The effect of recycle water quality on the flotation of a Platreef ore

Zandile P Peku

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Abstract

One of the major challenges facing mining houses today is to come up with strategies to maximize water resource utilisation. Water is a scarce resource, and every opportunity must be explored to maximize water conservation. Mining operations consume a lot of water for many activities including mineral processing, slurry transport, dust suppression and employee requirements. Apart from mining (3%), there are other competing demands for water from other sectors, for example, the municipal (6.1%), agricultural (62%), energy (2%), forestry (3%), industrial sectors (3%), and domestic (27%) (Askham & Van der Poll, 2017). There is therefore a need for the mining sector to reassess its water usage with a view to not only understanding water footprint but also ensuring maximum water resource utilization.

Mining operations not only consume a lot of water but also pose serious environmental hazards associated with tailings disposal, effluent discharge, and release of process water into the water-table. The wastewater produced in mineral processing contains a lot of suspended solid particles, heavy metal ions, residual flotation reagents, organics, and other pollutants. Most plants have on-site wastewater treatment plants to treat the effluent before recycling it back to the mineral processing plant (Park et al., Han & Ji, 2018). This practice is expensive due to the need to procure water treatment equipment and chemicals. Some researchers have proposed the development of closed-circuit operation approaches where the process water is recycled within the mineral processing plant. The effects of recycling process water are ore specific, i.e., each ore will respond differently to different water chemistries. Little research has been conducted to understand the effect of different specific ions and their concentrations on the Platreef ore. With the depletion of the Merensky and UG2 ore, mining houses are shifting their attention to the Platreef ore as an alternative platinum group metal resource. The timing of this project therefore becomes critical as new Platreef mines are being opened in South Africa according to Jacobsen (2021)

Studies by Boujounoui et al. (2015) show that increasing use of recycle water in flotation ores has negative effects on recovery and grade of the valuable minerals. These have been traced to the accumulation of dissolved compounds, inorganic and organic, which alter the chemistry of the system. However, some studies like Dzingai et al., (2020), Corin et al., (2011) etc. have indicated positive process benefits arising by recycling of process water. For example, an increase in the ionic strength of water has been shown to result in increased water recovery, solids recovery without affecting the grade in a sulphidic platinum group metal ores. This study therefore sought to investigate the effect of process water recycling (with focus on specific ions) on the flotation of the Platreef ore. The concentrations or window of concentrations beyond which the specific ions cause the flotation performance of the Platreef ore begins to decline have also be determined.

The study has shown that increasing the ionic strength of process water had a corresponding increase in the water recovery while the solids recovery did not always follow the same pattern. The spiking of ions at different concentration was used to determine which ions were beneficial to the flotation process and which ones were deleterious. It was also noted shown that Cu flotation only improved in the presence of Ca^{2+} ions. When other ions were introduced in the system the copper flotation was negatively affected because the copper grade and recovery were lower compared 3 SPW (synthetic plant water). Generally, the presence of the selected ions in synthetic process water improved the recovery of all the valuable minerals with the exception of nickel at 800 ppm Mg^{2+}. This study on recycling water usage in flotation serves as a contribution to ensuring a lower usage of potable water in floating the Platreef ore.

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List of Abbreviations

Pt	platinum
Pd	palladium
Cu	copper
Ni	nickel
PGE	platinum group element
PGM	platinum group metal
BMS	base metal sulphide
UG2	upper grade2
ppm	parts per million
rpm	revolutions per minute
SIBX	sodium isobutyl xanthate
TDS	total dissolved solids
UCT	University of Cape Town
RC1	first rougher concentrate (with RC2 being the second, RC3 being the third, etc.)
CMR	Centre for Minerals Research
g	grams
g/t	grams per ton
I.S	ionic strength
kg	kilograms
L	litres
mL/min	millilitres per minute
M	molarity
min	minutes
mg/L	milligrams per litre
mm	millimetres
mL	millilitres
NFG	naturally floatable gangue
XRD	X-ray diffraction
CMC	carboxymethyl cellulose
SPW	synthetic plant water
pH	potential hydrogen
$mol.dm^{-3}$	mole per decimetre cubed
ICP	inductively coupled plasma
ICP-OES	inductively coupled plasma optical emission spectroscopy
ICP-MS	inductively coupled plasma mass spectrometry

Leco	laboratory equipment corporation
vol%	volume percentage
ECD	equivalent circle diameter
MLA	mineral liberation analyser
QEMSCAN	quantitative evaluation of materials by scanning electron microscopy
AutoSEM	automated scanning electron microscopy
Std	standard
d	diameter
CDP	carbon disclosure project
DWS	department of water and sanitisation

1. INTRODUCTION

Mineral processing is one of the most water-consuming processes. Many operations are required to recycle water within their operations due to limitations on freshwater usage. Several research works have studied on the use of recycled process water to reduce freshwater consumption. Water in flotation circuits represents 80–85% of the volume of mineral pulp processed. Recirculating water in the flotation circuit can have adverse effects on the mineral separation because it may have a direct impact on the selectivity of the processes, and thus a thorough understanding of the effects of process water on the flotation process is required.

According to Slatter et al., (2009) it is not necessary to use potable water in the flotation processes as waters of a higher ionic strength tend to improve flotation performance. However, the threshold where ionic strength negatively affects the flotation performance is not clear. This is because in the flotation process different ions present in the process water play different roles. Levay et al (2001), Johnson (2003) and Slatter et al. (2009) have established that the concentrations of both organic and inorganic salts present in recycled process water have effects on the flotation performance of a particular ore. Typical organics are collectors, frothers and depressants while suspended matter, magnesium, calcium sulphate ions etc. are typical inorganic components.

Investigating specific ions and their concentrations beyond which flotation is adversely affected is necessary due to limited literature with regards to the concentration threshold beyond which specific ions found in process water would result in adverse effects on flotation. This study focuses on the effect selected ions have on the flotation performance of a Platreef ore which represents the recycling of plant water in the flotation circuit. Platinum and palladium as well as copper and nickel grade and recovery including solids and water recoveries are the key performance indicators.

1.1. Scope and Limitations

Flotation performance is affected by collectors, frothers, depressants, activators and dissolved ions according to Bradshaw et al., (1998). Muzinda and Schreithofer, (2018), and Ikumapayi et al., (2012), agreed and were able to show that some ions have affected the flotation performance negatively. Klimpel, (1995) observed that the grinding environment has a significant impact on the flotation performance.

Thus, for the purpose of this study, the following will be kept constant:

- Grinding (milling) media and mill type
- Collectors type and dosage
- Depressant type and dosage
- Frother type and dosage
- Flotation cell type, air flow rate and impeller speed, hence hydrodynamic properties.

Only the influence of Ca^{2+}, Mg^{2+}, SO_4^{2-}, NO^{3-} and $S_2O_3^{2-}$ ions on flotation parameters will be studied. The key indicators which will be used to evaluate the flotation performance are:

- The Pt, Pd, Cu and Ni grade (purity) of the recovered concentrate.
- The Pt, Pd, Cu and Ni recovery (valuable mineral)
- The water recovery to the concentrate
- The solids recovery to the concentrate

The major limitation of this study is that the methodology used in this study investigated the effect of the concentration of a particular ion independently while fixing the concentrations of other ions present in the SPW complex water matrix. This approach misses the interactive effects between the ions themselves. However, the methodology adopted in this study is reliable to establish the effects different ions on the flotation performance.

2. LITERATURE REVIEW

In South Africa, PGM-bearing ores are found in the Bushveld Complex, which contains extremely rich reserves of these minerals. The minerals include platinum, palladium, and rhodium, ruthenium, iridium, and osmium are less prevalent and less in demand (Jones, 2005). The Bushveld Complex is located in the north of the country and is mainly characterised by what are known as the eastern, northern, and western limbs (Cawthorn & Webb, 2001). Figure 1 shows the geographical location of the various limbs.

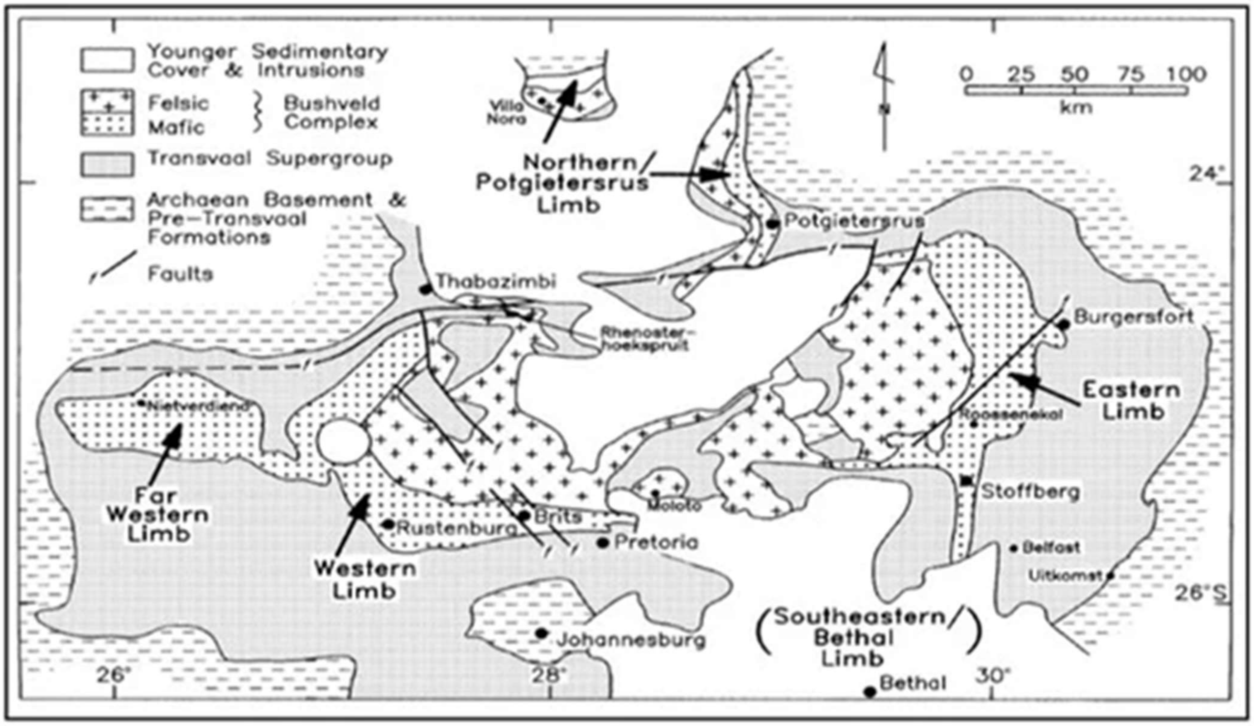


Figure 1: A geological plan view map of the Bushveld Complex (Cawthorn & Webb, 2001)

The Bushveld Complex hosts the largest concentration of PGMs in the world and includes three distinct mineral-bearing reefs i.e. Upper Group Chromitite No.2 (UG2) and Merensky Reef which, according to O'Connor & Alexandrova (2021), is the western limb operation which is mostly underground, the Platreef mineralisation of the northern limb of the Bushveld Complex which is often an open pit.

The mineral processing of the PGM involves comminution, flotation, smelting, converting, base metals refinery and precious metals refinery and is a water intensive process. This study focuses of the flotation of a Platreef ore using recycled water in an effort to reduce water consumption in mineral processing.

2.1. Froth Flotation

Froth flotation involves the three phases, namely, solid, water and froth; and according to Finkelstein and Lovell, (1972) it is not completely understood. In flotation the desired valuable mineral is attained by using the differences in surface properties of the valuable minerals and gangue minerals. Reagents (collectors, frothers, depressants, activators) are added to a ground slurry during flotation to render the desired mineral hydrophobic and then air bubbles are introduced to move the hydrophobic mineral to the froth phase whilst the hydrophilic mineral remains in the pulp or tailings according to Wills and Napier-Munn, (2006).

The three ways by which material can be recovered by flotation from pulp are (Wills and Napier-Munn, 2006):

- True flotation - selective attachment of materials to air bubbles
- Entrainment in the water which passes through the froth
- Aggregation - physical entrapment between particles in the froth attached to air bubbles

True flotation i.e., the attachment of valuable minerals to air bubbles, is the most important mechanism and represents the majority of particles that are recovered to the concentrate, (Wills and Napier-Munn, 2006). Figure 2 shows a conventional flotation cell used in laboratory operations.

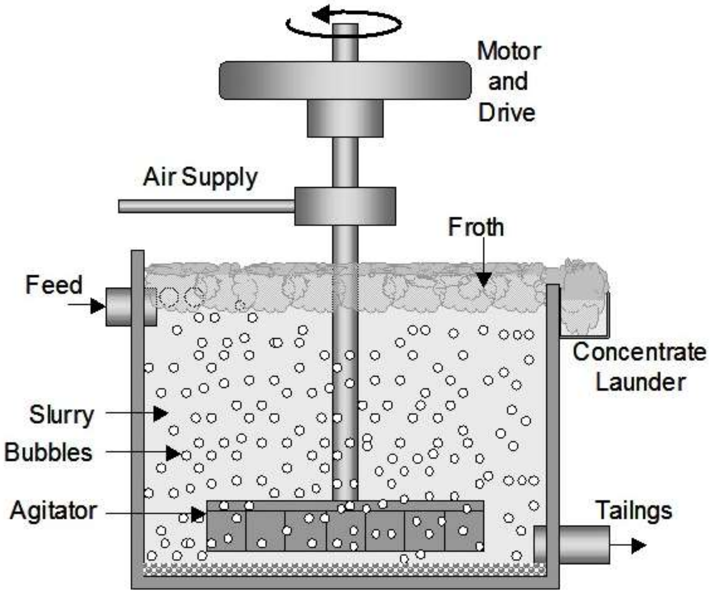
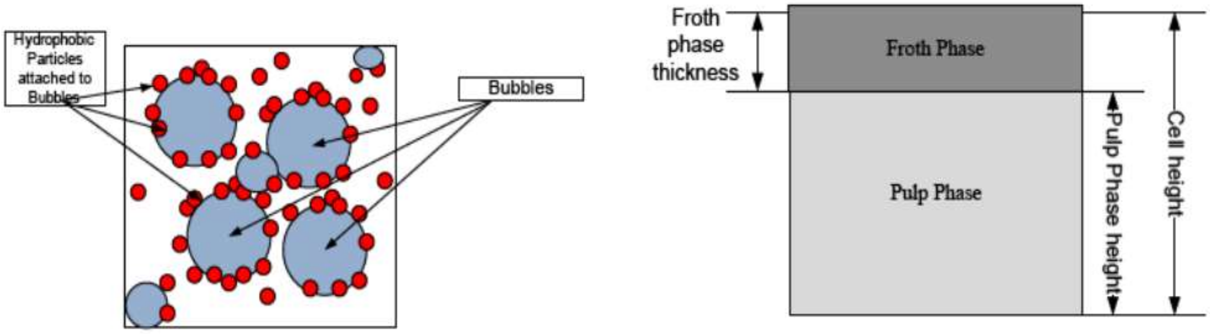


Figure 2: Conventional flotation cell (Tinoco and Valeria, 2011)

The flotation cell has a motor driven impeller used to agitate the slurry. Air is added near the impeller, which is designed to break the air into small bubbles. The impeller driven flotation cell is used for separating, recovering, and concentrating valuable mineral particles from undesired gangue. The hydrophobic mineral particles (often valuable mineral particles) attach to the surface of the bubbles as shown in Figure 3 (a) and then lift the minerals to the top of the flotation cell forming a mineral froth layer as shown in Figure 3 (b).



(a) (b)

Figure 3: (a) Loaded bubbles with minerals. (b) Froth phase or froth layer and pulp phase in flotation cell (Dzingai, 2019)

The concentrate launder, at top of the tank, collects the froth form layer (containing minerals). The tailings have outflow of slurry to the next flotation cell in the flotation bank (Ur Rehman, 1995).

2.2. Froth Phase

The function of the froth phase is to enhance the overall selectivity of the flotation process. According to Ata (2011) the froth achieves this by reducing the recovery of entrained material to the concentrate stream, while preferentially retaining the attached material. Froth is considered unstable when bubbles burst thus losing the valuable mineral to the pulp and reporting to the tailings. When the froth is too stable the efficiency of the flotation process is hindered due to gangue entrainment resulting in low selectivity therefore a balance between concentrate mineral recovery and froth stability is needed. The froth height for the pulp surface is illustrated in Figure 4.

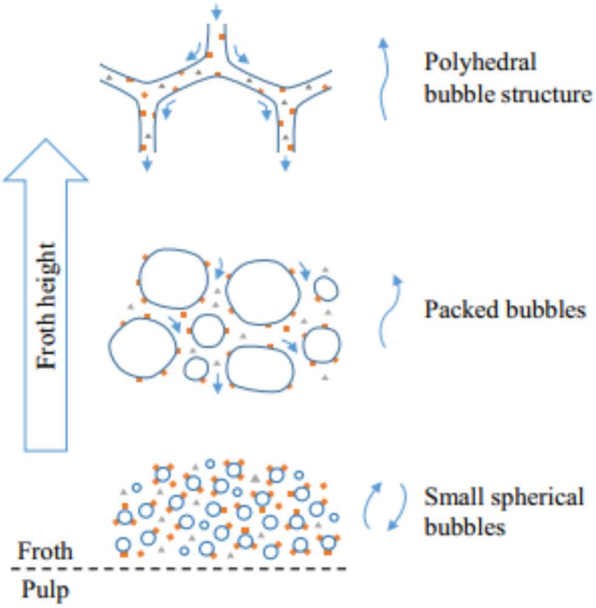


Figure 4: Froth structure at different height during a float test (Hu, 2014)

At the froth surface, larger bubbles tend to amalgamate and burst, indicating that the bubble structure becomes big and unstable and raptures, and the particles (hydrophobic valuable minerals attached to the bubbles) fall through the froth and can re-attach to other bubbles in the pulp, (Hu, 2014). Bradshaw, (1997) suggested that the collector mineral adsorption reactions tend to increase the hydrophobicity of the mineral particle which therefore increase the bubble loading.

2.3. The Pulp Phase

In the pulp phase, the hydrophobicity of the target mineral particles is enhanced by interacting with the added collector. The hydrophobic particles attach to air bubbles and float to the froth phase when controlled air is introduced into the float cell; this is called true flotation, (Wills & Napier-Munn, 2006). The interrelated systems of the flotation process are shown in Figure 5. In froth flotation operations it is very important to take all these factors into account; thus making it difficult to study the effect of any single factor in isolation (Klimpel, 1995).

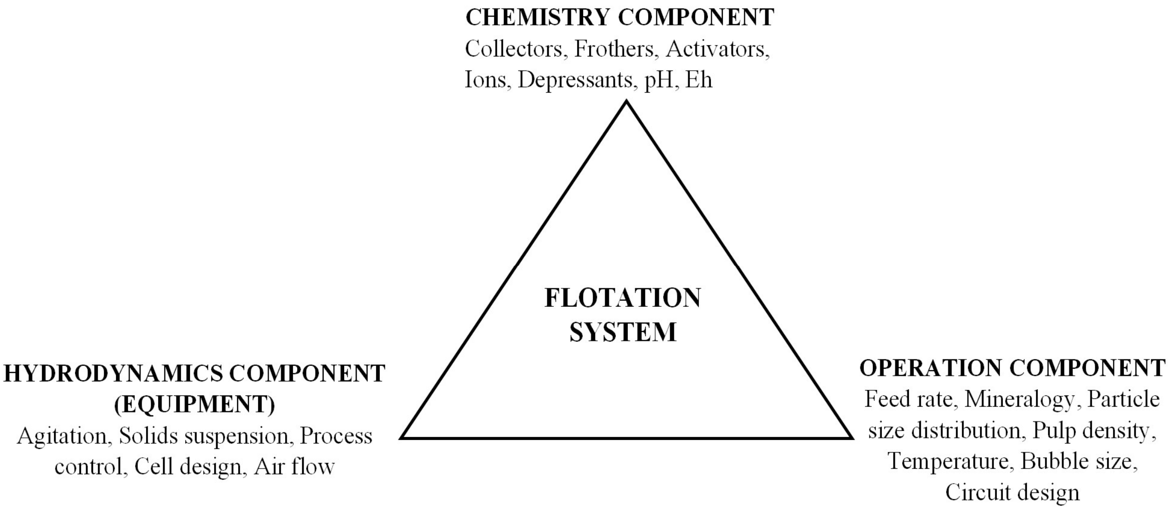


Figure 5: Interrelated components of the flotation system.

This study will focus on the chemistry component i.e., ions and Eh. The rest of the flotation system components, hydrodynamics and operation components, will be kept constant.

2.4. Flotation Reagents

The most important part of the flotation process is reagents. Diverse reagent suites comprising of collectors, depressants, frothers and activators are added to the slurry ore to modify the mineral surface chemistry and enhance differences in hydrophobicity between the valuable mineral and gangue mineral, thus enabling the separation of gangue from valuable minerals.

2.4.1. Collectors

To float most minerals, hydrophobicity must be imparted on them. Collectors are added to the pulp in order to achieve this, and time (conditioning time) is allowed for adsorption during agitation, (Wills & Napier-Munn, 2006).

According to Wills & Napier-Munn, (2006) collectors are organic compounds which render selected minerals water-repellent by adsorption of molecules or ions on to the mineral surface, reducing the stability of the hydrated layer separating the mineral surface from the air bubble to such a level that attachment of the particle to the bubble can be made on contact.

Wiese et al., (2005) states that xanthates are the most used collectors in the flotation of sulfide minerals because of their efficient role in mineral collection and low cost. The most widely used xanthates in industrial flotation of sulphide minerals are ethyl, isopropyl, isobutyl, amyl, and hexyl xanthates however new chemistries such as dithiophosphates and thiocarbamates are being used. Xanthates are renowned collectors for many heavy and precious metal sulphides (Fuerstenau, 1982). Figure 6 shows the general molecular structure of an alkyl xanthate, where R represents the alkyl chain.

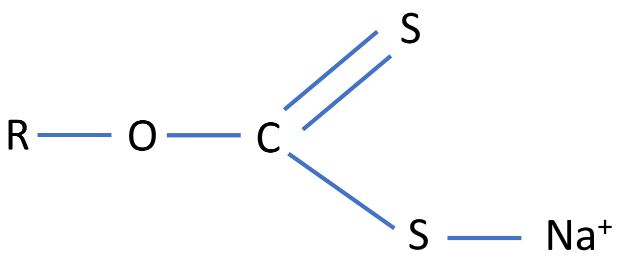


Figure 6: General molecular structure of alkyl xanthate (Castelyn, 2012)

The xanthate collector used in this study is sodium isobutyl xanthate (SIBX) and its structure is shown in Figure 7. Due to low cost and efficient role in mineral collection, xanthates are widely used in the flotation of sulphide minerals (Wiese et al., 2005; Lovell, 1982).

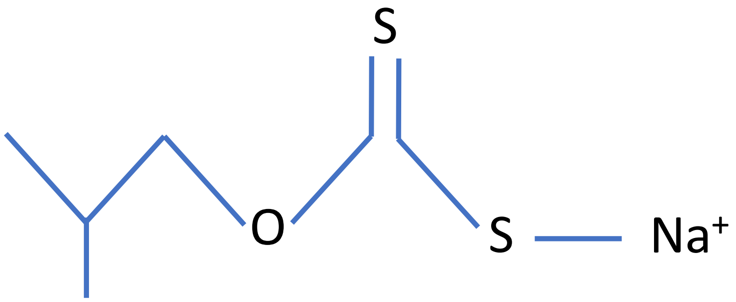


Figure 7: Sodium isobutyl xanthate structure

2.4.2. Adsorption mechanisms of collectors

Physisorption or chemisorption are processes by which collector adsorption occurs. Jeldres et al., (2016) observed that in a saline environment, where secondary ions are present, collector adsorption and flotation operation tend to be difficult, this is because the secondary ions cause colloidal precipitation and strong buffering especially in highly alkaline conditions. Bowden & Young, (2016) showed that the chemisorption of xanthate onto a chalcopyrite surface will occur in regions where Cu_2S is formed upon oxidation of the chalcopyrite surface. The adsorption of a collector onto a mineral surface is shown in Figure 8.

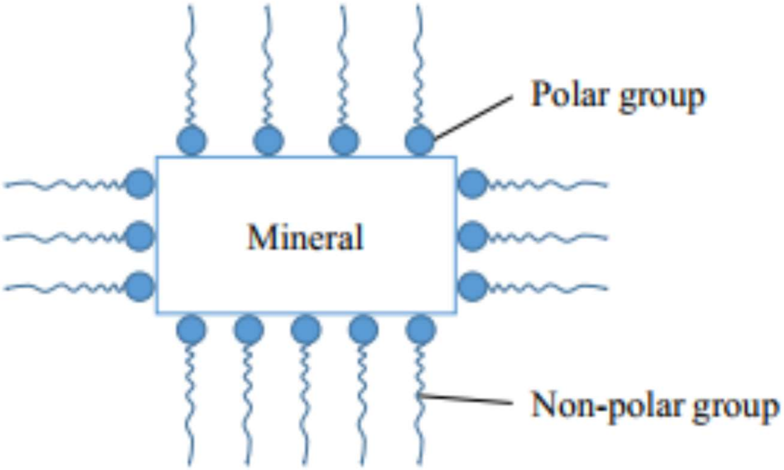


Figure 8: Collector adsorption onto the mineral surface, (Wills & Napier-Munn, 2006)

Weise et al., (2005) states that the hydrophilic collector polar group attaches to the mineral surface. The alkyl hydrocarbon chain makes the mineral surface hydrophobic, as it is orientated towards the pulp phase, and can therefore attach to the air bubble.

2.4.3. Depressants

Depressants are chemicals that prevent the absorption of collectors on certain minerals, they allow certain minerals to float while preventing others from floating (Cottrell, 1967). Depressants are used to prevent collector adsorption onto undesired mineral surfaces and thereby render the undesired mineral hydrophilic and improve flotation selectivity. There are many types of depressants with complex and varied actions. In most cases depressants are not fully understood and this makes the depression process more difficult to control than the application of other types of reagents, particularly when the froth phase is also affected by their action (Bradshaw et al., 1998).

Wills and Napier-Munn, 2006 states that depression is used to increase the selectivity of the flotation process by rendering certain minerals hydrophilic (water-avid), thus preventing their flotation. In sulphide mineral flotation organic depressants are used, in this study carboxymethyl cellulose (CMC) is used. Shortridge et al., (1999) showed that the CMC depresses gangue by preventing the formation of hydrophobic layer on the gangue mineral surface, forming large gangue aggregates and thereby increasing their heterocoagulative nature. Figure 9 shows the molecular structure of CMC.

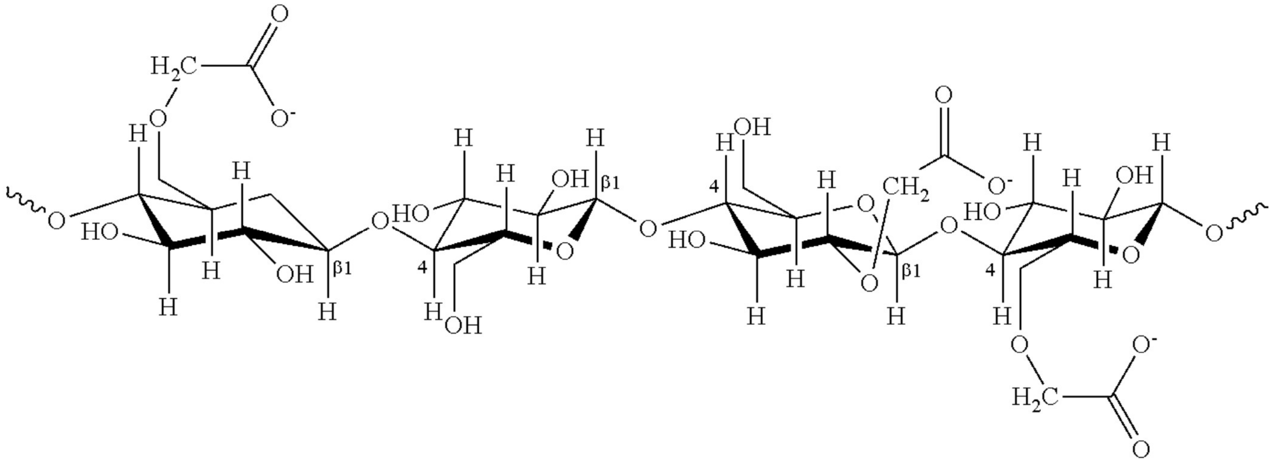


Figure 9: The molecular structure of CMC

2.4.4. Activators

Activators are reagents that alter the chemical nature of mineral surfaces to that they become hydrophobic due to the action of the collector. Wills and Napier-Munn, (2006) stated that activators are generally soluble salts which ionise in solution, the ions then react with the mineral surface. Activators are reagents which are used to enhance flotation performance. According to Bradshaw (1997) the commonly used activators are copper sulphate, ($CuSO_4$) and sodium sulphide, which is used as a sulphidising reagent for tarnished or oxidised ores.

2.5. Water Quality Issues in Mineral Processing

Water in the Mineral processing plants is recycled with the objective of reducing potable water consumption. However, this recycled water contains deleterious ions which affect, among other things, the strength of reagent action on valuable minerals. These ions include $S_2O_3^{2-}$, Ca^{2+}, F^-, NO_3^-, K^+, SO_4^{2-}, Na^+ and Cl^- (Dzingai et al, 2020). Other contaminating species include depressants, collectors, frothers, activators, base metals, and natural organic material (Dzingai et al, 2020). Water quality affects the following key phenomena in flotation:

- *Pulp chemistry*: the presence of ions at high concentrations beyond a certain threshold result in modified pulp viscosity which leads to entrainment and thus reduced grade (Kirjavainen et al., 2007).

- *Mineral surface chemistry and reagent action*: Ca^{2+} and SO_4^{2-} form complex species at the mineral surface, which lower the surface area available for hydrophobic bonding leading to inhibited collector adsorption and reduced floatability of the mineral (Dzingai et al, 2020).

- *Froth stability*: inorganic ions in water slow down inter-bubble drainage and thereby inhibit bubble coalescence and promote stability in the froth phase (Barker, 1986).

Ultimately the plant performance which includes the mineral grade and recovery is affected by the water quality used.

2.6. Impact of Ionic Strength on Flotation

The measure of concentration of electrolytes dissolved in a solution is defined as Ionic strength. The typical contaminating species in recycle water are: Ca^{2+}, Mg^{2+}, SO_4^{2-}, Cl^-, Na^+, K^+ and F^-, activators, collectors, depressants, frothers, colloidal materials and natural organic material; some of which exist naturally in water (Slatter et al., 2009). One of the major benefits of recycling water is that it retains some reagents which therefore decreases the use of reagents by approximately 50% (Slatter et al., 2009). It was also noted, however, that the reagent selectivity during flotation was reduced due to higher water content in the froth phase as the froth was over stabilised.

Ikumapayi et al., (2012) showed that when varying the Ca^{2+} and SO_4^{2-} concentrations there was a maximum concentration of the ions beyond which the flotation recoveries were affected in the study of pure sulphide minerals galena and chalcopyrite. The formation of an ion induced hydrophilic layer around the valuable mineral hindered collector adsorption thus affecting the flotation performance.
Parolis et al., (2008) showed increased adsorption of CMC depressant onto talc compared to K^+ ions when Ca^{2+} and Mg^{2+} ions were present in recycle water, this adsorption was even higher at increased ionic strength (more than 10^{-3} $mol.dm^{-3}$). The literature on the effect of water quality in the flotation of different minerals is summarised in Table 1.

Table 1: Experimental setup

Process Variables	**Corine et al., 2011**	**Ikumapayi et al., 2012**	**Manono et al., 2017**	**Dzingai et al., 2020**	**Dzingai et al., 2021**
pH	9	10.5	9 & 11	9	9
Sample grind	60%-75 µm	-150+38 µm	60%-75 µm	70%-75 µm	70%-75 µm
Flotation	Batch	Micro	Batch	Batch	Batch
Water tested	1, 2, 3 UCT SPW	Deionised + Process water	1, 5, 10 UCT SPW	1, 3, 5, 10 UCT SPW	1, 3, 5, 10 UCT SPW
Sample type	Merensky reef	Pure Galena mineral	PGM	Low-grade Cu-Ni-PGM	Low-grade Cu-Ni-PGM
Ion spiking	-	Ca^{2+} & SO_4^{2-}	-	Ca^{2+} & Mg^{2+}	SO_4^{2-}, NO_3^-, & $S_2O_3^{2-}$

Ikumapayi et al., (2012) conducted his experiments at pH 10.5 and Manono et al., (2017) at pH 9 and pH 11, the rest of the researchers conducted their experiments at alkaline pH 9. Although all the samples used were sulphide ores, they had different mineralogical composition. Apart from Ikumapayi et al., (2012) who used micro flotation with pure galena minerals, all other researchers used batch flotation with synthetic process water (SPW) which had an ionic strength of 0.024 M and 1023 mg/L TDS. The SPW was adjusted to 3 different strengths to determine the effect of increasing ionic strength on the key performance indicators.

Additionally, Dzingai et al, (2020) and Ikumapayi et al., (2012) looked at spiking specific ions to determine their individual effect on water quality and mineral grade and recovery. The common observation made from the different researchers was that increasing ionic strength increased froth stability leading to an increase in water recovery. The increased water recovery has been shown to increase solids recovery Manono et al (2012) showed through pulp bubble size measurements that increasing the ionic strength decreased the bubble size thus enabling the formation of smaller bubbles which in turn increase the bubble surface area. This increase in bubble surface area then enabled an increase in bubble- particle attachment and thus enhance water and solid recoveries.

Manono et al (2012) also showed that increasing the polysaccharide depressant reduced the stability of the froth. He noted that increasing the polysaccharide depressant dosage in the system led to:

- Decreased amount of solids reporting to concentrate
- Decreased non floatable gangue at high depressant dosages
- Increased Cu and Ni grade.

It was noted that at high alkaline pH 11, the increase in ionic strength increased the water recovery but decreased the solids recovery, this was accredited to the excess presence of hydroxyl ions which may have caused an increase in the mobility of the froth (Manono et al. 2017). Table 2 shows the impact of increasing ionic strength on the mineral grade and recovery.

Table 2: Effect of increased ionic strength on Cu and Ni grade and recovery

Effect of increase in ionic strength	**Corine et al., 2011**	**Manono et al., 2017**	**Dzingai et al., 2020**	**Dzingai et al., 2021**
Cu recovery	No significant change	Slight increase	No significant change	No significant change
Ni recovery	No significant change	Slight increase	Increase	Increase
Cu grade	Somewhat decreased	Decreased	No significant change	No significant change
Ni grade	Decreased	Decreased	Increase	Increase

When the ionic strength was increased from 1 SPW to 3, 5 and 10 SPW both the Cu and Ni recovery did not show any significant change according to Corin et al., (2011) and there was a slight/marginal increase observed by the other authors. This change was credited to the increase in naturally floatable gangue as the ionic strength of water increases the froth stability. Increasing the ionic strength increased the recovery of naturally floatable gangue which decreased the Cu and Ni grade. This was observed from the work done by Corin et al., (2011) and Manono et al, (2017), Dzingai et al., (2020) and Dzingai et al., (2021), but Dzingai et al., (2020) and Dzingai et al., (2021) saw an increase in the Ni recovery which was attributed to the dependency of the mineral grade on the type of ion under consideration and its effect on froth stability and gangue. This therefore necessitated the need to understand and operate within thresholds of each ion to maximize performance. Similar results were observed for the Ni recovery although Dzingai et al., (2020) and Dzingai et al., (2021) saw an increase in the Ni recovery as compared the slight/marginal increase observed by Manono.

Corin et al., (2011) and Manono et al., (2017) observed a decrease in both Cu and Ni grade at increased ionic strength, but Dzingai et al., (2020) and Dzingai et al., (2021) observed an increase in the Ni grade and no change in the Cu grade. This inconsistency can also be attributed to the difference in the type of sample used by the researchers. The low grade Finnish Cu-Ni PGM ore used by Dzingai et al., (2020) and Dzingai et al., (2021) seemed to respond positively to an increase in ionic strength when compared to the low grade South African PGM by Manono et al., (2017) and Merensky reef by Corin et al., (2011). All three ores are similar in that they are PGM ores but have different grades and gangue mineralogies which contributes to their different responses.

Observations from spiking different ions showed that:

- Ca^{2+} spiking: 400 mg/L Ca^{2+} is a threshold beyond which the Cu grade decreased. Ni grade increased and threshold was beyond project scope (Dzingai et al., 2020). Ikumapayi et al., (2012) found that the recovery of Galena increased when Ca^{2+} between 50-400 mg/L and decreased above 500 mg/L.

- Mg^{2+} spiking: increase in both Cu and Ni grade according to Dzingai et al., (2020) and both the Ni and Cu recoveries dropped insignificantly.

- NO_3^- spiking: A threshold concentration boundary for Cu and Ni grade between 528 mg/L and 880 mg/L NO_3^- was found for this given ore according to Dzingai et al., (2020).

- SO_4^{2-} spiking: Dzingai et al., (2020) found a threshold concentration boundary of 720 and 1200 mg/L SO_4^{2-}. Ikumapayi et al., (2012) found that galena flotation was negatively affected by the presence of SO_4^{2-} ions and the floated less in process water than in deionized water.

- $S_2O_3^{2-}$ spiking: Both Cu and Ni grades increased and the threshold lies outside of the concentrations considered in the study (Dzingai, 2020).

Spiking specific ions has shown that individual ions impact the flotation performance differently and have different thresholds beyond which the flotation performance is detrimental, thus it is essential to understand and operate within thresholds of each ion to maximize performance.

2.7. Flotation of Platreef ore

The Platreef ore has a relatively high base metal and talc content compared to its UG2 and Merensky counterparts. Various studies have been conducted to understand the effect of water recycling on the UG2 and Merensky ores. However, limited research has been conducted to evaluate the effect of water recycling in the processing of Platreef ores. This is due to the complexity of the Platreef ore, limited research funding as a few mining companies mine the Platreef ore in South Africa. Compared to UG2 and Merensky it is expected that the Platreef ore will respond differently to the different electrolytes and ionic strength due to different mineralogy.

Chalcopyrite, pentlandite and pyrrhotite are the major base metal sulphides (BMS) present in the Platreef ore. The main naturally floating gangue is talc. The traditional collector and depressant used in the flotation of Platreef ores are xanthate and CMC.

Becker et al., (2009) stated that 45% of the BMS is mostly in the form of pyrrhotite which is a slow floating mineral. The flowsheet for the Platreef processing is designed to target the pyrrhotite since some PGMs in the Platreef ore are associated with this slow-floating mineral. However, depending on the condition of the process water, the flotation of pyrrhotite may either be enhanced or depressed.

3. OBJECTIVES, HYPOTHESIS AND KEY QUESTIONS

3.1. Problem Statement

Mineral processing is one of the most intensive water-consuming processes. Several research works have focused on using recycled process water in an effort to reduce the use of fresh water consumption. However, during the flotation process, recycling water can have adverse effects on the mineral separation due to the build-up of the ions that are re-introduced to the circuit. A good understanding of the effects of the accumulation of these ions and their influence on the flotation performance is needed to manage water consumption.

Knowledge gaps identified:

Little work was done to determine the number of cycles beyond which the synthetic plant water be considered detrimental for the flotation process. This is important considering that the concentrations of ions increase with increasing number of cycles. Thi et al., (2020) was able to show that the effect of recycled water on the plant flotation performance could be predicted but, the results were not sufficient to generalize the observation worldwide because they were from one mine.

Work done investigated the effect of different ions on the base metal sulphide i.e., Cu and Ni grade and recovery but not much information on the direct effect on PGM, Pt and Pd, grade and recovery. This is based on the assumption that the PGMs are associated with BMS, hence the BMS are proxies for PGMs. However, in the Platreef ore, most of the PGMS are liberate and thus, results observed for the BMS may not apply for the PGMs.

Previous studies have focused on the UG2 and Merensky ores thus far. Merensky and UG2 ore are getting depleted and mining houses are shifting attention to the Platreef ore as an alternative PGM resource. The mineralogy of the Platreef is different from that of the UG2 and Merensky ores, therefore it is expected that the Platreef ore will respond different to different water chemistries. The study of the effect of water quality on the Platreef ore is very scarce in literature. Thus, this study will investigate the effect of recycle water on the flotation performance of a Platreef ore.

3.2. Objectives

This study will investigate focus on the Platreef ore and determine the effect of varying concentrations of calcium, sulfate, thiosulfate and magnesium ions spiked within a complex water matrix on:

- Pt and Pd grade and recovery
- Cu and Ni grade and recovery
- Water and solids recovery

3.3. Research Hypothesis

It is hypothesized for the Platreef ore flotation that:

- There exists a different concentration window(s) for different ions beyond which the flotation performance of the Platreef ore will decline. In terms of recovery, the presence of cations compresses the double layer thereby facilitating the bubble-particle interaction translating to improved recoveries. Some ions may activate the slow-floating valuable minerals translating to higher recoveries. However, the downside is that some ions may also passivate the valuable mineral surfaces through the formation of hydrophilic carbonates and hydroxyls. This will translate to lower recoveries. In terms of grade, some ions may activate the gangue leading to concentrate dilution. All these phenomena will happen as a function of ion type and concentration, and therefore there is need to determine the ion concentration for optimum metallurgical performance.

- An increase in cations in the process water will reduce the PGM recovery as the cations are known to compete with xanthate for adsorption onto the base metal mineral surface. Some PGMs in Platreef are associated with base metal sulphides and the loss of base metal sulphides means the loss of PGMs.

3.4. Key Questions

The following questions will be addressed during the study:

- How does increasing the ionic strength by increasing sulfate, thiosulfate and nitrate concentration affect the flotation grade and recovery of Platreef ore at pH range around 8 – 9.
- How does increasing the ionic strength by increasing calcium and magnesium concentration affect the flotation grade and recovery of Platreef ore flotation at pH values around 9?
- At what specific ionic concentration will the flotation performance be considered deleterious?

3.5. Impact of the Study

The study intends to:

- Reduce potable water usage in the minerals processing industry thus addressing the water issues facing South Africa.
- Recycle the water reporting to the tailings dam back into the process, thus reducing discharge to effluent as well as cost of water treatment which would otherwise be required prior to discharge.
- Contribute to the body of knowledge as not much research has been conducted on the effect of water quality on the flotation of the Platreef ore.

4. EXPERIMENTAL DESIGN

4.1. Mineralogical analysis

Mineralogical analysis was conducted on the ore to determine the mineral composition, structure, association, and liberation characteristics. This analysis was conducted on the Platreef ore at the flotation feed grind of 80% passing 75 µm. The analysis was conducted using two methods, i.e.

- X-Ray diffraction (XRD) analysis to determine the bulk modal mineralogy using a Bruker D8 X-ray diffractometer, with TOPAS software. X-ray powder diffraction is utilised as this is sufficient for the routine identification of minerals or phases in samples. The instrument model used is the Bruker D8 diffractometer which takes up to 90 samples for automated analysis. The results are interpreted by the mineralogist with the aid of DIFFRAC.EVA© software and a database for mineral or phase identification.

Sample preparation: The sample was pulverised in a microniser to obtain particle sizes less than 10 µm. Involves the pulverisation of the samples prior to analysis to obtain more accurate data, particularly for quantification. Then a binding aid was mixed with the sample to produce a homogenous sample and thereafter the mixture was pressed into a die to produce a pellet.

- Automated scanning electron microscopy (AutoSEM) analysis for PGM and BMS search to determine the PGM and BMS minerals species present, grain size, liberation, and mineral association characteristics. The systems employed for AutoSEM include three automated scanning electron microscopes equipped with energy-dispersive X-ray analysers and image analysers, including QEMSCAN™ (quantitative evaluation of minerals) and MLA (Mineral Liberation Analyser) systems. QEMSCAN™ which is the quantitative evaluation of minerals, and the MLA, a mineral liberation analyser system. Both implement chemistry and back scatter electron signals to identify the mineral phases and determine their degree of liberation within particles.

Sample preparation: The sample was split and riffled to get representative samples. These were then mixed with graphite, mounted in resin, and allowed to cure. These samples were then polished and ready for reading.

