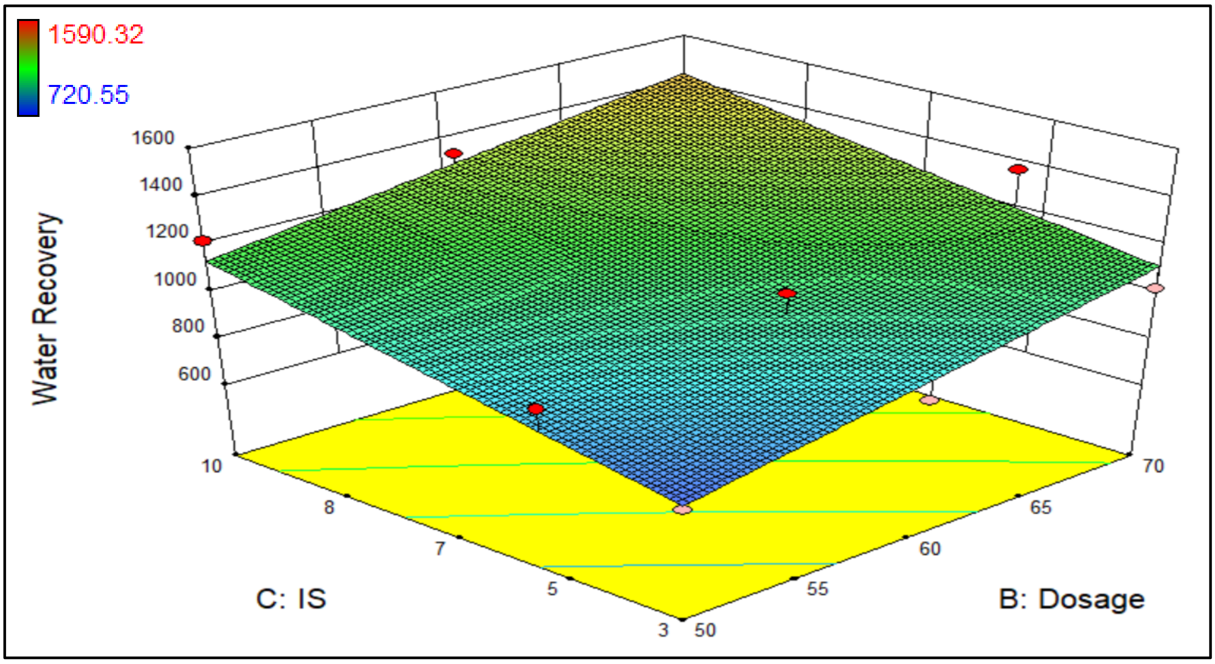

Figure 64 - 3D surface graph showing the effects of FD and IS on water recovery for Senfroth 200

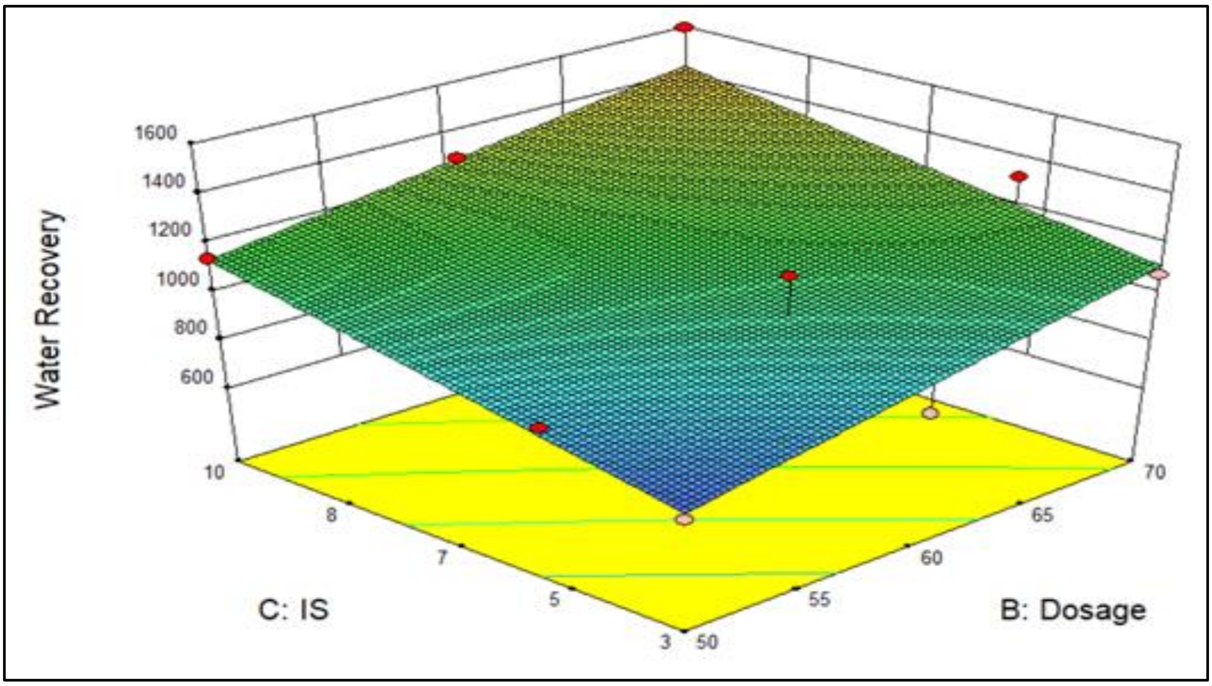

Figure 65 - 3D surface graph showing the effects of FD and IS on water recovery for Senfroth 516

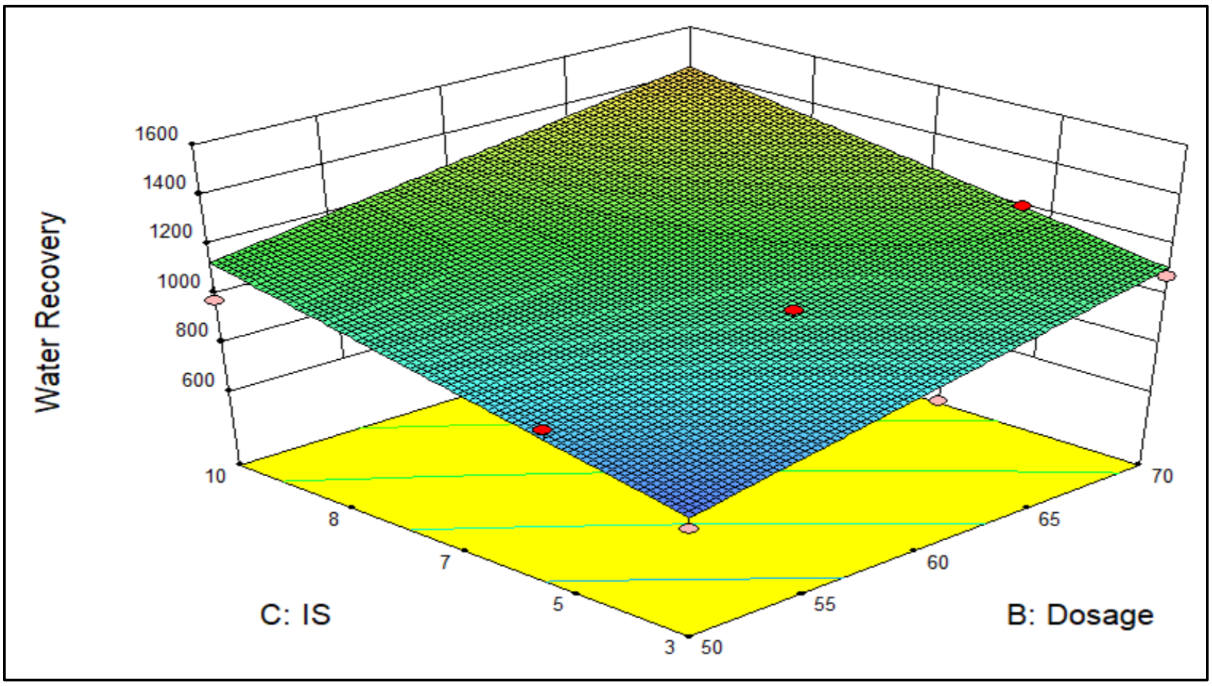

Figure 66 - 3D surface graph showing the effects of FD and IS on water recovery for Senfroth 580

5.4.2 Solids Recovery

Significant factors: **FT**, **FD** and **IS**
Terms used in the model: **FT**, **FD**, **IS**, **FT*****FD**, **FT*****IS**, **FD*****IS** and **FT*****FD*****IS**

<u>Resulting models</u>

For Senfroth 200: solids recovery = 16.59 + 0.72***FD** + 3.26***IS** - 0.04***FD*****IS**
For Senfroth 516: solids recovery = 22.13 + 0.57***FD** + 0.39***IS** + 0.02***FD*****IS**
For Senfroth 580: solids recovery= 10.48 + 1.02***FD** + 0.94***IS** - 0.02***FD*****IS**

Figure 67 shows that the solids recovery increases slightly with an increase in either frother dosage or ionic strength. The highest amount of solids recovered occurs when both frother dosage and ionic strength are high while the lowest amount of solids recovered occurs when both frother dosage and ionic strength are low.

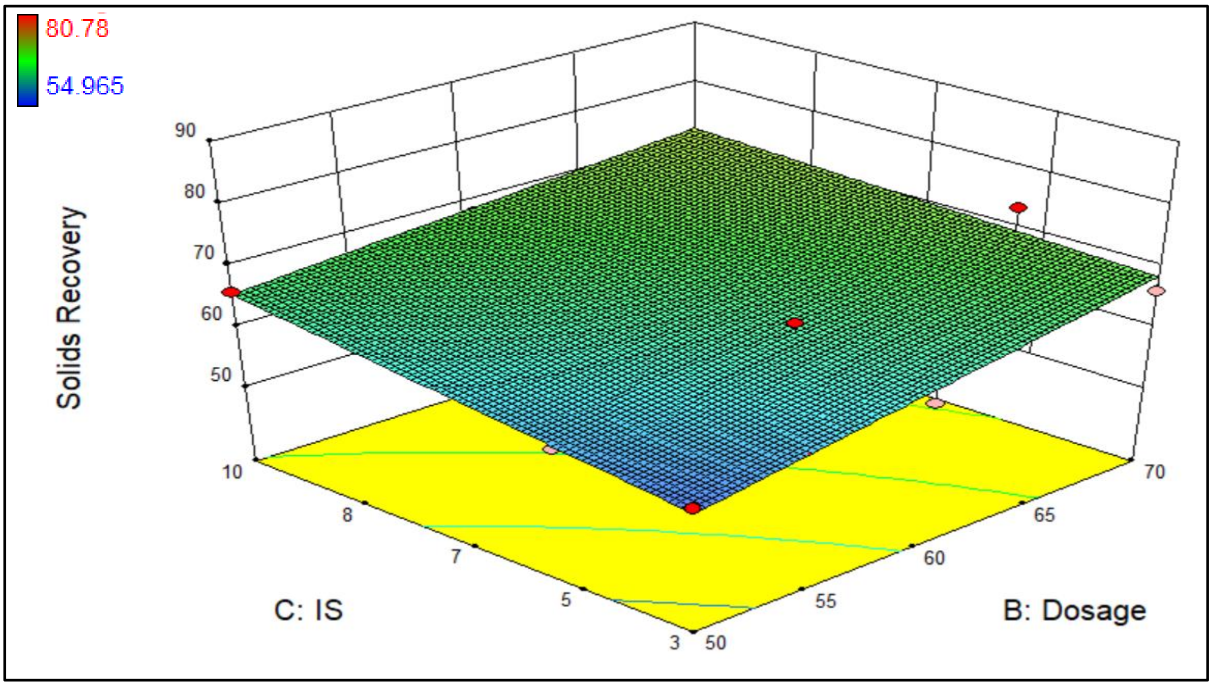

Figure 67 - 3D surface graph showing the effects of FD and IS on solids recovery for Senfroth 200

Figure 68 shows the same trend as Figure 67 however the change in solids recovery due to a change in frother dosage or ionic strength is much greater which shows that they have a greater impact when using Senfroth 516 compared to Senfroth 200.

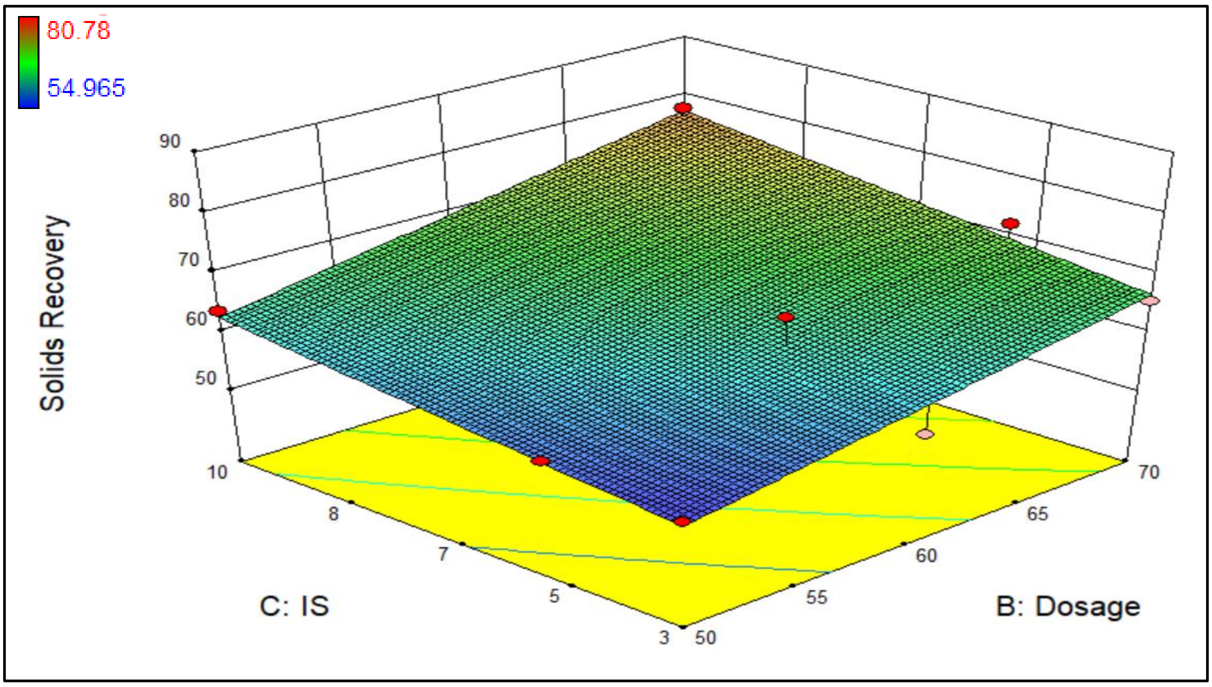

Figure 68 - 3D surface graph showing the effects of FD and IS on solids recovery for Senfroth 516

Figure 69 shows that increasing ionic strength appears to have little to no influence on the recovery of solids while increasing the frother dosage results in a significant increase in solids recovery. Increasing the frother dosage at a low ionic strength results in a larger increase in solids recovery than at a high ionic strength. The amount of solids recovered is highest at a high frother dosage and low ionic strength and lowest at a low frother dosage and high ionic strength.

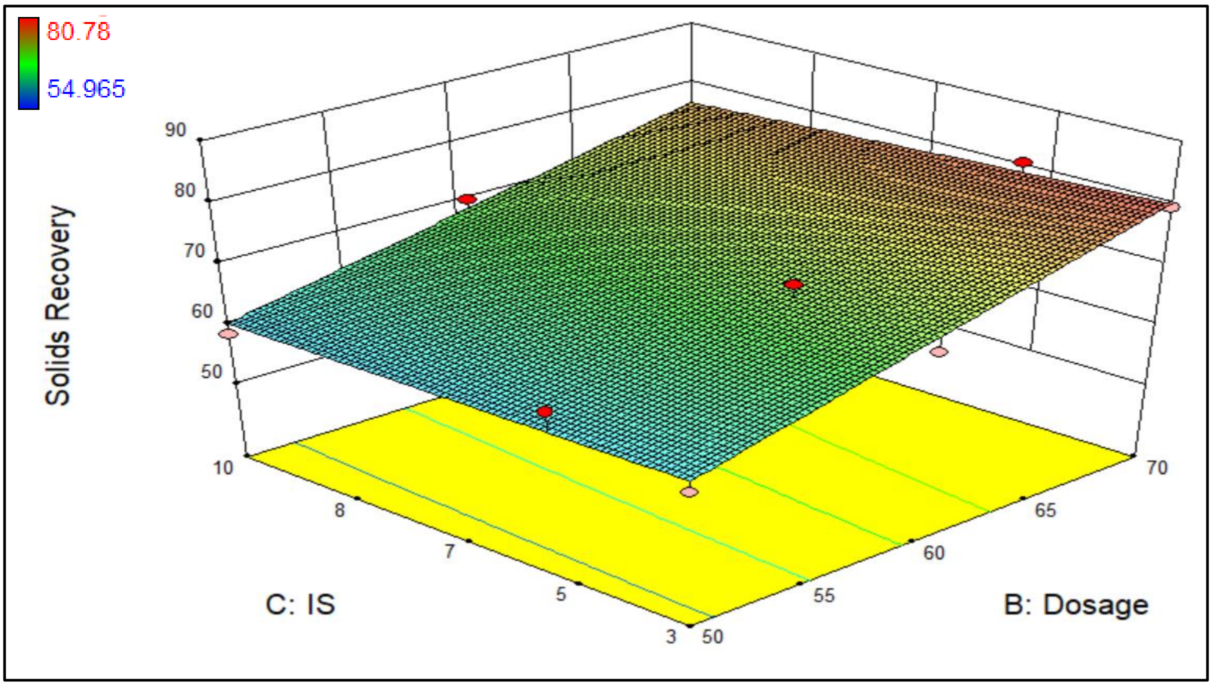

Figure 69 - 3D surface graph showing the effects of FD and IS on solids recovery for Senfroth 580

5.4.3 Copper Recovery

None of the factors were considered as significant for copper recovery.

5.4.4 Copper Grade

Significant factors: **FT** and **FD**
Terms used in the model: **FT** and **FD**

<u>Resulting models</u>

For Senfroth 200: copper grade = 4.10 - 0.02***FD**
For Senfroth 516: copper grade = 4.41 - 0.02***FD**
For Senfroth 580: copper grade = 4.50 - 0.03***FD**

Since there is only one nominal factor, a 2D graph consisting of all three frother types was plotted. Figure 70 shows that an increase in frother dosage for all frother types decreases the copper grade. Senfroth 200 appears to have the least effect on copper grade when increasing the frother dosage while Senfroth 580 appears to have the strongest effect. The difference in the grade of copper obtained between the three frother types is more significant at a higher dosage than at a lower dosage. The highest nickel grade is obtained at a low frother dosage using either Senfroth 200 or Senfroth 516.

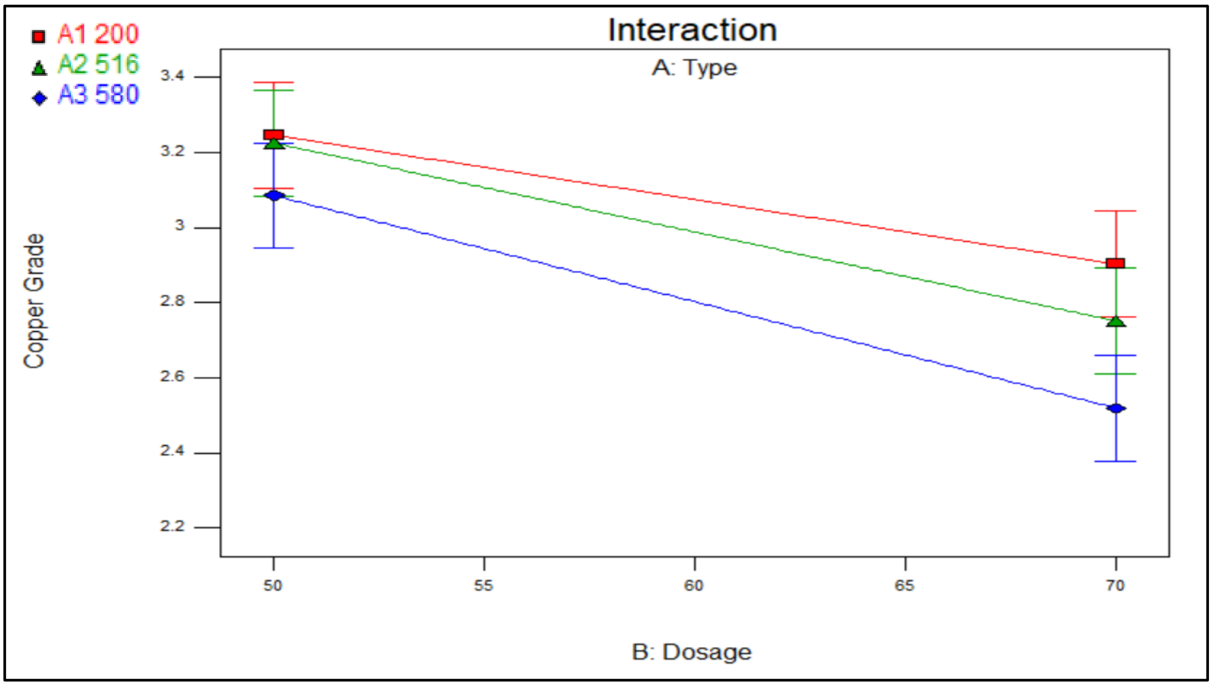

Figure 70 - 2D linear graph showing the effects of FT and FD on copper grade for Senfroth 200, 516 and 580

5.4.5 Nickel Recovery

Significant factors: **FT** and **FD**
Terms used in the model: **FT** and **FD**

Resulting models
For Senfroth 200: copper grade = 52.18 + 0.09***FD**
For Senfroth 516: copper grade = 44.88 + 0.19***FD**
For Senfroth 580: copper grade = 50.51 + 0.09***FD**

Since there is only one nominal factor, a 2D graph consisting of all three frother types was plotted. Figure 71 shows that an increase in frother dosage for all frother types increases the nickel recovery. Senfroth 516 appears to have the strongest effect on nickel recovery when increasing the frother dosage. The highest nickel grade is obtained at a low frother dosage using either Senfroth 200 or Senfroth 516.

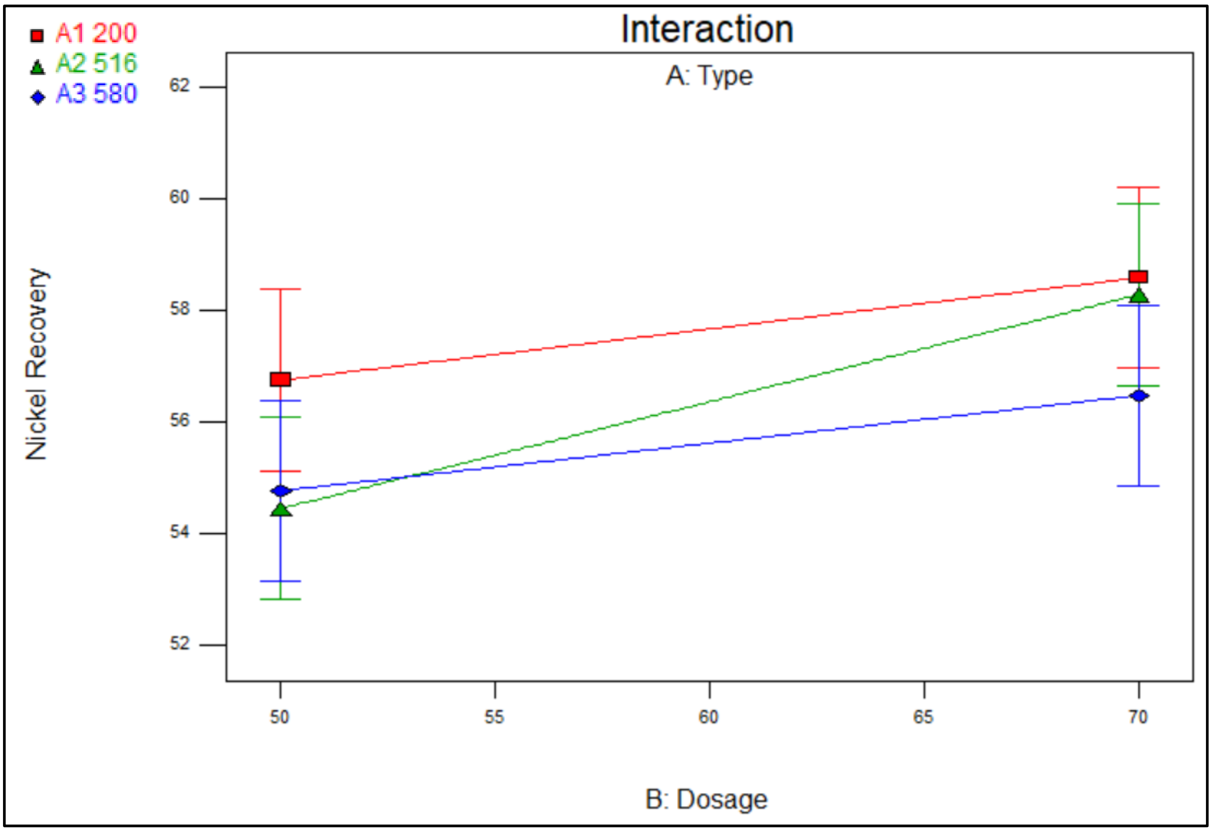

Figure 71 - 2D linear graph showing the effects of FT and FD on nickel recovery for Senfroth 200, 516 and 580

5.4.6 Nickel Grade

Significant factors: **FT** and **FD**
Terms used in the model: **FT**, **FD** and **FT***FD**

<u>Resulting models</u>

For Senfroth 200: nickel grade = 2.21 - 9.1x10^{-3}***FD**

For Senfroth 516: nickel grade = 2.29 - 0.01***FD**

For Senfroth 580: nickel grade = 2.27 - 0.01***FD**

Since there is only one nominal factor, a 2D graph consisting of all three frother types was plotted. Figure 72 shows that an increase in frother dosage for all frother types decreases the nickel grade. There appears to be little to no difference between the frother types in terms of the strength of their influence on the nickel grade as the three gradients are approximately the same. The difference in the grade of nickel obtained between the three frother types is slightly more significant at a higher dosage than at a lower dosage. The highest nickel grade is obtained at a low frother dosage using Senfroth 200.

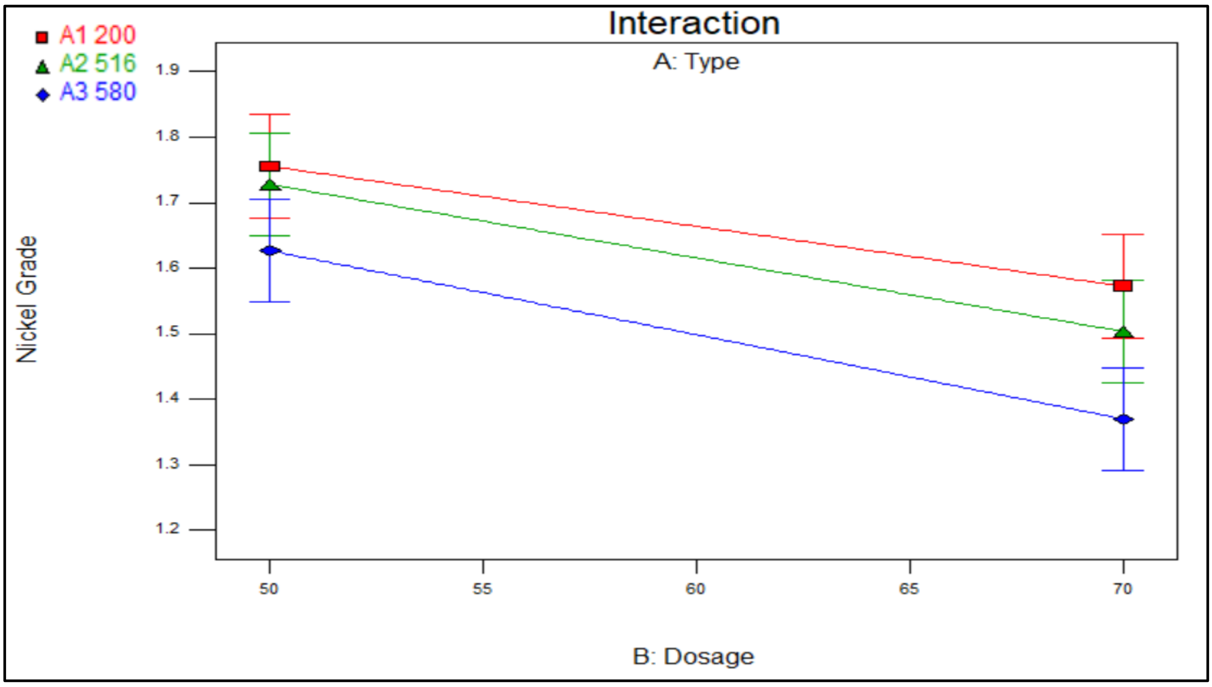

Figure 72 - 2D linear graph showing the effects of ft and FD on nickel grade for Senfroth 200, 516 and 580

6. Discussion

The objectives of this project were to investigate how changes in frother type, frother dosage and ionic strength affect the recovery and grade of the valuable minerals and to determine whether frother dosage can be managed under conditions of increased ionic strength while still maintaining flotation performance. Various tests were conducted as outlined in Section 4 and the results obtained from these tests will be discussed here in the form of answers to the key questions posed in Section 3.2.

6.1 How Does Changing the Frother Dosage Influence the Water, Solids, Copper and Nickel recoveries and the Copper and Nickel grades?

The results for all three frother types found that as the frother dosage increases at a constant ionic strength, the recovery of water and solids increases (Figures 25, 39 and 53). This implies that the froth becomes more stable with an increase in frother dosage (Wiese, 2009; Corin, et al., 2011). This increase in froth stability is likely due to the frother adsorbing at the air-water interface where it reduces the surface tension, reduces coalescence and stabilizes the bubbles (Wills & Finch, 2016; Aldrich & Feng, 2000; Bulatovic, 2007; Cho & Laskowski, 2002). The formation of smaller, more stable bubbles resulting from the reduction in coalescence, increases the surface area available for particle attachment which improves the solids recoveries (Hewitt, et al., 1994). A decrease in the rate of recovery of solids with time, as seen in Figures 23, 37 and 51, is expected since the amount of solids available for collection in the pulp phase decreases as more particles in the froth are collected.

Considering that more solids are reporting to the froth with increasing frother dosage, one would also expect the recoveries of copper and nickel to increase, however this is not the case. An increase in frother dosage tends to result in no change in the copper recovery and a slight increase in the nickel recovery with a simultaneous decrease in the grades of both. The nickel trends tend to agree with Wiese, et al. (2010), Wiese & Harris (2012) and Corin & Wiese (2014), however they found that the copper recoveries increased slightly with an increase in frother dosage while the copper recoveries in this study remained fairly constant.

The trends in the copper and nickel recoveries could be due to almost all the available copper and most of the nickel being recovered within the allotted time regardless of the frother dosage. This could be because chalcopyrite (represented by the copper recovery) is considered to be a fast-floating mineral while pentlandite (represented by the nickel recovery) is considered to be a slower floating mineral (Corin, et al., 2011). Figure 18 also shows that over 80% of the copper-sulphide and nickel-sulphide minerals are liberated or high grade middlings while the other less than 20% are locked or low grade middlings which essentially leaves approximately 80% of the copper and nickel available for collection. The final copper recoveries (Figures 30, 44 and 58) which tend to 80%, agree with this however the final nickel recoveries (Figures 35, 49 and 63) do not. This is because the QEMSCAN analysis for nickel only considered nickel-sulphides while the ICP-OES assay accounts for all nickel in the sample. For the Kevitsa ore, 10% of the copper and 20% of the nickel is contained within non-sulphide minerals (Musuku, et al., 2016). This reduces the available nickel to approximately 64% which agrees with the final nickel recoveries (Figures 35, 49 and 63).

The small changes in the recoveries of copper and nickel and the simultaneous decrease in their grades, along with the observation that the solids recoveries increase considerably with an increase in frother dosage, implies that the increase in the solids recoveries is due to an increase in gangue recovery. This has been seen by other researchers (Wiese & Harris, 2012; Corin & Wiese, 2014) and could be because more stable froths tend to increase gangue recovery (Triffett & Cilliers, 2004) since entrained gangue recovery is known to follow water recovery (Engelbrecht & Woodburn, 1975; Zheng, et al., 2006a,b; Neethling & Cilliers, 2002) due to particles being carried up to the froth with the water and becoming trapped in the Plateau borders thus hindering water and particle drainage (Kronberg, et al., 2014). The increased gangue is also likely due to entrainment and as a result of an increase in bubble surface area available for particle attachment (Hewitt, et al., 1994) which results in greater solids recoveries, a large portion of which is gangue material.

The statistical analysis done in Section 5.4 agrees with the above observations by showing that the recoveries of both water and solids increase and the grades of both copper and nickel decrease with an increase in frother dosage, while the copper and nickel recoveries are hardly affected, if at all.

6.2 How Does Changing the Ionic Strength Influence the Water, Solids, Copper and Nickel Recoveries and the Copper and Nickel grades?

