

An investigation of the effects of water injection on froth flotation.

In fulfilment of Master of Science in Chemical
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Abstract

The majority of platinum production in South Africa is from the UG-2 chromitite seam. Fine grinding of this material followed by flotation has resulted in a chromite entrainment problem which affects the efficiency of the downstream smelting furnace. Froth washing offers the potential for selective removal of chromite and possible improvements in platinum grade and recovery from the flotation concentrate.

This project was aimed at improving flotation efficiency using froth washing on a laboratory scale and evaluating its application to various stages on a platinum flotation plant. A synthetic mixture of minerals was chosen for the laboratory batch flotation test work to enable monitoring of the flotation and entrainment of fully liberated particles. Smith and Warren (1989) described entrainment as a function of water recovery. This simple model was used to compare the entrainment factor for froth washing tests.

Subsequent work focused on mixtures of two components, i.e. limestone (gangue) and Alsil P (floatable mineral) and the use of froth washing to reduce gangue entrainment. Several methods of froth washing were investigated and the use of a submerged wash water bar was chosen. Variables included the position for water injection, the rate of water addition, concentration of reagents and the stage of flotation (rougher, cleaner and scavenger).

Results indicated that the effectiveness of froth washing was mostly dependent on the stage of introduction and the positioning of the wash water. Laboratory tests found that the best positioning for washing was 3cm from the lip of the cell. Although tests on the scavenger stage alone were disappointing, froth washing from the start of flotation resulted in an increase in recovery of floatable material of approximately 10 percent when comparing the same mass recovery.

The tests conducted at Lonmin Platinum showed that the concentrate grade was increased by washing, but the flow of platinum (recovery) was reduced. Observations and results showed that the positioning of the wash bar at the upper surface of the froth inhibited its flow. A few tests, with the wash bar at the froth/pulp interface showed promise, although the mass flow decreased by approximately 15 percent the PGM content increased by 19 percent.

Table of Contents

Table of Contents	iv
1. Introduction	1
1.1. Background.....	1
1.2. Objectives	2
2. Literature Survey	4
2.1. The Bushveld Igneous Complex and the Upper Group 2 (UG2) reef	4
2.2. Froth Flotation Basics.....	6
2.3. Flotation Cell design.....	7
2.4. Flotation stages	9
2.5. Flotation Reagents	10
2.5.1. Frothers.....	10
2.5.2. Depressants.....	11
2.5.3. Collectors.....	12
2.6. True Flotation and Entrainment.....	12
2.6.1. Modeling entrainment as a function of water recovery	13
2.6.2. Solids Motion	14
2.7. Froth Properties	16
2.8. Froth Washing	18
2.8.1. Methods of wash water addition.....	18
2.8.2. Wash water distribution.....	18
2.8.3. Drainage in the froth and particle behaviour	19
2.8.4. Position of washing	20
3. Experimental Setup and Procedure.....	24
3.1. Objective.....	24
3.2. Test Minerals	24
3.2.1. Talc and Pyrophyllite	24
3.2.2. Limestone	25

3.2.3.	Chalcopyrite	26
3.3.	ICP Analysis	26
3.4.	Equipment.....	27
3.4.1.	Laboratory flotation test equipment.....	27
3.4.2.	Analytical equipment.....	27
3.4.3.	Flotation Reagents & other Analytical Chemicals	28
3.5.	Set-up:	28
3.5.1.	Start up and calibration.....	28
3.5.2.	Cell set-up.....	28
3.5.3.	Froth collection times	29
3.6.	Details of flotation procedure	29
3.6.1.	Test sample	29
3.6.2.	Sample and reagent addition.....	29
3.6.3.	Flotation test procedure	30
3.6.4.	Flotation concentrate	30
3.7.	Overview of tests conducted.....	30
3.7.1.	Alsil P only	30
3.7.2.	Limestone and Alsil P.....	30
3.7.3.	Chalcopyrite	31
3.7.4.	Acid Test (dissolution of limestone)	31
3.7.5.	Flotation tests in pilot scale cell	31
3.7.6.	Chalcopyrite and limestone	32
3.7.7.	Froth washing tests	32
3.7.8.	ICP analysis	32
3.7.9.	Industrial flotation cell tests	32
4.	Results and Discussion	34
4.1.	Overview of test work	34
4.2.	Preliminary Tests on Alsil P, limestone and chalcopyrite test material	34

4.3.	Comparison of effect of Guar gum and Carboxymethyl cellulose (CMC).....	37
4.4.	Pilot scale cell tests.....	38
4.5.	Modelling of Entrainment	40
4.6.	Flotation tests at varying depressant dosages (in the 5L metal cell)	43
4.7.	Froth washing	46
4.7.1.	Type of flotation cell	46
4.7.2.	Type of washing device	48
4.7.3.	Position of froth washing.....	51
4.7.4.	Wash water monitoring	54
4.7.5.	Frother Dosage	55
4.8.	Staged flotation.....	58
4.9.	Water Bias	71
4.10.	Three component system	74
4.11.	Industrial Flotation Tests	79
5.	Conclusions and recommendations	84
6.	References	88
Appendix A: Product Information Sheets		A1
Appendix B: Material and safety data sheets		B1
Appendix C: Salt conductivity calculations		C1
Appendix D: Flotation test data.....		D1

Figure 1: Chromitite layer of UG2 (Dunne C, 2011)	4
Figure 2: Map of the Bushveld igneous complex (The Merensky and UG2 reefs are located in the eastern and western limbs) (Cawthorn, 2001)	5
Figure 3: Rougher stages of the two concentrate process (Steyn, 2011)	6
Figure 4: Diagram of a typical mechanical flotation cell showing air supply and impeller	7
Figure 5: Schematic diagram of the flotation in a froth flotation cell in continuous operation	8
Figure 6: Schematic diagram of the flotation in a froth flotation cell (batch)	8
Figure 7: Typical Denver flotation cell with accessories	9
Figure 8: Typical flotation circuit showing how the rougher, cleaner, recleaner and scavenger cells are linked to each other (Meech J.A, 1992)	9
Figure 9: Graph to show relationship between DFI and CCC values for different frothers	11
Figure 10: Structure of propylene oxide	11
Figure 11: Recovery of silica gangue as a function of water recovery (Engelbrecht and Woodburn, 1975) (The dots represent the finest particle size fraction with the crosses larger and the triangles representing the largest particle size)	15
Figure 12: Typical relationship between particle size and degree of entrainment (Savassi <i>et al</i> , 1997)	16
Figure 13: Vertical cross section through a flowing foam, showing the rise of the bubbles into the froth (Cilliers, 2006)	17
Figure 14: Results obtained by Cillers, 2006 of insolubles recovery for in froth and surface washing	20
Figure 15: An example of froth washing in zinc flotation at Zinc Corporation of America's Balmat operation (Finch, 1994)	22
Figure 16: Shows how the percentage of gangue in the concentrate decreases with increasing wash water ratio in the Jameson cell in base and precious metals flotation. (Jameson, 2013)	22
Figure 17: Molecular structure of talc	25
Figure 18: Froth sampling device	33
Figure 19: Bar graph depicting recovery of Alsil P at different frother dosages in order to establish the frother dosage at which no further material was recovered	35
Figure 20: Uncontrollable froth created by Alsil P	35

Figure 21: Effect of Guar gum and CMC on recovery of floatable material.....	37
Figure 22: Pilot scale tests over 30 minutes (Recovery of Alsil P excluding spillages)	39
Figure 23: Recovery of water to the concentrate in pilot flotation cell tests	40
Figure 24: Graph depicting entrainment of un-floatable material (limestone) at varying depressant dosages	41
Figure 25: Mass of un-floatable material entrained at varying depressant dosages to fit Smith and Warren model	42
Figure 26: Plot of entrainment factor (e_g) vs. depressant dosage	43
Figure 27: Recovery of floatable material at various depressant dosages.....	44
Figure 28: Recovery of un-floatable material entrained at various depressant dosages.....	44
Figure 29: Mass percentage of water recovered into the concentrate at varying depressant dosages	45
Figure 30: Grade of concentrate (percentage of Alsil P recovered in total concentrate) recovered at various depressant dosages.....	46
Figure 31: Side view illustrating the difference in design of laboratory flotation cells.	47
Figure 32: Preliminary tests on the effect of cell type.....	47
Figure 33: Recovery of floatable material vs. mass of concentrate.....	48
Figure 34: Preliminary tests of foam rubber tubes for froth washing (recovery of floatable material – Alsil P).....	49
Figure 35: Comparison of the percentage entrainment of un-floatable particles for different washing devices.....	50
Figure 36: Grade of concentrate compared to the percentage of the Alsil P reporting to the concentrate for different washing devices	50
Figure 37: Comparison of recovery of floatable material for washing at different positions.....	52
Figure 38: Comparison of mass percentage of entrained particles over time for washing at different positions.....	53
Figure 39: Grade of concentrate compared to the percentage of Alsil P recovered for washing at different positions.....	53
Figure 40: Dyed wash water.....	54

Figure 41: Percentage of floatable material in the pulp recovered to the concentrate over time at varying frother dosages	55
Figure 42: Percentage of the un-floatable material in the pulp recovered to the concentrate over time at varying frother dosages	56
Figure 43: Grade of concentrate compared to the percentage Alsil P recovered to the concentrate for washing at different frother dosages	57
Figure 44: Graph to show fit of flotation tests with froth washing at varying frother dosages to the Smith and Warren entrainment model.....	57
Figure 45: Effect of scavenger frother dosage on grade of the concentrate compared to the recovery of Alsil P.....	59
Figure 46: Effect of a higher rougher frother concentration (60g/t) and variable scavenger frother additions. Cumulative plot of grade of concentrate vs. recovery of Alsil P.....	60
Figure 47: Repeat experiments on the effect of washing in the scavenging stage. (Frother addition was 50g/t frother in the rougher, 10g/t frother in the scavenger.)	61
Figure 48: Data from repeated runs (frother addition of 50g/t in the rougher and 10g/t in the scavenger). Cumulative data for recovery in the scavenger stage only fitted to the Smith and Warren model.	62
Figure 49: Effect of adding frother (equivalent to 10g/t of ore) to the scavenger wash water. Grade of concentrate vs. percentage recovery of Alsil P. The frother addition to the pulp was 50g/t in the rougher and 10g/t in the scavenger.....	63
Figure 50: Graph to show fit of scavenger stage flotation tests with froth washing to the Smith and Warren model. (Frother dosage of 50g/ton in the rougher and 10g/ton in the scavenger)	63
Figure 51: Grade of concentrate vs. the percentage recovery of Alsil P. Froth washing applied in the scavenger only. The frother addition was 60g/t frother in the rougher, 10g/t frother in the scavenger.....	65
Figure 52: Grade of concentrate vs. the percentage recovery of Alsil P. Froth washing applied in the scavenger only. The frother addition was 60g/t frother in the rougher, 10g/t frother in the scavenger.....	66
Figure 53: Graph to show fit of scavenger stage flotation tests with froth washing to the Smith and Warren model. (Frother dosage of 60g/ton in the rougher and 10g/ton in the scavenger)	66
Figure 54: Summary of floatable material recovery in staged flotation with washing in the scavenger.....	68

Figure 55: Grade of the concentrate compared to the percentage recovery of Alsil P with froth washing in the scavenger. Frother addition was 50g/ton in the rougher and 20g/ton in the scavenger.	69
Figure 56: Grade of concentrate compared to the percentage recovery of Alsil P with froth washing in the rougher only. Frother addition was 50g/ton in the rougher and 10g/ton in the scavenger. ...	70
Figure 57: Graph to show fit of scavenger stage flotation tests with froth washing in the rougher to the Smith and Warren model. (Frother dosage of 50g/ton in the rougher and 10g/ton in the scavenger).....	70
Figure 58: Effect of varying water bias on the grade and recovery of floatable material with froth washing at the scavenger stage. The frother addition was 50g/t in the rougher and 10g/t in the scavenger.	72
Figure 59: Graph to show fit of scavenger stage flotation tests with froth washing in the scavenger at varying water bias to the Smith and Warren model. (Frother dosage of 50g/ton in the rougher and 10g/ton in the scavenger).....	72
Figure 60: Comparison of floatable material grade and recovery for froth washing with a positive, negative and zero water bias.....	74
Figure 61: Recovery of chalcopyrite in a 3 component system for different depressant dosages...	75
Figure 62: Recovery of chalcopyrite in a three component system with washing with a positive bias. All experiments had Guar at 50g/t.	76
Figure 63: Recovery of chalcopyrite in a three component system with washing with a negative bias.....	77
Figure 64: Comparison of recovery of chalcopyrite in a 3 component system washing with positive and negative bias	77
Figure 65: Comparison of recovery of chalcopyrite with varying depressant dosages at a positive bias.....	78
Figure 66: Grade of chalcopyrite recovered in froth washing tests.....	79
Figure 67: Froth sampling device on industrial cell lip.....	79
Figure 68: Industrial flotation tests in a Cleaner cell	80
Figure 69: Industrial flotation tests in a cleaner cell	81
Figure 70: Industrial flotation tests in a cleaner scavenger cell.....	82
Figure 71: Industrial flotation tests in a recleaner cell	82

Figure 72: Conductivity calibration for runs conducted with salt in the wash water.	C1
Table 1: Chemical analysis of talc available from Idwala Chemicals	25
Table 2: Chemical analysis of the limestone from Idwala Chemicals.....	26
Table 3: R^2 values for relationship between recovery of un-floatable material (limestone) and water recovery	41
Table 4: Entrainment factor e_g and R^2 values for the relationship between limestone entrainment and water recovery with zero intercept.....	42
Table 5: Entrainment factor e_g and R^2 values for the relationship between limestone entrainment and water recovery with zero intercept.....	58
Table 6: Entrainment factor e_g and R^2 values for the relationship between entrainment and water recovery with zero intercept	62
Table 7: Entrainment factor e_g and R^2 values for the relationship between entrainment and water recovery with zero intercept for scavenger stage flotation when using a frother dosage of 50g/ton in the rougher and 10g/ton in the scavenger.....	64
Table 8: Entrainment factor e_g and R^2 values for the relationship between entrainment and water recovery with zero intercept for scavenger stage flotation when using a frother dosage of 60g/ton in the rougher and 10g/ton in the scavenger.....	67
Table 9: Summary of Entrainment factor e_g and R^2 values for the relationship between entrainment and water recovery with zero intercept. Flotation was conducted in 2 stages with the frother dosage varied in the rougher stage.	68
Table 10: Entrainment factor e_g and R^2 values for the relationship between entrainment and water recovery with zero intercept for rougher stage flotation when using a frother dosage of 50g/ton in the rougher and 10g/ton in the scavenger.....	71
Table 11: Entrainment factor e_g and R^2 values for the relationship between entrainment and water recovery with zero intercept for scavenger stage flotation at varying water bias when using a frother dosage of 50g/ton in the rougher and 10g/ton in the scavenger	73
Table 12: Raw data of wash water during salt runs.....	C2
Table 13: Raw data of concentrate during salt runs	C2
Table 14: Flotation test data for limestone and Alsil P system	D1
Table 15: Three component system results	D27
Table 16: Industrial flotation test results	D33

1. Introduction

1.1. Background

Flotation is a process by which valuable minerals are separated from gangue. Klimpel (1984) stated that flotation is an interactive engineering system involving many complex chemical and physical interactions. Flotation is used primarily in the minerals processing industry to recover fine valuable minerals from ore. This process is efficient and widely applicable.

Ninety percent of the world's primary platinum production occurs in South Africa and Russia. The demand for platinum is continually increasing but the supply is limited. According to the chamber of mines, mining is a critical earner of foreign exchange in South Africa therefore preventing the loss of platinum in processing is imperative (Brand South Africa, 2013). Jones, 2012 stated that the greatest loss of PGMs occurs during flotation amongst others processes. The total metal content of the platinum group minerals (PGM) of the mined ore is usually between 4.4 and 10.6 grams per ton and the cost of mining the narrow seams is a major proportion of the overall cost of production (Jones, 2012). In order to attain the maximum possible recovery all facets of the flotation system must be understood.

The Bushveld Igneous Complex (BIC) in South Africa contains the world's largest PGM deposits. (Chamber of mines South Africa, 2013) Flotation of PGMs from the UG2 reef was investigated in this project, as most of the current production comes from this reef (Cramer, 2004). The Chromite ($\text{FeO} \cdot \text{Cr}_2\text{O}_3$) content of UG2 ore exceeds 50 percent and significant difficulties in smelting can occur if the Cr_2O_3 content of the flotation concentrates exceed 2.5 percent (Hay and Roy, 2010). Chromite tends to crystallise and buildup in the smelter, causing operational problems such as loss of operational volume of the furnace and loss of recovery of valuables (Nell, 2004). Entrainment plays a significant role in the recovery of chromite into the final concentrate as chromite has a very low natural floatability (Hay and Roy, 2010). This project was aimed at reducing entrainment of chromite in flotation of UG2 ore.

The recovery of PGM and related sulphides by froth flotation from the BIC is complicated by the presence of naturally floatable gangue minerals such as talc. Talc is one of the main gangue minerals and constitutes 1 to 3 percent of the ore (Hay and Roy, 2010). Although talc is present in small quantities it contributes to the maintenance of froth stability during the recovery of PGM's in rougher and scavenger cells. The talc is also responsible for increasing the entrainment of gangue minerals. The talc must subsequently be depressed in the cleaner cells. The depression of talc requires a certain degree of control to maintain the froth stability while recovering slow floating PGM.

Entrainment is also a significant problem in differential flotation of copper, lead and zinc sulphide minerals as fine grinding must be used to liberate these minerals. Currently the Mount Isa mines

of Australia use the Jameson flotation cell for the separation of these minerals. This technology successfully employs froth washing as a means of reducing entrainment (Jameson, 2013). Therefore if froth washing can be effectively implemented in flotation plants treating UG2 ore, where chromite entrainment is a problem, recovery of PGMs could be improved.

1.2. Objectives

This project was aimed at investigating the effects of cell design (method of introducing wash water) and the use of operating parameters to maximize flotation efficiency. In particular, the effect of froth washing on a laboratory scale and its application to various flotation stages were investigated. The operating parameters under investigation were concentration of both floatable and un-floatable solids, the concentration of reagents and water injection (to reduce entrainment of gangue minerals). The bulk of the test work was conducted in laboratory scale devices.

Synthetic mixtures of materials were used in this project to simulate flotation of UG2 ore, as this made it easier to evaluate results and to avoid natural variations in ore composition. The synthetic system made it possible to change ore composition and to monitor entrainment using varying washing methods under controlled conditions. The most significant findings from laboratory tests were used as a guideline for pilot-plant tests in a UG2 concentrator plant.

The initial experiments were done with talc in order to assess the behaviour of talc in a flotation cell. Limestone was then added to the experiments to represent the un-floatable gangue minerals, which are recovered by entrainment. (Limestone was chosen, as the quantity of the limestone in test samples can be determined easily by leaching with dilute hydrochloric acid. Bags of ground limestone are available in various size ranges). Tests were conducted with varying frother and depressants dosages and thereafter the effect of froth washing was investigated on the talc and limestone system. The objective of these tests was to reduce the amount of limestone entrained by means of froth washing and investigate the effect on the amount of talc (desired mineral in this case) recovered.

Selected experiments were conducted with blue dyed wash water in order to visually track the movement of the wash water through the froth. A salt solution was also added to the wash water in certain experiments. The conductivity of the water in concentrate samples was measured and compared with the conductivity of the wash water. These experiments made it possible to determine how much of the wash water reports to the concentrate and how much entered the pulp. This gave a better understanding of the movement of the wash water through the froth.

Chalcopyrite (one of the sulphides associated with UG2 ore) was added to the synthetic mixture at a later stage to simulate a cleaner cell operation and to extend the experiments to a 3 component

system. The limestone and talc in the system represented gangue minerals with different flotation properties to be separated from the chalcopyrite. Tests were performed at different talc depressant dosages in order to determine the influence of talc recovery on the chalcopyrite recovery and gangue entrainment. Standard tests were conducted for comparison with the tests involving washing.

Towards the end of the investigation, a two-week period was spent at a platinum flotation plant, where tests of froth washing were conducted. A device was built in the UKZN Laboratory workshop to fit onto the lip of a flotation cell at a UG2 concentrator plant. The apparatus provided a means of sampling a portion of the froth flow with, and without washing.

2. Literature Survey

2.1. The Bushveld Igneous Complex and the Upper Group 2 (UG2) reef

The Bushveld Igneous Complex (Bushveld Complex) was formed approximately 2000 million years ago. It is a well differentiated geological structure with distinct layers which settled out when the deposit cooled, including layers of chromite and magnetite. Three of the layers contain major resources of PGMs, namely, the Merensky Reef, the Upper Group 2 chromitite (UG2) reef and the Platereef. (Platinum today, 2010) The major minerals found in the Merensky and UG2 reefs are similar but vary widely in the abundance of the minerals present. The UG2 reef is found approximately 15 to 400 meters below the Merensky Reef and comprises of a pegmatoidal feldspathic pyroxenite and chromitite. (Platinum today, 2010)



Figure 1: Chromitite layer of UG2 (Dunne C, 2011)

The PGMs are generally associated with fine grained base metal sulphides such as pyrrhotite, pentlandite and chalcopyrite. There are several chromitite layers and the second layer in the upper group (UG2 layer) has the largest concentration of sulphide minerals and PGMs of all the chromitite layers in the Bushveld Complex. (Platinum Today, 2010)

In order to extract the valuables from the ore, several processing stages including, crushing, milling, gravity concentration, flotation, magnetic and electrostatic separation, thickening amongst others are used (U.S Environmental Protection Agency, 1994). Several stages of flotation are used to reduce the mass of concentrate and to reduce its chromite (Cr_2O_3) content. If the Cr_2O_3 content of the concentrate exceeds 3 percent, operating problems in the smelting of the concentrate are experienced and the costs increase substantially. (Hay, 2008) The chromite gangue minerals have a very low floatability therefore most of the gangue minerals enter the concentrate by entrainment. (Hay, 2008)

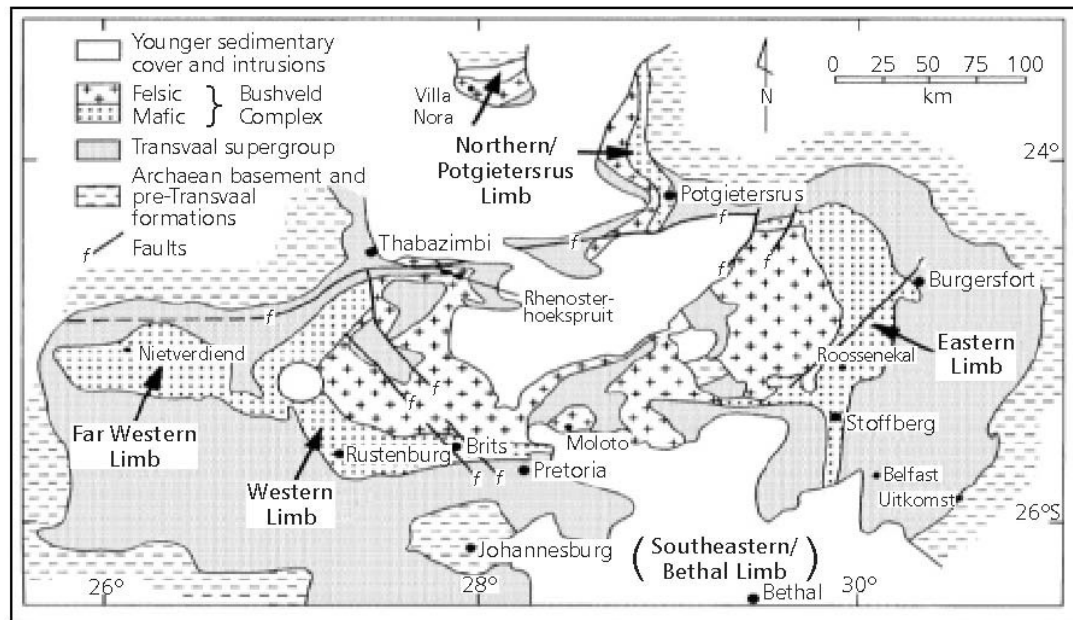


Figure 2: Map of the Bushveld igneous complex (The Merensky and UG2 reefs are located in the eastern and western limbs) (Cawthorn, 2001)

This project focuses on the recovery of the chalcopyrite and the elimination of gangue minerals, particularly chromite.