To fully characterise the sample, screened polished section mounts were prepared and analysed employing a specific mineral search for the sulphide minerals using the AutoSEM. The sizing is shown in Table 3.

Table 3: PSD for the AutoSEM analysis

Size fraction (µm)	Mass (%)
75	22.7
-75+38	36.9
-38+20	3.6
-20+10	28.8
-10	8.0
	100.0

All minerals identified were characterised based on relative abundance, liberation, size, and associations. The sample was screened into sized fractions and each polished section was searched. Reporting for individual minerals is dependent on a statistically representative number of BMS/PGM grains being found for that specific mineral. After analysis of the individual size fractions, the results were re-combined into a single result for the sample and the BMS/PGM results reflect only particles that are associated with BMS/PGM and are not representative of the total sample.

The AutoSEM analysis is based on a bright phase search, which seeks out PGE on the basis of their higher backscattered electron intensity under the electron beam, compared with gangue minerals. The bright phase, along with any other phases in the particle in which it occurs, was mapped using image analysis software, the Stream Essentials© software package. The bright PGM was identified through the setting up of a standards library and described in terms of the species present and their relative abundance, grain size distributions, liberation characteristics and mineral associations (i.e., what other minerals are associated with the identified PGM grains in particles). The PGM search analyses provided PGM species identification, grain size distribution, liberation characteristics and gangue associations of PGM-bearing particles detected in each sample.

Mineral liberation classification is based on liberation by particle composition. Liberation classes are defined in 12 groups ranging from 0 to 100 area-% (>=0,>10,>20,>30,>40,>50,>60,>70,>80,>90, 100 area %). Results in each class are cumulated from 100% liberated to 0% liberated.

Mineral association data were derived from shared boundaries between the BMS/PGM and other minerals, whether gangue or other BMS/PGM. The higher the associated percentage is, the greater the degree of boundary sharing between BMS/PGM mineral species and other minerals. Free surface refers to the perimeter of the particle that is exposed and does not share a grain boundary with any mineral.

Floatability indices were calculated according to a standard method suggested by the Minerals Processing Division of Mintek, based not only on the size of BMS/PGM and host particle, but also their modes of occurrence. The BMS/PGM grains were classified as fast-floating, slow-floating 1, slow-floating 2, and non-floating. The grain sizes were divided into size classes using the equivalent circle diameter (ECD). Image analysis measures the area of a grain in two dimensions, and as most grains are irregular in shape, the resultant area is converted into an equivalent area to that of a circle. The diameter of that circle is the equivalent circle diameter (ECD) of the grain. Grains larger than 3µm ECD are likely to be fast-floating, while those smaller than 3µm ECD were considered slow-floating.

4.2. Experimental Apparatus and Reagents

The following apparatus were used in the experiments:

- Denver flotation machine
- 2.5 L flotation cell
- Concentrate collection pan
- Laboratory-scale grinding mill
- High chrome steel rod milling media
- Weighing balance
- Drying oven
- Stopwatch
- Pipettes
- Glass beakers
- Filter pots
- Filter paper
- Wash bottle
- Compressed air

The following reagents were used for Platreef flotation in the experiments:

- Xanthate collector (SIBX)
- Frother (Senfroth 522)
- Depressant (Sendep 30E)
- Deionized water
- Tap water
- Inorganic Salts for making up the plant water:
    - ✓ $CaCl_2.2H_2O$
    - ✓ $MgCl_2$
    - ✓ $NaSO_4$
    - ✓ $NaNO_3$
    - ✓ $NaS_2O_3.5H_2O$

4.3. Experimental Method

To investigate the effect of water chemistry on the flotation performance of the Platreef ores, the following 2 approaches were used:

- Characterising the effect of the overall ionic strength of water on the flotation performance of the Platreef ore.
- Characterising the effect of increasing the concentrations of specific ions in water on the flotation performance of the Platreef ore. This approach is called spiking.

4.4. Sample preparation

A Platreef sample was obtained from the northern limb of the Bushveld complex in the North West Province of South Africa. Upon reception, the sample was crushed using a jaw crusher down to -1.7 mm. The sample was then blended, homogenised and rand riffle split using a rotary splitter into 1.5 kg samples in preparation for flotation testwork. The sample was then stored in a freezer to avoid the sample getting oxidized.

4 x 1.5 kg samples were removed and used for constructing a milling curve. The milling curve was constructed using high chrome steel media rods with the distribution shown in Table 4 to determine the time required to achieve the 80%-75 µm grind as per plant specification. The milling was done at 50% solids at a roller speed of 73 rpm. It should be noted that the water used during milling was the same water used during the flotation test.

Table 4: Stainless steel rod distribution

Rod Sizes (mm)	No. of rods	Mass (kg)
20	10	5,73
15	12	3,6
10	12	1,62
	Total	***10,95***

4.5. Flotation test procedure

The milled slurry was transferred into a 2.5 L Perspex cell, the cell was placed into a Denver flotation machine and the sample was agitated at an impeller speed of 1500 rpm. The airflow rate was set at 50 mL/min for all flotation experiments. The volume of the cell was made up to generate 35% solids using synthetic plant water at the required ionic strength. Figure 10 shows the laboratory setup for the flotation test work.

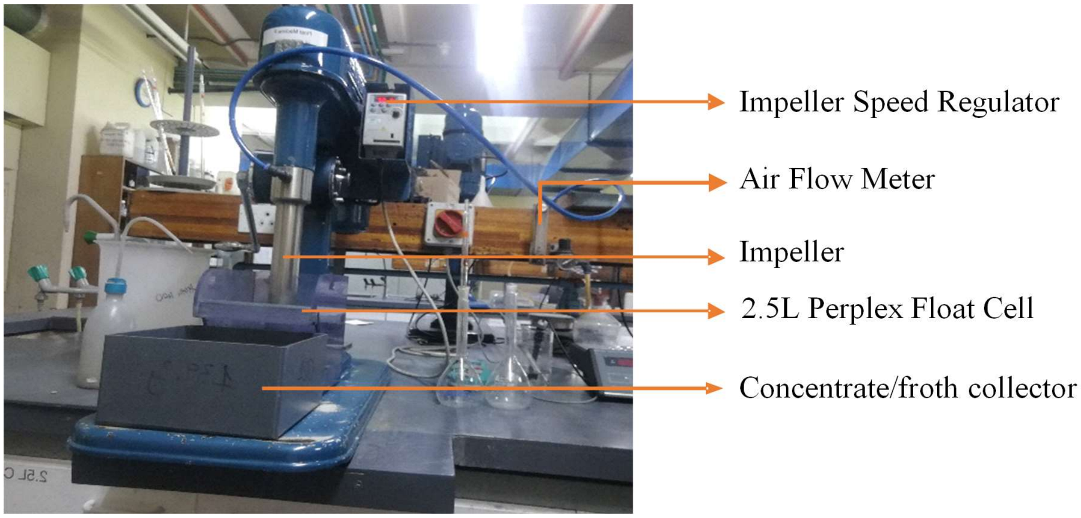


Figure 10: Laboratory Denver D12 flotation machine setup

Concentrates were collected at 1, 3, 7, 20, and 40 minutes respectively by scaping the froth into a collection pan every 15 seconds. The concentrates and tails were weighed (for wet mass), filtered, weighed (filter cake mass), dried, and weighed again (dry mass). These masses assist in water recovery determination for the tests. All tests were conducted in duplicate in order to ensure reproducibility of the tests. The duplicate samples were combined, blended, homogenised and riffle split to remove a sub-sample to get a representative sample for chemical analysis. Assays were done in singleton on the representative to avoid exceeding the budget. PGM, base metals, and sulphur assays were conducted at the Analytical Service Division at Mintek using Fire Assay, Inductively Coupled Plasma (ICP), and Leco methods, respectively. Below are the operating conditions and instruments for the methods used.

- Fire Assay (3E – Pt, Pd, and Au): The prill is transferred into a 50 mL beaker and dissolved with aqua-regia on a hotplate. When the dissolution is complete, the solution is transferred into a 25 mL volumetric flask containing an appropriate amount of HCl and internal standard, made up to volume with de-ionized water and assayed on the ICP-OES or ICP-MS, depending on the grade and required detection levels.

- ICP OES (BM): Ores and slags analysis, fusion followed by acid dissolution in HCl/HNO_3. ICP-3000 from the Skyway instrument was used for analysing.

- Leco (Total S): normal determination of Sulphur in solids by combustion.

4.5.1. Batch flotation testwork conditions

The baseline test was conducted using normal potable water from the Rand water board. All the reagents were made up to 1% solution using distilled water and then dosed and conditioned in the sequence shown in Table 5. Sodium isobutyl xanthate (SIBX), a thiol collector, was used as the sulphide collector while Senfroth 522, a polyglycol was used as a frother. The carboxymethylcellulose (CMC) depressant, Sendep 30E, was stirred for 2 hours to ensure complete hydration before dosing. It must also be noted that the depressant solution was left stirring (magnetic stirrer) throughout the testwork to ensure adequate dissolution. All the reagents were supplied by Senmin. SIBX and Sendep 30E were supplied in powder/solid form and the frother Senfroth 522 in a liquid form. It must also be noted that the active content was not considered when dosing the reagent during flotation testwork. Table 5 shows the best rougher flotation recipe developed in Mintek which will be used on the ore.

Table 5: Reagent dosage and conditioning time sequence

Reagent	**Type**	**Dosages (g/t)**	**Specific gravity (g/ml)**	**Purity (%)**	**Conditioning time (min)**
Collector	SIBX	120	1.17-1.18	>60	2
Depressant	Sendep 30E	300	0.55-067	55-77	3
Frother	Senfroth 522	50	0.83	-	1

4.5.2. Flotation testwork conditions for the effect of increasing ionic strength

Potable water was used as a baseline for increasing ionic strength study. Since the aim of the testwork was to determine the effect recycle water quality has on the flotation of a Platreef ore, standard UCT synthetic plant water (SPW) recipe (Wiese et al., 2005) was used. The SPW was made up by adding inorganic salts to distilled water to ensure that the water contained similar amounts of ions typically found in flotation process water. The inorganic salts were added in the sequence shown in Table 6 below to avoid any unwanted reactions occurring. Then the solution was stirred continuously to ensure that all the salts are dissolved and preserve the water chemistry. It must be noted the SPW was made-up as needed fresh each day, unused samples were discarded daily as per the Material Safety Data Sheet (MSDS) and Laboratory Guidelines.

Table 6: Inorganic salts addition sequence

Inorganic salt	Chemical formula
1. Magnesium sulphate	$MgSO_4$
2. Magnesium nitrate	$Mg(NO_3)_2.6H_2O$
3. Calcium nitrate	$Ca(NO_3)_2.4H_2O$
4. Calcium chloride	$CaCl_2.2H_2O$
5. Sodium chloride	$NaCl$
6. Sodium carbonate	Na_2CO_3

The influence of ionic strength on flotation was thus studied by multiplying 1 SPW by 3, 5, and 10 times as shown in Table 7 (Corin et al., 2011; Manono et al., 2018).

4.5.3. Flotation testwork conditions for the effect of spiking specific ions in 3SPW

Table 7 shows that 3 SPW was best to represent average current on-site Total Dissolved Solids (TDS) levels at the PGM operation and was thus used as the background make-up water for the effect of spiking specific ions study. Tests were conducted in which selected ions, Ca^{2+}, Mg^{2+}, SO_4^{2-}, $S_2O_3^{2-}$, and NO_3^- were spiked to represent the accumulation of that specific ion over and above all other ions present in the complex background process water (adapted from Dzingai et al., 2020; Dzingai et al., 2021). Each ion was spiked as shown in Table 7. The spiking values were selected based on the gaps observed during the literature review. Though most of the previous work focused on the BMS, some ionic strength ranges gave inconclusive or inadequate data which motivated how the spiking values were selected for this work.

Table 7: Ions present in standard synthetic plant water and the various ions spiked (adapted from Wiese et al., 2005; Corin et al., 2011; Manono et al., 2018; Dzingai et al., 2020; Dzingai et al., 2021)

Water Type			**Ca^{2+} (ppm)**	**Mg^{2+} (ppm)**	**Na^{+} (ppm)**	**Cl^{-} (ppm)**	**SO_4^{2-} (ppm)**	**$S_2O_3^{2-}$ (ppm)**	**NO_3^{2-} (ppm)**	**CO_3^{2-} (ppm)**	**TDS (mg/L)**	**IS [M]**
Potable water (RWB)			*6.31*	*2.65*	*11.25*	*5.82*	*<10*	-			*163.44*	
1SPW			80	70	153	287	240	-	176	17	1023	0.0243
3SPW			240	210	459	861	720	-	528	51	3069	0.073
5SPW			400	350	765	1435	1200	-	880	85	5115	0.1212
10SPW			800	700	1530	2870	2400	-	1760	850	10230	0.2426
Spiked waters	**Salts used for spiking**	**Purity (%)**										
3SPW + 110 mg/L Ca^{2+}	$CaCl_2.2H_2O$	97.5	**350**	210	459		720		528	51		
3SPW - 40 mg/L Ca^{2+}	$CaCl_2.2H_2O$	97.5	**200**	210	459		720		528	51		
3SPW + 590 mg/L Mg^{2+}	$MgCl_2$	98	240	**800**	459		720		528	51		
3SPW + 790 mg/L Mg^{2+}	$MgCl_2$	98	240	**1000**	459		720		528	51		
3SPW + 480 mg/L SO_4^{2-}	$NaSO_4$	98.5	240	210		861	**1200**		528	51		
3SPW + 1610 mg/L SO_4^{2-}	$NaSO_4$	98.5	240	210		861	**2400**		528	51		
3SPW + 72 mg/L NO_3^{2-}	$NaNO_3$	98	240	210		861	720		**600**	51		
3SPW + 272 mg/L NO_3^{2-}	$NaNO_3$	98	240	210		861	720		**800**	51		
3SPW + 100 mg/L $S_2O_3^{2-}$	$NaS_2O_3.5H_2O$	99	240	210		861	720	**100**	528	51		
3SPW + 150 mg/L $S_2O_3^{2-}$	$NaS_2O_3.5H_2O$	99	240	210		861	720	**150**	528	51		

It must be noted that for the single ion spiked synthetic plant waters, sodium/chloride salts of the ion of interest were used. For example, when spiking the SO_4^{2-}, sodium sulphate was used and when spiking Mg^{2+}, magnesium chloride was used. Previous study by Manono et al., (2016) showed minimal impact when using Na^{-}/$Cl^{-}$and were therefore deemed not to compete with the ions of interest. All the salts used for this were supplied by Merck (Sigma-Aldrich and was distributed by Associated Chemical Enterprises Pty Ltd (ACE Chem) located in Johannesburg, South Africa.

5. Results

5.1. Sample preparation

The milling curve, shown in Figure 11, was determined using high chrome steel media rods and potable water as process medium. It was found that the sample must be milled for 58 minutes to achieve a grind of 80%-75 µm on a 1.5 kg sample at 50% solids.

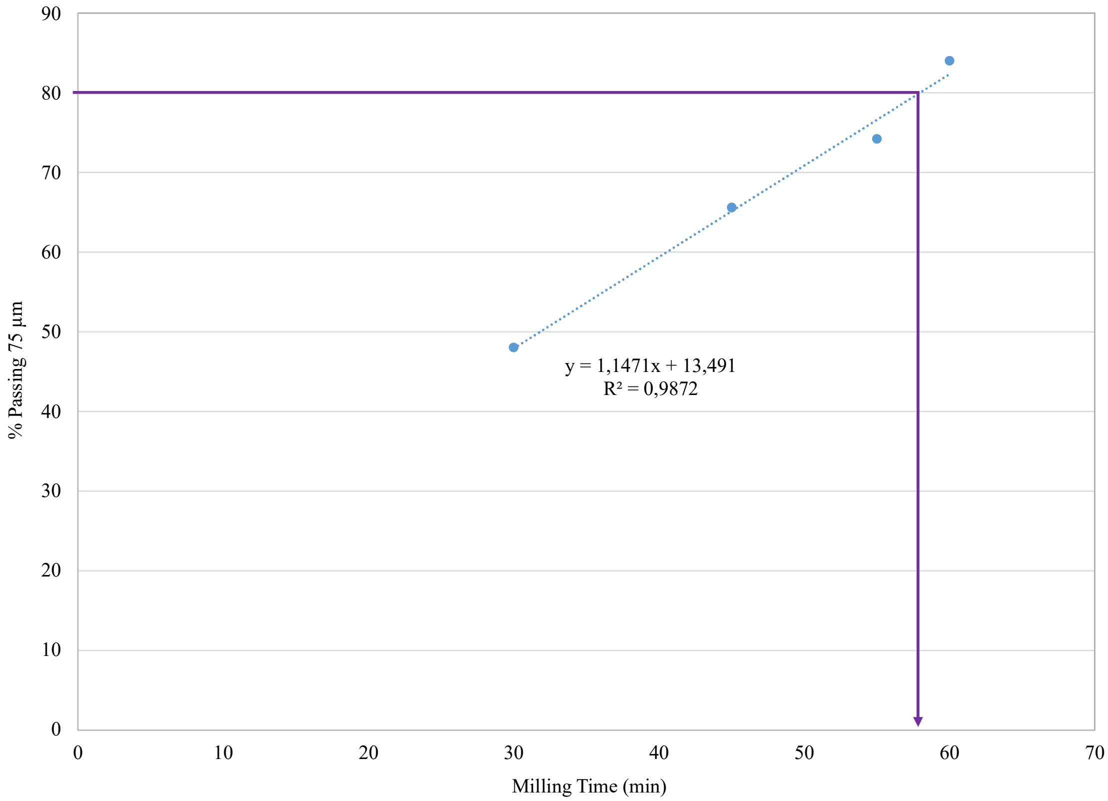


Figure 11: Milling curve

For any test, the type of water under investigation was used as process medium during milling and flotation. All samples were milled for the same time of 58 minutes for all the water types.

5.2. Sample mineralogy

Table 8 shows the bulk mineralogy for the Platreef ore. The most dominant gangue minerals for this ore were enstatite ($Mg_2Si_2O_6$), anorthite ($CaAl_2Si_2O_9$), oligoclase $(Na,Ca)(Si,Al)_4O_8$ and chlorite $(Mg, Fe)_5Al(Si_3Al)O_{10}(OH)_8$. There was also 0.8% Talc which is a naturally hydrophobic gangue mineral in most sulphide ores and determines the depressant type and dosage used during flotation.

Table 8: Bulk mineralogical composition for the flotation feed sample.

Bulk mineralogical composition as measured by Rietveld Refinement method		
Mineral	**Ideal Chemical Formula**	**XRD Analysis (mass%)**
Quartz	SiO_2	7.6
Enstatite	$Mg_2Si_2O_6$	29.9
Augite-Aegirine	$(Ca,Na)(Mg,Fe,Al,Ti)(Si,Al)_2O_6$	4.7
Hornblende	$Ca_2(Mg,Fe,Al)_5(Al,Si)_8O_{22}(OH)_2$	4.0
Mica	$K(Mg,Fe)_3[AlSi_3O_{10}(OH,F)_2$	2.0
Microcline	$KAlSi_3O_8$	4.1
Albite	$NaAlSi_3O_8$	4.4
Anorthite	$CaAl_2Si_2O_9$	15.1
Oligoclase	$(Na,Ca)(Si,Al)_4O_8$	12.8
Chlorite	$(Mg,Fe)_5Al(Si_3Al)O_{10}(OH)_8$	11.5
Lizardite	$Mg_3Si_2O_5(OH)_4$	0.7
Talc	$Mg_3Si_4O_{10}(OH)_2$	0.8
Calcine	$CaCO_3$	2.7
	Total	**100.0**

Table 9 shows the distribution of different PGM species in the sample. The PGE-tellurides were the dominant PGM species comprising ~60.2 vol% followed by PGE-sulphides, PGE- arsenides, and trace amounts of PGE-alloys. The liberation characteristics showed that 64.5% PGMs are liberated, 7.5% are associated with BMS and 8.5% PGMs are locked in gangue and cannot be recovered. These liberation characteristics are presented in Table 10 and Figure 12.

Table 9: PGM species distribution in the flotation feed sample

PGM	**PGM Vol%**
PtRhAsS	0.6
PtBiTe	18.7
PDBiTe	39.7
PtS	13.1
PtAs	25
PdTe	1.8
PtPdS	0.9
PdSb	0.1
PtPdAs	0.1
Total	**100**

Table 10: Liberation characteristics of the flotation feed sample at 80%-75µm

	PGM grain mode of occurance	
	Liberation Characteristic	**PGM Vol%**
L	Liberated PGMs	64.5
SL	PGMs associated with liberated BMS (Base Metal Sulphides)	7.5
SG	PGMs associated with BMS locked in Silicate or Oxide gangue particles	0
AG	PGMs attached to Silicate ot Oxide gangue particles	6.3
SAG	PGMs associated with BMS attached to Silicate or Oxide gangue particles	13.3
G	PGMs locked within Silicate or Oxide gangue particle	8.5
		100

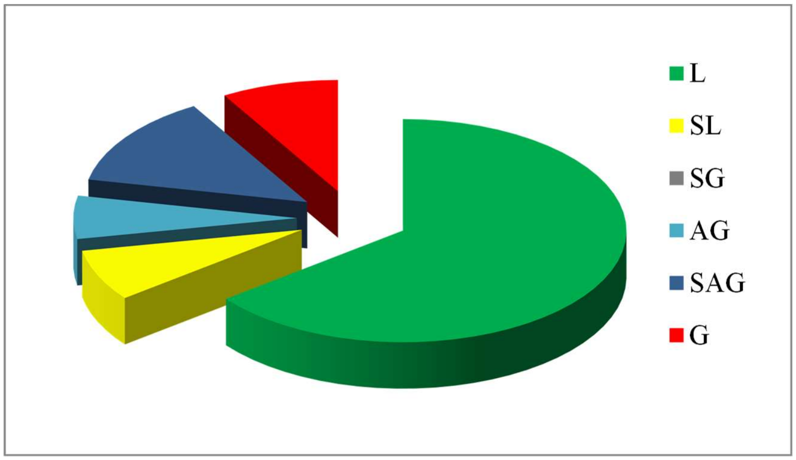


Figure 12: Pie chart presentation of the liberation characteristics of the sample

The floatability indices results are summarised in Table 11 and show that the majority of PGM grains observed report to the fast-floating category (~70.8 vol%), ~14.6 vol% to the slow-floating 1 category and ~6 vol% to the slow-floating 2 category. Approximately 8.5 vol% of PGM grains report to the non-floating category.

Table 11: PGM floatability index for the sample at 80%-75µm (Mintek, 2021)

PGM grain Flotability Index			
	Particle Characteristics	**PGM Vol%**	**#PGMs**
Fast Flotating	Liberated PGMs > 3µm ECD	63.4	19
	LiberatedBMS > 10µm ECD	7.5	5
Slow Floating 1	Liberated PGMs < 3µm ECD	1.1	13
	Liberated BMS < 10µm ECD	0	0
	PGMs > 3µm ECD attached to gangue	5.7	6
	BMS > 10µm ECD attached to gangue	7.8	12
Slow Floating 2	PGMs < 3µm ECD attached to gangue	0.5	4
	BMS < 10µm ECD attached to gangue	5.5	6
Non-floating	PGMs and/or BMS locked in gangue	8.5	21
		100	86

The bulk modal analysis presented in Table 12 shows that pentlandite is the major BMS species present followed by pyrrhotite and chalcopyrite. Approximately 8 mass% of pyrite is present. Galena and millerite are present in trace amounts (~0.1 mass%).

Table 12: BMS modal analysis for the Platreef sample

Mineral	**Ideal Chemical Formula**	**Mass %**	**No. of Grains**
Pyrite	FeS_2	8	1096
Pentlandite	$(Fe,Ni)_9S_8$	43,7	10751
Chalcopyrite	$CuFeS_2$	15,1	4023
Pyrrhotite	$Fe_{1-x}S$	33	7118
Millerite	NiS	0,1	23
Galena	PbS	0,1	58
		100	23069

The grain size distribution for the BMS species is plotted in Figure 13. The graph shows that majority of pyrite, pyrrhotite, pentlandite, chalcopyrite, galena and millerite grains are finer grained and report to the 0-53 µm grain size class. Note that the grain size data presented have been obtained from measurements on sectioned grains (i.e., in two dimensions only).

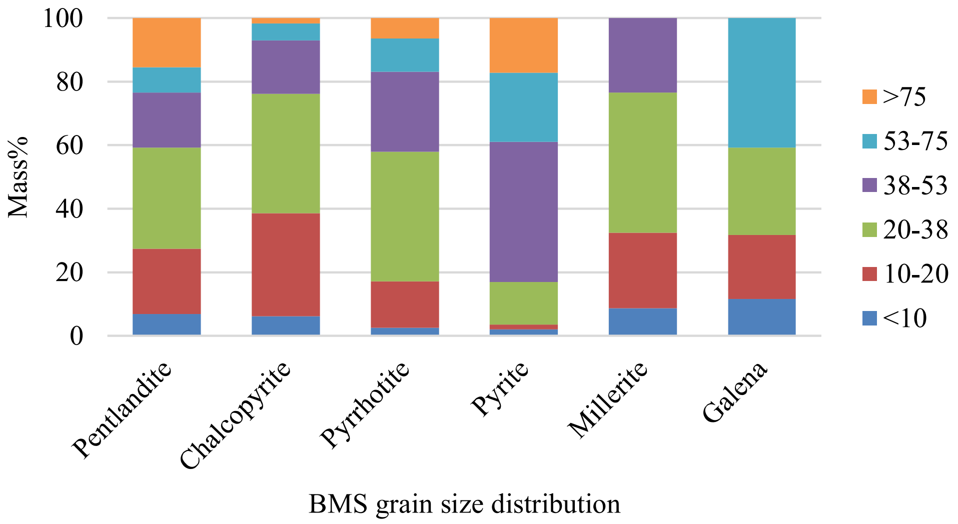


Figure 13: BMS grain size distribution for the sample at 80%-75µm

BMS mineral liberation classification presented in Figure 14 showed that pentlandite and pyrite are well liberated with more than 81 % better than 80 mass % liberated. Chalcopyrite and pyrrhotite are moderately liberated with more than 71% better than 80 mass % liberated. Millerite and galena are poorly liberated and due to low statistics, the data should be used with caution.

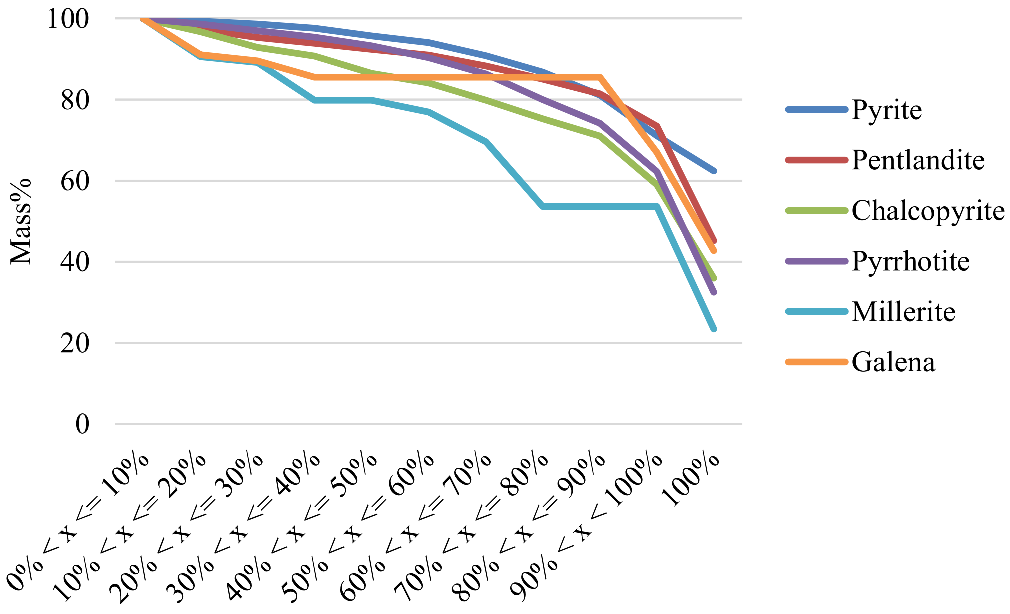


Figure 14: Liberation classification of the sample at 80%-75µm

The BMS mineral association data (see APPENDIX A) shows that the majority of BMS minerals are associated with free surface and minor to trace amounts associated with gangue and other BMS mineral phases. Millerite as an alteration of pentlandite appears to be evident in its high association with pentlandite.

5.3. Flotation Testwork Results

All flotation tests were conducted in duplicate to ensure reproducibility of the tests. Timed samples were collected over 1, 3, 7, 20, and 40 minutes time intervals. The duplicate samples for the first concentrate, RC1, were blended, homogenised and riffle split to obtain representative samples for chemical analysis. The same procedure was conducted for the rest of the flotation products. Chemical analysis was conducted in singleton, and no error was calculated on the grade and recovery data. Error bars were only calculated for solids and water recovery using equation (1) below.

$$Error = {std\ dev(v1, v2)} \Big/ {\sqrt{2}} \qquad (1)$$

Where v1 and v2 are the values for water or solids mass (g) for the duplicate samples. If the standard deviation is 10% or less, the test data was considered reproducible.

5.4. Baseline flotation test – potable water

The baseline test was conducted using potable water to observe the response of the Platreef ore. Figure 15 shows the platinum grade versus recovery graph for the baseline test.

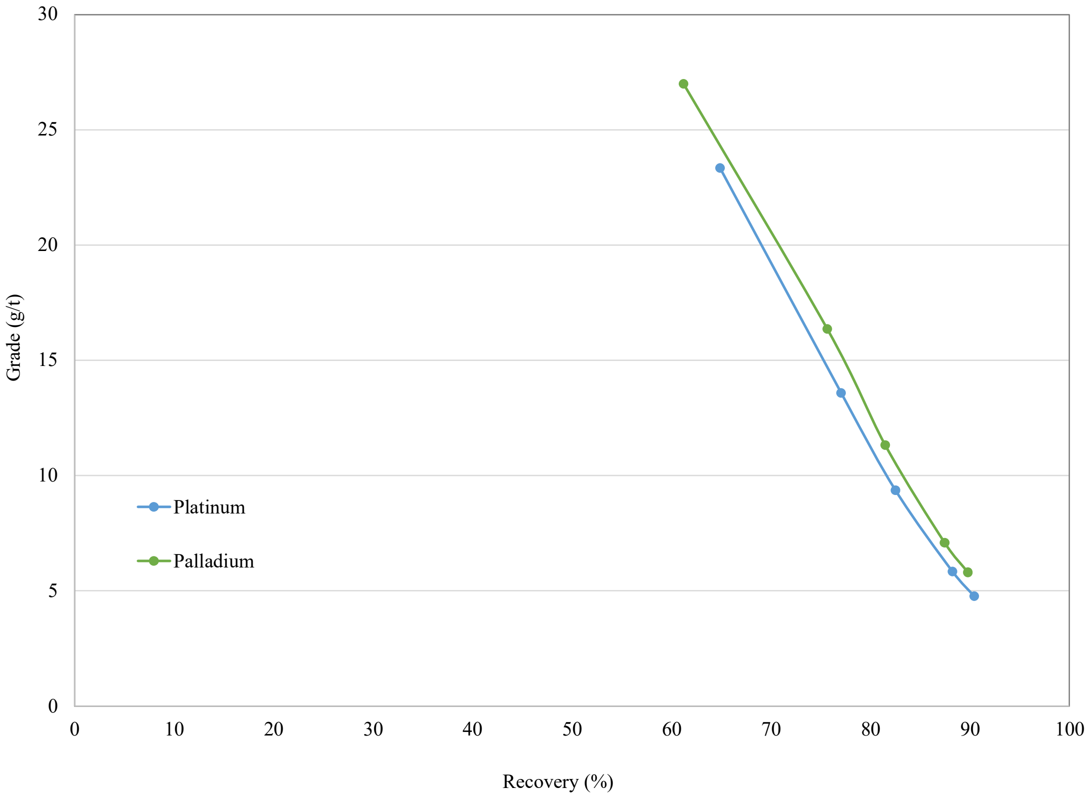


Figure 15: Platinum and palladium cumulative grade versus cumulative recovery for potable water (note that no error was calculated owing to single sample analysis as described in Section 4.5.

Figure 15 shows that after 40 minutes of flotation 90% platinum and palladium were recovered with palladium at a slightly higher grade than platinum.

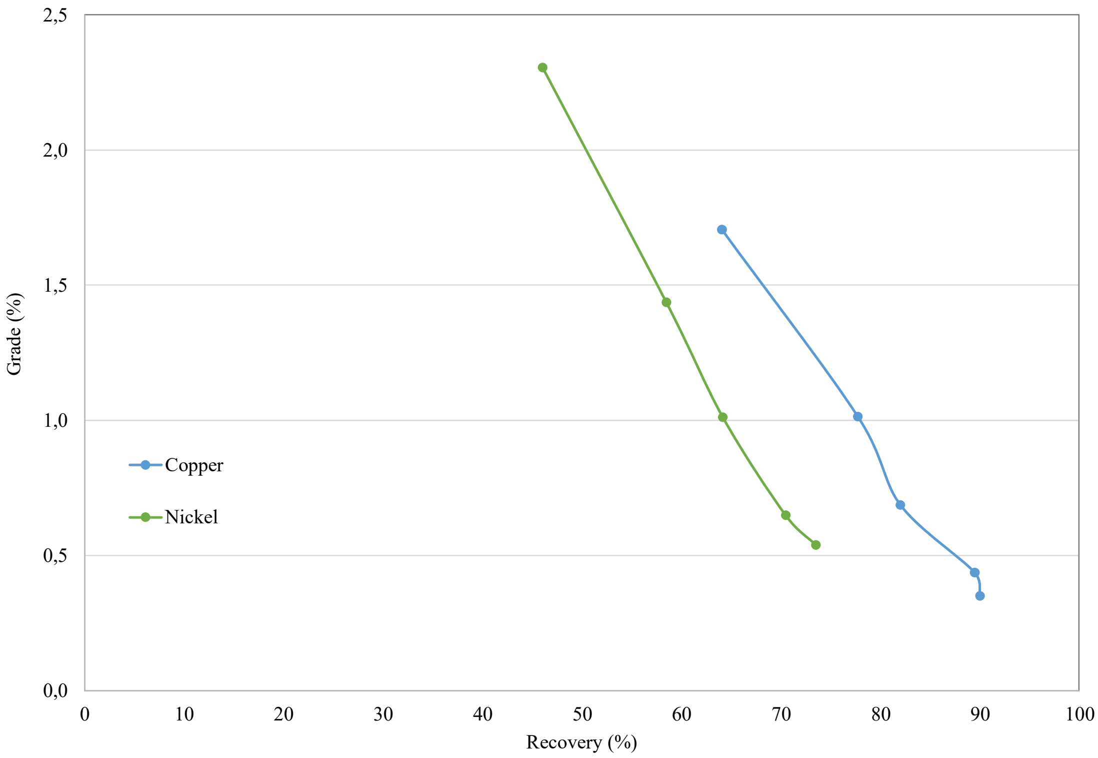


Figure 16: Copper and nickel cumulative grade versus cumulative recovery for potable water (note that no error was calculated owing to single sample analysis as described in Section 4.5.

Figure 16 shows that 90% of the copper was recovered at 40 minutes and only 74% nickel was recovered. The final cumulative nickel grade was slightly higher that the final cumulative copper grade.

5.5. Effect of ionic strength of synthetic plant water: 1, 3, 5 and 10 SPW

Figure 17 shows that as the ionic strength increases, the amount of water recovered also increases. During the first 10 minutes, 3 SPW and 10 SPW had the same water recovery rate. This is notably higher than the rate of recovery and amount of water recovered with 1 and 5 SPW. However, beyond 10 minutes, 10 SPW continued to recover more water than 1, 3 and 5 SPW and it was noted that none of the graphs levelled off within the flotation time considered.

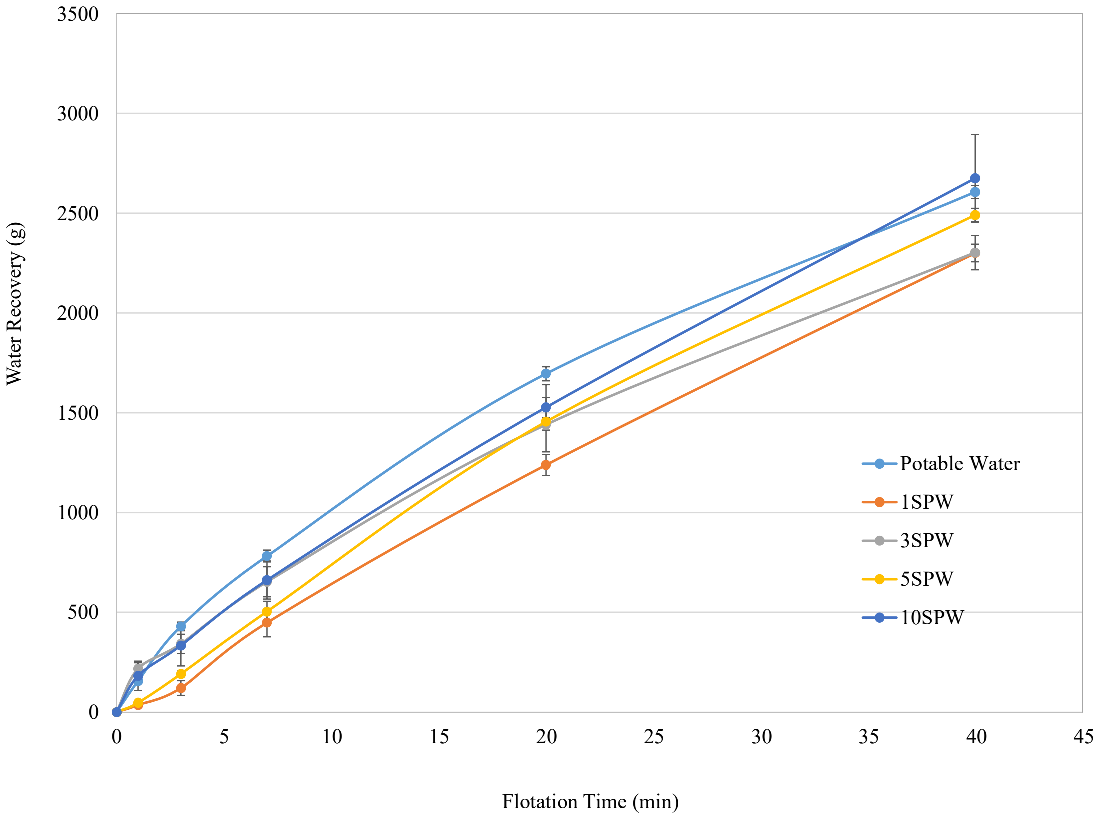


Figure 17: Water recovery versus time for 1, 3, 5 and 10 SPW and potable water (Note that the values presented are the average values between tests which were performed in duplicate, and the error bars represent the standard error between duplicate tests).

The final amount of water recovered by the SPWs is 2300.5 g; 2302.25 g; 2490.60 g; and 2675.15 g for the 1; 3; 5; and 10 SPW, respectively. Potable water recovered more water and showed greater rate of recovery compared to all the SPW.

Figure 18 shows the solids recovery as a function of time. It can be seen from Figure 18 that as the ionic strength of the synthetic plant water increases, there is a decrease in solids recovery but for potable water, significantly higher solids recovery and greater rate of recovery were observed.

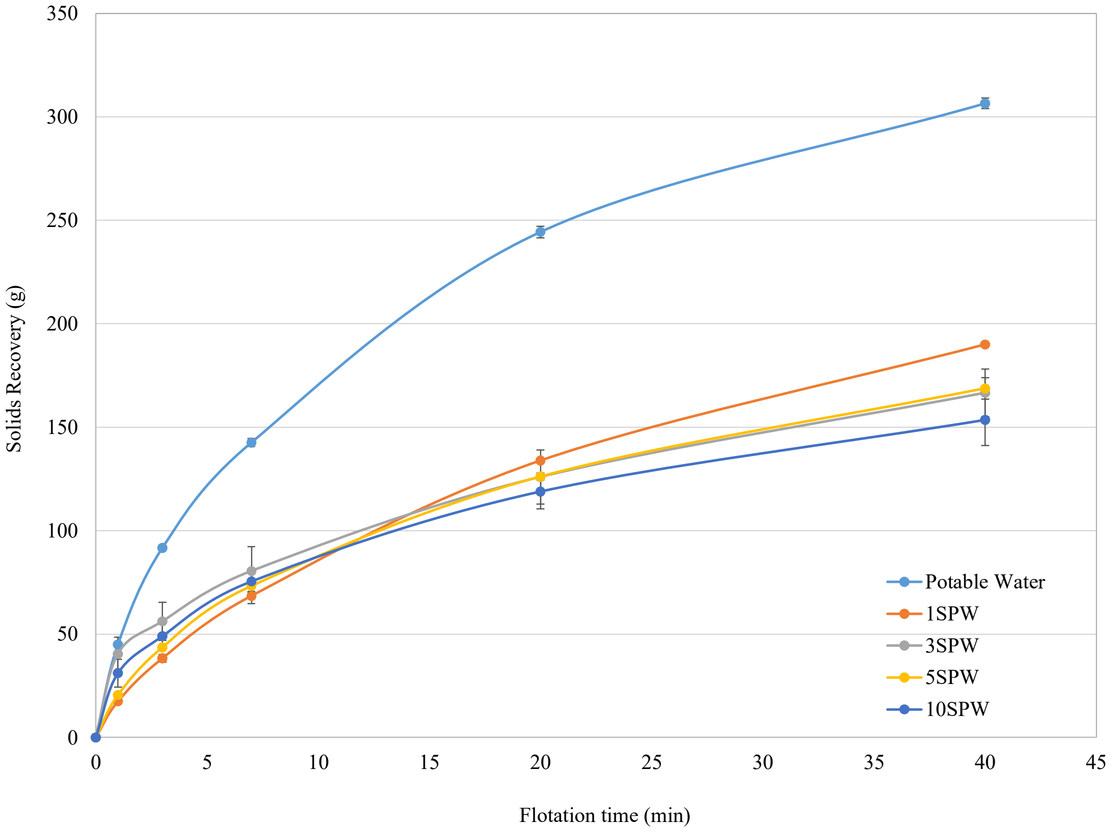


Figure 18: Solids recovery versus time for 1, 3, 5 and 10 SPW and potable water (Note that the values presented are the average values between tests which were performed in duplicate, and the error bars represent the standard error between duplicate tests).

Overall, potable water recovered more solids followed by 1 SPW then 3 and 5 SPW were equal and 10 SPW was the lowest. The graphs did not plateau, showing that there were still more solids to be recovered. According to the errors shown, apart from 1SPW, the SPW tests recovered almost the same amount of solids at the end of the flotation time.

Figure 19 shows that the solids recovery increases with water recovery into the concentrate. However, for the first 700 g of water recovered, the solids recovered is comparable for all the SPWs.

