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**Research Article**

# An Assessment of the Flotation Response of a PGM Scavenger Bank at Varying Reagent Dosages

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## Abstract

The behavior of a scavenger flotation bank of an industrial PGM concentrator was studied towards improving overall flotation efficiencies. The six-cell scavenger bank was selected for the study as it is most likely that most PGM minerals that go into the scavenger bank are slow floating. Comparison of the slow floating ratios (SFRs) across the six scavenger cells in series showed relatively high SFRs for the first four cells, suggesting good float abilities. The SFR reduced drastically in Cell 5 due to either depleted reagents or diminished mineral content, making this cell a suitable candidate for reagent boosting. The effect of depressant and collector dosages on grade and recovery of the feed to scavenger Cell 5 was established from batch flotation tests. Addition of depressant to the feed of cell 5 of the scavengers increased slow floating ratio (SFR) from 6.21 to about 11 at a dosage of 25 g/t, which brought the performance of cell 5 to the same level as of the preceding cells. Recovery and grade were also best at 25 g/t depressant dosage. Depressant addition had a more significant effect on the SFR and improved the flotation recovery of slow floating mineral species. Collector addition was associated with faster flotation kinetics with collector dosage of 60 g/t giving the best kinetics; however, collector addition had minimal effect on the SFR. The flotation kinetic data from the Cell 5 feed batch flotation tests was modeled. The five-parameter modified Kelsall model, showed the best fit to the experimental results.

**Keywords:** Flotation; PGMs, Scavenger; Recovery; Kinetics; Slow-floating ratio

## Introduction

Platinum group of metals (PGMs) are generally associated with base metal sulphides. These base metal sulphides are mainly concentrated by froth flotation, a selective process in which minerals are separated according to their physico-chemical surface properties [1]. Simple treatment of the minerals with specific chemicals will make some minerals hydrophilic and others hydrophobic. Passing or injecting air through the mineral containing slurry and simultaneously agitating the tank creates bubbles. The impeller creates the bubbles by shearing action and disperses them throughout the volume of the cell. The hydrophobic particles attach themselves to air bubbles and get ‘floated’ to the surface of the pulp.

The floatable mineral species can be classified as fast-floating and slow-floating. Fast floating species are those mineral particles that are well liberated and or contain exposed mineral species that are easily rendered hydrophobic by flotation collectors while slow floating species either not well liberated or contain minerals species that not very hydrophobic. It has been shown that recovery of the slow floating fractions is dependent on the kinetic differential between slow floating minerals and slow floating gangue [2]. This differential is termed the slow floating ratio (SFR) which is defined as the fraction of the slow floating rate constant for PGMs to the slow floating rate constant for slow floating or entrained gangue (KPS/KGS). SFR is an indicator of the relative float abilities of the slow floating value bearing minerals and slow floating gangue species. However, for the ore under investigation in this current study most of the floatable PGMs are associated with sulphide minerals. A higher SFR is indicative of higher kinetics of the slow floating mineral fractions relative to the slow floating gangue. The SFR is affected by factors such as mineralogy, and the degree of liberation and manipulating the SFR is known to improve the overall recovery

[2]. Hay [2] reported improved grade and recovery at the cleaner cells after manipulating the SFR by depressant additions. Since the cleaner cells are mainly composed of the fast-floating species, it was important to verify whether the same improvements in grade and recovery could be observed at the scavenger bank where the slow floating species are the dominant species and this forms the hypothesis and basis of this current study. To study this effect, investigations were done on the response of the SFR on collector and depressant additions. It is also known that depressants and collectors interact directly with the mineral or gangue particles, so adding them influences the differential kinetics between the mineral and slow floating or entrained gangue particles. In order to calculate SFR, the batch flotation rate data from the experiments is imported to Kincalc®, which is proprietary software used in this study, details for the Kincalc® calculator software are provided in the manual explained in [2]. The kinetic parameters relating to Kelsall's unmodified equation (Kelsall, 1961) were generated by the Kincalc® software program and calculator gives the kinetic ratios like the slow float ratio (SFR).

The work presented in this study involves investigation of ways of improving recovery of slow floating minerals at a MF1 Platinum Group Metal milling and flotation plant in the Great Dyke of Zimbabwe. This study was conducted with an aim of improving flotation of PGMs by measuring the slow floating ratio (SFR) and analyzing the effect on grade and recoveries as dosages of flotation reagents are altered. The fast-floating fractions are usually recovered earlier on in the flotation circuit whilst the slower floating values are recovered at the back end of the circuit in the scavengers. The work presented here investigates the use of reagents in improving flotation kinetics of the slow floating fraction and improve its recovery in this part of the circuit to prevent the values being lost with the tailings. Batch flotation rate tests were conducted on "in plant pulp" sampled from the scavenger where the slow floating fraction was most likely to be present.

Some kinetic modelling work was also undertaken, existing flotation models were used on the data generated from the study, in addition to the already existing models, the results from this study were also tested against the expanded version of the Kelsall modified equation that has not been reported elsewhere.

## Modeling Theory

Batch flotation tests in literature have confirmed first order kinetics (Imauzami, 1963; Tomilson and Fleming, 1965; Harris and Chakravarti, 1970; Jameson et. al., 1977; Dowling et. al., 1985; Rastogi et. al.; 1985). In continuous flotation processes, first order kinetics have also been proven (Jowett and Safvi, 1960; Barnwal et. al., 2006). There are several first order flotation models that have been dev eloped by several researchers:

1. **Classical model [3]**

$$\frac{dc_{ij}}{dt} = -K_{ij}c_{ij} \qquad [1]$$

2. **Klimpel model [4]**

$$R = R_{\infty}\left(1-\frac{1}{kt}\left(1-e^{-kt}\right)\right) \qquad [2]$$

3. **Kelsall (unmodified) model [5]**

$$R = \left(1-\varphi\right)\left(1-e^{-kf^{t}}\right)+\varphi\left(1-e^{-ks^{t}}\right) \qquad [3]$$

4. **Kelsall (modified) model [6]**

$$R = \left(R_{\infty}-\varphi\right)\left(1-e^{-kf^{t}}\right)+\varphi\left(1-e^{-ks^{t}}\right) \qquad [4]$$

5. **Gamma model [7]**

$$R = R_{\infty}\left[1-\left[\frac{k}{k+t}\right]^{P}\right] \qquad [5]$$

6. **Fully mixed model [7]**

$$R = R_{\infty}\left[1-\left[\frac{1}{1+\frac{t}{k}}\right]\right] \qquad [6]$$

where: $C_{ij}$ = concentration of subclass j in mineral species i, $K_{ij}$ = flotation rate constant of subclass j, R = recovery of mineral (%), $R_{\infty}$ = recovery at infinite time (%), k = rate constant representing the largest allowable value of a rectangular distribution ($min^{-1}$) and t = flotation time, $k_f$ = fast-floating rate constant ($min^{-1}$), $k_s$ = slow-floating rate constant ($min^{-1}$), φ = slow-floating fraction and t = time (min).