The results for all three frother types found that as the ionic strength increases at a constant frother dosage, the recovery of both water and solids increases (Figures 25 and 39) except for Senfroth 580 where the ionic strength appears to not affect the solids recovery (Figure 53). This could be due to unknown interactions between the ions and the components of Senfroth 580. The increase in the water and solids recoveries implies that the froth becomes more stable with an increase in ionic strength (Wiese, 2009; Corin, et al., 2011). This could be because the presence of ions influences the surface tension (Quinn, et al., 2007; Iwasaki, et al., 1980; Viviers, 1979), and inhibits bubble coalescence which results in smaller, more stable bubbles and therefore a more stable froth (Hewitt, et al., 1994; Marruci & Nicodemo, 1967; Craig, et al., 1993; Zieminski & Whittemore, 1971; Laskowski, et al., 2003). The increased solids recoveries could also be due to ion-induced compression of the electrical double layers which allows for better particle-bubble attachment (Kurniawan, et al., 2011; Farrokhpay & Zanin, 2012; Scamehorn, 1989; Kronberg, et al., 2014), or to more particles becoming trapped in the Plateau borders since the presence of ions slows inter-bubble drainage (Manono, et al., 2013).

Despite the increase in the solids recoveries, the copper recoveries (Figures 30, 44 and 58) experience no change with an increase in ionic strength which is likely due to liberation constraints mentioned in Section 6.1. This finding agrees with literature (Corin, et al., 2011; Manono, et al., 2012; Manono, et al., 2018; Corin & Wiese, 2014). The statistical analysis also shows that neither ionic strength nor frother dosage were considered to be significant factors in the recovery of copper.

Figures 35, 49 and 63 show that the nickel recoveries experience slight changes with an increase in ionic strength however the statistical analysis shows that, overall, ionic strength was not considered to be a significant factor in the recovery of nickel. The slight changes shown in Figures 35, 49 and 63 also did not appear to form any consistent trends therefore this, accompanied by the statistical analysis, lends itself to the conclusion that ionic strength and nickel recovery are not directly related. This also agrees with literature (Corin, et al., 2011; Manono, et al., 2012; Manono, et al., 2018). Any slight changes in the nickel recoveries could be related to activation of the nickel-gangue composites (Chandra & Gerson, 2009; Finkelstein, 1997; Lui, et al., 2013) since some of the nickel is contained in non-liberated pentlandite (Musuku, et al., 2016). The substantial increase in the froth stability and solids recoveries with no accompanying large increases in the copper or nickel recoveries, again suggests that the extra solids recovered are due to gangue (Triffett & Cilliers, 2004). This is further backed up by the increased water recoveries which imply that the gangue increased since entrained gangue, some of which may contain nickel-composites, tends to follow the water recoveries recovery (Engelbrecht & Woodburn, 1975; Zheng, et al., 2006a,b; Neethling & Cilliers, 2002).

The grades of both copper and nickel (Figures 30, 35, 44, 49, 58 and 63) exhibit subtle changes that mimic the subtle changes in the copper and nickel recoveries. This is expected since small increases or decreases in the recoveries should result in the same changes in the grade. The nickel grades appear to decrease and then remain the same or increase with a change from 3 SPW to 5 SPW to 10 SPW. This could be due to nickel-gangue composites being recovered at higher ionic strengths (Chandra & Gerson, 2009; Finkelstein, 1997; Lui, et al., 2013). However, the changes in both copper and nickel are not significant enough to be able to confidently relate changes in ionic strength to changes in grade. This, accompanied by the statistical analysis in Section 5.4 whereby ionic strength was considered an insignificant factor with regards to the grades of copper and nickel, implies that any slight changes in grade are not directly related to changes in ionic strength. This disagrees with literature (Corin, et al., 2011; Manono, et al., 2012; Corin & Wiese, 2014; Manono, et al., 2018) since the grades of copper and nickel have usually been found to decrease with an increase in ionic strength which is attributed to increased gangue recoveries.

6.3 How Does the Frother Type Influence the Water, Solids, Copper and Nickel recoveries and the Copper and Nickel grades?

The three frother types used for this work were Senfroth 200, Senfroth 516 and Senfroth 580 which are each composed of varying amounts of alcohol, polyethylene glycol and polypropyl glycol. The exact compositions are not known. Frother composition and molecular weight can influence the flotation performance (Pugh, 2000; Klimpel & Hansen, 1988; Klimpel & Isherwood, 1991; Bulatovic, 2007; Wiese & Harris, 2012) and therefore the three frother types are examined as to their effects on the recoveries of water, solids, copper and nickel and the grades of copper and nickel.

The frother type did not appear to affect the total water recoveries since the final values all ranged from 750g to 1400g (Figures 25, 39 and 53) except for 10_70 using Senfroth 516 which had an outlying higher recovery of approximately 1600g. This agrees with the statistical analysis (Figures 64, 65 and 66) which only considered the final cumulative water recoveries and determined frother type not to be a significant factor. The differences between the frother types is more noticeable when looking at the rate at which water was recovered (Figures 22, 36 and 50) because Senfroth 580 had much faster initial rates after which the water recoveries slowed down, while the other two had slower initial rates but the rates remained fairly consistent. This shows a greater initial water pull for Senfroth 580 meaning that concentrate 1 and 2 would recover more water than when the other two frothers are used.

The frother type appeared to influence the solids recoveries with Senfroth 580 (Figure 53) pulling slightly more total mass than Senfroth 200 and Senfroth 516 (Figures 25 and 39). The statistical analysis agrees with this in that frother type was considered to be a significant factor in the recovery of solids. It also shows that while both ionic strength and frother dosages were influential in the solids recoveries for Senfroth 200 (Figure 67) and slightly more so for Senfroth 516 (Figure 68), only frother dosage appeared to be influential when using Senfroth 580 (Figure 69) and its influence was considerably more than when compared to the other two frothers. This could be due to an aspect of Senfroth 580's composition interacting with the ions in the process water. As with the water recoveries, using Senfroth 580 resulted in initial solids recovery rates that were considerably higher and then slowed down (Figure 51), while the other frother types produced slower initial rates which remained more consistent (Figures 23 and 37). This shows that Senfroth 580 has greater mass pull abilities and that the majority of the solids are collected in concentrate 1 and 2.

With regards to copper, both the graphs (Figures 30, 44 and 58) and the statistical analysis (Section 5.4.3 and 5.4.4) showed that the recoveries were unaffected by a change in frother type, but the grades were. The grades obtained decreased from Senfroth 200 to Senfroth 516 to Senfroth 580. This is shown more clearly in Figure 70 with the differences becoming greater with an increase in frother dosage.

The nickel recoveries, however, are shown to be influenced by the frother type as seen in Figure 71. Senfroth 200 appears to recover more nickel than Senfroth 580 but the increase in the recovery of nickel as a result of an increase in frother dosage is the same for both. Senfroth 516 appears to have a greater influence on nickel recovery causing it to experience a larger increase with an increase in frother dosage when compared to Senfroth 200 and Senfroth 580. This means that at a low frother dosage, Senfroth 200 gives better nickel recoveries compared to Senfroth 516 and Senfroth 580, which both give similar, lower recoveries. However, at a high frother dosage, both Senfroth 200 and Senfroth 516 give similar recoveries that are higher than when using Senfroth 580. The three frother types all appear to increase the nickel grades to approximately the same extent with an increase in frother dosage (Figure 72), but Senfroth 200 gives the highest grades while Senfroth 580 results in the lowest grades.

6.4 How Does a Simultaneous Change in Both Frother Dosage and Ionic Strength Influence the Water, Solids, Copper and Nickel Recoveries and the Copper and Nickel Grades and what are the On-Site Implications?

Both ionic strength and frother dosage appear to stabilize the froth by inhibiting bubble coalescence and stabilising the bubbles (Manono, et al., 2012; Harris, 1982; Quinn, et al., 2007; Iwasaki, et al., 1980; Viviers, 1979; Hewitt, et al., 1994; Marruci & Nicodemo, 1967; Craig, et al., 1993; Zieminski & Whittemore, 1971; Laskowski, et al., 2003; Wills & Finch, 2016; Aldrich & Feng, 2000; Bulatovic, 2007; Cho & Laskowski, 2002). It has also been postulated that the ability of the frother to decrease surface tension increases in more electrolytic solutions (Quinn, et al., 2007; Iwasaki, et al., 1980; Craig, et al., 1993; Manono, et al., 2018; Kurniawan, et al., 2011; Peng & Seaman, 2011; Finch, et al., 2008). Therefore it is important to understand how frothers act under conditions of increased ionic strength as this will impact plant procedures in operations where water is recycled. The simultaneous action of increasing the ionic strength and decreasing the frother dosage can be examined using the statistical analysis done in Section 5.4.

Figures 64, 65 and 66 show that ionic strength and dosage are very similar in their level of influence on the water recovery however ionic strength is slightly more influential than frother dosage. This implies that increasing the ionic strength and decreasing the frother dosage by the same amount will result in a small increase in the water recovery which agrees with Figures 25, 39 and 53. The highest and lowest water recoveries are obtained when both ionic strength and frother dosage are high and low respectively as seen in Figures 64, 65 and 66.

Figures 67, 68 and 69 show that frother dosage is more influential than ionic strength in the recovery of solids which implies that increasing the ionic strength and decreasing the frother dosage by the same amount will result in a decrease in the solids recovery which agrees with Figures 25, 39 and 53. The highest solids recoveries are obtained at a high ionic strength and high frother dosage for Senfroth 200 and Senfroth 516 while the lowest solids recoveries are obtained at a low ionic strength and low frother dosage (Figures 67 and 68). For Senfroth 580, the highest solids recoveries are obtained at high frother dosages with ionic strength appearing not to have much influence (Figure 69).

Since neither frother dosage nor ionic strength influence the copper recovery, changing either of these variables will have no impact on the copper recovery. Only frother dosage is influential in the recovery of nickel (Figure 71) and therefore decreasing the frother dosage and increasing the ionic strength will decrease the nickel recovery with a larger decrease for Senfroth 516 than the other two frothers. The grades of both copper and nickel either increase or remain the same with an increase in ionic strength and a decrease in frother dosage because, as shown in Figures 70 and 72, only the frother dosage influences the grades.

Overall, a simultaneous increase in ionic strength and decrease in frother dosage by the same amount will increase the water recoveries and decrease the solids recoveries. It will also slightly decrease the nickel recoveries while having no effect on the copper recoveries. The grades of both will either increase or remain the same. This makes it important to manage frother dosage under conditions of increased ionic strength in order to maximize flotation performance. This would depend on the ore mineralogy, requirements of the plant with regards to the recoveries and grades of the valuable minerals, and the amount of water required by downstream processes. This means that, depending on the plant, it may be possible for frother usage to be reduced in processes where water is heavily recycled.

7. Conclusions

The objectives of this study were to understand how frother dosage, type and ionic strength influenced flotation performance, both individually and simultaneously, in order to determine whether frother dosage can be managed under conditions of increased ionic strength while still maintaining flotation performance. Considering that frothers and ionic strength play similar roles in stabilising the froth during flotation, knowledge of how these two variables interact could prove beneficial to plant performance. If it can be established that frother dosage can be decreased under conditions of increased ionic strength, while still maintaining flotation performance, then this could result in a decrease in the quantity and frother spend required for flotation as well as allow the mining industry to recycle more of their water without the need for extensive cleaning which in turn will reduce the amount of fresh water required for flotation.

7.1 Individual Effects of Frother Dosage, Ionic Strength and Frother Type

Increasing the frother dosage resulted in:

- An increase in the water and solids recoveries
- No change in the copper recoveries and a slight increase in the nickel recoveries
- A decrease in both the copper and nickel grades
- An increase in the amount of gangue recovered

Increasing the ionic strength resulted in:

- An increase in the water and solids recoveries
- No change in the copper and nickel recoveries
- No significant change in the copper and nickel grades

In changing the frother type, it was found that:

- Frother type did not affect the final water recoveries but it affected the final solids recoveries with Senfroth 580 pulling slightly more solids.
- For both the water and solids recoveries, the use of Senfroth 580 resulted in initially faster rates which slowed down, when compared to Senfroth 200 and Senfroth 516 whose initial rates were slower but remained more consistent.
- The copper recoveries were unaffected by a change in frother type.
- Senfroth 200 recovers more nickel than Senfroth 580 but the increase in nickel recovery as a result of an increase in frother dosage is the same for both. Senfroth 516 has the greatest influence on nickel recovery causing it to experience a larger increase with an increase in frother dosage when compared to Senfroth 200 and Senfroth 580.
- The use of Senfroth 200 resulted in the highest copper and nickel grades followed by Senfroth 516. The difference in the copper grades between the three frother types increased with an increase in frother dosage while all three frother types increased the nickel grades to the same extent with an increase in frother dosage.

7.2 Simultaneous Effects of Frother Dosage and Ionic Strength

Since the main aim of this study was to understand how frother dosage and ionic strength interact, both variables were investigated simultaneously. It appears that frother dosage and ionic strength can be used interchangeably due to their froth stabilising abilities, however:

- Ionic strength was slightly more influential than frother dosage in the recovery of water. The highest and lowest water recoveries were obtained when both ionic strength and frother dosage are high and low respectively.
- Frother dosage was more influential than ionic strength in the recovery of solids, particularly in the case of Senfroth 580. The highest and lowest solids recoveries were obtained when both ionic strength and frother dosage were high and low respectively for Senfroth 200 and Senfroth 516, while for Senfroth 580, the highest and lowest solids recoveries were obtained at a high and low frother dosage respectively, regardless of the ionic strength.
- Ionic strength was not considered to be an influential factor in either the recoveries or grades of copper and nickel.

Based on these observations, a simultaneous increase in ionic strength and decrease in frother dosage by the same amount will increase the water recoveries and decrease the solids recoveries. It will also slightly decrease the nickel recoveries while having no effect on the copper recoveries. The grades of both will either increase or remain the same.

7.3 Answers to the Hypotheses and Industrial Relevance

- A combination of high frother dosage and high ionic strength resulted in the most stable froth as indicated by the water and solids recoveries, but it did not improve the copper recovery, had very little impact on the nickel recovery, and decreased the grades of both copper and nickel due to increased gangue recoveries as a result of the more stable froth.

- The frother dosage can be decreased in operations where plant water is recycled but the amount by which the ionic strength of the water is allowed to increase, and the amount by which the frother dosage is decreased, need to be tailored to suit the needs of the plant with regards to water recovery and the recoveries and grades of the valuable minerals. This is because ionic strength and frother dosage have varying levels of influence as mentioned previously and therefore must be monitored.

Overall, managing the frother dosage under conditions of increased ionic strength could result in a decrease in the quantity and cost of frothers required for flotation. It may also allow the mining industry to recycle more of their water without the need for extensive cleaning which in turn will reduce the amount of fresh water required for flotation and reduce environmental discharge.

8. Recommendations

After considering the results of this study and the conclusions that were drawn, the following recommendations are made:

- Use different ore types for the same study and evaluate whether the observations of this study can be extended to other ores.

- Determine the composition of the frothers used.

- Consider the use of other frother types for the same study to determine the effects of frother composition on flotation performance.

- Consider the effect of other water components, such as organic and biological factors, on flotation performance.

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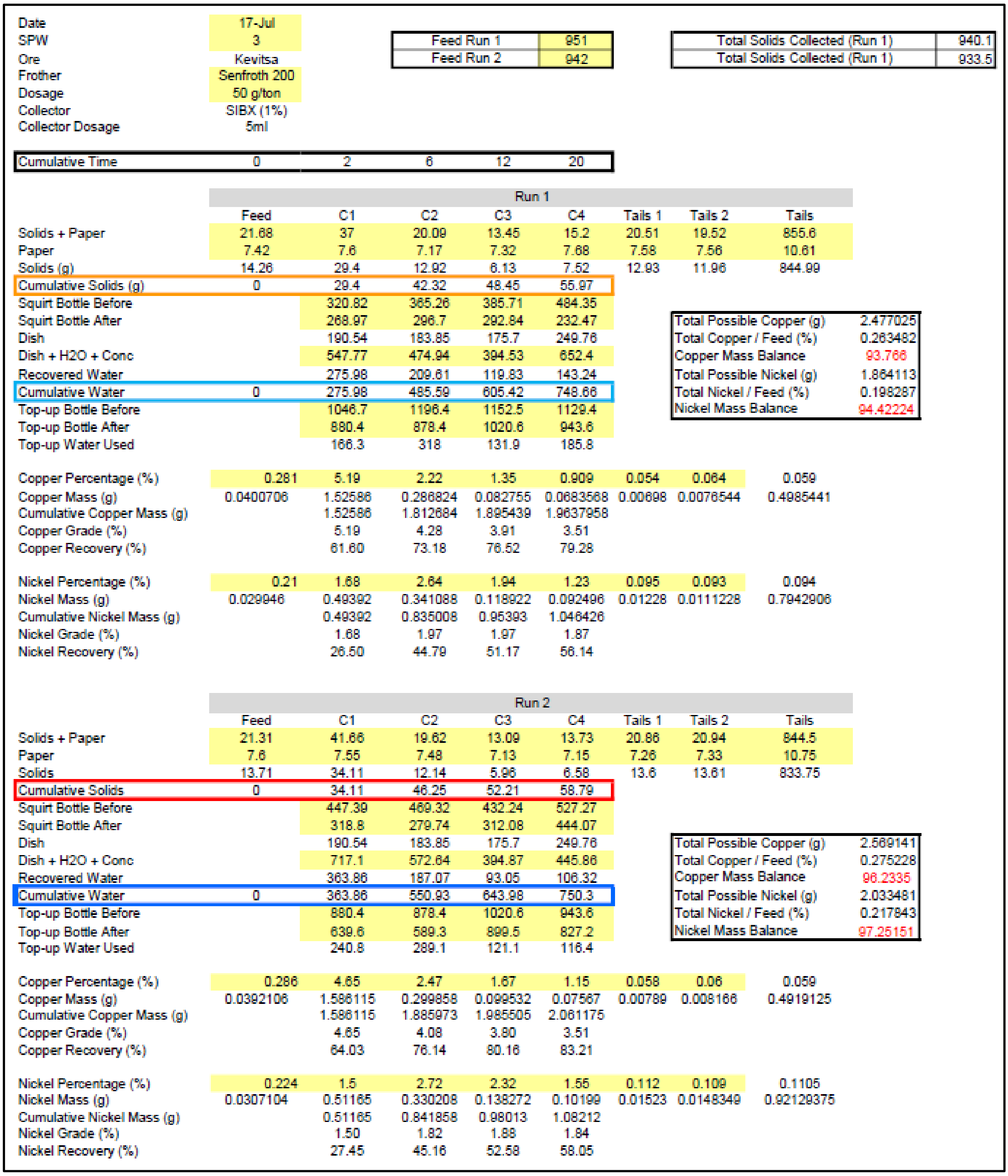
10. Appendices

10.1 Senfroth 200 Raw Data



Date	17-Jul
SPW	3
Ore	Kevitsa
Frother	Senfroth 200
Dosage	50 g/ton
Collector	SIBX (1%)
Collector Dosage	5ml

Feed Run 1	951
Feed Run 2	942

Total Solids Collected (Run 1)	940.1
Total Solids Collected (Run 1)	933.5

Cumulative Time	0	2	6	12	20

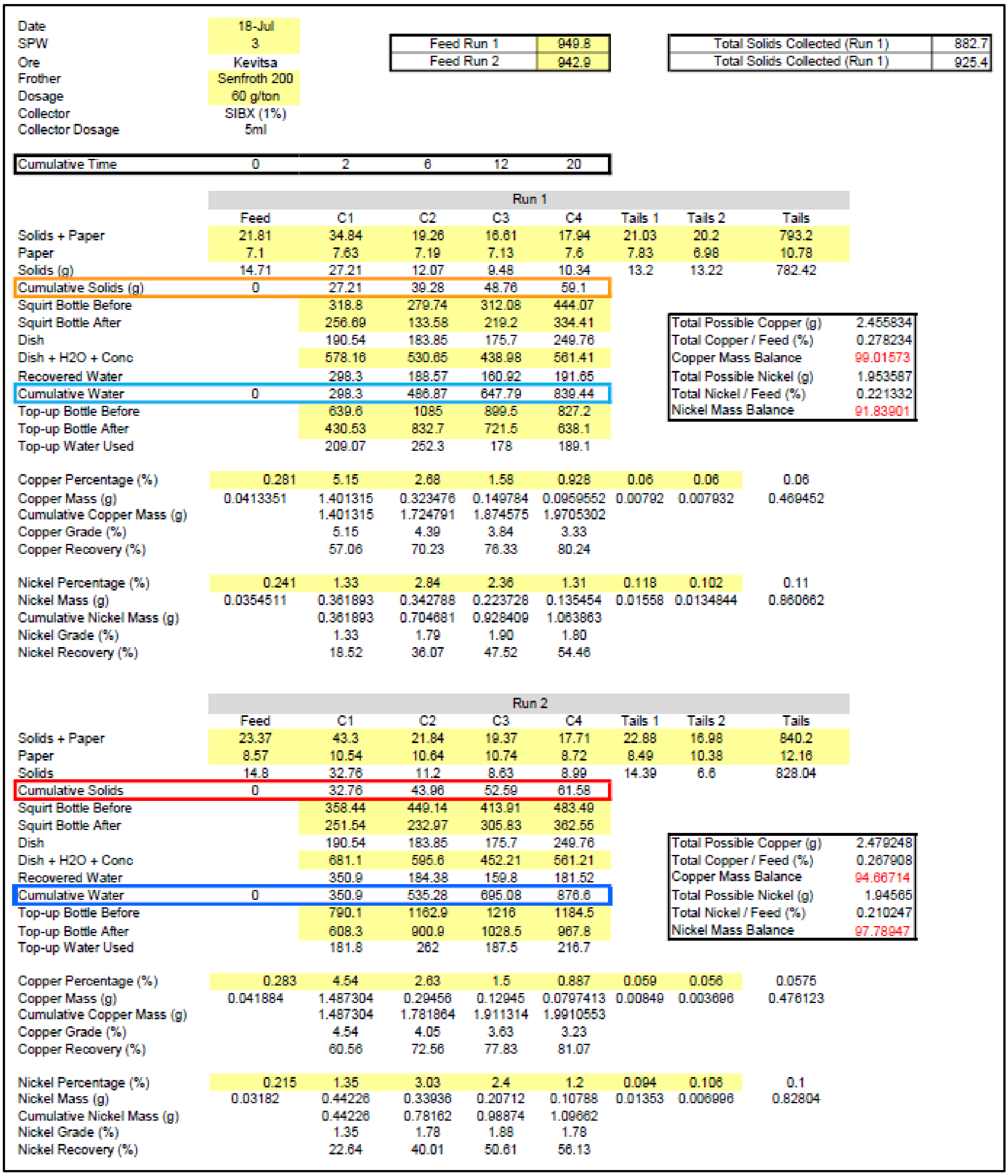
	Run 1							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	21.68	37	20.09	13.45	15.2	20.51	19.52	855.6
Paper	7.42	7.6	7.17	7.32	7.68	7.58	7.56	10.61
Solids (g)	14.26	29.4	12.92	6.13	7.52	12.93	11.96	844.99
Cumulative Solids (g)	0	29.4	42.32	48.45	55.97			
Squirt Bottle Before		320.82	365.26	385.71	484.35			
Squirt Bottle After		268.97	296.7	292.84	232.47			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		547.77	474.94	394.53	652.4			
Recovered Water		275.98	209.61	119.83	143.24			
Cumulative Water	0	275.98	485.59	605.42	748.66			
Top-up Bottle Before		1046.7	1196.4	1152.5	1129.4			
Top-up Bottle After		880.4	878.4	1020.6	943.6			
Top-up Water Used		166.3	318	131.9	185.8			
Copper Percentage (%)	0.281	5.19	2.22	1.35	0.909	0.054	0.064	0.059
Copper Mass (g)	0.0400706	1.52586	0.286824	0.082755	0.0683568	0.00698	0.0076544	0.4985441
Cumulative Copper Mass (g)		1.52586	1.812684	1.895439	1.9637958			
Copper Grade (%)		5.19	4.28	3.91	3.51			
Copper Recovery (%)		61.60	73.18	76.52	79.28			
Nickel Percentage (%)	0.21	1.68	2.64	1.94	1.23	0.095	0.093	0.094
Nickel Mass (g)	0.029946	0.49392	0.341088	0.118922	0.092496	0.01228	0.0111228	0.7942906
Cumulative Nickel Mass (g)		0.49392	0.835008	0.95393	1.046426			
Nickel Grade (%)		1.68	1.97	1.97	1.87			
Nickel Recovery (%)		26.50	44.79	51.17	56.14			

Total Possible Copper (g)	2.477025
Total Copper / Feed (%)	0.263482
Copper Mass Balance	93.766
Total Possible Nickel (g)	1.864113
Total Nickel / Feed (%)	0.198287
Nickel Mass Balance	94.42224

	Run 2							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	21.31	41.66	19.62	13.09	13.73	20.86	20.94	844.5
Paper	7.6	7.55	7.48	7.13	7.15	7.26	7.33	10.75
Solids	13.71	34.11	12.14	5.96	6.58	13.6	13.61	833.75
Cumulative Solids	0	34.11	46.25	52.21	58.79			
Squirt Bottle Before		447.39	469.32	432.24	527.27			
Squirt Bottle After		318.8	279.74	312.08	444.07			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		717.1	572.64	394.87	445.86			
Recovered Water		363.86	187.07	93.05	106.32			
Cumulative Water	0	363.86	550.93	643.98	750.3			
Top-up Bottle Before		880.4	878.4	1020.6	943.6			
Top-up Bottle After		639.6	589.3	899.5	827.2			
Top-up Water Used		240.8	289.1	121.1	116.4			
Copper Percentage (%)	0.286	4.65	2.47	1.67	1.15	0.058	0.06	0.059
Copper Mass (g)	0.0392106	1.586115	0.299858	0.099532	0.07567	0.00789	0.008166	0.4919125
Cumulative Copper Mass (g)		1.586115	1.885973	1.985505	2.061175			
Copper Grade (%)		4.65	4.08	3.80	3.51			
Copper Recovery (%)		64.03	76.14	80.16	83.21			
Nickel Percentage (%)	0.224	1.5	2.72	2.32	1.55	0.112	0.109	0.1105
Nickel Mass (g)	0.0307104	0.51165	0.330208	0.138272	0.10199	0.01523	0.0148349	0.92129375
Cumulative Nickel Mass (g)		0.51165	0.841858	0.98013	1.08212			
Nickel Grade (%)		1.50	1.82	1.88	1.84			
Nickel Recovery (%)		27.45	45.16	52.58	58.05			

Total Possible Copper (g)	2.569141
Total Copper / Feed (%)	0.275228
Copper Mass Balance	96.2335
Total Possible Nickel (g)	2.033481
Total Nickel / Feed (%)	0.217843
Nickel Mass Balance	97.25151

Figure 73 - Raw data for Senfroth 200 at 3 SPW and 50 g/ton



Date	18-Jul
SPW	3
Ore	Kevitsa
Frother	Senfroth 200
Dosage	60 g/ton
Collector	SIBX (1%)
Collector Dosage	5ml

Feed Run 1	949.8
Feed Run 2	942.9

Total Solids Collected (Run 1)	882.7
Total Solids Collected (Run 1)	925.4

Cumulative Time	0	2	6	12	20

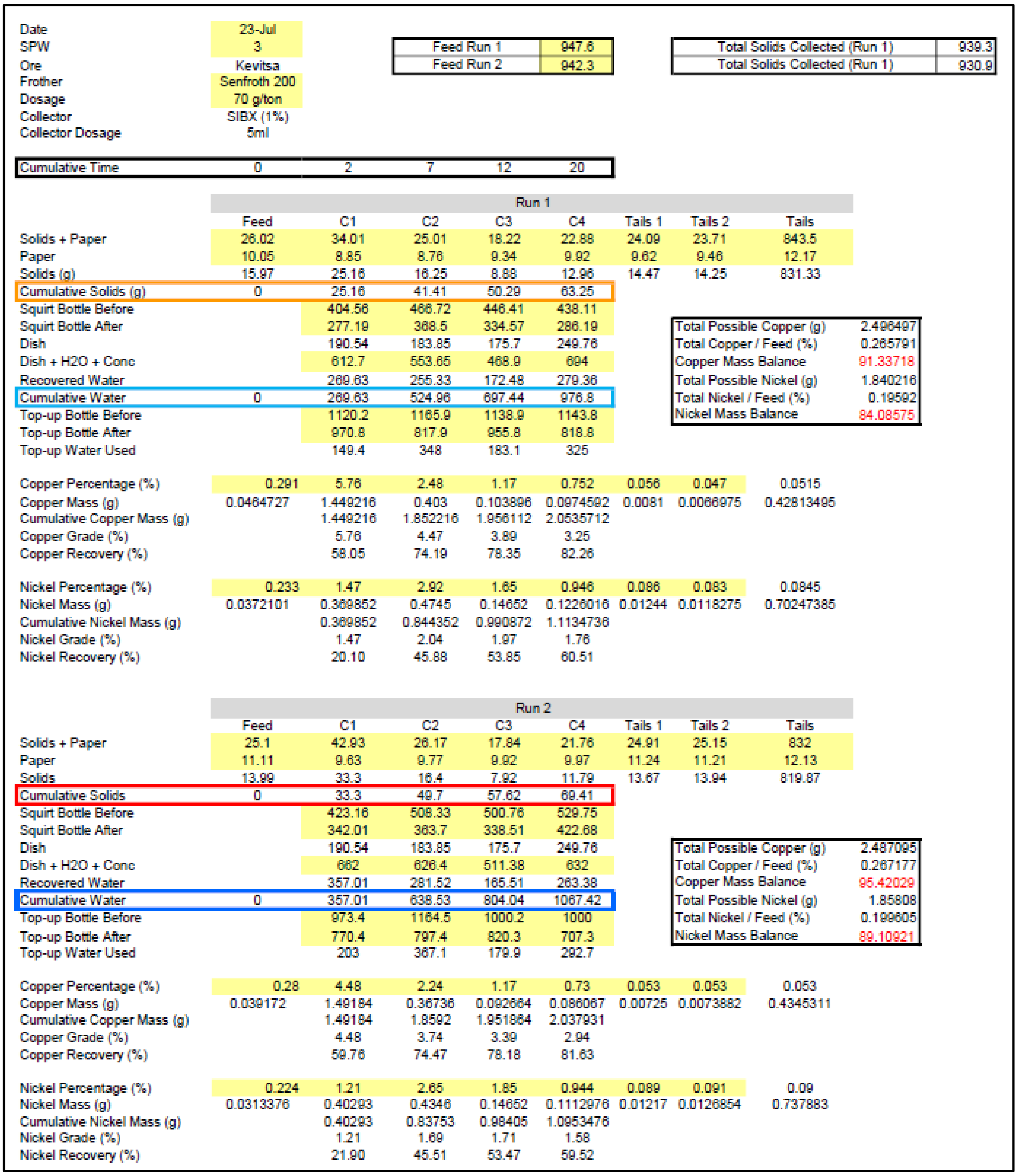
	Run 1							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	21.81	34.84	19.26	16.61	17.94	21.03	20.2	793.2
Paper	7.1	7.63	7.19	7.13	7.6	7.83	6.98	10.78
Solids (g)	14.71	27.21	12.07	9.48	10.34	13.2	13.22	782.42
Cumulative Solids (g)	0	27.21	39.28	48.76	59.1			
Squirt Bottle Before		318.8	279.74	312.08	444.07			
Squirt Bottle After		256.69	133.58	219.2	334.41			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		578.16	530.65	438.98	561.41			
Recovered Water		298.3	188.57	160.92	191.65			
Cumulative Water	0	298.3	486.87	647.79	839.44			
Top-up Bottle Before		639.6	1085	899.5	827.2			
Top-up Bottle After		430.53	832.7	721.5	638.1			
Top-up Water Used		209.07	252.3	178	189.1			
Copper Percentage (%)	0.281	5.15	2.68	1.58	0.928	0.06	0.06	0.06
Copper Mass (g)	0.0413351	1.401315	0.323476	0.149784	0.0959552	0.00792	0.007932	0.469452
Cumulative Copper Mass (g)		1.401315	1.724791	1.874575	1.9705302			
Copper Grade (%)		5.15	4.39	3.84	3.33			
Copper Recovery (%)		57.06	70.23	76.33	80.24			
Nickel Percentage (%)	0.241	1.33	2.84	2.36	1.31	0.118	0.102	0.11
Nickel Mass (g)	0.0354511	0.361893	0.342788	0.223728	0.135454	0.01558	0.0134844	0.860662
Cumulative Nickel Mass (g)		0.361893	0.704681	0.928409	1.063863			
Nickel Grade (%)		1.33	1.79	1.90	1.80			
Nickel Recovery (%)		18.52	36.07	47.52	54.46			

Total Possible Copper (g)	2.455834
Total Copper / Feed (%)	0.278234
Copper Mass Balance	99.01573
Total Possible Nickel (g)	1.953587
Total Nickel / Feed (%)	0.221332
Nickel Mass Balance	91.83901

	Run 2							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	23.37	43.3	21.84	19.37	17.71	22.88	16.98	840.2
Paper	8.57	10.54	10.64	10.74	8.72	8.49	10.38	12.16
Solids	14.8	32.76	11.2	8.63	8.99	14.39	6.6	828.04
Cumulative Solids	0	32.76	43.96	52.59	61.58			
Squirt Bottle Before		358.44	449.14	413.91	483.49			
Squirt Bottle After		251.54	232.97	305.83	362.55			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		681.1	595.6	452.21	561.21			
Recovered Water		350.9	184.38	159.8	181.52			
Cumulative Water	0	350.9	535.28	695.08	876.6			
Top-up Bottle Before		790.1	1162.9	1216	1184.5			
Top-up Bottle After		608.3	900.9	1028.5	967.8			
Top-up Water Used		181.8	262	187.5	216.7			
Copper Percentage (%)	0.283	4.54	2.63	1.5	0.887	0.059	0.056	0.0575
Copper Mass (g)	0.041884	1.487304	0.29456	0.12945	0.0797413	0.00849	0.003696	0.476123
Cumulative Copper Mass (g)		1.487304	1.781864	1.911314	1.9910553			
Copper Grade (%)		4.54	4.05	3.63	3.23			
Copper Recovery (%)		60.56	72.56	77.83	81.07			
Nickel Percentage (%)	0.215	1.35	3.03	2.4	1.2	0.094	0.106	0.1
Nickel Mass (g)	0.03182	0.44226	0.33936	0.20712	0.10788	0.01353	0.006996	0.82804
Cumulative Nickel Mass (g)		0.44226	0.78162	0.98874	1.09662			
Nickel Grade (%)		1.35	1.78	1.88	1.78			
Nickel Recovery (%)		22.64	40.01	50.61	56.13			