Although talc is present in small amounts in UG2 ore, it has a significant effect on flotation. Talc has a great stabilising effect on the froth which increases the amount of gangue minerals. Talc recovery can be reduced by the addition of polymeric depressants (Mailula, 2003). It is intended that the chalcopyrite will represent the portion of nickel and copper sulphides in UG2 ore.

Due to the complex mineralogy of UG2 ore, all valuables cannot be recovered in one stage of crushing and flotation. After primary grinding and flotation, the tailings still contain a significant proportion of the PGMs, as they are locked within chromite and silicate-rich particles (Maharaj, 2011). A second grind followed by flotation is therefore required, to liberate the remaining PGMs. The two concentrate process was originally developed for UG2 ore, using the concept of separating slow and fast floating minerals. The floatability of medium and slow floating valuables are enhanced using a combination of regrinding and reagents or the medium and slow floating minerals are recovered separate to the fast floating minerals. (Hay, 2008) The success of this process is dependent on the ore's mineralogy and the ability to manipulate the medium and slow floating minerals relative to the gangue.

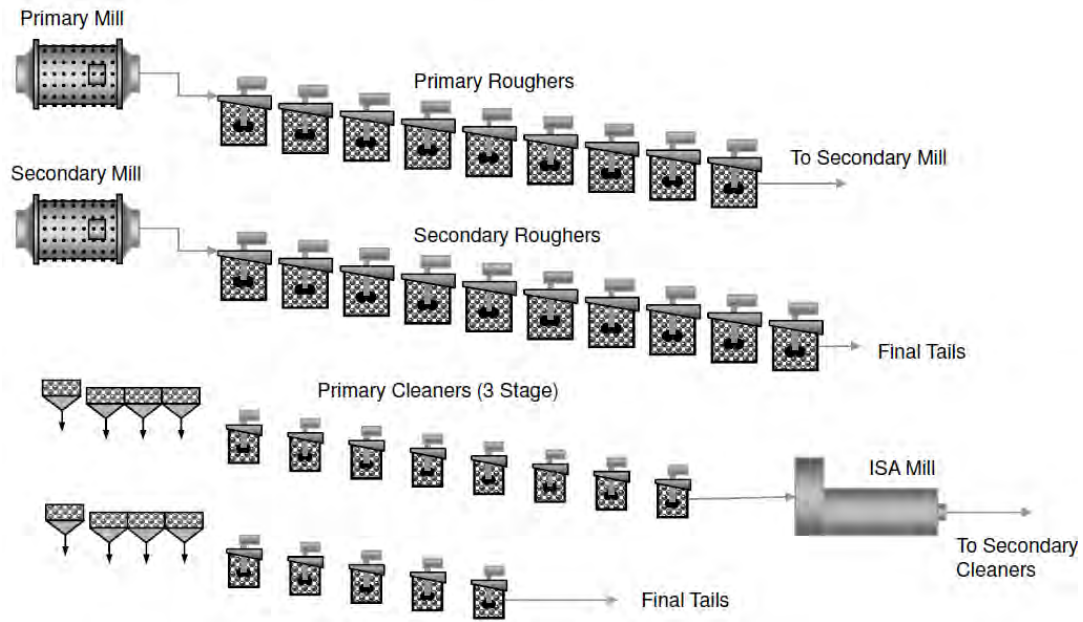


Figure 3: Rougher stages of the two concentrate process (Steyn, 2011)

Figure 3 above shows a flow diagram for the rougher stages of a two concentrate process. This process aims to achieve maximum recovery by floating the ore as coarse as possible in the primary roughers followed by further milling and flotation in secondary roughers for recovery of finer particles. Entrainment of gangue minerals is more of a problem when the ore is finely ground, as less sedimentation of these minerals occurs in the zone below the froth.

The aim of this project was to selectively reduce gangue entrainment by the addition of wash water to the froth. It was anticipated that the wash water would improve drainage in the froth by aiding the flow of unattached particles (i.e. gangue) back into the pulp.

2.2. Froth Flotation Basics

Relatively small bubbles (about 3mm) of air are passed into a suspension of solids, usually less than about 300µm in size. Mineral particles which have a hydrophobic surface adhere to the bubbles and are carried into a froth layer on the surface, which slowly overflows. For selective capture to occur the valuable mineral must be naturally floatable or be coated with a collector. (Crozier 1992) In the case of this project Alsil P (talc substitute) is a naturally floatable mineral and the chalcopryite concentrate must be coated with a suitable collector for selective flotation. Crozier (1992) suggests that once the desired particle adheres to the bubble there are two other main mechanisms by which the bubbles are loaded. These are by multiple particle-bubble collisions in the pulp which eventually lead to particle adhesion and micro-bubble formation directly on the mineral surface within the bubble formation zone of the pulp.

2.3. Flotation Cell design

There are two main types of flotation cells used in industry; these are the column flotation cell and the mechanical flotation cell. Column flotation cells are used largely in the coal industry for their improved selectivity (McKeon, 2001). The mineral processing industry employs the use of mechanical flotation cells. Hence it was decided to conduct the froth washing experiments using a laboratory mechanical flotation cell.

Mechanically agitated cells involve complex interactions between the bubbles (gas), particles (solids) and the liquid phase. The impeller provides the energy for bubble breakup and the mixing of the particles in suspension so that the particles and bubbles contact each other. (Evans *et al*, 2008) Therefore the amount of energy input is essential to the efficient operation of a flotation cell. The energy input of the cell for this investigation was based on the size of the cell and the relative mass added. (Evans *et al*, 2008)

The mechanical cell is fitted with an air supply and an impeller (See figure 4 below). The impeller cuts up the continuous air flow into smaller bubbles which are introduced into the pulp suspended in the cell. (Mineral processing techniques, 2004)

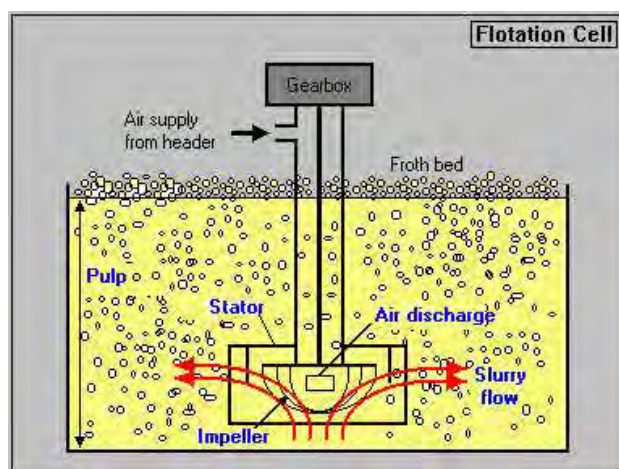


Figure 4: Diagram of a typical mechanical flotation cell showing air supply and impeller.

Figure 5 below illustrates a continuous flotation system, which the ore to be separated enters at the bottom of the cell from one side, the tails containing un-floated material is taken away from the opposite side. The froth is collected on top of the pulp and migrates to the overflow. Figure 6 represents the batch system that was used in this project. The ore and water were introduced to the cell and reagents were added and mixed with the pulp, (called “conditioning”). The experiment was started by starting the air flow and the froth is removed by periodic scraping towards the

overflow. Water was added manually to maintain the pulp level. The air flow was terminated after the experiment and contents of the cell are removed for filtering, drying and sampling.

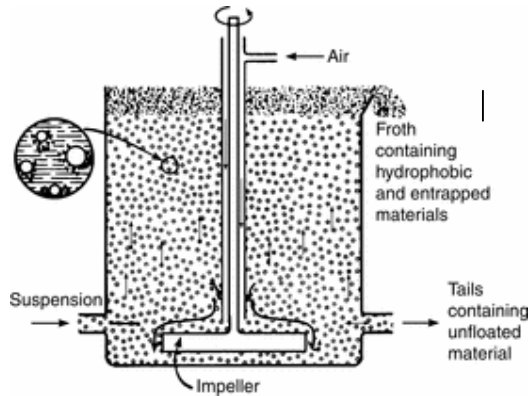


Figure 5: Schematic diagram of the flotation in a froth flotation cell in continuous operation

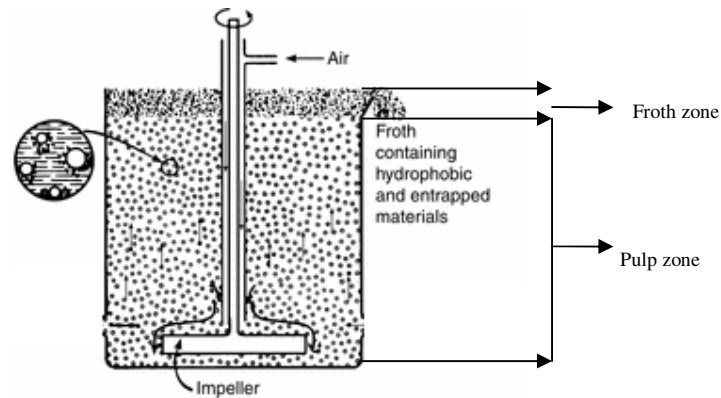


Figure 6: Schematic diagram of the flotation in a froth flotation cell (batch)

(Chengliang J, Xiang Huai W, 2006)

A Denver laboratory flotation mechanism was used for the laboratory experiments. As shown in the figure below. The device has a suspended type mechanism which is supported on a spring-balanced moveable arm. Air is introduced through a valve located on the shaft. The height of the agitator can be changed by adjusting the hand crank and locking the column at the required height.



Figure 7: Typical Denver flotation cell with accessories

A previously determined impellor speed of 700rpm was used. This was confirmed with tests described in the experimental setup Section 3.

2.4. Flotation stages

Flotation is usually done in stages to improve the separation of minerals and to maximize recovery. The Flotation circuit starts with a rougher and the rougher concentrate is pumped to a cleaner stage. The tailings from the rougher stage gravitate to a scavenger stage, but the concentrate from this stage may be recycled. Re-grinding is often used where appropriate. Figure 7 illustrates a multiple-stage circuit. The overall process is similar to a multi-stage distillation column.

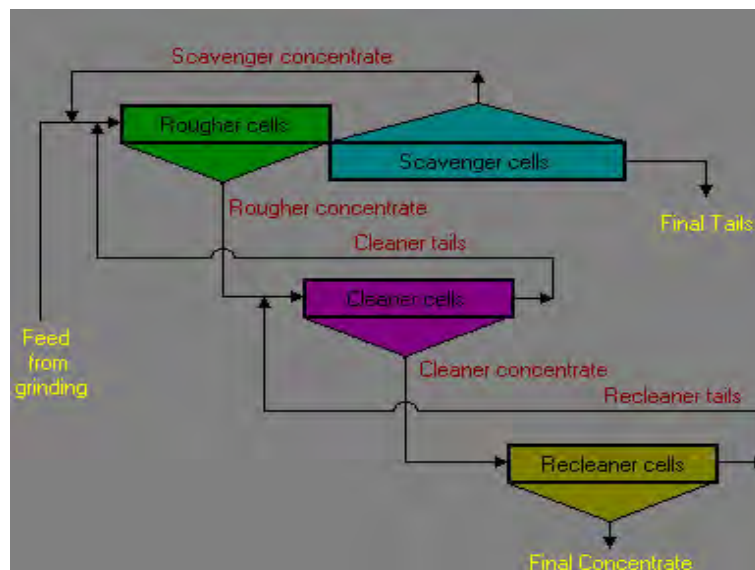


Figure 8: Typical flotation circuit showing how the rougher, cleaner, recleaner and scavenger cells are linked to each other (Meech J.A, 1992)

Since the scavenger contains the largest amount of gangue particles in relation to the floatable material, it is most susceptible to entrainment (due to the high air flow rate and shallow froth). This project will be focused on testing the effectiveness of froth washing in the scavenger stage. The froth properties for the different stages of flotation differ. The rougher and cleaner stages of flotation have a deep stable froth, because the floatable minerals stabilize the froth. This allows the gangue minerals to drain, and the gangue content is relatively low. However, the froth of the scavenger stage is less stable and the operator is forced to use much shallower froth, when trying to recover the slow floating minerals. Entrainment of gangue minerals is more of a problem under these conditions, particularly if the ore has been finely ground. Staged flotation conducted in this project took this change in froth depth into account.

2.5. Flotation Reagents

Chemical reagents in flotation are of great importance. The addition of reagents serves to either assist in the froth creation and stability or to aid in the selectivity of the flotation process by rendering of particles hydrophobic or hydrophilic. Reagents are obtained in concentrated form. The dosage of reagents is measured in grams per ton of ore (g/ton), which normally refers to a ton of feed, even if the experiment is performed on a concentrate.

2.5.1. Frothers

Flotation of minerals is normally done in a water suspension. Frothers are water soluble organic reagents and the main purpose of the frother is to lower the surface tension between water and air. This reduces the size of bubbles formed by the impeller and it provides some stability to the froth at the surface of the flotation cell. The surfactant is concentrated at the air-water interface and it reduces the tendency of bubbles to coalesce in the froth. The froth breaks down because of the coalescence of bubbles into larger bubbles. This is caused by thinning of the water film between bubbles and contact between bubbles. The froth may be stabilised by adherence of mineral particles to the bubble surfaces, as the rate of drainage of the water between the bubbles is slowed down the particles form a barrier between bubbles. Frothers are organic compounds with hydroxyl group(s) to provide stability in water. (<http://www.miningbasics.com/>)

The foam stability index (DFI) and the critical coalescence concentration (CCC) can be used for selection of a suitable frother. Figure 9 below depicts the relationship between DFI and CCC for selected frothers which are in use on flotation plants. The frothers with a high DFI and low CCC (i.e. top left upper corner of the diagram) are powerful frothers whereas those with high CCC and low DFI values are weaker and more selective frothers.

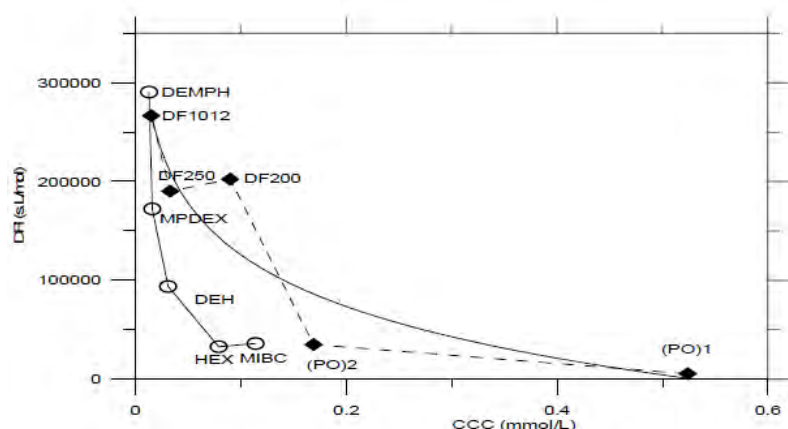


Figure 9: Graph to show relationship between DFI and CCC values for different frothers

A polyglycol type frother was chosen to be used. These frothers are produced by Dow chemicals under the trade name of Dowfroth in a range of differing molecular weights and properties. Dowfroth 200 was chosen as it was available at UKZN from previous work done on UG2 ore. It is a low molecular weight frother (206 grams per mole) which is totally soluble in water. Figure 10 shows that Dowfroth 200 (DF200) is a fairly powerful frother.

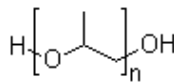


Figure 10: Structure of propylene oxide

(<http://www.chemblink.com/products/25322-69-4.htm>)

Dowfroth 200 consists of three propylene oxide groups ($n = 3$ in figure 8).

Forssberg (1988) suggested that the amount of frother used indirectly controls the degree of entrainment as it controls the amount of water recovered. Therefore the experiments carried out in this project were done at varying frother dosages.

2.5.2. Depressants

Depressants can be used to improve the separation of undesirable minerals which have floatability similar to the desired minerals. The depressant either coats the surface of the unwanted minerals making them hydrophilic or prevents the collector from being adsorbed onto the minerals to be depressed thereby inhibiting its flotation. Talc is an example of a mineral which has natural floatability and it must be depressed, as the additional mass in the concentrate results in higher smelting costs. Water-soluble polymers with a high molecular weight are used to suppress flotation of talc. They are adsorbed by molecular bonding, creating a hydrophilic layer. A comparative study conducted by Laskowski, *et al* (1997) of the adsorption of dextrin and guar gum onto talc

showed that guar gum exhibited better depressive ability than dextrin. The depression was also shown to be independent of pH. They suggested by this study that the better depressant activity of guar gum may be attributed to the favorable cis-configuration of the hydroxyl groups, when compared to the trans-hydroxyl groups of dextrin, as well as its higher molecular weight. Bradshaw, Harris, Koopal and Shortridge (2000) conducted a study on the effect of chemical composition and molecular weight of polysaccharide depressants on the flotation of talc. CMC and modified guar gum reagents were used to reduce the floatability of talc. Their results indicated that strong depression was achieved by the guar-based polymers and the CMC reagents were less effective depressants of talc. Hence, Guar gum was chosen for depression of talc in this investigation.

2.5.3. Collectors

Collectors are reagents which coat the surface of the mineral making it hydrophobic. Collectors for the flotation of sulphide ores are usually thiols or can hydrolyse to a thiol. They have organic chains to provide hydrophobicity and they all contain sulphur. Xanthates are commonly used collectors as they interact with the majority of sulphide minerals. They react to form metal xanthate and dixanthogen. The selectivity of xanthates is low without the use of additional reagents. At a pH of below 3, the half-life of all xanthates is reduced to minutes (Crozier, 1992). For the purposes of this project a collector was used to aid in the flotation of chalcopyrite.

Dai *et al* (2006) concluded that because of the strong electron donating power of xanthates, they can react strongly with the metal cation on the surfaces of copper and iron sulphides through forming normal covalent bonds. Crozier (1992) states that there are several collectors that is appropriate for flotation of chalcopyrite. Of these Sodium Isobutyl Xanthate (SIBX) was chosen because of availability. In order for the SIBX to be absorbed onto the chalcopyrite the cell contents must be at pH 9. They suggested that the dosage be between 12 and 15 grams per ton of ore.

Hence, reagents used for this project were Dowfroth 200 as the frother, Guar gum as the depressant and SIBX was used as the collector for the tests conducted with chalcopyrite.

2.6. True Flotation and Entrainment

Particles from the pulp in the flotation cell generally enter the froth by 2 mechanisms, namely true flotation and entrainment. True flotation occurs when particles attach to the surface of the air bubbles in the froth due to their hydrophobic nature (Kaya, 1989).

Entrainment however, is the process by which particles enter the base of the flotation froth and are transferred up and out of the flotation cell suspended in the water between the bubbles (Smith and

Warren, 1989).). Entrainment is the main means by which gangue is recovered, however it is a non-selective process and both hydrophobic and hydrophilic particles are recovered by entrainment. The mass and shape of particles has a direct effect on entrainment. Emin (2008) stated that: “The separation efficiency and selectivity of flotation are directly proportional to recoveries of the mineral species in the feed due to true flotation and entrainment.” The mechanism for entrainment will be examined in more detail below.

2.6.1. Modeling entrainment as a function of water recovery

Warren (1985); Smith and Warren (1989) described entrainment as a function of water recovery as follows:

$$R_g = e_g R_w \quad \dots(1)$$

Where

R_g is the recovery of fine-sized gangue,

e_g is the degree of entrainment or the entrainment factor

and R_w is the recovery of water in a given time

Further work done by Kirjavainen (1989); who used the model to link gangue recovery to water recovery for a continuous flotation system at steady state:

$$R_i = P_i R_w \quad \dots(2)$$

Where

R_i is recovery of the i th size fraction,

P is the probability factor for the water recovery, (The probability depends on particle characteristics and process variables)

This equation can be modified for batch flotation (Kirjavainen, 1996) as follows

$$R_i = 1 - \exp(-P/R_w) \quad \dots(3)$$

Kirjavainen, (1996) also described the relationship between the entrainment factor and the Newtonian region as follows:

$$P = \frac{w^{0.7}}{w^{0.7} + B \phi^{0.5} \mu^{0.5} v_m^{0.5} - 0.5 \phi^{0.4}} \quad \dots(4)$$

Where

w is the water recovery rate (kg/m²/s)

m is the particle mass (pg)

μ is the pulp viscosity (mPa.s)

b is a constant = 0.00694

and ψ is the dynamic shape factor

A limited number of parameters can be used and hence most models which take entrainment into account are simplified. These models may take particle size and pulp density into account. Water recovery depends on the froth thickness as well as the aeration rate of the cell. One of the most significant findings in the work done by Cilek and Umucu (1992) was the strong dependency of entrainment on water recovery. Their results showed that entrainment is dependent on water recovery as well as aeration rate, percentage solids by weight in the pulp, flotation time, froth depth, frother concentration and the slime content of feed.

2.6.2. Solids Motion

Particles in the froth are either attached to the bubble lamellae or unattached and free to move through the plateau borders. The presence of unattached particles is due to non-selective entrainment of particles from the pulp into the froth, which includes hydrophobic particles that had become detached from the bubble surface due to bursting or coalescence of the bubbles. Attached particles follow the bubbles but unattached particles tend to follow the liquid. (Neethling, 2001)

The turbulent flow in stirred flotation cells contributes to entrainment. The pulp-froth interface acts as a wall that prevents contamination of the froth by entrained particles. (Emin, 2008) Therefore an optimum level of turbulence should be used in order to ensure that efficient flotation and minimal entrainment is achieved. In tests conducted by Emin (2008) it was found that the lowest grade of concentrate was achieved under turbulent conditions proving that turbulence can be directly related to entrainment.

Emin (2008) stated that entrainment of fine particles can be directly related to the recovery of water. Therefore the mass of particles entrained can be related to the amount of water recovered in the froth to determine if this trend holds. This had been demonstrated as early as 1975 by Engelbrecht and Woodburn. Figure 11 shows their data. The straight line trend between silica recovery and water recovery indicates that the recovery of gangue is proportional to the recovery of water.