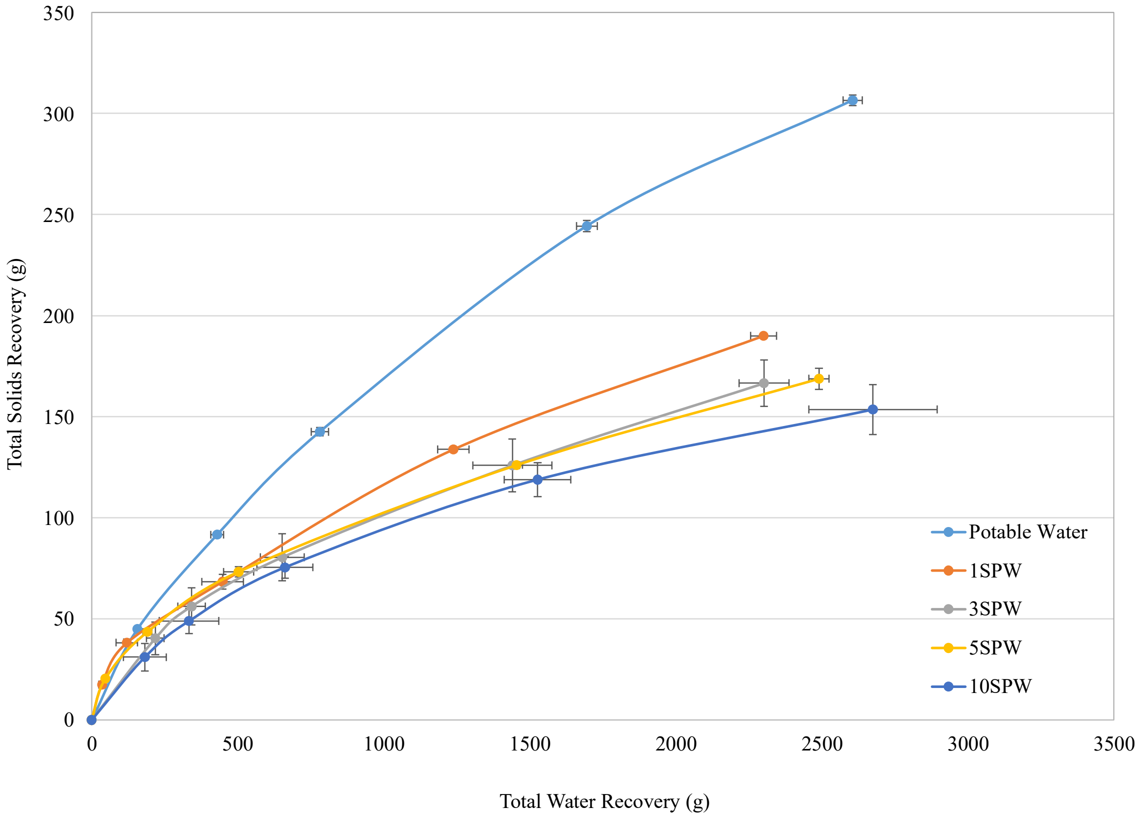


Figure 19: Solids recovery versus water recovery for 1, 3, 5 and 10 SPW and potable water (Note that the values presented are the average values between tests which were performed in duplicate, and the error bars represent the standard error between duplicate tests).

Above 700 g water recovery, the highest solids were recovered per unit water recovered for potable water. For the SPW, the solids recovery per unit water recovery increased in the following order: 10<3<5<1 SPW.

Table 13 shows the breakdown on the solids and water recovery for increasing ionic strength in water including the associated std. errors.

Table 13: Solids and water recovery for increasing ionic strength in water including the associated std. errors.

Water [I.S]	Spiking	Solids Recovery [g]	Solids Recovery [Std_Error]	Water Recovery [g]	Water Recovery [Std_Error]
Potable water	-	306.50	2.60	2605.90	32.50
1 SPW	-	190.00	0.80	2300.50	44.20
3 SPW	-	166.60	11.50	2302.25	85.65
5 SPW	-	168.75	5.25	2490.60	34.60
10 SPW	-	153.55	12.35	2675.15	219.65

Figure 20 shows the platinum recovery time curves for potable water and the synthetic plant water at different ionic strength.

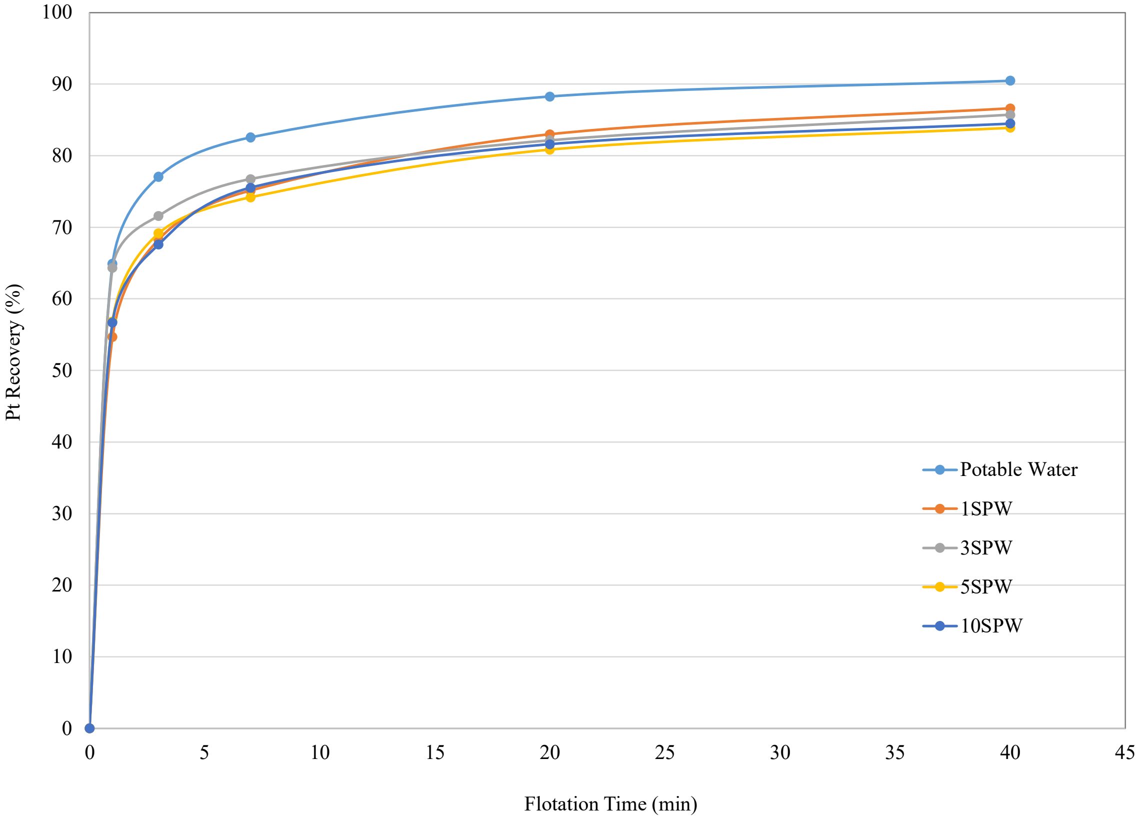


Figure 20: Platinum recovery versus time for 1, 3, 5 and 10 SPW (note that no error was calculated owing to single sample analysis as described in Section 4.5)

From Figure 20, more than 80% of the platinum was recovered in the first 5 minutes of flotation when using potable water and 20 minutes of flotation when using the SPW. The general trend from Figure 20 shows that 1, 3, 5 and 10 SPW achieved similar overall platinum recoveries of 86.61, 85.68, 83.89, and 84.5% respectively. Potable water achieved the highest overall Pt recovery of 90.45% which was 5% more than the Pt recoveries achieved by the SPW. All the curves plateaued getting to the end of the float, showing that no metals were recovered at that point but gangue through entrainment.

Figure 21 shows that platinum grade-recovery plot for SPW at different ionic strength.

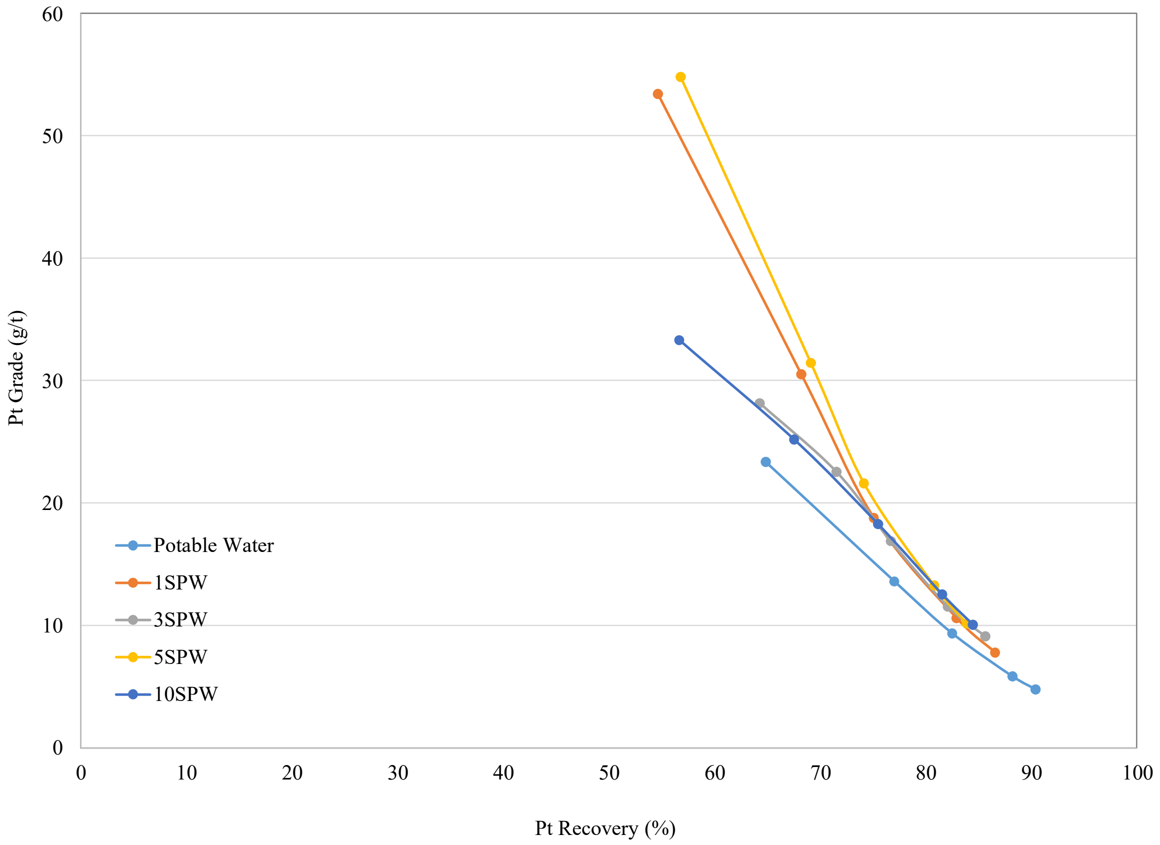


Figure 21: Platinum grade versus recovery for 1, 3, 5 and 10 SPW and potable water (note that no error was calculated owing to single sample analysis as described in Section 4.5)

From Figure 21, as the platinum recovery increases there is a decrease in grade for all SPW and potable water. While the highest final recovery (90.45%) is given by potable water, the highest final grade (10.17 g/t) was achieved by the 5 SPW. For the 1 SPW the platinum grade of the recovered concentrate was 7.79 g/t, for 3 SPW and 5 SPW it was 9.11 g/t and 10.17 g/t respectively and 10 SPW gave 10.05 g/t. For the potable water the platinum grade for the recovered concentrate was the lowest at 4.7 g/t.

Figure 22 shows the recovery of palladium to the concentrate as a function of flotation time for 1, 3, 5 and 10 SPW and potable water.

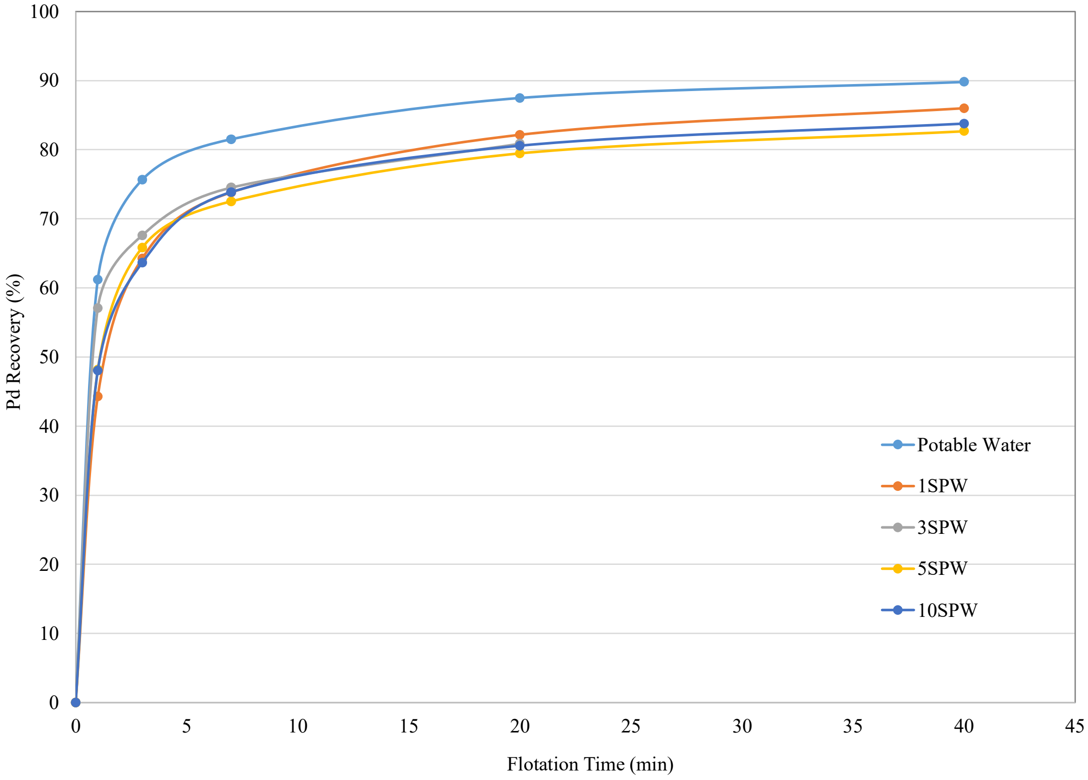


Figure 22: Palladium recovery versus time for 1, 3, 5 and 10 SPW and potable water (note that no error was calculated owing to single sample analysis as described in Section 4.5)

As was the case for the platinum, most of the palladium was recovered in 20 minutes and there was the same general trend for the palladium recovery curve for 1, 3, 5 and 10 SPW for the entire flotation time. Using potable water, 80% of the Pd was recovered in 7 minutes flotation time and the additional time added 10% more. Similar to the platinum recovery versus time curve, Figure 20, the curve plateaued showing that the metal recovery has stopped and only gangue was recovered at this point during flotation.

Figure 23 depicts the palladium grade as a function of its recovery.

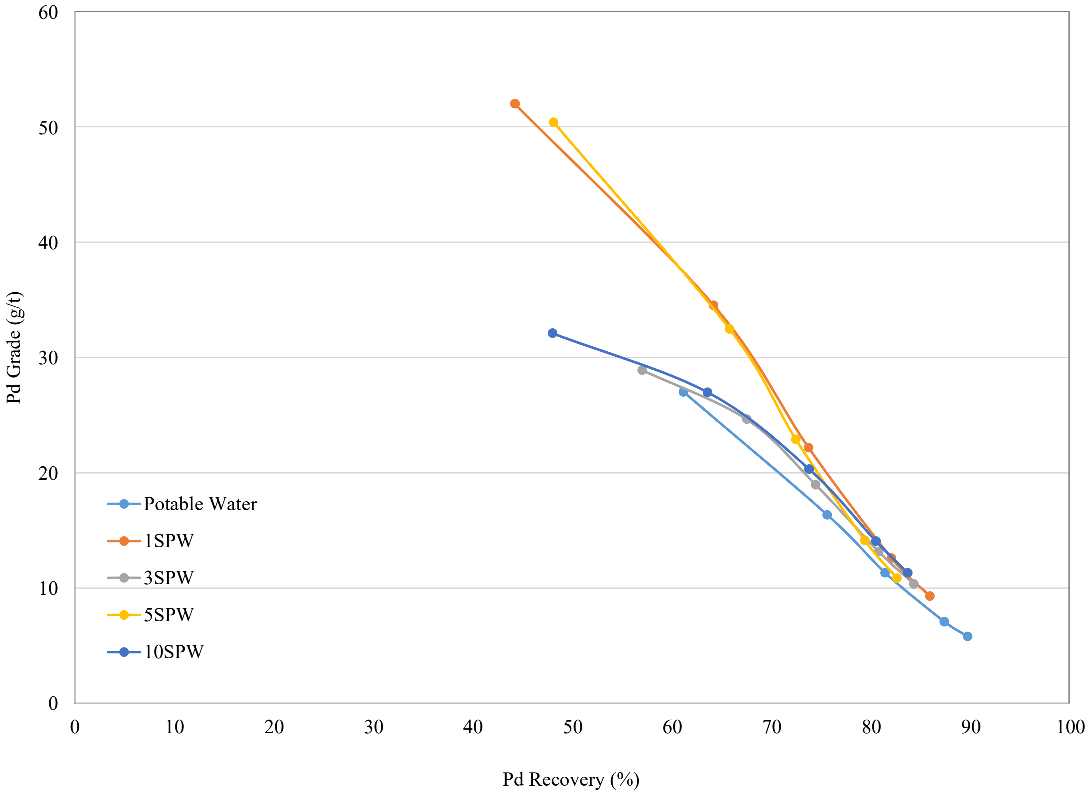


Figure 23: Palladium grade versus recovery for 1, 3, 5 and 10 SPW and potable water (note that no error was calculated owing to single sample analysis as described in Section 4.5)

Below 20 g/t Pd grade the grade-recovery curves for all the water types follow a similar trend. Above 20 g/t Pd grade, the grade-recovery curve for 1 and 5 SPW follow a similar trend and, 3 and 10 SPW follow similar trend. As expected, the palladium recovery increases the concentrate grade decreases for all the water types. 1 SPW achieved an 86% palladium recovery at a palladium grade of 9.3 g/t, while 3 SPW achieved 84.37% palladium recovery at 10.38 g/t palladium grade. 5 and 10 SPW recovered 82.68% and 83.77% palladium at 10.88 g/t and 11.34 g/t palladium grade, respectively. Potable water achieved the lowest palladium grade of 5.81 g/t at the highest Pd recovery of 89.81%.

Figure 24 illustrates the copper recovery versus time for potable water and 1, 3, 5 and 10 SPW.

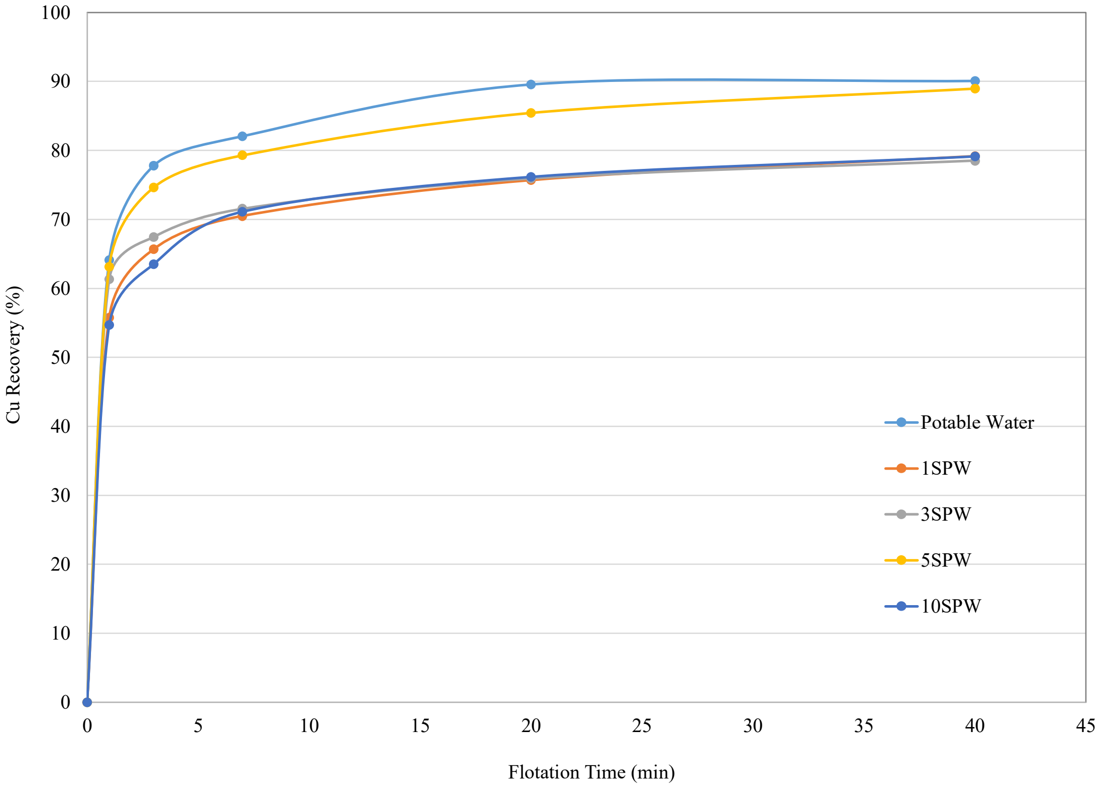


Figure 24: Copper recovery versus time for 1, 3, 5 and 10 SPW and potable water (note that no error was calculated owing to single sample analysis as described in Section 4.5)

Figure 24 shows that most of the copper was recovered in the first 3 concentrates. For the 1, 3 and 10 SPW water types, the copper trend is similar although the Cu recovery into the 1st concentrate was higher for 3 SPW water type. The 5 SPW copper trend was similar to that of potable water, although, the potable water copper trend started higher, both ended at same recovery which was 10% more than 1, 3 and 10 SPW.

Figure 25 shows the copper grade as a function of recovery.

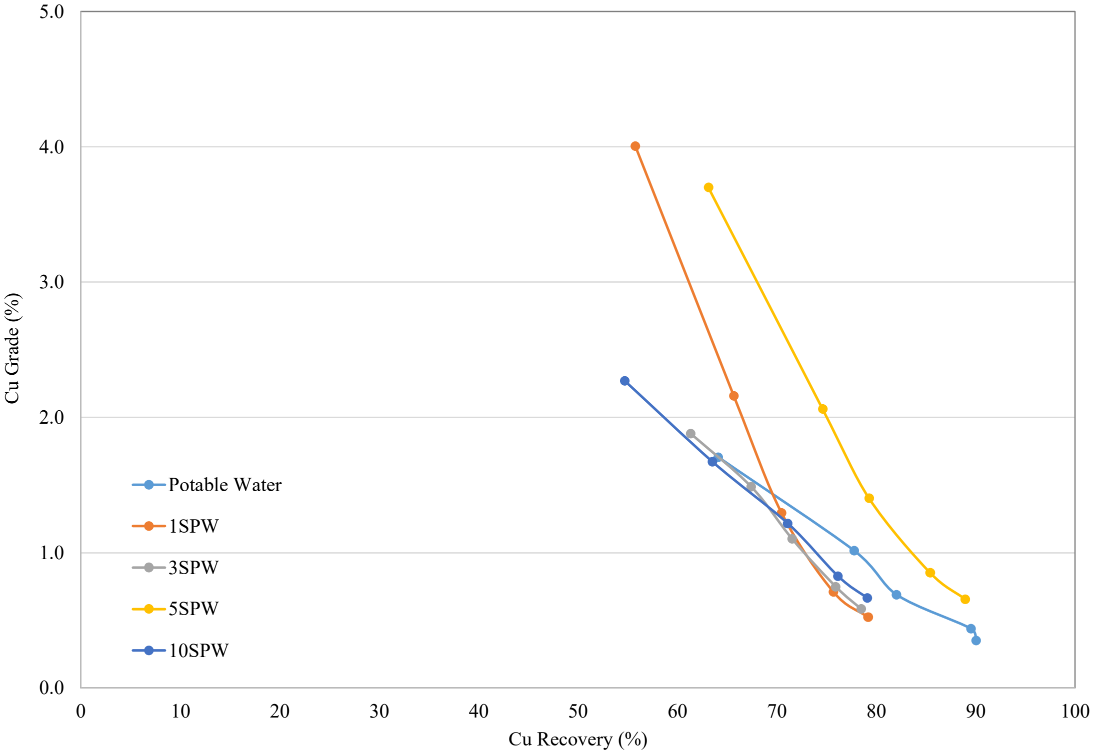


Figure 25: Copper grade versus recovery for 1, 3, 5 and 10 SPW and potable water (note that no error was calculated owing to single sample analysis as described in Section 4.5)

Figure 25 shows that the highest final Cu recovery was achieved by potable water and 5 SPW while the highest final grade is given by 3 SPW, 5 SPW and 10 SPW. As the copper recovery increases there is a decrease in the grade for each specific water type, as expected. The copper grade for 1 SPW was 0.52%, while for 3 SPW and 5 SPW it was 0.58% and 0.66% respectively, and for 10 SPW it was 0.66%. For potable water, the Cu grade was lowest at 0.54%. The Cu grade-recovery curve for the 5 SPW shifted to the far right indicating superior flotation performance.

Figure 26 shows the nickel recovery as a function of time.

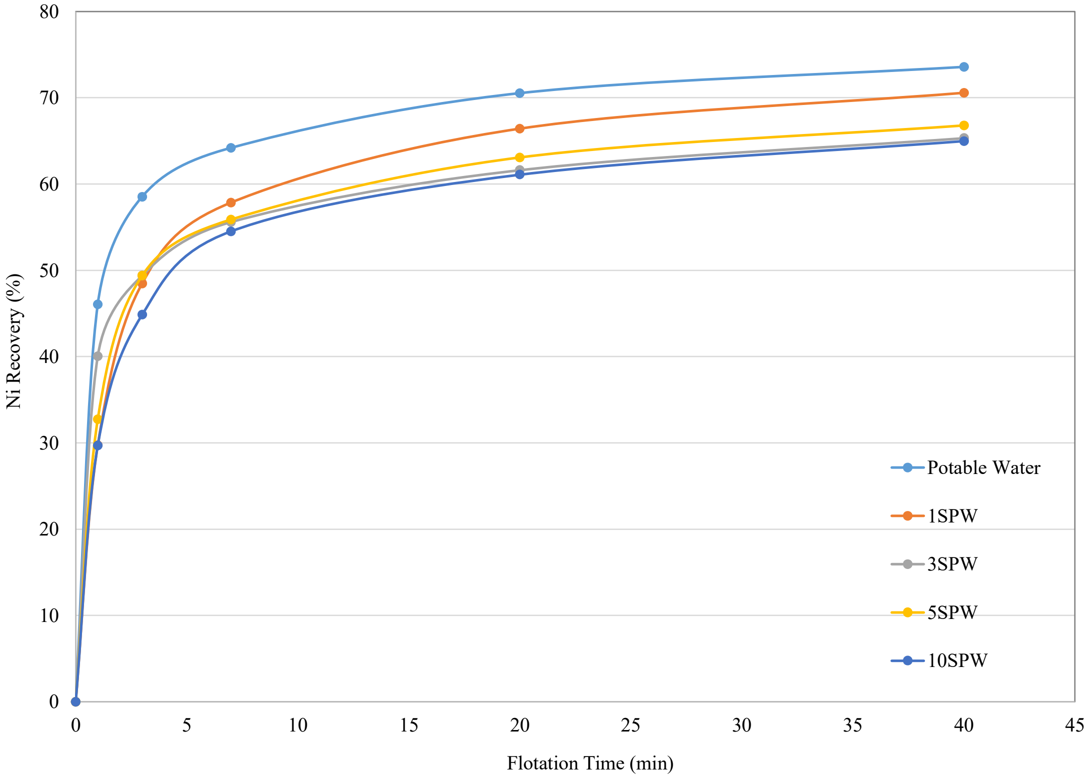


Figure 26: Nickel recovery versus time for 1, 3, 5 and 10 SPW and potable water (note that no error was calculated owing to single sample analysis as described in Section 4.5)

Figure 26 shows the recovery of nickel to the concentrate as a function of flotation time, for 1, 3, 5 and 10 SPW and potable water. Potable water recovered most of the nickel followed by 1 SPW, 5 SPW then 3 and 10 SPW. Overall the nickel recovery in both potable and synthetic plant water was lower compared to the copper recovered. The highest nickel recovery was for potable water at 73.54 while the lowest copper recovery was for 1, 3 and 10 SPW at 79.10%.

Figure 27 depicts the nickel grade as a function of its recovery.

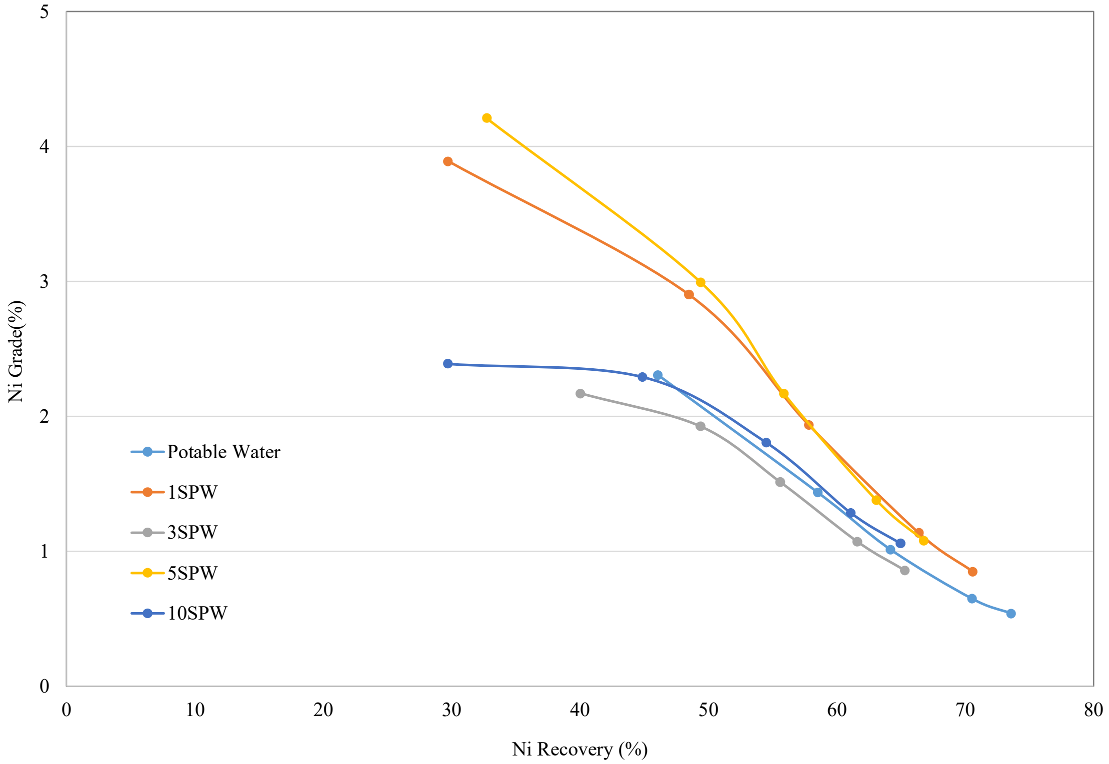


Figure 27: Nickel grade versus recovery for 1, 3, 5 and 10 SPW and potable water (note that no error was calculated owing to single sample analysis as described in Section 4.5)

3 SPW shifted to the far left indicating the worst flotation performance. For 1 SPW, the 70.6% nickel recovered constituted of a nickel grade of 0.85%. 3 SPW achieved a nickel recovery of 65.3% at 0.86% nickel grade. 5 and 10 SPW recovered 66.8% and 65% nickel concentrate respectively at the same nickel grade of 1.1%. Potable water achieved a 73.57% Ni at the lowest Ni grade of 0.54%.

Key findings: 1, 3, 5 and 10 SPW and potable water.

- Increasing ionic strength of water increases the cumulative water recovered to the concentrate, Figure 19.
- Both platinum (Figure 20) and palladium (Figure 22) recovery rate curves plateaued showing that no metal was recovered.
- Overall copper recovery (Figure 24) was higher than nickel recovery (Figure 26).
- 5 SPW recovered the same amount of copper as potable water (Figure 24).
- 1, 3 and 10 SPW recovered the same amount of copper (Figure 24).
- 3, 5 and 10 SPW recovered the same amount of nickel (Figure 26).
- Both potable water and 1 SPW achieved more than 70% nickel recovery (Figure 26).

5.6. Flotation response upon spiking of 3 SPW with Ca^{2+} and Mg^{2+}

Figure 28 illustrates the effect of the ion on water recovery to the concentrate per unit time.

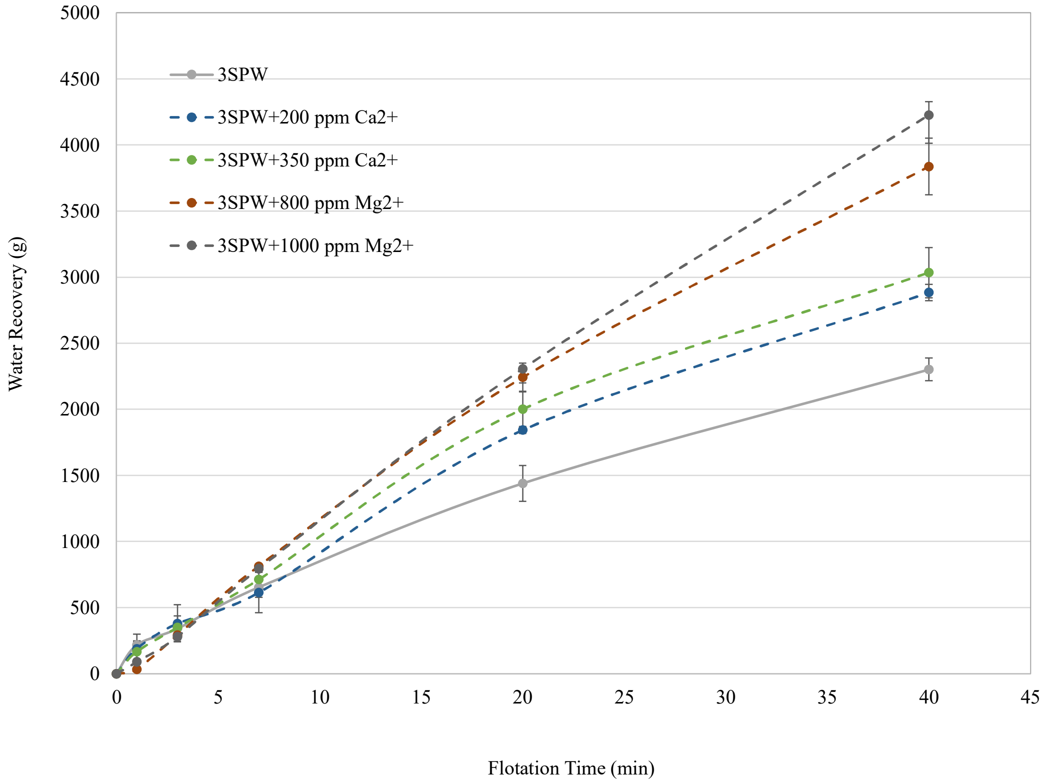


Figure 28: Water recovery per flotation time during Ca^{2+} *and* Mg^{2+} *spiking (Note that the values presented are the average values between tests which were performed in duplicate, and the error bars represent the standard error between duplicate tests).*

The results show that cation spiking increases water recoveries above that of the 3 SPW. 1000 ppm Mg^{2+} recovered the most water in comparison to the other spiked cation concentrations.

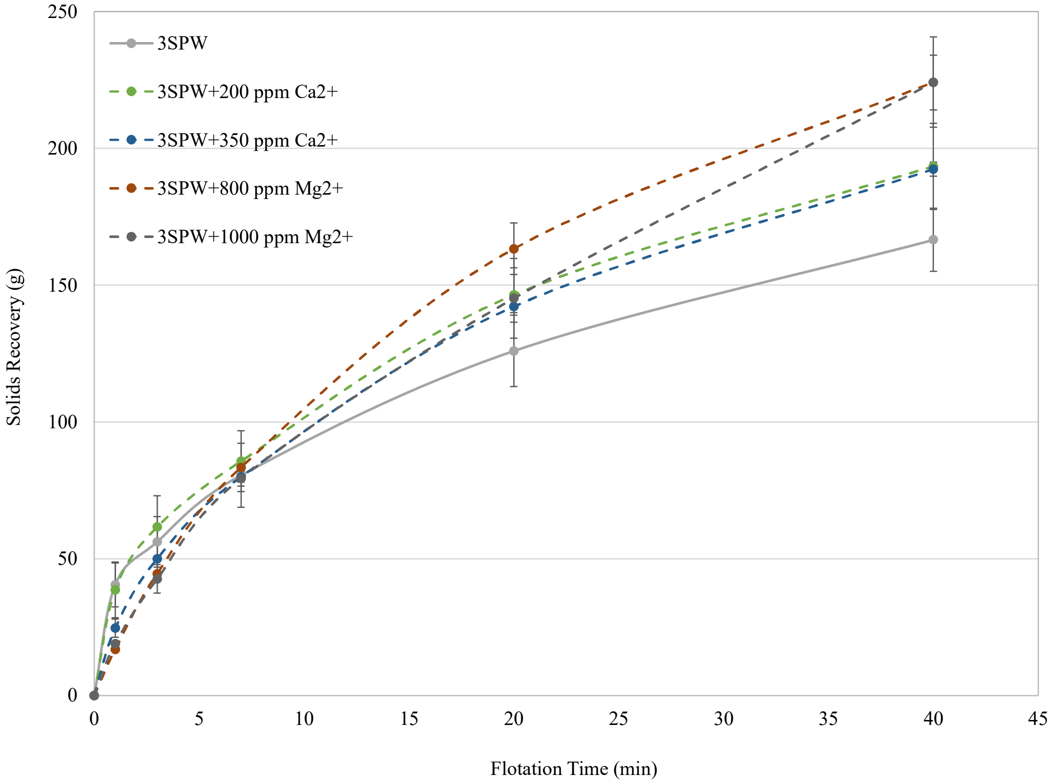


Figure 29: Solids recovery per flotation time during Ca^{2+} and Mg^{2+} spiking (Note that the values presented are the average values between tests which were performed in duplicate, and the error bars represent the standard error between duplicate tests).

Figure 29 shows that Mg^{2+} ion spiking achieved the highest solids recoveries in comparison to the Ca^{2+} ion spiking. The unspiked 3 SPW achieved the lowest solids recovery. Increasing the Mg^{2+} spiking concentration from 800 to 1000 ppm resulted in similar solids recovery. A similar trend is observed when the Ca^{2+}anionic concentration is spiked from 3SPW (240 ppm) to 200 and 350 ppm.
Figure 30 shows the total solids and water recovered to the concentrate.

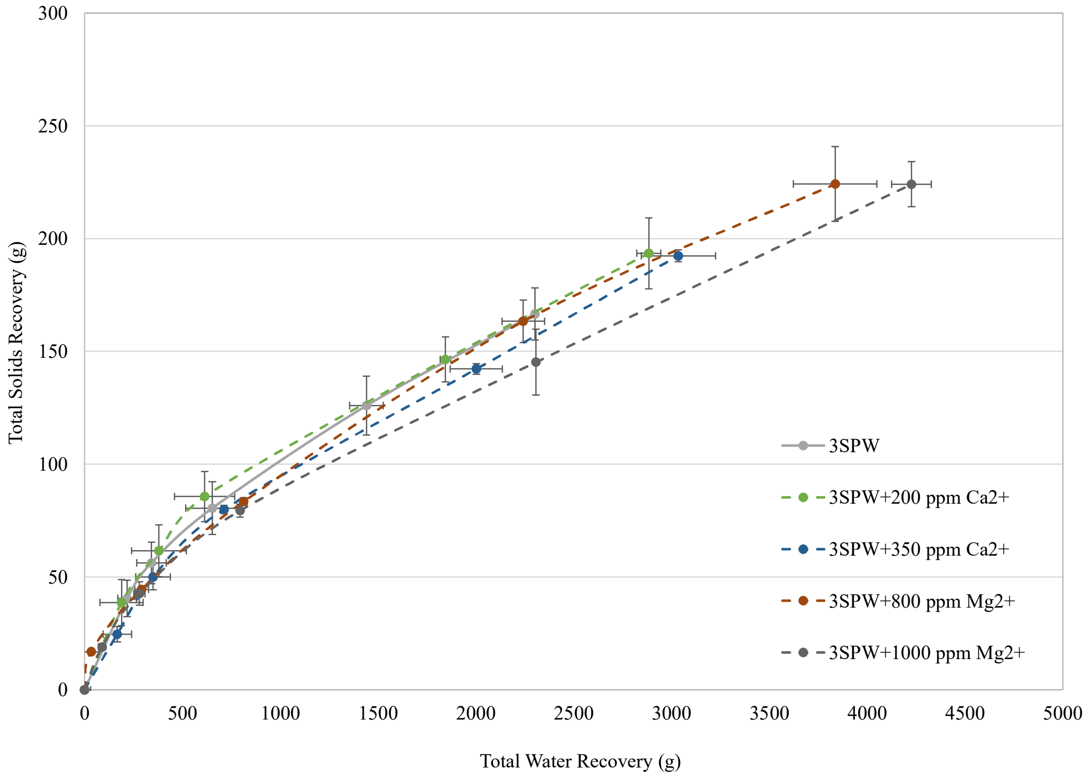


Figure 30: Solids recovery versus water recovery at different levels of cationic spiking (Note that the values presented are the average values between tests which were performed in duplicate, and the error bars represent the standard error between duplicate tests).

Table 14 shows the breakdown of the solids and water recovery as 3 SPW and different cationic spiking including the associated std. error.

Table 14: Solids and water recovery for 3 SPW and cationic spiking including the associated std. errors.

Water [I.S]	**Spiking**	**Solids Recovery [g]**	**Solids Recovery [Std_Error]**	**Water Recovery [g]**	**Water Recovery [Std_Error]**
3 SPW	-	166.60	11.50	2302.25	85.65
3SPW	200 ppm Ca^{2+}	193.45	15.75	2883.60	62.20
	350 ppm Ca^{2+}	192.40	2.60	1032.70	189.75
	800 ppm Mg^{2+}	224.20	16.50	3836.48	213.75
	1000 ppm Mg^{2+}	224.10	10.00	4226.35	101.35

Spiking of Ca^{2+} and Mg^{2+} increased the solids recovery above that of 3 SPW regardless of the concentration. There was an increase in water recovery when spiking with Ca^{2+} and Mg^{2+}, the Mg^{2+} gave the highest water recovery. 1000 ppm Mg^{2+} recovers more water compared to 800 ppm Mg^{2+} however despite having a higher ionic strength, both 1000 ppm Mg^{2+} and 800 ppm Mg^{2+} recovered similar amounts of solids.

The Pt recovery kinetics are shown in Figure 31.

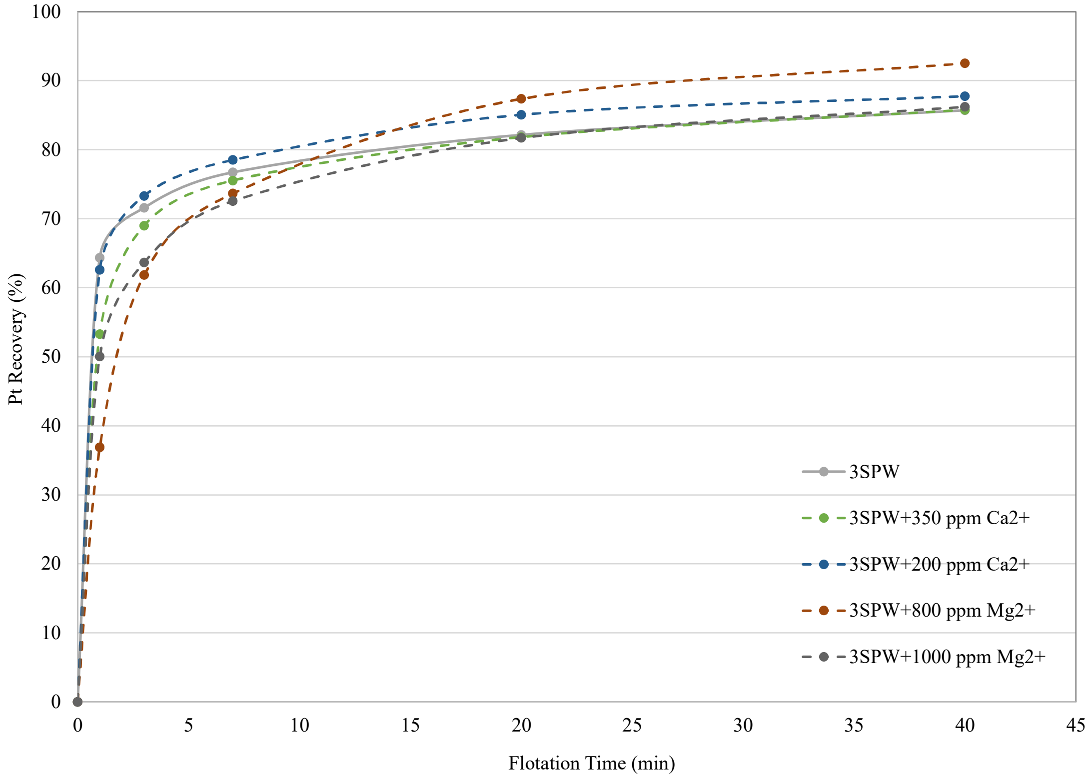


Figure 31: Platinum recovery versus time upon spiking (note that no error was calculated owing to single sample analysis as described in Section 4.5)

There was no significant difference in overall platinum recovery as the ionic strength of water increases, only at 800 ppm Mg^{2+} was there a notable increase in platinum recovery. For the Ca^{2+}, reducing the concentration from 240 ppm to 200 ppm showed some slight increase in the platinum recovery.