Total Possible Copper (g)	2.479248
Total Copper / Feed (%)	0.267908
Copper Mass Balance	94.66714
Total Possible Nickel (g)	1.94565
Total Nickel / Feed (%)	0.210247
Nickel Mass Balance	97.78947

Figure 74 - Raw data for Senfroth 200 at 3 SPW and 60 g/ton



Date	23-Jul
SPW	3
Ore	Kevitsa
Frother	Senfroth 200
Dosage	70 g/ton
Collector	SIBX (1%)
Collector Dosage	5ml

Feed Run 1	947.6
Feed Run 2	942.3

Total Solids Collected (Run 1)	939.3
Total Solids Collected (Run 1)	930.9

Cumulative Time	0	2	7	12	20

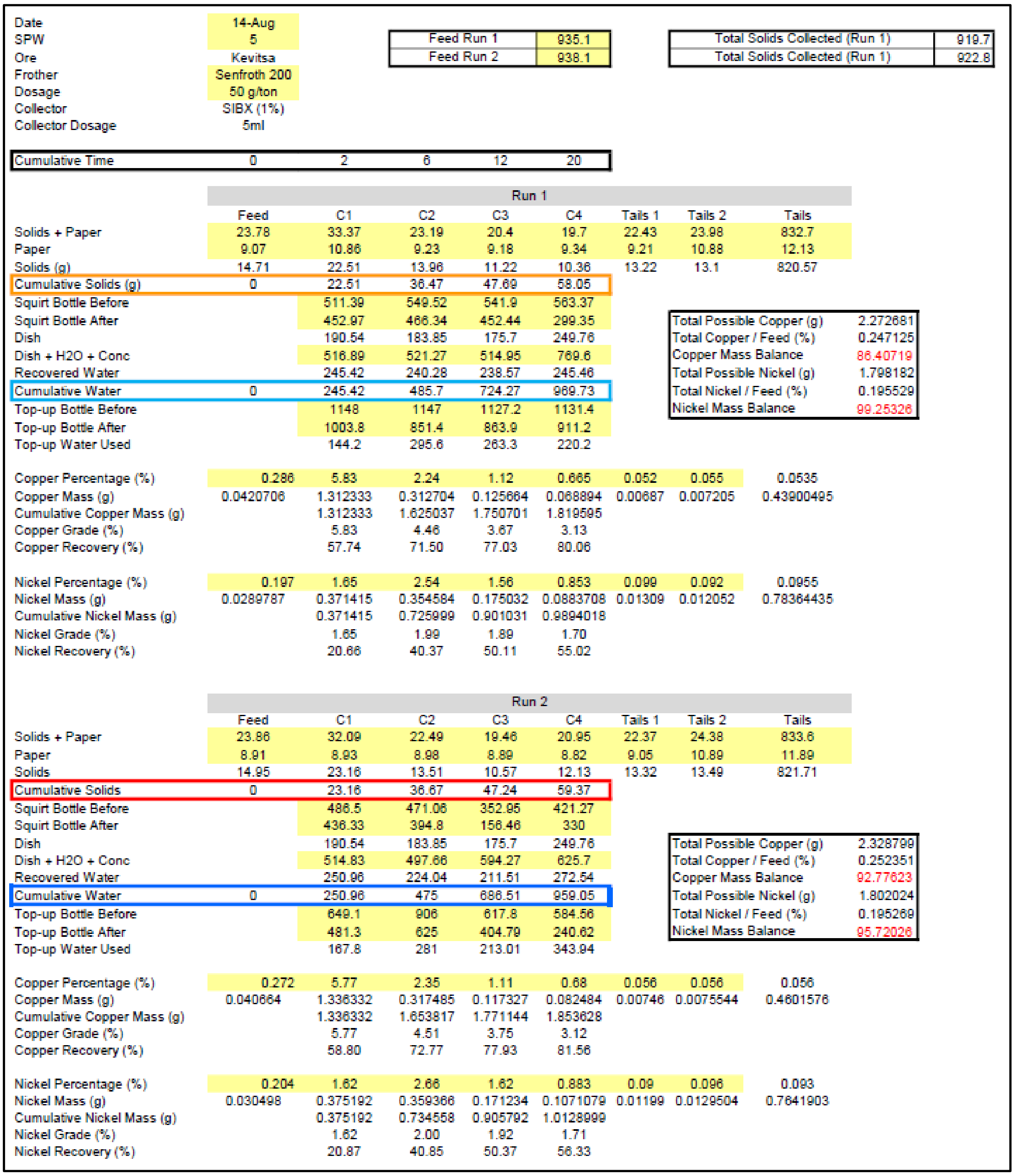
	Run 1							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	26.02	34.01	25.01	18.22	22.88	24.09	23.71	843.5
Paper	10.05	8.85	8.76	9.34	9.92	9.62	9.46	12.17
Solids (g)	15.97	25.16	16.25	8.88	12.96	14.47	14.25	831.33
Cumulative Solids (g)	0	25.16	41.41	50.29	63.25			
Squirt Bottle Before		404.56	466.72	446.41	438.11			
Squirt Bottle After		277.19	368.5	334.57	286.19			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		612.7	553.65	468.9	694			
Recovered Water		269.63	255.33	172.48	279.36			
Cumulative Water	0	269.63	524.96	697.44	976.8			
Top-up Bottle Before		1120.2	1165.9	1138.9	1143.8			
Top-up Bottle After		970.8	817.9	955.8	818.8			
Top-up Water Used		149.4	348	183.1	325			
Copper Percentage (%)	0.291	5.76	2.48	1.17	0.752	0.056	0.047	0.0515
Copper Mass (g)	0.0464727	1.449216	0.403	0.103896	0.0974592	0.0081	0.0066975	0.42813495
Cumulative Copper Mass (g)		1.449216	1.852216	1.956112	2.0535712			
Copper Grade (%)		5.76	4.47	3.89	3.25			
Copper Recovery (%)		58.05	74.19	78.35	82.26			
Nickel Percentage (%)	0.233	1.47	2.92	1.65	0.946	0.086	0.083	0.0845
Nickel Mass (g)	0.0372101	0.369852	0.4745	0.14652	0.1226016	0.01244	0.0118275	0.70247385
Cumulative Nickel Mass (g)		0.369852	0.844352	0.990872	1.1134736			
Nickel Grade (%)		1.47	2.04	1.97	1.76			
Nickel Recovery (%)		20.10	45.88	53.85	60.51			

Total Possible Copper (g)	2.496497
Total Copper / Feed (%)	0.265791
Copper Mass Balance	91.33718
Total Possible Nickel (g)	1.840216
Total Nickel / Feed (%)	0.19592
Nickel Mass Balance	84.08575

	Run 2							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	25.1	42.93	26.17	17.84	21.76	24.91	25.15	832
Paper	11.11	9.63	9.77	9.92	9.97	11.24	11.21	12.13
Solids	13.99	33.3	16.4	7.92	11.79	13.67	13.94	819.87
Cumulative Solids	0	33.3	49.7	57.62	69.41			
Squirt Bottle Before		423.16	508.33	500.76	529.75			
Squirt Bottle After		342.01	363.7	338.51	422.68			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		662	626.4	511.38	632			
Recovered Water		357.01	281.52	165.51	263.38			
Cumulative Water	0	357.01	638.53	804.04	1067.42			
Top-up Bottle Before		973.4	1164.5	1000.2	1000			
Top-up Bottle After		770.4	797.4	820.3	707.3			
Top-up Water Used		203	367.1	179.9	292.7			
Copper Percentage (%)	0.28	4.48	2.24	1.17	0.73	0.053	0.053	0.053
Copper Mass (g)	0.039172	1.49184	0.36736	0.092664	0.086067	0.00725	0.0073882	0.4345311
Cumulative Copper Mass (g)		1.49184	1.8592	1.951864	2.037931			
Copper Grade (%)		4.48	3.74	3.39	2.94			
Copper Recovery (%)		59.76	74.47	78.18	81.63			
Nickel Percentage (%)	0.224	1.21	2.65	1.85	0.944	0.089	0.091	0.09
Nickel Mass (g)	0.0313376	0.40293	0.4346	0.14652	0.1112976	0.01217	0.0126854	0.737883
Cumulative Nickel Mass (g)		0.40293	0.83753	0.98405	1.0953476			
Nickel Grade (%)		1.21	1.69	1.71	1.58			
Nickel Recovery (%)		21.90	45.51	53.47	59.52			

Total Possible Copper (g)	2.487095
Total Copper / Feed (%)	0.267177
Copper Mass Balance	95.42029
Total Possible Nickel (g)	1.85808
Total Nickel / Feed (%)	0.199605
Nickel Mass Balance	89.10921

Figure 75 - Raw data for Senfroth 200 at 3 SPW and 70 g/ton



Date	14-Aug
SPW	5
Ore	Kevitsa
Frother	Senfroth 200
Dosage	50 g/ton
Collector	SIBX (1%)
Collector Dosage	5ml

Feed Run 1	935.1
Feed Run 2	938.1

Total Solids Collected (Run 1)	919.7
Total Solids Collected (Run 1)	922.8

Cumulative Time	0	2	6	12	20

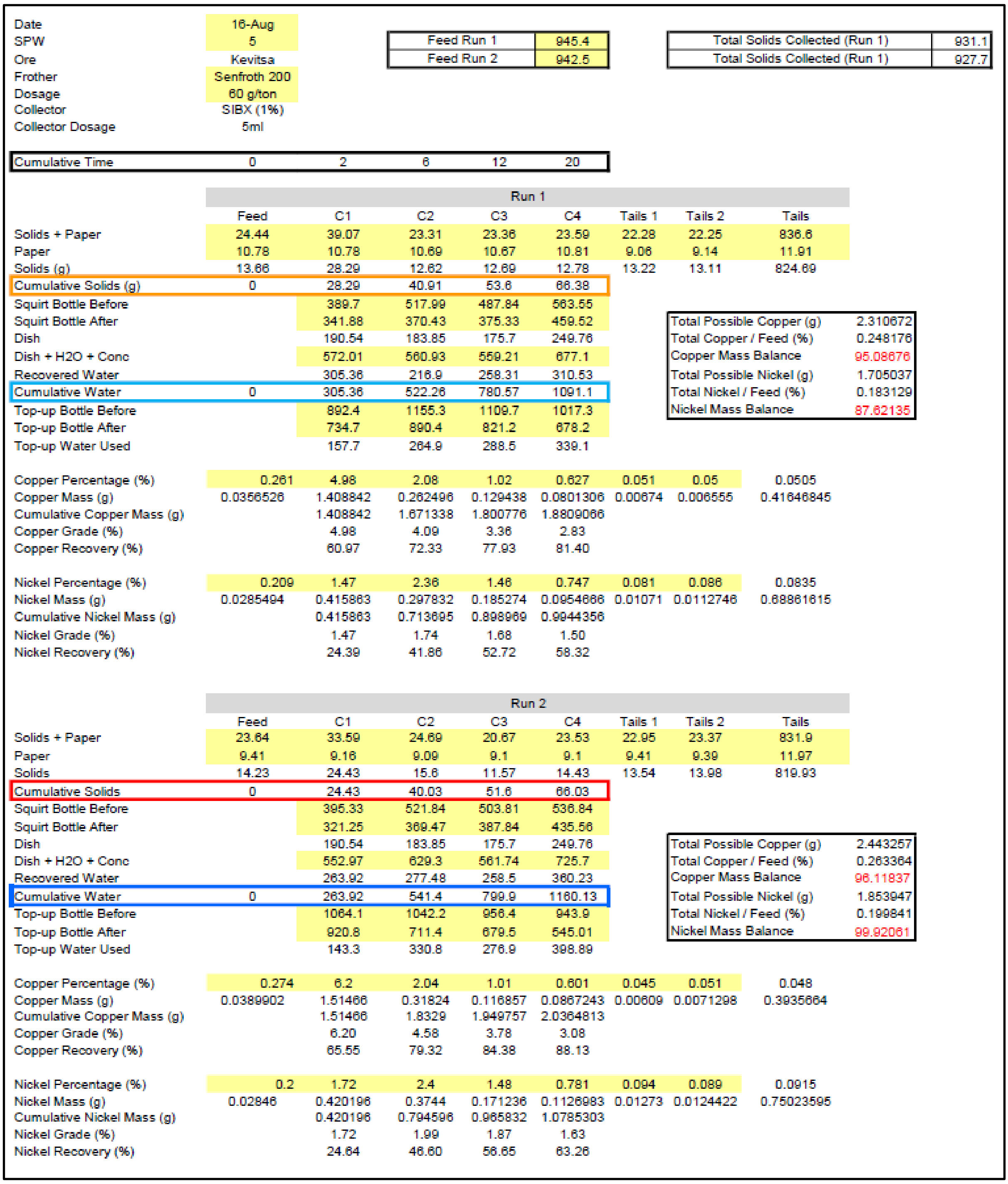
Run 1	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	23.78	33.37	23.19	20.4	19.7	22.43	23.98	832.7
Paper	9.07	10.86	9.23	9.18	9.34	9.21	10.88	12.13
Solids (g)	14.71	22.51	13.96	11.22	10.36	13.22	13.1	820.57
Cumulative Solids (g)	0	22.51	36.47	47.69	58.05			
Squirt Bottle Before		511.39	549.52	541.9	563.37			
Squirt Bottle After		452.97	466.34	452.44	299.35			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		516.89	521.27	514.95	769.6			
Recovered Water		245.42	240.28	238.57	245.46			
Cumulative Water	0	245.42	485.7	724.27	969.73			
Top-up Bottle Before		1148	1147	1127.2	1131.4			
Top-up Bottle After		1003.8	851.4	863.9	911.2			
Top-up Water Used		144.2	295.6	263.3	220.2			
Copper Percentage (%)	0.286	5.83	2.24	1.12	0.665	0.052	0.055	0.0535
Copper Mass (g)	0.0420706	1.312333	0.312704	0.125664	0.068894	0.00687	0.007205	0.43900495
Cumulative Copper Mass (g)		1.312333	1.625037	1.750701	1.819595			
Copper Grade (%)		5.83	4.46	3.67	3.13			
Copper Recovery (%)		57.74	71.50	77.03	80.06			
Nickel Percentage (%)	0.197	1.65	2.54	1.56	0.853	0.099	0.092	0.0955
Nickel Mass (g)	0.0289787	0.371415	0.354584	0.175032	0.0883708	0.01309	0.012052	0.78364435
Cumulative Nickel Mass (g)		0.371415	0.725999	0.901031	0.9894018			
Nickel Grade (%)		1.65	1.99	1.89	1.70			
Nickel Recovery (%)		20.66	40.37	50.11	55.02			

Total Possible Copper (g)	2.272681
Total Copper / Feed (%)	0.247125
Copper Mass Balance	86.40719
Total Possible Nickel (g)	1.798182
Total Nickel / Feed (%)	0.195529
Nickel Mass Balance	99.25326

Run 2	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	23.86	32.09	22.49	19.46	20.95	22.37	24.38	833.6
Paper	8.91	8.93	8.98	8.89	8.82	9.05	10.89	11.89
Solids	14.95	23.16	13.51	10.57	12.13	13.32	13.49	821.71
Cumulative Solids	0	23.16	36.67	47.24	59.37			
Squirt Bottle Before		486.5	471.06	352.95	421.27			
Squirt Bottle After		436.33	394.8	156.46	330			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		514.83	497.66	594.27	625.7			
Recovered Water		250.96	224.04	211.51	272.54			
Cumulative Water	0	250.96	475	686.51	959.05			
Top-up Bottle Before		649.1	906	617.8	584.56			
Top-up Bottle After		481.3	625	404.79	240.62			
Top-up Water Used		167.8	281	213.01	343.94			
Copper Percentage (%)	0.272	5.77	2.35	1.11	0.68	0.056	0.056	0.056
Copper Mass (g)	0.040664	1.336332	0.317485	0.117327	0.082484	0.00746	0.0075544	0.4601576
Cumulative Copper Mass (g)		1.336332	1.653817	1.771144	1.853628			
Copper Grade (%)		5.77	4.51	3.75	3.12			
Copper Recovery (%)		58.80	72.77	77.93	81.56			
Nickel Percentage (%)	0.204	1.62	2.66	1.62	0.883	0.09	0.096	0.093
Nickel Mass (g)	0.030498	0.375192	0.359366	0.171234	0.1071079	0.01199	0.0129504	0.7641903
Cumulative Nickel Mass (g)		0.375192	0.734558	0.905792	1.0128999			
Nickel Grade (%)		1.62	2.00	1.92	1.71			
Nickel Recovery (%)		20.87	40.85	50.37	56.33			

Total Possible Copper (g)	2.328799
Total Copper / Feed (%)	0.252351
Copper Mass Balance	92.77623
Total Possible Nickel (g)	1.802024
Total Nickel / Feed (%)	0.195269
Nickel Mass Balance	95.72026

Figure 76 - Raw data for Senfroth 200 at 5 SPW and 50 g/ton



Date	16-Aug
SPW	5
Ore	Kevitsa
Frother	Senfroth 200
Dosage	60 g/ton
Collector	SIBX (1%)
Collector Dosage	5ml

Feed Run 1	945.4
Feed Run 2	942.5

Total Solids Collected (Run 1)	931.1
Total Solids Collected (Run 1)	927.7

Cumulative Time	0	2	6	12	20

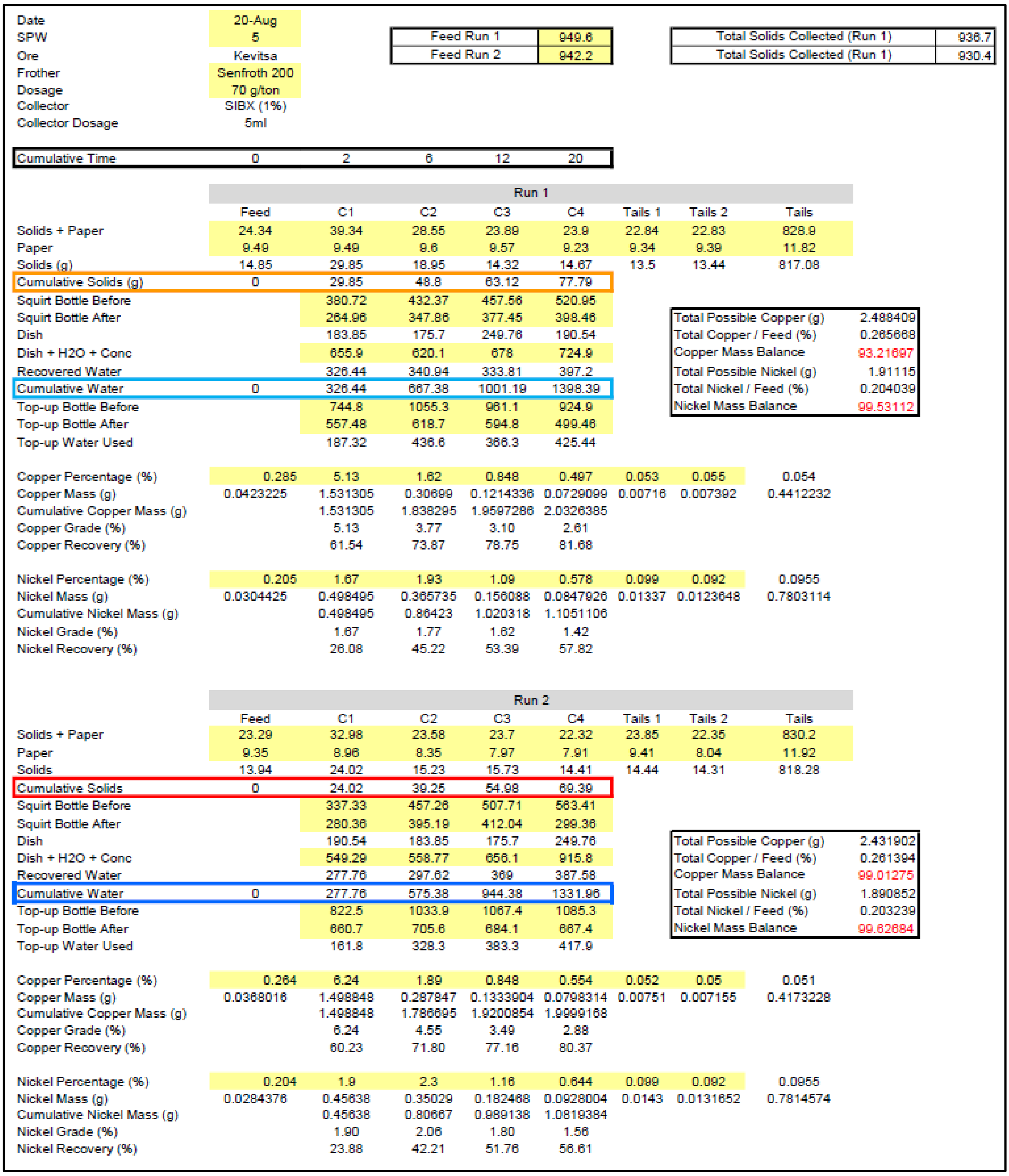
	Run 1							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	24.44	39.07	23.31	23.36	23.59	22.28	22.25	836.6
Paper	10.78	10.78	10.69	10.67	10.81	9.06	9.14	11.91
Solids (g)	13.66	28.29	12.62	12.69	12.78	13.22	13.11	824.69
Cumulative Solids (g)	0	28.29	40.91	53.6	66.38			
Squirt Bottle Before		389.7	517.99	487.84	563.55			
Squirt Bottle After		341.88	370.43	375.33	459.52			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		572.01	560.93	559.21	677.1			
Recovered Water		305.36	216.9	258.31	310.53			
Cumulative Water	0	305.36	522.26	780.57	1091.1			
Top-up Bottle Before		892.4	1155.3	1109.7	1017.3			
Top-up Bottle After		734.7	890.4	821.2	678.2			
Top-up Water Used		157.7	264.9	288.5	339.1			
Copper Percentage (%)	0.261	4.98	2.08	1.02	0.627	0.051	0.05	0.0505
Copper Mass (g)	0.0356526	1.408842	0.262496	0.129438	0.0801306	0.00674	0.006555	0.41646845
Cumulative Copper Mass (g)		1.408842	1.671338	1.800776	1.8809066			
Copper Grade (%)		4.98	4.09	3.36	2.83			
Copper Recovery (%)		60.97	72.33	77.93	81.40			
Nickel Percentage (%)	0.209	1.47	2.36	1.46	0.747	0.081	0.086	0.0835
Nickel Mass (g)	0.0285494	0.415863	0.297832	0.185274	0.0954666	0.01071	0.0112746	0.68861615
Cumulative Nickel Mass (g)		0.415863	0.713695	0.898969	0.9944356			
Nickel Grade (%)		1.47	1.74	1.68	1.50			
Nickel Recovery (%)		24.39	41.86	52.72	58.32			

Total Possible Copper (g)	2.310672
Total Copper / Feed (%)	0.248176
Copper Mass Balance	95.08676
Total Possible Nickel (g)	1.705037
Total Nickel / Feed (%)	0.183129
Nickel Mass Balance	87.62135

	Run 2							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	23.64	33.59	24.69	20.67	23.53	22.95	23.37	831.9
Paper	9.41	9.16	9.09	9.1	9.1	9.41	9.39	11.97
Solids	14.23	24.43	15.6	11.57	14.43	13.54	13.98	819.93
Cumulative Solids	0	24.43	40.03	51.6	66.03			
Squirt Bottle Before		395.33	521.84	503.81	536.84			
Squirt Bottle After		321.25	369.47	387.84	435.56			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		552.97	629.3	561.74	725.7			
Recovered Water		263.92	277.48	258.5	360.23			
Cumulative Water	0	263.92	541.4	799.9	1160.13			
Top-up Bottle Before		1064.1	1042.2	956.4	943.9			
Top-up Bottle After		920.8	711.4	679.5	545.01			
Top-up Water Used		143.3	330.8	276.9	398.89			
Copper Percentage (%)	0.274	6.2	2.04	1.01	0.601	0.045	0.051	0.048
Copper Mass (g)	0.0389902	1.51466	0.31824	0.116857	0.0867243	0.00609	0.0071298	0.3935664
Cumulative Copper Mass (g)		1.51466	1.8329	1.949757	2.0364813			
Copper Grade (%)		6.20	4.58	3.78	3.08			
Copper Recovery (%)		65.55	79.32	84.38	88.13			
Nickel Percentage (%)	0.2	1.72	2.4	1.48	0.781	0.094	0.089	0.0915
Nickel Mass (g)	0.02846	0.420196	0.3744	0.171236	0.1126983	0.01273	0.0124422	0.75023595
Cumulative Nickel Mass (g)		0.420196	0.794596	0.965832	1.0785303			
Nickel Grade (%)		1.72	1.99	1.87	1.63			
Nickel Recovery (%)		24.64	46.60	56.65	63.26			

Total Possible Copper (g)	2.443257
Total Copper / Feed (%)	0.263364
Copper Mass Balance	96.11837
Total Possible Nickel (g)	1.853947
Total Nickel / Feed (%)	0.199841
Nickel Mass Balance	99.92061

Figure 77 - Raw data for Senfroth 200 at 5 SPW and 60 g/ton



Date	20-Aug
SPW	5
Ore	Kevitsa
Frother	Senfroth 200
Dosage	70 g/ton
Collector	SIBX (1%)
Collector Dosage	5ml

Feed Run 1	949.6
Feed Run 2	942.2

Total Solids Collected (Run 1)	936.7
Total Solids Collected (Run 1)	930.4

Cumulative Time	0	2	6	12	20

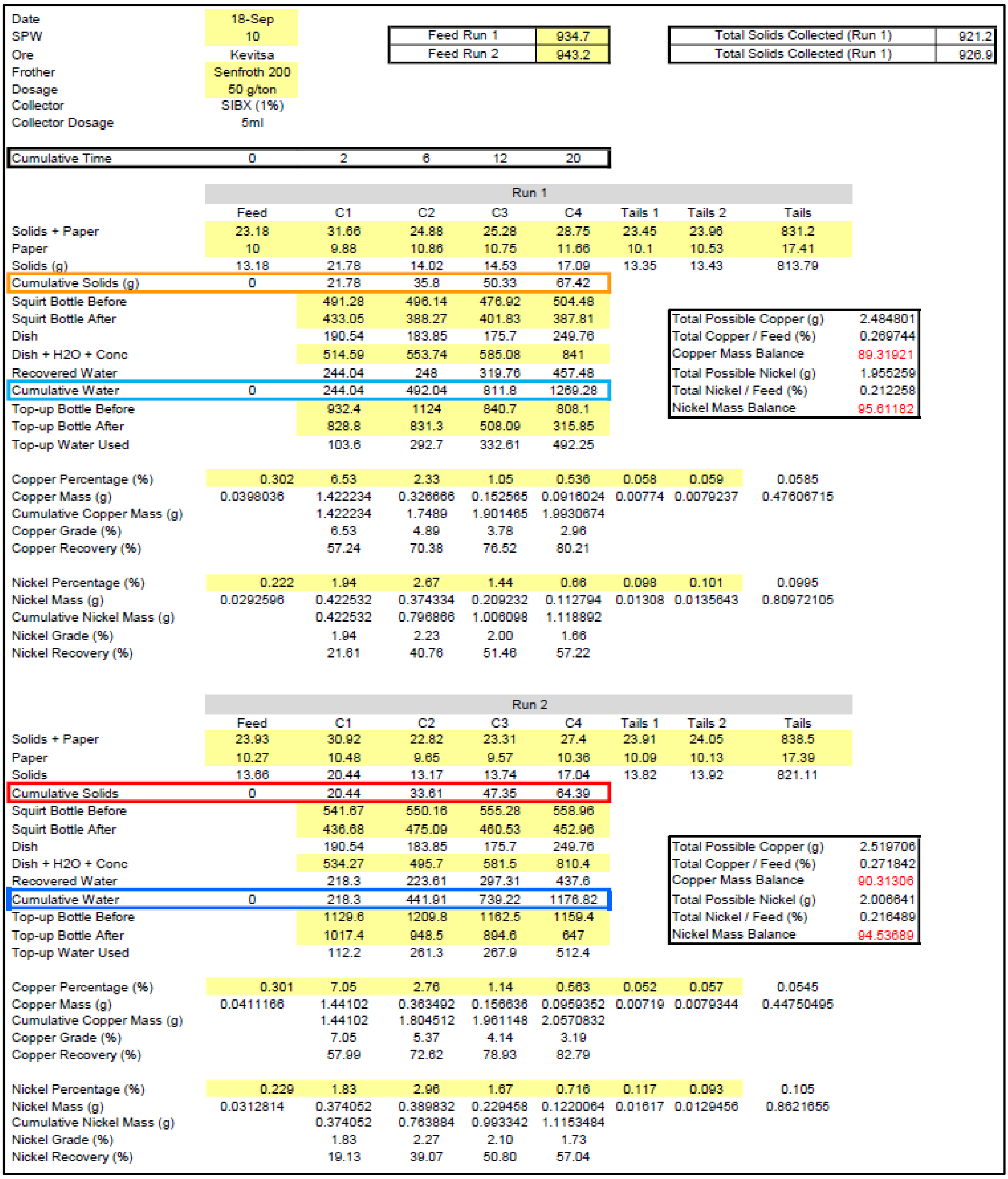
Run 1	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	24.34	39.34	28.55	23.89	23.9	22.84	22.83	828.9
Paper	9.49	9.49	9.6	9.57	9.23	9.34	9.39	11.82
Solids (g)	14.85	29.85	18.95	14.32	14.67	13.5	13.44	817.08
Cumulative Solids (g)	0	29.85	48.8	63.12	77.79			
Squirt Bottle Before		380.72	432.37	457.56	520.95			
Squirt Bottle After		264.96	347.86	377.45	398.46			
Dish		183.85	175.7	249.76	190.54			
Dish + H2O + Conc		655.9	620.1	678	724.9			
Recovered Water		326.44	340.94	333.81	397.2			
Cumulative Water	0	326.44	667.38	1001.19	1398.39			
Top-up Bottle Before		744.8	1055.3	961.1	924.9			
Top-up Bottle After		557.48	618.7	594.8	499.46			
Top-up Water Used		187.32	436.6	366.3	425.44			
Copper Percentage (%)	0.285	5.13	1.62	0.848	0.497	0.053	0.055	0.054
Copper Mass (g)	0.0423225	1.531305	0.30699	0.1214336	0.0729099	0.00716	0.007392	0.4412232
Cumulative Copper Mass (g)		1.531305	1.838295	1.9597286	2.0326385			
Copper Grade (%)		5.13	3.77	3.10	2.61			
Copper Recovery (%)		61.54	73.87	78.75	81.68			
Nickel Percentage (%)	0.205	1.67	1.93	1.09	0.578	0.099	0.092	0.0955
Nickel Mass (g)	0.0304425	0.498495	0.365735	0.156088	0.0847926	0.01337	0.0123648	0.7803114
Cumulative Nickel Mass (g)		0.498495	0.86423	1.020318	1.1051106			
Nickel Grade (%)		1.67	1.77	1.62	1.42			
Nickel Recovery (%)		26.08	45.22	53.39	57.82			

Total Possible Copper (g)	2.488409
Total Copper / Feed (%)	0.265668
Copper Mass Balance	93.21697
Total Possible Nickel (g)	1.91115
Total Nickel / Feed (%)	0.204039
Nickel Mass Balance	99.53112

Run 2	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	23.29	32.98	23.58	23.7	22.32	23.85	22.35	830.2
Paper	9.35	8.96	8.35	7.97	7.91	9.41	8.04	11.92
Solids	13.94	24.02	15.23	15.73	14.41	14.44	14.31	818.28
Cumulative Solids	0	24.02	39.25	54.98	69.39			
Squirt Bottle Before		337.33	457.26	507.71	563.41			
Squirt Bottle After		280.36	395.19	412.04	299.36			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		549.29	558.77	656.1	915.8			
Recovered Water		277.76	297.62	369	387.58			
Cumulative Water	0	277.76	575.38	944.38	1331.96			
Top-up Bottle Before		822.5	1033.9	1067.4	1085.3			
Top-up Bottle After		660.7	705.6	684.1	667.4			
Top-up Water Used		161.8	328.3	383.3	417.9			
Copper Percentage (%)	0.264	6.24	1.89	0.848	0.554	0.052	0.05	0.051
Copper Mass (g)	0.0368016	1.498848	0.287847	0.1333904	0.0798314	0.00751	0.007155	0.4173228
Cumulative Copper Mass (g)		1.498848	1.786695	1.9200854	1.9999168			
Copper Grade (%)		6.24	4.55	3.49	2.88			
Copper Recovery (%)		60.23	71.80	77.16	80.37			
Nickel Percentage (%)	0.204	1.9	2.3	1.16	0.644	0.099	0.092	0.0955
Nickel Mass (g)	0.0284376	0.45638	0.35029	0.182468	0.0928004	0.0143	0.0131652	0.7814574
Cumulative Nickel Mass (g)		0.45638	0.80667	0.989138	1.0819384			
Nickel Grade (%)		1.90	2.06	1.80	1.56			
Nickel Recovery (%)		23.88	42.21	51.76	56.61			

Total Possible Copper (g)	2.431902
Total Copper / Feed (%)	0.261394
Copper Mass Balance	99.01275
Total Possible Nickel (g)	1.890852
Total Nickel / Feed (%)	0.203239
Nickel Mass Balance	99.62684

Figure 78 - Raw data for Senfroth 200 at 5 SPW and 70 g/ton



Date	18-Sep
SPW	10
Ore	Kevitsa
Frother	Senfroth 200
Dosage	50 g/ton
Collector	SIBX (1%)
Collector Dosage	5ml