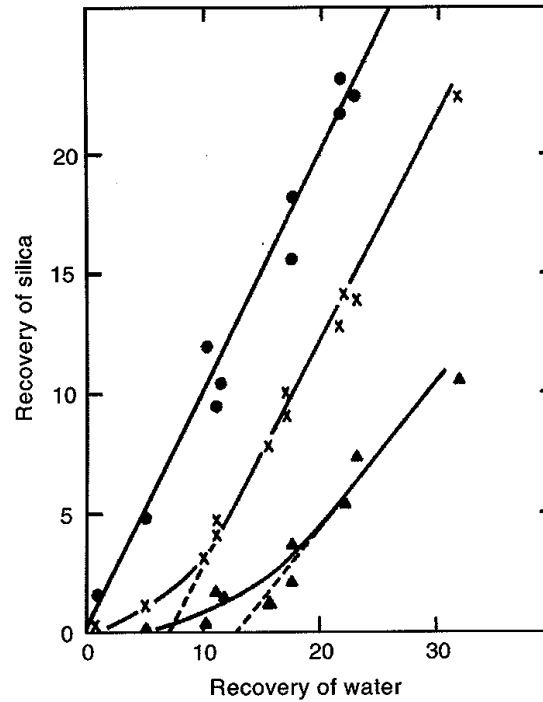


Figure 11: Recovery of silica gangue as a function of water recovery (Engelbrecht and Woodburn, 1975) (The dots represent the finest particle size fraction with the crosses larger and the triangles representing the largest particle size)

Experiments conducted by Neethling (2001), also demonstrated that the relationship between water recovery and gangue recovery was linear for fine particles. Extrapolation of the graph represented by the solid circles in figure 11 above produced a zero intercept for fine particles. For the larger particles represented by the crosses and triangles it is noted that the graph deviates from the straight line trend in the area of low water recovery. The gradient of the graphs also decrease with increasing particle size (i.e. the amount of silica recovered was higher for the finer particle size compared to the larger particle size with the same recovery of water). This indicates the dependency of entrainment on both particle size and water recovery.

Maachar *et al* (1992) also described the degree of entrainment as the ratio of the entrained solids recovered to the recovery of water. Entrainment is said to be insignificant with particle sizes greater than 50 μ m. (Smith *et al*, 1989) Therefore entrainment can be considered a significant factor in this investigation as the average particle size was 40 μ m.

Figure 12 below shows how the conditions (e.g. turbulence) effect entrainment, which decreases as the particle size increases. Curves of type A represent high degree of entrainment with little drainage of coarse particles, type B represents intermediate drainage and type C a low degree of drainage.

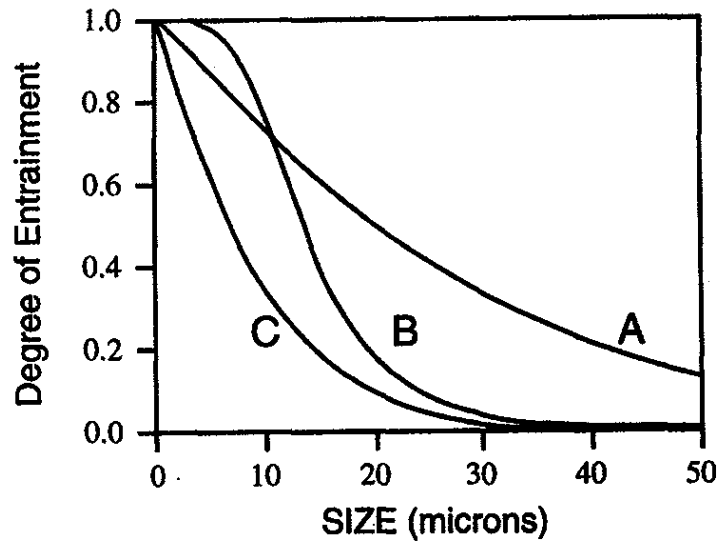


Figure 12: Typical relationship between particle size and degree of entrainment (Savassi *et al*, 1997)

Trahar and Warren (1976) performed a study in which it was assumed that all particles captured in the froth with no collector can be attributed to entrainment. They used comparative tests with collector and without, and assumed that the difference would reveal the percentage of the mineral that enters the froth by entrainment. However, this comparison may be complicated by the effect of hydrophobic particles on froth stability.

A stable froth is said to be composed of small bubbles which allows greater recovery of both entrained and attached particles as it allows less drainage and bubble coalescence. (Forssberg *et al*, 1987) Therefore gentle froth washing can allow for improved drainage by reducing bubble coalescence, and hence maintaining the small bubble size. Therefore entrained particles can be drained into the pulp whilst also improving recovery of valuables.

2.7. Froth Properties

Valuable minerals are concentrated in the froth phase. It is formed when air enters the flotation cell and mixes with the pulp. (Breward, 1999) The froth appears at the surface of the pulp due to the lower density of the air bubbles compared to the pulp. Figure 13 below shows a vertical cross section through flowing foam, the bubbles at the bottom are spherical and can be seen to change shape as they rise and coalesce. (Cilliers, 2006)



Figure 13: Vertical cross section through a flowing foam, showing the rise of the bubbles into the froth (Cilliers, 2006)

Cilliers, 2006, described froth behaviour as largely determining the fractional and relative recoveries of the valuable and the waste minerals from the pulp to the concentrate. Flotation froths are unstable and constantly undergo structural change due to the coalescence and bursting of bubbles at the surface. (Cilliers, 2006) Froth properties are very important in determining flotation performance (Shi *et al*, 2002). Two important aspects outlined in Shi *et al* (2002) are froth mobility and stability. The mobility refers to the vertical motion of the froth from the pulp-froth interface to the top surface of the froth and the horizontal motion of the froth toward the concentrate overflow weir. Stability describes the particle, bubble and water behaviour within the froth while it is flowing. (Shi *et al*, 2002). Shi *et al* (2002) described rheology as “the science of deformation and flow of matter”. Rheology is believed to affect both froth mobility and stability. A stable froth can be easily collected to recover the valuables. Froth washing can be considered to deform the froth and change the flow. Detailed studies of froth rheology have not been carried out therefore it is difficult to estimate how froth washing will affect the non-Newtonian flow of the froth.

2.8. Froth Washing

Froth washing is a means of reducing the amount of entrained material recovered in a concentrate. Entrainment is reduced by the addition of clear water into the froth from an external source, in most cases, in counter-flow to the entrained liquid. This water flushes the gangue back into the flotation cell. (Cunningham *et al*, 2006) Froth washing has been implemented in column flotation cells resulting in high grade flotation concentrate in a single stage of flotation (McKeon, 2001). McKeon, 2001, suggested that instead of replacement of conventional mechanical cells with column flotation cells, a more economical approach may be to implement the froth washing in the mechanical cells.

2.8.1. Methods of wash water addition

The design of froth washing systems is based mostly on trial and error, as the behaviour of wash water is not very well understood. Cunningham *et al* (2006) conducted experiments on different methods of introducing wash water. Wash water was injected through a vertical pipe placed above the froth, through the same pipe placed in the froth and through a tee that produced two opposing horizontal jets of water. The movement of the wash water was observed to be in the form of vortex pairs, when horizontal jets were used and the spread the wash water was improved. The vertical jet inside the froth provided a faster dispersal of the wash water than the jet above the froth. They concluded that it is never possible to remove all the gangue particles from the product as substantial back-mixing occurs independent of the type of wash water distributor used. The optimum placement of the wash water distributor injection point was used to minimize the entrainment.

Several studies have been conducted on the type of distributor used for froth washing. An investigation carried out by Sripada (1990) found that a single jet into the froth in a 50mm diameter column was more effective in reducing entrainment than a “shower head” distributor above the froth. This study also found that wash water added in a submerged jet resulted in better gangue reduction than the same jet above the froth. McKeon (2001) used a box with a perforated bottom to deliver wash water in vertical streams onto the top of the froth, whereas Finch *et al* (1990) introduced wash water through distribution pipes submerged in the froth.

2.8.2. Wash water distribution

Cunningham *et al* (2006) suggested that the optimum distribution of wash water was a uniform flow across the horizontal profile of the froth. For effective washing several distribution points will be required in no particular pattern. During this investigation, a dye was used as was done by

Cunningham *et al* (2006) to improve the visual contrast between the wash water and the froth. Cunningham *et al* (2006) also found that when the wash water was injected slightly above the top of the froth a small depression was formed at the point of entry. However when it was injected within the froth, a more even distribution was achieved. They suggested that this more even distribution could be due to small circulation near the point of injection. This investigation was aimed at finding the ideal position for froth washing.

2.8.3. Drainage in the froth and particle behaviour

It is expected that froth washing will improve the drainage in the froth. Two types of drainage in froth were described by Cutting *et al* (1986) namely, film drainage and column drainage. *Film drainage* is the process by which water and solids drain around the air bubbles at a slow rate throughout the whole froth structure and *column drainage* occurs when the material moves down rapidly at particular places in the froth when the hydrostatic pressure gradient is unstable. Column drainage tends to occur when there is an accumulation of wash water or solids. It is important to prevent this type of drainage as it could significantly reduce the recovery of valuables. A third type of drainage mentioned by Cunningham (2006) was *subduction drainage* which is caused by an accumulation of solids on the surface of the froth. When a clump of solids are formed on the froth surface reaches a certain size it sinks into the froth.

The introduction of wash water to the froth will invariably result in an increase in the liquid content of the froth. Cunningham (2006) found that instability in the froth occurs as the liquid content is increased. They concluded that when wash water was added to the froth the entering kinetic energy is quickly dissipated and that the wash water jets did not appear to have a significant effect on bubble coalescence or breakup. This falls beyond the scope of the proposed experiments therefore this will not be validated.

Experiments conducted by Seaman *et al* (2005) showed that detachment of particles from aggregates in the froth occurs largely at the pulp froth interface, in particular there is evidence that the particles selectively detach from aggregates according to their physical attributes. Therefore washing conducted at the pulp froth interface may aid in detachment of gangue minerals trapped between floatable particles. Seaman *et al* (2005) described four sub-processes that affect the detachment and re-attachment of particles in the froth phase, namely, bubble coalescence, particle detachment, particle drainage and particle re-attachment. They concluded that bubble coalescence caused the bubble lamella to break and the particles to fall to the base of a new larger bubble. The particles can drain back to the pulp zone, remain entrained in the froth or reattach to the surface of another bubble. This process is not thought to be selective in terms of particle type. Gouram-Badri *et al* (1997) conducted experiments which showed that the less hydrophobic mineral was

preferentially detached when bubbles coalesced. Particle detachment occurs when sufficient force is exerted to separate the particle from its aggregate (Seaman *et al*, 2005). Seaman *et al* (2005) concluded that particle drainage is a selective process with respect to size and density. Larger, denser particles will drain faster when compared to drainage of fine, less dense particles. They also concluded that hydrophobic particles had a greater probability of re-attachment in the froth phase.

2.8.4. Position of washing

Kaya et al (1990) recommended that wash water be distributed across the entire flotation cell. This would however result in a large amount of water being used which is recycled, not consumed. However, the residence time of the pulp in the flotation cells would be reduced, resulting in a drop in recovery. Cilliers, (2006), described two options for the addition of wash water, these were at the top of the froth or below the froth surface. Washing both below the froth surface and on top of the froth was investigated by Cilliers, (2006). Figure 14 below shows results obtained by Cilliers, 2006 of insolubles recovered with froth washing at the surface and in the froth. The aim was to reduce insoluble (gangue) recovery. Wash water flow was more effective when placed within the froth.

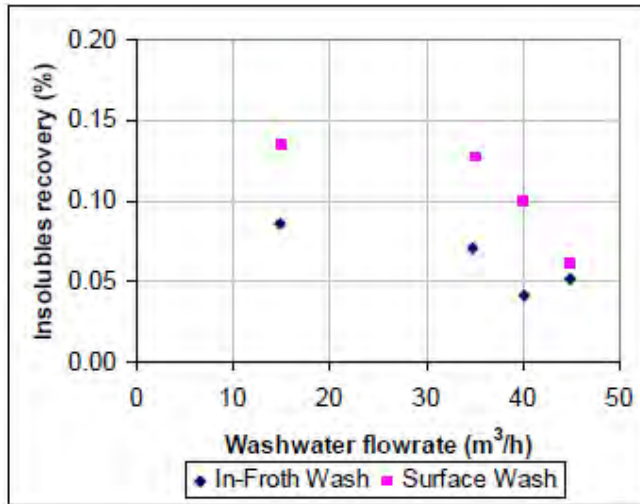


Figure 14: Results obtained by Cilliers, 2006 of insolubles recovery for in froth and surface washing.

Cowburn et al (2005) also found that in-froth washing generally increased washing efficiency. They found that in-froth washing produces a drier concentrate and the positioning of the washing at the pulp-froth interface allows for increased time for bubble drainage in the froth phase. (Cowburn, 2005) Washing from above the froth resulted in more of the froth being exposed to wash water, increasing the amount of water in the froth hence, increasing mobility and decreasing

bubble coalescence. It was found that although these factors improved froth recovery, it occasionally reduced the grade of the froth. Higher wash water flowrates can also lead to breakage of the froth in above-froth washing thereby reducing the recovery of minerals. (Cowburn, 2005)

The flow of wash water in column flotation cells is normally controlled so that it exceeds the flow of water leaving in the concentrate. This is called “a positive bias”. (Finch, 1994) The necessary control philosophy for mechanical cells is still unclear as enough test work has not been conducted in this type of cell. . Kaya et al (1990) conducted froth washing experiments in mineral flotation cells with varying wash water rates. They observed that the highest washing rates resulted in higher entrainment of gangue particles than the medium rate. Increased recovery was observed for the lowest washing rate when compared to no washing and an increase in both recovery and grade was achieved at the medium rate of washing. Kaya et al (1990) suggested that this could be due to the higher wash rates which resulted in greater mixing occurring in the froth and hence the washing was less effective. Young et al (2006) suggested that wash water should be added at a moderately positive bias as this will help minimize entrainment. A bias of 1.2 was suggested for operation and it was also suggested that higher biases up to 1.5 may lead to a reduction in the recovery of composite particles as they are weakly attached to the bubble. This would serve to improve the concentrate grade, but it would reduce recovery.

Therefore in this investigation a negative, zero and positive bias was tested.

Zinc Corporation of America’s Balmat operation has successfully employed the use of froth washing in all almost all flotation cells. In order to penetrate the stiff froth in the zinc cleaners the wash water was added with force as opposed to the usual gentle addition. (Finch, 1994)

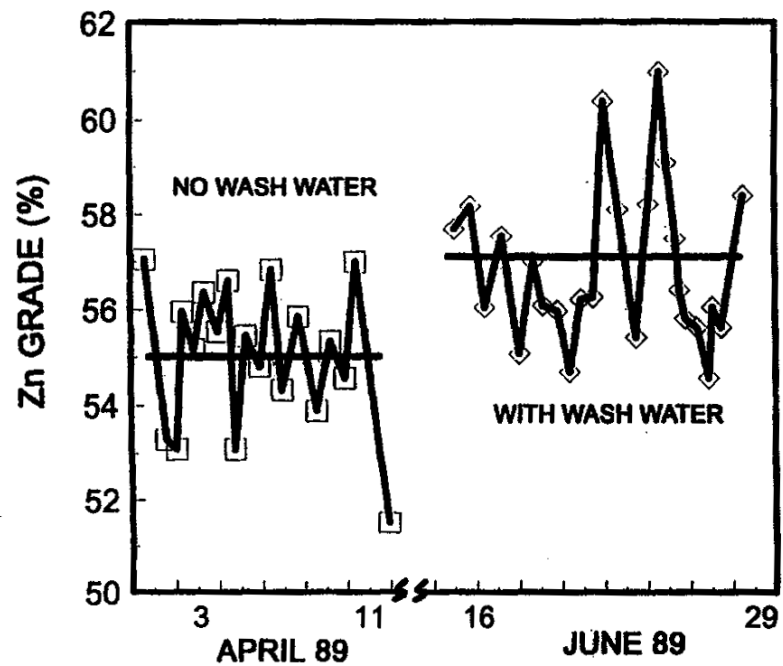


Figure 15: An example of froth washing in zinc flotation at Zinc Corporation of America's Balmat operation (Finch, 1994)

The above figure shows zinc grade improvement after washing addition. It is hoped that this kind of grade improvement can be achieved for PGM flotation in South Africa.

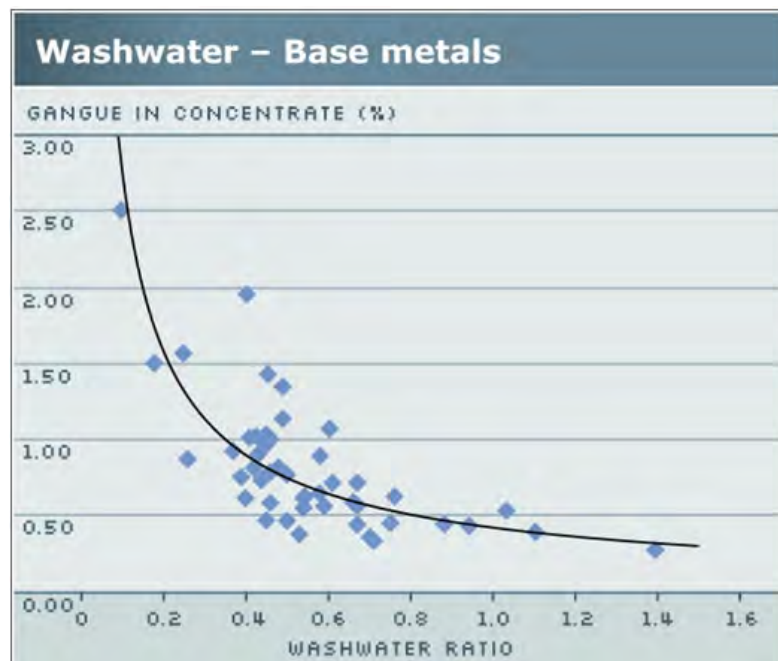


Figure 16: Shows how the percentage of gangue in the concentrate decreases with increasing wash water ratio in the Jameson cell in base and precious metals flotation. (Jameson, 2013)

Figure 16 above shows how froth washing can be used to reduce the gangue in the concentrate of a base metals flotation cell by increasing the washwater ratio. The amount of wash water required is based on the volume of water in the concentrate. According to Jameson (2013), this relationship of wash water ratio to gangue in concentrate varies for different applications. It was suggested by Jameson (2013) that the plateau is reached at high wash water rates as at this point the gangue material consists mostly of composite particles. Further gangue removal at this point requires regrinding of the pulp in order to liberate the gangue particles.

In order to ensure the reliability of the results obtained a procedure was developed for the execution of the tests. This is outlined in the following section.

3. Experimental Setup and Procedure

3.1. Objective

The purpose of the procedures outlined below is to achieve the following:

- Characterise test materials in terms of floatability.
- Determine the effects of varying reagent dosages on flotation of test materials.
- Determine the effects of froth washing on flotation.

3.2. Test Minerals

PGMs are liberated at different particle sizes depending on the reef that the ore originates from. The average PGM grain size of the Merensky reef is 45µm whereas that of UG2 is 15µm. The particle size distribution of the PGMs is also affected by the degree of alteration that the ore undergoes. (Hay, 2008) The PGMs in UG2 ore occur in association with or within base metal sulphides which are present at a larger size (approximately 30µm). They also appear locked in siliceous minerals at approximately 5µm and in the gangue and base metal sulphide grain boundary. (Steyn, 2011) Therefore fine grinding is required for liberation of PGMs in siliceous minerals. This increases the chromite entrainment. By way of comparison, processing of copper ore normally has a liberation size for the chalcopyrite of approximately 45 microns. (Cilek and Umucu, 2001)

3.2.1. Talc and Pyrophyllite

Talc is a hydrated magnesium sheet silicate composed of a layer of magnesium-oxygen/hydroxyl octahedra, between two layers of silicon-oxygen tetrahedra. The chemical formula of talc is $\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$. Its hydrophobic nature and inertness can be attributed to the fact that the surfaces near the base do not contain hydroxyl groups or active ions. Ionic bonds are only present in the three layer form. These layers are held together by (weak) molecular forces. The minerals tend to break along these planes and the surfaces are hydrophobic, having no hydroxyl ions.

Talc is a significant constituent of the gangue in platinum bearing ore bodies in South Africa. A depressant is added to reduce the recovery of talc and the cost of depressant is much greater than any other reagent. Hence, if talc recovery can be reduced by froth washing, this could reduce expenditure on reagents in a flotation plant. (Shortridge *et al*, 2000).

In view of the method proposed to measure limestone in flotation samples, (digestion in dilute hydrochloric acid), it should be noted that talc is insoluble in water and weak acids and alkalis (http://www.luzenac.com/talc_the_mineral.htm). Hence, talc is suitable to represent the floatable

material in simple two-component flotation tests, as it is naturally hydrophobic and it will not react with a weak solution of hydrochloric acid.

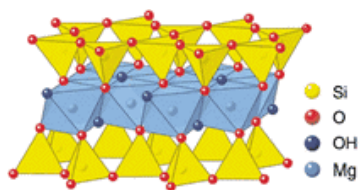


Figure 17: Molecular structure of talc

(http://www.luzenac.com/talc_the_mineral.htm)

Idwala chemicals was able to provide a mineral pyrophyllite as a substitute for talc. Although the elemental composition differs the physical properties are similar. Pyrophyllite is also a layered aluminium silicate mineral and has a chemical formula of $\text{Al}_2\text{Si}_4\text{O}_{10}(\text{OH})_2$. (G. P. Tomaino, Minerals Technologies Inc.) Pyrophyllite is traded under the name of Alsil P by Idwala chemicals. Below is the chemical analysis of Alsil P obtained from Idwala chemicals. Alsil P was diluted in a solution of weak hydrochloric acid and found to be insoluble as with talc.

Table 1: Chemical analysis of talc available from Idwala Chemicals

Compound	Typical Percentage
SiO_2	53
Al_2O_3	33
Fe_2O_3	0.1

3.2.2. Limestone

Limestone is a calcium carbonate powder generally lacking any crystalline structure. It is naturally hydrophilic and it is therefore appropriate to represent the gangue mineral. The limestone available for use was manufactured from white marble which is mined locally and subjected to dry grinding and air classification to separate it into different size fractions. Details of the limestone used in the experiments (Kulu-40) appear in Appendix A. It should be noted that 50 per cent (by mass) is less than 40 μm , and hence, there is a significant probability of entrainment of the fine limestone particles. It reacts with hydrochloric acid to produce water, carbon dioxide and calcium chloride

(aqueous salt). This property of limestone makes it possible to determine the limestone content of samples rapidly and at minimal cost, by determining the loss of mass due to acid digestion.

Table 2: Chemical analysis of the limestone from Idwala Chemicals

Compound	Typical Percentage
CaCO_3	91.5
MgCO_3	3.5
SiO_2	4.0
Fe_2O_3	0.12
Al_2O_3	0.1

Of these compounds only silicon dioxide does not react with hydrochloric acid therefore it is expected that approximately 96 percent of the limestone will react. Although total reaction of all the limestone would be ideal, the method of analysis took into account the insoluble fraction which was checked by tests on samples of the limestone.

3.2.3. Chalcopyrite

Chalcopyrite (CuFeS_2) is the most common mineral mined for its copper content. It has a bright golden colour and is one of the minerals referred to as “fool’s gold”. Chalcopyrite usually occurs as an association with pyrite, pyrrhotite and pentlandite, or fine-grained inclusions in silicate gangue. (Hay 2008) The chalcopyrite available for the initial tests was a concentrate from a previous project on copper ore and therefore pre-treatment was required before using it.

3.3. ICP Analysis

One way of measuring recovery of base metal sulphides is to digest samples in nitric acid and to send diluted samples for elemental analysis by ICP spectrometry. In order to analyse the amount of chalcopyrite present in the test samples, a mixture of nitric and hydrochloric acid was added, to dissolve both the chalcopyrite and the limestone. The copper concentration in the solution was determined (by the Department of Chemistry at UKZN), using an Induced Couple Plasma (ICP)

mass spectrometer. The ICP analysis of the samples can be divided into four stages: introduction-atomizing, ionization, separation in mass and detection. A sample of the solution is taken and converted to an aerosol in a vapourisation chamber. The aerosol is injected into an argon plasma torch at sufficiently high temperatures to vapourise, dissociate, atomize and ionize the majority of the elements present. The principle of the spectrometer is based on the separation of the elements according to the load and mass. The detection of the processes involves the counting of negatively and positively charged ions and the spectrum is then converted into a concentration with the aid of software and external calibrations. (Iramis, 2010) The ICP results were used to determine the amount of copper in the concentrate samples and the subsample of the tailings. The copper recovery was calculated and this was used as a proxy for PGM recovery.