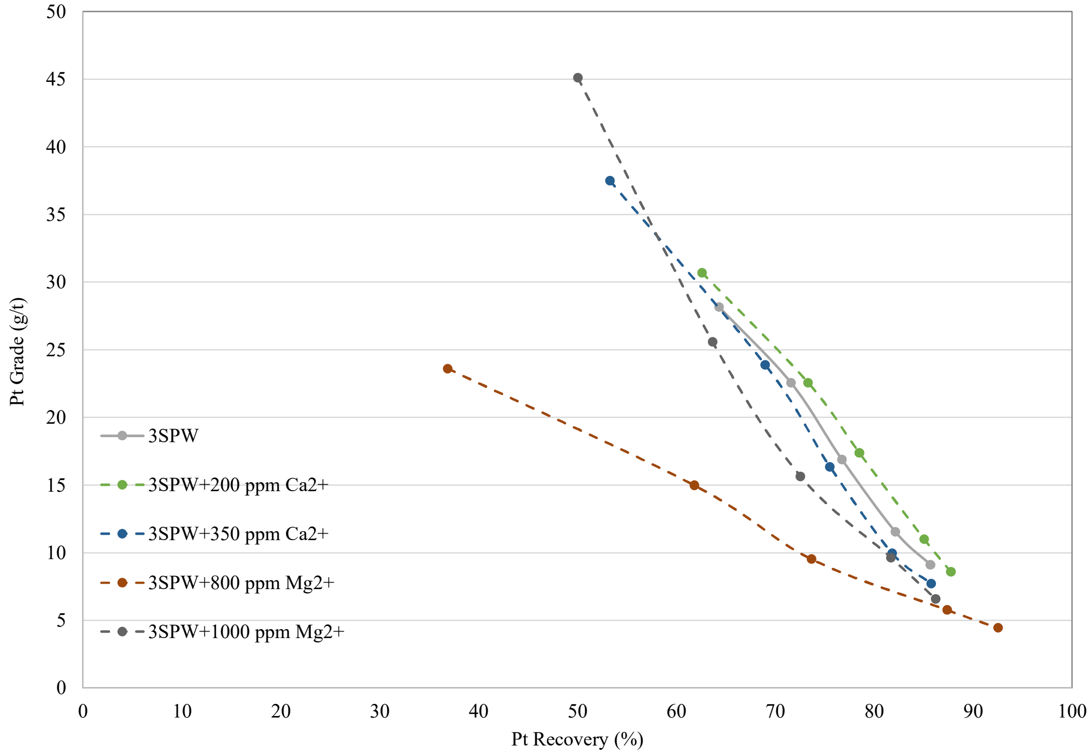


Figure 32: Platinum grade per platinum concentrate recovered at different cationic concentrations (note that no error was calculated owing to single sample analysis as described in Section 4.5)

The Pt grade versus recovery curves, shown in Figure 32, show that spiking Mg^{2+} to 800 ppm resulted in the lowest Pt grade. The results further show that spiking the Mg^{2+} cations from 800 to 1000 ppm increased the grade from 4.45 g/t to 6.59 g/t. For the Ca^{2+} ions there was not much difference in the platinum grade when compared to 3 SPW.

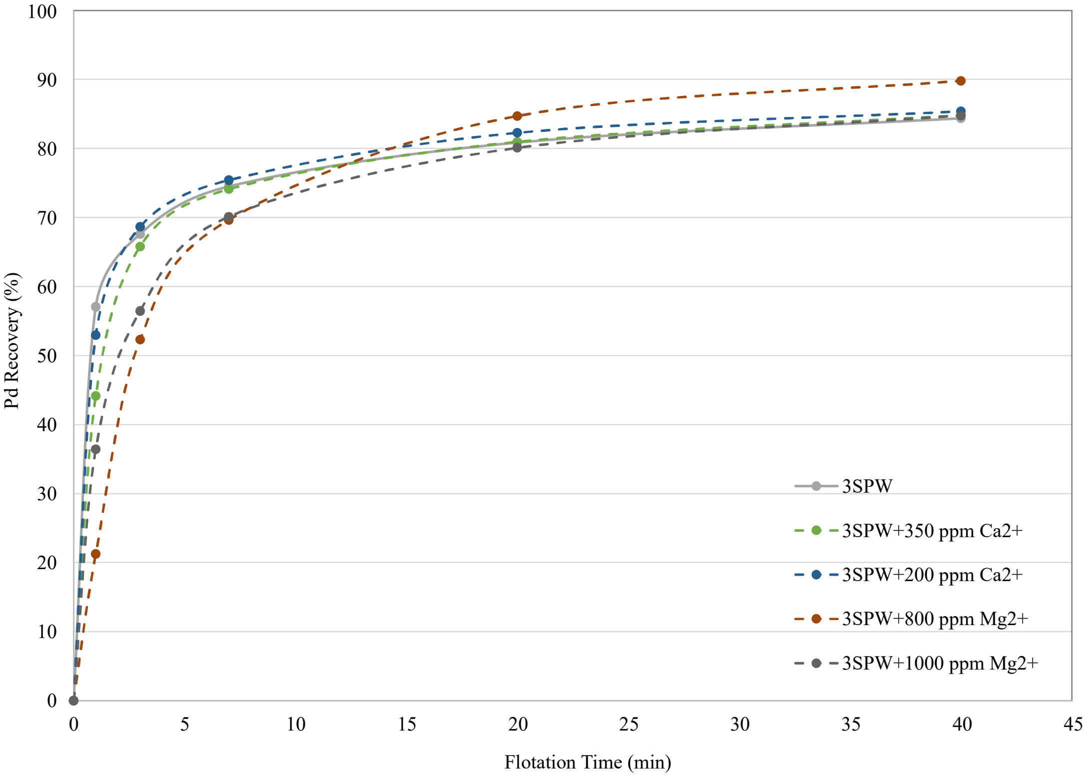


Figure 33: Palladium recovery versus flotation time for cation spiking (note that no error was calculated owing to single sample analysis as described in Section 4.5)

Figure 33 shows that spiking Mg^{2+} to 800 ppm achieved the highest overall palladium recovery of 90%. The other cation spiking tests achieved lower and similar Pd recoveries of 85%.

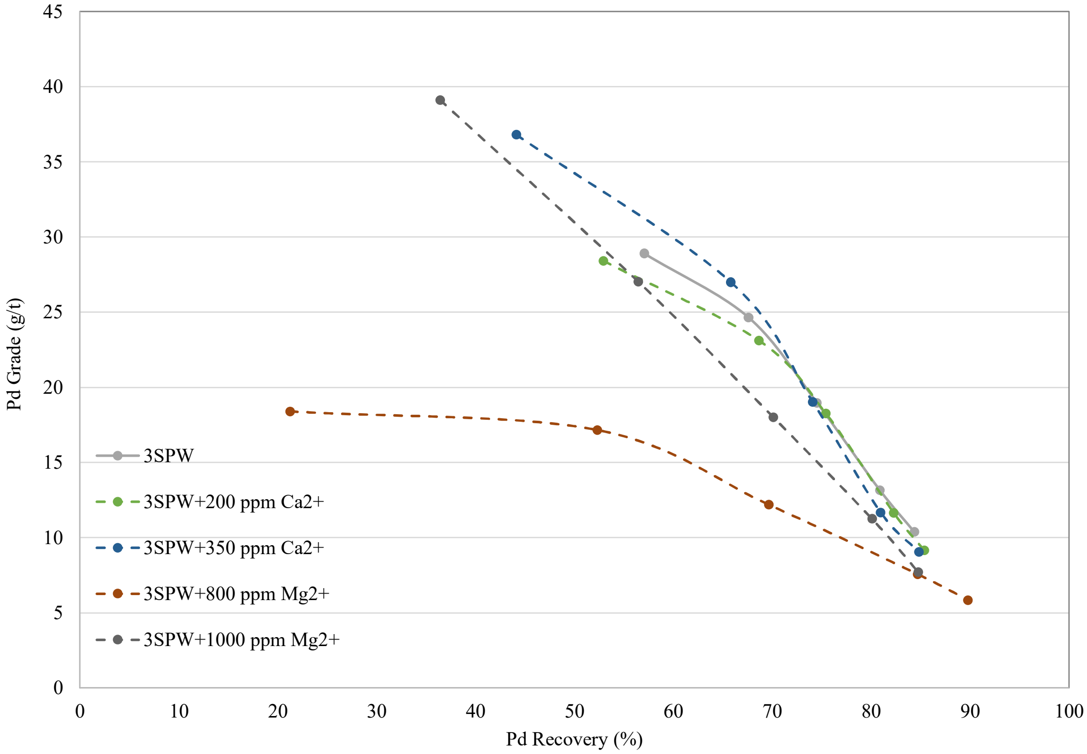


Figure 34: Palladium grade versus palladium recovery for different cationic spiking concentrations (note that no error was calculated owing to single sample analysis as described in Section 4.5)

Figure 34 shows that the lowest overall palladium grade was obtained when spiking with 800 ppm Mg^{2+}. None of the cationic spiking tests gave a palladium grade higher than the one for the unspiked 3 SPW.

Figure 35 shows the effect of cationic spiking on the recovery of copper.

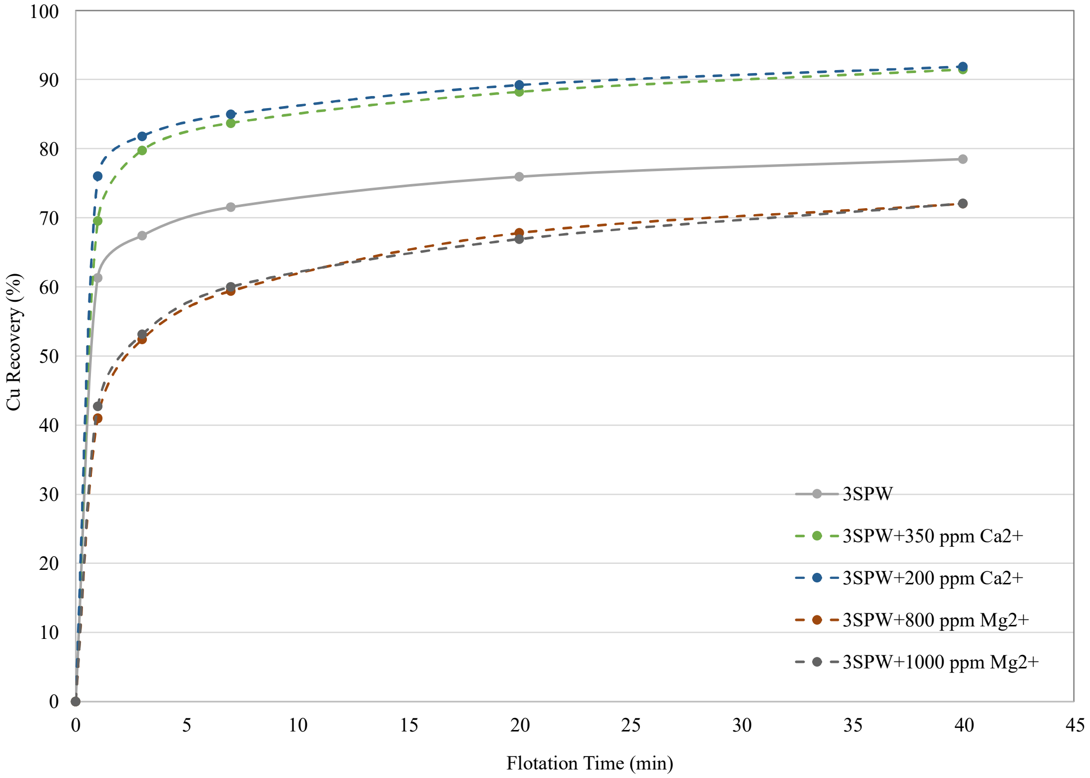


Figure 35: Copper grade versus flotation time at different cationic spiking concentrations (note that no error was calculated owing to single sample analysis as described in Section 4.5)

An increase in the copper recovery was observed when the Ca^{2+} cations were spiked. The copper recovery increased from 78.49% for the unspiked 3 SPW to similar Cu recovery of 91.86% for both 200 ppm and 350 ppm Ca^{2+}. Spiking of the Ca^{2+} concentration did not have an effect on the Cu recovery. 3 SPW seemed to be a minimum turning point for a Cu recovery versus Ca^{2+} concentration. On the other hand, spiking of the Mg^{2+} cations decreased the copper recovery from 78.5% for the unspiked 3 SPW to 72.1% for 800 ppm and 1000 ppm.

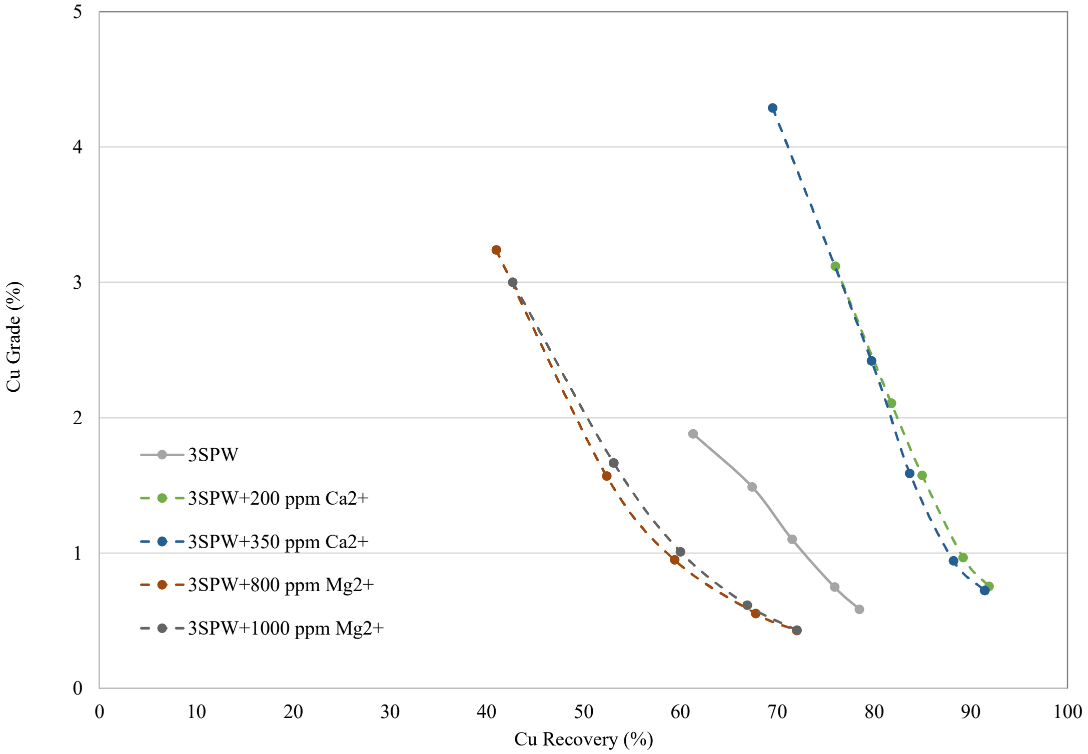


Figure 36: Copper grade versus copper recovery at different cationic spiking concentrations (note that no error was calculated owing to single sample analysis as described in Section 4.5)

Figure 36 shows the copper grade versus recovery as a function of cationic spiking. The Ca^{2+} cations increased the grade from 0.58% for unspiked 3 SPW to 0.72% for Ca^{2+} cationic concentrations. The copper grade decreased to 0.43% as a result of spiking with Mg^{2+} cations.

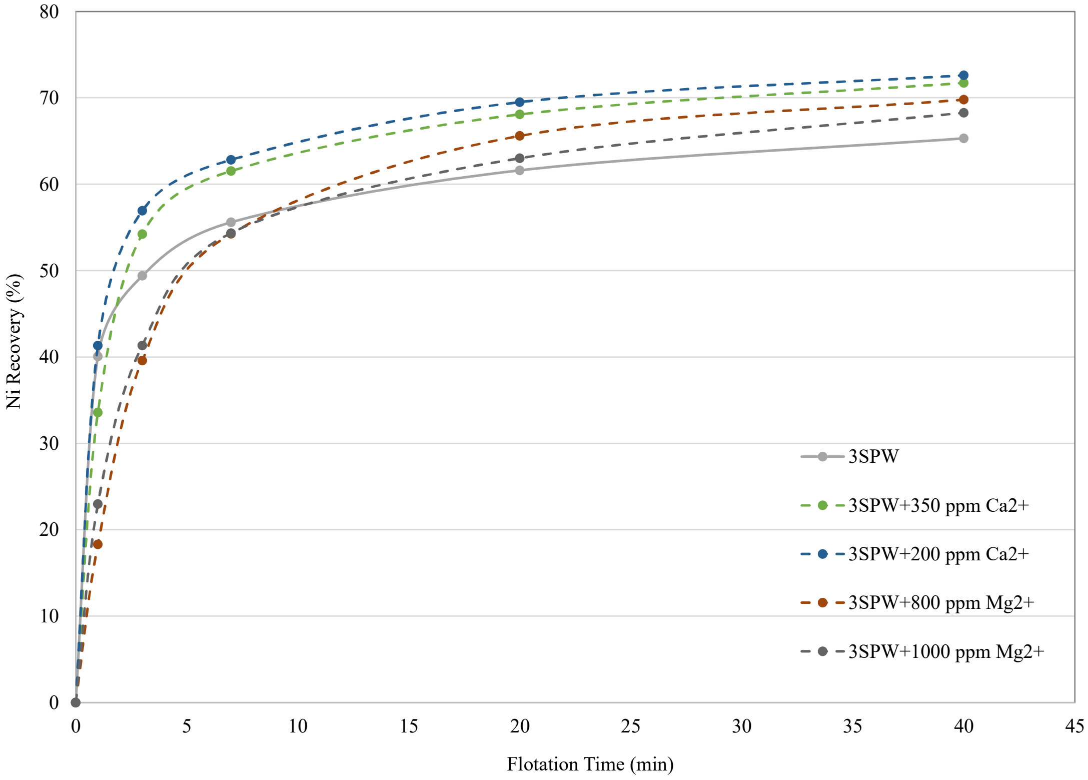


Figure 37: Nickel recovery versus time at different cationic spiking concentrations (note that no error was calculated owing to single sample analysis as described in Section 4.5)

Figure 37 shows that cationic spiking increased the nickel recovery compared to the unspiked 3 SPW. The nickel recovery increased in the following order: 1000 ppm Mg^{2+} < 800 ppm Mg^{2+} < 350 ppm Ca^{2+} < 200 ppm Ca^{2+}. The Ca^{2+} cationic spiking gave the highest nickel recovery than the Mg^{2+} cationic spiking.

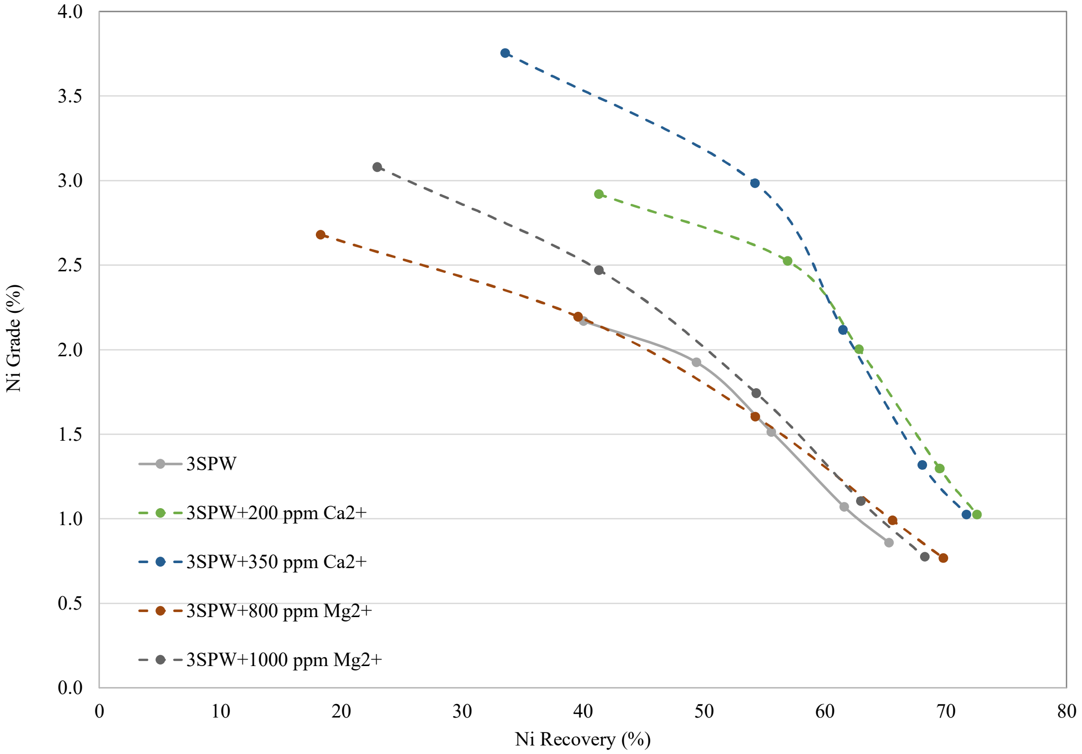


Figure 38: Nickel grade versus recovery at different cationic spiking concentrations (note that no error was calculated owing to single sample analysis as described in Section 4.5)

Figure 38 shows the nickel grade versus recovery at different cationic spiking concentration. The highest nickel grade of 1.03% was achieved when spiking with Ca^{2+} while the lowest Ni grade of 0.77% was achieved when spiking with Mg^{2+}.

Key findings for spiking 3 SPW with Ca^{2+} and Mg^{2+} at different concentrations:

- Mg^{2+} achieved the highest water recovery at 1000 ppm concentration. All cationic spiking increased the water recovery compared to the unspiked 3 SPW (Figure 28).
- Spiking with Mg^{2+} cations gave the highest solid recovery compared to Ca^{2+} cations (Figure 29).
- Spiking 3 SPW with 800 ppm Mg^{2+} improved the platinum (Figure 32) and palladium (Figure 34) recovery, but the final platinum and palladium grade were lower.
- Copper (Figure 36) and nickel (Figure 38) recovery and grade were highest when 3 SPW was spiked with Ca^{2+} cations.
- Copper (Figure 36) and nickel (Figure 38) recovery and grade were lowest when 3 SPW was spiked with Mg^{2+} cations compared to spiking with Ca^{2+} cations.

5.7. Flotation response upon spiking of 3 SPW with SO_4^{2-}; NO_3^-; and $S_2O_3^{2-}$ anions

The previous section dealt with assessing the effect of cationic spiking (Mg^{2+} and Ca^{2+}) on flotation performance. This section deals with the effect of spiking 3 SPW with SO_4^{2-}; NO_3^-; and $S_2O_3^{2-}$ anions. The spike response is then compared with 3 SPW. Figure 39 depicts the water recovery as s function of flotation time for spiking with SO_4^{2-}; NO_3^-; and $S_2O_3^{2-}$ anions.

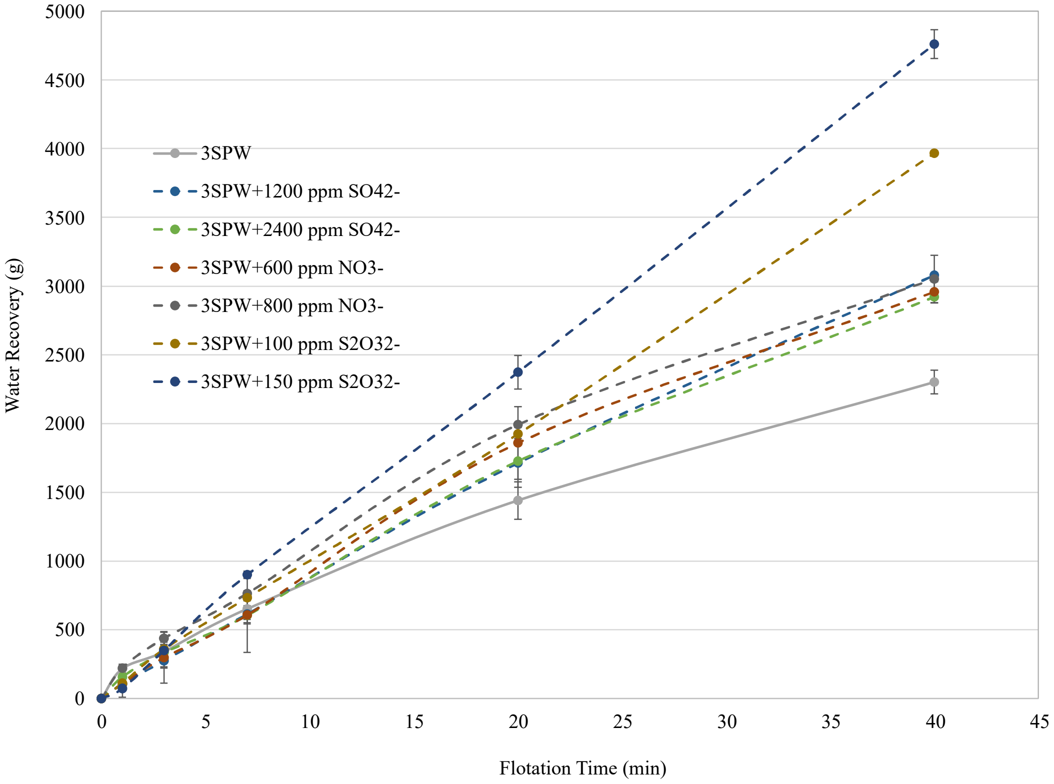


Figure 39: Water recovery per flotation time at different anionic concentration spiking (Note that the values presented are the average values between tests which were performed in duplicate, and the error bars represent the standard error between duplicate tests).

Figure 39 shows that the spiking of anions was found to result in higher water recoveries than the 3 SPW. 150 ppm $S_2O_3^{2-}$ spiking achieved the highest water recovery followed by 100 ppm $S_2O_3^{2-}$. The other anionic spiking converged to similar water recovery values.

Figure 40 shows the solids recovery as a function of flotation time for spiking with SO_4^{2-}; NO_3^-; and $S_2O_3^{2-}$ anions.

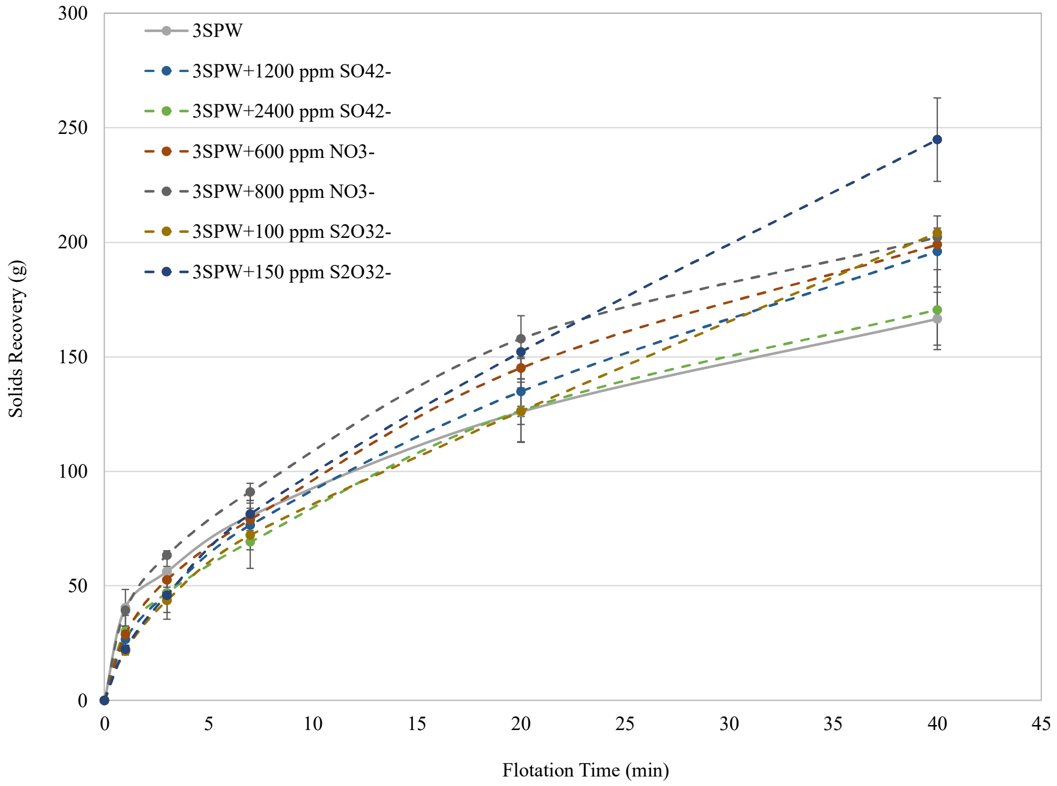


Figure 40: Solids recovered per unit flotation time during anionic spiking (Note that the values presented are the average values between tests which were performed in duplicate, and the error bars represent the standard error between duplicate tests).

According to Figure 40, 150 ppm $S_2O_3^{2-}$ pulled more solids and 2400 ppm SO_4^{2-} pulled the least solids. All the other tests achieved intermediate similar water recoveries.

The data in Table 15 and Figure 41 shows that upon spiking of the selected anions, water and solids recovery was higher when compared to the 3 SPW.

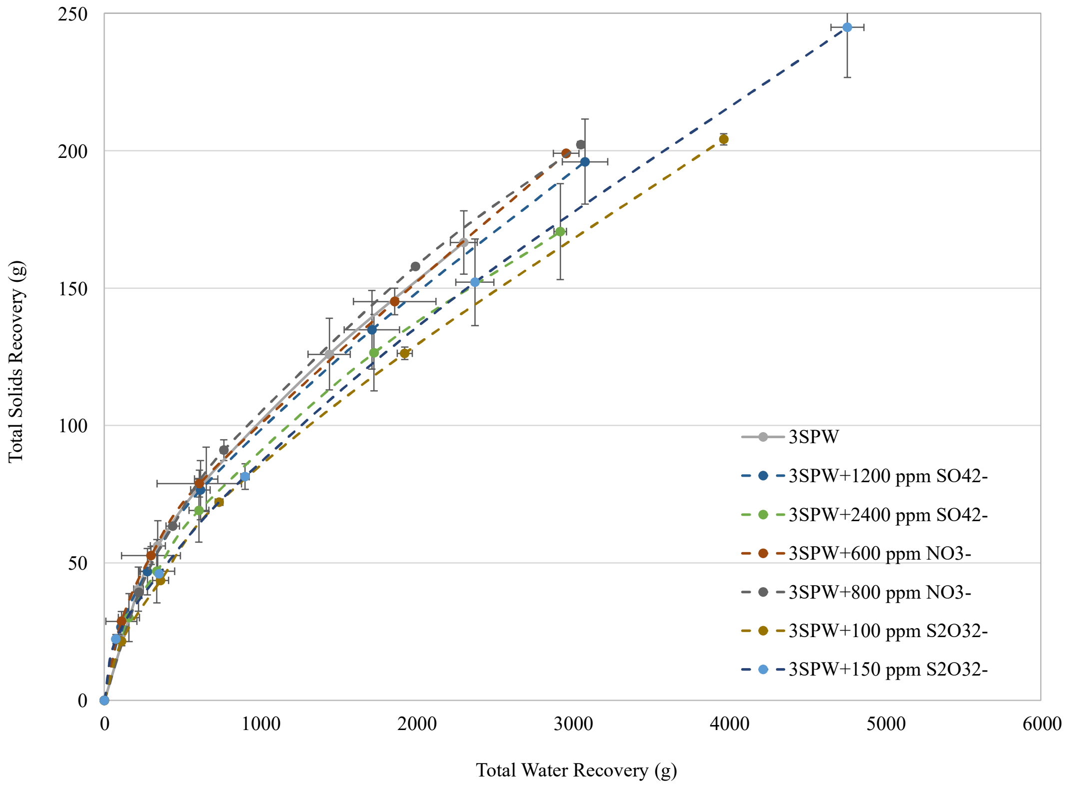


Figure 41: Solids recovery versus water recovery at different anionic spiking concentrations (Note that the values presented are the average values between tests which were performed in duplicate, and the error bars represent the standard error between duplicate tests).

Table 15: Overall mass pull per water recovery at different ionic concentrations including std. error values

Water [I.S]	Spiking	Solids Recovery [g]	Solids Recovery [Std_Error]	Water Recovery [g]	Water Recovery [Std_Error]
3 SPW	-	166.60	11.50	2302.25	85.65
3SPW	1200 ppm SO_4^{2-}	196.00	15.50	3079.30	145.90
	2400 ppm SO_4^{2-}	170.55	17.45	2920.65	40.75
	600 ppm NO_3^-	199.00	0.90	2958.70	81.70
	800 ppm NO_3^-	202.20	0.70	3052.25	20.65
	100 ppm $S_2O_3^{2-}$	204.15	2.05	3967.25	2.55
	150 ppm $S_2O_3^{2-}$	244.85	18.25	4759.90	105.20

Spiking $S_2O_3^{2-}$ at 150 ppm pulled the highest amount of water and solids than the other anions. Increasing the spiking concentration for $SO_4^{2-}$and NO_3^- anions did not show any significant change in the water and solids recovery.

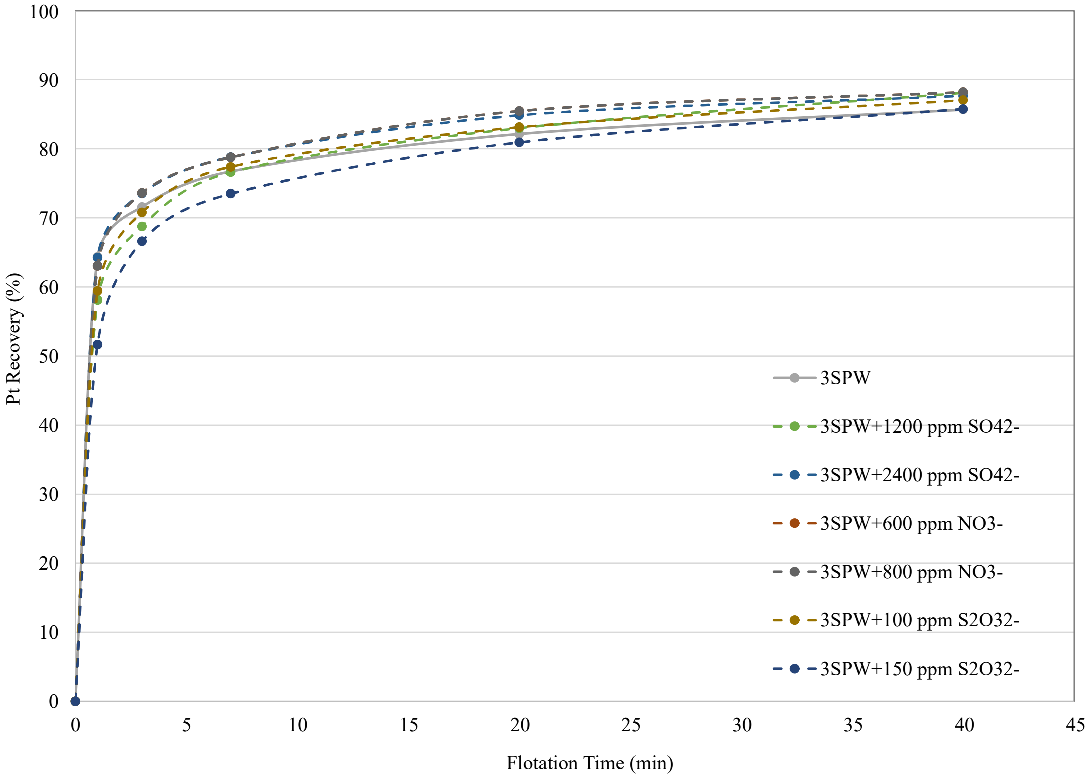


Figure 42: Platinum recovery versus flotation time (note that no error was calculated owing to single sample analysis as described in Section 4.5)

According to Figure 42, there was a slight increase in platinum recovery for all anionic spiking excluding 150 ppm $S_2O_3^{2-}$ which achieved the same platinum recovery as the 3 SPW. As the concentration of NO_3^- increased from 600 to 800 ppm, the platinum recovery decreased significantly from 59.2% to 47.9%. Furthermore, in spiking $S_2O_3^{2-}$ from 100 to 150 ppm there was no significant increase in platinum recovery, from 60.1% to 60.5%. However, spiking SO_4^{2-} from 1200 to 2400 ppm resulted in a slight decrease from 88.1% to 87.7% to Pt recovery.

Figure 43 shows the Pt grade-recovery curve for spiking with SO_4^{2-}; NO_3^-; and $S_2O_3^{2-}$ anions.

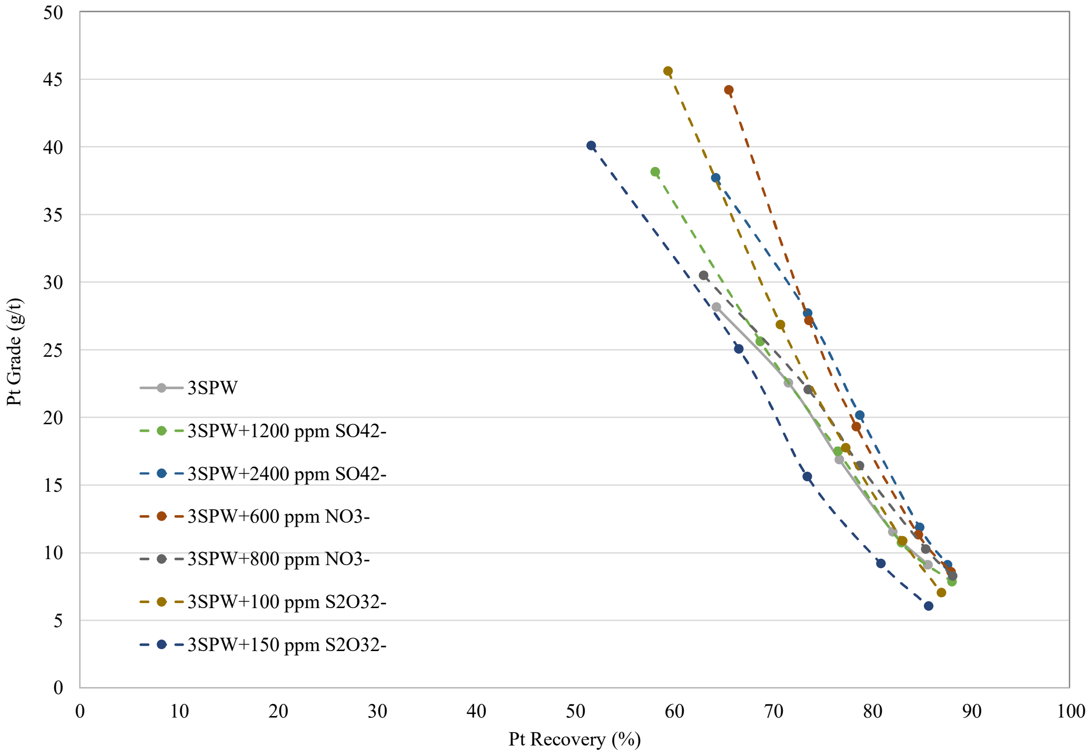


Figure 43: Platinum grade versus platinum concentrate recovered at varying anionic concentrations. (Note that no error was calculated owing to single sample analysis as described in Section 4.5)

According to Figure 43, increasing the spiking concentration of SO_4^{2-} from 1200 ppm to 2400 ppm resulted in decreased platinum grade. The same trend was observed when the spiking concentration of $S_2O_3^{2-}$ was increased from 100 ppm to 150 ppm. No significant change in Pt grade was observed when NO_3^- concentration was increased.

Figure 44 shows the Pd recovery-time curves for SO_4^{2-}; NO_3^-; and $S_2O_3^{2-}$ anions.

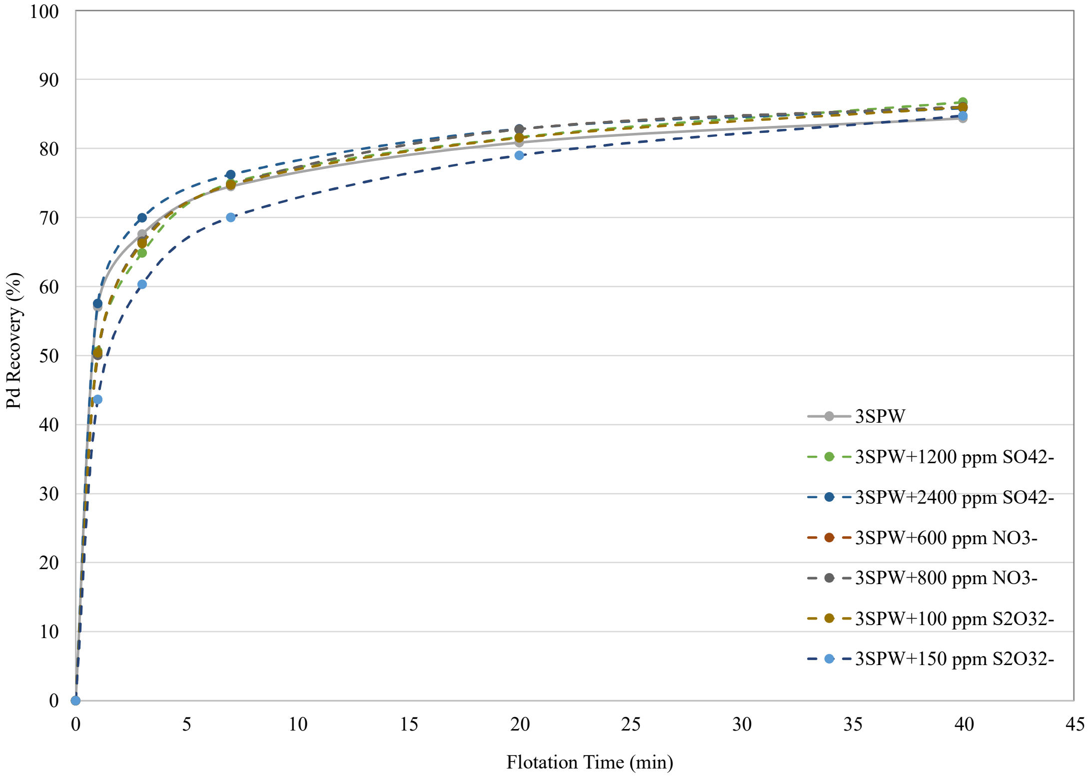


Figure 44: Palladium recovery versus flotation time upon anionic spiking (note that no error was calculated owing to single sample analysis as described in Section 4.5)

Figure 44 shows that all anionic spiking concentration gave palladium recovery similar to that of 3 SPW. No significant change in palladium recoveries was observed when all the anions were spiked regardless of the concentration.

Figure 45 shows the Pd grade-recovery curves for spiking with SO_4^{2-}; NO_3^-; and $S_2O_3^{2-}$ anions.