Feed Run 1	934.7
Feed Run 2	943.2

Total Solids Collected (Run 1)	921.2
Total Solids Collected (Run 1)	926.9

Cumulative Time	0	2	6	12	20

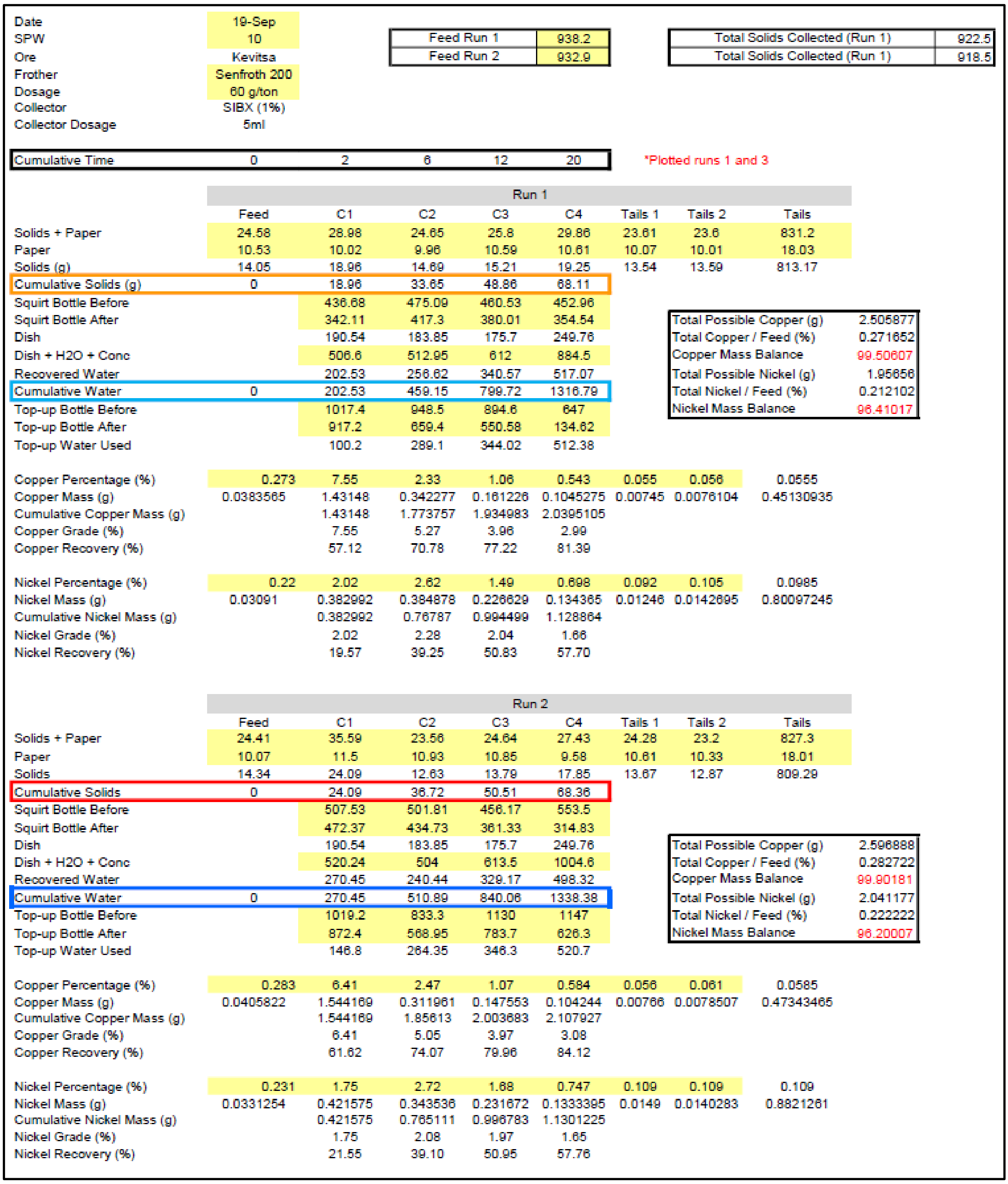
	Run 1							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	23.18	31.66	24.88	25.28	28.75	23.45	23.96	831.2
Paper	10	9.88	10.86	10.75	11.66	10.1	10.53	17.41
Solids (g)	13.18	21.78	14.02	14.53	17.09	13.35	13.43	813.79
Cumulative Solids (g)	0	21.78	35.8	50.33	67.42			
Squirt Bottle Before		491.28	496.14	476.92	504.48			
Squirt Bottle After		433.05	388.27	401.83	387.81			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		514.59	553.74	585.08	841			
Recovered Water		244.04	248	319.76	457.48			
Cumulative Water	0	244.04	492.04	811.8	1269.28			
Top-up Bottle Before		932.4	1124	840.7	808.1			
Top-up Bottle After		828.8	831.3	508.09	315.85			
Top-up Water Used		103.6	292.7	332.61	492.25			
Copper Percentage (%)	0.302	6.53	2.33	1.05	0.536	0.058	0.059	0.0585
Copper Mass (g)	0.0398036	1.422234	0.326666	0.152565	0.0916024	0.00774	0.0079237	0.47606715
Cumulative Copper Mass (g)		1.422234	1.7489	1.901465	1.9930674			
Copper Grade (%)		6.53	4.89	3.78	2.96			
Copper Recovery (%)		57.24	70.38	76.52	80.21			
Nickel Percentage (%)	0.222	1.94	2.67	1.44	0.66	0.098	0.101	0.0995
Nickel Mass (g)	0.0292596	0.422532	0.374334	0.209232	0.112794	0.01308	0.0135643	0.80972105
Cumulative Nickel Mass (g)		0.422532	0.796866	1.006098	1.118892			
Nickel Grade (%)		1.94	2.23	2.00	1.66			
Nickel Recovery (%)		21.61	40.76	51.46	57.22			

Total Possible Copper (g)	2.484801
Total Copper / Feed (%)	0.269744
Copper Mass Balance	89.31921
Total Possible Nickel (g)	1.955259
Total Nickel / Feed (%)	0.212258
Nickel Mass Balance	95.61182

	Run 2							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	23.93	30.92	22.82	23.31	27.4	23.91	24.05	838.5
Paper	10.27	10.48	9.65	9.57	10.36	10.09	10.13	17.39
Solids	13.66	20.44	13.17	13.74	17.04	13.82	13.92	821.11
Cumulative Solids	0	20.44	33.61	47.35	64.39			
Squirt Bottle Before		541.67	550.16	555.28	558.96			
Squirt Bottle After		436.68	475.09	460.53	452.96			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		534.27	495.7	581.5	810.4			
Recovered Water		218.3	223.61	297.31	437.6			
Cumulative Water	0	218.3	441.91	739.22	1176.82			
Top-up Bottle Before		1129.6	1209.8	1162.5	1159.4			
Top-up Bottle After		1017.4	948.5	894.6	647			
Top-up Water Used		112.2	261.3	267.9	512.4			
Copper Percentage (%)	0.301	7.05	2.76	1.14	0.563	0.052	0.057	0.0545
Copper Mass (g)	0.0411166	1.44102	0.363492	0.156636	0.0959352	0.00719	0.0079344	0.44750495
Cumulative Copper Mass (g)		1.44102	1.804512	1.961148	2.0570832			
Copper Grade (%)		7.05	5.37	4.14	3.19			
Copper Recovery (%)		57.99	72.62	78.93	82.79			
Nickel Percentage (%)	0.229	1.83	2.96	1.67	0.716	0.117	0.093	0.105
Nickel Mass (g)	0.0312814	0.374052	0.389832	0.229458	0.1220064	0.01617	0.0129456	0.8621655
Cumulative Nickel Mass (g)		0.374052	0.763884	0.993342	1.1153484			
Nickel Grade (%)		1.83	2.27	2.10	1.73			
Nickel Recovery (%)		19.13	39.07	50.80	57.04			

Total Possible Copper (g)	2.519706
Total Copper / Feed (%)	0.271842
Copper Mass Balance	90.31306
Total Possible Nickel (g)	2.006641
Total Nickel / Feed (%)	0.216489
Nickel Mass Balance	94.53689

Figure 79 - Raw data for Senfroth 200 at 10 SPW and 50 g/ton



Date	19-Sep
SPW	10
Ore	Kevitsa
Frother	Senfroth 200
Dosage	60 g/ton
Collector	SIBX (1%)
Collector Dosage	5ml

Feed Run 1	938.2
Feed Run 2	932.9

Total Solids Collected (Run 1)	922.5
Total Solids Collected (Run 1)	918.5

Cumulative Time	0	2	6	12	20

*Plotted runs 1 and 3

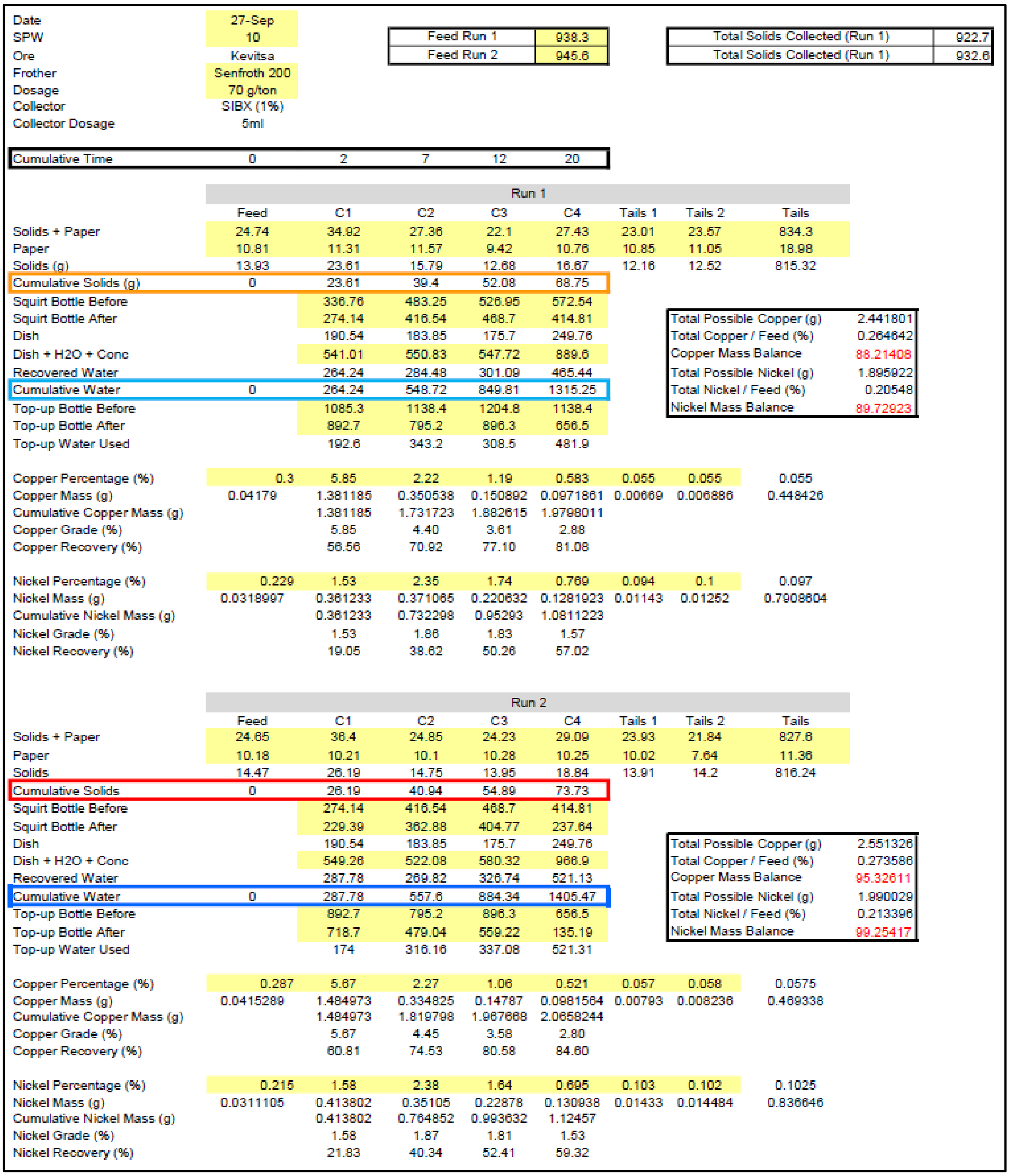
	Run 1							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	24.58	28.98	24.65	25.8	29.86	23.61	23.6	831.2
Paper	10.53	10.02	9.96	10.59	10.61	10.07	10.01	18.03
Solids (g)	14.05	18.96	14.69	15.21	19.25	13.54	13.59	813.17
Cumulative Solids (g)	0	18.96	33.65	48.86	68.11			
Squirt Bottle Before		436.68	475.09	460.53	452.96			
Squirt Bottle After		342.11	417.3	380.01	354.54			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		506.6	512.95	612	884.5			
Recovered Water		202.53	256.62	340.57	517.07			
Cumulative Water	0	202.53	459.15	799.72	1316.79			
Top-up Bottle Before		1017.4	948.5	894.6	647			
Top-up Bottle After		917.2	659.4	550.58	134.62			
Top-up Water Used		100.2	289.1	344.02	512.38			
Copper Percentage (%)	0.273	7.55	2.33	1.06	0.543	0.055	0.056	0.0555
Copper Mass (g)	0.0383565	1.43148	0.342277	0.161226	0.1045275	0.00745	0.0076104	0.45130935
Cumulative Copper Mass (g)		1.43148	1.773757	1.934983	2.0395105			
Copper Grade (%)		7.55	5.27	3.96	2.99			
Copper Recovery (%)		57.12	70.78	77.22	81.39			
Nickel Percentage (%)	0.22	2.02	2.62	1.49	0.698	0.092	0.105	0.0985
Nickel Mass (g)	0.03091	0.382992	0.384878	0.226629	0.134365	0.01246	0.0142695	0.80097245
Cumulative Nickel Mass (g)		0.382992	0.76787	0.994499	1.128864			
Nickel Grade (%)		2.02	2.28	2.04	1.66			
Nickel Recovery (%)		19.57	39.25	50.83	57.70			

Total Possible Copper (g)	2.505877
Total Copper / Feed (%)	0.271652
Copper Mass Balance	99.50607
Total Possible Nickel (g)	1.95656
Total Nickel / Feed (%)	0.212102
Nickel Mass Balance	96.41017

	Run 2							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	24.41	35.59	23.56	24.64	27.43	24.28	23.2	827.3
Paper	10.07	11.5	10.93	10.85	9.58	10.61	10.33	18.01
Solids	14.34	24.09	12.63	13.79	17.85	13.67	12.87	809.29
Cumulative Solids	0	24.09	36.72	50.51	68.36			
Squirt Bottle Before		507.53	501.81	456.17	553.5			
Squirt Bottle After		472.37	434.73	361.33	314.83			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		520.24	504	613.5	1004.6			
Recovered Water		270.45	240.44	329.17	498.32			
Cumulative Water	0	270.45	510.89	840.06	1338.38			
Top-up Bottle Before		1019.2	833.3	1130	1147			
Top-up Bottle After		872.4	568.95	783.7	626.3			
Top-up Water Used		146.8	264.35	346.3	520.7			
Copper Percentage (%)	0.283	6.41	2.47	1.07	0.584	0.056	0.061	0.0585
Copper Mass (g)	0.0405822	1.544169	0.311961	0.147553	0.104244	0.00766	0.0078507	0.47343465
Cumulative Copper Mass (g)		1.544169	1.85613	2.003683	2.107927			
Copper Grade (%)		6.41	5.05	3.97	3.08			
Copper Recovery (%)		61.62	74.07	79.96	84.12			
Nickel Percentage (%)	0.231	1.75	2.72	1.68	0.747	0.109	0.109	0.109
Nickel Mass (g)	0.0331254	0.421575	0.343536	0.231672	0.1333395	0.0149	0.0140283	0.8821261
Cumulative Nickel Mass (g)		0.421575	0.765111	0.996783	1.1301225			
Nickel Grade (%)		1.75	2.08	1.97	1.65			
Nickel Recovery (%)		21.55	39.10	50.95	57.76			

Total Possible Copper (g)	2.596888
Total Copper / Feed (%)	0.282722
Copper Mass Balance	99.90181
Total Possible Nickel (g)	2.041177
Total Nickel / Feed (%)	0.222222
Nickel Mass Balance	96.20007

Figure 80 - Raw data for Senfroth 200 at 10 SPW and 60 g/ton



Date	27-Sep
SPW	10
Ore	Kevitsa
Frother	Senfroth 200
Dosage	70 g/ton
Collector	SIBX (1%)
Collector Dosage	5ml

Feed Run 1	938.3
Feed Run 2	945.6

Total Solids Collected (Run 1)	922.7
Total Solids Collected (Run 1)	932.6

Cumulative Time	0	2	7	12	20

	Run 1							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	24.74	34.92	27.36	22.1	27.43	23.01	23.57	834.3
Paper	10.81	11.31	11.57	9.42	10.76	10.85	11.05	18.98
Solids (g)	13.93	23.61	15.79	12.68	16.67	12.16	12.52	815.32
Cumulative Solids (g)	0	23.61	39.4	52.08	68.75			
Squirt Bottle Before		336.76	483.25	526.95	572.54			
Squirt Bottle After		274.14	416.54	468.7	414.81			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		541.01	550.83	547.72	889.6			
Recovered Water		264.24	284.48	301.09	465.44			
Cumulative Water	0	264.24	548.72	849.81	1315.25			
Top-up Bottle Before		1085.3	1138.4	1204.8	1138.4			
Top-up Bottle After		892.7	795.2	896.3	656.5			
Top-up Water Used		192.6	343.2	308.5	481.9			
Copper Percentage (%)	0.3	5.85	2.22	1.19	0.583	0.055	0.055	0.055
Copper Mass (g)	0.04179	1.381185	0.350538	0.150892	0.0971861	0.00669	0.006886	0.448426
Cumulative Copper Mass (g)		1.381185	1.731723	1.882615	1.9798011			
Copper Grade (%)		5.85	4.40	3.61	2.88			
Copper Recovery (%)		56.56	70.92	77.10	81.08			
Nickel Percentage (%)	0.229	1.53	2.35	1.74	0.769	0.094	0.1	0.097
Nickel Mass (g)	0.0318997	0.361233	0.371065	0.220632	0.1281923	0.01143	0.01252	0.7908604
Cumulative Nickel Mass (g)		0.361233	0.732298	0.95293	1.0811223			
Nickel Grade (%)		1.53	1.86	1.83	1.57			
Nickel Recovery (%)		19.05	38.62	50.26	57.02			

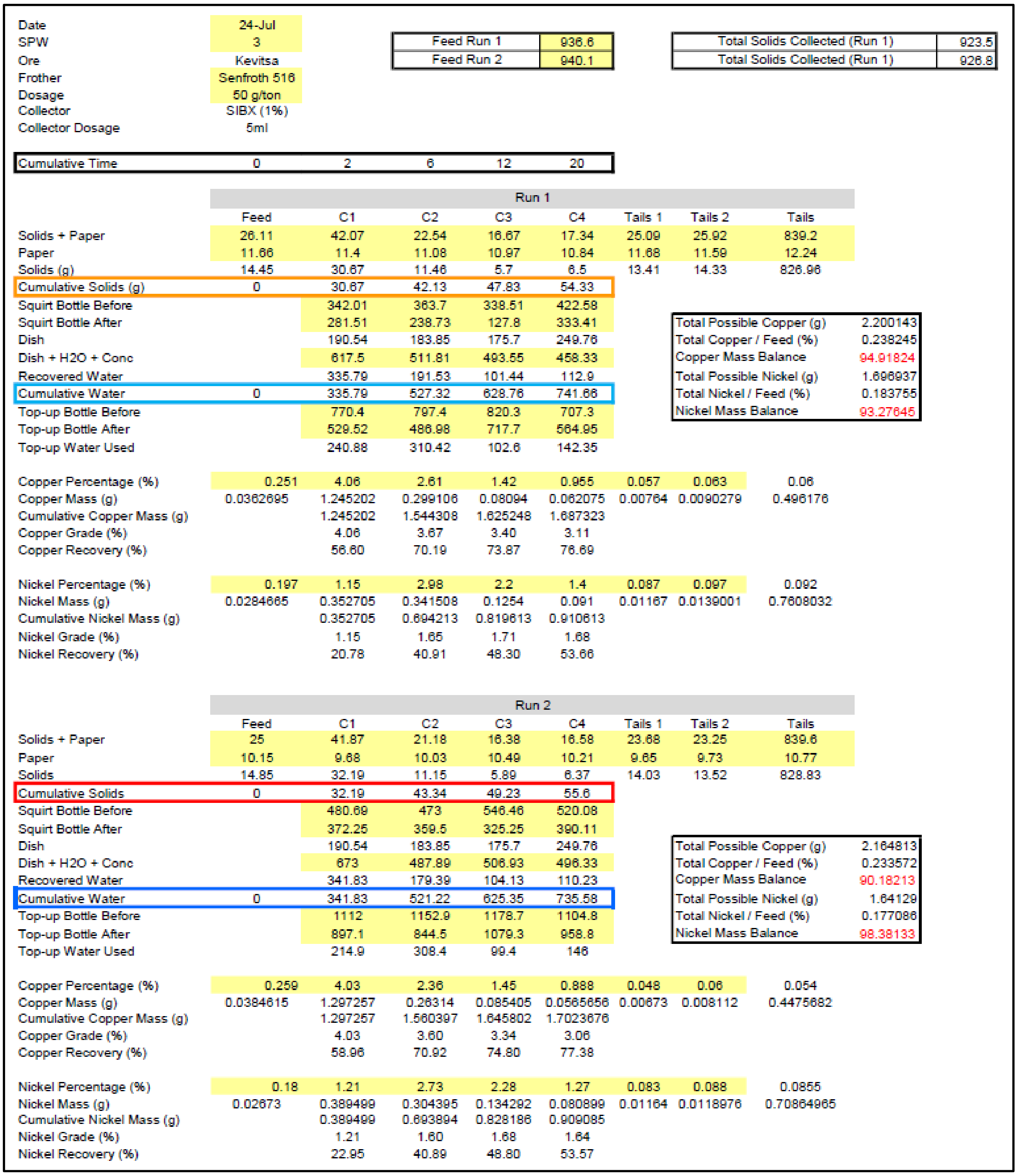
Total Possible Copper (g)	2.441801
Total Copper / Feed (%)	0.264642
Copper Mass Balance	88.21408
Total Possible Nickel (g)	1.895922
Total Nickel / Feed (%)	0.20548
Nickel Mass Balance	89.72923

	Run 2							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	24.65	36.4	24.85	24.23	29.09	23.93	21.84	827.6
Paper	10.18	10.21	10.1	10.28	10.25	10.02	7.64	11.36
Solids	14.47	26.19	14.75	13.95	18.84	13.91	14.2	816.24
Cumulative Solids	0	26.19	40.94	54.89	73.73			
Squirt Bottle Before		274.14	416.54	468.7	414.81			
Squirt Bottle After		229.39	362.88	404.77	237.64			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		549.26	522.08	580.32	966.9			
Recovered Water		287.78	269.82	326.74	521.13			
Cumulative Water	0	287.78	557.6	884.34	1405.47			
Top-up Bottle Before		892.7	795.2	896.3	656.5			
Top-up Bottle After		718.7	479.04	559.22	135.19			
Top-up Water Used		174	316.16	337.08	521.31			
Copper Percentage (%)	0.287	5.67	2.27	1.06	0.521	0.057	0.058	0.0575
Copper Mass (g)	0.0415289	1.484973	0.334825	0.14787	0.0981564	0.00793	0.008236	0.469338
Cumulative Copper Mass (g)		1.484973	1.819798	1.967668	2.0658244			
Copper Grade (%)		5.67	4.45	3.58	2.80			
Copper Recovery (%)		60.81	74.53	80.58	84.60			
Nickel Percentage (%)	0.215	1.58	2.38	1.64	0.695	0.103	0.102	0.1025
Nickel Mass (g)	0.0311105	0.413802	0.35105	0.22878	0.130938	0.01433	0.014484	0.836646
Cumulative Nickel Mass (g)		0.413802	0.764852	0.993632	1.12457			
Nickel Grade (%)		1.58	1.87	1.81	1.53			
Nickel Recovery (%)		21.83	40.34	52.41	59.32			

Total Possible Copper (g)	2.551326
Total Copper / Feed (%)	0.273586
Copper Mass Balance	95.32611
Total Possible Nickel (g)	1.990029
Total Nickel / Feed (%)	0.213396
Nickel Mass Balance	99.25417

Figure 81 - Raw data for Senfroth 200 at 10 SPW and 70 g/ton

10.2 Senfroth 516 Raw Data



Date	24-Jul
SPW	3
Ore	Kevitsa
Frother	Senfroth 516
Dosage	50 g/ton
Collector	SIBX (1%)
Collector Dosage	5ml

Feed Run 1	936.6
Feed Run 2	940.1

Total Solids Collected (Run 1)	923.5
Total Solids Collected (Run 1)	926.8

Cumulative Time	0	2	6	12	20

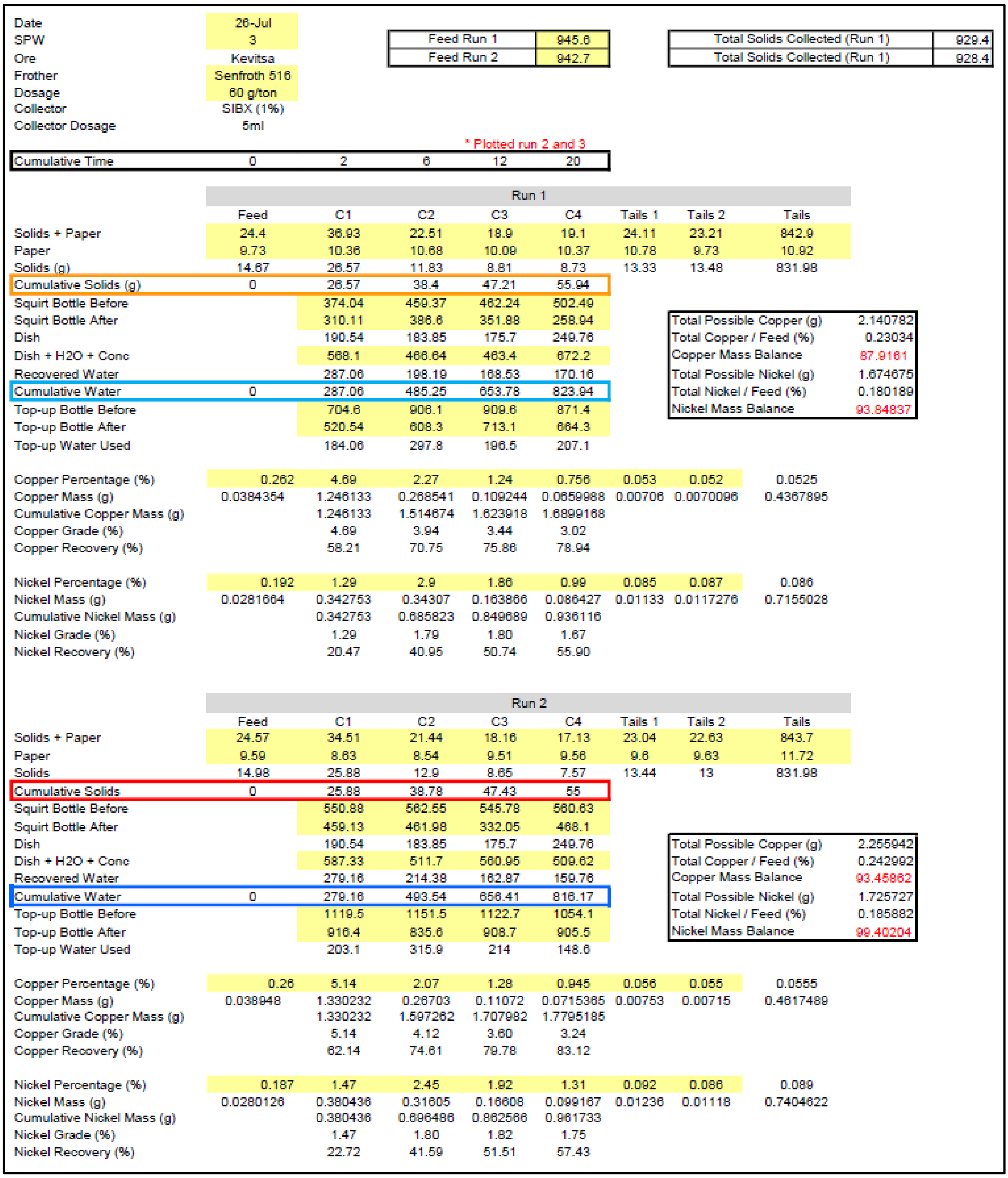
	Run 1							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	26.11	42.07	22.54	16.67	17.34	25.09	25.92	839.2
Paper	11.66	11.4	11.08	10.97	10.84	11.68	11.59	12.24
Solids (g)	14.45	30.67	11.46	5.7	6.5	13.41	14.33	826.96
Cumulative Solids (g)	0	30.67	42.13	47.83	54.33			
Squirt Bottle Before		342.01	363.7	338.51	422.58			
Squirt Bottle After		281.51	238.73	127.8	333.41			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		617.5	511.81	493.55	458.33			
Recovered Water		335.79	191.53	101.44	112.9			
Cumulative Water	0	335.79	527.32	628.76	741.66			
Top-up Bottle Before		770.4	797.4	820.3	707.3			
Top-up Bottle After		529.52	486.98	717.7	564.95			
Top-up Water Used		240.88	310.42	102.6	142.35			
Copper Percentage (%)	0.251	4.06	2.61	1.42	0.955	0.057	0.063	0.06
Copper Mass (g)	0.0362695	1.245202	0.299106	0.08094	0.062075	0.00764	0.0090279	0.496176
Cumulative Copper Mass (g)		1.245202	1.544308	1.625248	1.687323			
Copper Grade (%)		4.06	3.67	3.40	3.11			
Copper Recovery (%)		56.60	70.19	73.87	76.69			
Nickel Percentage (%)	0.197	1.15	2.98	2.2	1.4	0.087	0.097	0.092
Nickel Mass (g)	0.0284665	0.352705	0.341508	0.1254	0.091	0.01167	0.0139001	0.7608032
Cumulative Nickel Mass (g)		0.352705	0.694213	0.819613	0.910613			
Nickel Grade (%)		1.15	1.65	1.71	1.68			
Nickel Recovery (%)		20.78	40.91	48.30	53.66			

Total Possible Copper (g)	2.200143
Total Copper / Feed (%)	0.238245
Copper Mass Balance	94.91824
Total Possible Nickel (g)	1.696937
Total Nickel / Feed (%)	0.183755
Nickel Mass Balance	93.27645

	Run 2							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	25	41.87	21.18	16.38	16.58	23.68	23.25	839.6
Paper	10.15	9.68	10.03	10.49	10.21	9.65	9.73	10.77
Solids	14.85	32.19	11.15	5.89	6.37	14.03	13.52	828.83
Cumulative Solids	0	32.19	43.34	49.23	55.6			
Squirt Bottle Before		480.69	473	546.46	520.08			
Squirt Bottle After		372.25	359.5	325.25	390.11			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		673	487.89	506.93	496.33			
Recovered Water		341.83	179.39	104.13	110.23			
Cumulative Water	0	341.83	521.22	625.35	735.58			
Top-up Bottle Before		1112	1152.9	1178.7	1104.8			
Top-up Bottle After		897.1	844.5	1079.3	958.8			
Top-up Water Used		214.9	308.4	99.4	146			
Copper Percentage (%)	0.259	4.03	2.36	1.45	0.888	0.048	0.06	0.054
Copper Mass (g)	0.0384615	1.297257	0.26314	0.085405	0.0565656	0.00673	0.008112	0.4475682
Cumulative Copper Mass (g)		1.297257	1.560397	1.645802	1.7023676			
Copper Grade (%)		4.03	3.60	3.34	3.06			
Copper Recovery (%)		58.96	70.92	74.80	77.38			
Nickel Percentage (%)	0.18	1.21	2.73	2.28	1.27	0.083	0.088	0.0855
Nickel Mass (g)	0.02673	0.389499	0.304395	0.134292	0.080899	0.01164	0.0118976	0.70864965
Cumulative Nickel Mass (g)		0.389499	0.693894	0.828186	0.909085			
Nickel Grade (%)		1.21	1.60	1.68	1.64			
Nickel Recovery (%)		22.95	40.89	48.80	53.57			

Total Possible Copper (g)	2.164813
Total Copper / Feed (%)	0.233572
Copper Mass Balance	90.18213
Total Possible Nickel (g)	1.64129
Total Nickel / Feed (%)	0.177086
Nickel Mass Balance	98.38133

Figure 82 - Raw data for Senfroth 516 at 3 SPW and 50 g/ton



Date	26-Jul
SPW	3
Ore	Kevitsa
Frother	Senfroth 516
Dosage	60 g/ton
Collector	SIBX (1%)
Collector Dosage	5ml