3.4. Equipment

3.4.1. Laboratory flotation test equipment

A Denver flotation mechanism with two types of 5 L flotation cells were used to carry out the majority of the test work. Initial tests were carried out in a stainless steel flotation cell and later froth washing tests were carried out in a clear PVC cell to allow for better observation of the froth behaviour. Limited tests were performed in a 43L batch flotation cell with Outokumpu type impellor. A froth washing device was made up in the laboratory with the assistance of the workshop staff. The washer was constructed from foam tubing and PVC piping. The size range suitable for flotation and entrainment experiments was determined from the literature survey to be in the region of 40 microns (as per liberation size of valuables in chalcopyrite). The Alsil P and limestone purchased was in the 40 micron range. All reagents were available in concentrated form therefore 1 percent solutions were made to use for tests. Commissioning of the equipment was performed at the start to ensure that the equipment was in working order. No leaks were found and the impellor as well as the air supply worked well in both the laboratory scale as well as the pilot scale cell. The final plant tests were carried out with a sampling device constructed in the UKZN workshop that fitted on the lip of the industrial cell and allowed for washing of a representative sample of the overflow.

3.4.2. Analytical equipment

A pressure filter was used to remove most of the water from the samples of concentrate and tailings, prior to drying in an oven. The solid samples were then sub-sampled for analysis with the aid of a riffle. An Inductively Coupled Plasma (ICP) Spectrometer was available at the School of

Chemistry (Westville Campus) to determine the copper concentration in solutions obtained by acid digestion of samples containing chalcopyrite.

3.4.3. Flotation Reagents & other Analytical Chemicals

The addition of reagents was staged for all flotation tests according to the required conditioning time. During conditioning the impellor was switched on however, the air was turned off. All flotation tests were conducted using frother Dowfroth 200 as a frother; dosages were varied from test to test and a conditioning time of half a minute was used. Two types of depressant were tested; these were Guar gum and CMC. The depressant was given a conditioning time of 5 minutes after addition. Tests conducted with chalcopyrite required the addition of the sulphide mineral collector SIBX. A conditioning time of half a minute was used for this reagent. All conditioning times were based on the advice of previous students who had used the reagents. Nitric acid and hydrochloric acid were also used in the analysis of the flotation concentrates.

3.5. Set-up:

3.5.1. Start up and calibration

The 5 liter cell and 43 liter flotation cells were checked for leaks by filling with water. The impellor of the Denver flotation machine was checked for acceptable operation and the air rotameter was checked for air flow. A calibration of the rotameter was provided.

Tap water was available near the apparatus and this was used for all experiments. The containers for collection of the flotation concentrates were weighed and marked prior to tests and wash bottles were filled and on hand at the beginning of the tests.

3.5.2. Cell set-up

The cell agitation was selected on a visual basis. The speed of 700rpm chosen, ensured that the solids were kept in suspension but did not result in any spillage. The addition of air to the cell caused an increase to the pulp level, and therefore the pulp level before the introduction of air to the cell was marked off and used as a standard for all rougher cell simulation tests. This amounted to approximately 4.2L of water that was added to the contents of the flotation cell to make up the flotation pulp. Air was added at a rate of approximately 28 liters per minute. The scavenger simulation required a shallow froth layer therefore a higher pulp level. This was marked accordingly after trial runs were conducted. Scavenger tests were conducted with approximately 4.4L of water to make up the pulp. Slight adjustments were made to the air flow in order to

maintain the froth depth at approximately 5cm thick in the rougher and approximately 2cm in the scavenger tests.

In order to examine the effect of froth washing on the froth layer the concentrate froth had to flow naturally over the lip of the cell. (The conventional method of hand scraping of the froth in batch tests could not be used).

3.5.3. Froth collection times

According to Eurys Mineral Consultants (2009) the following issues are of importance when determining froth collection times:

1. *The shape of the recovery-time curve can be accurately described mathematically*
2. *The fast floating fraction collected at the start of the test is adequately represented and measured.*
3. *The slow floating fraction collected towards the end of the test is adequately represented and measured.*
4. *Sufficient sample is generated so that all analyses can be assayed. If this is not possible then duplicate/triplicate tests should be done.*

The tests were conducted such that a distinct fast floating and slow floating section could be shown on the graph of recovery versus time.

3.6. Details of flotation procedure

3.6.1. Test sample

Samples for the tests were sourced from Idwala chemicals and the laboratory. Alsil P and Limestone were obtained from Idwala chemicals in the selected size range and a chalcopryrite concentrate was obtained from the laboratory. (See Appendix A for details) The total sample added to the cell was 1 kilogram.

3.6.2. Sample and reagent addition

- 1 kilogram of sample was charged to the flotation cell and water was added until approximately 5cm below marked pulp level.
- The impellor was then switched on at the previously decided speed (700rpm).
- Water was then added to make up to the marked pulp level. Making up a pulp of approximately 4.2L.

- The timer was then started. The Depressant was added for those tests requiring it and allowed to condition for 5 minutes, Frother was added 1 minute prior to the pulp being ready for flotation and the Collector was added approximately 30 seconds before flotation. The collector was pH sensitive therefore the pH was measured and adjusted prior to its addition.

3.6.3. Flotation test procedure

The test was commenced by starting up the air flow, the timer was switched on when the first concentrate began to flow over the cell lip. Excessive addition of air can result in the air disrupting the froth therefore care was taken that the airflow was not increased above the maximum which had been determined experimentally. The concentrate was collected in containers. The material that adhered to the sides of the cell was washed down regularly using the wash bottle water; this water was also used to maintain the pulp level in the cell during the run. The length of the run was determined experimentally in the initial runs and maintained for most tests as a constant for comparison.

3.6.4. Flotation concentrate

The concentrates that were collected in pre-weighed containers, weighed and then filtered. The filtered product was dried in an oven and the dry mass was recorded. From these results the mass of water and solids in each concentrate were determined and the mass of solids in the tails was determined by difference.

3.7. Overview of tests conducted

3.7.1. Alsil P only

Tests were conducted with Alsil P only to determine the floatability of the Alsil P and determine the conditions for further tests.

3.7.2. Limestone and Alsil P

Tests were carried out with 100 grams of Alsil P and 900 grams of limestone. These tests formed the basis against which the froth washing test results were compared. The concentrate samples were filtered and dried prior to determining the limestone content by dissolution in hydrochloric acid as outlined in Section 2.5.2.

3.7.3. Chalcopyrite

Initial tests with chalcopyrite were conducted to determine the floatability of the concentrate and conditions required for its flotation. . It is assumed that some oxidation must have taken place therefore acid washing with a weak solution of hydrochloric acid was conducted. Different approaches to acid washing were attempted, the first was to wash with a 10 percent hydrochloric acid solution and then oven dry the filtered solid. This was then weighed and floated. The next attempt was to wash with a weaker acid solution (1 percent) and oven dry the solid before flotation. Flotation was also attempted with the acid washed chalcopyrite without drying. In order to float the chalcopyrite it must be coated with a collector. A mass of 30 grams of chalcopyrite was used and the SIBX collector was added at 10 grams per ton of ore to the cell. The pH of the cell contents was tested and sodium hydroxide was added until a pH between 9 and 10 was achieved. The Nickel and Copper sulphides content of the UG2 ore varies therefore an estimate was used. A figure of 700 parts per million (ppm) of Nickel and 180 ppm of Copper was estimated from work being done on UG2 ore in another project (Ramlal NV, (by communication)). Samples of chalcopyrite concentrate were dissolved in an oxidizing acid mixture (see 3.7.8), to determine the copper content. The samples from flotation tests, in which chalcopyrite was present, were first treated with 10 percent HCl, to determine the mass loss (due to limestone dissolution). The oxidizing acid treatment was then used to dissolve the chalcopyrite. The solution was analysed for copper using Inductively Coupled Plasma Mass Spectrometry (ICP) for copper. The percentage of copper in the sample was converted to a percentage of chalcopyrite using the molecular weight. This was used in analysis of chalcopyrite recovery and grade.

3.7.4. Acid Test (dissolution of limestone)

The samples were sub-sampled by the method of cone and quartering, larger samples were passed through the riffle. 10 gram sub samples were made up for testing. Tests conducted on 10 gram samples of Alsil P and limestone alone revealed that addition of 30ml of 32% hydrochloric acid and 30ml of water results in complete reaction of the limestone, and that Alsil P does not react. Once the reaction was complete the solution was filtered and dried to calculate the mass of limestone that was reacted.

3.7.5. Flotation tests in pilot scale cell

A mass of 1 kilogram of talc and 9 kilograms of limestone was placed in the pilot cell and water was added until the pulp reached the required level. Only a few tests were performed in this cell, as

the large amount of Alsil P required resulted in an uncontrollable froth and the cell design did not allow for the implementation of froth washing.

3.7.6. Chalcopyrite and limestone

Tests were conducted with chalcopyrite and limestone as the gangue mineral as described previously.

3.7.7. Froth washing tests

Washing was tested in the rougher and scavenger stage of flotation. The position of the washer, rate of washing, and reagent addition to washing water were tested. Tests conducted with a negative water bias required and increase in air flow to maintain the froth flow. These airflow adjustments were made by visual observation of froth flow.

3.7.8. ICP analysis

A five gram sub-sample was prepared by simultaneous addition of 10ml of 32% hydrochloric acid and 10ml of nitric acid. This was placed on a heater and stirred, using a magnetic stirrer for ten minutes. The solution was removed from the heater and allowed to cool before filtering. The filtrate was then diluted in a 500ml flask. The filtered solution was then filtered again using a syringe and a microporous filter. Approximately 12ml of the solution was placed in a vial. Batches of vials were sent for ICP analysis at the University of KwaZulu Natal Westville Campus.

3.7.9. Industrial flotation cell tests

The plant tests were conducted by placing the froth washing device over the lip of the flotation cell using the vertical slots shown in figure 14. The washer bar position was adjusted for different tests. The samples were collected in buckets over 3 minute intervals. The samples were analysed for PGM content by Lonmin.



Figure 18: Froth sampling device

The wash water was injected into the froth via a porous horizontal tube across the width of the unit, (connected to the central vertical tube shown in the picture). The bucket for collecting the sample was placed on the rods on the outside of the unit. A converging chute was used to direct the froth from the cell overflow into the bucket.

4. Results and Discussion

4.1. Overview of test work

Initial test work was carried out on the test minerals used for the project. Flotation tests were carried out at varying conditions. These tests provided a basis against which further tests could be compared. Data for preliminary work was represented by graphs of percentage dry mass recovery of floatable (Alsil P) and un-floatable material. These recoveries were represented as a percentage of the floatable and un-floatable material introduced to the cell respectively. Grade of the concentrate was calculated as the percentage of floatable material in the concentrate on a dry basis. Frother and depressant dosages were varied at first to establish base cases against which the froth washing data could be compared. When the froth washing tests were started it was decided to represent the results as a comparison of the percentage recovery of the total floatable material introduced to the cell against the mass percentage of the total feed reporting to the concentrate. Grade/recovery curves are generally used when selling concentrates however, in the case of a plant with its own smelter controlling mass flows to maximize metal production is of greater importance. Using a mass flow in this context makes it easier to optimize the production from a number of concentrators. The desired result was an improvement in recovery of valuable floatable material without significant reduction in the mass of feed recovered in the concentrate.

4.2. Preliminary Tests on Alsil P, limestone and chalcopyrite test material

Alsil P is hydrophobic material therefore initial tests were conducted on samples of Alsil P alone to establish the extent to which Alsil P floats. Frother dosages of 30g/ton of ore, 50g/ton of ore and 70g/ton of ore were tested. The frother dosage was varied so that the point at which further addition of frother would no longer result in greater recovery of floatable material. The amount of Alsil P and water in the system and the froth depth and height were kept constant for each run as described in section 3.5. The water that flows out of the cell with the froth was replaced by manual addition of water with a wash bottle to maintain a specified pulp level. Tests were run until the flow of froth out of the cell ceased (approximately 5 minutes). Results for the tests conducted in figure 19 below show that no further recovery of floatable material was achieved above a frother dosage of 50g/ton of ore.

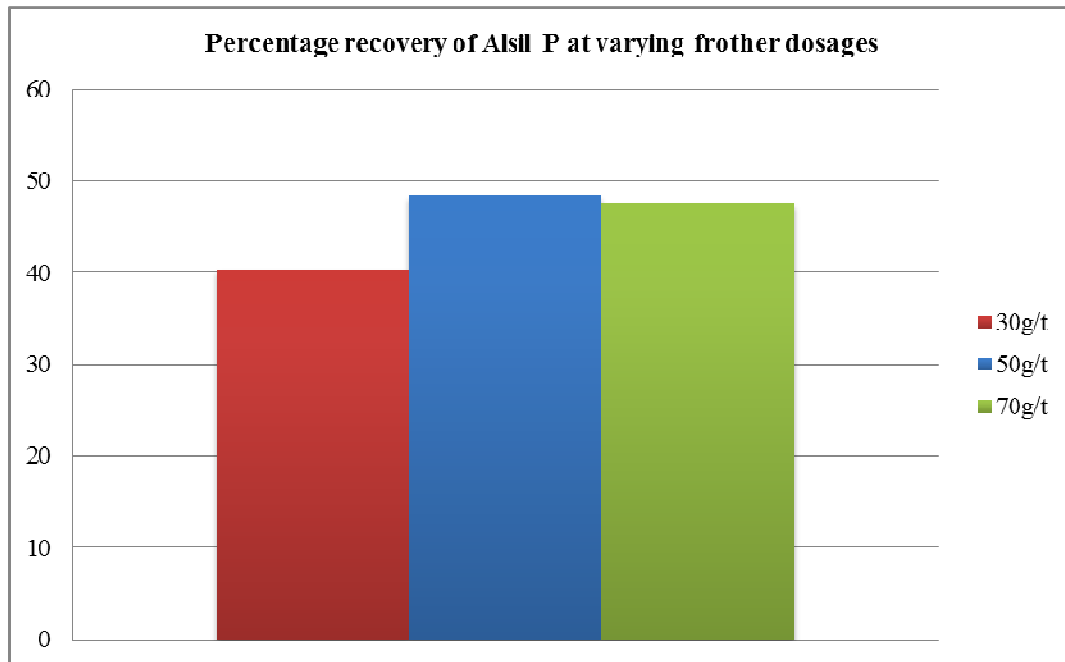


Figure 19: Bar graph depicting recovery of Alsil P at different frother dosages in order to establish the frother dosage at which no further material was recovered.

Typical UG2 ore contains about 5 percent talc and hence, given a normal ore loading for a 5 litre cell of 1 kilogram, 50 gram samples of Alsil P were used for the initial tests. The most noteworthy observation made was the significant bubble coalescence at the surface of the froth. The froth was sticky and voluminous, and bubbles popped at the surface causing Alsil P to stick to the walls of the cell. This bubble coalescence can be attributed to the structure and nature of Alsil P particle.

Preliminary tests revealed that only fifty percent of the Alsil P was recovered in the froth. An attempt was made to separate the floatable Alsil P from the un-floatable by flotation. The floatable portion would then be used for tests. This however, proved unsuccessful as the attempted flotation of more than two hundred grams of Alsil P in the five litre cell was uncontrollable. The froth built up and eventually overflowed from all sides of the cell as illustrated in figure 20.



Figure 20: Uncontrollable froth created by Alsil P

This implied that attempted flotation of large amounts of Alsil P in the large cell would be ineffective as the same result was expected. The amount of Alsil P added to the 5 litre cell was then corrected to 100 grams to compensate for the portion that did not float. This ensured that the cell contains approximately 5 percent floatable material and 95 percent un-floatable material made up of Limestone and Alsil P. Tests to confirm that only 50 percent of the Alsil P would float naturally was successful.

Tests were then conducted on the limestone alone to determine if this material had any natural floatability. By the nature of the froth, it was observed that some limestone was carried over by entrainment as the particles did not appear to adhere to the air bubbles as they did with tests done on Alsil P. Approximately 0.78 percent of the limestone that was introduced to the cell was recovered in the froth by entrainment and the froth collected contained 4 percent of the water from the flotation cell. This test confirmed that the limestone had no natural floatability.

Preliminary tests were performed on the chalcopyrite to determine whether it would float and what conditions were required for its flotation. The chalcopyrite concentrate had a dull grey-brown appearance. The first attempt at flotation with no pre-treatment failed as nothing floated with the addition of collector. The concentrate was then washed with dilute Hydro chloric acid before flotation as described in Section 3.7.4. The chalcopyrite concentrate changed to a bright golden colour after acid washing. Of the methods attempted the first method of acid wash (with 10 percent acid and then drying) yielded the greatest recovery. Samples of the concentrate and the tail from the first test conducted were digested in nitric acid and sent for ICP analysis.

Once the floatability of Alsil P and limestone alone had been investigated, tests were performed on a mixture of limestone and Alsil P. The system requires 95 percent un-floatable mineral, therefore 90 percent of solids loaded to the cell were limestone as a 10 percent loading of Alsil P resulted in 5 percent floatable material in the cell. A frother dosage of 50 g/ton of ore was used unless stated otherwise. The addition of limestone to the cell had a considerable effect on the froth produced by Alsil P alone. The limestone stabilized the froth and the structure appeared to be similar to that observed at UKZN when performing tests on UG2 ore. The presence of a significant proportion of hydrophilic particles (limestone) in the froth prevented premature bubble coalescence. Recovery of Alsil P increased and a small amount of entrainment was noted (Approximately 1.3 percent of the un-floatable material in the flotation cell was recovered).

In order to examine the amount of entrainment in the 5 litre cell, a run was conducted with only limestone in the system. The result of this test was that more limestone was entrained in the presence of Alsil P than the limestone alone. During the limestone only run approximately 0.78 percent of limestone was entrained in the froth concentrate, however, in the run conducted with both limestone and Alsil P, limestone recovery increased to 0.89 per cent. An understanding of the behaviour and movement of Alsil P in the froth is required to explain this outcome. This is beyond the scope of this project; however it can be assumed that the movement of the Alsil P particles from the pulp to the froth increases water recovery and hence it increases limestone recovery by entrainment. The focus of this investigation will be on how to reduce entrainment of limestone by adding wash water.

4.3. Comparison of effect of Guar gum and Carboxymethyl cellulose (CMC)

The literature survey showed that two types of depressant were being used for talc depression by the South African platinum industry, namely CMC and Guar gum. Although the literature survey indicated that CMC is a less effective depressant for talc, tests were carried out to confirm these findings for Alsil P.

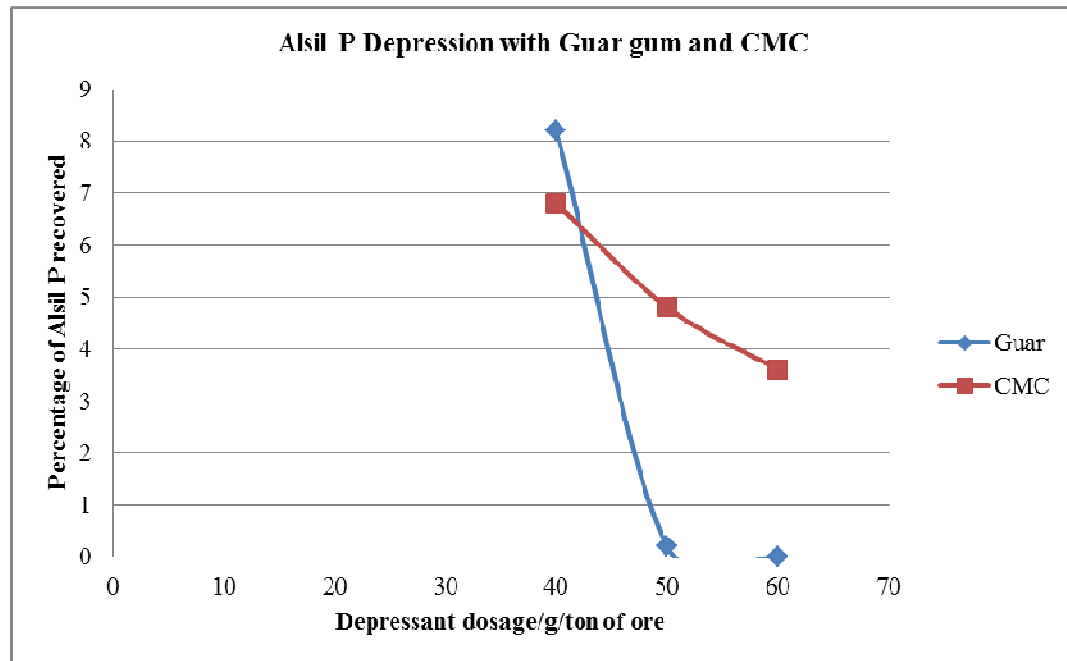


Figure 21: Effect of Guar gum and CMC on recovery of floatable material

Results of tests in Figure 21 revealed that guar gum was most effective for the depression of Alsil P in the Alsil P/limestone system, validating the information found in literature. Steenberg (1982) found that CMC adsorbs in a flat two dimensional formation on the talc whereas the guar adsorb in a three dimensional formation with extended tails and loops. If this applies to this investigation it can be concluded that the guar is a better depressant for Alsil P due to the significantly greater adsorption of guar onto Alsil P as opposed to CMC.

A series of tests were then run with the guar gum at different dosages. Tests were conducted with Guar gum dosages from 50 grams per ton of ore to 200 grams per ton of ore. These tests were analysed for recovery of Alsil P as well as entrainment. Results of these tests are discussed later in section 4.5.

4.4. Pilot scale cell tests

A small number of tests were conducted in a 43 liter pilot scale flotation cell with 9 kilograms of limestone and 1 kilogram of Alsil P. Frother and depressant dosages were varied. Initial tests conducted with Alsil P and limestone and no depressant resulted in an uncontrollable froth and much more bubble coalescence (due to the larger amount of Alsil P present). A significant amount of the concentrate was lost due to the bubbles coalescing and flowing over the sides of the cell. It was not possible to include these losses to the concentrate therefore data presented does not include these losses. These tests were run for a time period of approximately 30 minutes until the froth ran out and the overflow ceased. Addition of the depressant resulted in a less voluminous froth. The froth weakened before all the valuables were retrieved therefore the frother dosage was increased. This however had the opposite effect to what was expected.