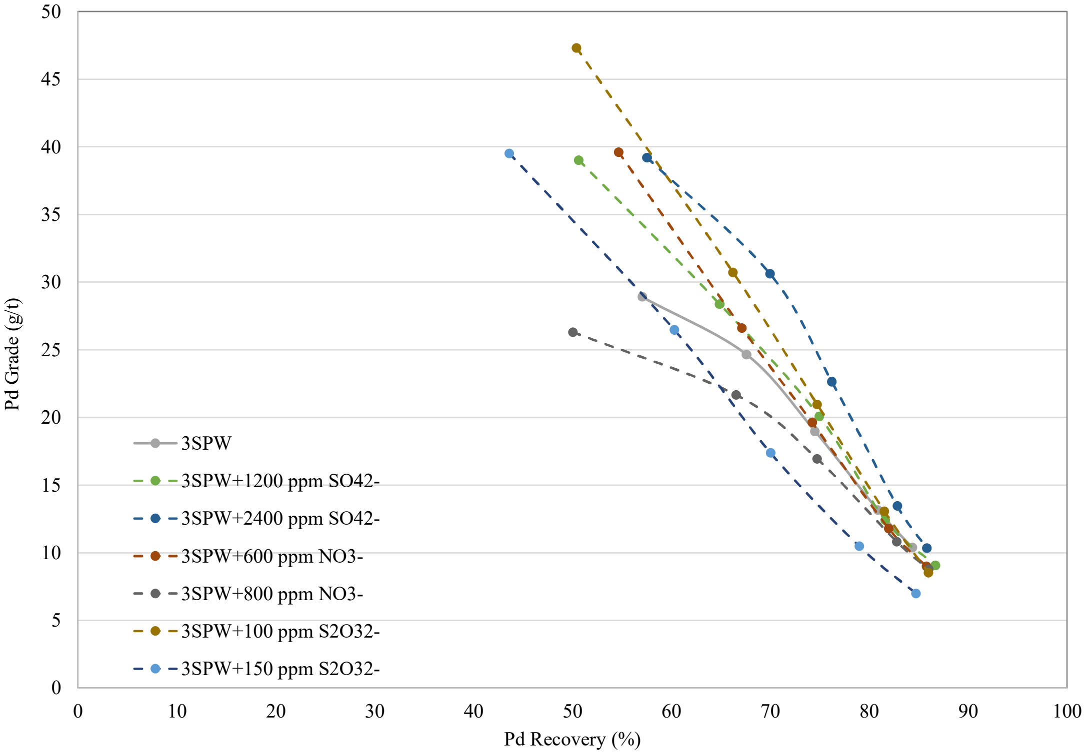


Figure 45: Palladium grade versus palladium recovery at varying anionic concentrations. (note that no error was calculated owing to single sample analysis as described in Section 4.5)

According to Figure 45, increasing the spiking concentration of SO_4^{2-} from 1200 ppm to 2400 ppm resulted in increased palladium grade. The opposite trend was observed when the concentration of $S_2O_3^{2-}$ was increased from 100 ppm to 150 ppm, as the Pd grade increased from 8.5 g/t to 7 g/t. When spiking 3 SPW to 600 ppm NO_3^- concentration, the graph shows that a Pd initial grade of 39 g/t was achieved while at 800 ppm the initial grade dropped to 26g/t which was lower that the Pd initial grade of 28 g/t of 3 SPW. This means that the NO_3^- ion at 600 ppm improved the Pd flotation selectivity thus recovering higher grade Pd in the first concentrate. At 800 ppm the Pd flotation selectivity decreased significantly, showing that 800 ppm NO_3^- was the maximum concentration beyond which the Pd grade begin to get negatively impacted. No significant change in Pd final grade was observed when the NO_3^- concentration was increased.

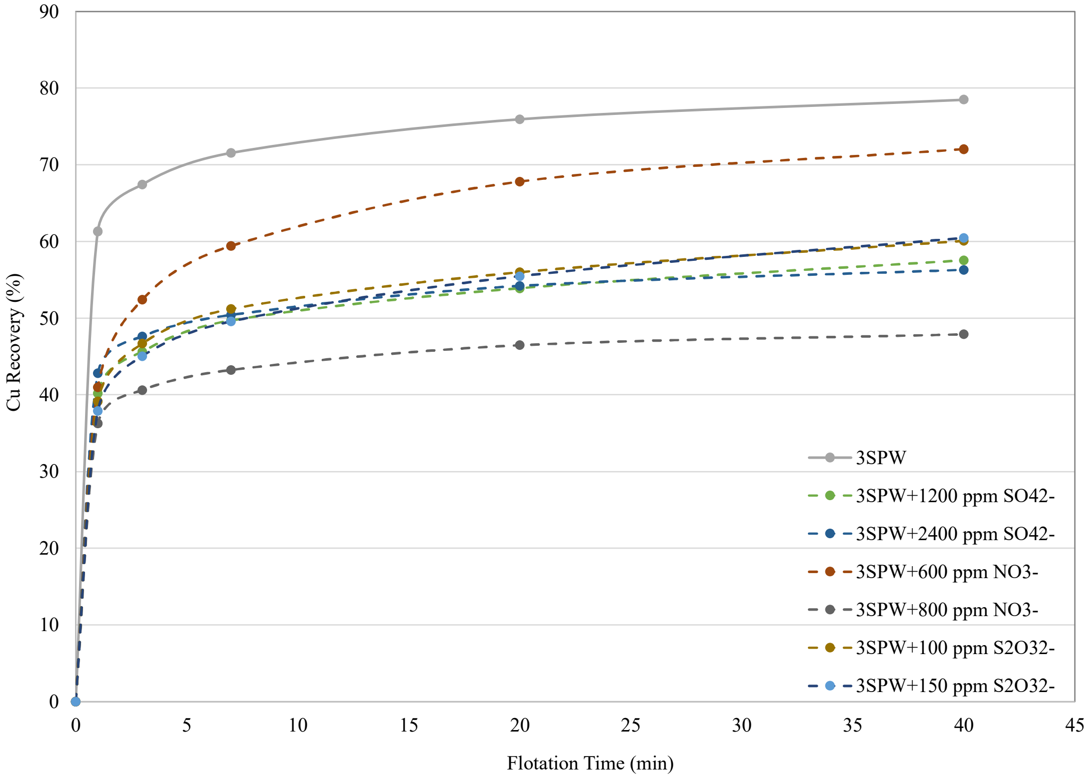


Figure 46: Copper recovery versus time for anionic spiking. (note that no error was calculated owing to single sample analysis as described in Section 4.5)

Figure 46 shows that spiking the 3 SPW with different anions generally decreased the copper recovery. The copper recovery was highest when using unspiked 3 SPW with 800 ppm NO_3^- recovering the lowest copper recovery and all the other test conditions achieving intermediate Cu recoveries. Spiking $S_2O_3^{2-}$ from 100 to 150 ppm did not have any significant effect on the copper recovery. The same trend was observed when SO_4^{2-} concentrate was increased from 1200 and 2400 ppm. Copper recovery dropped from ~80% to between 40 and 60% as a result of anionic spiking.

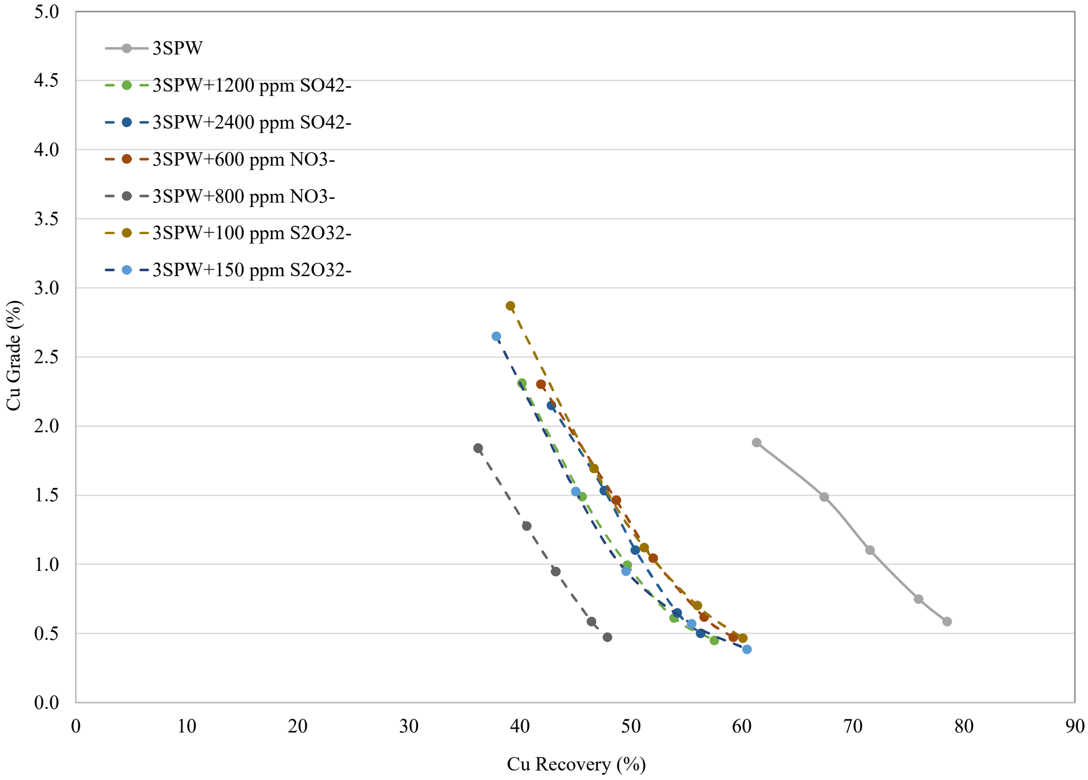


Figure 47: Copper grade versus copper recovery at different levels of anionic concentration (note that no error was calculated owing to single sample analysis as described in Section 4.5).

Figure 47 shows that anionic spiking affected mostly the copper recovery as the final copper grade remained constant.

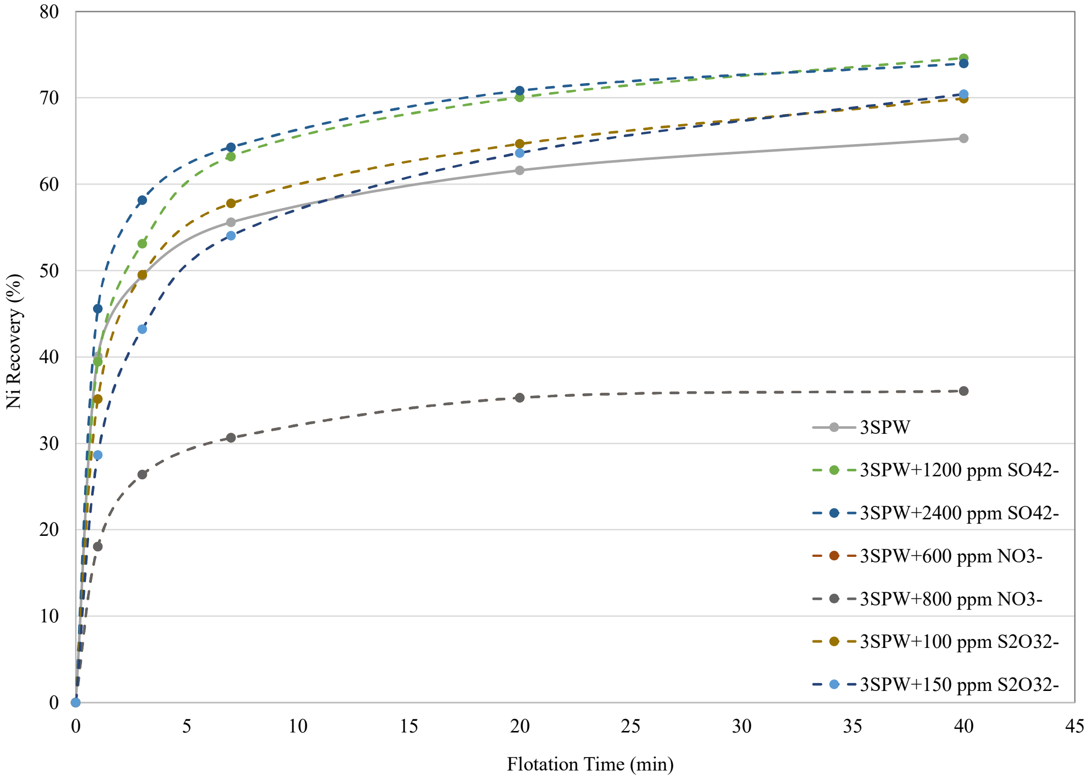


Figure 48: Nickel recovery versus flotation time at different anionic concentrations (note that no error was calculated owing to single sample analysis as described in Section 4.5)

Figure 48 shows that spiking the 3 SPW with 800 ppm NO_3^- decreased the nickel recovery from 65.3% to 36.1%. Spiking with $S_2O_3^{2-}$ increased the nickel recovery from 65.3 to 70.4%. Spiking with SO_4^{2-} increased the nickel recovery from 65.3% to 74.6%. Increasing the spiking concentration of SO_4^{2-} from 1200 to 2400 ppm and $S_2O_3^{2-}$ from 100 to 150 ppm did not have any significant effect on the nickel recovery.

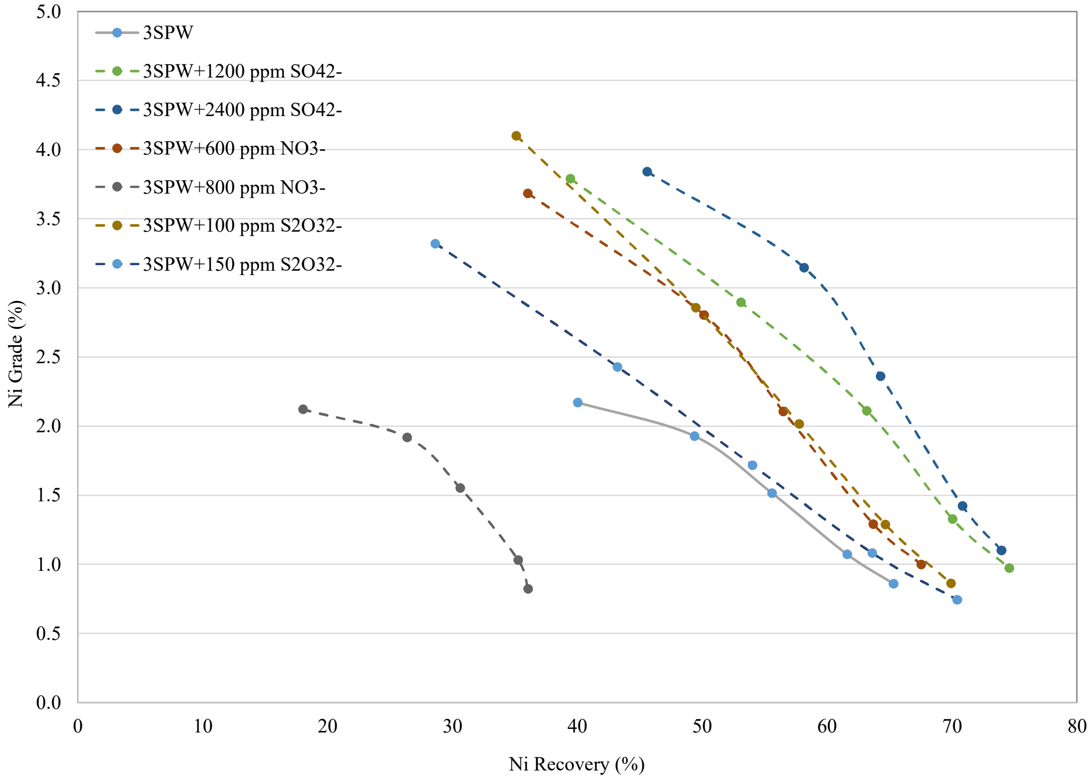


Figure 49: Nickel grade versus recovery at different anionic concentrations (note that no error was calculated owing to single sample analysis as described in Section 4.5)

Figure 49 shows that SO_4^{2-} concentration spiking at 2400 ppm achieved the highest grade of 1.1% while $S_2O_3^{2-}$ spiking at 150 ppm achieved the lowest at 0.74%. SO_4^{2-} concentration spiking improved the flotation performance of the 3 SPW as the grade-recovery curved moved to the far right regardless of the SO_4^{2-} anion concentration indicating superior flotation performance. The overall nickel recovery increased from 70.4% for 3SPW to 74.0% for 2400 ppm SO_4^{2-}. This was accompanied by increased nickel grade from 0.74% for 3 SPW to 1.10% for 2400 ppm SO_4^{2-}. Spiking with 800 ppm NO_3^- had an insignificant effect on the nickel grade but was detrimental to the nickel recovery.

6. Discussion

The main objective of this study was to investigate the effect of water quality and the impact of selected ions on the flotation performance of a Platreef ore from the Northern Limb of the Bushveld Complex in South Africa. Similar studies have been conducted using other PGM ores, i.e., UG2 and Merensky, and analysis was done looking mostly at base metal sulphides (Cu and Ni metal grades and recoveries) since they are associated with PGMs (Tadie et al., 2017). However, in this Platreef ore, the mineralogical analysis conducted has shown that 64.5% of the PGMs are liberated and are not associated with BMS and thus results observed for BMS may not apply for PGMs. This study is unique in that it is one of the few studies which looks at the Platreef ore and, analysis is done targeting platinum and palladium metals together with copper and nickel elements. The key performance indicators used for this study were the metal grade and recovery, water recovery, and solids recovery.

The baseline condition considered potable tap water from Rand Water Board. Thereafter, UCT SPW (Wiese et al., 2005) of varying ionic strength: 1, 3, 5, and 10 SPW representing ionic strengths of 0.0243, 0.073, 0.121, 0.243 M, respectively were tested and compared with the baseline potable water with total dissolved solids of 163 mg/L.

Upon analysis of on-site process water sourced from the Platreef operation, it was found to be similar to the 3 SPW water make-up. Hence, 3 SPW was maintained as the complex water matrix in which selected ions were spiked to known ionic concentrations. The main aim for spiking the 3 SPW with ions was to simulate the recycling of water in the plant to understand the effect of the accumulation of specific ions; Ca^{2+}; Mg^{2+}; SO_4^{2-}; NO_3^-; and $S_2O_3^{2-}$ on the flotation performance of the Platreef ore.

6.1. Effect of water quality on flotation performance: 1, 3, 5, and 10 SPW, and potable water

Increasing ionic strength increased the water recovered to the concentrate in the order 1 SPW = 3 SPW < 5 SPW < 10 SPW. Similar observations were made by Corin et al. (2011); Ejtemaei et al. (2016) and Wiese et al. (2007) where an increase in water recovery was observed with increase in the ionic strength of water and speculated it to have been caused by an enhancement in froth stability due to the presence of high amounts of ions. Manono et al (2012) showed through pulp bubble size measurements that increasing the ionic strength decreased the bubble size thus increasing the froth height. This is because smaller bubbles take up less volume individually, but because there are more of them due to the reduced coalescence, the overall bubble volumetric fraction in the pulp increases, thus leading to a taller and more stable froth layer. The bubble diameter decreased in the order $d_{10SPW} < d_{5SPW} < d_{3SPW}$ which enabled for the formation of smaller bubbles which in turn increased the bubble surface area. This increase in bubble surface area increases water recovery owing to the amount of water at the bubble surface. While increased bubble particle attachment increases solids recovery.

However, for the solids recovery the opposite trend was observed from the data, i.e., decrease in solids recovery with increase in ionic strength. The solids recovery decreased in the following the order: 1 SPW > 3 SPW = 5 SPW > 10 SPW. According to Corin et al., (2010) the presence of the CMC (Sendep 30E) depressant during flotation reduces the solids recovery to the concentrate because of the reduced NFG recovery. Similar observations were also made by Manono et al. (2019) who showed that increasing the ionic strength of process water enhances the adsorption of CMC onto naturally floatable gangue, NFG, imparting a coagulative nature onto the gangue mineral particles and thereby inhibiting their flotation. Additionally, Manono et al. (2020) stated that the presence of specific ions in process

water had effects on the behaviour of gangue. Species such as Ca^{2+}, $CaOH^+$, and $CaNO_3^+$ cause the gangue mineral surface to be inactive and thus cause depression of gangue.
Increasing the ionic strength of water decreased the copper recovery from 90 to 79.1% for 1 through 10 SPW. At 5 SPW the copper recovery was not significantly affected. The copper grade increased with an increase in ionic strength following the order of potable water < 1 SPW < 3 SPW < 5 SPW = 10. The nickel recovered when ionic strength was increased was lower than that of potable water and followed the order of potable water > 1 SPW > 5 SPW > 3 SPW = 10 SPW. The nickel grade followed the order of potable water < 1 SPW = 3 SPW < 10 SPW < 5 SPW. The platinum and palladium recovery decreased with an increase in ionic strength in the order of potable water > 1 SPW > 3 SPW > 10 SPW > 5 SPW. The platinum and palladium grade increased following the order of potable water < 1 SPW < 3 SPW < 10 SPW < 5 SPW.

Increasing the ionic strength of the SPW during flotation of a Platreef ore reduced the overall metal recovery, for both PGMs and BMS, when compared to potable water and significantly decreased the solids recovery as shown in Table 13. This was because an increase in the ionic strength of process water enhances the adsorption of CMC onto NFG, imparting a coagulative nature onto the gangue mineral particles and thereby inhibiting their flotation (Manono et al. 2019). Hence an increase in metal grade was observed for both PGMs and BMS due to depressed NFG.

6.2. Effect of spiking 3 SPW with Ca^{2+} and Mg^{2+} on flotation performance

The results showed that more water and solids were recovered when the 3 SPW was spiked with Ca^{2+} and Mg^{2+} ions regardless of the concentrations. While the water recovery increased with increasing cationic concentration, i.e., from 800 ppm to 1000 ppm Mg^{2+}, the solids recovery remained constant.

It was interesting to note that Mg^{2+} and Ca^{2+} had different impacts on the Cu recovery when compared to one another as well as the un-spiked 3 SPW. An increase in Ca^{2+}, regardless of the concentration, increased the Cu recovery by 13% and a slight increase in grade of 0.14%, while an increase in Mg^{2+}, regardless of the concentration, decreased the Cu recovery by 6% and a 0.15% decrease in Cu grade when compared to the un-spiked 3 SPW. This means that the for the Platreef ore Mg^{2+} ions may have enhanced the gangue depression. Laskowski and Castro, (2017) found out that Mg^{2+} ions form hydrolysis products that strongly depresses molybdenite (a sulphide mineral) over typical plant pH ranges when investigating the hydrolysis of metallic ions in mineral processing circuits and its effect on flotation. For nickel, spiking the concentrations of the Mg^{2+} and Ca^{2+} cations increased the nickel recovery; however higher nickel recoveries were observed when spiking with Ca^{2+}.

The spiking of the Ca^{2+} cations increased both nickel grade and recovery while the spiking of the Mg^{2+} ions increased the nickel recovery but decreased the nickel grade. A similar observation was shown by Ikumapayi et al (2010) when floating complex sulphide ores at pH 10.5-11 using Hallimond tube flotation. It was observed that the chalcopyrite recovery was enhanced at high Ca^{2+} ions concentration. The improvement was due to the formation of $CaOH^+$ species at high pH, the adsorption of such species enhances collector adsorption and hence improves the recovery. This suggests that accumulation of Ca^{2+} ions, to the threshold of 400 ppm as discovered by Dzingai et al. (2019), in recycled process water improves the flotation of both Cu and Ni (in terms of grade and recovery) as has been seen in other studies (Corin & Wiese, 2014; Boujounoui et al., 2015). Gaudin & Charles (1953) looked at separating pyrite from arsenopyrite using hexyl thioethylamine as collector and discovered that increasing Ca^{2+} ions in process water resulted in increased adsorption of Ca^{2+} ions onto valuable mineral surface thus hindering collector adsorption in sulphide flotation, The platinum and palladium recoveries increased by 6% when 3 SPW was spiked with 1000 ppm Mg^{2+}. A slight increase was observed when the 3 SPW was spiked with 200 ppm Ca^{2+} ions. In both tests the Pt and Pd grades were lower than the Pt and Pd grades achieved by the un-spiked 3 SPW. The data clearly shows that for the Platreef ore, PGMs and BMS flotation is affected by both ion type and concentration. The mineralogy study conducted on the ore indicated that 64.5 vol% of the PGMs are liberated and recoverable, and 20.8 vol% are the PGMs associated with BMS. Further analysis showed that of the 20.8 vol%; 7,5 vol% are PGMs associated with liberated BMS which are recoverable and 13.3 vol% are PGMs associated with BMS attached to gangue which are slow floating and need longer flotation time to recover. It is important to determine the ion type and concentration where both PGM and BMS can float. Hence, understanding and optimisation of the water chemistry is therefore critical to increase metal extraction from the Platreef ore.

This analysis is clearly showing that for the Platreef ore, the majority of the PMGs are not associated with BMS and thus BMS cannot be used as a proxy for PGMs. Shamaila and O'Connor, (2008) stated that the use of the Merensky and UG2 reagent suite for flotation of the Platreef cannot be effectively translated, due to the fact that the Platreef is almost barren of sulphide minerals in some areas. Under such reagent suites PGMs within the Platreef have been found to report to flotation tailings.

6.3. Effect of spiking 3SPW with NO_3^- on flotation performance

The solids and water recovery increased as the concentration of NO_3^- ions increased from 600 to 800 ppm. Without separating the effects of individual ions, Corin et al. (2014) suggested that the increase in NO_3^- ions caused the froth to be significantly more stable as a result of the inadvertent activation of gangue.

At 600 ppm NO_3^- spiking, both nickel grade and recovery had a slight increase of 1.4 g/t and 2.2% respectively and were higher than the un-spiked 3 SPW. This shows that NO_3^- ions have an impact on collector selectivity and gangue depression, as the nickel grade and recovery increased above that of 3 SPW when spiked with NO_3^- which is contrary to literature on increasing overall ionic strength (Manono et al., 2016). Increasing the spiked NO_3^- concentration to 800 ppm had both nickel grade and recovery lowered by 30% and 0.04 g/t respectively compared to the un-spiked 3 SPW. This suggests that the nickel flotation has a threshold at 600 ppm NO_3^- beyond which flotation is unfavourable. The substantial decrease in nickel recovery suggests that the effect of the depressant was negatively affected by the increase in nitrate ions above 600 ppm.

The copper grade and recovery decreased by 1.1 g/t and 6.6% respectively upon spiking with 600 ppm NO_3^-. Increasing the spiking concentration to 800 ppm NO_3^- further decreased the copper recovery by 30% but the grade was similar to the 600 ppm NO_3^- spiking. Increasing the NO_3^- concentration in 3 SPW from 600 to 800 ppm showed no change in the grade but a high drop in recovery, this means NO_3^- may have a negative impact on the collector selectivity and depressant effect at 800 ppm owing to pulp chemical species which may be present in the system such as nitric acid. According to this data, the presence of NO_3^- ions above 528 ppm is detrimental to the flotation of BMS.

Looking at the PGMs, Figure 43 and Figure 45 showed that the increase in NO_3^- concentration had an average of 2% increase in both platinum and palladium recoveries and a decrease in both platinum and palladium grade by 1 g/t. Introducing the nitrate ions in the 3 SPW increased the solids recovery which translated to an increase in gangue recovery, which according to the mineralogical is associated with the PGMs and thus the PGM recovery increased, while the grade was lowered.

6.4. Effect of spiking 3 SPW with SO_4^{2-} on flotation performance

The water and solids recovery when the 3SPW was spiked by SO_4^{2-} increased above that of the un-spiked 3 SPW. The recovery of both water and solids was highest at 1200 ppm SO_4^{2-} concentration. Although increasing the concentration of the SO_4^{2-} ions to 2400 ppm lowered the water and solids recovery, they are higher than 3 SPW. According to Bicak et al. (2012) the presence of dissolved ions like SO_4^{2-} and $S_2O_3^{2-}$ in water results in increase in froth stability. Similar observations by Corin et al (2014) and Dzingai et al (2019) showed that increasing ionic strength for a Merensky reef ore resulted in high solids and water recovery and introduced more naturally floatable gangue (NFG) to the final concentrate which was because of the gangue activating nature of SO_4^{2-}. Similar observations were made in this study when the ionic strength was increased by spiking of the SO_4^{2-}.

The data shows that spiking 3 SPW with SO_4^{2-} was not favourable for copper flotation. Copper recovery decreased significantly by 22% at both SO_4^{2-} ion concentrations and also dropped the copper grade which is attributed to the increase in NFG recovery which is known to be associated with PGMs and not BMS according to the sample mineralogy. The nickel on the other hand increased by 8% and the nickel grade was also higher when compared to the un-spiked 3 SPW. Nickel flotation was favoured as seen by an increase in both nickel grade and recovery. Although for the low-grade Cu-Ni-PGM ore used by Dzingai et al. (2019) it was found that 1200 ppm was the maximum sulphate concentration beyond which the copper grade was affected, the Platreef ore data shows the copper recovery and grade was negatively affected regardless the sulphate concentration. Sinche-Gonzalez & Fornasiero (2021) found that flotation of copper minerals is not affected by the presence of sulphate in the process water when floating a Cu-Mo ore but for a Cu-Zn ore there is a gradual decrease in Cu recoveries and grades with increasing sulphate concentration due to gangue activation in the presence of sulphate leading to more zinc reporting to the concentrate. Sinche-Gonzalez & Fornasiero (2021) concluded that it is possible that pyrite was activated by complexes of sulphate and metal ions such as Cu ions which form from chalcopyrite-like surfaces.

A slight increase in the platinum and palladium recoveries was observed regardless of the SO_4^{2-} concentration owing to the increase in solids recovery. For both platinum and palladium, the grade remained the same when 3 SPW was spiked with 2400 ppm SO_4^{2-} but dropped slightly when spiked at 1200 ppm SO_4^{2-} concentration, showing that PGM flotation is favourable at 2400 ppm SO_4^{2-} concentration.

The results showed that for the Platreef ore, the SO_4^{2-} concentration limit for PGM flotation is 2400 ppm where both palladium and platinum show an increase in recovery without affecting the grade. For BMS, the nickel flotation was favourable regardless of the concentration whereas the copper flotation was adversely affected at the conditions tested in this study.

6.5. Effect of spiking 3 SPW with $S_2O_3^{2-}$ on flotation performance

The flotation performance of the Platreef ore was observed when 3 SPW was spiked with $S_2O_3^{2-}$. The solids and water recovery increased with increasing $S_2O_3^{2-}$ concentration in 3 SPW. According to Bicak et al. (2012) the presence of dissolved $S_2O_3^{2-}$ ions in water results in increase in froth stability. The copper recovery decreased significantly by 18% regardless of the $S_2O_3^{2-}$ concentration. The copper grade decreased in the order of 3 SPW> 100 ppm $S_2O_3^{2-}$ > 150 ppm $S_2O_3^{2-}$. The nickel on the other hand

increased in recovery by 10% regardless of $S_2O_3^{2-}$ concentration. The nickel grade was only decreased at 150 ppm $S_2O_3^{2-}$ concentration.
For the PGMs, there was a 1.2% increase in both platinum and palladium recoveries at 100 ppm $S_2O_3^{2-}$ and at 150 ppm the recoveries were unchanged. The platinum and palladium grade however decreased regardless of the $S_2O_3^{2-}$ concentration.

Spiking with $S_2O_3^{2-}$ ions increased the water and solids recovery and thus more NFG was recovered to the concentrate, demonstrating the gangue activating nature of $S_2O_3^{2-}$ (Corin et al., 2014). In a study conducted by Dzingai et al. (2019) which looked at 60 and 78 ppm $S_2O_3^{2-}$ concentration ranges, it was suggested that the increase in $S_2O_3^{2-}$ concentration is good for flotation as exemplified by increases in copper and nickel grade upon increase in $S_2O_3^{2-}$ concentration. It should be noted that this study is looking at double $S_2O_3^{2-}$ concentration owing to Dzingai et al (2019) noting that there was no threshold found and was assumed to be outside the range considered. For the current study, the threshold seemed to lie above 100 ppm for PGMs and Ni but for the Cu the threshold lies between the 78 ppm and 100 ppm.

Increasing the ionic strength by spiking with $S_2O_3^{2-}$ ions showed a slight increase in PGM recovery as measured by Pt and Pd recovery however the grade was impacted negatively due to the presence of $S_2O_3^{2-}$ ions which resulted in high water and solids recovery concentrating more naturally floatable gangue than un-spiked conditions. Kirjavainen et al. (2002) investigated Cu-Ni ores and concluded that thiosulphate ions reduced the effect of hydrophilic compounds on sulphide particles resulting in improved flotation. Other studies showed that thiosulphate ions are harmful to flotation. Yasemin et al. (2018) showed that thiosulfate was the major parameter affecting flotation performance of a Cu-Pd-Zn ore and observed that the grade and recovery of copper and lead reduced dramatically by the presence of thiosulfate ions in water.

The findings of this study show that an increase in $S_2O_3^{2-}$ concentrations is good for Pt, Pd and Ni flotation at least 100 ppm concentration. This was shown by increases in Pt, Pd and Ni recovery and grade when $S_2O_3^{2-}$ ions were introduced in the system. Copper flotation in the presence of thiosulphate ions is not favourable under the concentrations considered in this study.

7. CONCLUSIONS

The main objective of this study was to assess the effect of increased ionic strength and the effect of spiking selected ions on the flotation response of a Platreef ore. To determine the relationship between the key performance indicators and the factors influencing them, four key questions, as outlined in Section 3.4, were formulated. The validity of the postulated hypothesis could be examined upon answering this key questions.

1. How does the increase in ionic strength affect flotation performance?

Increasing the ionic strength increased the froth stability, recovering more water. The solids, copper and nickel recoveries and grades decreased when increasing ionic strength of water. The platinum and palladium recovery decreased when ionic strength was increased in the order; potable water > 1 SPW > 3 SPW > 10 SPW> 5 SPW and the grade decreased following the order 5 SPW > 10 SPW > 3 SPW > 1 SPW > potable water.

2. How does increasing the sulfate, thiosulfate and nitrate ion concentration affect the flotation grade and recovery of Platreef ore?

SO_4^{2-}: Nickel recovery increased following the order: 3 SPW< 1200 ppm SO_4^{2-} < 2400 ppm SO_4^{2-} and Ni grade decreased in the following the order: 1200 ppm SO_4^{2-} > 2400 ppm SO_4^{2-} > 3 SPW. Copper recovery decreased in the order 3 SPW > 1200 ppm SO_4^{2-} > 2400 ppm SO_4^{2-} and the Cu grade also decreased in the order 3 SPW > 2400 ppm SO_4^{2-} > 1200 ppm SO_4^{2-}. The platinum recovery increased regardless the SO_4^{2-} concentration and the Pd recovery increased following the order of 1200 ppm SO_4^{2-} > 2400 ppm SO_4^{2-} > 3 SPW. Both the platinum and palladium grade followed the order of 2400 ppm SO_4^{2-} = 3 SPW > 1200 ppm SO_4^{2-}.

$S_2O_3^{2-}$: Copper recovery decreased significantly regardless of the $S_2O_3^{2-}$ concentration, the grade also dropped in the order of 3 SPW > 100 ppm $S_2O_3^{2-}$ > 150 ppm $S_2O_3^{2-}$. The nickel grade increased regardless of the $S_2O_3^{2-}$ concentration, and the nickel grade followed the trend 3 SPW = 100 ppm $S_2O_3^{2-}$ > 150 ppm $S_2O_3^{2-}$. The platinum and palladium recovery and grade followed the same trend. The recovery followed the trend 100 ppm $S_2O_3^{2-}$ > 150 ppm $S_2O_3^{2-}$ = 3 SPW and the grade dropped following the order 3 SPW > 100 ppm $S_2O_3^{2-}$ > 150 ppm $S_2O_3^{2-}$.

NO_3^-: The copper recovery decreased following the order 3 SPW > 600 ppm NO_3^- > 800 ppm NO_3^-, and the grade dropped regardless the NO_3^- concentration. Both the nickel grade and recovery followed the order 600 ppm NO_3^- > 3 SPW > 800 ppm NO_3^-. The platinum and palladium recovery increased regardless of the NO_3^- concentration. The platinum and palladium grade dropped regardless the NO_3^- concentration.

3. How does increasing the calcium and magnesium ionic strength affect the flotation grade and recovery of Platreef ore.

Ca^{2+}: The copper grade and recovery increased regardless of the Ca^{2+} concentration. The nickel recovery increased in the order 3 SPW < 350 ppm Ca^{2+} < 200 ppm Ca^{2+} and the nickel grade increased regardless the Ca^{2+} concentration. The platinum recovery increased in the order 350 ppm Ca^{2+} = 3 SPW < 200 ppm Ca^{2+} and the grade dropped following the trend 3 SPW > 200 ppm Ca^{2+} > 350 ppm Ca^{2+}. The palladium recovery increased regardless of the Ca^{2+} concentration and the palladium grade dropped regardless the Ca^{2+} concentration.

Mg^{2+}: The copper grade and recovery both decreased regardless of the Mg^{2+} concentration. The nickel recovery increased in the order 3 SPW < 1000 ppm Mg^{2+} < 800 ppm Mg^{2} and the nickel grade decreased regardless of the ppm Mg^{2+} concentration. There was a significant increase in both platinum and palladium recoveries at 800 ppm Mg^{2+} but both remained the same as 3 SPW at 1000 ppm Mg^{2+}. The Pt and Pd grades decreased regardless of the concentrations.

4. At what concentration of the selected ions will the flotation performance be considered deleterious?

SO_4^{2-}: spiking at 1200 ppm SO_4^{2-} showed a drop in the platinum and palladium grade and upon increasing the concentration to 2400 ppm SO_4^{2-} the grade remained the same as 3 SPW. Both the copper grade and recovery decreased regardless of the SO_4^{2-} concentration, hence the SO_4^{2-} ions at these concentrations are detrimental to the flotation of copper.

$S_2O_3^{2-}$: The copper grade and recovery were both lower when spiked with the $S_2O_3^{2-}$ ions regardless the concentration. The $S_2O_3^{2-}$ showed that 100 ppm gave nickel grade equal to 3 SPW and at 150 ppm the nickel grade decreased, this suggests that 100 ppm $S_2O_3^{2-}$ is the maximum concentration beyond which there is negative impact on the nickel flotation circuit. The platinum, palladium and copper flotation were also negatively affected by the presence of $S_2O_3^{2-}$ ions in the process water regardless of the concentrations. It is also worth noting that that copper recovery also dropped.

NO_3^-: Copper grade and recovery decreased in the presence of NO_3^- ions regardless of the tested concentration. At 600 ppm the nickel grade and recovery improved and at 800 ppm nickel grade and recovery dropped, this suggests that 600 ppm is the maximum concentration beyond which there is negative impact on the nickel flotation circuit. The platinum and palladium recovery improved, and the grade dropped regardless the concentration.

Ca^{2+}: The platinum and palladium recovery improved, and the grade dropped regardless the concentration.

Mg^{2+}: the presence of Mg^{2+} in the process water improved the recovery for nickel, platinum and palladium and dropped the copper recovery. The copper, nickel, platinum, and palladium grades all dropped regardless the Mg^{2+} concentration.

7.1. Concluding remarks

The study has shown that increasing the ionic strength of process water had a corresponding increase in the water recovery while the solids recovery did not always follow the same trend. The spiking of ions at different concentration was used to determine which ions were beneficial to the flotation process and which ones were deleterious. It was interesting to note that Cu flotation was only improved in the presence of Ca^{2+} ions. When other ions were introduced in the system the copper flotation was negatively affected because the copper grade and recovery were lower compared 3 SPW. Generally, the presence of the selected ions in synthetic process water improved the recovery of all the valuable minerals with the exception of nickel at 800 ppm Mg^{2+}. This work proved the hypothesis suggested in Section 3.3.

It is evident from this study that water quality influences the flotation performance of the Platreef ore. The findings of this study have shown that an increase in synthetic process water ionic strength results in an increase in water and solid recovery thus increasing the flotation of NFG reporting to the concentrate and resulting in a decrease in the grade of valuable minerals. It was also noted that spiking the individual ions affected the flotation performance depending on the concentration of the ions. There is therefore a need to thoroughly understand the threshold beyond which the individual ions are considered detrimental to the flotation performance.

Further, the discussion has shown that the effects of synthetic process water quality are ion specific. With the depletion of the Merensky and UG2 ore, mining houses are shifting their attention to the Platreef ore as an alternative PGM resource. It therefore becomes critical to understand the effects water quality has on the flotation performance of the Platreef ore and thus reduce potable water consumption in the mining sector. Additionally, the cost of potable water can be reduced by modifying the water treatment process to produce water of known and consistent quality which will assist in sustaining good operational performance.

Askham & Van der Poll (2017) in their study on water sustainability of selected mining companies in South Africa showed that the area of water and supply chain management in the mining sector was found to be neglected and that similar results were reported by the Carbon Disclosure Project's (CDP) South Africa Water Report of 2013 and the 2008 Global Study. They also indicated that, for many of the mining companies mentioned, obtaining or renewing a new water use licence from the Department of Water and Sanitisation (DWS) was challenging and time consuming and posed a risk for the continued operation of companies and could hamper foreign companies from expanding and investing in South Africa. Hence this study on recycling water usage in flotation serves as a contribution to ensuring a lower usage of potable water in floating the Platreef ore.

8. RECOMMENDATIONS

The following are recommended:

- Investigating the effect of reagent dosages to quantify how reagent consumption is impacted by spiking ions and increasing ionic strength of process water.
- Reagent adsorption studies in water having different chemistries.
- Conduct cleaning testwork to determine the effect of improved recovery during spiking.
- Platreef ore variability testwork to investigate if the findings of this study are sustained.
- Surface speciation studies to identify the species adsorbed on different minerals present in the Platreef ore.

9. REFERENCES

Allison, S.A.; O'Connor, C.T., (2011). An investigation into the flotation behavior of pyrrhotite, *Minerals Engineering* 98, pp 202–207.

Askham, Theresa M. and Van der Poll, Huibrecht M. , (2017), Water Sustainability of Selected Mining Companies in South Africa, *Sustainability*, 9, issue 6, pp. 1-16.

Ata, S. (2001). Phenomena in the froth phase of flotation — A review, *International Journal of Mineral Processing* 102-103, pp. 1-12.

Barker, L.M. (1986). The effect of electrolytes on the flotation of pyrite. MSc. Eng Thesis, University of Cape Town, *Chemical Engineering*.

Bicak, O., et al. (2012). Flotation of Yenipazar (Yozgat) Complex Sulphide Ore. *Department of Mining Engineering*, Hacettepe University, Ankara, 391-399.

Boujounoui, K., Abidi, A., Bacaoui, A., El Amari, K., & Yaacoubi, A. (2015). The influence of water quality on the flotation performance of complex sulphide ores: Case study at Hajar Mine, Morocco. *Journal of the Southern African Institute of Mining and Metallurgy*, 115(12), 1243-1251.

Bowden, J. L. and Young, C. A. (2016) Xanthate chemisorption at copper and chalcopyrite surfaces. *Journal of the Southern African Institute of Mining and Metallurgy*, 116, 503-508.

Bradshaw, D.J.; Harris, P.J.; O'Connor, C.T., (1998), Synergistic interactions between reagents in sulphide flotation, *Journal of South African Institute of Minerals and Metallurgy* 98, pp 189–194.

Bradshaw, D. J. (1997). Synergistic effects between thiol collectors used in flotation of pyrite.

Castelyn, D. (2012). The effect of mixing thiol collectors in the flotation of pure sulphide ores, Cape Town: *The Department of Chemical Engineering*.

Cawthorn, R.G.; Webb, S.J. (2001). Connectivity between western and eastern limbs of the Bushveld Complex. Tectonophysics 2001, 330, 195–209.

Corin, K.C., Reddy, A., Miyen, L., Wiese, J.G. & Harris, P.J. (2010). The effect of ionic strength of plant water on valuable mineral and gangue recovery in a platinum bearing ore from the Merensky reef. *Minerals Engineering*. 24: 131-137.

Corin, K. C., Reddy, A., Miyen, L., Wiese, J.G. & Harris, P.J. (2011). 'The effect of ionic strength of plant water on valuable mineral and gangue recovery in a platinum bearing ore from the Merensky reef', *Minerals Engineering*. Elsevier Ltd, 24(2), pp. 131–137.

Corin, K.C.; Wiese, J.G., (2014). Investigating froth stability: A comparative study of ionic strength and frother dosage. *Minerals Engineering*. 66: 130–134.

Cottrell, A. 1967. An introduction to Metallurgy. 1st edition. London: Edward Arnold Publishers.

Dzingai M. (2019). The effect of ion accumulation owing to water recycling on flotation performance., Engineering and the Built Environment ,Department of Chemical Engineering.Viewed 2022 May 24. Available from: http://hdl.handle.net/11427/31601.