Feed Run 1	945.6
Feed Run 2	942.7

Total Solids Collected (Run 1)	929.4
Total Solids Collected (Run 1)	928.4

* Plotted run 2 and 3

Cumulative Time	0	2	6	12	20

Run 1

	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	24.4	36.93	22.51	18.9	19.1	24.11	23.21	842.9
Paper	9.73	10.36	10.68	10.09	10.37	10.78	9.73	10.92
Solids (g)	14.67	26.57	11.83	8.81	8.73	13.33	13.48	831.98
Cumulative Solids (g)	0	26.57	38.4	47.21	55.94			
Squirt Bottle Before		374.04	459.37	462.24	502.49			
Squirt Bottle After		310.11	386.6	351.88	258.94			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		568.1	466.64	463.4	672.2			
Recovered Water		287.06	198.19	168.53	170.16			
Cumulative Water	0	287.06	485.25	653.78	823.94			
Top-up Bottle Before		704.6	906.1	909.6	871.4			
Top-up Bottle After		520.54	608.3	713.1	664.3			
Top-up Water Used		184.06	297.8	196.5	207.1			
Copper Percentage (%)	0.262	4.69	2.27	1.24	0.756	0.053	0.052	0.0525
Copper Mass (g)	0.0384354	1.246133	0.268541	0.109244	0.0659988	0.00706	0.0070096	0.4367895
Cumulative Copper Mass (g)		1.246133	1.514674	1.623918	1.6899168			
Copper Grade (%)		4.69	3.94	3.44	3.02			
Copper Recovery (%)		58.21	70.75	75.86	78.94			
Nickel Percentage (%)	0.192	1.29	2.9	1.86	0.99	0.085	0.087	0.086
Nickel Mass (g)	0.0281664	0.342753	0.34307	0.163866	0.086427	0.01133	0.0117276	0.7155028
Cumulative Nickel Mass (g)		0.342753	0.685823	0.849689	0.936116			
Nickel Grade (%)		1.29	1.79	1.80	1.67			
Nickel Recovery (%)		20.47	40.95	50.74	55.90			

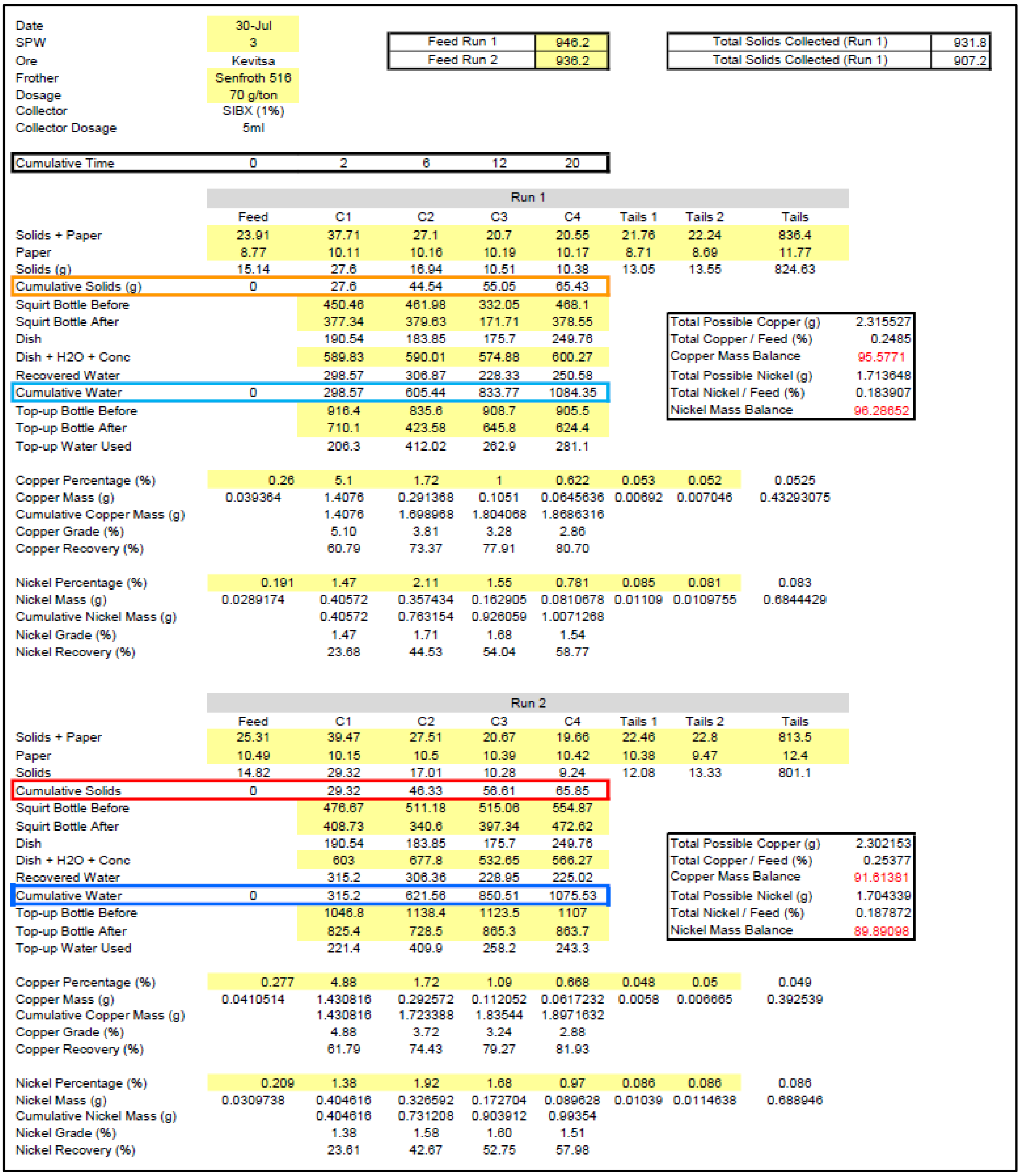
Total Possible Copper (g)	2.140782
Total Copper / Feed (%)	0.23034
Copper Mass Balance	87.9161
Total Possible Nickel (g)	1.674675
Total Nickel / Feed (%)	0.180189
Nickel Mass Balance	93.84837

Run 2

	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	24.57	34.51	21.44	18.16	17.13	23.04	22.63	843.7
Paper	9.59	8.63	8.54	9.51	9.56	9.6	9.63	11.72
Solids	14.98	25.88	12.9	8.65	7.57	13.44	13	831.98
Cumulative Solids	0	25.88	38.78	47.43	55			
Squirt Bottle Before		550.88	562.55	545.78	560.63			
Squirt Bottle After		459.13	461.98	332.05	468.1			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		587.33	511.7	560.95	509.62			
Recovered Water		279.16	214.38	162.87	159.76			
Cumulative Water	0	279.16	493.54	656.41	816.17			
Top-up Bottle Before		1119.5	1151.5	1122.7	1054.1			
Top-up Bottle After		916.4	835.6	908.7	905.5			
Top-up Water Used		203.1	315.9	214	148.6			
Copper Percentage (%)	0.26	5.14	2.07	1.28	0.945	0.056	0.055	0.0555
Copper Mass (g)	0.038948	1.330232	0.26703	0.11072	0.0715365	0.00753	0.00715	0.4617489
Cumulative Copper Mass (g)		1.330232	1.597262	1.707982	1.7795185			
Copper Grade (%)		5.14	4.12	3.60	3.24			
Copper Recovery (%)		62.14	74.61	79.78	83.12			
Nickel Percentage (%)	0.187	1.47	2.45	1.92	1.31	0.092	0.086	0.089
Nickel Mass (g)	0.0280126	0.380436	0.31605	0.16608	0.099167	0.01236	0.01118	0.7404622
Cumulative Nickel Mass (g)		0.380436	0.696486	0.862566	0.961733			
Nickel Grade (%)		1.47	1.80	1.82	1.75			
Nickel Recovery (%)		22.72	41.59	51.51	57.43			

Total Possible Copper (g)	2.255942
Total Copper / Feed (%)	0.242992
Copper Mass Balance	93.45862
Total Possible Nickel (g)	1.725727
Total Nickel / Feed (%)	0.185882
Nickel Mass Balance	99.40204

Figure 83 - Raw data for Senfroth 516 at 3 SPW and 60 g/ton



Date	30-Jul
SPW	3
Ore	Kevitsa
Frother	Senfroth 516
Dosage	70 g/ton
Collector	SIBX (1%)
Collector Dosage	5ml

Feed Run 1	946.2
Feed Run 2	936.2

Total Solids Collected (Run 1)	931.8
Total Solids Collected (Run 1)	907.2

Cumulative Time	0	2	6	12	20

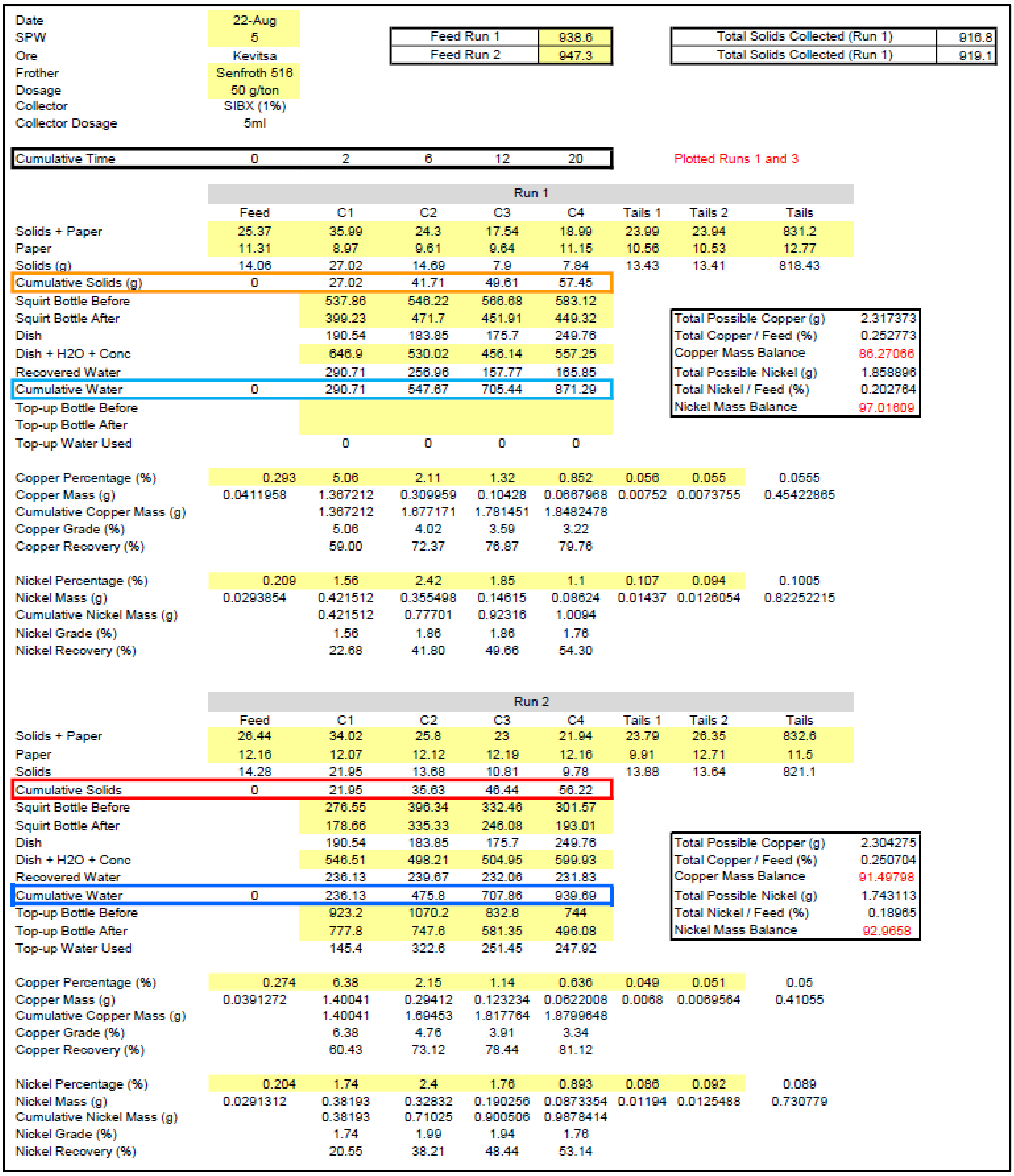
	Run 1							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	23.91	37.71	27.1	20.7	20.55	21.76	22.24	836.4
Paper	8.77	10.11	10.16	10.19	10.17	8.71	8.69	11.77
Solids (g)	15.14	27.6	16.94	10.51	10.38	13.05	13.55	824.63
Cumulative Solids (g)	0	27.6	44.54	55.05	65.43			
Squirt Bottle Before		450.46	461.98	332.05	468.1			
Squirt Bottle After		377.34	379.63	171.71	378.55			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		589.83	590.01	574.88	600.27			
Recovered Water		298.57	306.87	228.33	250.58			
Cumulative Water	0	298.57	605.44	833.77	1084.35			
Top-up Bottle Before		916.4	835.6	908.7	905.5			
Top-up Bottle After		710.1	423.58	645.8	624.4			
Top-up Water Used		206.3	412.02	262.9	281.1			
Copper Percentage (%)	0.26	5.1	1.72	1	0.622	0.053	0.052	0.0525
Copper Mass (g)	0.039364	1.4076	0.291368	0.1051	0.0645636	0.00692	0.007046	0.43293075
Cumulative Copper Mass (g)		1.4076	1.698968	1.804068	1.8686316			
Copper Grade (%)		5.10	3.81	3.28	2.86			
Copper Recovery (%)		60.79	73.37	77.91	80.70			
Nickel Percentage (%)	0.191	1.47	2.11	1.55	0.781	0.085	0.081	0.083
Nickel Mass (g)	0.0289174	0.40572	0.357434	0.162905	0.0810678	0.01109	0.0109755	0.6844429
Cumulative Nickel Mass (g)		0.40572	0.763154	0.926059	1.0071268			
Nickel Grade (%)		1.47	1.71	1.68	1.54			
Nickel Recovery (%)		23.68	44.53	54.04	58.77			

Total Possible Copper (g)	2.315527
Total Copper / Feed (%)	0.2485
Copper Mass Balance	95.5771
Total Possible Nickel (g)	1.713648
Total Nickel / Feed (%)	0.183907
Nickel Mass Balance	96.28652

	Run 2							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	25.31	39.47	27.51	20.67	19.66	22.46	22.8	813.5
Paper	10.49	10.15	10.5	10.39	10.42	10.38	9.47	12.4
Solids	14.82	29.32	17.01	10.28	9.24	12.08	13.33	801.1
Cumulative Solids	0	29.32	46.33	56.61	65.85			
Squirt Bottle Before		476.67	511.18	515.06	554.87			
Squirt Bottle After		408.73	340.6	397.34	472.62			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		603	677.8	532.65	566.27			
Recovered Water		315.2	306.36	228.95	225.02			
Cumulative Water	0	315.2	621.56	850.51	1075.53			
Top-up Bottle Before		1046.8	1138.4	1123.5	1107			
Top-up Bottle After		825.4	728.5	865.3	863.7			
Top-up Water Used		221.4	409.9	258.2	243.3			
Copper Percentage (%)	0.277	4.88	1.72	1.09	0.668	0.048	0.05	0.049
Copper Mass (g)	0.0410514	1.430816	0.292572	0.112052	0.0617232	0.0058	0.006665	0.392539
Cumulative Copper Mass (g)		1.430816	1.723388	1.83544	1.8971632			
Copper Grade (%)		4.88	3.72	3.24	2.88			
Copper Recovery (%)		61.79	74.43	79.27	81.93			
Nickel Percentage (%)	0.209	1.38	1.92	1.68	0.97	0.086	0.086	0.086
Nickel Mass (g)	0.0309738	0.404616	0.326592	0.172704	0.089628	0.01039	0.0114638	0.688946
Cumulative Nickel Mass (g)		0.404616	0.731208	0.903912	0.99354			
Nickel Grade (%)		1.38	1.58	1.60	1.51			
Nickel Recovery (%)		23.61	42.67	52.75	57.98			

Total Possible Copper (g)	2.302153
Total Copper / Feed (%)	0.25377
Copper Mass Balance	91.61381
Total Possible Nickel (g)	1.704339
Total Nickel / Feed (%)	0.187872
Nickel Mass Balance	89.89098

Figure 84 - Raw data for Senfroth 516 at 3 SPW and 70 g/ton



Date	22-Aug
SPW	5
Ore	Kevitsa
Frother	Senfroth 516
Dosage	50 g/ton
Collector	SIBX (1%)
Collector Dosage	5ml

Feed Run 1	938.6
Feed Run 2	947.3

Total Solids Collected (Run 1)	916.8
Total Solids Collected (Run 1)	919.1

Cumulative Time	0	2	6	12	20

Plotted Runs 1 and 3

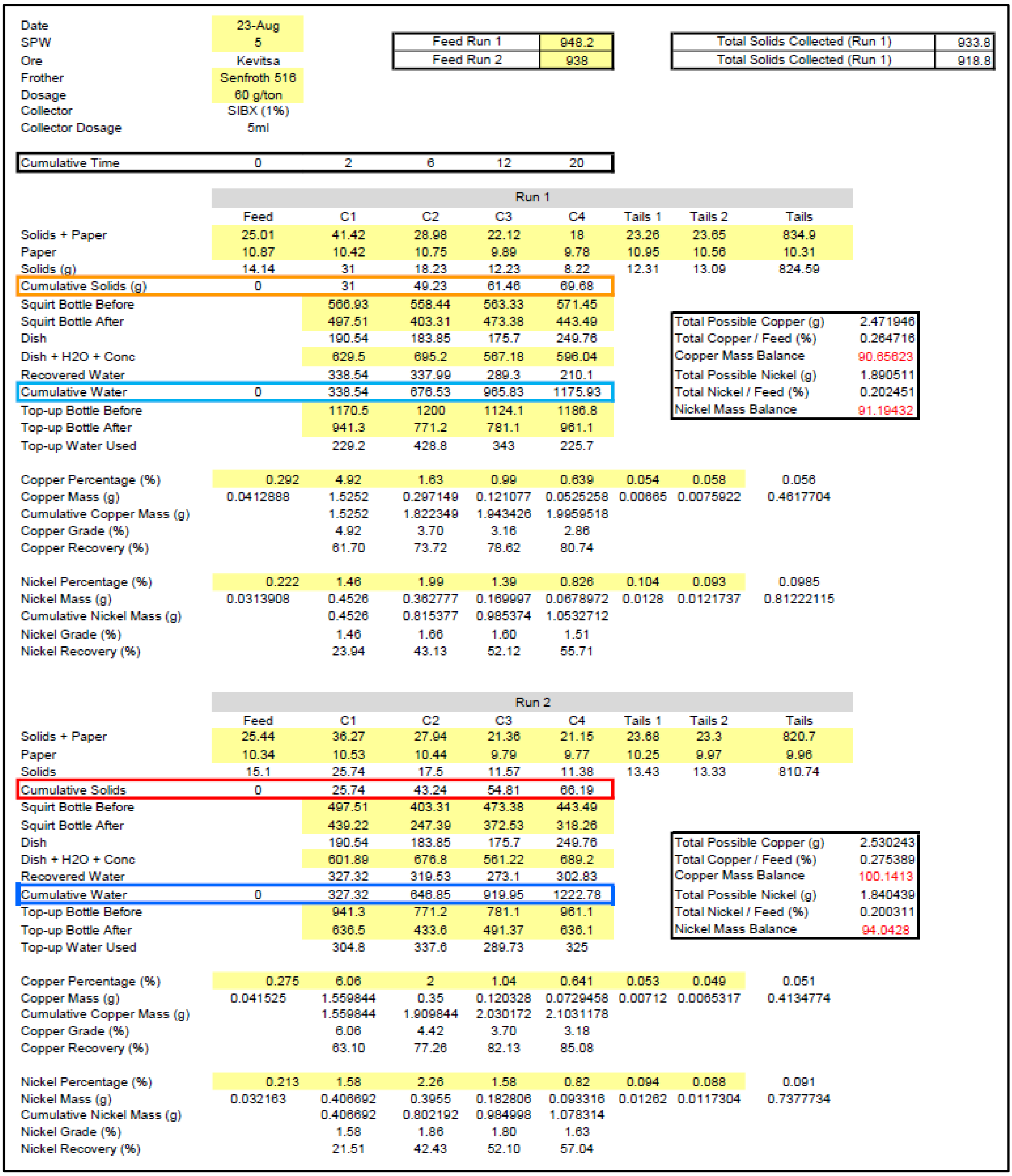
	Run 1							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	25.37	35.99	24.3	17.54	18.99	23.99	23.94	831.2
Paper	11.31	8.97	9.61	9.64	11.15	10.56	10.53	12.77
Solids (g)	14.06	27.02	14.69	7.9	7.84	13.43	13.41	818.43
Cumulative Solids (g)	0	27.02	41.71	49.61	57.45			
Squirt Bottle Before		537.86	546.22	566.68	583.12			
Squirt Bottle After		399.23	471.7	451.91	449.32			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		646.9	530.02	456.14	557.25			
Recovered Water		290.71	256.96	157.77	165.85			
Cumulative Water	0	290.71	547.67	705.44	871.29			
Top-up Bottle Before								
Top-up Bottle After								
Top-up Water Used		0	0	0	0			
Copper Percentage (%)	0.293	5.06	2.11	1.32	0.852	0.056	0.055	0.0555
Copper Mass (g)	0.0411958	1.367212	0.309959	0.10428	0.0667968	0.00752	0.0073755	0.45422865
Cumulative Copper Mass (g)		1.367212	1.677171	1.781451	1.8482478			
Copper Grade (%)		5.06	4.02	3.59	3.22			
Copper Recovery (%)		59.00	72.37	76.87	79.76			
Nickel Percentage (%)	0.209	1.56	2.42	1.85	1.1	0.107	0.094	0.1005
Nickel Mass (g)	0.0293854	0.421512	0.355498	0.14615	0.08624	0.01437	0.0126054	0.82252215
Cumulative Nickel Mass (g)		0.421512	0.77701	0.92316	1.0094			
Nickel Grade (%)		1.56	1.86	1.86	1.76			
Nickel Recovery (%)		22.68	41.80	49.66	54.30			

Total Possible Copper (g)	2.317373
Total Copper / Feed (%)	0.252773
Copper Mass Balance	86.27066
Total Possible Nickel (g)	1.858896
Total Nickel / Feed (%)	0.202764
Nickel Mass Balance	97.01609

	Run 2							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	26.44	34.02	25.8	23	21.94	23.79	26.35	832.6
Paper	12.16	12.07	12.12	12.19	12.16	9.91	12.71	11.5
Solids	14.28	21.95	13.68	10.81	9.78	13.88	13.64	821.1
Cumulative Solids	0	21.95	35.63	46.44	56.22			
Squirt Bottle Before		276.55	396.34	332.46	301.57			
Squirt Bottle After		178.66	335.33	246.08	193.01			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		546.51	498.21	504.95	599.93			
Recovered Water		236.13	239.67	232.06	231.83			
Cumulative Water	0	236.13	475.8	707.86	939.69			
Top-up Bottle Before		923.2	1070.2	832.8	744			
Top-up Bottle After		777.8	747.6	581.35	496.08			
Top-up Water Used		145.4	322.6	251.45	247.92			
Copper Percentage (%)	0.274	6.38	2.15	1.14	0.636	0.049	0.051	0.05
Copper Mass (g)	0.0391272	1.40041	0.29412	0.123234	0.0622008	0.0068	0.0069564	0.41055
Cumulative Copper Mass (g)		1.40041	1.69453	1.817764	1.8799648			
Copper Grade (%)		6.38	4.76	3.91	3.34			
Copper Recovery (%)		60.43	73.12	78.44	81.12			
Nickel Percentage (%)	0.204	1.74	2.4	1.76	0.893	0.086	0.092	0.089
Nickel Mass (g)	0.0291312	0.38193	0.32832	0.190256	0.0873354	0.01194	0.0125488	0.730779
Cumulative Nickel Mass (g)		0.38193	0.71025	0.900506	0.9878414			
Nickel Grade (%)		1.74	1.99	1.94	1.76			
Nickel Recovery (%)		20.55	38.21	48.44	53.14			

Total Possible Copper (g)	2.304275
Total Copper / Feed (%)	0.250704
Copper Mass Balance	91.49798
Total Possible Nickel (g)	1.743113
Total Nickel / Feed (%)	0.18965
Nickel Mass Balance	92.9658

Figure 85 - Raw data for Senfroth 516 at 5 SPW and 50 g/ton



Date	23-Aug
SPW	5
Ore	Kevitsa
Frother	Senfroth 516
Dosage	60 g/ton
Collector	SIBX (1%)
Collector Dosage	5ml

Feed Run 1	948.2
Feed Run 2	938

Total Solids Collected (Run 1)	933.8
Total Solids Collected (Run 1)	918.8

Cumulative Time	0	2	6	12	20

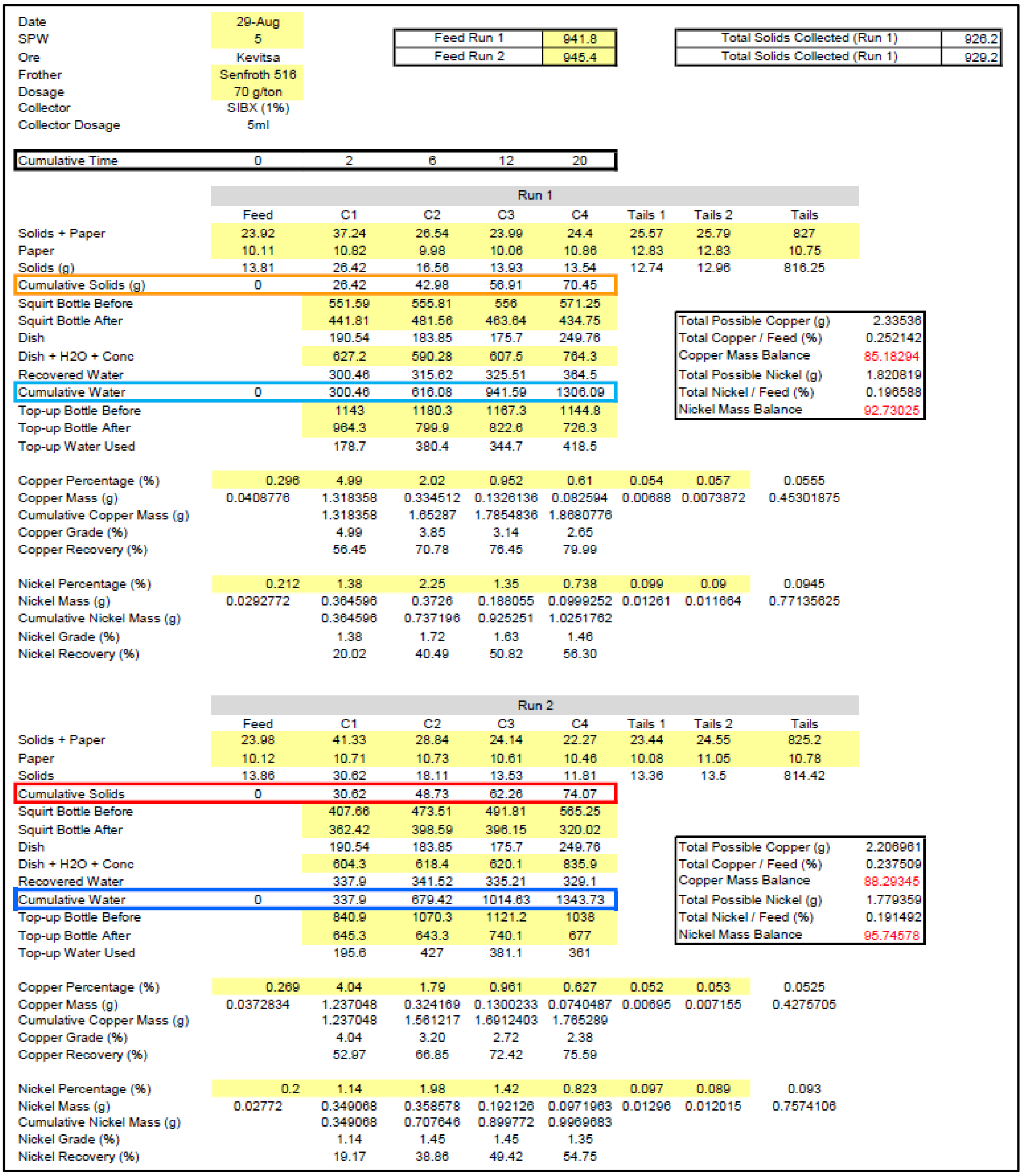
	Run 1							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	25.01	41.42	28.98	22.12	18	23.26	23.65	834.9
Paper	10.87	10.42	10.75	9.89	9.78	10.95	10.56	10.31
Solids (g)	14.14	31	18.23	12.23	8.22	12.31	13.09	824.59
Cumulative Solids (g)	0	31	49.23	61.46	69.68			
Squirt Bottle Before		566.93	558.44	563.33	571.45			
Squirt Bottle After		497.51	403.31	473.38	443.49			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		629.5	695.2	567.18	596.04			
Recovered Water		338.54	337.99	289.3	210.1			
Cumulative Water	0	338.54	676.53	965.83	1175.93			
Top-up Bottle Before		1170.5	1200	1124.1	1186.8			
Top-up Bottle After		941.3	771.2	781.1	961.1			
Top-up Water Used		229.2	428.8	343	225.7			
Copper Percentage (%)	0.292	4.92	1.63	0.99	0.639	0.054	0.058	0.056
Copper Mass (g)	0.0412888	1.5252	0.297149	0.121077	0.0525258	0.00665	0.0075922	0.4617704
Cumulative Copper Mass (g)		1.5252	1.822349	1.943426	1.9959518			
Copper Grade (%)		4.92	3.70	3.16	2.86			
Copper Recovery (%)		61.70	73.72	78.62	80.74			
Nickel Percentage (%)	0.222	1.46	1.99	1.39	0.826	0.104	0.093	0.0985
Nickel Mass (g)	0.0313908	0.4526	0.362777	0.169997	0.0678972	0.0128	0.0121737	0.81222115
Cumulative Nickel Mass (g)		0.4526	0.815377	0.985374	1.0532712			
Nickel Grade (%)		1.46	1.66	1.60	1.51			
Nickel Recovery (%)		23.94	43.13	52.12	55.71			

Total Possible Copper (g)	2.471946
Total Copper / Feed (%)	0.264716
Copper Mass Balance	90.65623
Total Possible Nickel (g)	1.890511
Total Nickel / Feed (%)	0.202451
Nickel Mass Balance	91.19432

	Run 2							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	25.44	36.27	27.94	21.36	21.15	23.68	23.3	820.7
Paper	10.34	10.53	10.44	9.79	9.77	10.25	9.97	9.96
Solids	15.1	25.74	17.5	11.57	11.38	13.43	13.33	810.74
Cumulative Solids	0	25.74	43.24	54.81	66.19			
Squirt Bottle Before		497.51	403.31	473.38	443.49			
Squirt Bottle After		439.22	247.39	372.53	318.26			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		601.89	676.8	561.22	689.2			
Recovered Water		327.32	319.53	273.1	302.83			
Cumulative Water	0	327.32	646.85	919.95	1222.78			
Top-up Bottle Before		941.3	771.2	781.1	961.1			
Top-up Bottle After		636.5	433.6	491.37	636.1			
Top-up Water Used		304.8	337.6	289.73	325			
Copper Percentage (%)	0.275	6.06	2	1.04	0.641	0.053	0.049	0.051
Copper Mass (g)	0.041525	1.559844	0.35	0.120328	0.0729458	0.00712	0.0065317	0.4134774
Cumulative Copper Mass (g)		1.559844	1.909844	2.030172	2.1031178			
Copper Grade (%)		6.06	4.42	3.70	3.18			
Copper Recovery (%)		63.10	77.26	82.13	85.08			
Nickel Percentage (%)	0.213	1.58	2.26	1.58	0.82	0.094	0.088	0.091
Nickel Mass (g)	0.032163	0.406692	0.3955	0.182806	0.093316	0.01262	0.0117304	0.7377734
Cumulative Nickel Mass (g)		0.406692	0.802192	0.984998	1.078314			
Nickel Grade (%)		1.58	1.86	1.80	1.63			
Nickel Recovery (%)		21.51	42.43	52.10	57.04			

Total Possible Copper (g)	2.530243
Total Copper / Feed (%)	0.275389
Copper Mass Balance	100.1413
Total Possible Nickel (g)	1.840439
Total Nickel / Feed (%)	0.200311
Nickel Mass Balance	94.0428

Figure 86 - Raw data for Senfroth 516 at 5 SPW and 60 g/ton



Date	29-Aug
SPW	5
Ore	Kevitsa
Frother	Senfroth 516
Dosage	70 g/ton
Collector	SIBX (1%)
Collector Dosage	5ml

Feed Run 1	941.8
Feed Run 2	945.4

Total Solids Collected (Run 1)	926.2
Total Solids Collected (Run 1)	929.2

Cumulative Time	0	2	6	12	20

Run 1

	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	23.92	37.24	26.54	23.99	24.4	25.57	25.79	827
Paper	10.11	10.82	9.98	10.06	10.86	12.83	12.83	10.75
Solids (g)	13.81	26.42	16.56	13.93	13.54	12.74	12.96	816.25
Cumulative Solids (g)	0	26.42	42.98	56.91	70.45			
Squirt Bottle Before		551.59	555.81	556	571.25			
Squirt Bottle After		441.81	481.56	463.64	434.75			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		627.2	590.28	607.5	764.3			
Recovered Water		300.46	315.62	325.51	364.5			
Cumulative Water	0	300.46	616.08	941.59	1306.09			
Top-up Bottle Before		1143	1180.3	1167.3	1144.8			
Top-up Bottle After		964.3	799.9	822.6	726.3			
Top-up Water Used		178.7	380.4	344.7	418.5			
Copper Percentage (%)	0.296	4.99	2.02	0.952	0.61	0.054	0.057	0.0555
Copper Mass (g)	0.0408776	1.318358	0.334512	0.1326136	0.082594	0.00688	0.0073872	0.45301875
Cumulative Copper Mass (g)		1.318358	1.65287	1.7854836	1.8680776			
Copper Grade (%)		4.99	3.85	3.14	2.65			
Copper Recovery (%)		56.45	70.78	76.45	79.99			
Nickel Percentage (%)	0.212	1.38	2.25	1.35	0.738	0.099	0.09	0.0945
Nickel Mass (g)	0.0292772	0.364596	0.3726	0.188055	0.0999252	0.01261	0.011664	0.77135625
Cumulative Nickel Mass (g)		0.364596	0.737196	0.925251	1.0251762			
Nickel Grade (%)		1.38	1.72	1.63	1.46			
Nickel Recovery (%)		20.02	40.49	50.82	56.30			