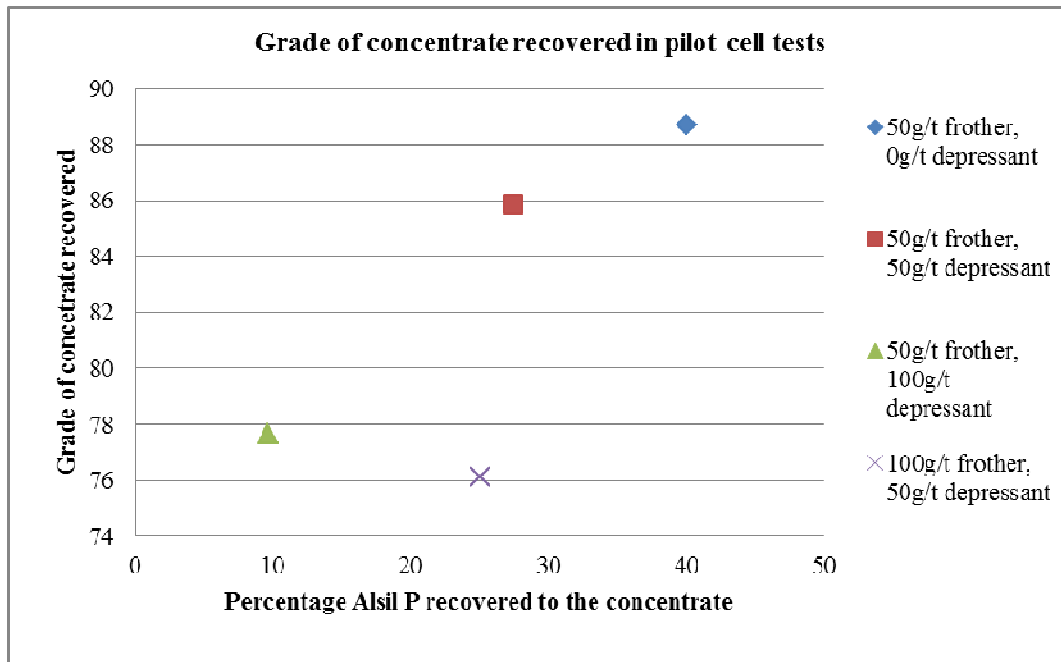


Figure 22: Pilot scale tests over 30 minutes (Recovery of Alsil P excluding spillages)

Figure 22 shows that the grade of the concentrate (% Alsil P), recovered in 30 minutes was reduced progressively as the depressant dosage was increased. This result was expected. The doubling of the frother concentration, (at 50 g/t depressant) had an adverse effect on the grade of concentrate. This effect could be due to the formation of smaller, more stable bubbles, resulting in more entrainment of limestone, relative to flotation of Alsil P. It is possible that since Alsil P (talc) has a 3 dimensional layered sheet it may be more difficult to adhere to the smaller bubbles created by excess frother. Figure 23 shows that there was a greater recovery of water to the concentrate during the run with a higher frother dosage. This can be attributed to the larger amount of water being carried into the froth between the smaller bubbles. Smaller bubbles may also reduce the capacity of the drainage of water from the froth. It can be seen that the excess frother depresses the Alsil P.

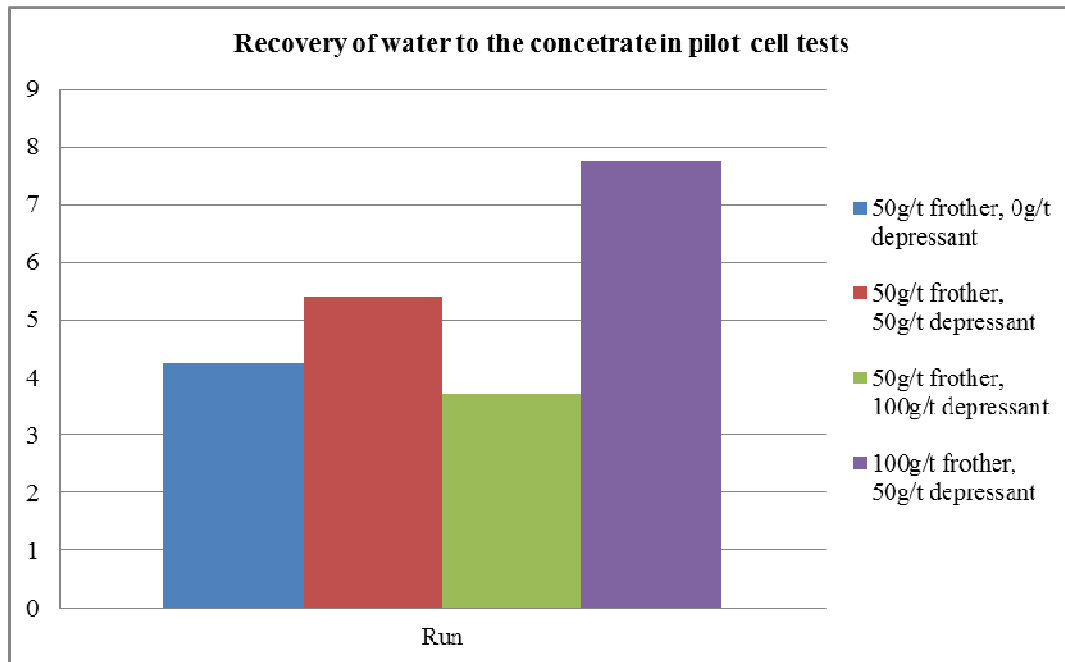


Figure 23: Recovery of water to the concentrate in pilot flotation cell tests

Due to the difficulties experienced with the synthetic test materials with the pilot cell all further test work was carried out in the laboratory scale 5 liter cells.

4.5. Modelling of Entrainment

Entrainment is said to be a non-selective process, prior work by Emin (2001) showed that entrainment can be directly related to the amount of water carried into the concentrate. Figure 24 shows a cumulative plot of the mass of limestone entrained against volume of water in the concentrate. Straight line trends were fitted to the data, Table 3 shows the R^2 values for these relationships.

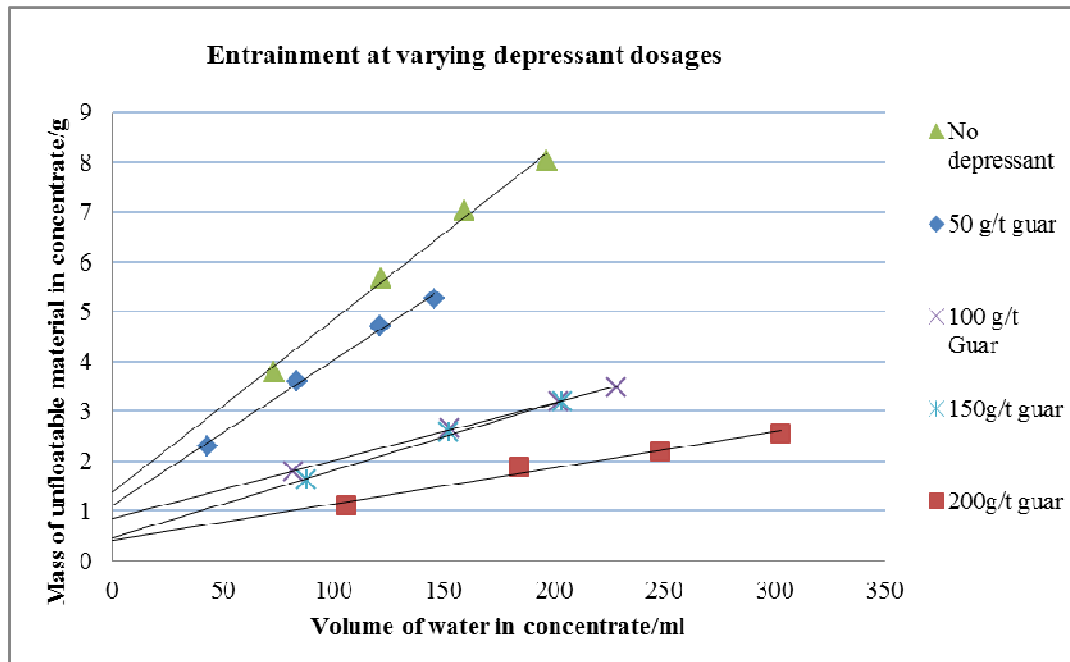


Figure 24: Graph depicting entrainment of un-floatable material (limestone) at varying depressant dosages

The data in figure 24 was obtained at fixed time intervals (3, 6, 9, 12 minutes). The surprising result was that the water recovery remained in the same range, despite a significant reduction in the mass recovery of Alsil P as the depressant dosage was increased.

Table 3: R^2 values for relationship between recovery of un-floatable material (limestone) and water recovery

Depressant dosage/g/ton of ore	R squared
0	0.9938
50	0.9959
100	0.9990
150	0.9965
200	0.9739

The R^2 values presented in table 3 are all above 0.9 showing a good fit of the data to the straight line. These trends also compare well with that found in literature (Neethling, 2001), presented in section 2.8.2. The data was fitted to Smith and Warren's (1989) description of entrainment as a function of water recovery.

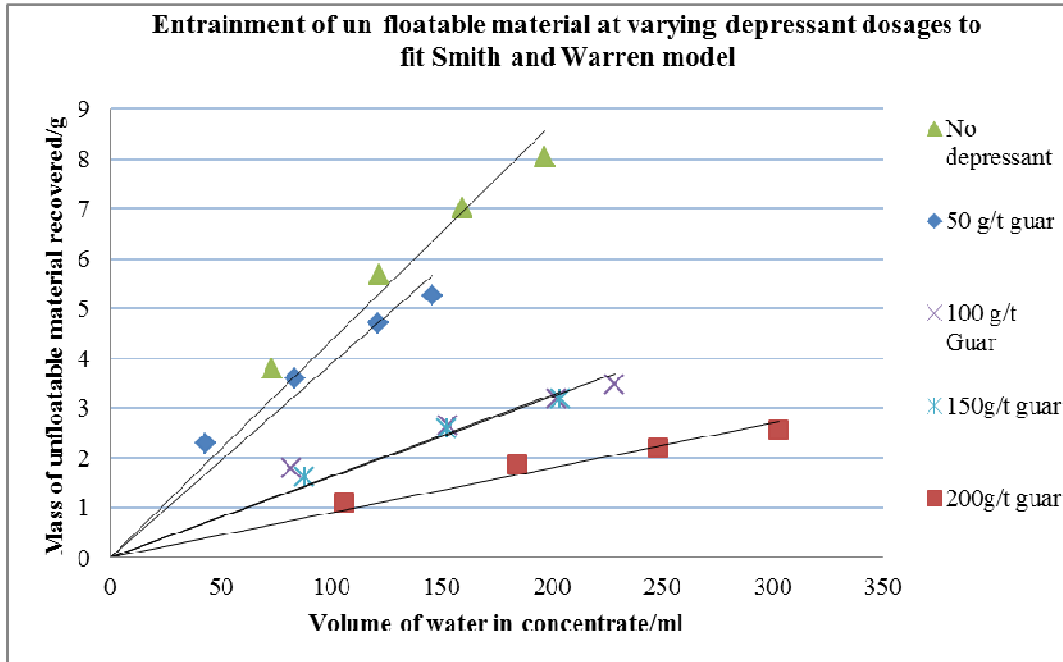


Figure 25: Mass of un-floatable material entrained at varying depressant dosages to fit Smith and Warren model

Table 4: Entrainment factor e_g and R^2 values for the relationship between limestone entrainment and water recovery with zero intercept

Depressant dosage/g/ton of ore	Entrainment factor e_g	R squared
0	0.0434	0.9188
50	0.0388	0.8663
100	0.0163	0.9470
150	0.0162	0.8218
200	0.009	0.9042

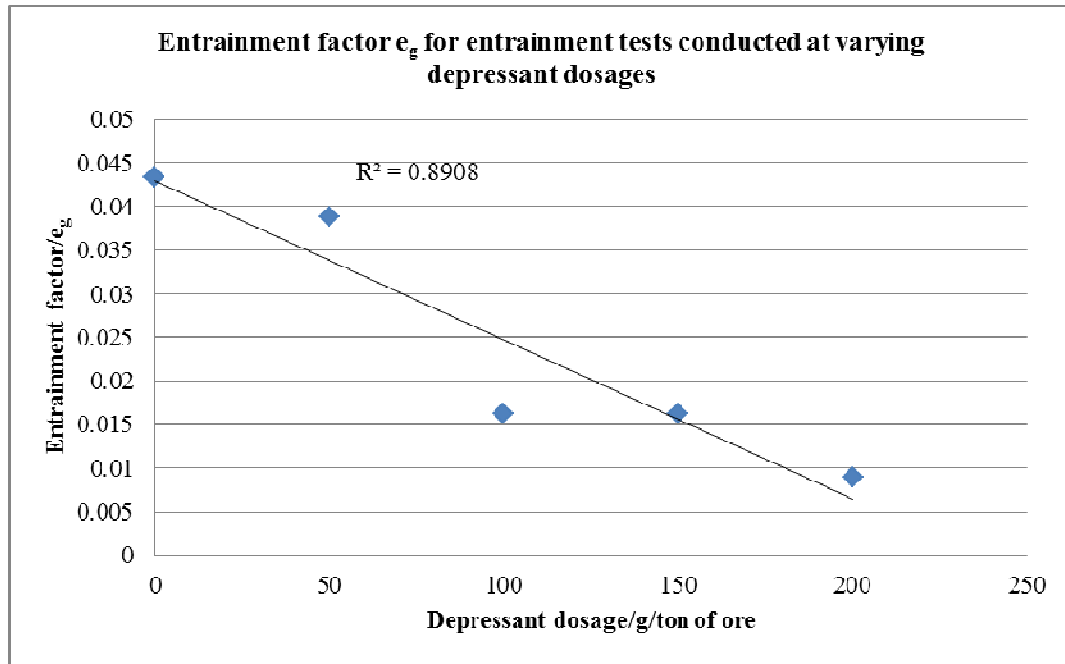


Figure 26: Plot of entrainment factor (e_g) vs. depressant dosage

The data was fitted in Figure 25 with a straight line trend with zero intercept. The gradient of the graph is the entrainment factor e_g , is noted to decrease with increase in depressant dosage, this can again be attributed to the decrease in floatable material assisting the gangue minerals into the concentrate. The R^2 values in table 4 for this fit of the data are a good fit. Figure 26 above shows the plot of entrainment factor against depressant dosage. The linear trend fitted to this data results in an R^2 value of 0.89. More detailed entrainment models are more difficult to fit as they require among others, particle size, pulp density, froth thickness and aeration of the cell.

4.6. Flotation tests at varying depressant dosages (in the 5L metal cell)

The tests on the effects of varying depressant dosages (0g/ton and 200g/ton) on Alsil P were conducted in a 5L flotation cell. During the first test, with no depressant, the flow of concentrate reduced to essentially nothing at 12 minutes. Therefore in order to standardise the tests for the sake of comparison the tests were conducted over a total time period of 12 minutes each with a sample removed after 3 minute intervals. Figure 27 below shows that the recovery of Alsil P was reduced as depressant dosage was increased. Very little difference was observed between dosages of 150g/t and 200g/t and it appears that the Alsil P was fully depressed. Visually the material in the froth for these runs seemed to be entrained rather than attached to the bubbles. Therefore it can be assumed that any addition of depressant above 150g/t would result in no significant recovery of Alsil P.

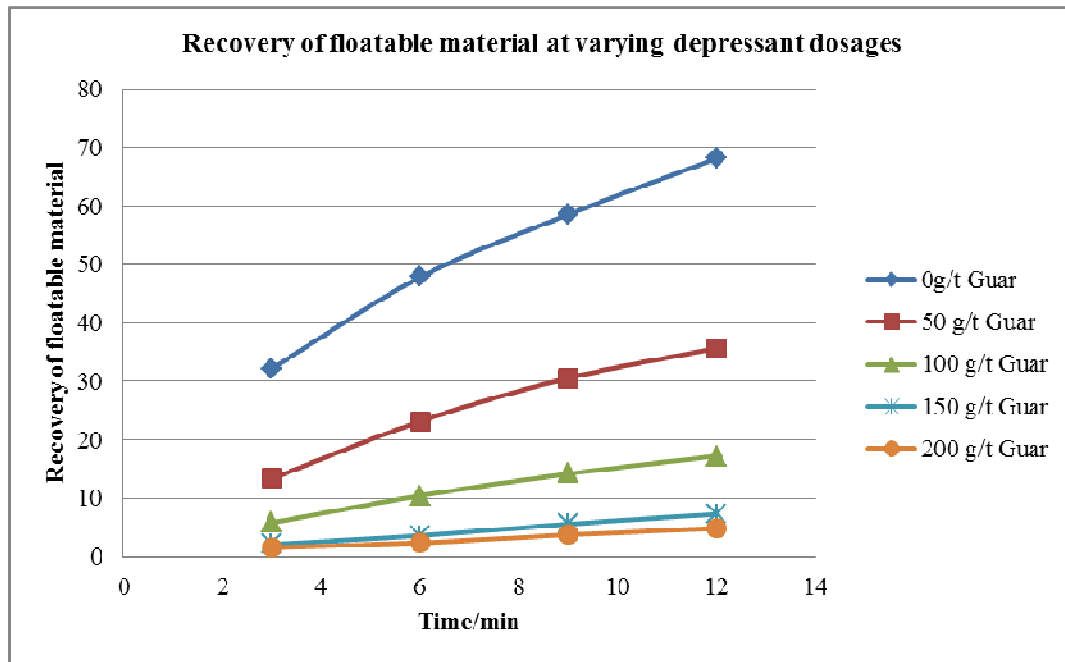


Figure 27: Recovery of floatable material at various depressant dosages

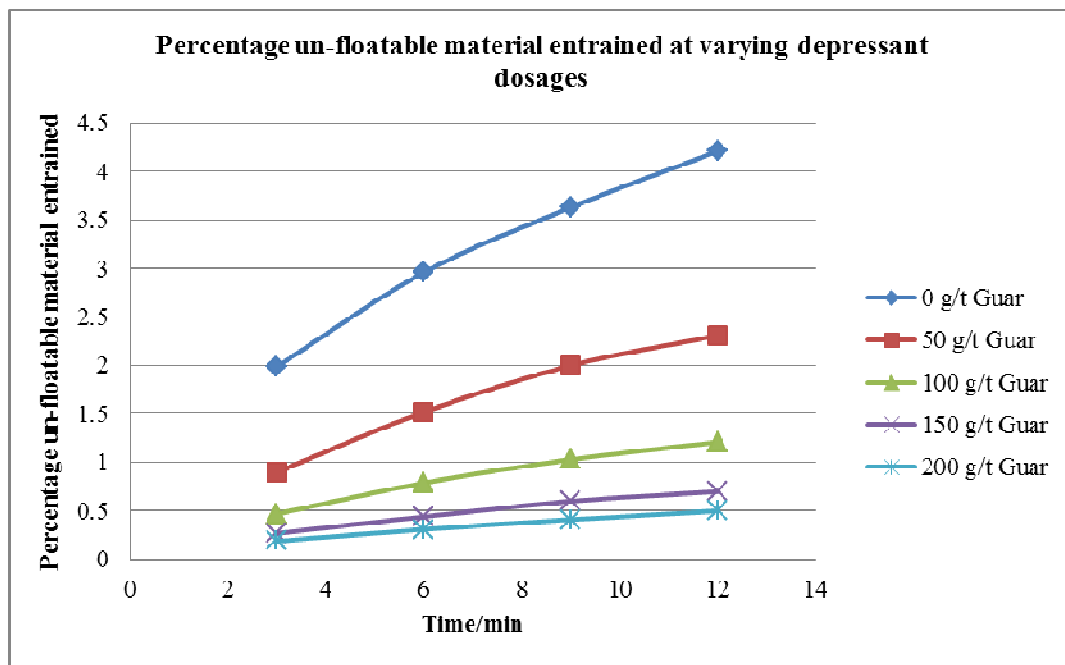


Figure 28: Recovery of un-floatable material entrained at various depressant dosages

The amount of un-floatable material that was entrained was represented as a percentage of the total un-floatable material in the cell and plotted against time. Figure 29 shows the same trend in

recovery as that of the floatable material in figure 28. This strengthens the idea that the floatable material in a flotation cell plays a significant role in the amount of gangue minerals entrained.

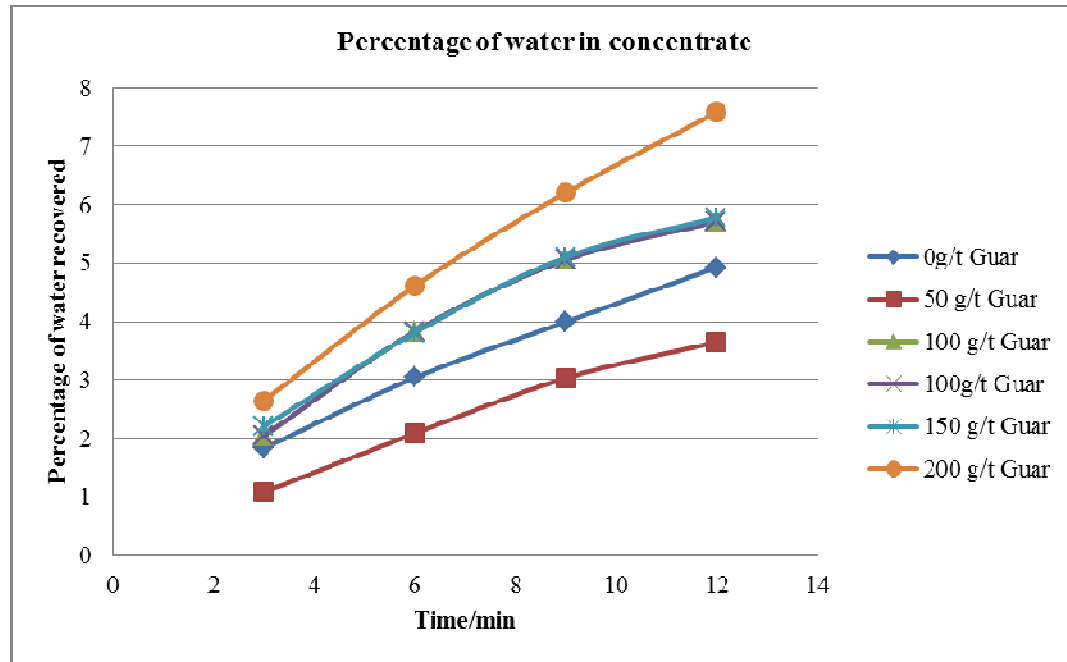


Figure 29: Mass percentage of water recovered into the concentrate at varying depressant dosages

Depressant weakens the froth and in Figure 29 it is noted that the froth initially, (at 50 g/t depressant) was drier, as the flow was less voluminous, giving the froth time to drain. However, at higher dosages, it became progressively wetter, as the flow of solids attached to bubbles was reduced. This can be attributed to the weakened froth and less floatable material available to strengthen the bubbles. The grade of the concentrate was calculated as the percentage of Alsil P in the total concentrate collected. In Figure 30 below, comparison of the final grade of Alsil P for each of these depressant dosages shows that the grade of concentrate decreased with an increase in depressant. When comparing the trends of the recovery of Alsil P and un-floatable material in Figures 27 and 28, it would seem that the grade of the concentrate recovered is almost constant. The major change occurs between dosages of 100g/t and 150g/t, the grade drops from 71 percent to 62 percent. This is due to the fact that the Alsil P recovery was becoming more dependent on entrainment and that it was present at relatively low concentration.

In view of the observations above and the fact that platinum mines add some depressant to control the flow of froth, it was decided that all future experiments on froth washing would be conducted using a depressant dosage of 50g/t.

At this dosage the froth resembled the froth in industrial flotation cells as it appeared more stable. The bubbles were even in size with less popping of bubbles at the surface compared to higher dosages. Higher frother dosages also resulted in a wetter froth. The driest froth is also intuitively

the best froth condition for the plant, where there is sufficient time for the gangue minerals to drain away, but the recovery of the floatable minerals is still adequate.