The development of these models was described in previous work [3-5,7,8].

### Five-parameter modified Kelsall model development

Prior to fitting, the Modified Kelsall model (Equation 4), the equation was adjusted by inclusion of the fast-floating fraction of PGMs, $I_{PF}$ and the non-floating fraction, IPN:

From the definition of recovery:

$$R_{\infty} = 1 - I_{PN} \qquad [7]$$

where: $I_{PN}$ is the fraction of non-floating PGMs, such that:

$$I_{PF}+I_{PS}+I_{PN} = 1 \qquad [8]$$

Thus, $I_{PN}$ can be incorporated into Equation 4, as follows.

$$R = (1-I_{PN}-I_{PS})(1-e^{-kf^{t}})+I_{PS}(1-e^{-ks^{t}}) \qquad [9]$$

By making $I_{PF}$ subject of formula in Equation 8:

$$\Rightarrow R = (I_{PF})(1-e^{-kf^{t}})+I_{PS}(1-e^{-ks^{t}}) \qquad [10]$$

$$\Rightarrow R = I_{PF}-I_{PF}\cdot e^{-kf^{t}}+I_{PS}-I_{PS}\cdot e^{-ks^{t}} \qquad [11]$$

By making $I_{PN}$ subject of formula in Equation 8:

$$\therefore R = 1-I_{PF}\cdot e^{-kf^{t}}-I_{PS}\cdot e^{-ks^{t}}-I_{PN} \qquad [12]$$

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Equation 12 was used to calculate the flotation parameters, within the following boundary conditions:

$I_{PF} + I_{PS} + I_{PN} = 1.$

$K_{PF} > K_{PS}$

## Materials and Methods

This section can be also divided by subheadings. Provide sufficient detail to allow the work to be reproduced. Methods already published should be indicated by a reference: only relevant modifications should be described.

### Scavenger cell bank – boundary under investigation

The schematic diagram of the flotation plant from which the scope of the current study was generated is shown in Figure 1. The flotation process follows a milling process in a MF1 (mill-float) arrangement. The investigations in this study focused on the scavenger bank of this circuit. The layout of the six-cell scavenger bank that was evaluated in this work is shown in Figure 2.

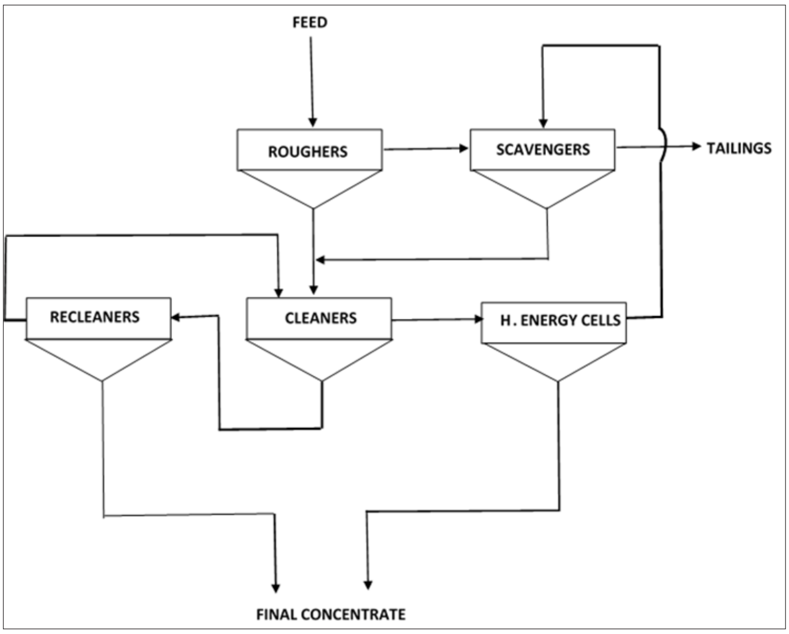

**Figure 1:** Schematic diagram for the PGM concentrator section.

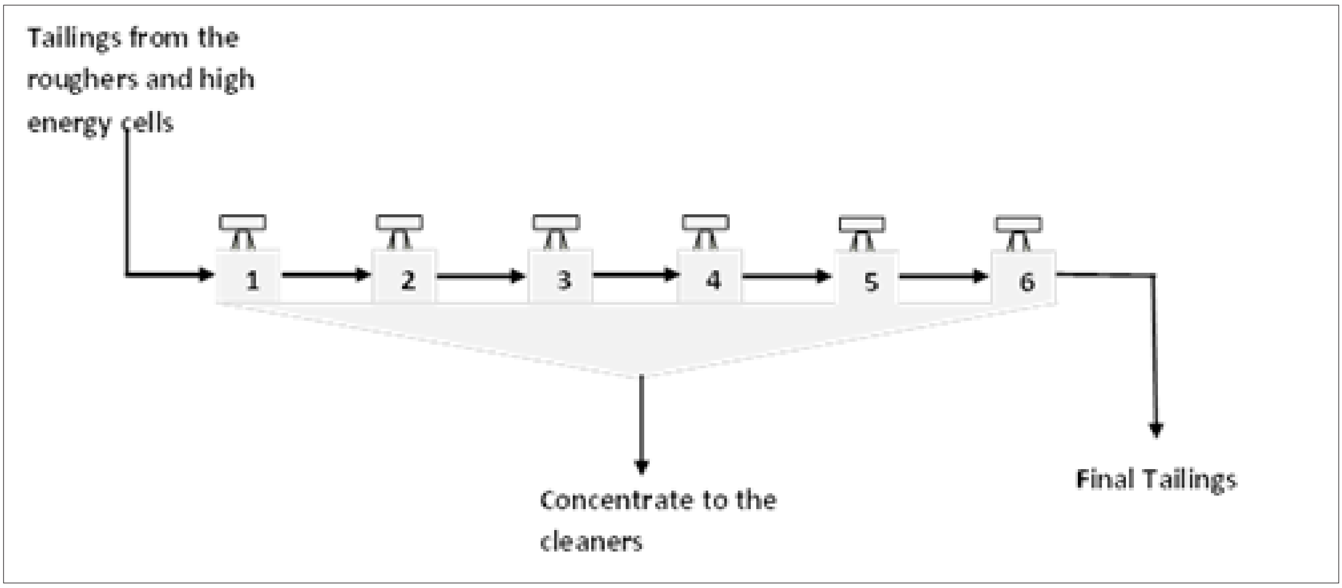

**Figure 2:** Schematic for the six-cell scavenger bank under investigation.

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The scavenger bank is made up of six equisized 16 $m^3$ induced-air cells controlled by a SCADA system. The pulp level in the cells is regulated using dart valves and the pH of the pulp phase in the scavenger bank was maintained between 8 and 10.