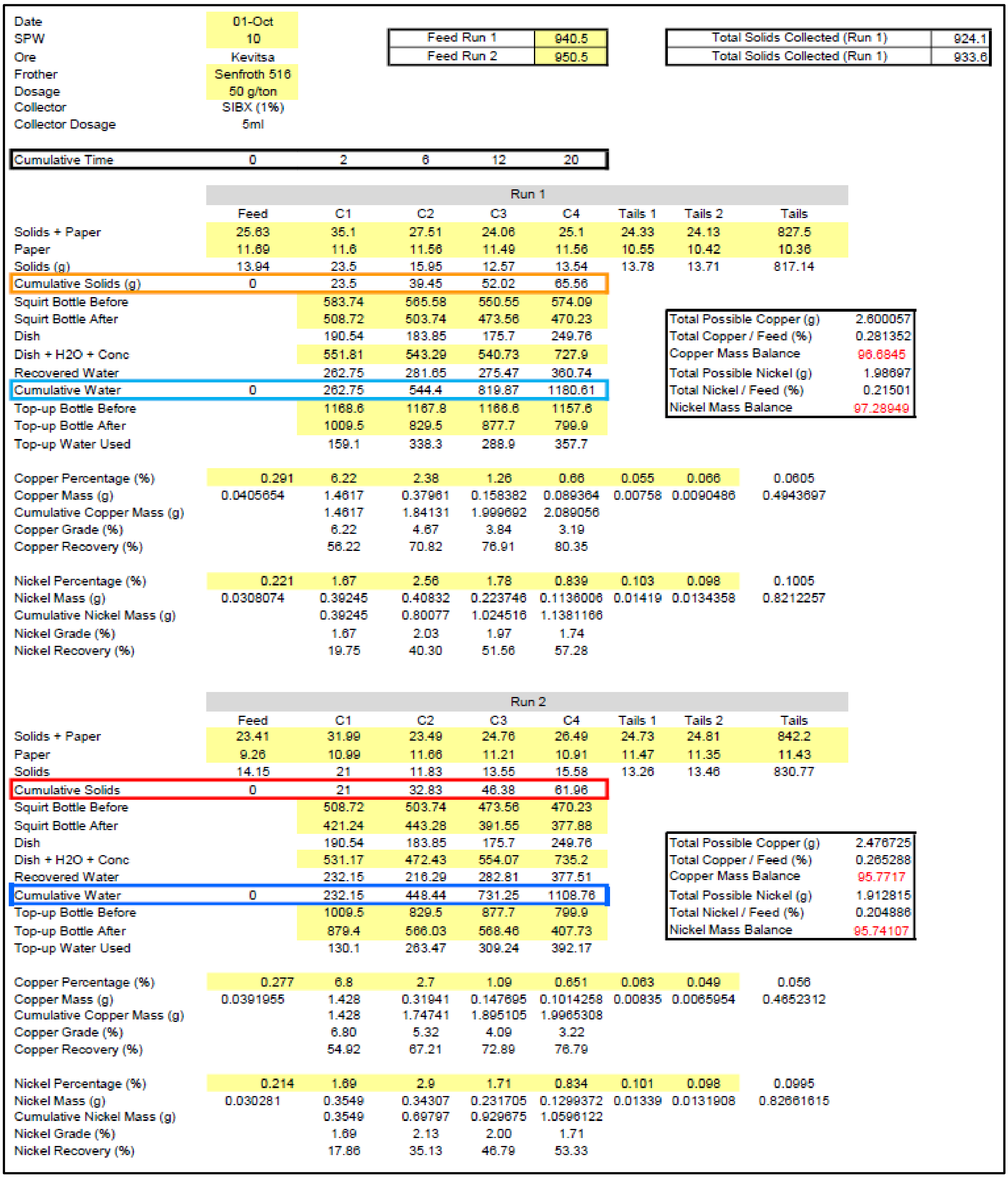
Total Possible Copper (g)	2.33536
Total Copper / Feed (%)	0.252142
Copper Mass Balance	85.18294
Total Possible Nickel (g)	1.820819
Total Nickel / Feed (%)	0.196588
Nickel Mass Balance	92.73025

Run 2

	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	23.98	41.33	28.84	24.14	22.27	23.44	24.55	825.2
Paper	10.12	10.71	10.73	10.61	10.46	10.08	11.05	10.78
Solids	13.86	30.62	18.11	13.53	11.81	13.36	13.5	814.42
Cumulative Solids	0	30.62	48.73	62.26	74.07			
Squirt Bottle Before		407.66	473.51	491.81	565.25			
Squirt Bottle After		362.42	398.59	396.15	320.02			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		604.3	618.4	620.1	835.9			
Recovered Water		337.9	341.52	335.21	329.1			
Cumulative Water	0	337.9	679.42	1014.63	1343.73			
Top-up Bottle Before		840.9	1070.3	1121.2	1038			
Top-up Bottle After		645.3	643.3	740.1	677			
Top-up Water Used		195.6	427	381.1	361			
Copper Percentage (%)	0.269	4.04	1.79	0.961	0.627	0.052	0.053	0.0525
Copper Mass (g)	0.0372834	1.237048	0.324169	0.1300233	0.0740487	0.00695	0.007155	0.4275705
Cumulative Copper Mass (g)		1.237048	1.561217	1.6912403	1.765289			
Copper Grade (%)		4.04	3.20	2.72	2.38			
Copper Recovery (%)		52.97	66.85	72.42	75.59			
Nickel Percentage (%)	0.2	1.14	1.98	1.42	0.823	0.097	0.089	0.093
Nickel Mass (g)	0.02772	0.349068	0.358578	0.192126	0.0971963	0.01296	0.012015	0.7574106
Cumulative Nickel Mass (g)		0.349068	0.707646	0.899772	0.9969683			
Nickel Grade (%)		1.14	1.45	1.45	1.35			
Nickel Recovery (%)		19.17	38.86	49.42	54.75			

Total Possible Copper (g)	2.206961
Total Copper / Feed (%)	0.237509
Copper Mass Balance	88.29345
Total Possible Nickel (g)	1.779359
Total Nickel / Feed (%)	0.191492
Nickel Mass Balance	95.74578

Figure 87 - Raw data for Senfroth 516 at 5 SPW and 70 g/ton



Date	01-Oct
SPW	10
Ore	Kevitsa
Frother	Senfroth 516
Dosage	50 g/ton
Collector	SIBX (1%)
Collector Dosage	5ml

Feed Run 1	940.5
Feed Run 2	950.5

Total Solids Collected (Run 1)	924.1
Total Solids Collected (Run 1)	933.6

Cumulative Time	0	2	6	12	20

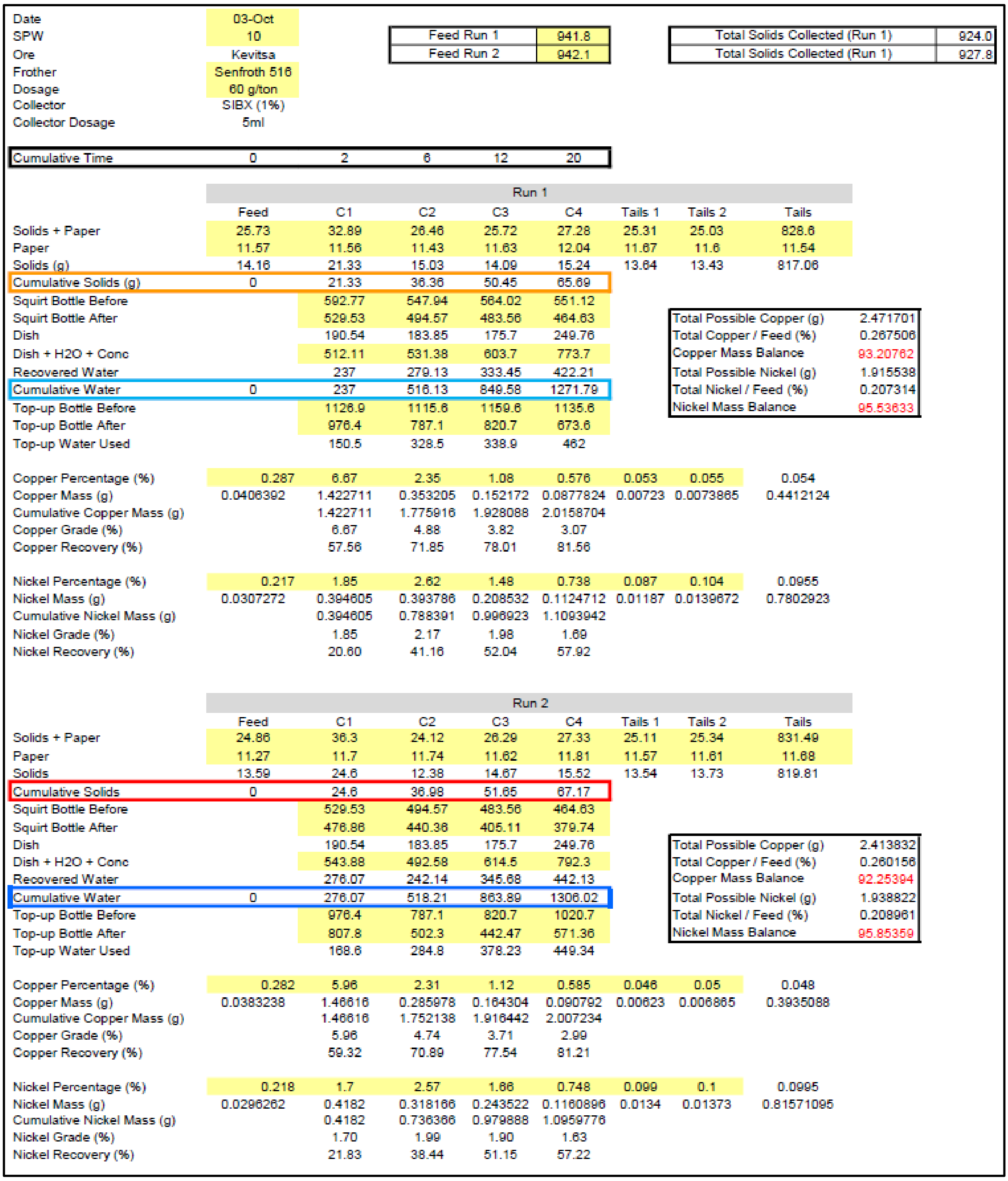
	Run 1							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	25.63	35.1	27.51	24.06	25.1	24.33	24.13	827.5
Paper	11.69	11.6	11.56	11.49	11.56	10.55	10.42	10.36
Solids (g)	13.94	23.5	15.95	12.57	13.54	13.78	13.71	817.14
Cumulative Solids (g)	0	23.5	39.45	52.02	65.56			
Squirt Bottle Before		583.74	565.58	550.55	574.09			
Squirt Bottle After		508.72	503.74	473.56	470.23			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		551.81	543.29	540.73	727.9			
Recovered Water		262.75	281.65	275.47	360.74			
Cumulative Water	0	262.75	544.4	819.87	1180.61			
Top-up Bottle Before		1168.6	1167.8	1166.6	1157.6			
Top-up Bottle After		1009.5	829.5	877.7	799.9			
Top-up Water Used		159.1	338.3	288.9	357.7			
Copper Percentage (%)	0.291	6.22	2.38	1.26	0.66	0.055	0.066	0.0605
Copper Mass (g)	0.0405654	1.4617	0.37961	0.158382	0.089364	0.00758	0.0090486	0.4943697
Cumulative Copper Mass (g)		1.4617	1.84131	1.999692	2.089056			
Copper Grade (%)		6.22	4.67	3.84	3.19			
Copper Recovery (%)		56.22	70.82	76.91	80.35			
Nickel Percentage (%)	0.221	1.67	2.56	1.78	0.839	0.103	0.098	0.1005
Nickel Mass (g)	0.0308074	0.39245	0.40832	0.223746	0.1136006	0.01419	0.0134358	0.8212257
Cumulative Nickel Mass (g)		0.39245	0.80077	1.024516	1.1381166			
Nickel Grade (%)		1.67	2.03	1.97	1.74			
Nickel Recovery (%)		19.75	40.30	51.56	57.28			

Total Possible Copper (g)	2.600057
Total Copper / Feed (%)	0.281352
Copper Mass Balance	96.6845
Total Possible Nickel (g)	1.98697
Total Nickel / Feed (%)	0.21501
Nickel Mass Balance	97.28949

	Run 2							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	23.41	31.99	23.49	24.76	26.49	24.73	24.81	842.2
Paper	9.26	10.99	11.66	11.21	10.91	11.47	11.35	11.43
Solids	14.15	21	11.83	13.55	15.58	13.26	13.46	830.77
Cumulative Solids	0	21	32.83	46.38	61.96			
Squirt Bottle Before		508.72	503.74	473.56	470.23			
Squirt Bottle After		421.24	443.28	391.55	377.88			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		531.17	472.43	554.07	735.2			
Recovered Water		232.15	216.29	282.81	377.51			
Cumulative Water	0	232.15	448.44	731.25	1108.76			
Top-up Bottle Before		1009.5	829.5	877.7	799.9			
Top-up Bottle After		879.4	566.03	568.46	407.73			
Top-up Water Used		130.1	263.47	309.24	392.17			
Copper Percentage (%)	0.277	6.8	2.7	1.09	0.651	0.063	0.049	0.056
Copper Mass (g)	0.0391955	1.428	0.31941	0.147695	0.1014258	0.00835	0.0065954	0.4652312
Cumulative Copper Mass (g)		1.428	1.74741	1.895105	1.9965308			
Copper Grade (%)		6.80	5.32	4.09	3.22			
Copper Recovery (%)		54.92	67.21	72.89	76.79			
Nickel Percentage (%)	0.214	1.69	2.9	1.71	0.834	0.101	0.098	0.0995
Nickel Mass (g)	0.030281	0.3549	0.34307	0.231705	0.1299372	0.01339	0.0131908	0.82661615
Cumulative Nickel Mass (g)		0.3549	0.69797	0.929675	1.0596122			
Nickel Grade (%)		1.69	2.13	2.00	1.71			
Nickel Recovery (%)		17.86	35.13	46.79	53.33			

Total Possible Copper (g)	2.476725
Total Copper / Feed (%)	0.265288
Copper Mass Balance	95.7717
Total Possible Nickel (g)	1.912815
Total Nickel / Feed (%)	0.204886
Nickel Mass Balance	95.74107

Figure 88 - Raw data for Senfroth 516 at 10 SPW and 50 g/ton



Date	03-Oct
SPW	10
Ore	Kevitsa
Frother	Senfroth 516
Dosage	60 g/ton
Collector	SIBX (1%)
Collector Dosage	5ml

Feed Run 1	941.8
Feed Run 2	942.1

Total Solids Collected (Run 1)	924.0
Total Solids Collected (Run 1)	927.8

Cumulative Time	0	2	6	12	20

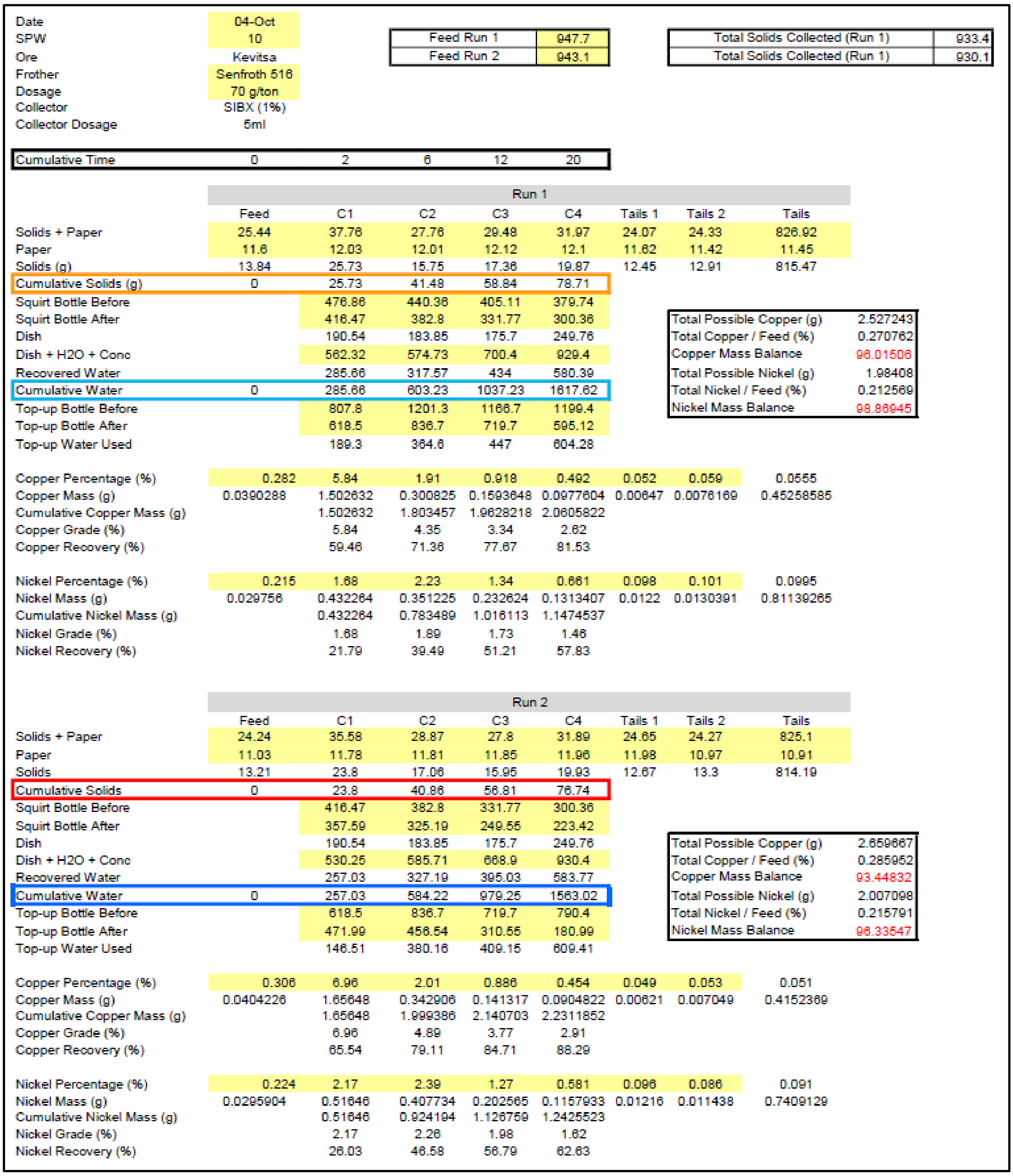
	Run 1							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	25.73	32.89	26.46	25.72	27.28	25.31	25.03	828.6
Paper	11.57	11.56	11.43	11.63	12.04	11.67	11.6	11.54
Solids (g)	14.16	21.33	15.03	14.09	15.24	13.64	13.43	817.06
Cumulative Solids (g)	0	21.33	36.36	50.45	65.69			
Squirt Bottle Before		592.77	547.94	564.02	551.12			
Squirt Bottle After		529.53	494.57	483.56	464.63			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		512.11	531.38	603.7	773.7			
Recovered Water		237	279.13	333.45	422.21			
Cumulative Water	0	237	516.13	849.58	1271.79			
Top-up Bottle Before		1126.9	1115.6	1159.6	1135.6			
Top-up Bottle After		976.4	787.1	820.7	673.6			
Top-up Water Used		150.5	328.5	338.9	462			
Copper Percentage (%)	0.287	6.67	2.35	1.08	0.576	0.053	0.055	0.054
Copper Mass (g)	0.0406392	1.422711	0.353205	0.152172	0.0877824	0.00723	0.0073865	0.4412124
Cumulative Copper Mass (g)		1.422711	1.775916	1.928088	2.0158704			
Copper Grade (%)		6.67	4.88	3.82	3.07			
Copper Recovery (%)		57.56	71.85	78.01	81.56			
Nickel Percentage (%)	0.217	1.85	2.62	1.48	0.738	0.087	0.104	0.0955
Nickel Mass (g)	0.0307272	0.394605	0.393786	0.208532	0.1124712	0.01187	0.0139672	0.7802923
Cumulative Nickel Mass (g)		0.394605	0.788391	0.996923	1.1093942			
Nickel Grade (%)		1.85	2.17	1.98	1.69			
Nickel Recovery (%)		20.60	41.16	52.04	57.92			

Total Possible Copper (g)	2.471701
Total Copper / Feed (%)	0.267506
Copper Mass Balance	93.20762
Total Possible Nickel (g)	1.915538
Total Nickel / Feed (%)	0.207314
Nickel Mass Balance	95.53633

	Run 2							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	24.86	36.3	24.12	26.29	27.33	25.11	25.34	831.49
Paper	11.27	11.7	11.74	11.62	11.81	11.57	11.61	11.68
Solids	13.59	24.6	12.38	14.67	15.52	13.54	13.73	819.81
Cumulative Solids	0	24.6	36.98	51.65	67.17			
Squirt Bottle Before		529.53	494.57	483.56	464.63			
Squirt Bottle After		476.86	440.36	405.11	379.74			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		543.88	492.58	614.5	792.3			
Recovered Water		276.07	242.14	345.68	442.13			
Cumulative Water	0	276.07	518.21	863.89	1306.02			
Top-up Bottle Before		976.4	787.1	820.7	1020.7			
Top-up Bottle After		807.8	502.3	442.47	571.36			
Top-up Water Used		168.6	284.8	378.23	449.34			
Copper Percentage (%)	0.282	5.96	2.31	1.12	0.585	0.046	0.05	0.048
Copper Mass (g)	0.0383238	1.46616	0.285978	0.164304	0.090792	0.00623	0.006865	0.3935088
Cumulative Copper Mass (g)		1.46616	1.752138	1.916442	2.007234			
Copper Grade (%)		5.96	4.74	3.71	2.99			
Copper Recovery (%)		59.32	70.89	77.54	81.21			
Nickel Percentage (%)	0.218	1.7	2.57	1.66	0.748	0.099	0.1	0.0995
Nickel Mass (g)	0.0296262	0.4182	0.318166	0.243522	0.1160896	0.0134	0.01373	0.81571095
Cumulative Nickel Mass (g)		0.4182	0.736366	0.979888	1.0959776			
Nickel Grade (%)		1.70	1.99	1.90	1.63			
Nickel Recovery (%)		21.83	38.44	51.15	57.22			

Total Possible Copper (g)	2.413832
Total Copper / Feed (%)	0.260156
Copper Mass Balance	92.25394
Total Possible Nickel (g)	1.938822
Total Nickel / Feed (%)	0.208961
Nickel Mass Balance	95.85359

Figure 89 - Raw data for Senfroth 516 at 10 SPW and 60 g/ton



Date	04-Oct
SPW	10
Ore	Kevitsa
Frother	Senfroth 516
Dosage	70 g/ton
Collector	SIBX (1%)
Collector Dosage	5ml

Feed Run 1	947.7
Feed Run 2	943.1

Total Solids Collected (Run 1)	933.4
Total Solids Collected (Run 1)	930.1

Cumulative Time	0	2	6	12	20

	Run 1							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	25.44	37.76	27.76	29.48	31.97	24.07	24.33	826.92
Paper	11.6	12.03	12.01	12.12	12.1	11.62	11.42	11.45
Solids (g)	13.84	25.73	15.75	17.36	19.87	12.45	12.91	815.47
Cumulative Solids (g)	0	25.73	41.48	58.84	78.71			
Squirt Bottle Before		476.86	440.36	405.11	379.74			
Squirt Bottle After		416.47	382.8	331.77	300.36			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		562.32	574.73	700.4	929.4			
Recovered Water		285.66	317.57	434	580.39			
Cumulative Water	0	285.66	603.23	1037.23	1617.62			
Top-up Bottle Before		807.8	1201.3	1166.7	1199.4			
Top-up Bottle After		618.5	836.7	719.7	595.12			
Top-up Water Used		189.3	364.6	447	604.28			
Copper Percentage (%)	0.282	5.84	1.91	0.918	0.492	0.052	0.059	0.0555
Copper Mass (g)	0.0390288	1.502632	0.300825	0.1593648	0.0977604	0.00647	0.0076169	0.45258585
Cumulative Copper Mass (g)		1.502632	1.803457	1.9628218	2.0605822			
Copper Grade (%)		5.84	4.35	3.34	2.62			
Copper Recovery (%)		59.46	71.36	77.67	81.53			
Nickel Percentage (%)	0.215	1.68	2.23	1.34	0.661	0.098	0.101	0.0995
Nickel Mass (g)	0.029756	0.432264	0.351225	0.232624	0.1313407	0.0122	0.0130391	0.81139265
Cumulative Nickel Mass (g)		0.432264	0.783489	1.016113	1.1474537			
Nickel Grade (%)		1.68	1.89	1.73	1.46			
Nickel Recovery (%)		21.79	39.49	51.21	57.83			

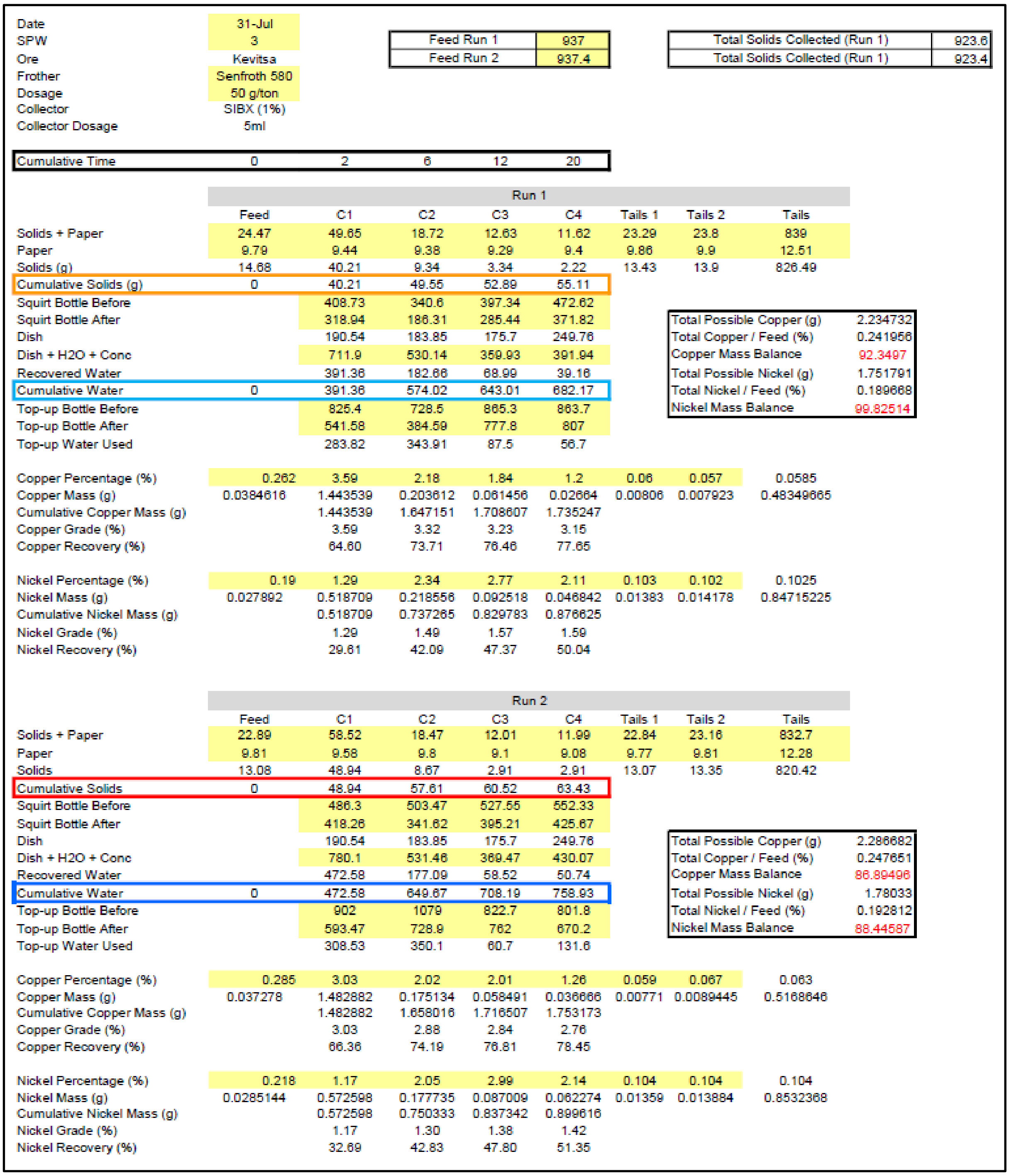
Total Possible Copper (g)	2.527243
Total Copper / Feed (%)	0.270762
Copper Mass Balance	96.01506
Total Possible Nickel (g)	1.98408
Total Nickel / Feed (%)	0.212569
Nickel Mass Balance	98.86945

	Run 2							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	24.24	35.58	28.87	27.8	31.89	24.65	24.27	825.1
Paper	11.03	11.78	11.81	11.85	11.96	11.98	10.97	10.91
Solids	13.21	23.8	17.06	15.95	19.93	12.67	13.3	814.19
Cumulative Solids	0	23.8	40.86	56.81	76.74			
Squirt Bottle Before		416.47	382.8	331.77	300.36			
Squirt Bottle After		357.59	325.19	249.55	223.42			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		530.25	585.71	668.9	930.4			
Recovered Water		257.03	327.19	395.03	583.77			
Cumulative Water	0	257.03	584.22	979.25	1563.02			
Top-up Bottle Before		618.5	836.7	719.7	790.4			
Top-up Bottle After		471.99	456.54	310.55	180.99			
Top-up Water Used		146.51	380.16	409.15	609.41			
Copper Percentage (%)	0.306	6.96	2.01	0.886	0.454	0.049	0.053	0.051
Copper Mass (g)	0.0404226	1.65648	0.342906	0.141317	0.0904822	0.00621	0.007049	0.4152369
Cumulative Copper Mass (g)		1.65648	1.999386	2.140703	2.2311852			
Copper Grade (%)		6.96	4.89	3.77	2.91			
Copper Recovery (%)		65.54	79.11	84.71	88.29			
Nickel Percentage (%)	0.224	2.17	2.39	1.27	0.581	0.096	0.086	0.091
Nickel Mass (g)	0.0295904	0.51646	0.407734	0.202565	0.1157933	0.01216	0.011438	0.7409129
Cumulative Nickel Mass (g)		0.51646	0.924194	1.126759	1.2425523			
Nickel Grade (%)		2.17	2.26	1.98	1.62			
Nickel Recovery (%)		26.03	46.58	56.79	62.63			

Total Possible Copper (g)	2.659667
Total Copper / Feed (%)	0.285952
Copper Mass Balance	93.44832
Total Possible Nickel (g)	2.007098
Total Nickel / Feed (%)	0.215791
Nickel Mass Balance	96.33547

Figure 90 - Raw data for Senfroth 516 at 10 SPW and 70 g/ton

10.3 Senfroth 580 Raw Data



Date	31-Jul
SPW	3
Ore	Kevitsa
Frother	Senfroth 580
Dosage	50 g/ton
Collector	SIBX (1%)
Collector Dosage	5ml