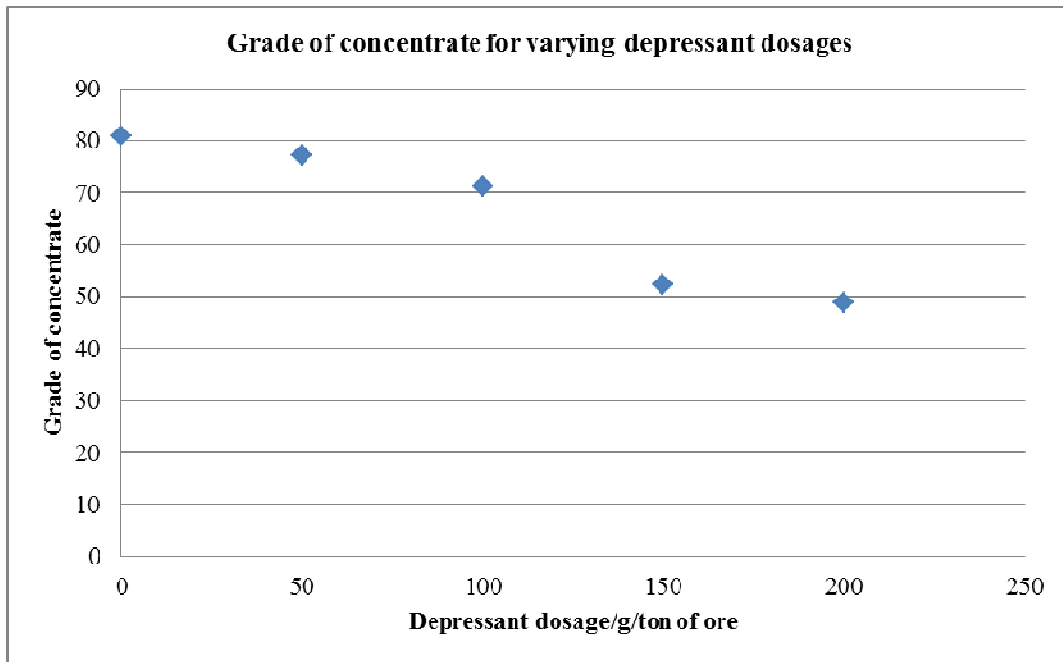


Figure 30: Grade of concentrate (percentage of Alsil P recovered in total concentrate) recovered at various depressant dosages

4.7. Froth washing

Froth washing tests were conducted in a Perspex laboratory scale flotation cell with the aid of a foam tube device constructed in the UKZN laboratory. The tube was relatively soft rubber, which made it possible to make several pinholes to disperse the water evenly along the length of the tube. Several parameters were varied in order to determine amongst others the best device, the position and the addition of frother to the wash water.

4.7.1. Type of flotation cell

As mentioned in section 3.4.1 there were two types of laboratory scale flotation cells available for froth washing experiments. The clear PVC cell was the preferred cell as it was possible to view the froth from the side and observe the effect of water injection. However, the shape of the stainless steel cell was different, with a settling zone before the overflow as shown in Figure 31. Therefore both cell types were tested.

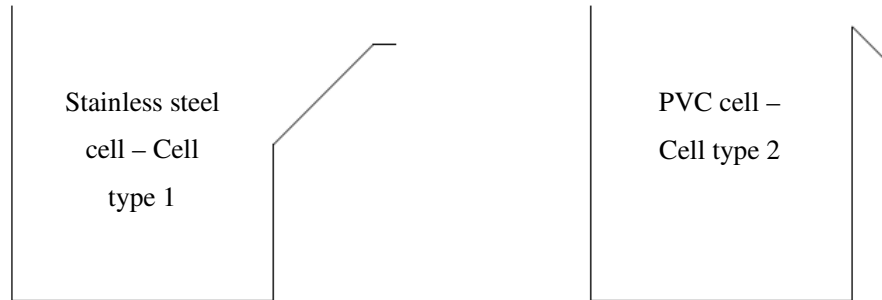


Figure 31: Side view illustrating the difference in design of laboratory flotation cells.

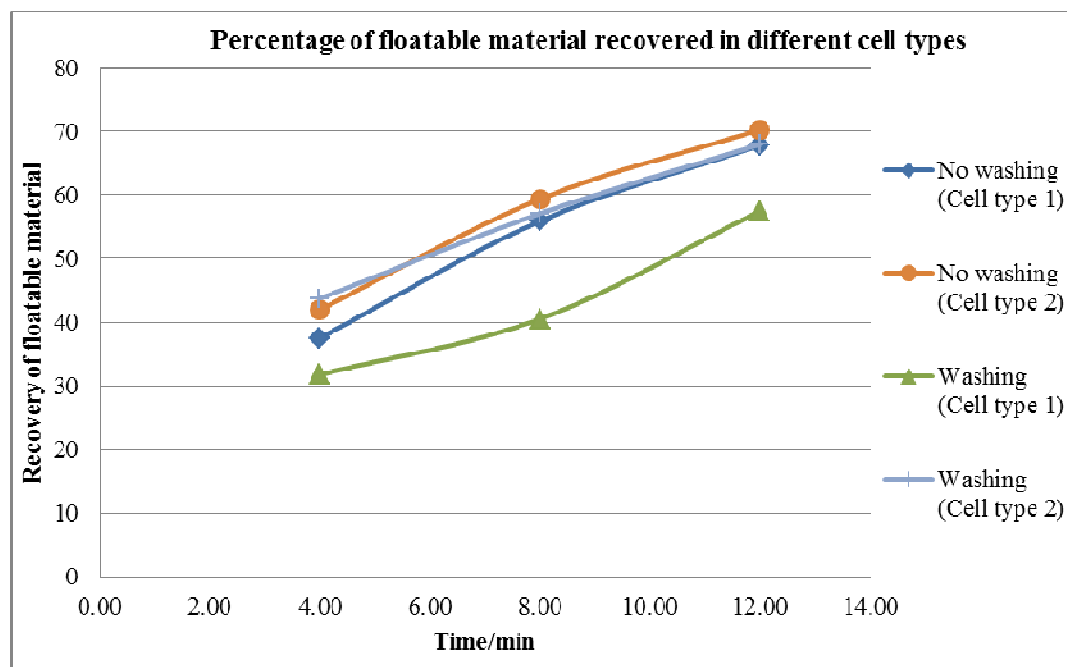


Figure 32: Preliminary tests on the effect of cell type

The results of preliminary tests are shown in figure 32. The effect of cell shape on recovery of floatable material (Alsil P) was marginal when no washing was done, with the results being slightly lower in the stainless steel cell.

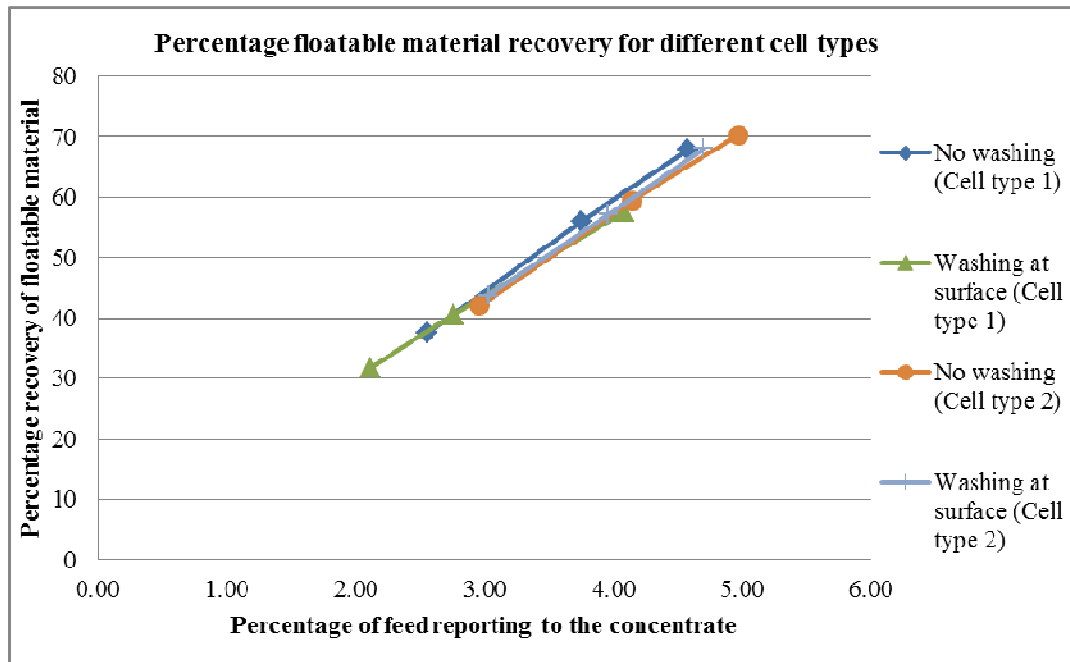


Figure 33: Recovery of floatable material vs. mass of concentrate

The effect of washing can be a reduction in entrainment and a reduction in the recovery of floatable material. Figure 33 shows the data from Figure 32, re-plotted in terms of mass of concentrate. This is similar to a grade/recovery curve and Figure 30 shows that washing has not been selective, with all the data falling on the same line.

It was concluded that the stainless steel cell offered no extra benefit and that further tests on froth washing should be conducted using only the clear PVC cell.

4.7.2. Type of washing device

Froth washing is not a widely used concept therefore there are not many specific designs that can be tested. In this project it is hoped to achieve a gentle, even, limited flow of water through the froth. It was felt that a jet of water has the potential to disrupt the froth and cause local downward flow of water and loss of recovery of floatable material. A foam rubber pipe with pin pricked holes was used to disperse the wash water in the froth. The pipe is available commercially for insulating hot water pipes. The foam rubber pipe was fitted into a PVC pipe for rigidity and placed across the width of the cell. One end of the pipe was sealed and the flexible tube was inserted at the other end with a funnel for manual addition of the wash water, which was controlled to maintain a constant pulp level (i.e. a zero bias). This made it possible to distribute the water flow evenly across the width of the cell. Two sizes of foam pipe were tested (25mm and 13mm internal diameter). The first round of tests was performed with many holes in the foam pipe. However, in view of the fact

that the flow was limited to maintain pulp level, it was decided that fewer holes had a better chance of distributing the flow evenly across the length of the tube.

Thereafter a smaller number of evenly distributed holes were made in the foam pipe. The two types of washing devices tested for which the results are indicated in Figures 34 to 36 were the 25mm foam pipe (device 1) and the 13mm foam pipe (device 2). The same numbers of holes were made in both devices except that those of the device 1 were distributed further apart due to the larger available surface.

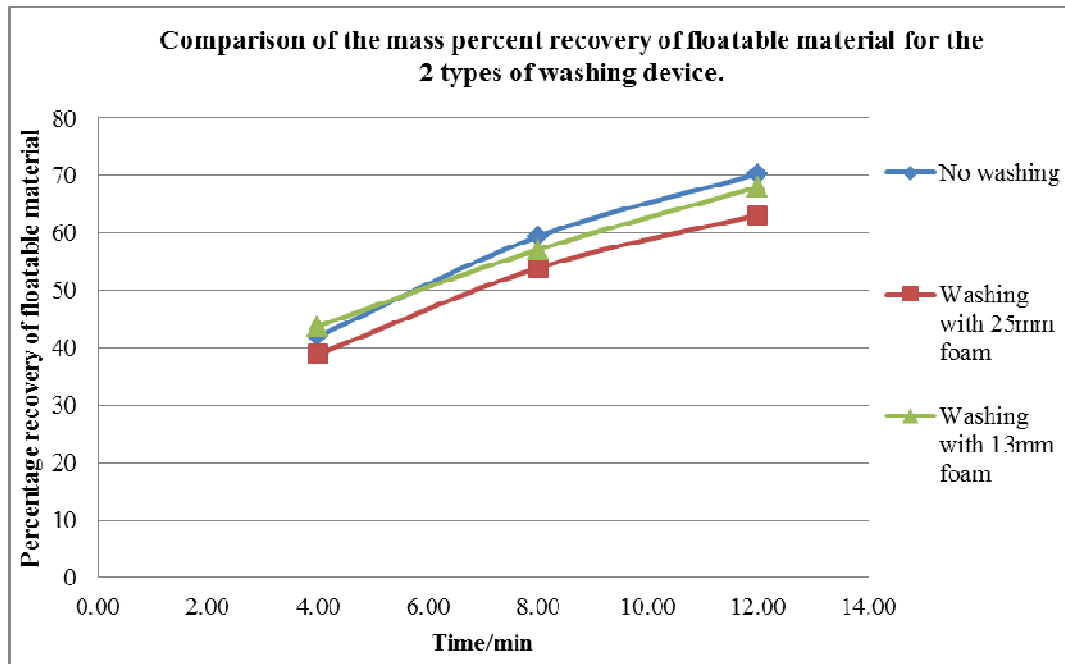


Figure 34: Preliminary tests of foam rubber tubes for froth washing (recovery of floatable material – Alsil P)

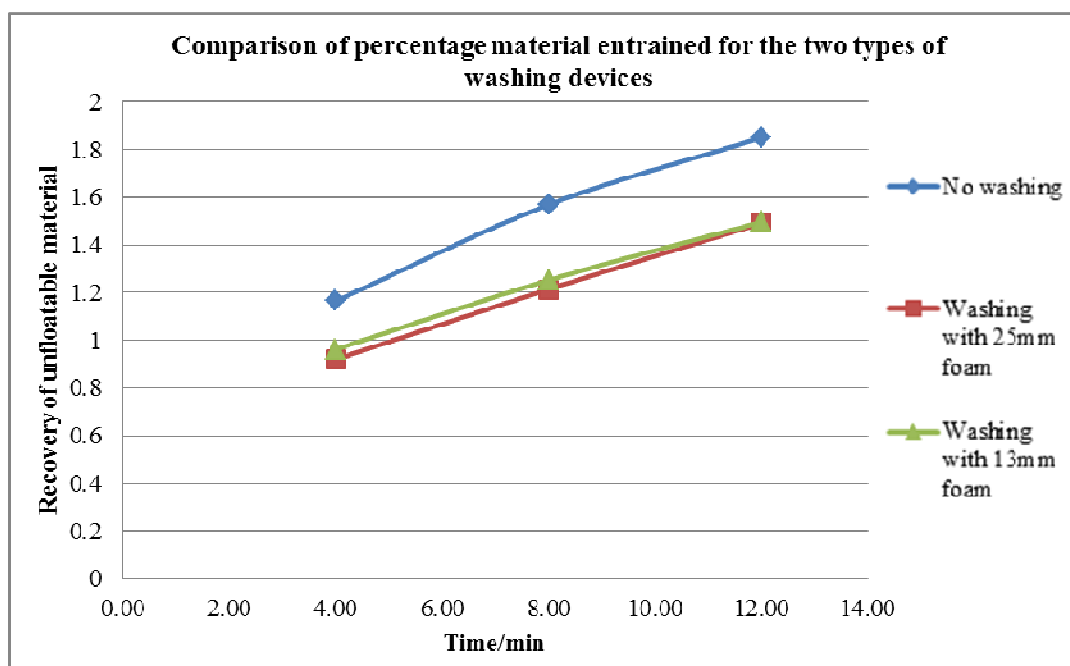


Figure 35: Comparison of the percentage entrainment of un-floatable particles for different washing devices

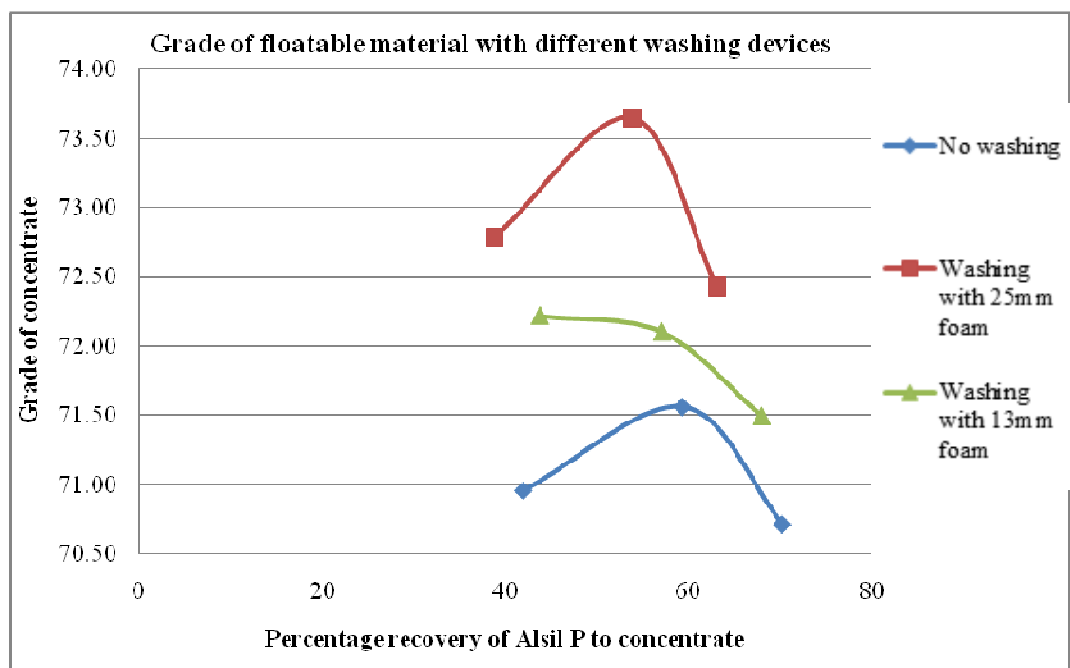


Figure 36: Grade of concentrate compared to the percentage of the Alsil P reporting to the concentrate for different washing devices

Results for the recovery of the floatable material Alsil P in Figure 34 shows little difference when comparing the devices. However; the entrainment depicted in Figure 35 shows that less limestone was entrained in the runs with froth washing. Figure 36 shows that the grade of Alsil P was greater in with the 25mm diameter pipe however the recovery decreased. By observation it was noted that the larger washing device held back the froth flow and collected more valuables over it than the smaller device. The wider distribution of wash water also did not make a difference to the recovery of Alsil P or the entrainment of the limestone. Based on this it was decided to use the smaller diameter pipe for future tests, (13mm).

4.7.3. Position of froth washing

The position at which froth washing was done was of great significance as it determines the effectiveness of the washing. Ideally the washing water should penetrate the froth and carry the entrained particles back to the pulp. Therefore if washing was introduced too close to the lip of the cell the wash water may not have enough time to penetrate the froth and if it is placed too far from the lip the entrained particles may still enter the froth after of the point of washing. In order to determine the ideal position for washing in the laboratory cell, tests were performed at two positions on the surface of the froth. Washing near the lip of the cell was eliminated as a possible position due to the small area available for the washer, position 1 in Figures 37 to 39 refers to washing at the position of approximately 3cm from the from the lip of the cell and approximately halfway between the cell lip to the impellor. Position 2 represents washing at the furthest possible point before the impellor shaft, approximately 6cm from the lip of the flotation cell.

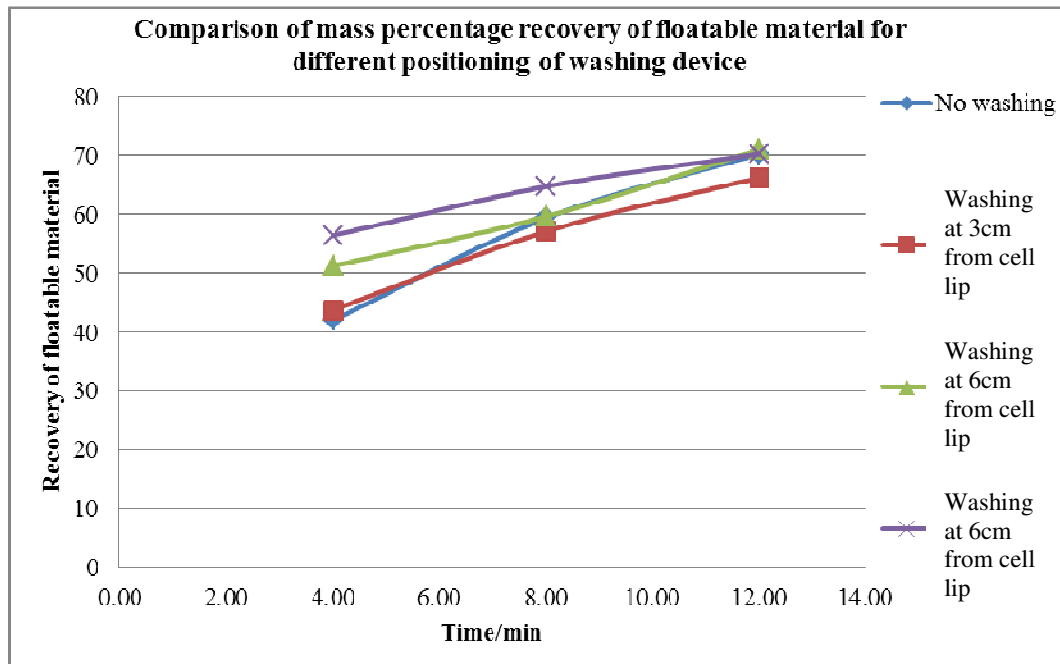


Figure 37: Comparison of recovery of floatable material for washing at different positions

Figure 37 shows that Alsil P recovery after 12 minutes was not affected by froth washing, at either position. However, Figure 38 shows that washing at position 1 (3cm from cell lip) results in considerably less entrainment than washing at position 2 and no washing. Since the aim of the froth washing was to reduce the amount of entrained particles, it was concluded that position 1 was most suitable for washing.

Figure 39 was a convenient way of summarising the benefit of froth washing. It shows that the grade and recovery of floatable material (Alsil P) was not significantly changed when washing was done at position 1, 3cm from the cell lip, while grade was actually reduced by about 10% when it was done at position 2. In order to leave smelter operations unaffected downstream of flotation it would be ideal to reduce the amount of entrained unwanted material whilst the recovery of the valuable portion remains unchanged. Further froth washing tests were conducted at position 1. In order to test the assumption that the best washing occurs at the position which allows the wash water to penetrate to the pulp-froth interface, a dye was introduced to the wash water.