### Particle size distribution of flotation plant feed

The mill product (feed to the flotation plant) was dried and subjected to sieve analysis to obtain the particle size distribution (PSD). The particle size distribution is shown in Figure 3. Fine grinding was achieved as ~80% of the feed is -38 μm in size, this grind after, mineral liberation analysis, was considered adequate for the flotation of PGMs and hence regrinding for further liberation was not done in the flotation plant.

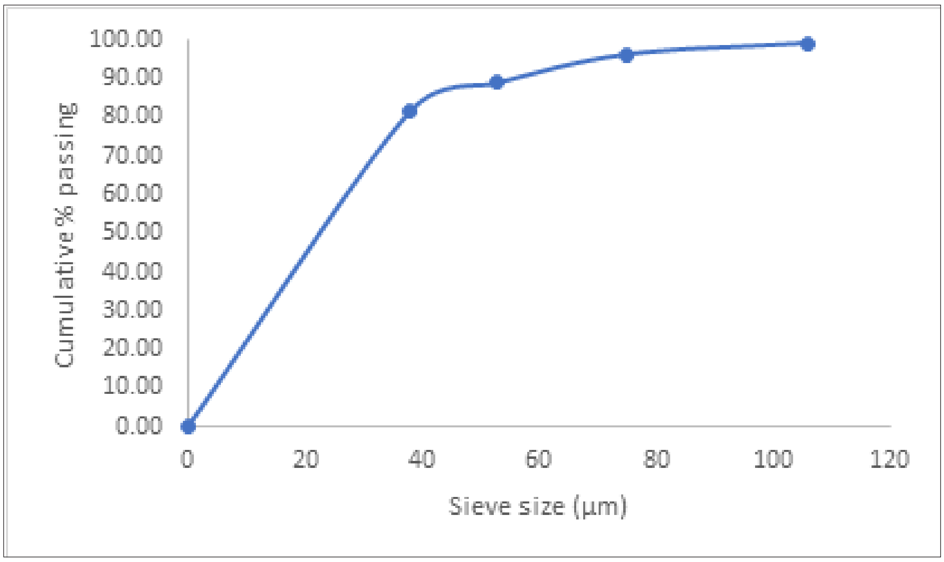

**Figure 3:** Particle size distribution (PSD) of the floatation plant feed.

### Sampling procedure

Sampling was carried out using sample cutters on a) feed to scavenger bank, c) final tailings from the bank and d) combined concentrate to the cleaners. The Inter-cell sampling between the respective scavenger cells was done on the corresponding concentrate and tailing streams. The concentrate was sampled from the cell launder using a lip sampler. The tailings stream was sampled using a dip sampler that was lowered into the cell. When the sampler was next to the tailings exit port, the lid of the sampler was opened by pulling a rope to collect the tailings sample. Samples collected over a shift were combined to form a composite sample that represents the stream in question. A sample of 1000 $cm^3$ was collected from each stream at intervals of 30 minutes and added to the sample bucket. In total 16 samples were collected as a composite per stream every 8-hour shift. The standard operating procedure required a composite of at least 6 samples to be taken over a 3-hour period to be considered as representative. Care was taken to obtain an adequate size of composite sample in order to enable the standard triplicate tests to be done and still maintain a contingency sample.

### Sample preparation for lab test work

The composite samples obtained from the flotation plant were transferred to the flotation lab in the sample holding buckets. Sedimentation occurred in transferring the samples from the plant to the flotation lab. The samples to be floated were re-agitated using a Denver D12 impeller to suspend the particles in order to obtain a homogenous slurry of pulp density about 30% solids by mass.

### Flotation reagents

The reagents used in the lab for the batch rate flotation test-work were SIBX (Sodium Isobutyl Xanthate) as a collector and CMC (Carboxyl Methyl Cellulose) as a depressant. Fresh solutions of SIBX collector were prepared daily by mixing the SIBX powder with de-ionized water to produce 1% solution strength and similarly, the depressant solutions were prepared by dissolving the granular CMC powder in de-ionized water to produce a 0.1% solution strength.

The variation of frother dosage was not investigated since frothers mainly influence bubble and froth stability, and it was also considered that the frother dosage added at the high energy cells was sufficient to give a reasonably stable froth at the scavenger bank.

### Batch flotation rate test - phase 1

The 1st phase of the flotation test-work involved sampling the "as is" feeds to the 6 scavenger cells of the scavenger bank (Figure 2). Laboratory batch flotation rate tests were carried out on the feed to each of the scavenger cells without addition of any flotation reagents. The homogenized slurries were transferred to a 2.5 l flotation cells and agitated using a Denver flotation machine set at 1200 rpm, with air inlet closed for about 60 s before air was introduced for flotation to resume. The froth was scrapped off every 15 s, and four sets of concentrates were collected at 120, 360, 900 and 1800 seconds. The dried samples were weighed for the construction of mass balance tables. The concentrates and tailings samples obtained from the flotation rate tests were then assayed for PGM content using NiS fire assay procedure with ICP-OES finish.

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The kinetic results of these batch rate tests were imported into Kincalc® software a (proprietary software) which calculates the Slow Float Ratio (SFR) from the data.

- **Use of Kincalc® to calculate SFR - Kincalc® Capabilities**

The first set of batch flotation tests were rate tests performed on the cell feeds to the six scavenger cells under identical conditions. These tests were aimed at identifying the most suitable scavenger cell for reagent dosage addition or boosting. Once flotation rate (recovery vs time and mass pull vs time) data from the experiments was imported to Kincalc®, the software or program kinetic generated parameters relating to Kelsall's unmodified equation [5]. The Kincalc® calculator gives the calculation of kinetic ratios like the slow float ratio (SFR) and cumulative recovery, grade and mass pull graphs and head grade.