Feed Run 1	937
Feed Run 2	937.4

Total Solids Collected (Run 1)	923.6
Total Solids Collected (Run 1)	923.4

Cumulative Time	0	2	6	12	20

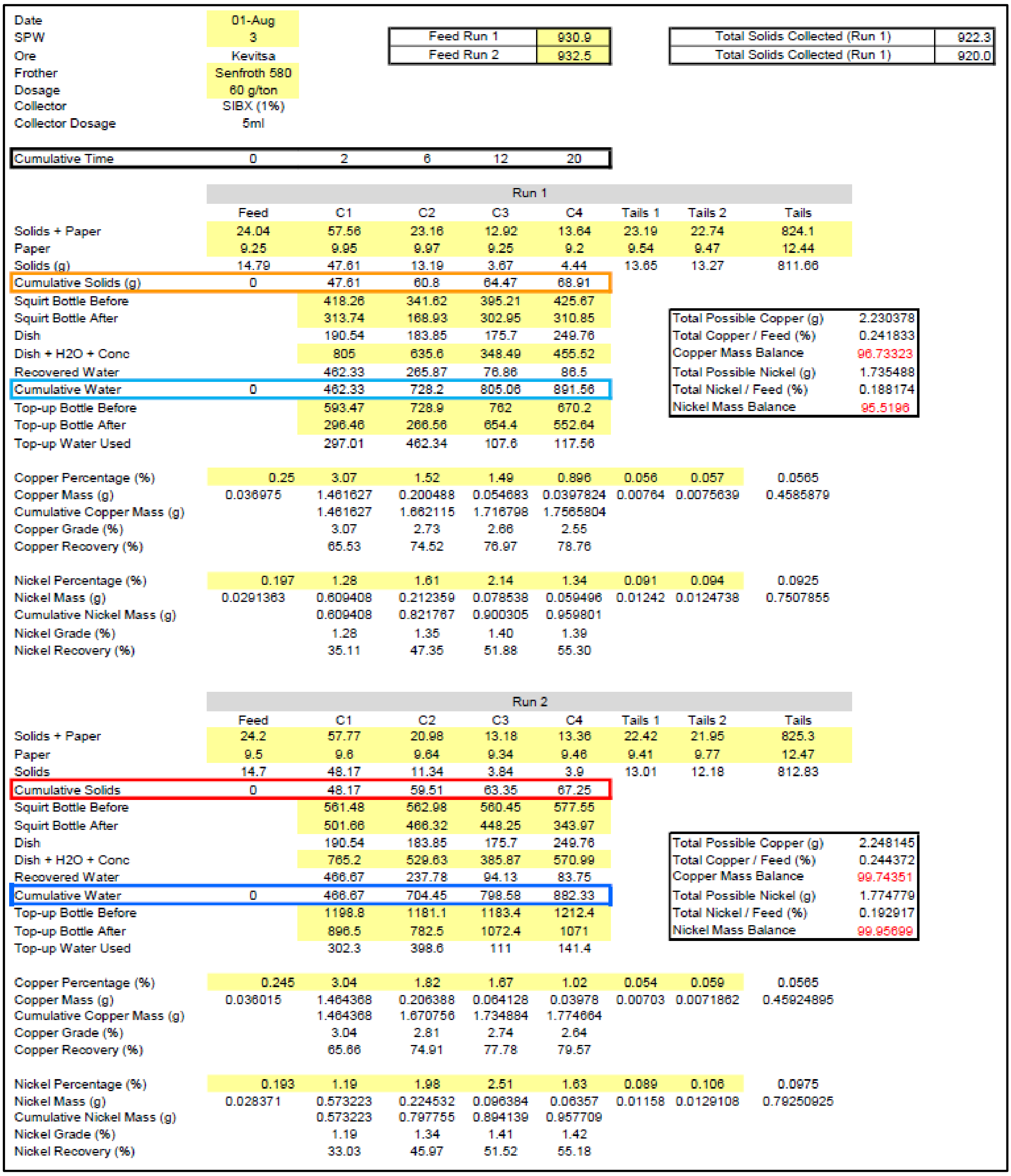
	Run 1							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	24.47	49.65	18.72	12.63	11.62	23.29	23.8	839
Paper	9.79	9.44	9.38	9.29	9.4	9.86	9.9	12.51
Solids (g)	14.68	40.21	9.34	3.34	2.22	13.43	13.9	826.49
Cumulative Solids (g)	0	40.21	49.55	52.89	55.11			
Squirt Bottle Before		408.73	340.6	397.34	472.62			
Squirt Bottle After		318.94	186.31	285.44	371.82			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		711.9	530.14	359.93	391.94			
Recovered Water		391.36	182.66	68.99	39.16			
Cumulative Water	0	391.36	574.02	643.01	682.17			
Top-up Bottle Before		825.4	728.5	865.3	863.7			
Top-up Bottle After		541.58	384.59	777.8	807			
Top-up Water Used		283.82	343.91	87.5	56.7			
Copper Percentage (%)	0.262	3.59	2.18	1.84	1.2	0.06	0.057	0.0585
Copper Mass (g)	0.0384616	1.443539	0.203612	0.061456	0.02664	0.00806	0.007923	0.48349665
Cumulative Copper Mass (g)		1.443539	1.647151	1.708607	1.735247			
Copper Grade (%)		3.59	3.32	3.23	3.15			
Copper Recovery (%)		64.60	73.71	76.46	77.65			
Nickel Percentage (%)	0.19	1.29	2.34	2.77	2.11	0.103	0.102	0.1025
Nickel Mass (g)	0.027892	0.518709	0.218556	0.092518	0.046842	0.01383	0.014178	0.84715225
Cumulative Nickel Mass (g)		0.518709	0.737265	0.829783	0.876625			
Nickel Grade (%)		1.29	1.49	1.57	1.59			
Nickel Recovery (%)		29.61	42.09	47.37	50.04			

Total Possible Copper (g)	2.234732
Total Copper / Feed (%)	0.241956
Copper Mass Balance	92.3497
Total Possible Nickel (g)	1.751791
Total Nickel / Feed (%)	0.189668
Nickel Mass Balance	99.82514

	Run 2							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	22.89	58.52	18.47	12.01	11.99	22.84	23.16	832.7
Paper	9.81	9.58	9.8	9.1	9.08	9.77	9.81	12.28
Solids	13.08	48.94	8.67	2.91	2.91	13.07	13.35	820.42
Cumulative Solids	0	48.94	57.61	60.52	63.43			
Squirt Bottle Before		486.3	503.47	527.55	552.33			
Squirt Bottle After		418.26	341.62	395.21	425.67			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		780.1	531.46	369.47	430.07			
Recovered Water		472.58	177.09	58.52	50.74			
Cumulative Water	0	472.58	649.67	708.19	758.93			
Top-up Bottle Before		902	1079	822.7	801.8			
Top-up Bottle After		593.47	728.9	762	670.2			
Top-up Water Used		308.53	350.1	60.7	131.6			
Copper Percentage (%)	0.285	3.03	2.02	2.01	1.26	0.059	0.067	0.063
Copper Mass (g)	0.037278	1.482882	0.175134	0.058491	0.036666	0.00771	0.0089445	0.5168646
Cumulative Copper Mass (g)		1.482882	1.658016	1.716507	1.753173			
Copper Grade (%)		3.03	2.88	2.84	2.76			
Copper Recovery (%)		66.36	74.19	76.81	78.45			
Nickel Percentage (%)	0.218	1.17	2.05	2.99	2.14	0.104	0.104	0.104
Nickel Mass (g)	0.0285144	0.572598	0.177735	0.087009	0.062274	0.01359	0.013884	0.8532368
Cumulative Nickel Mass (g)		0.572598	0.750333	0.837342	0.899616			
Nickel Grade (%)		1.17	1.30	1.38	1.42			
Nickel Recovery (%)		32.69	42.83	47.80	51.35			

Total Possible Copper (g)	2.286682
Total Copper / Feed (%)	0.247651
Copper Mass Balance	86.89496
Total Possible Nickel (g)	1.78033
Total Nickel / Feed (%)	0.192812
Nickel Mass Balance	88.44587

Figure 91 - Raw data for Senfroth 580 at 3 SPW and 50 g/ton



Date	01-Aug
SPW	3
Ore	Kevitsa
Frother	Senfroth 580
Dosage	60 g/ton
Collector	SIBX (1%)
Collector Dosage	5ml

Feed Run 1	930.9
Feed Run 2	932.5

Total Solids Collected (Run 1)	922.3
Total Solids Collected (Run 1)	920.0

Cumulative Time	0	2	6	12	20

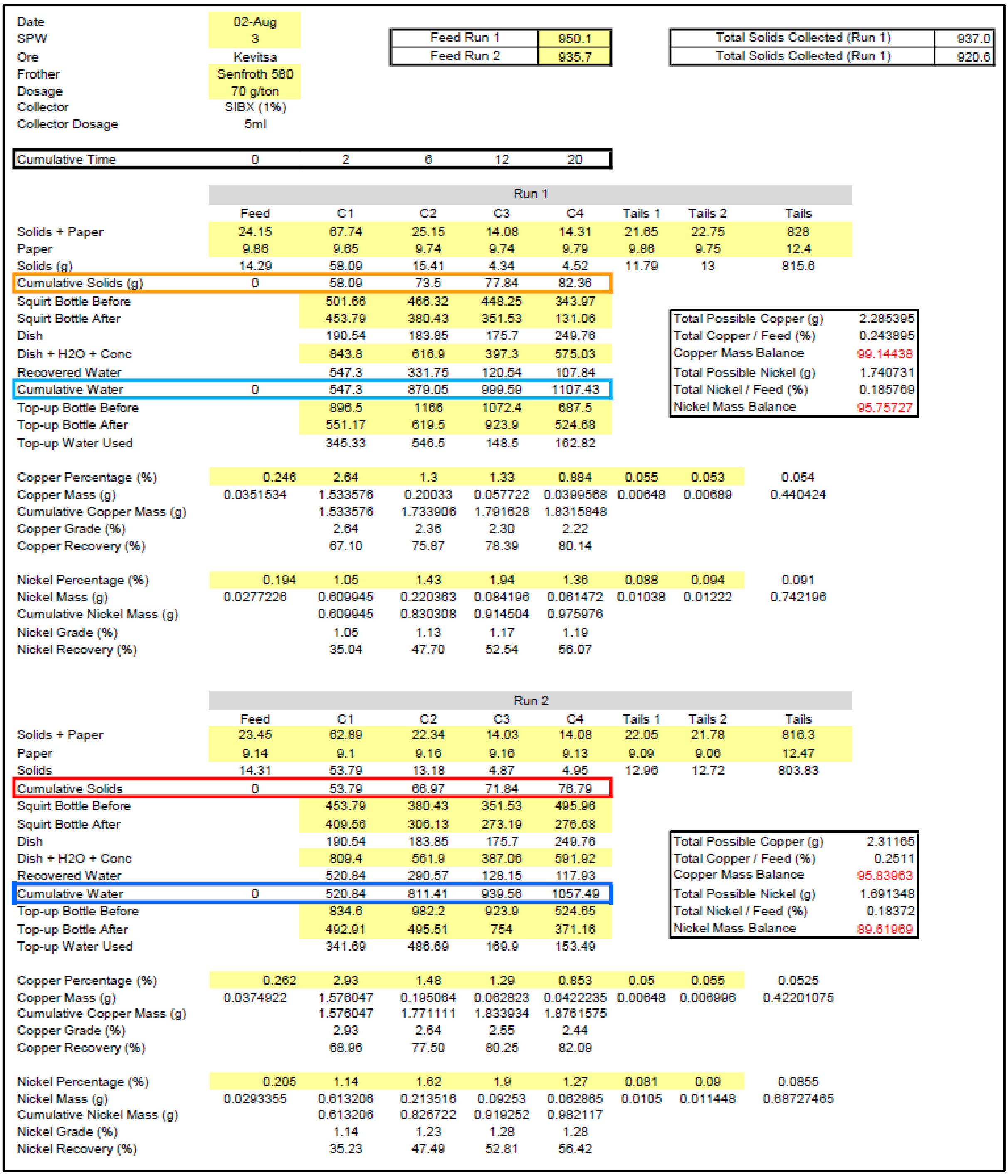
	Run 1							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	24.04	57.56	23.16	12.92	13.64	23.19	22.74	824.1
Paper	9.25	9.95	9.97	9.25	9.2	9.54	9.47	12.44
Solids (g)	14.79	47.61	13.19	3.67	4.44	13.65	13.27	811.66
Cumulative Solids (g)	0	47.61	60.8	64.47	68.91			
Squirt Bottle Before		418.26	341.62	395.21	425.67			
Squirt Bottle After		313.74	168.93	302.95	310.85			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		805	635.6	348.49	455.52			
Recovered Water		462.33	265.87	76.86	86.5			
Cumulative Water	0	462.33	728.2	805.06	891.56			
Top-up Bottle Before		593.47	728.9	762	670.2			
Top-up Bottle After		296.46	266.56	654.4	552.64			
Top-up Water Used		297.01	462.34	107.6	117.56			
Copper Percentage (%)	0.25	3.07	1.52	1.49	0.896	0.056	0.057	0.0565
Copper Mass (g)	0.036975	1.461627	0.200488	0.054683	0.0397824	0.00764	0.0075639	0.4585879
Cumulative Copper Mass (g)		1.461627	1.662115	1.716798	1.7565804			
Copper Grade (%)		3.07	2.73	2.66	2.55			
Copper Recovery (%)		65.53	74.52	76.97	78.76			
Nickel Percentage (%)	0.197	1.28	1.61	2.14	1.34	0.091	0.094	0.0925
Nickel Mass (g)	0.0291363	0.609408	0.212359	0.078538	0.059496	0.01242	0.0124738	0.7507855
Cumulative Nickel Mass (g)		0.609408	0.821767	0.900305	0.959801			
Nickel Grade (%)		1.28	1.35	1.40	1.39			
Nickel Recovery (%)		35.11	47.35	51.88	55.30			

Total Possible Copper (g)	2.230378
Total Copper / Feed (%)	0.241833
Copper Mass Balance	96.73323
Total Possible Nickel (g)	1.735488
Total Nickel / Feed (%)	0.188174
Nickel Mass Balance	95.5196

	Run 2							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	24.2	57.77	20.98	13.18	13.36	22.42	21.95	825.3
Paper	9.5	9.6	9.64	9.34	9.46	9.41	9.77	12.47
Solids	14.7	48.17	11.34	3.84	3.9	13.01	12.18	812.83
Cumulative Solids	0	48.17	59.51	63.35	67.25			
Squirt Bottle Before		561.48	562.98	560.45	577.55			
Squirt Bottle After		501.66	466.32	448.25	343.97			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		765.2	529.63	385.87	570.99			
Recovered Water		466.67	237.78	94.13	83.75			
Cumulative Water	0	466.67	704.45	798.58	882.33			
Top-up Bottle Before		1198.8	1181.1	1183.4	1212.4			
Top-up Bottle After		896.5	782.5	1072.4	1071			
Top-up Water Used		302.3	398.6	111	141.4			
Copper Percentage (%)	0.245	3.04	1.82	1.67	1.02	0.054	0.059	0.0565
Copper Mass (g)	0.036015	1.464368	0.206388	0.064128	0.03978	0.00703	0.0071862	0.45924895
Cumulative Copper Mass (g)		1.464368	1.670756	1.734884	1.774664			
Copper Grade (%)		3.04	2.81	2.74	2.64			
Copper Recovery (%)		65.66	74.91	77.78	79.57			
Nickel Percentage (%)	0.193	1.19	1.98	2.51	1.63	0.089	0.106	0.0975
Nickel Mass (g)	0.028371	0.573223	0.224532	0.096384	0.06357	0.01158	0.0129108	0.79250925
Cumulative Nickel Mass (g)		0.573223	0.797755	0.894139	0.957709			
Nickel Grade (%)		1.19	1.34	1.41	1.42			
Nickel Recovery (%)		33.03	45.97	51.52	55.18			

Total Possible Copper (g)	2.248145
Total Copper / Feed (%)	0.244372
Copper Mass Balance	99.74351
Total Possible Nickel (g)	1.774779
Total Nickel / Feed (%)	0.192917
Nickel Mass Balance	99.95699

Figure 92 - Raw data for Senfroth 580 at 3 SPW and 60 g/ton



Date	02-Aug
SPW	3
Ore	Kevitsa
Frother	Senfroth 580
Dosage	70 g/ton
Collector	SIBX (1%)
Collector Dosage	5ml

Feed Run 1	950.1
Feed Run 2	935.7

Total Solids Collected (Run 1)	937.0
Total Solids Collected (Run 1)	920.6

Cumulative Time	0	2	6	12	20

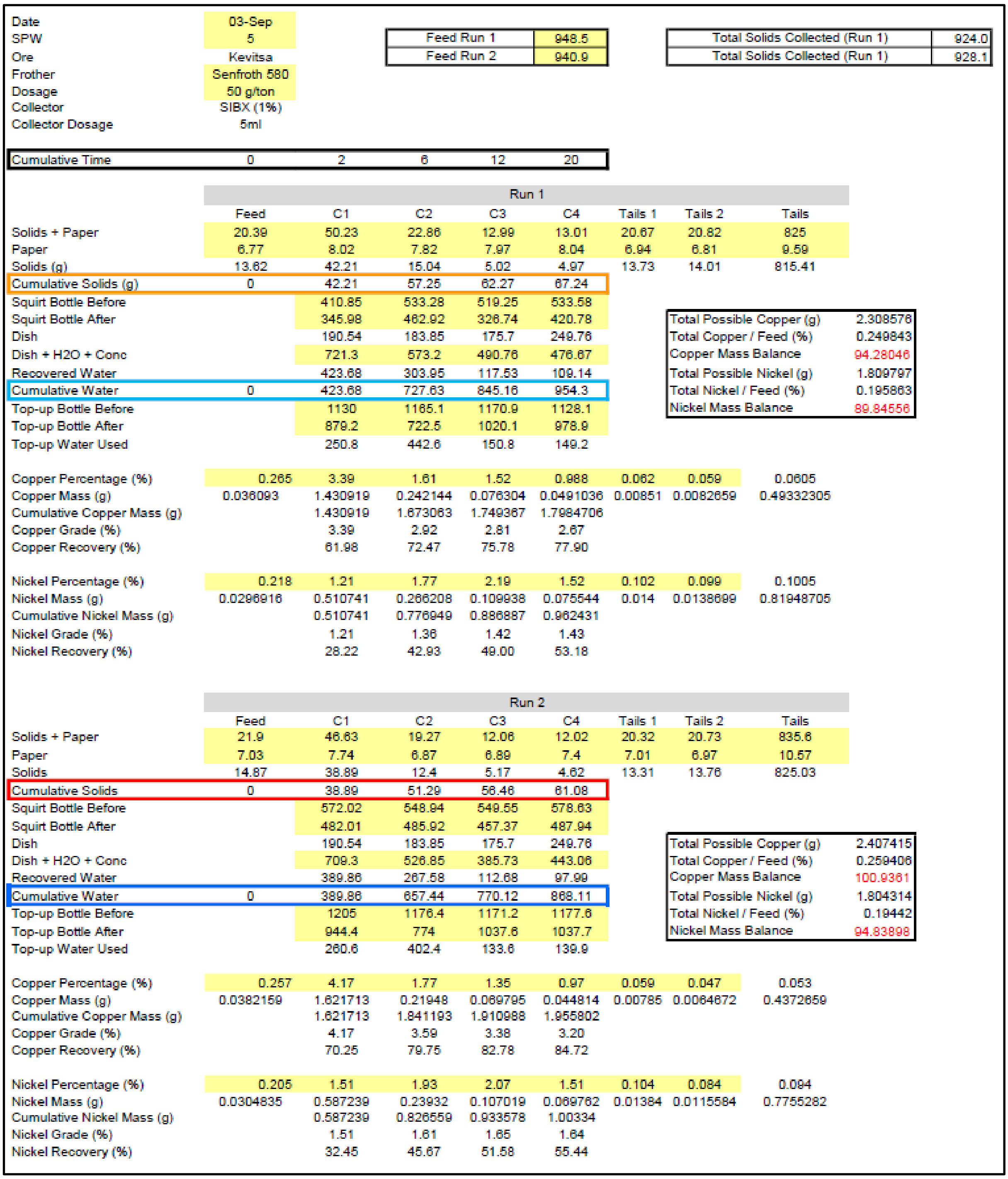
	Run 1							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	24.15	67.74	25.15	14.08	14.31	21.65	22.75	828
Paper	9.86	9.65	9.74	9.74	9.79	9.86	9.75	12.4
Solids (g)	14.29	58.09	15.41	4.34	4.52	11.79	13	815.6
Cumulative Solids (g)	0	58.09	73.5	77.84	82.36			
Squirt Bottle Before		501.66	466.32	448.25	343.97			
Squirt Bottle After		453.79	380.43	351.53	131.06			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		843.8	616.9	397.3	575.03			
Recovered Water		547.3	331.75	120.54	107.84			
Cumulative Water	0	547.3	879.05	999.59	1107.43			
Top-up Bottle Before		896.5	1166	1072.4	687.5			
Top-up Bottle After		551.17	619.5	923.9	524.68			
Top-up Water Used		345.33	546.5	148.5	162.82			
Copper Percentage (%)	0.246	2.64	1.3	1.33	0.884	0.055	0.053	0.054
Copper Mass (g)	0.0351534	1.533576	0.20033	0.057722	0.0399568	0.00648	0.00689	0.440424
Cumulative Copper Mass (g)		1.533576	1.733906	1.791628	1.8315848			
Copper Grade (%)		2.64	2.36	2.30	2.22			
Copper Recovery (%)		67.10	75.87	78.39	80.14			
Nickel Percentage (%)	0.194	1.05	1.43	1.94	1.36	0.088	0.094	0.091
Nickel Mass (g)	0.0277226	0.609945	0.220363	0.084196	0.061472	0.01038	0.01222	0.742196
Cumulative Nickel Mass (g)		0.609945	0.830308	0.914504	0.975976			
Nickel Grade (%)		1.05	1.13	1.17	1.19			
Nickel Recovery (%)		35.04	47.70	52.54	56.07			

Total Possible Copper (g)	2.285395
Total Copper / Feed (%)	0.243895
Copper Mass Balance	99.14438
Total Possible Nickel (g)	1.740731
Total Nickel / Feed (%)	0.185769
Nickel Mass Balance	95.75727

	Run 2							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	23.45	62.89	22.34	14.03	14.08	22.05	21.78	816.3
Paper	9.14	9.1	9.16	9.16	9.13	9.09	9.06	12.47
Solids	14.31	53.79	13.18	4.87	4.95	12.96	12.72	803.83
Cumulative Solids	0	53.79	66.97	71.84	76.79			
Squirt Bottle Before		453.79	380.43	351.53	495.96			
Squirt Bottle After		409.56	306.13	273.19	276.68			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		809.4	561.9	387.06	591.92			
Recovered Water		520.84	290.57	128.15	117.93			
Cumulative Water	0	520.84	811.41	939.56	1057.49			
Top-up Bottle Before		834.6	982.2	923.9	524.65			
Top-up Bottle After		492.91	495.51	754	371.16			
Top-up Water Used		341.69	486.69	169.9	153.49			
Copper Percentage (%)	0.262	2.93	1.48	1.29	0.853	0.05	0.055	0.0525
Copper Mass (g)	0.0374922	1.576047	0.195064	0.062823	0.0422235	0.00648	0.006996	0.42201075
Cumulative Copper Mass (g)		1.576047	1.771111	1.833934	1.8761575			
Copper Grade (%)		2.93	2.64	2.55	2.44			
Copper Recovery (%)		68.96	77.50	80.25	82.09			
Nickel Percentage (%)	0.205	1.14	1.62	1.9	1.27	0.081	0.09	0.0855
Nickel Mass (g)	0.0293355	0.613206	0.213516	0.09253	0.062865	0.0105	0.011448	0.68727465
Cumulative Nickel Mass (g)		0.613206	0.826722	0.919252	0.982117			
Nickel Grade (%)		1.14	1.23	1.28	1.28			
Nickel Recovery (%)		35.23	47.49	52.81	56.42			

Total Possible Copper (g)	2.31165
Total Copper / Feed (%)	0.2511
Copper Mass Balance	95.83963
Total Possible Nickel (g)	1.691348
Total Nickel / Feed (%)	0.18372
Nickel Mass Balance	89.61969

Figure 93 - Raw data for Senfroth 580 at 3 SPW and 70 g/ton



Date	03-Sep
SPW	5
Ore	Kevitsa
Frother	Senfroth 580
Dosage	50 g/ton
Collector	SIBX (1%)
Collector Dosage	5ml

Feed Run 1	948.5
Feed Run 2	940.9

Total Solids Collected (Run 1)	924.0
Total Solids Collected (Run 1)	928.1

Cumulative Time	0	2	6	12	20

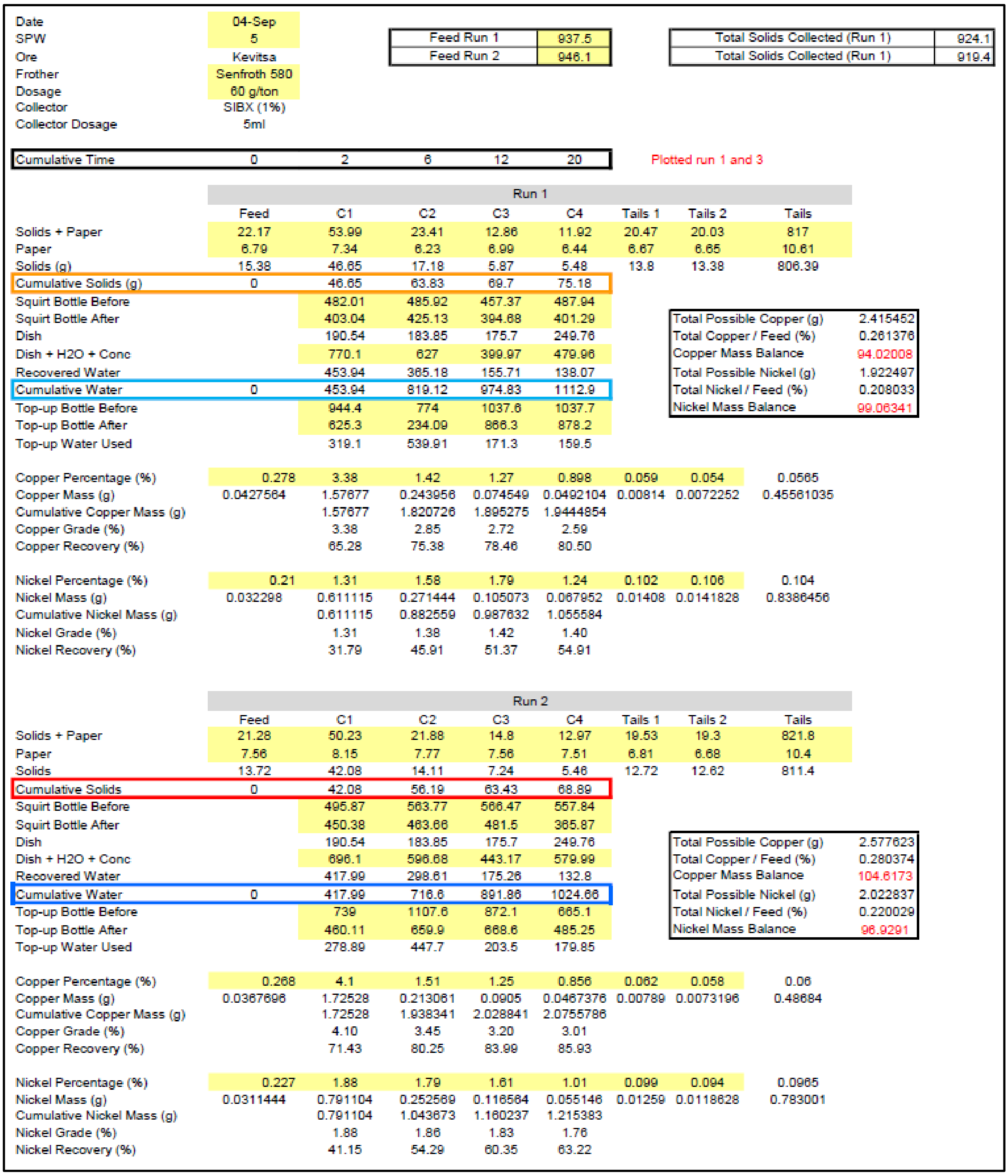
	Run 1							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	20.39	50.23	22.86	12.99	13.01	20.67	20.82	825
Paper	6.77	8.02	7.82	7.97	8.04	6.94	6.81	9.59
Solids (g)	13.62	42.21	15.04	5.02	4.97	13.73	14.01	815.41
Cumulative Solids (g)	0	42.21	57.25	62.27	67.24			
Squirt Bottle Before		410.85	533.28	519.25	533.58			
Squirt Bottle After		345.98	462.92	326.74	420.78			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		721.3	573.2	490.76	476.67			
Recovered Water		423.68	303.95	117.53	109.14			
Cumulative Water	0	423.68	727.63	845.16	954.3			
Top-up Bottle Before		1130	1165.1	1170.9	1128.1			
Top-up Bottle After		879.2	722.5	1020.1	978.9			
Top-up Water Used		250.8	442.6	150.8	149.2			
Copper Percentage (%)	0.265	3.39	1.61	1.52	0.988	0.062	0.059	0.0605
Copper Mass (g)	0.036093	1.430919	0.242144	0.076304	0.0491036	0.00851	0.0082659	0.49332305
Cumulative Copper Mass (g)		1.430919	1.673063	1.749367	1.7984706			
Copper Grade (%)		3.39	2.92	2.81	2.67			
Copper Recovery (%)		61.98	72.47	75.78	77.90			
Nickel Percentage (%)	0.218	1.21	1.77	2.19	1.52	0.102	0.099	0.1005
Nickel Mass (g)	0.0296916	0.510741	0.266208	0.109938	0.075544	0.014	0.0138699	0.81948705
Cumulative Nickel Mass (g)		0.510741	0.776949	0.886887	0.962431			
Nickel Grade (%)		1.21	1.36	1.42	1.43			
Nickel Recovery (%)		28.22	42.93	49.00	53.18			

Total Possible Copper (g)	2.308576
Total Copper / Feed (%)	0.249843
Copper Mass Balance	94.28046
Total Possible Nickel (g)	1.809797
Total Nickel / Feed (%)	0.195863
Nickel Mass Balance	89.84556

	Run 2							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	21.9	46.63	19.27	12.06	12.02	20.32	20.73	835.6
Paper	7.03	7.74	6.87	6.89	7.4	7.01	6.97	10.57
Solids	14.87	38.89	12.4	5.17	4.62	13.31	13.76	825.03
Cumulative Solids	0	38.89	51.29	56.46	61.08			
Squirt Bottle Before		572.02	548.94	549.55	578.63			
Squirt Bottle After		482.01	485.92	457.37	487.94			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		709.3	526.85	385.73	443.06			
Recovered Water		389.86	267.58	112.68	97.99			
Cumulative Water	0	389.86	657.44	770.12	868.11			
Top-up Bottle Before		1205	1176.4	1171.2	1177.6			
Top-up Bottle After		944.4	774	1037.6	1037.7			
Top-up Water Used		260.6	402.4	133.6	139.9			
Copper Percentage (%)	0.257	4.17	1.77	1.35	0.97	0.059	0.047	0.053
Copper Mass (g)	0.0382159	1.621713	0.21948	0.069795	0.044814	0.00785	0.0064672	0.4372659
Cumulative Copper Mass (g)		1.621713	1.841193	1.910988	1.955802			
Copper Grade (%)		4.17	3.59	3.38	3.20			
Copper Recovery (%)		70.25	79.75	82.78	84.72			
Nickel Percentage (%)	0.205	1.51	1.93	2.07	1.51	0.104	0.084	0.094
Nickel Mass (g)	0.0304835	0.587239	0.23932	0.107019	0.069762	0.01384	0.0115584	0.7755282
Cumulative Nickel Mass (g)		0.587239	0.826559	0.933578	1.00334			
Nickel Grade (%)		1.51	1.61	1.65	1.64			
Nickel Recovery (%)		32.45	45.67	51.58	55.44			

Total Possible Copper (g)	2.407415
Total Copper / Feed (%)	0.259406
Copper Mass Balance	100.9361
Total Possible Nickel (g)	1.804314
Total Nickel / Feed (%)	0.19442
Nickel Mass Balance	94.83898

Figure 94 - Raw data for Senfroth 580 at 5 SPW and 50 g/ton



Date	04-Sep
SPW	5
Ore	Kevitsa
Frother	Senfroth 580
Dosage	60 g/ton
Collector	SIBX (1%)
Collector Dosage	5ml

Feed Run 1	937.5
Feed Run 2	946.1

Total Solids Collected (Run 1)	924.1
Total Solids Collected (Run 1)	919.4

Cumulative Time	0	2	6	12	20

Plotted run 1 and 3

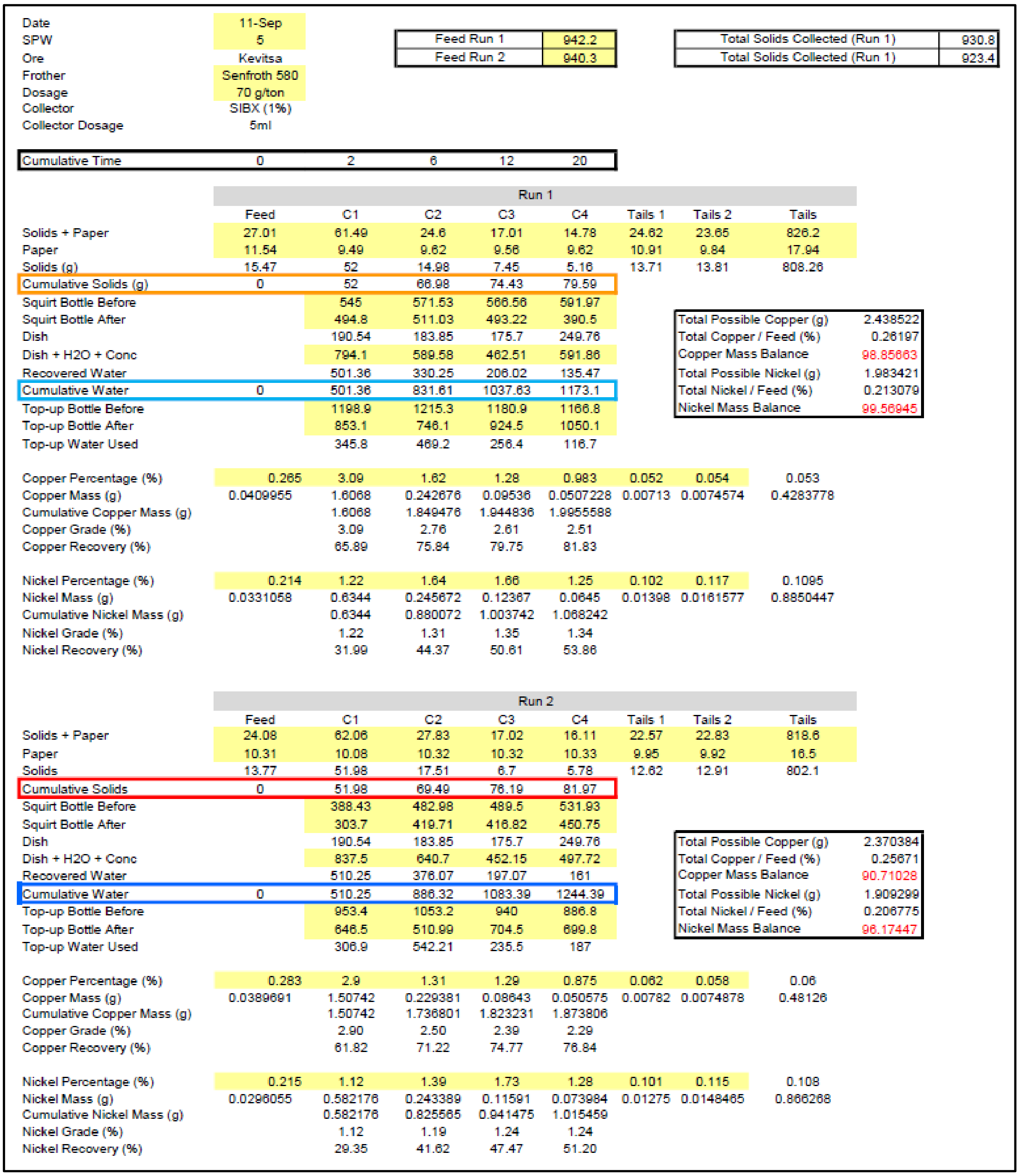
	Run 1							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	22.17	53.99	23.41	12.86	11.92	20.47	20.03	817
Paper	6.79	7.34	6.23	6.99	6.44	6.67	6.65	10.61
Solids (g)	15.38	46.65	17.18	5.87	5.48	13.8	13.38	806.39
Cumulative Solids (g)	0	46.65	63.83	69.7	75.18			
Squirt Bottle Before		482.01	485.92	457.37	487.94			
Squirt Bottle After		403.04	425.13	394.68	401.29			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		770.1	627	399.97	479.96			
Recovered Water		453.94	365.18	155.71	138.07			
Cumulative Water	0	453.94	819.12	974.83	1112.9			
Top-up Bottle Before		944.4	774	1037.6	1037.7			
Top-up Bottle After		625.3	234.09	866.3	878.2			
Top-up Water Used		319.1	539.91	171.3	159.5			
Copper Percentage (%)	0.278	3.38	1.42	1.27	0.898	0.059	0.054	0.0565
Copper Mass (g)	0.0427564	1.57677	0.243956	0.074549	0.0492104	0.00814	0.0072252	0.45561035
Cumulative Copper Mass (g)		1.57677	1.820726	1.895275	1.9444854			
Copper Grade (%)		3.38	2.85	2.72	2.59			
Copper Recovery (%)		65.28	75.38	78.46	80.50			
Nickel Percentage (%)	0.21	1.31	1.58	1.79	1.24	0.102	0.106	0.104
Nickel Mass (g)	0.032298	0.611115	0.271444	0.105073	0.067952	0.01408	0.0141828	0.8386456
Cumulative Nickel Mass (g)		0.611115	0.882559	0.987632	1.055584			
Nickel Grade (%)		1.31	1.38	1.42	1.40			
Nickel Recovery (%)		31.79	45.91	51.37	54.91			