Dzingai, M., Manono, M.S. & Corin, K.C., (2020). Simulating the effect of water recirculation on flotation through ion-spiking: Effect of Ca^{2+} and Mg^{2+}. *Minerals Engineering*, 10, 1033.

Dzingai, M., Manono, M.S. & Corin, K.C., (2021). Probing the effect of water recycling on flotation through anion spiking using a low-grade Cu-Ni-PGM ore: The effect of NO_3^-, SO_4^{2-} and $S_2O_3^{2-}$. *Minerals Engineering*, 11, 340. https: //doi.org/103390/min11040340.

Dzingai, T., McFadzean, B., Tadie, M., and Becker, M., (2021). Decoupling the effects of alteration on the mineralogy and flotation performance of Great Dyke PGE ores. *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 121, no. 9, pp. 475–486.

Ejtemaei, M., Plackowski, C., Nguyen, A. V., (2016). The effect of calcium, magnesium, and sulphate ions on the surface properties of copper activated sphalerite, *Minerals Engineering*, Volume 89, Pages 42-51, https://doi.org/10.1016/j.mineng.2016.01.005.

Farrokhpay, S.; Zanin, M., (2012). An investigation into the effect of water quality on froth stability. Adv. *Powder Technology*. 23, 493–497.

Feng, Q.M.; Feng, B.; Lu, Y.P., (2013). Influence of copper ions and calcium ions on adsorption of CMC on chlorite, *Transaction of Nonferrous Metals Society of China* 23, pp 237–242.

Fuerstenau, D. W., (1982), Activation in the flotation of sulphide minerals. Principles of Flotation, Institute of Mining and Metallurgy, Johannesburg, 183–198.

Gaudin, A.M., Charles, W.D., (1953). Adsorption of calcium and sodium on pyrite. *Minerals Engineering*, 195–200, February.

Hodgson, M., Agar, G.E. (1989). Electrochemical investigations into the flotation chemistry of pentlandite and pyrrhotite: Process water & xanthate interactions. *Canadian Metallurgical Quarterly* 28 (3), 189-198.

Hu, W. (2014) Flotation Circuit Optimisation and Design, Department of Earth and Science Engineering, Imperial College London. Available at http://hdl.handle.net/10044/1/24805

Ikumapayi, F., (2010). Flotation chemistry of complex sulphide ores: Recycling of process water and flotation selectivity. Luleå University of Technology, Department of Civil, Environmental and Natural Resources Engineering, *Sustainable Process Engineering*.

Ikumapayi, F., Makitalo, M., Johansson, B., Rao, K.H., (2012). Recycling of process water in sulphide flotation: effect of calcium and sulphate ions on flotation of galena. *Minerals Engineering* 39, pp.77–88.

Ikumapayi, F. and Makitalo, M., (2013). Recycling process water in sulphide flotation, Part A: Effect of calcium and sulphate on sphalerite recovery, 29 (4), pp. 183–192.

Jacobsen, J., (2021). Ivanplats to bring Platreef mine into production in 2024. Underground mining, Mining Magazine.

Jeldres, R. I., Forbes, L. and Cisternas, L. A., (2016). Effect of Seawater on Sulfide Ore Flotation: A Review, *Mineral Processing and Extractive Metallurgy Review*.

Jones, R.T., (2005). An overview of Southern African PGM smelting. In Nickel and Cobalt 2005, Challenges in Extraction and Production; Donald, J., Shoneville, R., Eds.; Canadian Institute of Mining, Metallurgy and Petroleum: Montreal, Quebec, Canada; pp. 147–178.

Johnson, N.W., (2003). Issues in maximization of recycling of water in a mineral processing plant. Proceedings of Water in Mining 2003, Brisbane, 13–15 October. Publication Series No. 6/2003. *Australian Institute of Mining and Metallurgy*, Melbourne. pp. 239–245.

Kawatra, S. K., (2009), Flotation Fundamentals, *Mining Engineering Handbook*.

Kirjavainen, V., (1996). Review and analysis of factors controlling the mechanical flotation of gangue minerals, *Minerals Engineering*, 46, pp. 21–34.

Kirjavainen, V. and Heiskanen, K., (2007). Some factors that affect beneficiation of sulphide nickel – copper ores, 20, pp. 629–633. doi: 10.1016/j.mineng.2007.01.001.

Kirjavainen, V., Schreithofer, N. and Heiskanen, K., (2002). Effect of calcium and thiosulfate ions on flotation selectivity of nickel-copper ores, *Minerals Engineering*, 15(1–2), pp. 1–5. Doi 10.1016/S0892-6875(01)00213-8.

Klimpel, R. R., (1995). The Influence of Frother Structure on Industrial Coal Flotation, High Efficiency Coal Preparation (Kawatra, ed.), *Society for Mining, Metallurgy, and Exploration*, Littleton, CO, pp. 141-151.

Klimpel, R. R., (1996). The effect of water chemistry, reagent type, and other environmental factors on the performance of industrial grinding and flotation processes involving sulphide minerals, *Society for mining, metallurgy and exploration*, 5002.

Laskowski, J. S., and Castro, S., (2017). Hydrolysis of metallic ions in mineral processing circuits and its effect on flotation, *COM Conference of Metallurgists*. doi: 10.14288/1.0347200.

Levay, G., Smart, R. St. C., Skinner, W. M., (2001). Impact of water quality on flotation performance, *South African Institute of Mining and Metallurgy*, 101(2), pp. 69-75.

Shengo, L.M., Gaydardzhiev, S., Kalenga, N.M., (2014). Assessment of water quality effects on flotation of copper–cobalt oxide ore, *Minerals Engineering*, Volume 65, 2014, Pages 145-148.

Manono, M. S., Corin, K. C. and Wiese, J. G. (2012) An investigation into the effect of various ions and their ionic strength on the flotation performance of a platinum bearing ore from the Merensky reef, *Minerals Engineering*. doi: 10.1016/j.mineng.2012.03.035.

Manono, M.S.; Corin, K.C.; Wiese, J.G., (2013). The effect of ionic strength of plant water on foam stability: A 2-phase flotation study. *Minerals Engineering*. 40, 57–67.

Manono, M. S., Corin, K. C. and Wiese, J. G., (2016). The influence of electrolytes present in process water on the flotation behaviour of a Cu-Ni containing ore, *Minerals Engineering*. Elsevier Ltd, 96–97, pp. 99–107.

Manono, M., Corin, K. and Wiese, J., (2018). Water quality effects on a sulfidic PGM ore: Implications for froth stability and gangue management, 54(4), pp. 1253–1265. doi:10.5277/ppmp18181.

Manono, M.S., Matibidi, K., Thubakgale, K. C., Corin, K. C., Wiese, J. G., (2017). Water Quality in PGM Ore Flotation: The effect of Ionic Strength and pH, Mine Water and Circular Economy, *International Mine Water Association*, pp. 777-784.

Mintek, Mintek's Analytical Chemistry Division, viewed 19 October 2022, < https://www.mintek.co.za/technical-divisions/analytical-services-asd/classical-chemistry/>

Mintek, Mintek's Analytical Chemistry Division, viewed 19 October 2022, <https://www.mintek.co.za/technical-divisions/analytical-services-asd/fire-assay/>

Mintek, Mintek's Analytical Chemistry Division, viewed 19 October 2022, <https://www.mintek.co.za/technical-divisions/analytical-services-asd/sample-preperation/>

Mintek, Mintek's Analytical Chemistry Division, viewed 19 October 2022, <https://www.mintek.co.za/technical-divisions/analytical-services-asd/spectroscopy/>

Mintek, Mintek's Mineralogical Division, viewed 17 October 2022, < https://www.mintek.co.za/technical-divisions/mineralogy/process-mineralogy/mineral-liberation-analyser-mla/>

Mintek, Mintek's Mineralogical Division, viewed 17 October 2022, <https://www.mintek.co.za/technical-divisions/mineralogy/process-mineralogy/qemscan/>

Mintek, Mintek's Mineralogical Division, viewed 17 October 2022, <https://www.mintek.co.za/technical-divisions/mineralogy/process-mineralogy/x-ray-diffraction/>

Musuku, B., Muzinda, I. and Lumsden, B., (2016). Cu-Ni processing improvements at First Quantum's Kevitsa mine, *Minerals Engineering*. Elsevier Ltd, 88, pp. 9–17. doi: 10.1016/j.mineng.2015.08.005.

Muzenda, E., (2010). An Investigation into the Effect of Water Quality on Flotation Performance, 4(9), pp.562–566.

Muzinda, I. and Schreithofer, N., (2018). Water quality effects on flotation: Impacts and control of residual xanthates, 125, pp. 34–41.

Niemi, A. J., (1995). Role of kinetics in modelling and control of flotation plants, *Powder Technology*, 82(1), pp. 69–77.

Nyabeze, W.; McFadzean, B., (2016). Adsorption of copper sulphate on PGM-bearing ores and its influence on froth stability and flotation kinetics, *Mineral Engineering,* 92, pp 28–36.

O'Connor, C.; Alexandrova, T., (2021). The Geological Occurrence, Mineralogy, and Processing by Flotation of Platinum Group Minerals (PGMs) in South Africa and Russia. Minerals 2021, 11, 54. https://doi.org/10.3390/ min11010054.

Park, J. H., Han, Y, Ji, S., (2018). Investigation of Mineral-Processing Wastewater Recycling Processes: A Pilot Study, *Molecular Diversity Preservation International and Multidisciplinary Digital Publishing Institute*, Sustainability.

Parolis, L.A.S.; van der Merwe, R.; Groenmeyer, G.V.; Harris, P.J., (2008), The influence of metal cations on the behaviour of carboxymethyl celluloses as talc depressants. Colloids Surf, *A Physicochemical Engineering Aspect 317*, pp 109–115.

Rehman, B. U., (2011). Modelling a Mineral Froth Flotation Process, *Master Thesis in Electronic Engineering*, Umea Institute of Technology.

Sinche-Gonzalez, M., Fornasiero, D., (2021). Understanding the effect of sulphate in mining-process water on sulphide flotation, *Minerals Engineering*, Volume 165, https://doi.org/10.1016/j.mineng.2021.106865.

Shamaila, S., C.T. O'Connor, C. T., (2008) The role of synthetic minerals in determining the relative flotation behaviour of Platreef PGE tellurides and arsenides, *Minerals Engineering*, Volume 21, Issues 12–14, Pages 899-904, https://doi.org/10.1016/j.mineng.2008.07.006.

Shortridge, P.G.; Harris, P.J.; Bradshaw, D.J., (1999), The influence of ions on the effectiveness of polysaccharide depressants in the flotation of talc. *In Polymers in Mineral Processing*, Proceedings of the 3rd UBC-McGill Bi-Annual International Symposium on Fundamentals of Mineral Processing, Quebec City, QC, Canada, 22–26 August 1999; Laskowski, J.S., Ed.; CIM: Quebec City, QC, Canada, pp. 155–169.

Slatter, K.A., Vaux, N.D., Plint, M., Cole, V., Dilsook, D., De oostendorp, N. P., (2009). Water management in Anglo Platinum Process Operations: Effects of Water Quality on Process Operations, pp. 46–55.

Tadie, M.; Corin, K.C.; Wiese, J.G.; O'Connor, C.T., (2017). Electrochemical interactions of platinum group minerals with copper sulphate, *Minerals Engineering*, Volume 112, 2017, Pages 43-49.

Tinoco,V.S.P., Valeria, S. (2011). Copper slag valorisation: Characterization and concentration techniques. 10.13140/RG.2.2.16089.06240.

Weimeng, H., (2014). Flotation circuit optimisation and design. *Imperial College London*, Department of Earth Science and Engineering.

Wiese, J., (2009). Investigating depressant behaviour in the flotation of selected Merensky ores, p. 140. *University of Cape Town*.

Wiese, J., Harris, P. and Bradshaw, D., (2005). Investigation of the role and interactions of a dithiophosphate collector in the flotation of sulphides from the Merensky reef, 18, pp. 791–800.

Wiese, J., Harris, P. and Bradshaw, D., (2005). The influence of the reagent suite on the flotation of ores from the Merensky reef', *Minerals Engineering*, 18(2 SPEC. ISS.), pp. 189–198.

Wiese, J. G., Harris, P. J., & Bradshaw, D. J., (2007). The response of sulphide and gangue minerals in selected Merensky ores to increased depressant dosages. *Minerals Engineering*, 20, 986-995.

Wills, B. A. and Napier-Munn, T., (2006). Introduction, *Wills' Mineral Processing Technology*.

Yasemin, O., Özlem, B., Elif, Ö., Zafir, E., (2018). Mitigation negative effects of thiosulfate on flotation performance of a Cu-Pb-Zn sulfide ore, *Minerals Engineering*, Volume 122, 2018, Pages 142-147.

10. APPENDIX A

10.1. Flotation feed sample analysis

Sample	**Pt**	**Pd**	**Rh**	**Au**	***3E+Au***	**Cu**	**Ni**	**S**	**Fe_2O_3**	**Al_2O_3**	**MgO**	**SiO_2**
	(g/t)	**(g/t)**	**(g/t)**	**(g/t)**	***(g/t)***	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
Feed 1	1,12	1,29	0,07	0,16	*2,63*	0,08	0,15	0,46	9,06	9,98	12,98	50,49
Feed 2	1,07	1,24	0,06	0,15	*2,52*	0,09	0,16	0,46	9,58	10,96	14,14	52,41
Average	1,09	1,26	0,07	0,16	*2,58*	0,09	0,16	0,46	9,32	10,47	13,56	51,45

10.2. Flotation feed sample size by assay

Size Fraction	Mass	Mass	Grade											
			Pt	Pd	Rh	Au	*3E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2
(µm)	(g)	(%)	(g/t)	(g/t)	(g/t)	(g/t)	*(g/t)*	(%)	(%)	(%)	(%)	(%)	(%)	(%)
+106-150	64,20	4,47	1,70	1,91	0,09	0,20	3,90	0,13	0,23	0,62	9,86	10,49	13,27	49,84
+75-106	232,70	16,20	1,44	1,62	0,08	0,20	3,34	0,08	0,18	0,53	9,22	10,01	12,80	52,41
+53-75	461,90	32,15	1,20	1,44	0,07	0,19	2,90	0,08	0,16	0,53	8,94	10,13	13,03	53,05
+38-53	114,00	7,93	0,71	0,85	0,05	0,17	1,78	0,06	0,11	0,36	8,57	10,22	13,04	52,95
+25-38	65,90	4,59	0,54	0,58	0,03	0,24	1,39	0,05	0,08	0,26	8,84	9,62	13,85	51,77
-25	498,00	34,66	0,76	0,43	0,03	1,15	2,37	0,05	0,07	0,16	10,09	8,75	17,08	54,34
Total	**1436,70**	**100,00**	**1,04**	**1,05**	**0,06**	**0,53**	**2,67**	**0,07**	**0,13**	**0,38**	**9,39**	**9,63**	**14,45**	**53,18**
			1,09	1,26	0,07	0,16	2,58	0,09	0,16	0,46	9,32	10,47	13,56	51,45
			5	*17*	*15*	*239*	*4*	*21*	*18*	*17*	*1*	*8*	*7*	*3*

Size Fraction	Mass	Mass	Distribution											
			Pt	Pd	Rh	Au	*3E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2
(µm)	(g)	(%)	(g/t)	(g/t)	(g/t)	(g/t)	*(g/t)*	(%)	(%)	(%)	(%)	(%)	(%)	(%)
+106-150	64,20	4,47	7,31	8,10	7,28	1,70	6,52	8,55	8,08	7,29	4,69	4,87	4,10	4,19
+75-106	232,70	16,20	22,44	24,90	23,46	6,16	20,23	19,31	22,93	22,60	15,90	16,84	14,35	15,96
+53-75	461,90	32,15	37,11	43,93	40,75	11,62	34,87	35,96	40,46	44,85	30,59	33,81	29,01	32,07
+38-53	114,00	7,93	5,42	6,40	7,18	2,57	5,28	7,30	6,87	7,52	7,24	8,42	7,16	7,90
+25-38	65,90	4,59	2,38	2,52	2,49	2,09	2,38	3,38	2,85	3,14	4,32	4,58	4,40	4,46
-25	498,00	34,66	25,34	14,14	18,83	75,85	30,72	25,51	18,81	14,60	37,25	31,48	40,98	35,41
Total	1436,70	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00

10.3. Platreef ore mineralogical data

10.3.1. BMS modal analysis

Mineral	Ideal Chemical Formula	Mass%	No. of Grains
Pyrite	FeS_2	8,0	1096
Pentlandite	$(Fe,Ni)_9S_8$	43,7	10751
Chalcopyrite	$CuFeS_2$	15,1	4023
Pyrrhotite	$Fe_{1-x}S$	33,0	7118
Millerite	NiS	0,1	23
Galena	PbS	0,1	58
		100	**23069**

10.3.2. BMS grain size distribution

Grain Size Class (µm ECD)	**Pentlandite** (Mass%)	**Chalcopyrite** (Mass%)	**Pyrrhotite** (Mass%)	**Pyrite** (Mass%)	**Millerite** (Mass%)	**Galena** (Mass%)
<10	6,83	6,18	2,54	2,03	8,73	11,51
10-20	20,58	32,39	14,52	1,42	23,75	20,16
20-38	31,90	37,60	40,84	13,43	44,07	27,61
38-53	17,24	16,85	25,22	44,21	23,45	0,00
53-75	7,98	5,35	10,42	21,75	0,00	40,72
>75	15,47	1,63	6,46	17,16	0,00	0,00
Total	**100**	**100**	**100**	**100**	**100**	**100**
No. of Grains Detected	**10751**	**4023**	**7118**	**1096**	**23**	**58**

10.3.3. BMS liberation

Cumulative Liberation (Mass%)											
Degree of Liberation	**0% < x <= 10%**	**10% < x <= 20%**	**20% < x <= 30%**	**30% < x <= 40%**	**40% < x <= 50%**	**50% < x <= 60%**	**60% < x <= 70%**	**70% < x <= 80%**	**80% < x <= 90%**	**90% < x < 100%**	**100%**
Pyrite	100,00	99,40	98,66	97,66	95,77	94,13	90,83	86,82	81,17	71,12	62,35
Pentlandite	100,00	97,31	95,28	93,88	92,45	90,99	88,27	85,10	81,44	73,45	45,21
Chalcopyrite	100,00	96,75	92,84	90,74	86,52	84,11	79,80	75,25	71,01	59,02	35,92
Pyrrhotite	100,00	98,66	96,96	95,45	93,32	90,35	86,34	79,97	74,18	62,30	32,54
Millerite	100,00	90,56	89,18	79,79	79,79	76,91	69,57	53,67	53,67	53,67	23,45
Galena	100,00	91,07	89,61	85,51	85,51	85,51	85,51	85,51	85,51	66,97	42,77

10.3.4. BMS association

Mineral	Pyrite	Pentlandite	Chalcopyrite	Millerite	Pyrrhotite	Galena
	%	%	%	%	%	%
Pyrite	0,00	0,48	0,90	2,02	1,68	2,86
Pentlandite	4,36	0,00	9,86	18,19	9,84	5,35
Chalcopyrite	3,75	4,71	0,00	0,60	1,41	9,33
Millerite	0,05	0,03	0,00	0,00	0,01	0,00
Pyrrhotite	8,86	6,66	2,21	4,08	0,00	1,55
Galena	0,07	0,01	0,06	0,00	0,01	0,00
Serpentine	0,00	0,00	0,00	0,00	0,00	0,00
Plagioclase	0,14	0,33	0,28	0,00	0,22	0,00
Calcite	0,04	0,04	0,02	0,00	0,03	0,36
Magnetite	0,10	0,54	0,34	0,00	1,13	0,29
Chromite	0,02	0,03	0,03	0,00	0,12	0,00
Titanite	0,01	0,01	0,03	0,00	0,01	0,00
Rutile	0,00	0,00	0,00	0,00	0,00	0,00
Ilmenite	0,01	0,00	0,00	0,00	0,01	0,00
Monazite-(Ce)	0,02	0,15	0,36	0,00	0,08	0,00
Apatite	0,00	0,04	0,00	0,00	0,01	0,00
Zircon	0,00	0,00	0,00	0,00	0,00	0,00
Hornblende	0,08	0,70	0,77	0,64	0,39	0,55
Mica	0,08	0,27	0,20	0,00	0,17	0,00
Quartz	0,53	0,40	0,85	0,49	0,38	1,23
Chlorite	0,07	0,31	0,33	0,00	0,31	0,69
Talc	0,00	0,04	0,04	0,00	0,16	0,00
Others	0,00	0,02	0,02	1,05	0,01	0,00
Orthopyroxene	0,92	1,33	1,83	0,69	2,59	0,66
Clinopyroxene	0,74	1,22	2,08	0,00	1,67	0,17
Olivine	0,08	0,10	0,21	0,18	0,46	0,00
Albite	0,55	0,74	1,77	1,93	0,81	0,00
Microcline	1,40	0,84	1,82	5,26	1,23	0,30
Anorthite	0,59	0,53	2,16	0,40	0,34	0,78
Free Surface	77,54	80,47	73,84	64,46	76,93	75,88
	100	100	100	100	100	100

10.3.5. Distribution of PGMs

PGM	PGM Vol %	# PGM grains	Average ECD (um)
PtRhAsS	0,6	2	3,8
PtBiTe	18,7	26	4,9
PdBiTe	39,7	26	5,4
PtS	13,1	15	4,6
PtAs	25,0	8	8,0
PdTe	1,8	1	9,1
PtPdS	0,9	6	2,6
PdSb	0,1	1	2,0
PtPdAs	0,1	1	2,5
	100,0	**86**	

10.3.6. PGM grain floatability index

	Particle Characteristics	PGM Vol %	# PGMs
Fast Floating	Liberated PGMs > 3um ECD	63,4%	19
	Liberated BMS > 10um ECD	7,5%	5
Slow Floating 1	Liberated PGMs < 3um ECD	1,1%	13
	Liberated BMS < 10um ECD		
	PGMs > 3um ECD attached to gangue	5,7%	6
	BMS > 10um ECD attached to gangue	7,8%	12
Slow Floating 2	PGMs < 3um ECD attached to gangue	0,5%	4
	BMS < 10um ECD attached to gangue	5,5%	6
Non-floating	PGMs and/or BMS locked in gangue	8,5%	21
		100,0%	86

10.3.7. Liberation Index (PGM and BMS area fraction)

Index	# PGM grains	PGM Vol %	Num %
<0.2	46	26,8	53,5
0.2 - 0.4	1	0,3	1,2
0.4 - 0.6	2	0,9	2,3
0.6 - 0.8			
0.8 - 1.0	37	72,0	43,0
	86	**100**	**100**

10.3.8. PGM grain size distribution

Class	# PGM grains	PGM Vol %	Num %
0 - 3	37	3,7	43,0
3 - 6	31	11,6	36,0
6 - 9	6	7,2	7,0
9 - 12	6	13,3	7,0
12 - 15	2	8,1	2,3
15 - 18	1	6,4	1,2
18 - 21	1	8,2	1,2
21 - 24			
24 - 27			
27 - 30			
>30	2	41,6	2,3
	86	**100**	**100**

10.3.9. PGM grain mode of occurrence

Liberation Characteristic		PGM Vol %	# PGM grains	# PGM grains <3um ECD
L	Liberated PGMs	64,5%	32	13
SL	PGMs associated with liberated BMS (Base Metal Sulfides)	7,5%	5	2
SG	PGMs associated with BMS locked in Silicate or Oxide gangue particles			
AG	PGMs attached to Silicate or Oxide gangue particles	6,3%	10	4
SAG	PGMs associated with BMS attached to Silicate or Oxide gangue particles	13,3%	18	5
G	PGMs locked within Silicate or Oxide gangue particles	8,5%	21	13
		100,0%	**86**	**37**

11. APPENDIX B

11.1. Baseline flotation data using RWB potable water

				Grade											Recovery										
Products	Mass	Mass	Float time	Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2	Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2
	(g)	(%)	min	(g/t)	(g/t)	(g/t)	*(g/t)*	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
RC1	44,95	3,01	1,00	23,35	27,00	2,76	*53,11*	1,71	2,31	8,36	19,44	6,73	13,85	43,43	64,89	61,22	53,88	62,33	64,11	46,07	58,29	6,25	1,90	2,94	2,35
RC2	46,70	3,12	2,00	4,21	6,13	0,53	*10,87*	0,35	0,60	2,19	13,73	7,61	17,25	50,70	12,16	14,44	10,77	13,26	13,67	12,46	15,87	4,59	2,23	3,80	2,86
RC3	50,95	3,41	4,00	1,74	2,27	0,24	*4,25*	0,10	0,25	1,19	12,47	7,42	17,58	53,69	5,48	5,83	5,32	5,65	4,26	5,66	9,41	4,54	2,38	4,23	3,30
RC4	101,70	6,80	13,00	0,91	1,16	0,15	*2,22*	0,09	0,14	0,35	11,49	8,75	16,91	53,05	5,72	5,95	6,64	5,90	7,49	6,33	5,52	8,36	5,59	8,12	6,51
RC5	62,20	4,16	20,00	0,57	0,75	0,10	*1,42*	0,01	0,11	0,27	10,29	9,65	15,65	53,69	2,19	2,35	2,71	2,31	0,52	3,04	2,61	4,58	3,77	4,60	4,03
RC (calc.)	306,50	20,50		4,77	5,81	0,59	*11,18*	0,35	0,54	1,93	12,92	8,24	16,37	51,52	90,45	89,81	79,31	89,45	90,06	73,57	91,70	28,33	15,88	23,70	19,04
RT	1188,75	79,50		0,13	0,17	0,04	*0,34*	0,01	0,05	0,05	8,43	11,26	13,59	56,47	9,55	10,19	20,69	10,55	9,94	26,43	8,30	71,67	84,12	76,30	80,96
Head (calc.)	1495,25	100,00		1,08	1,33	0,15	*2,56*	0,08	0,15	0,43	9,35	10,64	14,16	55,46	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
Head (meas.)	1500,00			1,09	1,26	0,16	*2,58*	0,09	0,16	0,46	9,32	10,47	13,56	51,45											
Variance (%)	*0*			*1*	*5*	*1*	*1*	*7*	*3*	*6*	*0*	*2*	*4*	*8*											

Cummulative	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RC1	44,95	3,01	1,00	23,35	27,00	2,76	53,11	1,71	2,31	8,36	19,44	6,73	13,85	43,43	64,89	61,22	53,88	62,33	64,11	46,07	58,29	6,25	1,90	2,94	2,35
RC1+2	91,65	6,13	3,00	13,60	16,37	1,62	31,58	1,01	1,44	5,21	16,53	7,18	15,58	47,13	77,05	75,67	64,65	75,59	77,79	58,53	74,16	10,84	4,14	6,75	5,21
RC1+2+3	142,60	9,54	7,00	9,36	11,33	1,13	21,82	0,69	1,01	3,78	15,08	7,27	16,29	49,48	82,53	81,50	69,97	81,24	82,05	64,20	83,57	15,38	6,51	10,98	8,51
RC1+2+3+4	244,30	16,34	20,00	5,84	7,10	0,72	13,66	0,44	0,65	2,35	13,59	7,88	16,55	50,96	88,25	87,45	76,61	87,14	89,54	70,53	89,09	23,75	12,11	19,10	15,01
RC1+2+3+4+5	306,50	20,50	40,00	4,77	5,81	0,59	11,18	0,35	0,54	1,93	12,92	8,24	16,37	51,52	90,45	89,81	79,31	89,45	90,06	73,57	91,70	28,33	15,88	23,70	19,04

Water Recovery

Top up water 6278,1

		C1	**C2**	**C3**	**C4**	**C5**	**FEED**	**TAILS**	
TEST 1A	**CONC**	44,10	46,30	50,20	106,50	62,00	1500,00	1190,90	1500,00
	mass pull (%)	2,94	3,09	3,35	7,10	4,13	100,00	79,39	
	CONC.	44,10	46,30	50,20	106,50	62,00	1500,00	1190,90	
	B + H2O initial	578,50	586,00	560,70	570,90	583,30			
	B + H2O final	422,70	372,60	276,00	272,00	169,30			
	WASH H2O	155,80	213,40	284,70	298,90	414,00			
	D + C + H2O	829,60	994,20	1182,50	1893,00	1893,00			
	DISH	480,40	476,20	503,00	509,00	509,40			
		349,20	518,00	679,50	1384,00	1383,60			
	H20 REC.	149,30	258,30	344,60	978,60	907,60			
						2638,40			

	Mass Rec	Water Rec	Cum mass	Cum water
			0	0
C1	44,10	149,30	44,10	149,30
C2	46,30	258,30	90,40	407,60
C3	50,20	344,60	140,60	752,20
C4	106,50	978,60	247,10	1730,80
C5	62,00	907,60	309,10	2638,40
F	**1500,00**			
T	1190,90			
T2	0,00			
T3	0,00			
%mass rec		**20,606667**		

Top up water 6359,1

		C1	**C2**	**C3**	**C4**	**C5**	**FEED**	**TAILS**	
TEST 1B	**CONC**	45,80	47,10	51,70	96,90	62,40	1500,00	1186,60	1490,50
	mass pull (%)	3,07	3,16	3,47	6,50	4,19	100,64	79,61	
	CONC.	45,80	47,10	51,70	96,90	62,40	1500,00	1186,60	
	B + H2O initial	585,80	582,20	583,30	578,10	578,90			
	B + H2O final	378,50	367,40	372,40	181,70	171,30			
	WASH H2O	207,30	214,80	210,90	396,40	407,60			
	D + C + H2O	896,60	1026,40	1125,20	1776,70	1892,20			
	DISH	480,40	476,20	503,00	433,80	509,40			
		416,20	550,20	622,20	1342,90	1382,80			
	H20 REC.	163,10	288,30	359,60	849,60	912,80			
						2573,40			

	Mass Rec	Water Rec	Cum mass	Cum water
			0	0
C1	45,80	163,10	45,80	163,10
C2	47,10	288,30	92,90	451,40
C3	51,70	359,60	144,60	811,00
C4	96,90	849,60	241,50	1660,60
C5	62,40	912,80	303,90	2573,40
F	**1490,50**			
T	1186,60			
T2	0,00			
T3	0,00			
%mass rec		**20,389131**		

Average mass pull (g)	0	44,95	46,70	50,95	101,70	62,20
Cum mass pull (g)	0	44,95	91,65	142,60	244,30	306,50
St Dev.	0	0,85	1,25	2,00	2,80	2,60
Average H2O Rec. (g)	0	156,20	273,30	352,10	914,10	910,20
Cum H2O Rec. (g)	0	156,20	429,50	781,60	1695,70	2605,90
St Dev.	0	6,90	21,90	29,40	35,10	32,50

g mass pull(g)/ water rec (g)	0,15	0,14	0,08	0,05	0,05
g mass pull(g)/ water rec (g) x 100%	14,75	13,85	8,26	4,83	4,86

11.2. Flotation data using UCT SPW

11.2.1. 1 SPW flotation data

				Grade										
Products	Mass	Mass	Float time	Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2
	(g)	(%)	min	(g/t)	(g/t)	(g/t)	*(g/t)*	(%)	(%)	(%)	(%)	(%)	(%)	(%)
RC1	17,50	1,17	1,00	53,40	52,00	5,85	*111,25*	4,01	3,89	16,65	25,52	3,48	12,70	30,70
RC2	20,75	1,38	2,00	11,20	19,80	0,99	*31,99*	0,60	2,07	5,05	16,44	5,29	17,25	43,85
RC3	30,15	2,01	4,00	3,89	6,51	0,39	*10,79*	0,20	0,71	2,44	14,30	6,46	17,74	47,28
RC4	65,45	4,37	13,00	2,05	2,62	0,25	*4,92*	0,10	0,30	1,75	13,63	7,58	16,75	47,28
RC5	56,15	3,75	20,00	1,11	1,41	0,19	*2,71*	0,08	0,17	0,93	11,88	9,07	15,90	48,35
RC (calc.)	190,00	12,68		7,79	9,30	0,85	*17,95*	0,52	0,85	3,35	14,62	7,21	16,34	45,69
RT	1308,45	87,32		0,18	0,22	0,05	*0,44*	0,02	0,05	0,05	8,65	11,32	13,62	52,30
Head (calc.)	1498,45	100,00		1,14	1,37	0,15	*2,66*	0,08	0,15	0,47	9,41	10,80	13,97	51,47
Head (meas.)	1500,00			1,09	1,26	0,16	*2,58*	0,09	0,16	0,46	9,32	10,47	13,56	51,45
Variance (%)	*0*			*4*	*9*	*2*	*3*	*2*	*1*	*2*	*1*	*3*	*3*	*0*
Cummulative	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RC1	17,50	1,17	1,00	53,40	52,00	5,85	111,25	4,01	3,89	16,65	25,52	3,48	12,70	30,70
RC1+2	38,25	2,55	3,00	30,51	34,53	3,21	68,25	2,16	2,90	10,36	20,60	4,46	15,17	37,83
RC1+2+3	68,40	4,56	7,00	18,77	22,18	1,97	42,92	1,29	1,94	6,87	17,82	5,34	16,30	42,00
RC1+2+3+4	133,85	8,93	20,00	10,60	12,62	1,13	24,34	0,71	1,14	4,37	15,77	6,43	16,52	44,58
RC1+2+3+4+5	190,00	12,68	40,00	7,79	9,30	0,85	17,95	0,52	0,85	3,35	14,62	7,21	16,34	45,69

	Recovery										
Products	Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
RC1	54,66	44,27	45,07	48,80	55,77	29,73	41,51	3,17	0,38	1,06	0,70
RC2	13,59	19,99	9,04	16,64	9,91	18,76	14,93	2,42	0,68	1,71	1,18
RC3	6,86	9,55	5,18	8,16	4,80	9,35	10,48	3,06	1,20	2,56	1,85
RC4	7,85	8,34	7,20	8,07	5,21	8,57	16,32	6,33	3,06	5,24	4,01
RC5	3,65	3,85	4,70	3,81	3,49	4,17	7,44	4,73	3,15	4,27	3,52
RC (calc.)	86,61	86,00	71,20	85,49	79,17	70,57	90,68	19,71	8,47	14,83	11,26
RT	13,39	14,00	28,80	14,51	20,83	29,43	9,32	80,29	91,53	85,17	88,74
Head (calc.)	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
Head (meas.)											
Variance (%)											
Cummulative	0	0	0	0	0	0	0	0	0	0	0
RC1	54,66	44,27	45,07	48,80	55,77	29,73	41,51	3,17	0,38	1,06	0,70
RC1+2	68,25	64,26	54,12	65,44	65,68	48,48	56,44	5,59	1,05	2,77	1,88
RC1+2+3	75,11	73,80	59,29	73,60	70,48	57,83	66,92	8,65	2,26	5,33	3,72
RC1+2+3+4	82,96	82,15	66,50	81,67	75,69	66,41	83,24	14,97	5,32	10,57	7,74
RC1+2+3+4+5	86,61	86,00	71,20	85,49	79,17	70,57	90,68	19,71	8,47	14,83	11,26

Water Recovery

Top up water 5761,9

		C1	C2	C3	C4	C5	FEED	TAILS	
TEST 2A	**CONC**	17,90	22,20	32,00	61,50	55,60	1500,00	1314,70	1503,90
	mass pull (%)	1,19	1,48	2,13	4,09	3,70	99,74	87,42	
	CONC.	17,90	22,20	32,00	61,50	55,60	1500,00	1314,70	
	B + H2O initial	570,10	588,60	573,60	688,50	587,50			
	B + H2O final	437,40	354,30	290,50	249,40	171,30			
	WASH H2O	132,70	234,30	283,10	439,10	416,20			
	D + C + H2O	677,40	843,80	1180,20	1781,60	2034,30			
	DISH	480,40	476,20	503,00	509,00	509,40			
		197,00	367,60	677,20	1272,60	1524,90			
	H20 REC.	46,40	111,10	362,10	772,00	1053,10			
						2344,70			

	Mass Rec	Water Rec	Cum mass	Cum water
			0	0
C1	17,90	46,40	17,90	46,40
C2	22,20	111,10	40,10	157,50
C3	32,00	362,10	72,10	519,60
C4	61,50	772,00	133,60	1291,60
C5	55,60	1053,10	189,20	2344,70
F	**1503,90**			
T	1314,70			
T2	0,00			
T3	0,00			
%mass rec		**12,580624**		

Top up water 6548,9

		C1	C2	C3	C4	C5	FEED	TAILS	
TEST 2B	**CONC**	17,10	19,30	28,30	69,40	56,70	1500,00	1302,20	1493,00
	mass pull (%)	1,15	1,29	1,90	4,65	3,80	100,47	87,22	
	CONC.	17,10	19,30	28,30	69,40	56,70	1500,00	1302,20	
	B + H2O initial	587,90	596,50	590,30	687,30	601,60			
	B + H2O final	431,00	282,90	231,80	197,20	111,00			
	WASH H2O	156,90	313,60	358,50	490,10	490,60			
	D + C + H2O	678,60	868,20	1183,70	1801,20	2127,90			
	DISH	480,40	476,20	503,00	433,80	509,40			
		198,20	392,00	680,70	1367,40	1618,50			
	H20 REC.	24,20	59,10	293,90	807,90	1071,20			
						2256,30			

	Mass Rec	Water Rec	Cum mass	Cum water
			0	0
C1	17,10	24,20	17,10	24,20
C2	19,30	59,10	36,40	83,30
C3	28,30	293,90	64,70	377,20
C4	69,40	807,90	134,10	1185,10
C5	56,70	1071,20	190,80	2256,30
F	**1493,00**			
T	1302,20			
T2	0,00			
T3	0,00			
%mass rec		**12,779638**		

Average mass pull (g)	0	17,50	20,75	30,15	65,45	56,15
Cum mass pull (g)	0	17,50	38,25	68,40	133,85	190,00
St Dev.	0	0,40	1,85	3,70	0,25	0,80
Average H2O Rec. (g)	0	35,30	85,10	328,00	789,95	1062,15
Cum H2O Rec. (g)	0	35,30	120,40	448,40	1238,35	2300,50
St Dev.	0	11,10	37,10	71,20	53,25	44,20

g mass pull(g)/ water rec (g)	0,50	0,24	0,09	0,08	0,05
	49,58	24,38	9,19	8,29	5,29

11.2.2. 3 SPW flotation data

				Grade													
Products	Mass	Mass	Float time	Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2
	(g)	(%)	min	(g/t)	(g/t)	(g/t)	*(g/t)*	(%)	(%)	(%)	(%)	(%)	(%)	(%)
RC1	40,45	2,70	1,00	28,15	28,90	2,97	*60,02*	1,88	2,17	8,88	17,30	6,01	13,55	38,29
RC2	15,75	1,05	2,00	8,16	13,70	0,81	*22,67*	0,48	1,30	3,81	14,37	5,31	17,66	44,39
RC3	24,30	1,62	4,00	3,76	5,84	0,39	*9,99*	0,21	0,56	2,32	13,15	6,46	16,91	44,71
RC4	45,45	3,03	13,00	2,10	2,86	0,27	*5,23*	0,12	0,29	1,87	12,87	7,42	16,15	46,42
RC5	40,65	2,71	20,00	1,55	1,77	0,21	*3,53*	0,08	0,20	1,24	12,08	8,88	15,72	47,92
RC (calc.)	166,60	11,10		9,11	10,38	0,98	*20,46*	0,58	0,86	3,67	13,94	7,09	15,67	44,37
RT	1334,00	88,90		0,19	0,24	0,05	*0,48*	0,02	0,06	0,07	8,61	10,94	13,81	51,55
Head (calc.)	1500,60	100,00		1,18	1,37	0,15	*2,70*	0,08	0,15	0,47	9,20	10,51	14,02	50,76
Head (meas.)	1500,00			1,09	1,26	0,16	*2,58*	0,09	0,16	0,46	9,32	10,47	13,56	51,45
Variance (%)	*0*			*8*	*8*	*1*	*5*	*4*	*6*	*2*	*1*	*0*	*3*	*1*
Cummulative	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RC1	40,45	2,70	1,00	28,15	28,90	2,97	60,02	1,88	2,17	8,88	17,30	6,01	13,55	38,29
RC1+2	56,20	3,75	3,00	22,55	24,64	2,36	49,55	1,49	1,93	7,46	16,48	5,81	14,70	40,00
RC1+2+3	80,50	5,36	7,00	16,88	18,97	1,77	37,61	1,10	1,51	5,91	15,47	6,01	15,37	41,42
RC1+2+3+4	125,95	8,39	20,00	11,54	13,15	1,23	25,92	0,75	1,07	4,45	14,53	6,52	15,65	43,23
RC1+2+3+4+5	166,60	11,10	40,00	9,11	10,38	0,98	20,46	0,58	0,86	3,67	13,94	7,09	15,67	44,37

	Recovery										
Products	Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
RC1	64,31	57,06	52,22	59,96	61,32	40,04	51,00	5,07	1,54	2,60	2,03
RC2	7,26	10,53	5,55	8,82	6,10	9,34	8,51	1,64	0,53	1,32	0,92
RC3	5,16	6,93	4,13	6,00	4,11	6,21	8,00	2,32	1,00	1,95	1,43
RC4	5,39	6,34	5,34	5,87	4,40	6,01	12,07	4,24	2,14	3,49	2,77
RC5	3,56	3,51	3,72	3,54	2,56	3,71	7,16	3,56	2,29	3,04	2,56
RC (calc.)	85,68	84,37	70,96	84,19	78,49	65,31	86,74	16,82	7,49	12,41	9,71
RT	14,32	15,63	29,04	15,81	21,51	34,69	13,26	83,18	92,51	87,59	90,29
Head (calc.)	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
Head (meas.)											
Variance (%)											
Cummulative	0	0	0	0	0	0	0	0	0	0	0
RC1	64,31	57,06	52,22	59,96	61,32	40,04	51,00	5,07	1,54	2,60	2,03
RC1+2	71,57	67,59	57,77	68,78	67,42	49,38	59,51	6,71	2,07	3,93	2,95
RC1+2+3	76,73	74,52	61,90	74,77	71,53	55,59	67,52	9,02	3,07	5,88	4,38
RC1+2+3+4	82,13	80,86	67,24	80,64	75,93	61,60	79,58	13,26	5,21	9,37	7,15
RC1+2+3+4+5	85,68	84,37	70,96	84,19	78,49	65,31	86,74	16,82	7,49	12,41	9,71

Water Recovery

Top up water 6637,1

		C1	C2	C3	C4	C5	FEED	TAILS	
TEST 3A	**CONC**	48,50	16,90	26,80	46,80	39,10		1326,90	1505,00
	PAPER	3,22	1,12	1,78	3,11	2,60	0,00	88,17	
	CONC.	48,50	16,90	26,80	46,80	39,10	0,00	1326,90	
	B + H2O initial	579,00	585,10	582,00	690,40	604,30			
	B + H2O final	419,20	410,50	274,10	232,90	137,10			
	WASH H2O	159,80	174,60	307,90	457,50	467,20			
	D + C + H2O	936,90	808,90	1176,30	1786,20	1827,50			
	DISH	480,40	476,20	503,00	433,80	509,40			
		456,50	332,70	673,30	1352,40	1318,10			
	H20 REC.	248,20	141,20	338,60	848,10	811,80			
						2387,90			

	Mass Rec	Water Rec	Cum mass	Cum water
			0	0
C1	48,50	248,20	48,50	248,20
C2	16,90	141,20	65,40	389,40
C3	26,80	338,60	92,20	728,00
C4	46,80	848,10	139,00	1576,10
C5	39,10	811,80	178,10	2387,90
F	**1505,00**			
T	1326,90			
T2	0,00			
T3	0,00			
%mass rec		**11,833887**		

Top up water 6445,9

		C1	C2	C3	C4	C5	FEED	TAILS	
TEST 3B	**CONC**	32,40	14,60	21,80	44,10	42,20		1341,10	1496,2
	PAPER	2,17	0,98	1,46	2,95	2,82	0,00	89,63	
	CONC.	32,40	14,60	21,80	44,10	42,20	0,00	1341,10	
	B + H2O initial	588,10	591,10	589,30	687,30	589,20			
	B + H2O final	339,20	318,70	266,10	250,60	140,60			
	WASH H2O	248,90	272,40	323,20	436,70	448,60			
	D + C + H2O	948,70	870,60	1130,40	1642,50	1912,10			
	DISH	480,40	476,20	503,00	433,80	509,40			
		468,30	394,40	627,40	1208,70	1402,70			
	H20 REC.	187,00	107,40	282,40	727,90	911,90			
						2216,60			