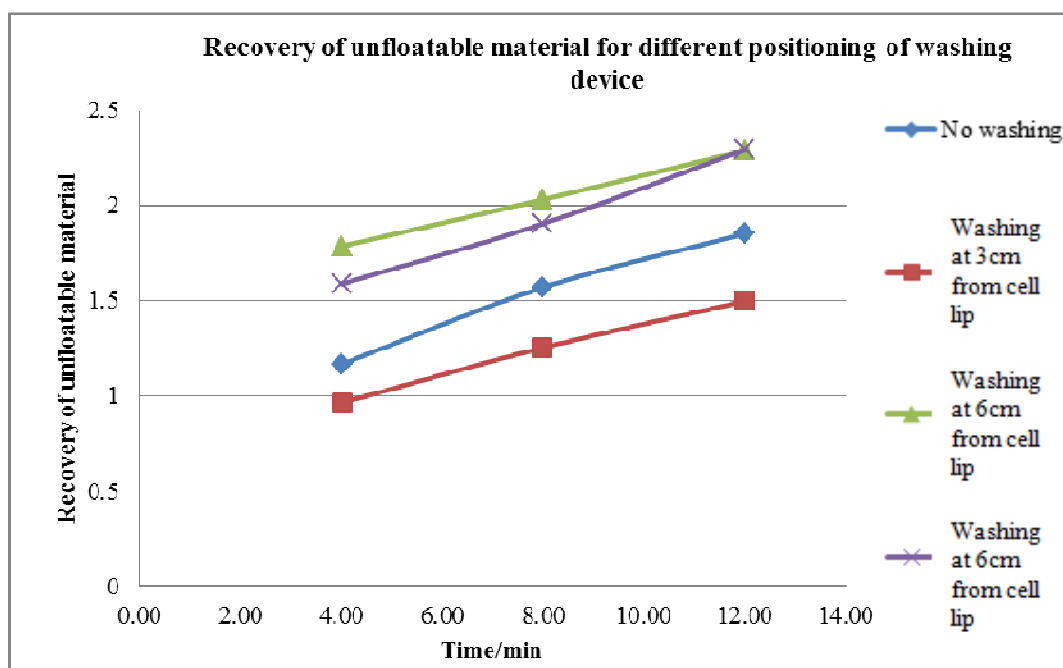


Figure 38: Comparison of mass percentage of entrained particles over time for washing at different positions

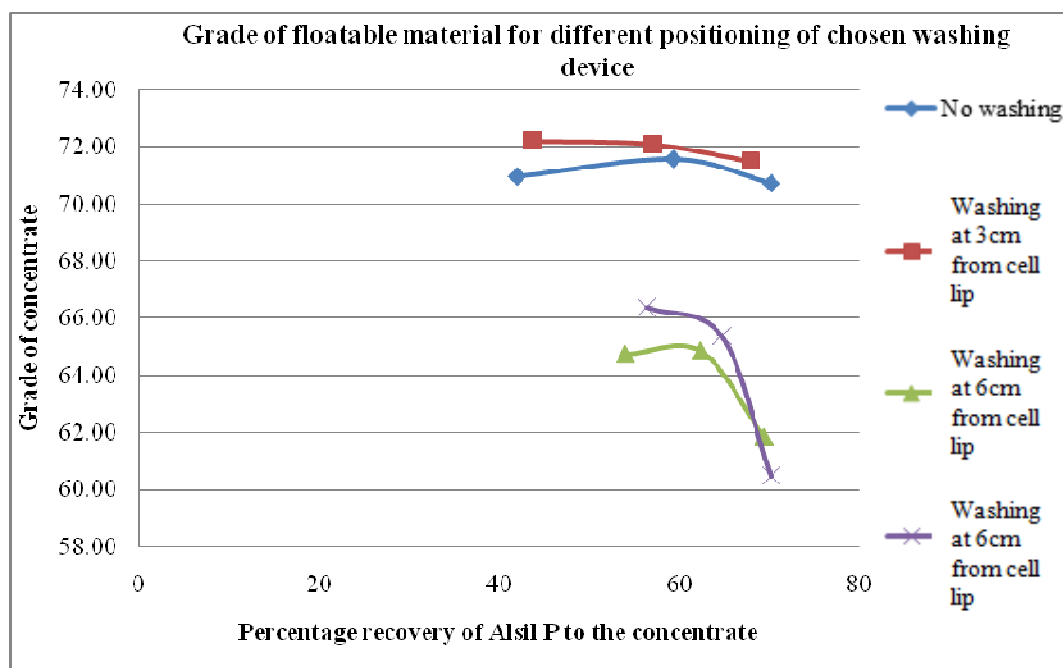


Figure 39: Grade of concentrate compared to the percentage of Alsil P recovered for washing at different positions

4.7.4. Wash water monitoring

Dyeing of the wash water allowed a visual indication of the flow of the water. These tests were done at an early stage and a wash position near the impeller was chosen (position 2), to facilitate visual observation of the wash water flow. Figure 40 below shows the pattern created by the dyed wash water. The red lines in figure 40 illustrates that from the point of injection to the lip of the cell the wash water penetrates the froth.



Figure 40: Dyed wash water

It was expected that the wash water would replace the water in the froth, effectively washing away the gangue minerals entrained by the bubbles. Therefore the result of perfect washing would be all of the wash water that enters the froth leaves in the concentrate. This was monitored by addition of salt to the wash water and measurements of conductivity of all concentrate samples and the pulp at the end of the run (tailings). By comparing the concentration of salt in the wash water to the concentration of the salt in the concentrate the amount of wash water exiting in the concentrate was estimated (See Appendix C). Results indicated that approximately 38 percent of wash water reports to the concentrate. The standard deviation of the results obtained from the five tests conducted was 5.4% which shows the close correlation between results. The deviation from perfect washing can be attributed to the drainage of the wash water through the froth into the pulp. Drainage through the full depth of the froth was required for effective washing and hence some of the wash water was mixed into the pulp when it reached the turbulent pulp-froth interface.

4.7.5. Frother Dosage

Earlier tests had shown that a dosage of 50g/t of frother was suitable for the flotation of Alsil P therefore this dosage was used for most of the tests described above. It was decided that additional froth washing tests should be performed to see if washing has any effect at higher frother dosages. Figure 41 shows that at dosages of 60g/t and 65g/t frother the recovery of Alsil P from the pulp is greater than that at 50g/t both with and without washing. It was expected that washing will reduce the recovery of Alsil P which is evident in figure 41.

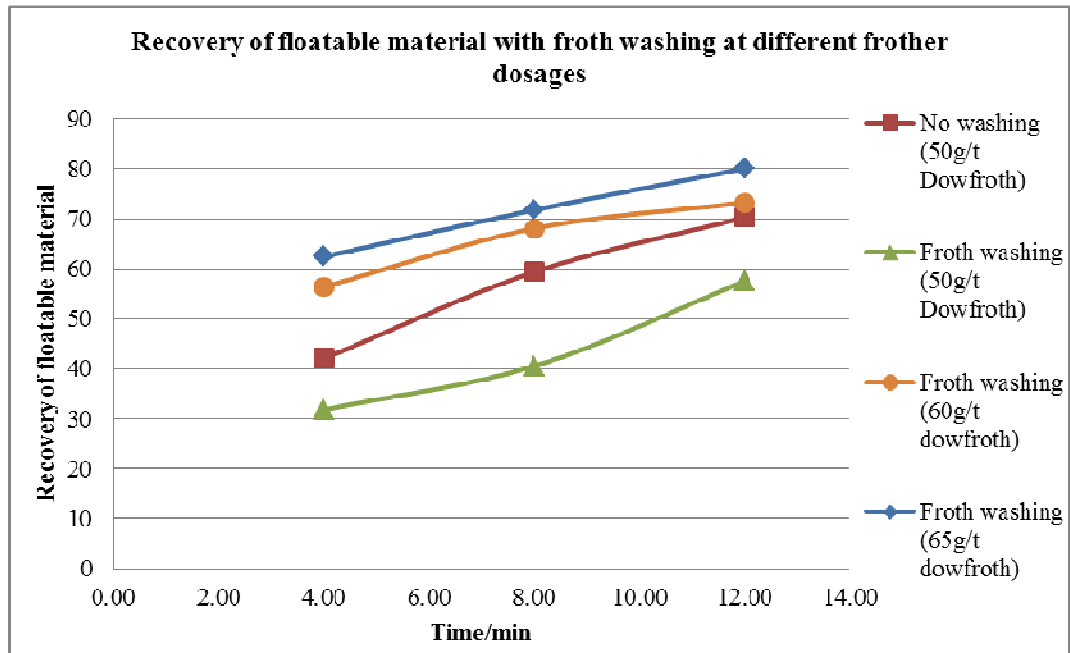


Figure 41: Percentage of floatable material in the pulp recovered to the concentrate over time at varying frother dosages

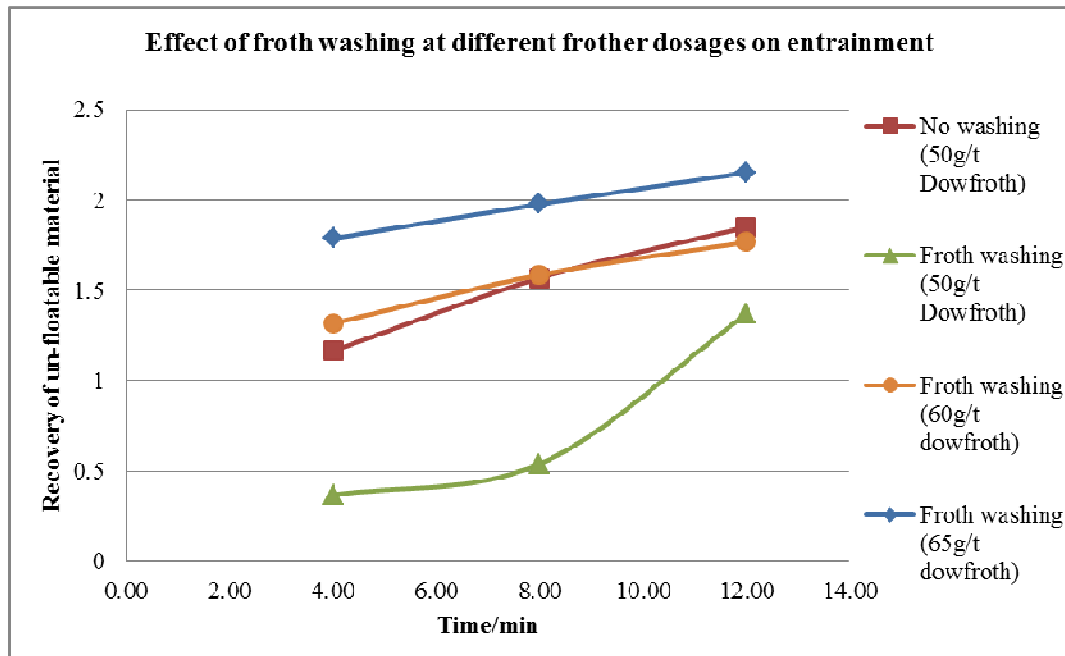


Figure 42: Percentage of the un-floatable material in the pulp recovered to the concentrate over time at varying frother dosages

Entrainment in Figure 42 is lowest with froth washing at 50g/t frother dosage. The highest dosage of frother (65g/t) resulted in the greatest amount of limestone entrained. The plot of grade of concentrate versus recovery of Alsil P to concentrate (Figure 43) provides the best overview of the results. It shows that the best results were obtained with a frother dosage of 60g/t. The displacement of the graph to the upper right is an indication of the best separation by flotation and washing. Therefore there may be benefit in washing when increasing the frother dosage. The increased frother dosage assists by improving the recovery of Alsil P and the froth washing controls the amount of limestone which is entrained. A too high frother dosage however, causes a higher degree of entrainment which the froth washing cannot successfully reduce. Frother dosages of 50g/t and 60g/t were used in the staged flotation tests that followed.

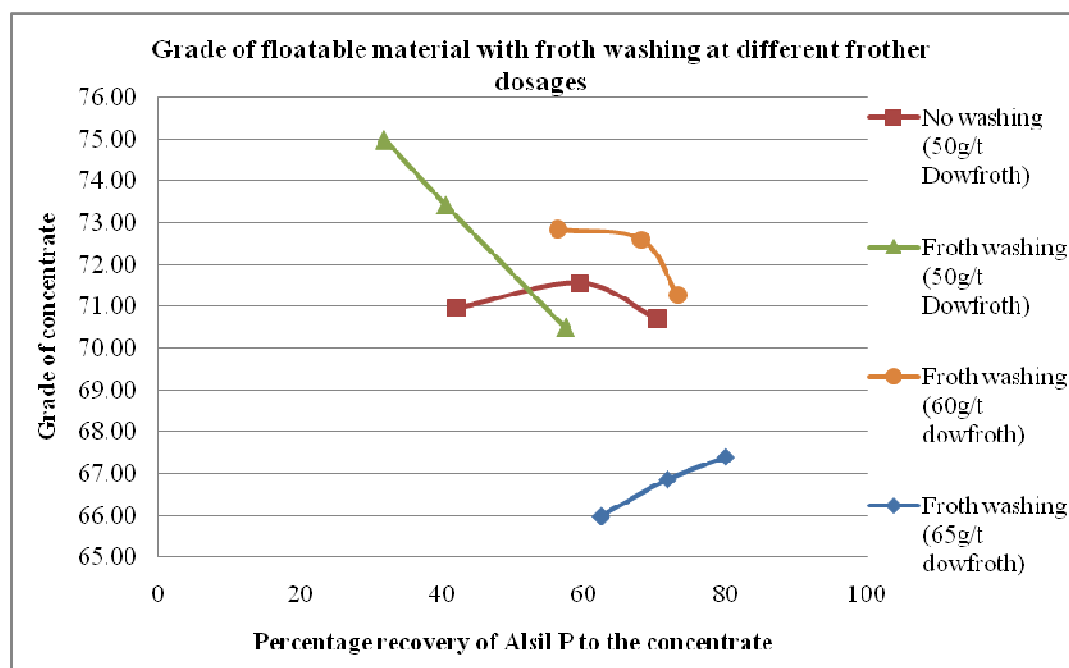


Figure 43: Grade of concentrate compared to the percentage Alsil P recovered to the concentrate for washing at different frother dosages

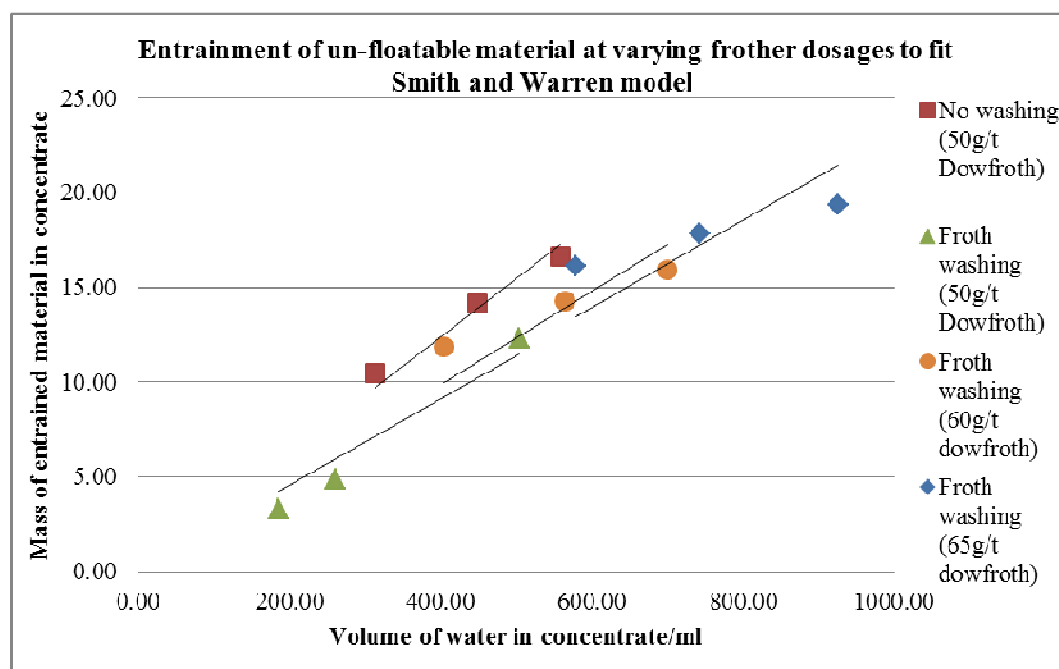


Figure 44: Graph to show fit of flotation tests with froth washing at varying frother dosages to the Smith and Warren entrainment model.

Table 5: Entrainment factor e_g and R^2 values for the relationship between limestone entrainment and water recovery with zero intercept

Frother dosage/g/ton of ore	Entrainment factor e_g	R squared
0 (No washing)	0.0310	0.9933
50 (Washing)	0.0227	0.9669
60 (Washing)	0.0247	0.9637
65 (Washing)	0.0232	0.09515

Table 5 shows that the addition of wash water decreases the entrainment factor when compared to no washing. The amount of material entrained per volume of water was decreased. However, it has been noted that the Smith and Warren model lines in Figure 44, which were forced to pass through the origin, did not fit the high concentration data well. The entrainment factors for the runs with washing were very similar, with a standard deviation of 0.001. This implies that the washing had the same effect of reducing the entrainment factor regardless of the frother dosage.

4.8. Staged flotation

As discussed in section 2.4, flotation occurs in several stages in order to maximise recovery. Laboratory work focused on minimising the gangue entrainment in the scavenger stage. The staged flotation tests were initially conducted with 50g/t guar gum depressant to ensure that the froth was stable, but the frother dosages were varied. A rougher and a scavenger stage were simulated in a single laboratory scale batch test with two samples collected for each stage. Washing was applied to the scavenger stage only hence the data for the rougher stage should be replicated in some of the tests. The rougher tests were conducted with a froth depth of approximately 5cm. Once the rougher simulation was complete, additional frother was added to the cell and the froth depth was adjusted to approximately 2cm, due to depletion of floatable material. Similar adjustments are made on industrial plants, in an attempt to recover slow-floating particles. Entrainment of gangue minerals is likely to be worse under these conditions and hence this is a logical place for the application of wash water.

Base cases of staged flotation with no froth washing were conducted at first for comparison with washing tests and to establish the best operating conditions. Investigations commenced with runs

at a dosage of 50g/t frother in the rougher and an additional dosage of 10g/t in the scavenger. This run was repeated with an increased dosage of 20g/t frother in the scavenger stage.

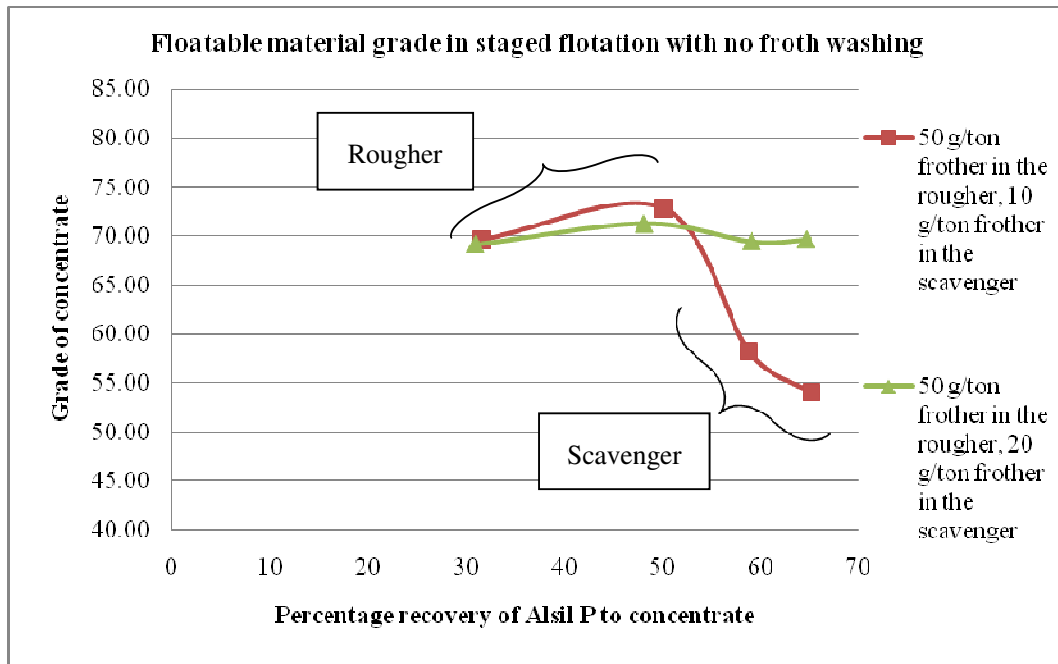


Figure 45: Effect of scavenger frother dosage on grade of the concentrate compared to the recovery of Alsil P.

The results in Figure 45 show good correlation of results in the rougher part of the experiment with the trends deviating at the scavenger stage. The recovery of floatable material (Alsil P) was higher when 20g/t of frother was added to the scavenger. This suggests that additional frother is required in the scavenger cell in order to maintain a froth that is able to carry floatable material to the concentrate. The amount of material entrained was higher for the lower frother dosage in the scavenger. Similar tests were done using a rougher stage frother concentration of 60g/t and variable addition of frother to the scavenger. The results are shown in figure 46.

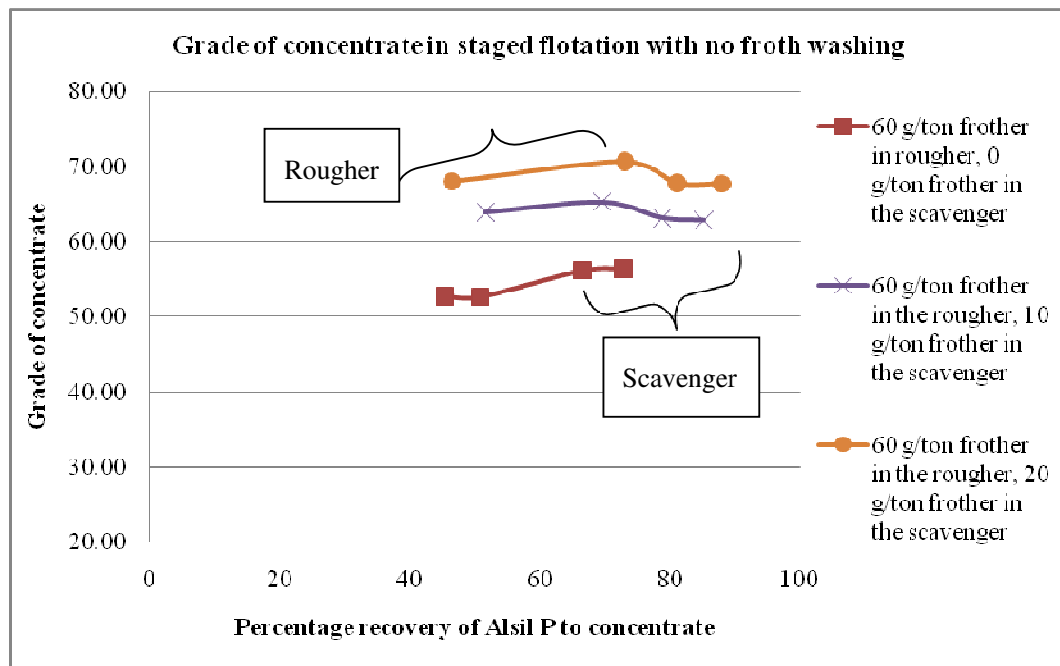


Figure 46: Effect of a higher rougher frother concentration (60g/t) and variable scavenger frother additions. Cumulative plot of grade of concentrate vs. recovery of Alsil P.

Figure 46 shows that there are significant advantages in using higher concentrations of frother. A comparison of Figures 45 and 46 shows a significant improvement in rougher recovery, for the same mass recovery. This was enhanced by further improvements in the scavenger stage. However, the rougher stage recoveries in Figure 46 should have been the same, and this raised questions about the repeatability of the two-stage experiments, (with washing). This could be due to variability of the amount of floatable material in the Alsil P, resulting in a variable amount recovered under standard rougher flotation conditions.

It was therefore decided that repeated rougher/scavenger experiments would be done, using a 50g/t frother addition in the rougher stage and a 10g/t addition to the scavenger stage. The data is shown in Figure 47. There is some variability in the data, but for the average recovery of floatable material (Alsil P) with washing the benefit of washing is apparent, with an increase in recovery of floatable material indicated.