The kinetic parameters were determined by fitting the experimentally obtained data into the Kelsall's unmodified rate equation using the KinCalc® flotation kinetics calculator. Details for the Kincalc® calculator are provided in the manual by [2]. The main parameter of interest in this study was the slow floating ratio (SFR). SFR is the fraction of the slow floating rate constant for PGMs to the slow floating rate constant for slow floating gangue (KPS/KGS).

From the definition of SFR, a higher SFR corresponds to higher kinetics for the slow floating PGM species relative to that for the slow floating. Thus, SFR was used to identify the specific scavenger cell within the bank where reagent addition or boosting will be most effective.

### Batch flotation rate test - phase 2

Phase 2 of the laboratory rate tests were carried out on "as-received" feed to Cell 5 of the scavenger bank. Cell 5 was found to be the most appropriate cell within the bank to add/boost reagents on the basis of results from the phase 1 flotation rate tests. The slurry feed to Cell 5 was floated at various depressant and collector dosages. Reagent conditioning was done for 60 s before air was introduced for flotation to resume. The same method described in the batch flotation rate tests phase 1 was followed in this phase of the test-work. The experimental matrix for batch flotation test phase 2 is summarized in Table 1.

**Table 1:** Experimental matrix for the flotation batch tests on each scavenger cell feed.

| Experiment | CMC Dosage (g/t) | SIBX Dosage (g/t) | Time (s) |
|---|---|---|---|
| 1 | - | - | 1800 |
| 2 | 25 | - | 1800 |
| 3 | 50 | - | 1800 |
| 4 | 100 | - | 1800 |
| 5 | - | 30 | 1800 |
| 6 | - | 60 | 1800 |

## Results and Discussion

### Batch flotation rate test phase 1 - Scavenger cell selection for reagent dosage addition

The Kincalc® software was used to calculate SFRs using the recovery-time data from the floatation rate tests done on feed samples to every flotation cell across the entire scavenger bank, the results are as shown in Figure 4.

Figure 4 shows that SFR was low in the feed to the first cell, increased to maximum in the second cell and plateaued off until the fourth cell. There was marked decrease in the SFR beyond the fourth scavenger cell to the last cell.

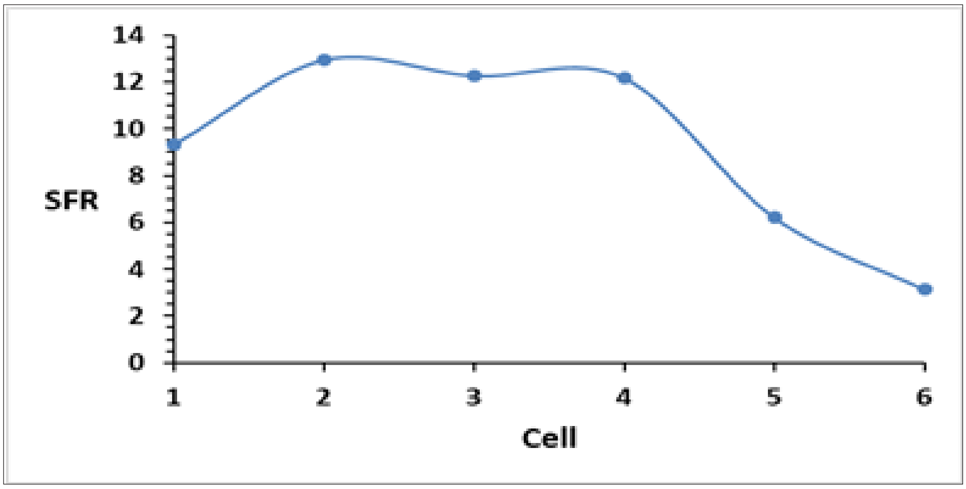

**Figure 4:** Slow Float Ratios across the six cells of the scavenger bank of the PGM concentrator.

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Since scavenger feed was composed of tailings from the rougher and high energy cells, it may have still contained some residual fast-floating mineral species from the previous banks. Since the fast floating species get depleted in preference to the slow floating species during flotation [2], it is likely that the first cell of the scavenger bank contained more fast floating mineral species which were preferentially floated to slow float species accounting for the low slow floating ratio observed in the first scavenger cell. As the fast-floating fraction diminishes in the next scavenger cells i.e. second and third cells, the SFR increased, and between the second and the fourth cells the slow floating minerals were being effectively floated. It was therefore strategic to boost reagents at the feed to scavenger cell five where the SFR decreased remarkably.

## Batch flotation rate test phase 2 – Effect of reagents and dosages on Cell 5 flotation performance

**Effect of depressant (CMC) addition on PGM grade and recovery of the feed to the scavenger cell 5:** Figure 5 shows results of cumulative recovery of PGM minerals as a function of time at depressant dosages of 0, 25, 50 and 100 g/t. The cumulative recovery increased with depressant dosage from 0 to 50 g/t and at dosages of 100g/t, the recovery drastically dropped to levels below that which were achieved without any depressant addition.

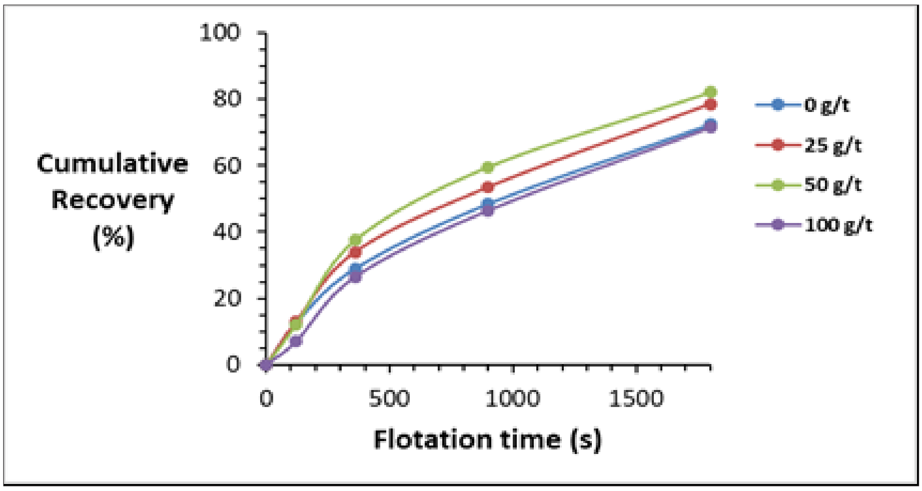

**Figure 5:** Cumulative recovery as a function of time at different depressant dosages.

The recovery vs time profiles for the flotation of cell 5 feed at different depressant dosages shows a gentle gradient without the common steep accent in the initial stages of flotation, this is indicative of slow floating material. The maximum cumulative PGM recovery obtained during flotation rate test for the as-received cell 5 feed without addition of depressant i.e. 0 g/t CMC was 73.7%. The highest recovery of 82% was obtained with 50 g/t depressant dosage. Depressant additions of 100 g/t resulted in a recovery drop to ~71.5%, most likely due to the inhibiting effect of excess depressant on the flotation of values. The decrease in recoveries with depressant additions have also been observed in previous work [9,10].