	Mass Rec	Water Rec	Cum mass	Cum water
			0	0
C1	32,40	187,00	32,40	187,00
C2	14,60	107,40	47,00	294,40
C3	21,80	282,40	68,80	576,80
C4	44,10	727,90	112,90	1304,70
C5	42,20	911,90	155,10	2216,60
F	**1496,20**			
T	1341,10			
T2	0,00			
T3	0,00			
%mass rec		**10,366261**		

Average mass pull (g)	0	40,45	15,75	24,30	45,45	40,65
Cum mass pull (g)	0	40,45	56,20	80,50	125,95	166,60
St Dev.	0	8,05	9,20	11,70	13,05	11,50
Average H2O Rec. (g)	0	217,60	124,30	310,50	788,00	861,85
Cum H2O Rec. (g)	0	217,60	341,90	652,40	1440,40	2302,25
St Dev.	0	30,60	47,50	75,60	135,70	85,65

g mass pull(g)/ water rec (g)	0,19	0,13	0,08	0,06	0,05
	18,59	12,67	7,83	5,77	4,72

11.2.3. 5 SPW flotation data

Products	Mass	Mass	Float time	Grade											Recovery										
	Mass	Mass	Float time	Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2	Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2
	(g)	(%)	min	(g/t)	(g/t)	(g/t)	*(g/t)*	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
RC1	20,55	1,38	1,00	54,80	50,40	8,64	*113,84*	3,70	4,21	13,30	27,38	4,38	14,50	33,80	56,83	48,16	69,61	52,84	63,13	32,74	40,23	3,73	0,54	1,29	0,89
RC2	23,05	1,54	2,00	10,60	16,50	0,89	*27,99*	0,60	1,91	4,16	16,87	6,31	18,07	43,85	12,33	17,68	8,04	14,57	11,48	16,66	14,11	2,58	0,88	1,80	1,30
RC3	24,45	1,64	4,00	4,07	5,86	0,39	*10,32*	0,23	0,70	2,36	15,01	7,37	18,57	47,70	5,02	6,66	3,74	5,70	4,67	6,48	8,49	2,43	1,09	1,96	1,50
RC4	52,80	3,54	13,00	2,50	2,83	0,25	*5,58*	0,14	0,36	1,75	14,73	8,24	18,74	48,77	6,66	6,95	5,17	6,65	6,14	7,19	13,60	5,15	2,63	4,28	3,31
RC5	42,65	2,86	20,00	1,42	1,63	0,18	*3,23*	0,10	0,23	1,26	13,75	9,62	17,58	49,63	3,06	3,23	3,01	3,11	3,54	3,71	7,91	3,88	2,48	3,24	2,72
RC (calc.)	163,50	10,95		10,17	10,88	1,40	*22,44*	0,66	1,08	3,50	16,41	7,71	17,78	46,26	83,89	82,68	89,57	82,88	88,96	66,78	84,34	17,77	7,62	12,58	9,73
RT	1330,00	89,05		0,24	0,28	0,02	*0,57*	0,01	0,07	0,08	9,34	11,50	15,19	52,73	16,11	17,32	10,43	17,12	11,04	33,22	15,66	82,23	92,38	87,42	90,27
Head (calc.)	1493,50	100,00		1,33	1,44	0,17	*2,96*	0,08	0,18	0,45	10,11	11,08	15,47	52,02	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
Head (meas.)	1500,00			1,09	1,26	0,16	*2,58*	0,09	0,16	0,46	9,32	10,47	13,56	51,45											
Variance (%)	*0*			*21*	*14*	*10*	*15*	*6*	*14*	*1*	*9*	*6*	*14*	*1*											

Cummulative	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RC1	20,55	1,38	1,00	54,80	50,40	8,64	113,84	3,70	4,21	13,30	27,38	4,38	14,50	33,80	56,83	48,16	69,61	52,84	63,13	32,74	40,23	3,73	0,54	1,29	0,89
RC1+2	43,60	2,92	3,00	31,43	32,48	4,54	68,45	2,06	2,99	8,47	21,82	5,40	16,39	39,11	69,15	65,84	77,65	67,41	74,61	49,40	54,34	6,30	1,42	3,09	2,19
RC1+2+3	68,05	4,56	7,00	21,60	22,91	3,05	47,57	1,40	2,17	6,27	19,38	6,11	17,17	42,20	74,18	72,50	81,39	73,11	79,28	55,88	62,83	8,73	2,51	5,06	3,70
RC1+2+3+4	120,85	8,09	20,00	13,26	14,14	1,83	29,22	0,85	1,38	4,30	17,34	7,04	17,86	45,07	80,84	79,45	86,56	79,77	85,42	63,07	76,43	13,88	5,14	9,34	7,01
RC1+2+3+4+5	163,50	10,95	40,00	10,17	10,88	1,40	22,44	0,66	1,08	3,50	16,41	7,71	17,78	46,26	83,89	82,68	89,57	82,88	88,96	66,78	84,34	17,77	7,62	12,58	9,73

Water Recovery

Top up water 6312,5

		C1	C2	C3	C4	C5	FEED	TAILS	
TEST 4A	**CONC**	20,00	22,70	33,20	51,90	46,20		1321,30	1495,30
	PAPER	1,34	1,52	2,22	3,47	3,09	0,00	88,36	
	CONC.	20,00	22,70	33,20	51,90	46,20	0,00	1321,30	
	B + H2O initial	582,10	593,70	588,90	683,40	602,40			
	B + H2O final	394,30	319,60	266,90	221,60	174,40			
	WASH H2O	187,80	274,10	322,00	461,80	428,00			
	D + C + H2O	734,80	902,40	1236,60	1826,60	2075,30			
	DISH	480,40	476,20	503,00	433,80	509,40			
		254,40	426,20	733,60	1392,80	1565,90			
	H20 REC.	46,60	129,40	378,40	879,10	1091,70			
						2525,20			

	Mass Rec	Water Rec	Cum mass	Cum water
			0	0
C1	20,00	46,60	20,00	46,60
C2	22,70	129,40	42,70	176,00
C3	33,20	378,40	75,90	554,40
C4	51,90	879,10	127,80	1433,50
C5	46,20	1091,70	174,00	2525,20
F	**1495,30**			
T	1321,30			
T2	0,00			
T3	0,00			
%mass rec		**11,636461**		

Top up water 6555,6

		C1	C2	C3	C4	C5	FEED	TAILS	
TEST 4B	**CONC**	21,10	23,40	26,20	53,70	39,10		1338,70	1502,2
	PAPER	1,40	1,56	1,74	3,57	2,60	0,00	89,12	
	CONC.	21,10	23,40	26,20	53,70	39,10	0,00	1338,70	
	B + H2O initial	587,80	597,20	590,10	681,00	595,20			
	B + H2O final	403,60	312,70	236,20	204,50	167,90			
	WASH H2O	184,20	284,50	353,90	476,50	427,30			
	D + C + H2O	733,40	941,70	1129,70	1987,90	1956,00			
	DISH	480,40	476,20	503,00	433,80	509,40			
		253,00	465,50	626,70	1554,10	1446,60			
	H20 REC.	47,70	157,60	246,60	1023,90	980,20			
						2456,00			

	Mass Rec	Water Rec	Cum mass	Cum water
			0	0
C1	21,10	47,70	21,10	47,70
C2	23,40	157,60	44,50	205,30
C3	26,20	246,60	70,70	451,90
C4	53,70	1023,90	124,40	1475,80
C5	39,10	980,20	163,50	2456,00
F	**1502,20**			
T	1338,70			
T2	0,00			
T3	0,00			
%mass rec		**10,884037**		

Average mass pull (g)	0	20,55	23,05	29,70	52,80	42,65
Cum mass pull (g)	0	20,55	43,60	73,30	126,10	168,75
St Dev.	0	0,55	0,90	2,60	1,70	5,25
Average H2O Rec. (g)	0	47,15	143,50	312,50	951,50	1035,95
Cum H2O Rec. (g)	0	47,15	190,65	503,15	1454,65	2490,60
St Dev.	0	0,55	14,65	51,25	21,15	34,60

g mass pull(g)/ water rec (g)	0,44	0,16	0,10	0,06	0,04
	43,58	16,06	9,50	5,55	4,12

11.2.4. 10 SPW Flotation data

Products	Mass	Mass	Float time	Grade											Recovery										
				Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2	Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2
	(g)	(%)	min	(g/t)	(g/t)	(g/t)	*(g/t)*	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
RC1	31,10	2,07	1,00	33,30	32,10	4,39	*69,79*	2,27	2,39	8,96	21,59	5,95	14,68	39,15	56,69	48,05	54,26	52,22	54,70	29,70	40,48	4,25	1,07	1,90	1,55
RC2	17,90	1,19	2,00	11,10	18,10	0,86	*30,06*	0,64	2,12	4,60	18,37	6,68	19,15	45,35	10,88	15,59	6,12	12,95	8,81	15,16	11,95	2,08	0,69	1,43	1,03
RC3	26,50	1,76	4,00	5,48	8,00	0,56	*14,04*	0,37	0,91	2,87	16,01	7,59	19,40	47,06	7,95	10,20	5,90	8,95	7,60	9,64	11,05	2,68	1,16	2,14	1,59
RC4	43,40	2,89	13,00	2,56	3,22	0,25	*6,03*	0,15	0,38	1,88	15,01	8,73	18,57	47,92	6,08	6,73	4,31	6,30	5,04	6,59	11,85	4,12	2,18	3,36	2,65
RC5	34,65	2,31	20,00	1,53	1,92	0,19	*3,64*	0,11	0,28	1,40	14,58	9,86	18,74	49,20	2,90	3,20	2,62	3,03	2,95	3,88	7,05	3,20	1,97	2,71	2,17
RC (calc.)	153,55	10,22		10,05	11,34	1,20	*22,59*	0,66	1,06	3,69	16,81	7,99	18,03	45,98	84,50	83,77	73,20	83,45	79,10	64,97	82,37	16,33	7,07	11,54	8,98
RT	1348,55	89,78		0,21	0,25	0,05	*0,51*	0,02	0,07	0,09	9,81	11,96	15,74	53,05	15,50	16,23	26,80	16,55	20,90	35,03	17,63	83,67	92,93	88,46	91,02
Head (calc.)	1502,10	100,00		1,22	1,38	0,17	*2,77*	0,09	0,17	0,46	10,52	11,55	15,97	52,33	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
Head (meas.)	1500,00			1,09	1,26	0,16	*2,58*	0,09	0,16	0,46	9,32	10,47	13,56	51,45											
Variance (%)	*0*			*11*	*10*	*8*	*7*	*0*	*7*	*0*	*13*	*10*	*18*	*2*											

Cummulative	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RC1	31,10	2,07	1,00	33,30	32,10	4,39	69,79	2,27	2,39	8,96	21,59	5,95	14,68	39,15	56,69	48,05	54,26	52,22	54,70	29,70	40,48	4,25	1,07	1,90	1,55
RC1+2	49,00	3,26	3,00	25,19	26,99	3,10	55,28	1,67	2,29	7,37	20,41	6,22	16,31	41,41	67,57	63,64	60,38	65,17	63,51	44,87	52,42	6,33	1,76	3,33	2,58
RC1+2+3	75,50	5,03	7,00	18,27	20,32	2,21	40,80	1,22	1,81	5,79	18,87	6,70	17,40	43,40	75,51	73,85	66,27	74,12	71,10	54,50	63,47	9,01	2,92	5,47	4,17
RC1+2+3+4	118,90	7,92	20,00	12,54	14,08	1,49	28,11	0,83	1,29	4,36	17,46	7,44	17,82	45,05	81,60	80,57	70,59	80,42	76,15	61,09	75,32	13,13	5,10	8,83	6,81
RC1+2+3+4+5	153,55	10,22	40,00	10,05	11,34	1,20	22,59	0,66	1,06	3,69	16,81	7,99	18,03	45,98	84,50	83,77	73,20	83,45	79,10	64,97	82,37	16,33	7,07	11,54	8,98

Water Recovery

Top up water

		C1	C2	C3	C4	C5	FEED	TAILS	
TEST 5A	**CONC**	37,90	17,30	25,70	46,30	38,70		1339,90	1505,80
	PAPER	2,52	1,15	1,71	3,07	2,57	0,00	88,98	
	CONC.	37,90	17,30	25,70	46,30	38,70	0,00	1339,90	
	B + H2O initial	585,30	593,30	592,40	694,00	606,20			
	B + H2O final	454,40	406,40	334,70	227,10	223,90			
	WASH H2O	130,90	186,90	257,70	466,90	382,30			
	D + C + H2O	904,30	860,90	1107,90	1830,30	2184,80			
	DISH	480,40	476,20	503,00	433,80	509,40			
		423,90	384,70	604,90	1396,50	1675,40			
	H20 REC.	255,10	180,50	321,50	883,30	1254,40			
						2894,80			

	Mass Rec	Water Rec	Cum mass	Cum water
			0	0
C1	37,90	255,10	37,90	255,10
C2	17,30	180,50	55,20	435,60
C3	25,70	321,50	80,90	757,10
C4	46,30	883,30	127,20	1640,40
C5	38,70	1254,40	165,90	2894,80
F	**1505,80**			
T	1339,90			
T2	0,00			
T3	0,00			
%mass rec		**11,017399**		

Top up water 6455,2

		C1	C2	C3	C4	C5	FEED	TAILS	
TEST 5B	**CONC**	24,30	18,50	27,30	40,50	30,60		1357,20	1498,40
	PAPER	1,62	1,23	1,82	2,70	2,04	0,00	90,58	
	CONC.	24,30	18,50	27,30	40,50	30,60	0,00	1357,20	
	B + H2O initial	589,50	599,00	592,00	674,90	592,10			
	B + H2O final	399,10	321,90	258,50	265,10	163,90			
	WASH H2O	190,40	277,10	333,50	409,80	428,20			
	D + C + H2O	803,50	894,40	1198,80	1731,30	2010,50			
	DISH	480,40	476,20	503,00	433,80	509,40			
		323,10	418,20	695,80	1297,50	1501,10			
	H20 REC.	108,40	122,60	335,00	847,20	1042,30			
						2455,50			

	Mass Rec	Water Rec	Cum mass	Cum water
			0	0
C1	24,30	108,40	24,30	108,40
C2	18,50	122,60	42,80	231,00
C3	27,30	335,00	70,10	566,00
C4	40,50	847,20	110,60	1413,20
C5	30,60	1042,30	141,20	2455,50
F	**1498,40**			
T	1357,20			
T2	0,00			
T3	0,00			
%mass rec		**9,4233849**		

Average mass pull (g)	0	31,10	17,90	26,50	43,40	34,65
Cum mass pull (g)	0	31,10	49,00	75,50	118,90	153,55
St Dev.	0	6,80	6,20	5,40	8,30	12,35
Average H2O Rec. (g)	0	181,75	151,55	328,25	865,25	1148,35
Cum H2O Rec. (g)	0	181,75	333,30	661,55	1526,80	2675,15
St Dev.	0	73,35	102,30	95,55	113,60	219,65

g mass pull(g)/ water rec (g)	0,17	0,12	0,08	0,05	0,03
	17,11	11,81	8,07	5,02	3,02

11.3. Ion spiking flotation data

11.3.1. Spiking calculations

Calculations

1 mol/L Ca = 40 g/L Ca = 40 000 p

40 L of distilled water — 350 ppm Ca2+

g/L	mol/L
0,35	0,00875

	MM g/mol	Salt	mol/L				
In	236,15	$Ca(NO_3)_2.4H_2O$	0,00300				
	147,01	$CaCl_{2.}2H_2O$	0,00575	0,85	g/L	33,82	g in 40L
Out	40,00	Ca^{2+}	0,00875				

40 L of distilled water — 200 ppm Ca2+

g/L	mol/L
0,20	0,005

	MM g/mol	Salt	mol/L				
In	236,15	$Ca(NO_3)_2.4H_2O$	0,00300				
	147,01	$CaCl_{2.}2H_2O$	0,00200	0,29	g/L	11,77	g in 40L
Out	40,00	Ca^{2+}	0,00500				

40 L of distilled water — 800 ppm Mg

g/L	mol/L
0,80	0,02

	MM g/mol	Salt	mol/L				
In	120,37	$MgSO_4$	0,01211				
	256,41	$Mg(NO_3)_2.6H_2O$	0,00125				
	95,21	$MgCl_2$	0,00664	0,63	g/L	25,27	g in 40L
Out	24,31	Mg^{2+}	0,02000				

40 L of distilled water — 1000 ppm Mg

g/L	mol/L
1,00	0,025

	MM g/mol	Salt	mol/L				
In	120,37	$MgSO_4$	0,01211				
	256,41	$Mg(NO_3)_2.6H_2O$	0,00125				
	95,21	$MgCl_2$	0,01164	1,11	g/L	44,31	g in 40L
Out	24,31	Mg^{2+}	0,02500				

40 L of distilled water — 1200 ppm SO_4^{2-}

g/L	mol/L
1,20	0,03

	MM g/mol	Salt	mol/L				
In	120,37	$MgSO_4$	0,01211				
	142,04	$NaSO_4$	0,01789	2,54	g/L	101,63	g in 40L
Out	96,06	$SO4^{2-}$	0,03000				

40 L of distilled water — 2400 ppm SO_4^{2-}

g/L	mol/L
2,40	0,06
0,00	
0,00	

	MM g/mol	Salt	mol/L				
In	120,37	$MgSO_4$	0,01211				
	142,04	$NaSO_4$	0,04789	6,80	g/L	272,07	g in 40L
Out	96,06	$SO4^{2-}$	0,06000				

40 L of distilled water — 600 ppm NO3

g/L	mol/L
0,60	0,015

	MM g/mol	Salt	mol/L				
In	236,15	$Ca(NO_3)_2.4H_2O$	0,00300				
	256,41	$Mg(NO_3)_2.6H_2O$	0,00228				
	84,99	$NaNO_3$	0,00972	0,8264314	g/L	33,06	g in 40L
Out	62,00	NO_3^-	0,01500				

40 L of distilled water — 800 ppm NO3

g/L	mol/L
0,80	0,02

	MM g/mol	Salt	mol/L				
In	236,15	$Ca(NO_3)_2.4H_2O$	0,00300				
	256,41	$Mg(NO_3)_2.6H_2O$	0,00228				
	84,99	$NaNO_3$	0,01472	1,2514049	g/L	50,06	g in 40L
Out	62,00	NO_3^-	0,02000				

40 L of distilled water — 100 ppm S2O3 — 0,10 — 0,0025

	MM g/mol	Salt	mol/L				
In							
	599,10	$NaS_2O_3^{2-}$	0,00250	1,49775	g/L	59,91	g in 40L
Out							

40 L of distilled water — 150 ppm S2O3

g/L	mol/L
0,15	0,00375

	MM g/mol	Salt	mol/L				
In							
	599,10	$NaS_2O_3^{2-}$	0,00375	2,246625	g/L	89,87	g in 40L
Out							

11.3.2. 3 SPW spiking with 200 ppm Ca^{2+} flotation data

				Grade											Recovery										
Products	Mass	Mass	Float time	Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2	Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2
	(g)	(%)	min	(g/t)	(g/t)	(g/t)	*(g/t)*	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
RC1	38,65	2,60	1,00	30,70	28,40	3,88	*62,98*	3,12	2,92	8,08	20,02	6,73	14,99	42,78	62,59	52,93	60,26	57,70	76,01	41,31	43,82	5,59	1,55	2,73	2,09
RC2	22,95	1,55	2,00	8,86	14,20	0,72	*23,78*	0,40	1,86	3,44	15,44	6,01	18,41	47,70	10,73	15,72	6,64	12,94	5,79	15,62	11,08	2,56	0,82	1,99	1,38
RC3	24,05	1,62	4,00	4,09	5,83	0,39	*10,31*	0,21	0,67	2,62	14,30	6,33	18,74	48,77	5,19	6,76	3,77	5,88	3,18	5,90	8,84	2,48	0,91	2,12	1,48
RC4	60,80	4,10	13,00	2,04	2,34	0,22	*4,60*	0,11	0,30	1,77	13,21	8,60	16,91	49,63	6,54	6,86	5,37	6,63	4,22	6,68	15,10	5,80	3,12	4,85	3,81
RC5	47,00	3,17	20,00	1,09	1,37	0,17	*2,63*	0,09	0,18	1,01	11,67	10,00	15,80	50,38	2,70	3,11	3,21	2,93	2,67	3,10	6,66	3,96	2,81	3,50	2,99
RC (calc.)	193,45	13,03		8,60	9,15	1,02	*18,77*	0,75	1,03	3,15	14,59	7,97	16,66	48,11	87,75	85,37	79,25	86,08	91,86	72,60	85,51	20,40	9,21	15,19	11,76
RT	1290,70	86,97		0,18	0,24	0,04	*0,46*	0,01	0,06	0,08	8,54	11,79	13,95	54,12	12,25	14,63	20,75	13,92	8,14	27,40	14,49	79,60	90,79	84,81	88,24
Head (calc.)	1484,15	100,00		1,28	1,40	0,17	*2,84*	0,11	0,18	0,48	9,33	11,29	14,30	53,34	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
Head (meas.)	1500,00			1,09	1,26	0,16	*2,58*	0,09	0,16	0,46	9,32	10,47	13,56	51,45											
Variance (%)	*0*			*17*	*11*	*8*	*10*	*25*	*19*	*4*	*0*	*8*	*5*	*4*											

Cummulative		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RC1	38,65	2,60	1,00	30,70	28,40	3,88	62,98	3,12	2,92	8,08	20,02	6,73	14,99	42,78	62,59	52,93	60,26	57,70	76,01	41,31	43,82	5,59	1,55	2,73	2,09
RC1+2	61,60	4,15	3,00	22,56	23,11	2,70	48,38	2,11	2,53	6,35	18,31	6,46	16,26	44,62	73,31	68,65	66,90	70,64	81,80	56,93	54,90	8,15	2,37	4,72	3,47
RC1+2+3	85,65	5,77	7,00	17,38	18,26	2,05	37,69	1,57	2,00	5,30	17,18	6,42	16,96	45,78	78,50	75,41	70,67	76,52	84,98	62,83	63,75	10,63	3,28	6,84	4,95
RC1+2+3+4	146,45	9,87	20,00	11,01	11,65	1,29	23,95	0,97	1,30	3,84	15,53	7,32	16,94	47,38	85,04	82,27	76,04	83,15	89,20	69,50	78,85	16,44	6,40	11,69	8,77
RC1+2+3+4+5	193,45	13,03	40,00	8,60	9,15	1,02	18,77	0,75	1,03	3,15	14,59	7,97	16,66	48,11	87,75	85,37	79,25	86,08	91,86	72,60	85,51	20,40	9,21	15,19	11,76

Water Recovery

Top up water 6887,3

		C1	C2	C3	C4	C5	FEED	TAILS	
TEST 7A	**CONC**	48,80	24,30	23,70	59,60	52,80		1280,70	1489,90
	PAPER	3,28	1,63	1,59	4,00	3,54	0,00	85,96	
	CONC.	48,80	24,30	23,70	59,60	52,80	0,00	1280,70	
	B + H2O initial	580,20	559,80	585,30	577,70	591,70			
	B + H2O final	479,10	336,30	312,70	239,50	295,30			
	WASH H2O	101,10	223,50	272,60	338,20	296,40			
	D + C + H2O	929,60	945,30	1046,00	1881,30	1987,40			
	DISH	480,40	476,20	503,00	433,80	509,40			
		449,20	469,10	543,00	1447,50	1478,00			
	H20 REC.	299,30	221,30	246,70	1049,70	1128,80			
						2945,80			

	Mass Rec	Water Rec	Cum mass	Cum water
C1	48,80	299,30	48,80	299,30
C2	24,30	221,30	73,10	520,60
C3	23,70	246,70	96,80	767,30
C4	59,60	1049,70	156,40	1817,00
C5	52,80	1128,80	209,20	2945,80
F	**1489,90**			
T	1280,70			
T2	0,00			
T3	0,00			
%mass rec		**14,041211**		

Top up water 6617,50

		C1	C2	C3	C4	C5	FEED	TAILS	
TEST 7B	**CONC**	28,50	21,60	24,40	62,00	41,20		1300,70	1478,40
	PAPER	1,93	1,46	1,65	4,19	2,79	0,00	87,98	
	CONC.	28,50	21,60	24,40	62,00	41,20	0,00	1300,70	
	B + H2O initial	579,70	596,60	589,30	564,90	585,50			
	B + H2O final	372,70	393,10	310,20	297,60	274,10			
	WASH H2O	207,00	203,50	279,10	267,30	311,40			
	D + C + H2O	794,00	863,50	1026,80	2173,20	1812,70			
	DISH	480,40	476,20	503,00	433,80	509,40			
		313,60	387,30	523,80	1739,40	1303,30			
	H20 REC.	78,10	162,20	220,30	1410,10	950,70			
						2821,40			

	Mass Rec	Water Rec	Cum mass	Cum water
C1	28,50	78,10	28,50	78,10
C2	21,60	162,20	50,10	240,30
C3	24,40	220,30	74,50	460,60
C4	62,00	1410,10	136,50	1870,70
C5	41,20	950,70	177,70	2821,40
F	**1478,40**			
T	1300,70			
T2	0,00			
T3	0,00			
%mass rec		**12,019751**		

Average mass pull (g)	0	38,65	22,95	24,05	60,80	47,00
Cum mass pull (g)	0	38,65	61,60	85,65	146,45	193,45
St Dev.	0	10,15	11,50	11,15	9,95	15,75
Average H2O Rec. (g)	0	188,70	191,75	233,50	1229,90	1039,75
Cum H2O Rec. (g)	0	188,70	380,45	613,95	1843,85	2883,60
St Dev.	0	110,60	140,15	153,35	26,85	62,20

g mass pull(g)/ water rec (g)	0,20	0,12	0,10	0,05	0,05
	20,48	11,97	10,30	4,94	4,52

11.3.3. 3 SPW spiking with 350 ppm Ca^{2+} flotation data

				Grade											Recovery										
Products	Mass	Mass	Float time	Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2	Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2
	(g)	(%)	min	(g/t)	(g/t)	(g/t)	*(g/t)*	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
RC1	24,60	1,65	1,00	37,50	36,80	4,92	*79,22*	4,29	3,76	10,45	22,73	5,62	14,24	38,93	53,29	44,13	44,71	48,08	69,54	33,56	36,13	3,94	0,82	1,62	1,19
RC2	25,40	1,70	2,00	10,70	17,50	1,39	*29,59*	0,61	2,24	4,41	16,58	6,35	17,91	47,28	15,70	21,67	13,06	18,54	10,21	20,67	15,74	2,97	0,96	2,10	1,49
RC3	29,95	2,01	4,00	3,78	5,68	0,40	*9,86*	0,20	0,67	2,56	14,44	7,08	18,57	49,84	6,54	8,29	4,43	7,29	3,95	7,29	10,78	3,05	1,26	2,57	1,85
RC4	62,25	4,18	13,00	1,75	2,26	0,23	*4,24*	0,11	0,29	1,77	13,31	8,75	16,91	49,84	6,29	6,86	5,29	6,51	4,51	6,56	15,49	5,83	3,23	4,86	3,85
RC5	50,20	3,37	20,00	1,36	1,58	0,20	*3,14*	0,10	0,20	1,03	11,91	9,88	16,28	51,13	3,94	3,87	3,71	3,89	3,24	3,65	7,27	4,21	2,95	3,77	3,18
RC (calc.)	192,40	12,91		7,72	9,04	1,00	*17,76*	0,72	1,03	3,16	14,76	8,07	16,80	48,44	85,76	84,82	71,21	84,31	91,45	71,72	85,41	19,99	9,22	14,91	11,56
RT	1297,45	87,09		0,19	0,24	0,06	*0,49*	0,01	0,06	0,08	8,76	11,78	14,21	54,98	14,24	15,18	28,79	15,69	8,55	28,28	14,59	80,01	90,78	85,09	88,44
Head (calc.)	1489,85	100,00		1,16	1,38	0,18	*2,72*	0,10	0,18	0,48	9,53	11,30	14,54	54,13	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
Head (meas.)	1500,00			1,09	1,26	0,16	*2,58*	0,09	0,16	0,46	9,32	10,47	13,56	51,45											
Variance (%)	*0*			*6*	*9*	*17*	*6*	*19*	*19*	*4*	*2*	*8*	*7*	*5*											

Cummulative		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RC1	24,60	1,65	1,00	37,50	36,80	4,92	79,22	4,29	3,76	10,45	22,73	5,62	14,24	38,93	53,29	44,13	44,71	48,08	69,54	33,56	36,13	3,94	0,82	1,62	1,19
RC1+2	50,00	3,36	3,00	23,89	27,00	3,12	54,01	2,42	2,99	7,38	19,61	5,99	16,10	43,17	68,99	65,80	57,77	66,63	79,75	54,23	51,88	6,90	1,78	3,72	2,68
RC1+2+3	79,95	5,37	7,00	16,35	19,01	2,10	37,47	1,59	2,12	5,58	17,67	6,40	17,03	45,67	75,52	74,09	62,20	73,91	83,70	61,52	62,66	9,95	3,04	6,28	4,53
RC1+2+3+4	142,20	9,54	20,00	9,96	11,68	1,28	22,92	0,94	1,32	3,91	15,76	7,43	16,98	47,50	81,82	80,95	67,50	80,42	88,21	68,07	78,14	15,78	6,27	11,14	8,37
RC1+2+3+4+5	192,40	12,91	40,00	7,72	9,04	1,00	17,76	0,72	1,03	3,16	14,76	8,07	16,80	48,44	85,76	84,82	71,21	84,31	91,45	71,72	85,41	19,99	9,22	14,91	11,56

Water Recovery

Top up water 6942,9

		C1	C2	C3	C4	C5	FEED	TAILS	
TEST 6A	**CONC**	21,20	23,10	37,50	62,70	50,50		1293,50	1488,50
	PAPER	1,42	1,55	2,52	4,21	3,39	0,00	86,90	
	CONC.	21,20	23,10	37,50	62,70	50,50	0,00	1293,50	
	B + H2O initial	586,20	595,90	569,10	584,10	591,80			
	B + H2O final	417,60	346,40	312,10	216,20	252,30			
	WASH H2O	168,60	249,50	257,00	367,90	339,50			
	D + C + H2O	764,20	916,60	1236,30	2299,30	1988,50			
	DISH	480,40	476,20	503,00	433,80	509,40			
		283,80	440,40	733,30	1865,50	1479,10			
	H20 REC.	94,00	167,80	438,80	1434,90	1089,10			
						3224,60			

			Cum mass	Cum water
	Mass Rec	Water Rec	0	0
C1	21,20	94,00	21,20	94,00
C2	23,10	167,80	44,30	261,80
C3	37,50	438,80	81,80	700,60
C4	62,70	1434,90	144,50	2135,50
C5	50,50	1089,10	195,00	3224,60
F	**1488,50**			
T	1293,50			
T2	0,00			
T3	0,00			
%mass rec		**13,100437**		

Top up water 6844

		C1	C2	C3	C4	C5	FEED	TAILS	
TEST 6B	**CONC**	28,00	27,70	22,40	61,80	49,90		1301,40	1491,20
	PAPER	1,88	1,86	1,50	4,14	3,35	0,00	87,27	
	CONC.	28,00	27,70	22,40	61,80	49,90	0,00	1301,40	
	B + H2O initial	584,80	590,30	588,70	570,20	591,40			
	B + H2O final	487,00	338,20	308,10	241,20	245,00			
	WASH H2O	97,80	252,10	280,60	329,00	346,40			
	D + C + H2O	845,70	955,00	1092,70	1968,20	1882,00			
	DISH	480,40	476,20	503,00	433,80	509,40			
		365,30	478,80	589,70	1534,40	1372,60			
	H20 REC.	239,50	199,00	286,70	1143,60	976,30			
						2845,10			

			Cum mass	Cum water
	Mass Rec	Water Rec	0	0
C1	28,00	239,50	28,00	239,50
C2	27,70	199,00	55,70	438,50
C3	22,40	286,70	78,10	725,20
C4	61,80	1143,60	139,90	1868,80
C5	49,90	976,30	189,80	2845,10
F	**1491,20**			
T	1301,40			
T2	0,00			
T3	0,00			
%mass rec		**12,728004**		

Average mass pull (g)	0	24,60	25,40	29,95	62,25	50,20
Cum mass pull (g)	0	24,60	50,00	79,95	142,20	192,40
St Dev.	0	3,40	5,70	1,85	2,30	2,60
Average H2O Rec. (g)	0	166,75	183,40	362,75	1289,25	1032,70
Cum H2O Rec. (g)	0	166,75	350,15	712,90	2002,15	3034,85
St Dev.	0	72,75	88,35	12,30	133,35	189,75

g mass pull(g)/ water rec (g)	0,15	0,14	0,08	0,05	0,05
	14,75	13,85	8,26	4,83	4,86

11.3.4. 3 SPW spiking with 800 ppm Mg^{2+} flotation data

Products	Mass	Mass	Float time	Grade										
	Mass	Mass	Float time	Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2
	(g)	(%)	min	(g/t)	(g/t)	(g/t)	*(g/t)*	(%)	(%)	(%)	(%)	(%)	(%)	(%)
RC1	16,85	1,15	1,00	23,60	18,40	2,66	*44,66*	3,24	2,68	13,00	23,73	4,55	14,21	37,22
RC2	27,65	1,89	2,00	9,72	16,40	0,87	*26,99*	0,55	1,90	4,64	16,16	6,58	16,75	46,21
RC3	38,90	2,65	4,00	3,28	6,50	0,34	*10,12*	0,24	0,93	2,42	13,85	7,71	17,08	48,77
RC4	79,90	5,45	13,00	1,85	2,75	0,23	*4,83*	0,14	0,35	1,47	13,00	8,43	16,91	50,27
RC5	60,90	4,15	20,00	0,91	1,22	0,15	*2,28*	0,09	0,17	0,67	11,19	9,86	15,40	51,34
RC (calc.)	224,20	15,29		4,45	5,84	0,49	*10,78*	0,43	0,77	2,68	13,85	8,17	16,31	48,82
RT	1242,10	84,71		0,07	0,12	0,03	*0,22*	0,03	0,06	0,07	9,09	10,89	14,29	54,87
Head (calc.)	1466,30	100,00		0,74	1,00	0,10	*1,83*	0,09	0,17	0,47	9,82	10,48	14,59	53,95
Head (meas.)	1500,00			1,09	1,26	0,16	*2,58*	0,09	0,16	0,46	9,32	10,47	13,56	51,45
Variance (%)	*0*			*33*	*21*	*35*	*29*	*6*	*9*	*2*	*5*	*0*	*8*	*5*
Cummulative		0	0	0	0	0	0	0	0	0	0	0	0	0
RC1	16,85	1,15	1,00	23,60	18,40	2,66	44,66	3,24	2,68	13,00	23,73	4,55	14,21	37,22
RC1+2	44,50	3,03	3,00	14,98	17,16	1,55	33,68	1,57	2,20	7,81	19,02	5,81	15,79	42,80
RC1+2+3	83,40	5,69	7,00	9,52	12,19	0,98	22,69	0,95	1,61	5,29	16,61	6,70	16,39	45,59
RC1+2+3+4	163,30	11,14	20,00	5,77	7,57	0,62	13,95	0,55	0,99	3,42	14,84	7,54	16,65	47,88
RC1+2+3+4+5	224,20	15,29	40,00	4,45	5,84	0,49	10,78	0,43	0,77	2,68	13,85	8,17	16,31	48,82

Products	Recovery										
	Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
RC1	36,89	21,24	30,52	28,03	40,98	18,30	31,90	2,78	0,50	1,12	0,79
RC2	24,93	31,07	16,38	27,80	11,42	21,29	18,68	3,10	1,18	2,16	1,62
RC3	11,84	17,33	9,00	14,67	7,01	14,66	13,71	3,74	1,95	3,10	2,40
RC4	13,71	15,06	12,51	14,38	8,40	11,33	17,10	7,21	4,38	6,31	5,08
RC5	5,14	5,09	6,22	5,17	4,23	4,20	5,94	4,73	3,91	4,38	3,95
RC (calc.)	92,51	89,79	74,63	90,05	72,03	69,79	87,34	21,57	11,93	17,09	13,84
RT	7,49	10,21	25,37	9,95	27,97	30,21	12,66	78,43	88,07	82,91	86,16
Head (calc.)	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
Head (meas.)											
Variance (%)											
Cummulative	0	0	0	0	0	0	0	0	0	0	0
RC1	36,89	21,24	30,52	28,03	40,98	18,30	31,90	2,78	0,50	1,12	0,79
RC1+2	61,82	52,32	46,89	55,84	52,40	39,60	50,58	5,88	1,68	3,28	2,41
RC1+2+3	73,66	69,64	55,90	70,50	59,40	54,26	64,29	9,62	3,63	6,39	4,81
RC1+2+3+4	87,37	84,70	68,41	84,88	67,80	65,60	81,40	16,83	8,02	12,70	9,88
RC1+2+3+4+5	92,51	89,79	74,63	90,05	72,03	69,79	87,34	21,57	11,93	17,09	13,84

Water Recovery

Top up water

		C1	C2	C3	C4	C5	FEED	TAILS
TEST 8A	**CONC**	17,10	28,20	39,80	68,80	53,80		1242,10
	PAPER							
	CONC.	17,10	28,20	39,80	68,80	53,80	0,00	1242,10
	B + H2O initial	571,00	598,80	571,30	599,00	572,50		
	B + H2O final	378,70	455,40	403,30	139,50	235,10		
	WASH H2O	192,30	143,40	168,00	459,50	337,40		
	D + C + H2O	671,00	923,00	1284,70	2265,10	2390,00		
	DISH	480,40	476,20	503,00	433,80	509,40		
		190,60	446,80	781,70	1831,30	1880,60		
	H20 REC.	-18,80	275,20	573,90	1303,00	1489,40		
						3622,70		

	Mass Rec	Water Rec	Cum mass	Cum water
C1	17,10	-18,80	17,10	-18,80
C2	28,20	275,20	45,30	256,40
C3	39,80	573,90	85,10	830,30
C4	68,80	1303,00	153,90	2133,30
C5	53,80	1489,40	207,70	3622,70
F	**1449,80**			
T	1242,10			
T2	0,00			
T3	0,00			
%mass rec		**14,326114**		

Top up water 6455,2

		C1	C2	C3	C4	C5	FEED	TAILS
TEST 8B	**CONC**	16,60	27,10	38,00	91,00	68,00	1214,50	
	PAPER							
	CONC.	16,60	27,10	38,00	91,00	68,00	1214,50	0,00
	B + H2O initial	572,40	600,50	574,90	602,10	572,50		
	B + H2O final	483,40	411,20	344,70	140,20	233,00		
	WASH H2O	89,00	189,30	230,20	461,90	339,50		
	D + C + H2O	672,70	933,10	1240,50	2541,20	2616,10		
	DISH	480,40	476,20	503,00	433,80	509,40		
		192,30	456,90	737,50	2107,40	2106,70		
	H20 REC.	86,70	240,50	469,30	1554,50	1699,20		
						4050,20		

	Mass Rec	Water Rec	Cum mass	Cum water
C1	16,60	86,70	16,60	86,70
C2	27,10	240,50	43,70	327,20
C3	38,00	469,30	81,70	796,50
C4	91,00	1554,50	172,70	2351,00
C5	68,00	1699,20	240,70	4050,20
F	**240,70**			
T	0,00			
T2	0,00			
T3	0,00			
%mass rec		**100**		

Average mass pull (g)	0	16,85	27,65	38,90	79,90	60,90
Cum mass pull (g)	0	16,85	44,50	83,40	163,30	224,20
St Dev.	0	0,25	0,80	1,70	9,40	16,50
Average H2O Rec. (g)	0	33,95	257,85	521,60	1428,75	1594,30
Cum H2O Rec. (g)	0	33,95	291,80	813,40	2242,15	3836,45
St Dev.	0	52,75	35,40	16,90	108,85	213,75

g mass pull(g)/ water rec (g)	0,50	0,11	0,07	0,06	0,04
	49,63	10,72	7,46	5,59	3,82

11.3.5. 3 SPW spiking with 1000 ppm Mg^{2+} flotation data

Products	Mass	Mass	Float time	Grade											Recovery										
				Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2	Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2
	(g)	(%)	min	(g/t)	(g/t)	(g/t)	*(g/t)*	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
RC1	19,00	1,29	1,00	45,10	39,10	6,18	*90,38*	3,00	3,08	13,00	24,02	4,57	14,33	37,22	50,04	36,43	42,78	42,65	42,70	22,98	35,45	3,21	0,56	1,29	0,89
RC2	23,60	1,61	2,00	9,88	17,30	0,98	*28,16*	0,59	1,98	5,08	16,73	6,14	17,08	45,99	13,61	20,02	8,43	16,51	10,43	18,35	17,21	2,78	0,94	1,91	1,37
RC3	36,80	2,51	4,00	4,14	7,57	0,42	*12,13*	0,25	0,90	2,66	14,44	7,18	17,25	48,77	8,90	13,66	5,63	11,09	6,89	13,01	14,05	3,74	1,71	3,01	2,26
RC4	65,80	4,48	13,00	2,38	3,09	0,28	*5,75*	0,14	0,34	1,40	12,98	8,29	16,91	50,49	9,14	9,97	6,71	9,40	6,90	8,66	13,22	6,01	3,54	5,28	4,19
RC5	78,90	5,38	20,00	0,98	1,21	0,17	*2,36*	0,09	0,17	0,67	11,17	9,73	15,89	51,55	4,51	4,68	4,74	4,61	5,14	5,27	7,59	6,20	4,98	5,95	5,13
RC (calc.)	224,10	15,27		6,59	7,71	0,84	*15,14*	0,43	0,78	2,72	13,91	8,07	16,40	48,98	86,21	84,76	68,29	84,25	72,06	68,26	87,51	21,94	11,74	17,44	13,84
RT	1243,35	84,73		0,19	0,25	0,07	*0,51*	0,03	0,07	0,07	8,92	10,94	14,00	54,98	13,79	15,24	31,71	15,75	27,94	31,74	12,49	78,06	88,26	82,56	86,16
Head (calc.)	1467,45	100,00		1,17	1,39	0,19	*2,74*	0,09	0,17	0,47	9,68	10,50	14,36	54,06	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
Head (meas.)	1500,00			1,09	1,26	0,16	*2,58*	0,09	0,16	0,46	9,32	10,47	13,56	51,45											
Variance (%)	*0*			*7*	*10*	*21*	*7*	*6*	*12*	*3*	*4*	*0*	*6*	*5*											

Cummulative		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RC1	19,00	1,29	1,00	45,10	39,10	6,18	90,38	3,00	3,08	13,00	24,02	4,57	14,33	37,22	50,04	36,43	42,78	42,65	42,70	22,98	35,45	3,21	0,56	1,29	0,89
RC1+2	42,60	2,90	3,00	25,59	27,02	3,30	55,91	1,66	2,47	8,61	19,98	5,44	15,85	42,08	63,65	56,45	51,21	59,15	53,13	41,33	52,65	5,99	1,50	3,20	2,26
RC1+2+3	79,40	5,41	7,00	15,65	18,01	1,96	35,62	1,01	1,74	5,85	17,41	6,25	16,50	45,18	72,55	70,11	56,84	70,24	60,02	54,34	66,70	9,73	3,22	6,21	4,52
RC1+2+3+4	145,20	9,89	20,00	9,64	11,25	1,20	22,08	0,62	1,10	3,84	15,40	7,18	16,69	47,59	81,69	80,08	63,55	79,64	66,92	62,99	79,92	15,74	6,76	11,50	8,71
RC1+2+3+4+5	224,10	15,27	40,00	6,59	7,71	0,84	15,14	0,43	0,78	2,72	13,91	8,07	16,40	48,98	86,21	84,76	68,29	84,25	72,06	68,26	87,51	21,94	11,74	17,44	13,84