Total Possible Copper (g)	2.415452
Total Copper / Feed (%)	0.261376
Copper Mass Balance	94.02008
Total Possible Nickel (g)	1.922497
Total Nickel / Feed (%)	0.208033
Nickel Mass Balance	99.06341

	Run 2							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	21.28	50.23	21.88	14.8	12.97	19.53	19.3	821.8
Paper	7.56	8.15	7.77	7.56	7.51	6.81	6.68	10.4
Solids	13.72	42.08	14.11	7.24	5.46	12.72	12.62	811.4
Cumulative Solids	0	42.08	56.19	63.43	68.89			
Squirt Bottle Before		495.87	563.77	566.47	557.84			
Squirt Bottle After		450.38	463.66	481.5	365.87			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		696.1	596.68	443.17	579.99			
Recovered Water		417.99	298.61	175.26	132.8			
Cumulative Water	0	417.99	716.6	891.86	1024.66			
Top-up Bottle Before		739	1107.6	872.1	665.1			
Top-up Bottle After		460.11	659.9	668.6	485.25			
Top-up Water Used		278.89	447.7	203.5	179.85			
Copper Percentage (%)	0.268	4.1	1.51	1.25	0.856	0.062	0.058	0.06
Copper Mass (g)	0.0367696	1.72528	0.213061	0.0905	0.0467376	0.00789	0.0073196	0.48684
Cumulative Copper Mass (g)		1.72528	1.938341	2.028841	2.0755786			
Copper Grade (%)		4.10	3.45	3.20	3.01			
Copper Recovery (%)		71.43	80.25	83.99	85.93			
Nickel Percentage (%)	0.227	1.88	1.79	1.61	1.01	0.099	0.094	0.0965
Nickel Mass (g)	0.0311444	0.791104	0.252569	0.116564	0.055146	0.01259	0.0118628	0.783001
Cumulative Nickel Mass (g)		0.791104	1.043673	1.160237	1.215383			
Nickel Grade (%)		1.88	1.86	1.83	1.76			
Nickel Recovery (%)		41.15	54.29	60.35	63.22			

Total Possible Copper (g)	2.577623
Total Copper / Feed (%)	0.280374
Copper Mass Balance	104.6173
Total Possible Nickel (g)	2.022837
Total Nickel / Feed (%)	0.220029
Nickel Mass Balance	96.9291

Figure 95 - Raw data for Senfroth 580 at 5 SPW and 60 g/ton



Date	11-Sep
SPW	5
Ore	Kevitsa
Frother	Senfroth 580
Dosage	70 g/ton
Collector	SIBX (1%)
Collector Dosage	5ml

Feed Run 1	942.2
Feed Run 2	940.3

Total Solids Collected (Run 1)	930.8
Total Solids Collected (Run 1)	923.4

Cumulative Time	0	2	6	12	20

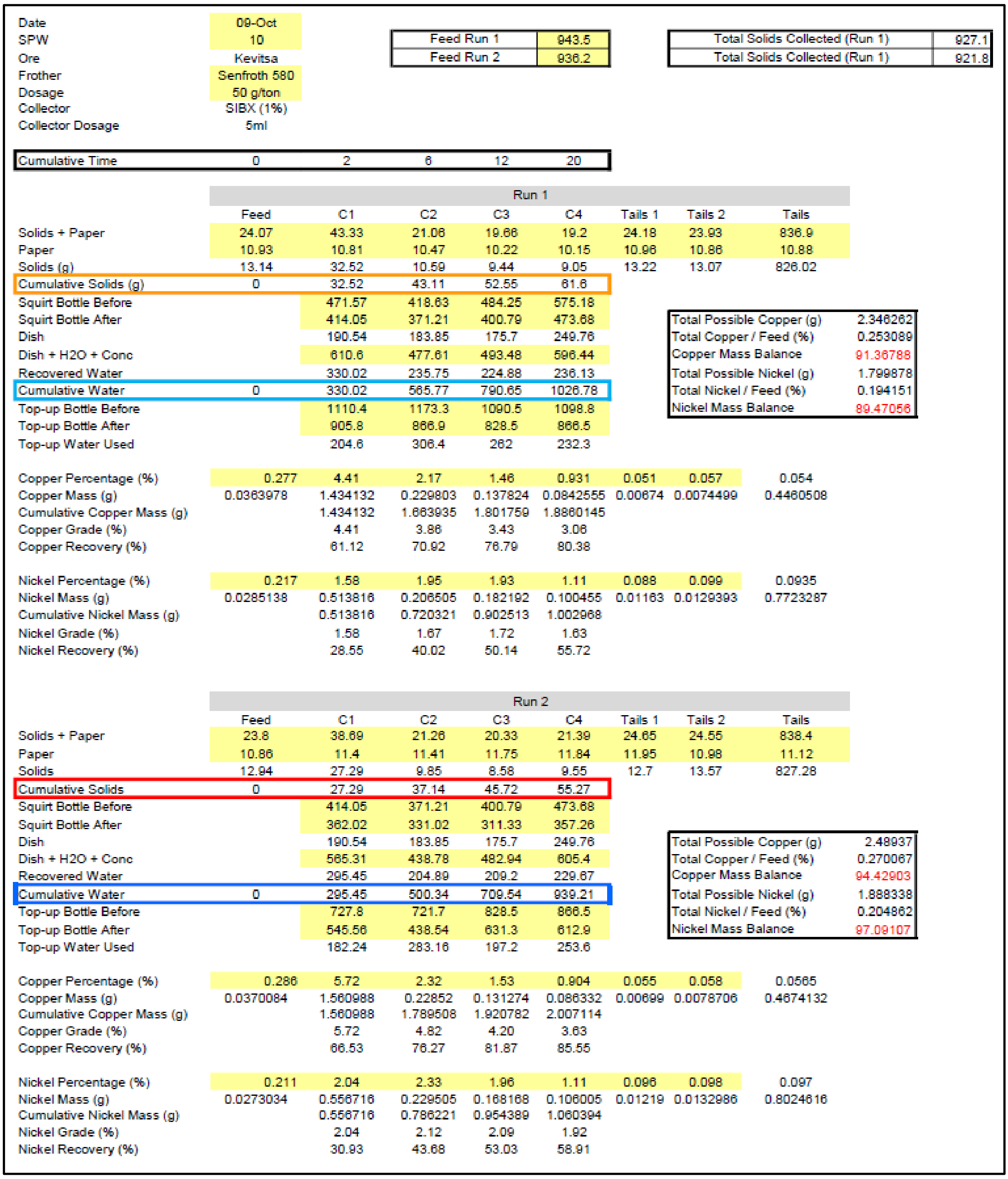
	Run 1							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	27.01	61.49	24.6	17.01	14.78	24.62	23.65	826.2
Paper	11.54	9.49	9.62	9.56	9.62	10.91	9.84	17.94
Solids (g)	15.47	52	14.98	7.45	5.16	13.71	13.81	808.26
Cumulative Solids (g)	0	52	66.98	74.43	79.59			
Squirt Bottle Before		545	571.53	566.56	591.97			
Squirt Bottle After		494.8	511.03	493.22	390.5			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		794.1	589.58	462.51	591.86			
Recovered Water		501.36	330.25	206.02	135.47			
Cumulative Water	0	501.36	831.61	1037.63	1173.1			
Top-up Bottle Before		1198.9	1215.3	1180.9	1166.8			
Top-up Bottle After		853.1	746.1	924.5	1050.1			
Top-up Water Used		345.8	469.2	256.4	116.7			
Copper Percentage (%)	0.265	3.09	1.62	1.28	0.983	0.052	0.054	0.053
Copper Mass (g)	0.0409955	1.6068	0.242676	0.09536	0.0507228	0.00713	0.0074574	0.4283778
Cumulative Copper Mass (g)		1.6068	1.849476	1.944836	1.9955588			
Copper Grade (%)		3.09	2.76	2.61	2.51			
Copper Recovery (%)		65.89	75.84	79.75	81.83			
Nickel Percentage (%)	0.214	1.22	1.64	1.66	1.25	0.102	0.117	0.1095
Nickel Mass (g)	0.0331058	0.6344	0.245672	0.12367	0.0645	0.01398	0.0161577	0.8850447
Cumulative Nickel Mass (g)		0.6344	0.880072	1.003742	1.068242			
Nickel Grade (%)		1.22	1.31	1.35	1.34			
Nickel Recovery (%)		31.99	44.37	50.61	53.86			

Total Possible Copper (g)	2.438522
Total Copper / Feed (%)	0.26197
Copper Mass Balance	98.85663
Total Possible Nickel (g)	1.983421
Total Nickel / Feed (%)	0.213079
Nickel Mass Balance	99.56945

	Run 2							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	24.08	62.06	27.83	17.02	16.11	22.57	22.83	818.6
Paper	10.31	10.08	10.32	10.32	10.33	9.95	9.92	16.5
Solids	13.77	51.98	17.51	6.7	5.78	12.62	12.91	802.1
Cumulative Solids	0	51.98	69.49	76.19	81.97			
Squirt Bottle Before		388.43	482.98	489.5	531.93			
Squirt Bottle After		303.7	419.71	416.82	450.75			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		837.5	640.7	452.15	497.72			
Recovered Water		510.25	376.07	197.07	161			
Cumulative Water	0	510.25	886.32	1083.39	1244.39			
Top-up Bottle Before		953.4	1053.2	940	886.8			
Top-up Bottle After		646.5	510.99	704.5	699.8			
Top-up Water Used		306.9	542.21	235.5	187			
Copper Percentage (%)	0.283	2.9	1.31	1.29	0.875	0.062	0.058	0.06
Copper Mass (g)	0.0389691	1.50742	0.229381	0.08643	0.050575	0.00782	0.0074878	0.48126
Cumulative Copper Mass (g)		1.50742	1.736801	1.823231	1.873806			
Copper Grade (%)		2.90	2.50	2.39	2.29			
Copper Recovery (%)		61.82	71.22	74.77	76.84			
Nickel Percentage (%)	0.215	1.12	1.39	1.73	1.28	0.101	0.115	0.108
Nickel Mass (g)	0.0296055	0.582176	0.243389	0.11591	0.073984	0.01275	0.0148465	0.866268
Cumulative Nickel Mass (g)		0.582176	0.825565	0.941475	1.015459			
Nickel Grade (%)		1.12	1.19	1.24	1.24			
Nickel Recovery (%)		29.35	41.62	47.47	51.20			

Total Possible Copper (g)	2.370384
Total Copper / Feed (%)	0.25671
Copper Mass Balance	90.71028
Total Possible Nickel (g)	1.909299
Total Nickel / Feed (%)	0.206775
Nickel Mass Balance	96.17447

Figure 96 - Raw data for Senfroth 580 at 5 SPW and 70 g/ton



Date	09-Oct
SPW	10
Ore	Kevitsa
Frother	Senfroth 580
Dosage	50 g/ton
Collector	SIBX (1%)
Collector Dosage	5ml

Feed Run 1	943.5
Feed Run 2	936.2

Total Solids Collected (Run 1)	927.1
Total Solids Collected (Run 1)	921.8

Cumulative Time	0	2	6	12	20

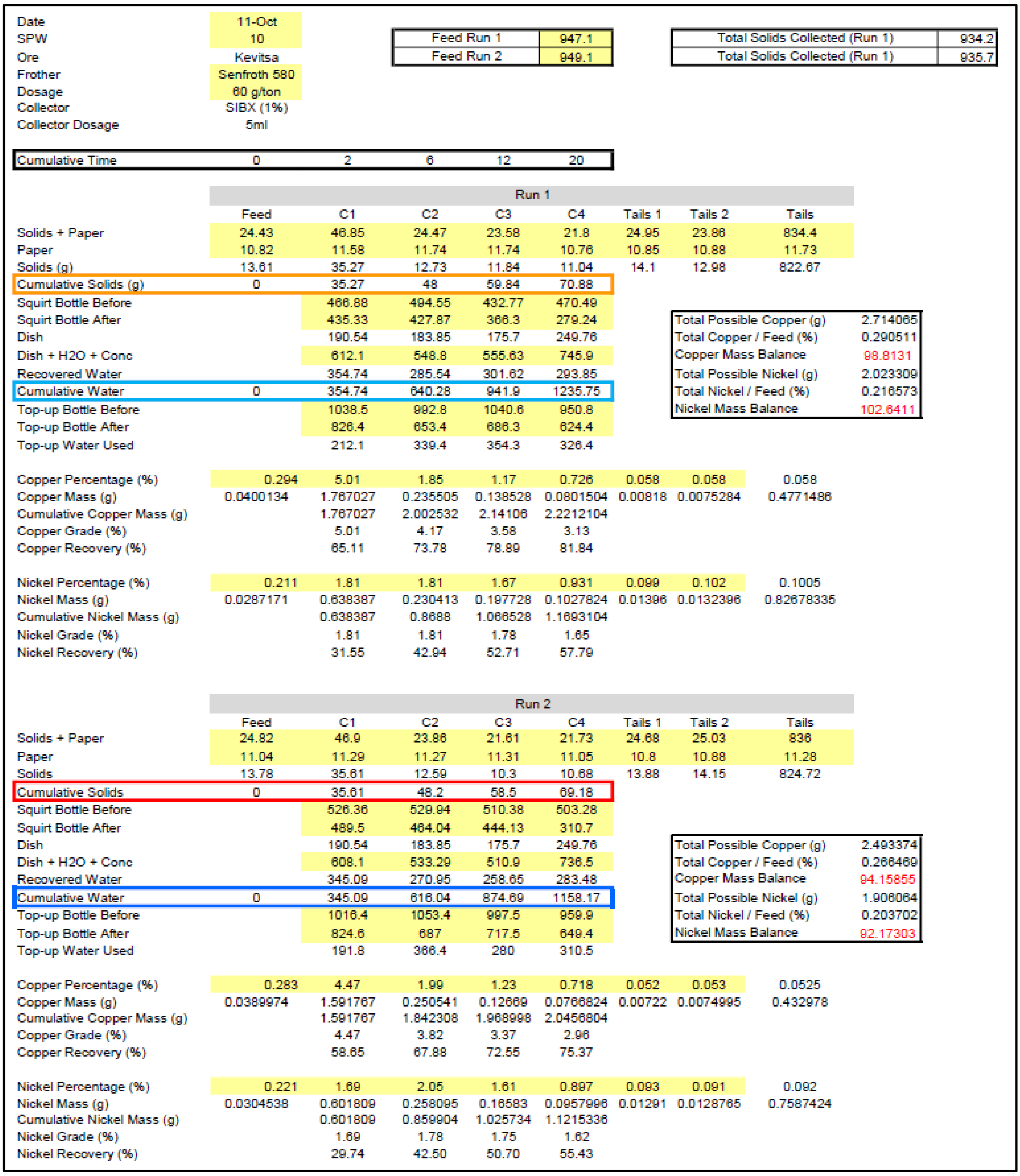
	Run 1							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	24.07	43.33	21.06	19.66	19.2	24.18	23.93	836.9
Paper	10.93	10.81	10.47	10.22	10.15	10.96	10.86	10.88
Solids (g)	13.14	32.52	10.59	9.44	9.05	13.22	13.07	826.02
Cumulative Solids (g)	0	32.52	43.11	52.55	61.6			
Squirt Bottle Before		471.57	418.63	484.25	575.18			
Squirt Bottle After		414.05	371.21	400.79	473.68			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		610.6	477.61	493.48	596.44			
Recovered Water		330.02	235.75	224.88	236.13			
Cumulative Water	0	330.02	565.77	790.65	1026.78			
Top-up Bottle Before		1110.4	1173.3	1090.5	1098.8			
Top-up Bottle After		905.8	866.9	828.5	866.5			
Top-up Water Used		204.6	306.4	262	232.3			
Copper Percentage (%)	0.277	4.41	2.17	1.46	0.931	0.051	0.057	0.054
Copper Mass (g)	0.0363978	1.434132	0.229803	0.137824	0.0842555	0.00674	0.0074499	0.4460508
Cumulative Copper Mass (g)		1.434132	1.663935	1.801759	1.8860145			
Copper Grade (%)		4.41	3.86	3.43	3.06			
Copper Recovery (%)		61.12	70.92	76.79	80.38			
Nickel Percentage (%)	0.217	1.58	1.95	1.93	1.11	0.088	0.099	0.0935
Nickel Mass (g)	0.0285138	0.513816	0.206505	0.182192	0.100455	0.01163	0.0129393	0.7723287
Cumulative Nickel Mass (g)		0.513816	0.720321	0.902513	1.002968			
Nickel Grade (%)		1.58	1.67	1.72	1.63			
Nickel Recovery (%)		28.55	40.02	50.14	55.72			

Total Possible Copper (g)	2.346262
Total Copper / Feed (%)	0.253089
Copper Mass Balance	91.36788
Total Possible Nickel (g)	1.799878
Total Nickel / Feed (%)	0.194151
Nickel Mass Balance	89.47056

	Run 2							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	23.8	38.69	21.26	20.33	21.39	24.65	24.55	838.4
Paper	10.86	11.4	11.41	11.75	11.84	11.95	10.98	11.12
Solids	12.94	27.29	9.85	8.58	9.55	12.7	13.57	827.28
Cumulative Solids	0	27.29	37.14	45.72	55.27			
Squirt Bottle Before		414.05	371.21	400.79	473.68			
Squirt Bottle After		362.02	331.02	311.33	357.26			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		565.31	438.78	482.94	605.4			
Recovered Water		295.45	204.89	209.2	229.67			
Cumulative Water	0	295.45	500.34	709.54	939.21			
Top-up Bottle Before		727.8	721.7	828.5	866.5			
Top-up Bottle After		545.56	438.54	631.3	612.9			
Top-up Water Used		182.24	283.16	197.2	253.6			
Copper Percentage (%)	0.286	5.72	2.32	1.53	0.904	0.055	0.058	0.0565
Copper Mass (g)	0.0370084	1.560988	0.22852	0.131274	0.086332	0.00699	0.0078706	0.4674132
Cumulative Copper Mass (g)		1.560988	1.789508	1.920782	2.007114			
Copper Grade (%)		5.72	4.82	4.20	3.63			
Copper Recovery (%)		66.53	76.27	81.87	85.55			
Nickel Percentage (%)	0.211	2.04	2.33	1.96	1.11	0.096	0.098	0.097
Nickel Mass (g)	0.0273034	0.556716	0.229505	0.168168	0.106005	0.01219	0.0132986	0.8024616
Cumulative Nickel Mass (g)		0.556716	0.786221	0.954389	1.060394			
Nickel Grade (%)		2.04	2.12	2.09	1.92			
Nickel Recovery (%)		30.93	43.68	53.03	58.91			

Total Possible Copper (g)	2.48937
Total Copper / Feed (%)	0.270067
Copper Mass Balance	94.42903
Total Possible Nickel (g)	1.888338
Total Nickel / Feed (%)	0.204862
Nickel Mass Balance	97.09107

Figure 97 - Raw data for Senfroth 580 at 10 SPW and 50 g/ton



Date	11-Oct
SPW	10
Ore	Kevitsa
Frother	Senfroth 580
Dosage	60 g/ton
Collector	SIBX (1%)
Collector Dosage	5ml

Feed Run 1	947.1
Feed Run 2	949.1

Total Solids Collected (Run 1)	934.2
Total Solids Collected (Run 1)	935.7

Cumulative Time	0	2	6	12	20

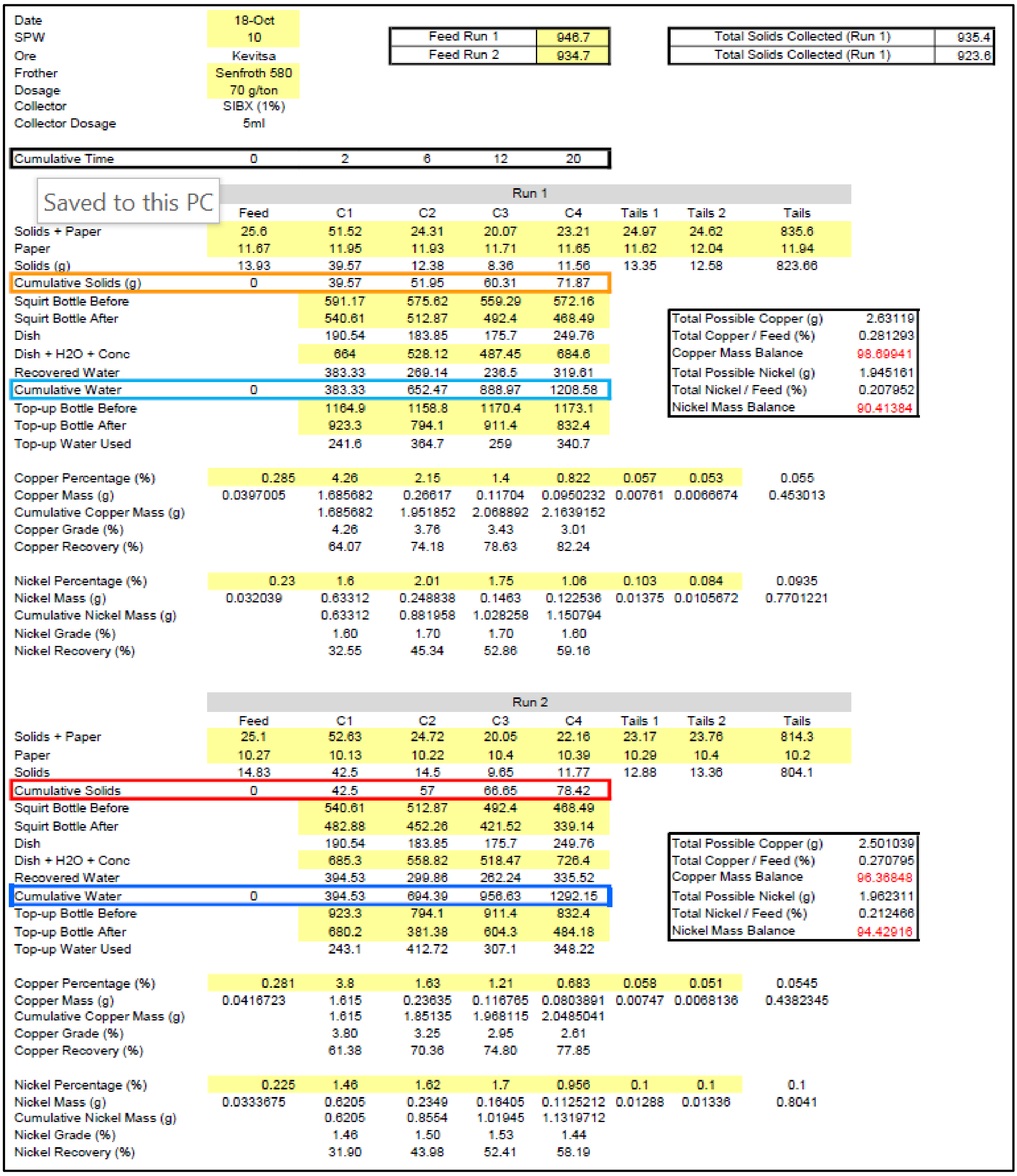
	Run 1							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	24.43	46.85	24.47	23.58	21.8	24.95	23.86	834.4
Paper	10.82	11.58	11.74	11.74	10.76	10.85	10.88	11.73
Solids (g)	13.61	35.27	12.73	11.84	11.04	14.1	12.98	822.67
Cumulative Solids (g)	0	35.27	48	59.84	70.88			
Squirt Bottle Before		466.88	494.55	432.77	470.49			
Squirt Bottle After		435.33	427.87	366.3	279.24			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		612.1	548.8	555.63	745.9			
Recovered Water		354.74	285.54	301.62	293.85			
Cumulative Water	0	354.74	640.28	941.9	1235.75			
Top-up Bottle Before		1038.5	992.8	1040.6	950.8			
Top-up Bottle After		826.4	653.4	686.3	624.4			
Top-up Water Used		212.1	339.4	354.3	326.4			
Copper Percentage (%)	0.294	5.01	1.85	1.17	0.726	0.058	0.058	0.058
Copper Mass (g)	0.0400134	1.767027	0.235505	0.138528	0.0801504	0.00818	0.0075284	0.4771486
Cumulative Copper Mass (g)		1.767027	2.002532	2.14106	2.2212104			
Copper Grade (%)		5.01	4.17	3.58	3.13			
Copper Recovery (%)		65.11	73.78	78.89	81.84			
Nickel Percentage (%)	0.211	1.81	1.81	1.67	0.931	0.099	0.102	0.1005
Nickel Mass (g)	0.0287171	0.638387	0.230413	0.197728	0.1027824	0.01396	0.0132396	0.82678335
Cumulative Nickel Mass (g)		0.638387	0.8688	1.066528	1.1693104			
Nickel Grade (%)		1.81	1.81	1.78	1.65			
Nickel Recovery (%)		31.55	42.94	52.71	57.79			

Total Possible Copper (g)	2.714065
Total Copper / Feed (%)	0.290511
Copper Mass Balance	98.8131
Total Possible Nickel (g)	2.023309
Total Nickel / Feed (%)	0.216573
Nickel Mass Balance	102.6411

	Run 2							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	24.82	46.9	23.86	21.61	21.73	24.68	25.03	836
Paper	11.04	11.29	11.27	11.31	11.05	10.8	10.88	11.28
Solids	13.78	35.61	12.59	10.3	10.68	13.88	14.15	824.72
Cumulative Solids	0	35.61	48.2	58.5	69.18			
Squirt Bottle Before		526.36	529.94	510.38	503.28			
Squirt Bottle After		489.5	464.04	444.13	310.7			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		608.1	533.29	510.9	736.5			
Recovered Water		345.09	270.95	258.65	283.48			
Cumulative Water	0	345.09	616.04	874.69	1158.17			
Top-up Bottle Before		1016.4	1053.4	997.5	959.9			
Top-up Bottle After		824.6	687	717.5	649.4			
Top-up Water Used		191.8	366.4	280	310.5			
Copper Percentage (%)	0.283	4.47	1.99	1.23	0.718	0.052	0.053	0.0525
Copper Mass (g)	0.0389974	1.591767	0.250541	0.12669	0.0766824	0.00722	0.0074995	0.432978
Cumulative Copper Mass (g)		1.591767	1.842308	1.968998	2.0456804			
Copper Grade (%)		4.47	3.82	3.37	2.96			
Copper Recovery (%)		58.65	67.88	72.55	75.37			
Nickel Percentage (%)	0.221	1.69	2.05	1.61	0.897	0.093	0.091	0.092
Nickel Mass (g)	0.0304538	0.601809	0.258095	0.16583	0.0957996	0.01291	0.0128765	0.7587424
Cumulative Nickel Mass (g)		0.601809	0.859904	1.025734	1.1215336			
Nickel Grade (%)		1.69	1.78	1.75	1.62			
Nickel Recovery (%)		29.74	42.50	50.70	55.43			

Total Possible Copper (g)	2.493374
Total Copper / Feed (%)	0.266469
Copper Mass Balance	94.15855
Total Possible Nickel (g)	1.906064
Total Nickel / Feed (%)	0.203702
Nickel Mass Balance	92.17303

Figure 98 - Raw data for Senfroth 580 at 10 SPW and 60 g/ton



Date	18-Oct
SPW	10
Ore	Kevitsa
Frother	Senfroth 580
Dosage	70 g/ton
Collector	SIBX (1%)
Collector Dosage	5ml

Feed Run 1	946.7
Feed Run 2	934.7

Total Solids Collected (Run 1)	935.4
Total Solids Collected (Run 1)	923.6

	Run 1							
Cumulative Time	0	2	6	12	20			
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	25.6	51.52	24.31	20.07	23.21	24.97	24.62	835.6
Paper	11.67	11.95	11.93	11.71	11.65	11.62	12.04	11.94
Solids (g)	13.93	39.57	12.38	8.36	11.56	13.35	12.58	823.66
Cumulative Solids (g)	0	39.57	51.95	60.31	71.87			
Squirt Bottle Before		591.17	575.62	559.29	572.16			
Squirt Bottle After		540.61	512.87	492.4	468.49			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		664	528.12	487.45	684.6			
Recovered Water		383.33	269.14	236.5	319.61			
Cumulative Water	0	383.33	652.47	888.97	1208.58			
Top-up Bottle Before		1164.9	1158.8	1170.4	1173.1			
Top-up Bottle After		923.3	794.1	911.4	832.4			
Top-up Water Used		241.6	364.7	259	340.7			
Copper Percentage (%)	0.285	4.26	2.15	1.4	0.822	0.057	0.053	0.055
Copper Mass (g)	0.0397005	1.685682	0.26617	0.11704	0.0950232	0.00761	0.0066674	0.453013
Cumulative Copper Mass (g)		1.685682	1.951852	2.068892	2.1639152			
Copper Grade (%)		4.26	3.76	3.43	3.01			
Copper Recovery (%)		64.07	74.18	78.63	82.24			
Nickel Percentage (%)	0.23	1.6	2.01	1.75	1.06	0.103	0.084	0.0935
Nickel Mass (g)	0.032039	0.63312	0.248838	0.1463	0.122536	0.01375	0.0105672	0.7701221
Cumulative Nickel Mass (g)		0.63312	0.881958	1.028258	1.150794			
Nickel Grade (%)		1.60	1.70	1.70	1.60			
Nickel Recovery (%)		32.55	45.34	52.86	59.16			

Total Possible Copper (g)	2.63119
Total Copper / Feed (%)	0.281293
Copper Mass Balance	98.69941
Total Possible Nickel (g)	1.945161
Total Nickel / Feed (%)	0.207952
Nickel Mass Balance	90.41384

	Run 2							
	Feed	C1	C2	C3	C4	Tails 1	Tails 2	Tails
Solids + Paper	25.1	52.63	24.72	20.05	22.16	23.17	23.76	814.3
Paper	10.27	10.13	10.22	10.4	10.39	10.29	10.4	10.2
Solids	14.83	42.5	14.5	9.65	11.77	12.88	13.36	804.1
Cumulative Solids	0	42.5	57	66.65	78.42			
Squirt Bottle Before		540.61	512.87	492.4	468.49			
Squirt Bottle After		482.88	452.26	421.52	339.14			
Dish		190.54	183.85	175.7	249.76			
Dish + H2O + Conc		685.3	558.82	518.47	726.4			
Recovered Water		394.53	299.86	262.24	335.52			
Cumulative Water	0	394.53	694.39	956.63	1292.15			
Top-up Bottle Before		923.3	794.1	911.4	832.4			
Top-up Bottle After		680.2	381.38	604.3	484.18			
Top-up Water Used		243.1	412.72	307.1	348.22			
Copper Percentage (%)	0.281	3.8	1.63	1.21	0.683	0.058	0.051	0.0545
Copper Mass (g)	0.0416723	1.615	0.23635	0.116765	0.0803891	0.00747	0.0068136	0.4382345
Cumulative Copper Mass (g)		1.615	1.85135	1.968115	2.0485041			
Copper Grade (%)		3.80	3.25	2.95	2.61			
Copper Recovery (%)		61.38	70.36	74.80	77.85			
Nickel Percentage (%)	0.225	1.46	1.62	1.7	0.956	0.1	0.1	0.1
Nickel Mass (g)	0.0333675	0.6205	0.2349	0.16405	0.1125212	0.01288	0.01336	0.8041
Cumulative Nickel Mass (g)		0.6205	0.8554	1.01945	1.1319712			
Nickel Grade (%)		1.46	1.50	1.53	1.44			
Nickel Recovery (%)		31.90	43.98	52.41	58.19			

Total Possible Copper (g)	2.501039
Total Copper / Feed (%)	0.270795
Copper Mass Balance	96.36848
Total Possible Nickel (g)	1.962311
Total Nickel / Feed (%)	0.212466
Nickel Mass Balance	94.42916

Figure 99 - Raw data for Senfroth 580 at 10 SPW and 70 g/ton