Figure 6a shows the plots for cumulative grade, generally, the grade decreased with time for all depressant dosages. The general grade differential between the initial and final concentrates was ~5 g/t, this small difference is indicative of minimal contamination of the concentrate by gangue as a result of depressant addition. The depressant dosage of 25 g/t gave the highest concentrate grade. The regions in the graph where the grade is high corresponds to much higher uptake of values minerals relative to the gangue species. This suggests that the depressant dosage caused the mineral values to be preferentially floated in the early stages of the test when the depressant acts effectively on the gangue minerals.

However excessive depressant additions generally inhibit value mineral recovery [11]. In addition to inhibiting flotation of entrained gangue species, excess depressant additions create a highly inactive slurry atmosphere with a higher proportion of the mineral surfaces being coated with the depressant [12]. As a result, the value mineral surfaces also become unavailable for attachment to the air bubbles depressing recovery significantly.

The grade-recovery curves (Figure 6b) show the expected inverse relationship. The results also show that 25g/t depressant dosage gives the highest grades of concentrate at any given recovery followed by 50 g/t dosage. When considerations of cost and performance are made the optimum depressant dosage would be 25 g/t.

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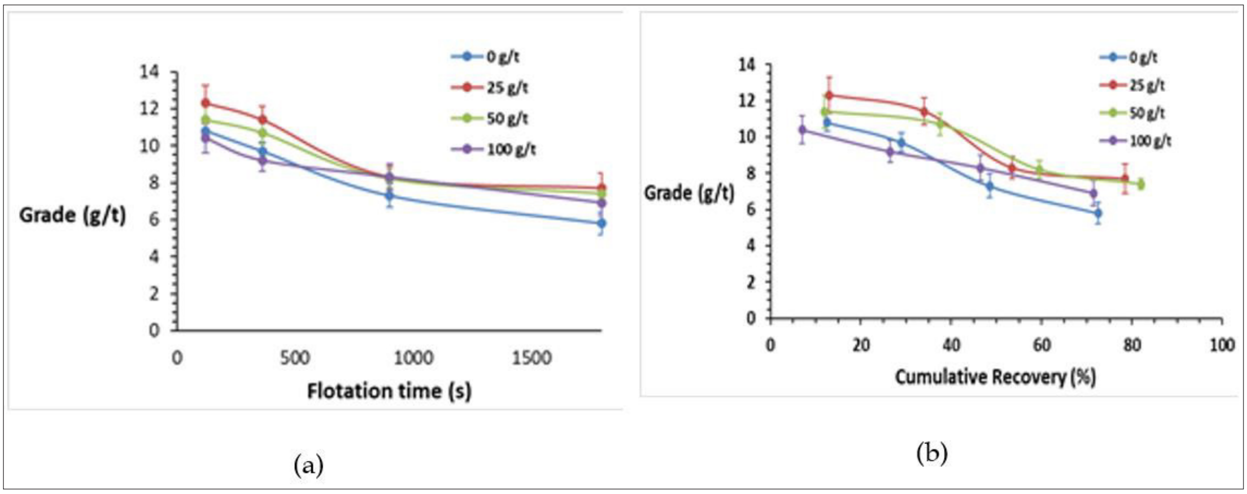

**Figure 6:** a) Grade as a function of time at different depressant dosages, b) Grade-recovery relationships for various depressant dosages.

**Effect of collector (SIBX) addition on PGM grade and recovery of the feed to scavenger cell 5:** The collector dosage was varied from 0, 30 and 60 g/t. The recovery-time curves are shown in Figure 7 and the results demonstrate that the higher the collector dosage the higher the recovery. The higher collector dosages also caused a significant increase in the flotation kinetics as seen from the gradient of the graphs for 30 g/t and 60 g/t in the first 200s. compared to that of 0 g/t and suggests that increased collector strength improves the rate of uptake of slow floating values. Although 60 g/t collector dosage initially gave a faster flotation response, the final recovery obtained at the end of the test was comparable to that obtained with 30 g/t.

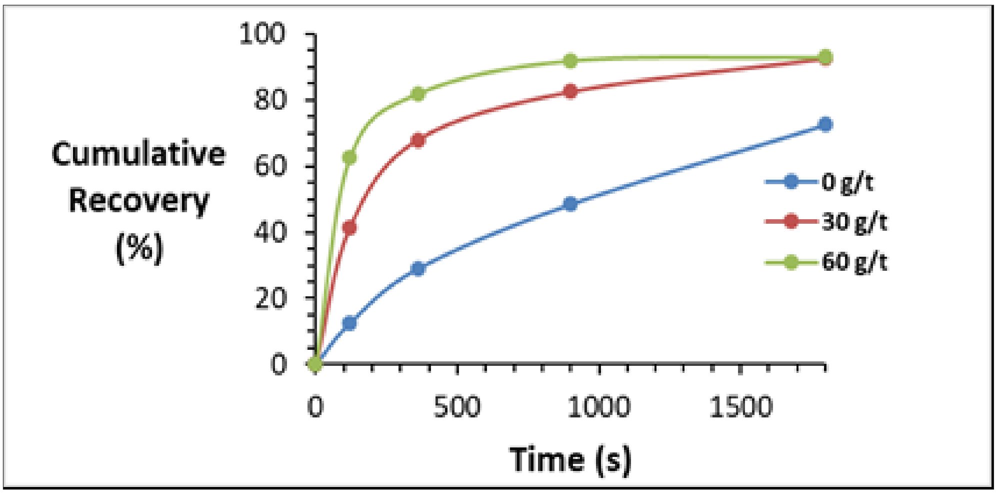

**Figure 7:** Cumulative recovery as a function of time at various collector dosages.

Figure 8a shows the corresponding cumulative grade as a function of collector dosage. The concentrate grades obtained with collector addition are significantly higher than those obtained with just the addition of depressant, as seen in Figure 6 (a). Figure 8 (a) shows there was a gentle drop in the concentrate grade with time at all the collector dosages suggesting that as flotation progressed, values were being depleted and this was accompanied by a steady increase in the relative uptake of gangue material. The collector dosage of 30 g/t collector resulted in a higher concentrate grade compared to dosages of 0 g/t and 60 g/t.