Water Recovery

Top up water

		C1	C2	C3	C4	C5	FEED	TAILS
TEST 9A	**CONC**	19,10	28,70	34,50	77,50	74,30		1221,70
	PAPER							
	CONC.	19,10	28,70	34,50	77,50	74,30	0,00	1221,70
	B + H2O initial	570,60	598,90	580,30	581,90	600,20		
	B + H2O final	437,90	371,10	488,70	525,20	444,70		
	WASH H2O	132,70	227,80	91,60	56,70	155,50		
	D + C + H2O	703,60	970,50	1108,60	2091,50	2552,00		
	DISH	480,40	476,20	503,00	433,80	509,40		
		223,20	494,30	605,60	1657,70	2042,60		
	H20 REC.	71,40	237,80	479,50	1523,50	1812,80		
						4125,00		

	Mass Rec	Water Rec	Cum mass	Cum water
C1	19,10	71,40	19,10	71,40
C2	28,70	237,80	47,80	309,20
C3	34,50	479,50	82,30	788,70
C4	77,50	1523,50	159,80	2312,20
C5	74,30	1812,80	234,10	4125,00
F	**1455,80**			
T	1221,70			
T2	0,00			
T3	0,00			
%mass rec		**16,080506**		

Top up water 6455,2

		C1	C2	C3	C4	C5	FEED	TAILS
TEST 9B	**CONC**	18,90	18,50	39,10	54,10	83,50		1265,00
	PAPER							
	CONC.	18,90	18,50	39,10	54,10	83,50	0,00	1265,00
	B + H2O initial	572,20	600,00	561,60	591,10	581,80		
	B + H2O final	472,90	425,30	408,60	246,60	143,90		
	WASH H2O	99,30	174,70	153,00	344,50	437,90		
	D + C + H2O	706,60	812,90	1244,00	2333,90	3056,60		
	DISH	480,40	476,20	503,00	433,80	509,40		
		226,20	336,70	741,00	1900,10	2547,20		
	H20 REC.	108,00	143,50	548,90	1501,50	2025,80		
						4327,70		

	Mass Rec	Water Rec	Cum mass	Cum water
C1	18,90	108,00	18,90	108,00
C2	18,50	143,50	37,40	251,50
C3	39,10	548,90	76,50	800,40
C4	54,10	1501,50	130,60	2301,90
C5	83,50	2025,80	214,10	4327,70
F	**1479,10**			
T	1265,00			
T2	0,00			
T3	0,00			
%mass rec		**14,475019**		

Average mass pull (g)	0	19,00	23,60	36,80	65,80	78,90
Cum mass pull (g)	0	19,00	42,60	79,40	145,20	224,10
St Dev.	0	0,10	5,20	2,90	14,60	10,00
Average H2O Rec. (g)	0	89,70	190,65	514,20	1512,50	1919,30
Cum H2O Rec. (g)	0	89,70	280,35	794,55	2307,05	4226,35
St Dev.	0	18,30	28,85	5,85	5,15	101,35

g mass pull(g)/ water rec (g)	0,21	0,12	0,07	0,04	0,04
	21,18	12,38	7,16	4,35	4,11

11.3.6. 3 SPW spiking with 1200 ppm SO_4^{2-} flotation data

				Grade											Recovery										
Products	Mass	Mass	Float time	Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2	Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2
	(g)	(%)	min	(g/t)	(g/t)	(g/t)	*(g/t)*	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
RC1	26,60	1,78	1,00	38,15	39,00	5,98	*83,13*	2,31	3,79	12,00	23,23	5,64	12,62	37,44	58,11	50,64	57,07	54,28	40,19	39,46	44,74	4,30	0,93	1,62	1,23
RC2	20,25	1,36	2,00	9,17	14,40	0,79	*24,36*	0,41	1,72	3,55	15,30	7,07	16,13	47,28	10,63	14,23	5,74	12,11	5,43	13,63	10,08	2,16	0,89	1,58	1,19
RC3	29,65	1,98	4,00	4,63	6,96	0,42	*12,01*	0,21	0,87	2,61	14,44	7,05	17,08	49,20	7,86	10,07	4,47	8,74	4,07	10,10	10,85	2,98	1,30	2,44	1,81
RC4	58,35	3,90	13,00	1,91	2,34	0,23	*4,48*	0,11	0,30	1,52	13,20	8,09	16,52	50,27	6,38	6,67	4,82	6,42	4,20	6,85	12,43	5,36	2,93	4,65	3,64
RC5	61,15	4,09	20,00	1,46	1,70	0,21	*3,37*	0,09	0,19	1,07	12,27	9,45	15,62	50,70	5,11	5,07	4,61	5,06	3,64	4,55	9,17	5,22	3,59	4,61	3,84
RC (calc.)	196,00	13,12		7,85	9,06	1,09	*18,00*	0,45	0,97	3,18	14,67	7,92	15,75	48,19	88,10	86,69	76,71	86,61	57,53	74,59	87,26	20,02	9,64	14,90	11,71
RT	1298,40	86,88		0,16	0,21	0,05	*0,42*	0,05	0,05	0,07	8,85	11,20	13,58	54,87	11,90	13,31	23,29	13,39	42,47	25,41	12,74	79,98	90,36	85,10	88,29
Head (calc.)	1494,40	100,00		1,17	1,37	0,19	*2,73*	0,10	0,17	0,48	9,61	10,77	13,87	53,99	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
Head (meas.)	1500,00			1,09	1,26	0,16	*2,58*	0,09	0,16	0,46	9,32	10,47	13,56	51,45											
Variance (%)	*0,00*			*7*	*9*	*20*	*6*	*19*	*10*	*4*	*3*	*3*	*2*	*5*											
Cummulative		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
RC1	26,60	1,78	1,00	38,15	39,00	5,98	83,13	2,31	3,79	12,00	23,23	5,64	12,62	37,44	58,11	50,64	57,07	54,28	40,19	39,46	44,74	4,30	0,93	1,62	1,23
RC1+2	46,85	3,14	3,00	25,62	28,37	3,74	57,73	1,49	2,90	8,35	19,80	6,26	14,14	41,69	68,75	64,88	62,81	66,39	45,62	53,09	54,81	6,46	1,82	3,20	2,42
RC1+2+3	76,50	5,12	7,00	17,49	20,07	2,45	40,01	0,99	2,11	6,12	17,72	6,56	15,28	44,60	76,61	74,95	67,28	75,14	49,70	63,19	65,66	9,44	3,12	5,64	4,23
RC1+2+3+4	134,85	9,02	20,00	10,75	12,40	1,49	24,64	0,61	1,33	4,13	15,76	7,22	15,81	47,05	82,99	81,62	72,10	81,55	53,89	70,04	78,09	14,80	6,05	10,29	7,86
RC1+2+3+4+5	196,00	13,12	40,00	7,85	9,06	1,09	18,00	0,45	0,97	3,18	14,67	7,92	15,75	48,19	88,10	86,69	76,71	86,61	57,53	74,59	87,26	20,02	9,64	14,90	11,71

Water Recovery

Top up water 7065,3

		C1	C2	C3	C4	C5	FEED	TAILS
TEST 10A	**CONC**	29,40	25,90	32,00	61,90	62,30		1272,20
	PAPER							
	CONC.	29,40	25,90	32,00	61,90	62,30	0,00	1272,20
	B + H2O initial	589,90	597,30	589,70	576,40	588,60		
	B + H2O final	370,30	347,30	317,70	184,80	259,70		
	WASH H2O	219,60	250,00	272,00	391,60	328,90		
	D + C + H2O	828,60	973,50	1163,50	2100,30	2235,70		
	DISH	480,40	476,20	503,00	433,80	509,40		
		348,20	497,30	660,50	1666,50	1726,30		
	H20 REC.	99,20	221,40	356,50	1213,00	1335,10		
						3225,20		

	Mass Rec	Water Rec	Cum mass	Cum water
C1	29,40	99,20	29,40	99,20
C2	25,90	221,40	55,30	320,60
C3	32,00	356,50	87,30	677,10
C4	61,90	1213,00	149,20	1890,10
C5	62,30	1335,10	211,50	3225,20
F	**1483,70**			
T	1272,20			
T2	0,00			
T3	0,00			
%mass rec		**14,254903**		

Top up water 6925,4

		C1	C2	C3	C4	C5	FEED	TAILS
TEST 10B	**CONC**	23,80	14,60	27,30	54,80	60,00		1324,60
	PAPER							
	CONC.	23,80	14,60	27,30	54,80	60,00	0,00	1324,60
	B + H2O initial	589,60	595,90	590,70	586,20	593,40		
	B + H2O final	425,60	383,60	271,50	197,10	217,00		
	WASH H2O	164,00	212,30	319,20	389,10	376,40		
	D + C + H2O	781,10	821,00	1171,50	1861,20	2342,90		
	DISH	480,40	476,20	503,00	433,80	509,40		
		300,70	344,80	668,50	1427,40	1833,50		
	H20 REC.	112,90	117,90	322,00	983,50	1397,10		
						2933,40		

	Mass Rec	Water Rec	Cum mass	Cum water
C1	23,80	112,90	23,80	112,90
C2	14,60	117,90	38,40	230,80
C3	27,30	322,00	65,70	552,80
C4	54,80	983,50	120,50	1536,30
C5	60,00	1397,10	180,50	2933,40
F	**1505,10**			
T	1324,60			
T2	0,00			
T3	0,00			
%mass rec		**11,992559**		

Average mass pull (g)	0	26,60	20,25	29,65	58,35	61,15
Cum mass pull (g)	0	26,60	46,85	76,50	134,85	196,00
St Dev.	0	2,80	8,45	10,80	14,35	15,50
Average H2O Rec. (g)	0	106,05	169,65	339,25	1098,25	1366,10
Cum H2O Rec. (g)	0	106,05	275,70	614,95	1713,20	3079,30
St Dev.	0	6,85	44,90	62,15	176,90	145,90

g mass pull(g)/ water rec (g)	0,25	0,12	0,09	0,05	0,04
	25,08	11,94	8,74	5,31	4,48

11.3.7. 3 SPW spiking with 2400 ppm SO_4^{2-} flotation data

				Grade											Recovery										
Products	Mass	Mass	Float time	Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2	Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2
	(g)	(%)	min	(g/t)	(g/t)	(g/t)	*(g/t)*	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
RC1	30,15	2,02	1,00	37,70	39,20	5,06	*81,96*	2,15	3,84	11,50	22,30	6,69	11,52	37,86	64,25	57,54	57,95	60,52	42,84	45,59	47,97	4,59	1,22	1,60	1,42
RC2	16,80	1,13	2,00	9,77	15,20	0,84	*25,81*	0,43	1,90	4,25	15,87	7,18	15,60	46,21	9,28	12,43	5,36	10,62	4,77	12,57	9,88	1,82	0,73	1,21	0,97
RC3	22,20	1,49	4,00	4,19	5,78	0,44	*10,41*	0,19	0,70	2,35	13,78	7,41	16,75	49,20	5,26	6,25	3,71	5,66	2,79	6,12	7,22	2,09	1,00	1,72	1,36
RC4	57,35	3,84	13,00	1,87	2,37	0,23	*4,47*	0,10	0,29	1,51	13,00	8,27	16,45	49,84	6,06	6,62	5,01	6,28	3,79	6,55	11,98	5,08	2,87	4,35	3,56
RC5	44,05	2,95	20,00	1,13	1,40	0,17	*2,70*	0,07	0,18	1,07	12,40	9,28	16,91	50,38	2,81	3,00	2,84	2,91	2,10	3,12	6,49	3,73	2,48	3,44	2,77
RC (calc.)	170,55	11,42		9,09	10,34	1,16	*20,59*	0,50	1,10	3,54	14,87	8,03	15,65	47,42	87,66	85,83	74,88	85,99	56,29	73,96	83,53	17,31	8,30	12,32	10,08
RT	1322,70	88,58		0,17	0,22	0,05	*0,43*	0,05	0,05	0,09	9,16	11,45	14,36	54,55	12,34	14,17	25,12	14,01	43,71	26,04	16,47	82,69	91,70	87,68	89,92
Head (calc.)	1493,25	100,00		1,18	1,38	0,18	*2,73*	0,10	0,17	0,48	9,82	11,06	14,51	53,74	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
Head (meas.)	1500,00			1,09	1,26	0,16	*2,58*	0,09	0,16	0,46	9,32	10,47	13,56	51,45											
Variance (%)	*0*			*8*	*9*	*14*	*6*	*18*	*10*	*5*	*5*	*6*	*7*	*4*											

Cummulative		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RC1	30,15	2,02	1,00	37,70	39,20	5,06	81,96	2,15	3,84	11,50	22,30	6,69	11,52	37,86	64,25	57,54	57,95	60,52	42,84	45,59	47,97	4,59	1,22	1,60	1,42
RC1+2	46,95	3,14	3,00	27,71	30,61	3,55	61,87	1,53	3,15	8,91	20,00	6,86	12,98	40,85	73,53	69,97	63,31	71,14	47,62	58,16	57,84	6,41	1,95	2,81	2,39
RC1+2+3	69,15	4,63	7,00	20,16	22,64	2,55	45,35	1,10	2,36	6,80	18,00	7,04	14,19	43,53	78,79	76,21	67,02	76,80	50,40	64,28	65,06	8,49	2,95	4,53	3,75
RC1+2+3+4	126,50	8,47	20,00	11,87	13,45	1,50	26,82	0,65	1,42	4,40	15,73	7,60	15,22	46,39	84,85	82,83	72,03	83,08	54,19	70,83	77,04	13,58	5,82	8,88	7,31
RC1+2+3+4+5	170,55	11,42	40,00	9,09	10,34	1,16	20,59	0,50	1,10	3,54	14,87	8,03	15,65	47,42	87,66	85,83	74,88	85,99	56,29	73,96	83,53	17,31	8,30	12,32	10,08

Water Recovery

Top up water 6565,9

		C1	**C2**	**C3**	**C4**	**C5**	**FEED**	**TAILS**
TEST 11A	**CONC**	38,90	19,60	22,20	59,70	47,60		1307,50
	PAPER							
	CONC.	38,90	19,60	22,20	59,70	47,60	0,00	1307,50
	B + H2O initial	591,30	595,50	591,80	577,00	595,20		
	B + H2O final	376,00	430,40	285,10	235,90	252,40		
	WASH H2O	215,30	165,10	306,70	341,10	342,80		
	D + C + H2O	959,60	886,30	1050,90	1883,50	2142,90		
	DISH	480,40	476,20	503,00	433,80	509,40		
		479,20	410,10	547,90	1449,70	1633,50		
	H20 REC.	225,00	225,40	219,00	1048,90	1243,10		
						2961,40		

		Mass Rec	Water Rec	Cum mass	Cum water
	C1	38,90	225,00	38,90	225,00
1342,40	C2	19,60	225,40	58,50	450,40
	C3	22,20	219,00	80,70	669,40
	C4	59,70	1048,90	140,40	1718,30
	C5	47,60	1243,10	188,00	2961,40
	F	**1495,50**			
	T	1307,50			
	T2	0,00			
	T3	0,00			
	%mass rec		**12,571046**		

Top up water 6773,1

		C1	**C2**	**C3**	**C4**	**C5**	**FEED**	**TAILS**
TEST 11B	**CONC**	21,40	14,00	22,20	55,00	40,50		1337,90
	PAPER							
	CONC.	21,40	14,00	22,20	55,00	40,50	0,00	1337,90
	B + H2O initial	588,50	590,90	592,50	589,00	596,40		
	B + H2O final	395,10	408,90	378,30	273,40	249,80		
	WASH H2O	193,40	182,00	214,20	315,60	346,60		
	D + C + H2O	784,40	805,20	1059,80	1998,40	2039,80		
	DISH	480,40	476,20	503,00	433,80	509,40		
		304,00	329,00	556,80	1564,60	1530,40		
	H20 REC.	89,20	133,00	320,40	1194,00	1143,30		
						2879,90		

		Mass Rec	Water Rec	Cum mass	Cum water
C1	21,40	89,20		21,40	89,20
C2	14,00	133,00		35,40	222,20
C3	22,20	320,40		57,60	542,60
C4	55,00	1194,00		112,60	1736,60
C5	40,50	1143,30		153,10	2879,90
F	**1491,00**				
T	1337,90				
T2	0,00				
T3	0,00				
%mass rec		**10,268276**			

Average mass pull (g)	0	30,15	16,80	22,20	57,35	44,05
Cum mass pull (g)	0	30,15	46,95	69,15	126,50	170,55
St Dev.	0	8,75	11,55	11,55	13,90	17,45
Average H2O Rec. (g)	0	157,10	179,20	269,70	1121,45	1193,20
Cum H2O Rec. (g)	0	157,10	336,30	606,00	1727,45	2920,65
St Dev.	0	67,90	114,10	63,40	9,15	40,75

g mass pull(g)/ water rec (g)		0,19	0,09	0,08	0,05	0,04
		19,19	9,38	8,23	5,11	3,69

11.3.8. 3 SPW spiking with 600 ppm NO_3^- flotation data

				Grade											Recovery										
Products	Mass	Mass	Float time	Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2	Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2
	(g)	(%)	min	(g/t)	(g/t)	(g/t)	*(g/t)*	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
RC1	28,80	1,93	1,00	44,20	39,60	5,46	*89,02*	2,30	3,68	11,00	22,07	6,94	12,88	41,50	65,57	54,66	54,85	59,52	41,91	36,05	42,64	4,52	1,19	1,70	1,47
RC2	23,85	1,60	2,00	6,60	10,90	0,66	*18,16*	0,45	1,74	3,69	15,44	8,54	16,05	51,34	8,11	12,46	5,50	10,05	6,78	14,10	11,84	2,62	1,21	1,75	1,51
RC3	26,25	1,76	4,00	3,54	5,65	0,38	*9,57*	0,20	0,71	2,68	13,94	9,16	16,75	53,69	4,79	7,11	3,48	5,83	3,32	6,33	9,47	2,60	1,43	2,01	1,73
RC4	66,25	4,45	13,00	1,83	2,44	0,24	*4,51*	0,11	0,32	1,81	12,94	10,79	15,85	54,34	6,24	7,75	5,55	6,94	4,60	7,20	16,14	6,09	4,24	4,80	4,43
RC5	53,85	3,61	20,00	1,20	1,47	0,19	*2,86*	0,08	0,21	1,07	11,39	10,03	16,52	53,91	3,33	3,79	3,57	3,58	2,62	3,84	7,75	4,36	3,21	4,07	3,57
RC (calc.)	199,00	13,36		8,59	8,99	1,05	*18,60*	0,47	1,00	3,28	14,27	9,54	15,74	51,92	88,03	85,77	72,96	85,92	59,23	67,54	87,84	20,19	11,27	14,32	12,71
RT	1290,80	86,64		0,18	0,23	0,06	*0,47*	0,05	0,07	0,07	8,70	11,58	14,52	54,98	11,97	14,23	27,04	14,08	40,77	32,46	12,16	79,81	88,73	85,68	87,29
Head (calc.)	1489,80	100,00		1,30	1,40	0,19	*2,89*	0,11	0,20	0,50	9,44	11,31	14,68	54,57	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
Head (meas.)	1500,00			1,09	1,26	0,16	*2,58*	0,09	0,16	0,46	9,32	10,47	13,56	51,45											
Variance (%)	*0*			*19*	*11*	*24*	*12*	*24*	*27*	*8*	*1*	*8*	*8*	*6*											
Cummulative		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RC1	28,80	1,93	1,00	44,20	39,60	5,46	89,02	2,30	3,68	11,00	22,07	6,94	12,88	41,50	65,57	54,66	54,85	59,52	41,91	36,05	42,64	4,52	1,19	1,70	1,47
RC1+2	52,65	3,53	3,00	27,17	26,60	3,28	56,92	1,46	2,80	7,69	19,06	7,67	14,32	45,96	73,67	67,12	60,35	69,57	48,69	50,16	54,48	7,13	2,40	3,45	2,98
RC1+2+3	78,90	5,30	7,00	19,31	19,63	2,32	41,17	1,04	2,11	6,02	17,36	8,16	15,13	48,53	78,46	74,23	63,83	75,40	52,00	56,49	63,95	9,73	3,82	5,46	4,71
RC1+2+3+4	145,15	9,74	20,00	11,33	11,78	1,37	24,44	0,62	1,29	4,10	15,34	9,36	15,46	51,18	84,70	81,98	69,39	82,34	56,61	63,69	80,09	15,83	8,07	10,26	9,14
RC1+2+3+4+5	199,00	13,36	40,00	8,59	8,99	1,05	18,60	0,47	1,00	3,28	14,27	9,54	15,74	51,92	88,03	85,77	72,96	85,92	59,23	67,54	87,84	20,19	11,27	14,32	12,71

Water Recovery

Top up water 7150,4

		C1	C2	C3	C4	C5	FEED	TAILS
TEST 12A	**CONC**	25,30	24,10	24,60	66,30	59,60		1282,40
	PAPER							
	CONC.	25,30	24,10	24,60	66,30	59,60	0,00	1282,40
	B + H2O initial	588,20	596,30	590,00	585,00	592,80		
	B + H2O final	348,10	324,10	286,20	224,10	215,60		
	WASH H2O	240,10	272,20	303,80	360,90	377,20		
	D + C + H2O	754,90	874,30	1057,80	2119,50	2227,40		
	DISH	480,40	476,20	503,00	433,80	509,40		
		274,50	398,10	554,80	1685,70	1718,00		
	H20 REC.	9,10	101,80	226,40	1258,50	1281,20		
						2877,00		

	Mass Rec	Water Rec	Cum mass	Cum water
C1	25,30	9,10	25,30	9,10
C2	24,10	101,80	49,40	110,90
C3	24,60	226,40	74,00	337,30
C4	66,30	1258,50	140,30	1595,80
C5	59,60	1281,20	199,90	2877,00
F	**1482,30**			
T	1282,40			
T2	0,00			
T3	0,00			
%mass rec		**13,485799**		

Top up water 6905,2

		C1	C2	C3	C4	C5	FEED	TAILS
TEST 12B	**CONC**	32,30	23,60	27,90	66,20	48,10		1299,20
	PAPER							
	CONC.	32,30	23,60	27,90	66,20	48,10	0,00	1299,20
	B + H2O initial	588,00	591,90	589,30	579,70	595,20		
	B + H2O final	422,40	385,00	241,20	240,20	181,70		
	WASH H2O	165,60	206,90	348,10	339,50	413,50		
	D + C + H2O	887,00	984,60	1271,20	2083,90	1888,20		
	DISH	480,40	476,20	503,00	433,80	509,40		
		406,60	508,40	768,20	1650,10	1378,80		
	H20 REC.	208,70	277,90	392,20	1244,40	917,20		
						3040,40		

	Mass Rec	Water Rec	Cum mass	Cum water
C1	32,30	208,70	32,30	208,70
C2	23,60	277,90	55,90	486,60
C3	27,90	392,20	83,80	878,80
C4	66,20	1244,40	150,00	2123,20
C5	48,10	917,20	198,10	3040,40
F	**1497,30**			
T	1299,20			
T2	0,00			
T3	0,00			
%mass rec		**13,230482**		

Average mass pull (g)	0	28,80	23,85	26,25	66,25	53,85
Cum mass pull (g)	0	28,80	52,65	78,90	145,15	199,00
St Dev.	0	3,50	3,25	4,90	4,85	0,90
Average H2O Rec. (g)	0	108,90	189,85	309,30	1251,45	1099,20
Cum H2O Rec. (g)	0	108,90	298,75	608,05	1859,50	2958,70
St Dev.	0	99,80	187,85	270,75	263,70	81,70

g mass pull(g)/ water rec (g)	0,26	0,13	0,08	0,05	0,05
	26,45	12,56	8,49	5,29	4,90

11.3.9. 3 SPW spiking with 800 ppm NO_3^- flotation data

Products	Mass	Mass	Float time	Grade											Recovery										
				Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2	Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2
	(g)	(%)	min	(g/t)	(g/t)	(g/t)	*(g/t)*	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
RC1	39,25	2,65	1,00	30,50	26,30	4,54	*61,34*	1,84	2,12	7,53	17,87	6,82	14,74	43,43	63,03	50,05	64,67	56,82	36,25	18,05	41,18	3,83	1,53	2,60	2,08
RC2	24,15	1,63	2,00	8,32	14,10	0,63	*23,05*	0,36	1,59	3,28	14,44	6,67	17,58	48,99	10,58	16,51	5,52	13,14	4,36	8,33	11,04	1,91	0,92	1,91	1,44
RC3	27,60	1,86	4,00	3,55	6,11	0,36	*10,02*	0,19	0,71	2,50	13,15	6,99	18,24	49,84	5,16	8,18	3,61	6,53	2,63	4,25	9,61	1,98	1,10	2,26	1,68
RC4	66,90	4,51	13,00	1,90	2,48	0,20	*4,58*	0,10	0,32	1,85	12,95	8,60	17,25	50,49	6,69	8,04	4,86	7,23	3,22	4,64	17,24	4,74	3,29	5,18	4,12
RC5	44,30	2,99	20,00	1,17	1,51	0,17	*2,85*	0,06	0,08	1,37	9,90	6,87	17,25	49,31	2,73	3,24	2,73	2,98	1,42	0,78	8,43	2,40	1,74	3,43	2,67
RC (calc.)	202,20	13,63		8,28	8,77	1,11	*18,17*	0,47	0,82	3,11	13,44	7,42	16,93	48,59	88,19	86,02	81,39	86,69	47,89	36,06	87,50	14,86	8,59	15,37	11,99
RT	1281,70	86,37		0,18	0,23	0,04	*0,44*	0,08	0,23	0,07	12,15	12,47	14,71	56,26	11,81	13,98	18,61	13,31	52,11	63,94	12,50	85,14	91,41	84,63	88,01
Head (calc.)	1483,90	100,00		1,28	1,39	0,19	*2,86*	0,13	0,31	0,48	12,33	11,78	15,01	55,22	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
Head (meas.)	1500,00			1,09	1,26	0,16	*2,58*	0,09	0,16	0,46	9,32	10,47	13,56	51,45											
Variance (%)	*0*			*17*	*10*	*20*	*11*	*57*	*100*	*5*	*32*	*13*	*11*	*7*											

Cummulative		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RC1	39,25	2,65	1,00	30,50	26,30	4,54	61,34	1,84	2,12	7,53	17,87	6,82	14,74	43,43	63,03	50,05	64,67	56,82	36,25	18,05	41,18	3,83	1,53	2,60	2,08
RC1+2	63,40	4,27	3,00	22,05	21,65	3,05	46,75	1,28	1,92	5,91	16,56	6,76	15,82	45,54	73,61	66,56	70,20	69,95	40,61	26,38	52,22	5,74	2,45	4,50	3,52
RC1+2+3	91,00	6,13	7,00	16,44	16,94	2,23	35,61	0,95	1,55	4,88	15,53	6,83	16,56	46,85	78,77	74,73	73,80	76,48	43,24	30,63	61,83	7,72	3,56	6,76	5,20
RC1+2+3+4	157,90	10,64	20,00	10,28	10,81	1,37	22,46	0,59	1,03	3,59	14,44	7,58	16,85	48,39	85,46	82,78	78,66	83,71	46,47	35,27	79,07	12,46	6,85	11,94	9,33
RC1+2+3+4+5	202,20	13,63	40,00	8,28	8,77	1,11	18,17	0,47	0,82	3,11	13,44	7,42	16,93	48,59	88,19	86,02	81,39	86,69	47,89	36,06	87,50	14,86	8,59	15,37	11,99

Water Recovery

Top up water 7108,6

		C1	C2	C3	C4	C5	FEED	TAILS
TEST 13A	**CONC**	41,40	21,60	31,80	63,90	42,80		1273,80
	PAPER							
	CONC.	41,40	21,60	31,80	63,90	42,80	0,00	1273,80
	B + H2O initial	588,00	597,20	590,90	580,10	585,70		
	B + H2O final	382,30	334,20	262,50	249,70	192,80		
	WASH H2O	205,70	263,00	328,40	330,40	392,90		
	D + C + H2O	944,80	938,70	1252,80	2029,70	1990,30		
	DISH	480,40	476,20	503,00	433,80	509,40		
		464,40	462,50	749,80	1595,90	1480,90		
	H20 REC.	217,30	177,90	389,60	1201,60	1045,20		
						3031,60		

	Mass Rec	Water Rec		Cum mass	Cum water
C1	41,40	217,30		41,40	217,30
C2	21,60	177,90		63,00	395,20
C3	31,80	389,60		94,80	784,80
C4	63,90	1201,60		158,70	1986,40
C5	42,80	1045,20		201,50	3031,60
F	**1475,30**				
T	1273,80				
T2	0,00				
T3	0,00				
%mass rec		**13,658239**			

Top up water 6837,1

		C1	C2	C3	C4	C5	FEED	TAILS
TEST 13B	**CONC**	37,10	26,70	23,40	69,90	45,80		1289,60
	PAPER							
	CONC.	37,10	26,70	23,40	69,90	45,80	0,00	1289,60
	B + H2O initial	579,20	596,90	590,10	585,50	592,80		
	B + H2O final	409,50	430,60	320,80	254,10	259,80		
	WASH H2O	169,70	166,30	269,30	331,40	333,00		
	D + C + H2O	912,70	925,70	1059,10	2088,90	1961,90		
	DISH	480,40	476,20	503,00	433,80	509,40		
		432,30	449,50	556,10	1655,10	1452,50		
	H20 REC.	225,50	256,50	263,40	1253,80	1073,70		
						3072,90		

	Mass Rec	Water Rec		Cum mass	Cum water
C1	37,10	225,50		37,10	225,50
C2	26,70	256,50		63,80	482,00
C3	23,40	263,40		87,20	745,40
C4	69,90	1253,80		157,10	1999,20
C5	45,80	1073,70		202,90	3072,90
F	**1492,50**				
T	1289,60				
T2	0,00				
T3	0,00				
%mass rec		**13,59464**			

Average mass pull (g)	0	39,25	24,15	27,60	66,90	44,30
Cum mass pull (g)	0	39,25	63,40	91,00	157,90	202,20
St Dev.	0	2,15	0,40	3,80	0,80	0,70
Average H2O Rec. (g)	0	221,40	217,20	326,50	1227,70	1059,45
Cum H2O Rec. (g)	0	221,40	438,60	765,10	1992,80	3052,25
St Dev.	0	4,10	43,40	19,70	6,40	20,65

g mass pull(g)/ water rec (g)	0,18	0,11	0,08	0,05	0,04
	17,73	11,12	8,45	5,45	4,18

11.3.10. 3 SPW spiking with 100 ppm $S_2O_3^{2-}$ flotation data

Products	Mass	Mass	Float time	Grade										
				Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2
	(g)	(%)	min	(g/t)	(g/t)	(g/t)	*(g/t)*	(%)	(%)	(%)	(%)	(%)	(%)	(%)
RC1	21,55	1,47	1,00	45,60	47,30	5,35	*98,25*	2,87	4,10	13,90	26,59	4,17	12,70	33,80
RC2	22,05	1,50	2,00	8,52	14,50	0,89	*23,91*	0,54	1,64	4,26	16,44	5,89	17,41	46,63
RC3	28,50	1,95	4,00	3,83	6,03	0,46	*10,32*	0,25	0,73	2,75	14,87	6,46	18,41	49,42
RC4	54,15	3,70	13,00	1,75	2,54	0,27	*4,56*	0,14	0,32	1,43	12,74	7,61	17,74	50,49
RC5	77,90	5,32	20,00	0,83	1,15	0,15	*2,13*	0,08	0,17	0,52	10,65	9,51	15,88	51,55
RC (calc.)	204,15	13,93		7,05	8,51	0,85	*16,42*	0,46	0,86	2,89	14,10	7,63	16,56	48,57
RT	1261,00	86,07		0,17	0,23	0,05	*0,45*	0,05	0,06	0,06	8,28	10,90	14,08	54,55
Head (calc.)	1465,15	100,00		1,13	1,38	0,16	*2,67*	0,11	0,17	0,45	9,09	10,44	14,42	53,72
Head (meas.)	1500,00			1,09	1,26	0,16	*2,58*	0,09	0,16	0,46	9,32	10,47	13,56	51,45
Variance (%)	*0*			*3*	*9*	*5*	*4*	*26*	*11*	*1*	*2*	*0*	*6*	*4*

Products	Recovery										
	Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
RC1	59,43	50,42	48,57	54,11	39,15	35,12	45,04	4,30	0,59	1,30	0,93
RC2	11,36	15,81	8,27	13,47	7,54	14,38	14,12	2,72	0,85	1,82	1,31
RC3	6,60	8,50	5,52	7,52	4,51	8,27	11,78	3,18	1,20	2,48	1,79
RC4	5,73	6,80	6,16	6,31	4,80	6,89	11,64	5,18	2,69	4,55	3,47
RC5	3,91	4,43	4,92	4,24	4,09	5,26	6,03	6,23	4,84	5,85	5,10
RC (calc.)	87,04	85,97	73,44	85,66	60,09	69,92	88,62	21,61	10,18	15,99	12,60
RT	12,96	14,03	26,56	14,34	39,91	30,08	11,38	78,39	89,82	84,01	87,40
Head (calc.)	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
Head (meas.)											
Variance (%)											

Cummulative		0	0	0	0	0	0	0	0	0	0	0	0	0
RC1	21,55	1,47	1,00	45,60	47,30	5,35	98,25	2,87	4,10	13,90	26,59	4,17	12,70	33,80
RC1+2	43,60	2,98	3,00	26,85	30,71	3,09	60,65	1,69	2,86	9,02	21,46	5,04	15,08	40,29
RC1+2+3	72,10	4,92	7,00	17,75	20,96	2,05	40,76	1,12	2,02	6,54	18,85	5,60	16,40	43,90
RC1+2+3+4	126,25	8,62	20,00	10,89	13,06	1,29	25,23	0,70	1,29	4,35	16,23	6,47	16,97	46,72
RC1+2+3+4+5	204,15	13,93	40,00	7,05	8,51	0,85	16,42	0,46	0,86	2,89	14,10	7,63	16,56	48,57

Cummulative	0	0	0	0	0	0	0	0	0	0	0
RC1	59,43	50,42	48,57	54,11	39,15	35,12	45,04	4,30	0,59	1,30	0,93
RC1+2	70,79	66,23	56,84	67,59	46,69	49,50	59,16	7,02	1,44	3,11	2,23
RC1+2+3	77,39	74,73	62,36	75,11	51,20	57,77	70,95	10,20	2,64	5,59	4,02
RC1+2+3+4	83,12	81,54	68,52	81,42	56,00	64,66	82,59	15,38	5,33	10,14	7,50
RC1+2+3+4+5	87,04	85,97	73,44	85,66	60,09	69,92	88,62	21,61	10,18	15,99	12,60

Water Recovery

Top up water

		C1	C2	C3	C4	C5	FEED	TAILS
TEST 14A	**CONC**	19,80	24,10	28,90	55,70	73,60		1285,50
	PAPER							
	CONC.	19,80	24,10	28,90	55,70	73,60	0,00	1285,50
	B + H2O initial	574,00	602,60	588,00	594,40	604,80		
	B + H2O final	471,50	572,00	371,90	128,70	81,80		
	WASH H2O	102,50	30,60	216,10	465,70	523,00		
	D + C + H2O	715,60	829,00	1096,60	2168,00	3098,30		
	DISH	480,40	476,20	503,00	433,80	509,40		
		235,20	352,80	593,60	1734,20	2588,90		
	H20 REC.	112,90	298,10	348,60	1212,80	1992,30		
						3964,70		

	Mass Rec	Water Rec		Cum mass	Cum water
C1	19,80	112,90		19,80	112,90
C2	24,10	298,10		43,90	411,00
C3	28,90	348,60		72,80	759,60
C4	55,70	1212,80		128,50	1972,40
C5	73,60	1992,30		202,10	3964,70
F	**1487,60**				
T	1285,50				
T2	0,00				
T3	0,00				
%mass rec		**13,585641**			

Top up water 8345,2

		C1	C2	C3	C4	C5	FEED	TAILS
TEST 14B	**CONC**	23,30	20,00	28,10	52,60	82,20		1236,50
	PAPER							
	CONC.	23,30	20,00	28,10	52,60	82,20	0,00	1236,50
	B + H2O initial	573,30	599,40	587,80	592,00	602,60		
	B + H2O final	468,60	435,90	377,00	259,20	74,50		
	WASH H2O	104,70	163,50	210,80	332,80	528,10		
	D + C + H2O	717,90	858,50	1143,40	1985,20	3213,70		
	DISH	480,40	476,20	503,00	433,80	509,40		
		237,50	382,30	640,40	1551,40	2704,30		
	H20 REC.	109,50	198,80	401,50	1166,00	2094,00		
						3969,80		

	Mass Rec	Water Rec		Cum mass	Cum water
C1	23,30	109,50		23,30	109,50
C2	20,00	198,80		43,30	308,30
C3	28,10	401,50		71,40	709,80
C4	52,60	1166,00		124,00	1875,80
C5	82,20	2094,00		206,20	3969,80
F	**1442,70**				
T	1236,50				
T2	0,00				
T3	0,00				
%mass rec		**14,292646**			

Average mass pull (g)	0	21,55	22,05	28,50	54,15	77,90
Cum mass pull (g)	0	21,55	43,60	72,10	126,25	204,15
St Dev.	0	1,75	0,30	0,70	2,25	2,05
Average H2O Rec. (g)	0	111,20	248,45	375,05	1189,40	2043,15
Cum H2O Rec. (g)	0	111,20	359,65	734,70	1924,10	3967,25
St Dev.	0	1,70	51,35	24,90	48,30	2,55

g mass pull(g)/ water rec (g)	0,19	0,09	0,08	0,05	0,04
	19,38	8,88	7,60	4,55	3,81

11.3.11. 3 SPW spiking with 150 ppm $S_2O_3^{2-}$ flotation data

				Grade											Recovery										
Products	Mass	Mass	Float time	Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2	Pt	Pd	Au	*2E+Au*	Cu	Ni	S	Fe_2O_3	Al_2O_3	MgO	SiO_2
	(g)	(%)	min	(g/t)	(g/t)	(g/t)	*(g/t)*	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
RC1	22,30	1,51	1,00	40,10	39,50	5,59	*85,19*	2,65	3,32	11,40	23,02	4,76	14,13	37,65	51,67	43,62	47,38	47,34	37,89	28,64	36,98	3,68	0,70	1,44	1,06
RC2	23,70	1,60	2,00	10,90	14,20	0,82	*25,92*	0,47	1,59	3,35	14,58	6,25	17,08	46,21	14,93	16,67	7,39	15,31	7,14	14,58	11,55	2,48	0,98	1,86	1,38
RC3	35,40	2,40	4,00	3,37	5,55	0,36	*9,28*	0,20	0,79	1,97	13,57	7,84	17,58	47,92	6,89	9,73	4,84	8,19	4,54	10,82	10,15	3,44	1,84	2,85	2,13
RC4	70,75	4,79	13,00	1,82	2,56	0,26	*4,64*	0,13	0,35	1,39	12,52	7,87	17,25	50,38	7,44	8,97	6,99	8,18	5,90	9,58	14,25	6,35	3,69	5,59	4,49
RC5	92,70	6,27	20,00	0,90	1,25	0,15	*2,30*	0,08	0,19	0,81	11,29	9,05	16,37	51,13	4,82	5,74	5,28	5,31	4,99	6,81	10,92	7,50	5,56	6,96	5,96
RC (calc.)	244,85	16,57		6,06	6,99	0,77	*13,82*	0,39	0,74	2,35	13,36	7,87	16,66	48,74	85,75	84,73	71,88	84,33	60,46	70,43	83,85	23,44	12,77	18,71	15,02
RT	1233,15	83,43		0,20	0,25	0,06	*0,51*	0,05	0,06	0,09	8,66	10,67	14,38	54,76	14,25	15,27	28,12	15,67	39,54	29,57	16,15	76,56	87,23	81,29	84,98
Head (calc.)	1478,00	100,00		1,17	1,37	0,18	*2,72*	0,11	0,17	0,47	9,44	10,21	14,75	53,77	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
Head (meas.)	1500,00			1,09	1,26	0,16	*2,58*	0,09	0,16	0,46	9,32	10,47	13,56	51,45											
Variance (%)	*0*			*7*	*8*	*15*	*5*	*23*	*13*	*1*	*1*	*2*	*9*	*5*											

Cummulative		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RC1	22,30	1,51	1,00	40,10	39,50	5,59	85,19	2,65	3,32	11,40	23,02	4,76	14,13	37,65	51,67	43,62	47,38	47,34	37,89	28,64	36,98	3,68	0,70	1,44	1,06
RC1+2	46,00	3,11	3,00	25,06	26,47	3,13	54,65	1,53	2,43	7,25	18,67	5,53	15,65	42,06	66,60	60,29	54,76	62,65	45,03	43,22	48,53	6,15	1,69	3,30	2,43
RC1+2+3	81,40	5,51	7,00	15,62	17,37	1,93	34,92	0,95	1,72	4,96	16,45	6,53	16,49	44,61	73,49	70,02	59,60	70,83	49,57	54,03	58,68	9,60	3,52	6,15	4,57
RC1+2+3+4	152,15	10,29	20,00	9,21	10,48	1,15	20,84	0,57	1,08	3,30	14,62	7,15	16,84	47,29	80,93	78,99	66,60	79,02	55,47	63,61	72,93	15,94	7,21	11,75	9,05
RC1+2+3+4+5	244,85	16,57	40,00	6,06	6,99	0,77	13,82	0,39	0,74	2,35	13,36	7,87	16,66	48,74	85,75	84,73	71,88	84,33	60,46	70,43	83,85	23,44	12,77	18,71	15,02

Water Recovery

Top up water 11129,4

		C1	C2	C3	C4	C5	FEED	TAILS
TEST 15A	**CONC**	23,90	22,80	39,40	81,80	95,20		1194,50
	PAPER							
	CONC.	23,90	22,80	39,40	81,80	95,20	0,00	1194,50
	B + H2O initial	572,00	598,90	586,00	593,10	602,20		
	B + H2O final	389,90	476,00	419,80	303,20	83,70		
	WASH H2O	182,10	122,90	166,20	289,90	518,50		
	D + C + H2O	771,00	888,30	1284,90	2373,60	3492,80		
	DISH	480,40	476,20	503,00	433,80	509,40		
		290,60	412,10	781,90	1939,80	2983,40		
	H20 REC.	84,60	266,40	576,30	1568,10	2369,70		
						4865,10		

	Mass Rec	Water Rec	Cum mass	Cum water
C1	23,90	84,60	23,90	84,60
C2	22,80	266,40	46,70	351,00
C3	39,40	576,30	86,10	927,30
C4	81,80	1568,10	167,90	2495,40
C5	95,20	2369,70	263,10	4865,10
F	**1457,60**			
T	1194,50			
T2	0,00			
T3	0,00			
%mass rec		**18,05022**		

Top up water 6455,2

		C1	C2	C3	C4	C5	FEED	TAILS
TEST 15B	**CONC**	20,70	24,60	31,40	59,70	90,20		1271,80
	PAPER							
	CONC.	20,70	24,60	31,40	59,70	90,20	0,00	1271,80
	B + H2O initial	572,40	602,20	587,20	592,80	602,10		
	B + H2O final	442,80	462,20	407,10	227,90	122,30		
	WASH H2O	129,60	140,00	180,10	364,90	479,80		
	D + C + H2O	694,20	927,30	1239,40	2235,20	3482,40		
	DISH	480,40	476,20	503,00	433,80	509,40		
		213,80	451,10	736,40	1801,40	2973,00		
	H20 REC.	63,50	286,50	524,90	1376,80	2403,00		
						4654,70		

	Mass Rec	Water Rec	Cum mass	Cum water
C1	20,70	63,50	20,70	63,50
C2	24,60	286,50	45,30	350,00
C3	31,40	524,90	76,70	874,90
C4	59,70	1376,80	136,40	2251,70
C5	90,20	2403,00	226,60	4654,70
F	**1498,40**			
T	1271,80			
T2	0,00			
T3	0,00			
%mass rec		**15,122798**		

Average mass pull (g)	0	22,30	23,70	35,40	70,75	92,70
Cum mass pull (g)	0	22,30	46,00	81,40	152,15	244,85
St Dev.	0	1,60	0,70	4,70	15,75	18,25
Average H2O Rec. (g)	0	74,05	276,45	550,60	1472,45	2386,35
Cum H2O Rec. (g)	0	74,05	350,50	901,10	2373,55	4759,90
St Dev.	0	10,55	0,50	26,20	121,85	105,20

g mass pull(g)/ water rec (g)	0,30	0,09	0,06	0,05	0,04
	30,11	8,57	6,43	4,80	3,88

APPENDIX B