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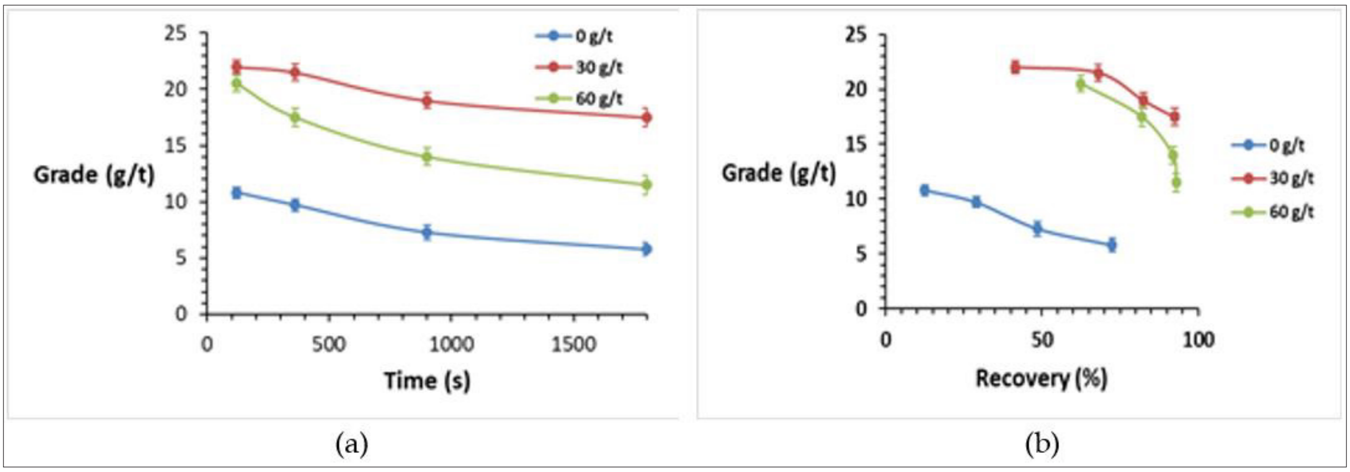

**Figure 8:** a) Grade as function of time at different collector dosages, b) Grade-recovery relationships at different collector dosages.

The 60g/t dosage resulted in the highest-grade differential between the initial and final concentrate than for the other collector dosages. This suggests that the higher collector dosage led to a rapid increase in the uptake of gangue material by either aggressively floating the floatable gangue or by increasing entrainment. The misreporting of gangue particles due to increased hydrophobicity caused by high collector additions was also reported by Duarte & Grano [13]. Typical grade recovery curves were also observed for this test-work as seen in Figure 8b. The results show a clear advantage of the collector dosage of 30g/t which records the highest grades at any given recovery and the drop-in grade as recovery increases is the smallest indicating that there is minimal pull of gangue to the concentrate as flotation progresses.

**Effect of depressant (CMC) and collector (SIBX) addition on the Slow Float Ratio (SFR) in Cell 5:** The recovery vs time data from batch flotation rate test 2 was imported from Excel into Kincalc®. Kincalc® calculated the kinetic parameters of the Kelsall's unmodified equation by data fitting using linear regression. The selected parameters that were generated from the software were;

$K_{PF}$ = fast floating rate of PGMs

$K_{PS}$ = slow floating rate of PGMs

$K_{GF}$ = fast floating rate of entrained gangue

$K_{GS}$ = slow floating rate of entrained gangue

The values obtained above were used to calculate the slow floating ratio (SFR), as shown in Table 2.

**Table 2:** Summary of Kelsall Parameters for tests on scavenger Cell 5 feed as calculated from the Kincalc®.

| Flotation Parameter | As-Received | Depressant Additions | | | Collector Additions | |
|---|---|---|---|---|---|---|
| | No reagents added | 25 g/t | 50 g/t | 100 g/t | 30 g/t | 60 g/t |
| KGF | 0.0247 | 0.0507 | 0.0661 | 0.0282 | 0.3807 | 0.3909 |
| KGS | 0.0041 | 0.0009 | 0.00311 | 0.0031 | 0.0087 | 0.0087 |
| KPS | 0.0252 | 0.01 | 0.0316 | 0.0185 | 0.044 | 0.0562 |
| KPF | 0.4777 | 0.1558 | 1.36 | 0.4808 | 0.6482 | 1.9694 |
| SFR | 6.21 | 10.95 | 10.16 | 5.92 | 5.01 | 6.47 |

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Figure 9a shows the variation of SFR with increasing depressant addition. As can be seen the slow floating ratio initially increased with depressant addition up to 25 g/t and further depressant additions resulted in a decrease in SFR. This suggests that the dosage of 25 g/t gives the best recovery rate, and this is in line with the results of recovery vs time graph which showed superior recovery performance at 25 g/t depressant dosage. These results mean that In the absence of collector addition the depressant dosage of 25 g/t improves the flotation and recovery of slow floating PGM minerals as it gives higher SFR [14].

Figure 9b shows that there is no significant change in the SFR with increase in the collector dosage as the SFR across all collector dosages remain in the range between about 5-6. The magnitudes of the SFRs obtained with collector addition are much lower than those obtained with depressant addition suggesting that depressant addition has a much greater influence on flotation and recovery of slow floating species than collector addition.

The addition of depressant dosage of 25 g/t on the feed to cell 5 increases the SFR from about 6 to 11 which is almost double, see Figure 9(a). The SFR of 11 suggests that the performance of cell 5 would have been improved to the levels of performance of cell 2,3 and 4 according to Figure 3 by addition of depressant to cell 5, this impact is illustrated in Figure 10 [15].

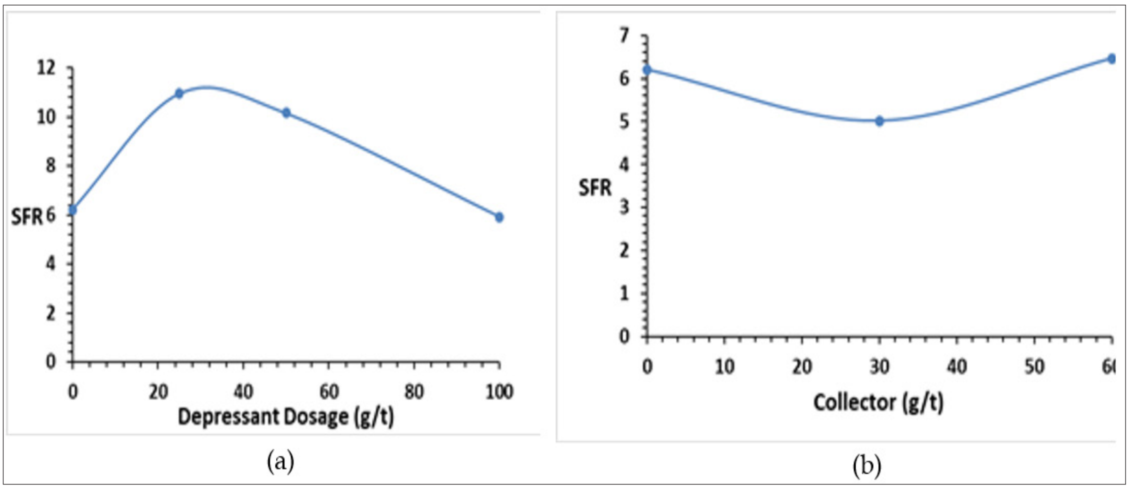

**Figure 9:** Variation of SFR with a) depressant dosage, b) collector dosage.

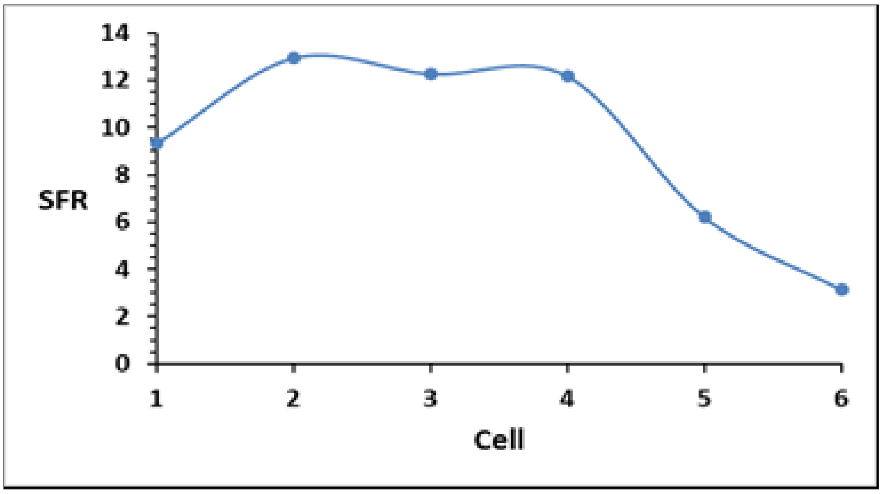

**Figure 10:** The impact of adding 25g/t depressant to the SFR of cell 5.

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## Modeling - Identification of the most applicable model by determination of flotation parameters

**Model fitting of data:** Four first order flotation models Modified Kelsall Model, Fully Mixed Model, Klimpel Model and Classical Model fitted into the experimental results using the generalized reduced gradient code of the Excel Solver function [16].

It can be seen from Figures 11 to 13 that the kinetics of flotation of the Cell 5 feed were near first order. The $R^2$ values for each of the model at each reagent dosage are shown in Table 3.

**Table 3:** Regression values for the first order models against the experimental recovery results.

| Model | As-Received | Depressant Additions | | | Collector Additions | |
|---|---|---|---|---|---|---|
| | | 25 g/t | 50 g/t | 100 g/t | 30 g/t | 60 g/t |
| Classical | 0.9855 | 0.9886 | 0.9947 | 0.9947 | 0.9863 | 0.9933 |
| Klimpel | 0.9889 | 0.9917 | 0.996 | 0.9962 | 0.9967 | 0.9993 |
| Fully mixed | 0.9924 | 0.9921 | 0.996 | 0.9954 | 0.9993 | 0.9996 |
| Modified Kelsall | 0.9992 | 0.9963 | 0.9947 | 0.9947 | 0.997 | 1 |

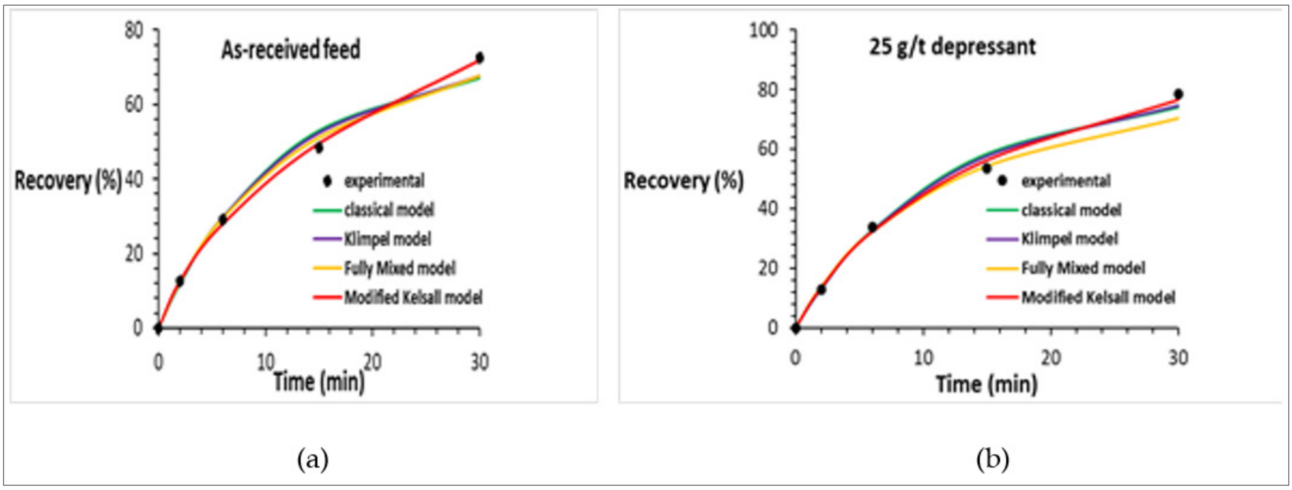

**Figure 11:** Comparison between experimental and model recoveries for a) as-received feed, b) 25 g/t depressant additions.

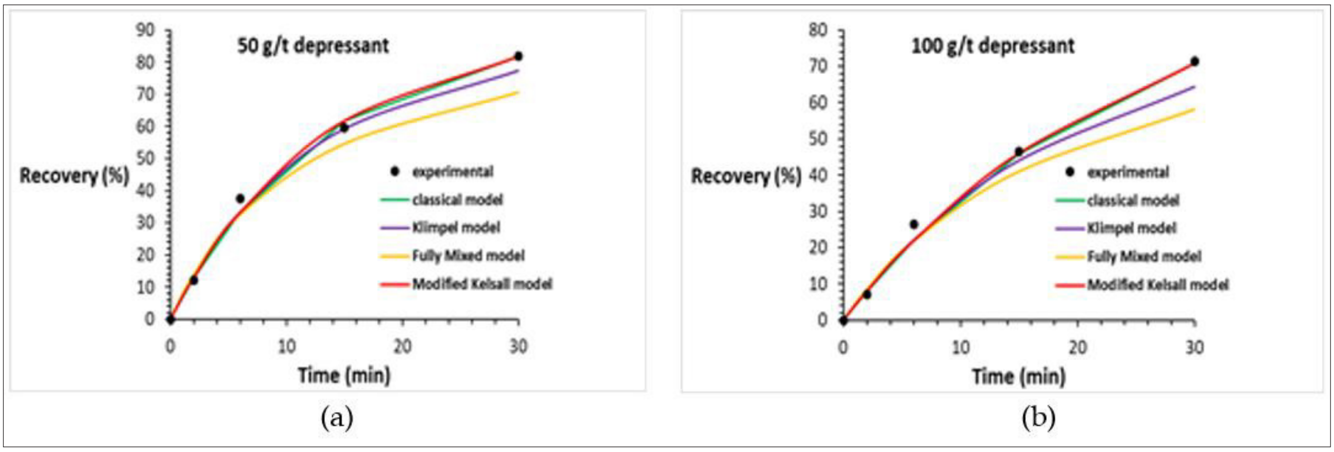

**Figure 12:** Comparison between experimental and model recoveries for a) 50 g/t depressant additions, b) 100 g/t depressant additions.

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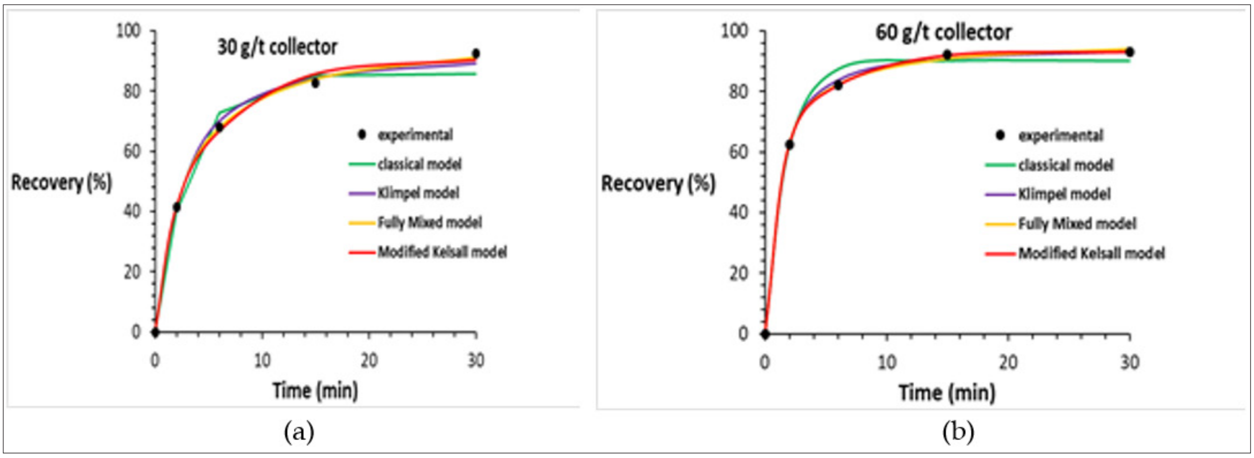

**Figure 13:** Comparison between experimental and model recoveries for a) 30 g/t collector additions, b) 60 g/t collector additions.

All the four sets of predicted results had reasonably good correlation with experimental results. The Fully Mixed and Modified Kelsall models had a highest correlation, with all $R^2$ values greater than 0.9990. However, the Modified Kelsall model had the best correlation and this suggests that it the best predictor of the flotation process and therefore a more reliable source of the flotation parameters [17-19].

## Conclusion

Recovery of slow-floating PGMs plays an important role on the overall recoveries of a flotation plant. Optimization of reagent dosage across the circuit is essential in achieving the maximum possible recovery. The slow floating ratio (SFR) was calculated using the Kincalc®, and the calculator is based on the Kelsall unmodified equation. This ratio indicates the relative floatability of slow floating mineral to slow floating entrained gangue and was used to compare the relative effects of different reagent dosages. Analysis of the SFR of the "as is" scavenger cells demonstrated that SFR significantly dropped in cell 5 making this cell a suitable candidate for reagent addition or boosting.

Addition of depressant to the feed of cell 5 of the scavengers increased slow floating ratio (SFR) from 6.21 to about 11 at a dosage of 25 g/t which brings the performance of cell 5 to be at par with that of the preceding cells. Recovery and grade were also best at 25 g/t depressant dosage than at other dosages tested. The results show that depressant addition has a more significant effect on the SFR and thus improves the flotation recovery of slow floating mineral species. Collector addition to the scavenger cell 5 feed were associated with faster flotation kinetics with collector dosage of 60 g/t giving the best kinetics, however collector addition had minimal effect with SFR. The projection from cell 2 to 4 suggests that an elevation of SFR in cell 5 by reagent additions will likely improve Cell 6 performance as will likely boost floatability in cell 6.

The kinetics of the process were modelled by fitting experimental data to a number of first order kinetic models The Modified Kelsall model that was adjusted to also include the proportion non-floating species had the best fit of the experimental results.

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## Conflict of Interest

No conflict of interest.

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