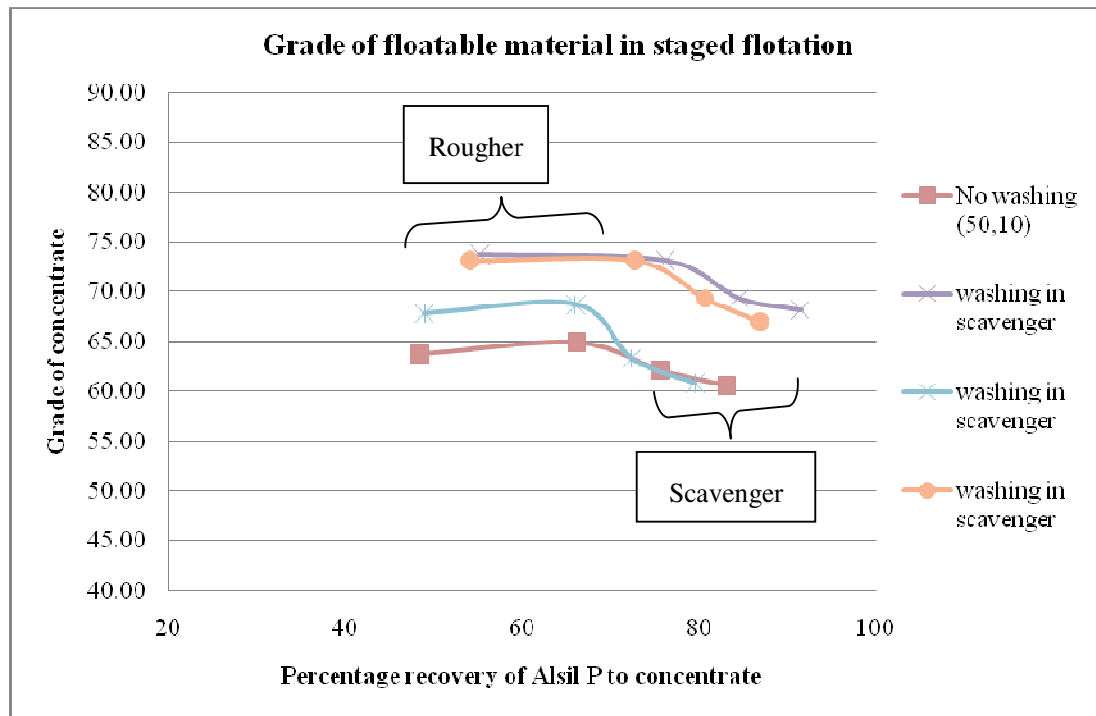


Figure 47: Repeat experiments on the effect of washing in the scavenging stage. (Frother addition was 50g/t frother in the rougher, 10g/t frother in the scavenger.)

Since froth washing is expected to reduce entrainment, it should improve the grade of the concentrate and hence result in an improved recovery for a given (dry) mass of concentrate. First attempts at washing in the scavenger stage were made with frother dosages of 50g/t in the rougher and 10g/t in the scavenger. Figure 47 shows that, on average, there was an improvement in recovery of floatable material with washing of the froth. There was a good correlation between the results of 2 of the 3 washing tests run, showing repeatability of results. The entrainment data for these 2 tests were then fitted to the Smith and Warren entrainment model.

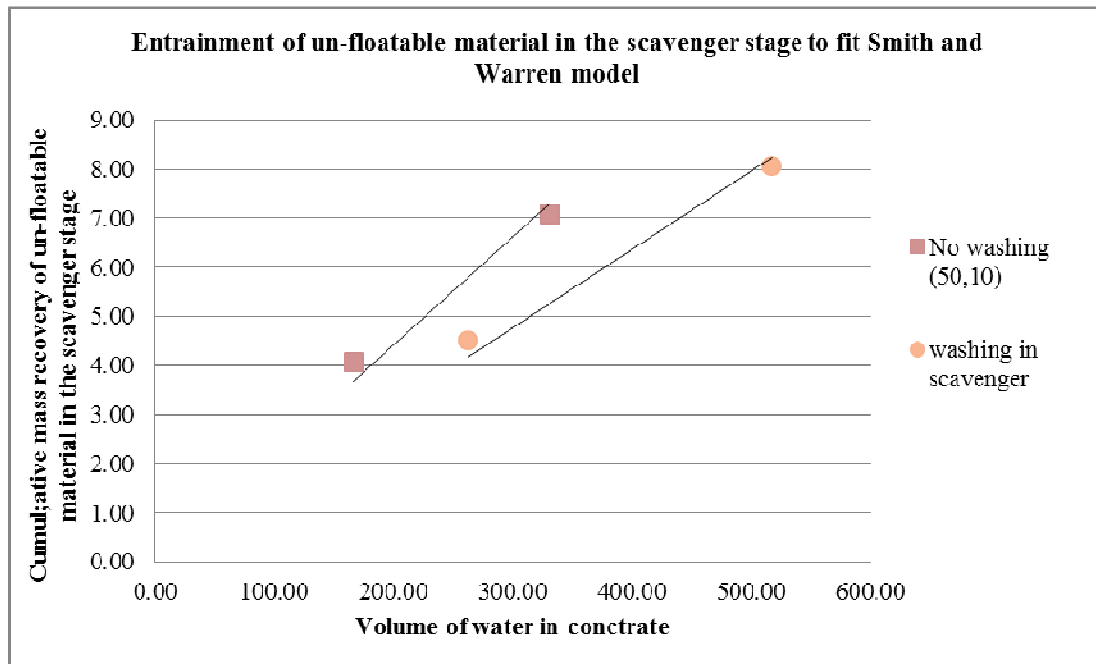


Figure 48: Data from repeated runs (frother addition of 50g/t in the rougher and 10g/t in the scavenger). Cumulative data for recovery in the scavenger stage only fitted to the Smith and Warren model.

Table 6: Entrainment factor e_g and R^2 values for the relationship between entrainment and water recovery with zero intercept

Run	Entrainment factor e_g	R squared
No washing	0.022	0.9546
Washing in scavenger	0.0159	0.9777

The entrainment factor was reduced when froth washing was introduced in the scavenger stage from 0.022 to 0.0159.

It was noted that wash water did not contain frother and that it could therefore affect froth stability adversely. The next experiment was to add frother to the wash water so that its concentration was equivalent to adding 10g/t of ore. Figure 49 shows that the effect of frother in the wash water was negligible, but it confirmed the benefit of washing.

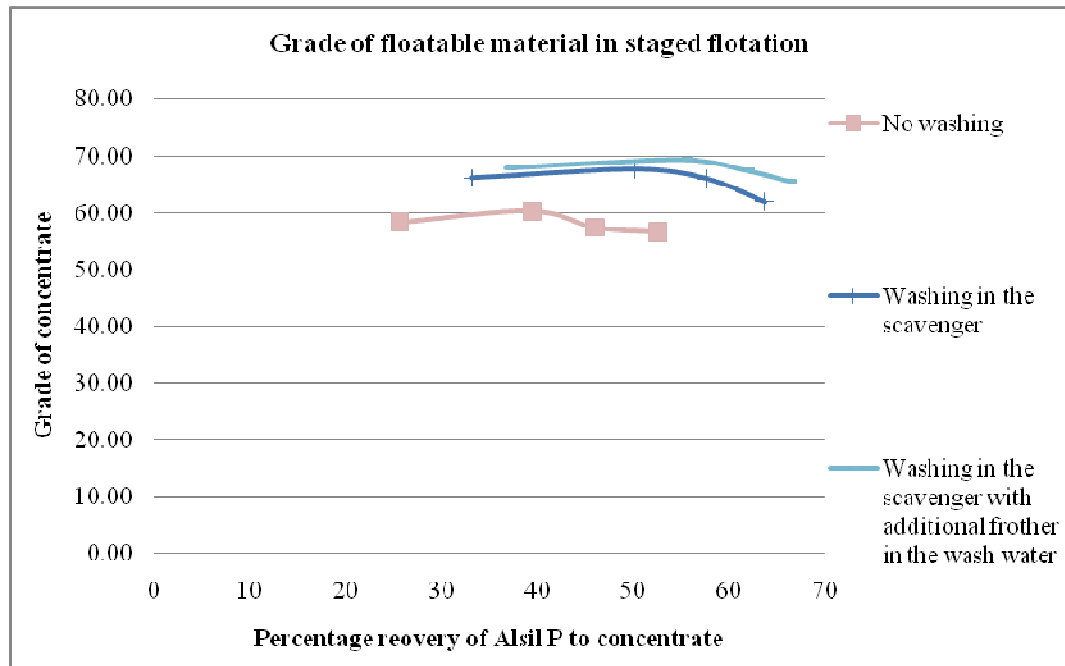


Figure 49: Effect of adding frother (equivalent to 10g/t of ore) to the scavenger wash water. Grade of concentrate vs. percentage recovery of Alsil P. The frother addition to the pulp was 50g/t in the rougher and 10g/t in the scavenger.

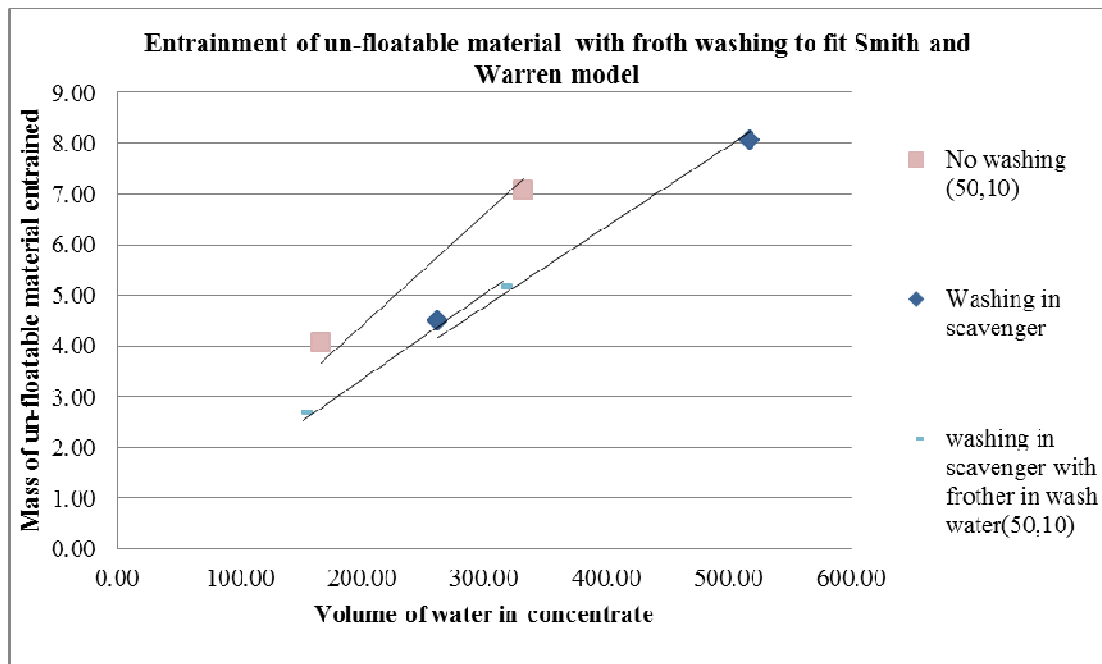


Figure 50: Graph to show fit of scavenger stage flotation tests with froth washing to the Smith and Warren model. (Frother dosage of 50g/ton in the rougher and 10g/ton in the scavenger)

Table 7: Entrainment factor e_g and R^2 values for the relationship between entrainment and water recovery with zero intercept for scavenger stage flotation when using a frother dosage of 50g/ton in the rougher and 10g/ton in the scavenger

Run	Entrainment factor e_g	R squared
No washing	0.022	0.9546
Washing in scavenger	0.0159	0.9777
Washing in scavenger with frother in wash water	0.0167	0.9883

Results obtained from fitting of entrainment data for froth washing with additional frother in the wash water resulted in a lower entrainment factor than that obtained with no washing. Washing without frother in the wash water however, returned a similar result to washing with frother in the wash water. This serves to further confirm that addition of frother to the wash water has little influence on the effect of froth washing.

The next set of experiments was to repeat the two-stage tests, with an increased frother concentration in the rougher stage (60 g/t), as this concentration had yielded better results in single-stage experiments.

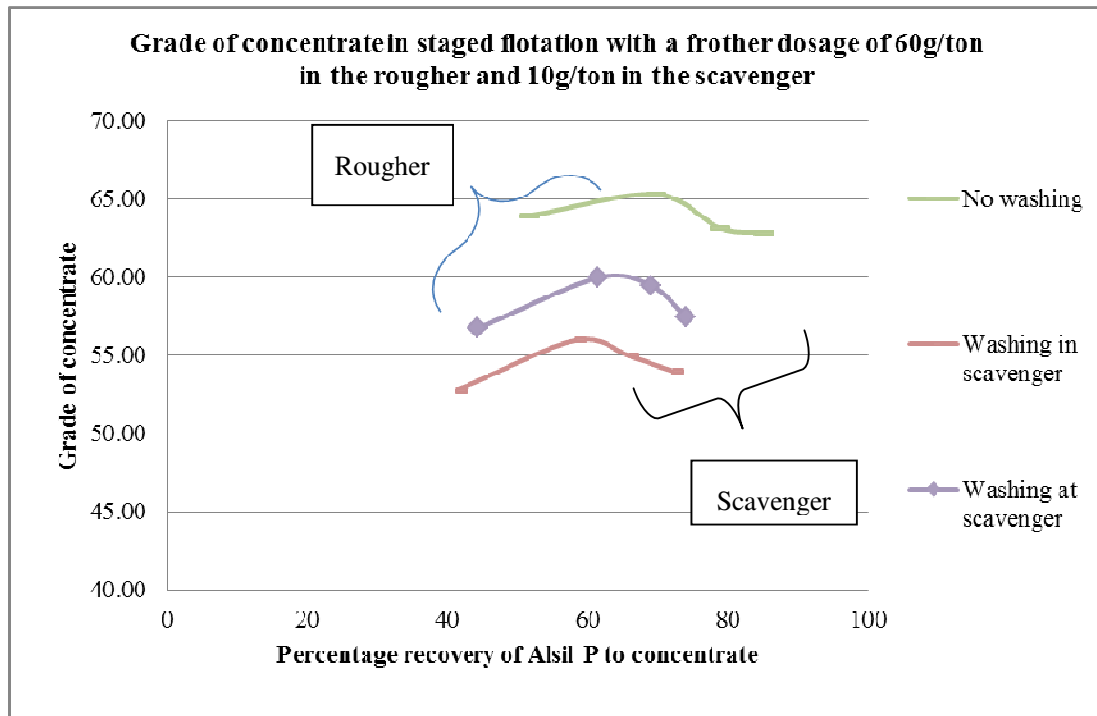


Figure 51: Grade of concentrate vs. the percentage recovery of Alsil P. Froth washing applied in the scavenger only. The frother addition was 60g/t frother in the rougher, 10g/t frother in the scavenger.

Figure 51 shows the effects of increasing the amount of frother in the rougher stage from 50g/t to 60g/t and maintaining the addition of 10g/t in the scavenger. Froth washing reduced the recovery of floatable material and the grade. Although this result is counter intuitive, it is possible that the froth washer bar itself caused an obstruction to the flow of the froth. Froth washing with frother in the wash water under these conditions delivers a similar result; the additional frother in the wash water does not improve the recovery of the Alsil P. When comparing the results in Figure 52 it appears that at the higher dosage of frother, there is no conclusive evidence of the benefit of froth washing.

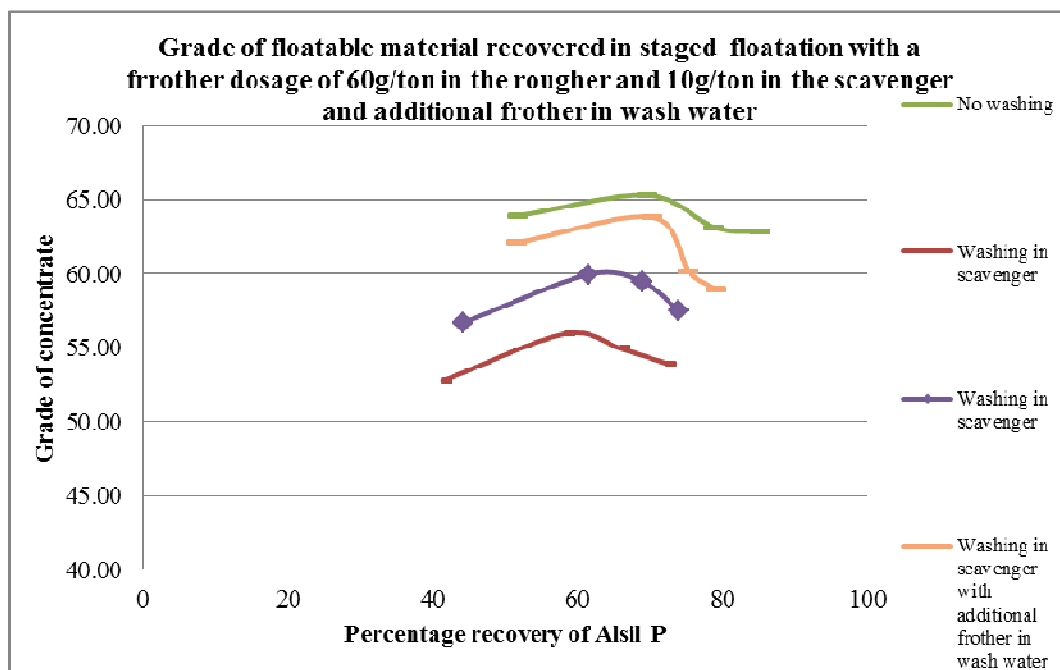


Figure 52: Grade of concentrate vs. the percentage recovery of Alsil P. Froth washing applied in the scavenger only. The frother addition was 60g/t frother in the rougher, 10g/t frother in the scavenger.

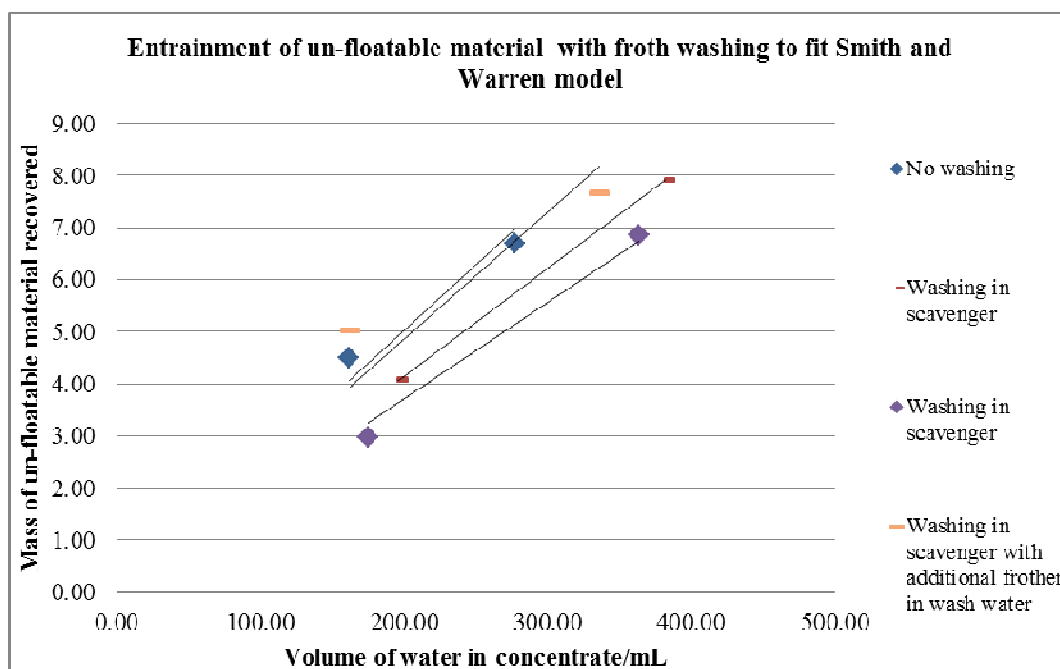


Figure 53: Graph to show fit of scavenger stage flotation tests with froth washing to the Smith and Warren model. (Frother dosage of 60g/ton in the rougher and 10g/ton in the scavenger)

Table 8: Entrainment factor e_g and R^2 values for the relationship between entrainment and water recovery with zero intercept for scavenger stage flotation when using a frother dosage of 60g/ton in the rougher and 10g/ton in the scavenger

Run	Entrainment factor e_g	R squared
No washing	0.0251	0.8938
Washing in scavenger	0.0185	0.9964
Washing in scavenger	0.0207	0.9999
Washing in scavenger with frother in wash water	0.0244	0.9542

Results obtained when plotting entrainment data for runs conducted with a dosage of 60g/ton frother in the rougher and 10g/ton frother in the scavenger showed similar trends for washing in the scavenger as for dosages of 50g/ton in the rougher and 10g/ton in the scavenger. Additional frother in the wash water did not result in any reduction in entrainment factor when compared to washing with water.

Figure 54 represents a combination of the data obtained from staged washing with varying frother dosages in the rougher to facilitate a comparison of results. The best grade and recovery of floatable material is achieved at 50g/t frother in the rougher, 10g/t frother in the scavenger with no frother in the wash water. Washing with additional frother produced worse results. This is a good result as lower reagent consumption reduces the operating costs.

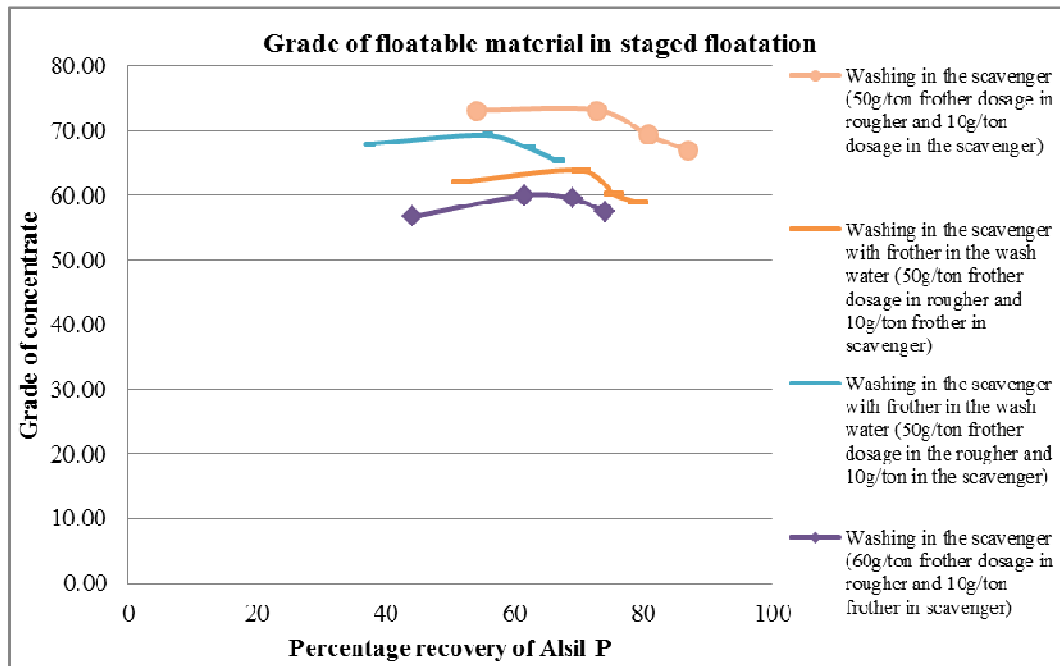


Figure 54: Summary of floatable material recovery in staged flotation with washing in the scavenger.

Table 9: Summary of Entrainment factor e_g and R^2 values for the relationship between entrainment and water recovery with zero intercept. Flotation was conducted in 2 stages with the frother dosage varied in the rougher stage.

Run	Entrainment factor e_g	R squared
No washing	0.0251	0.8938
Washing in scavenger (50g/ton frother in rougher, 10g/ton frother in scavenger)	0.0159	0.9777
Washing in scavenger with frother in wash water (50g/ton frother in rougher, 10g/ton frother in scavenger)	0.0167	0.9883
Washing in scavenger (60g/ton frother in rougher, 10g/ton frother in scavenger)	0.0185	0.9964
Washing in scavenger (60g/ton frother in rougher, 10g/ton frother in scavenger)	0.0207	0.9999

Washing in scavenger with frother in wash water (60g/ton frother in rougher, 10g/ton frother in scavenger)	0.0244	0.9542
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Table 9 above confirms the above findings in terms of reduction of entrainment, the entrainment factor obtained with washing in the scavenger with a frother dosage of 50g/ton in the rougher and 10g/ton frother in the scavenger was the lowest.

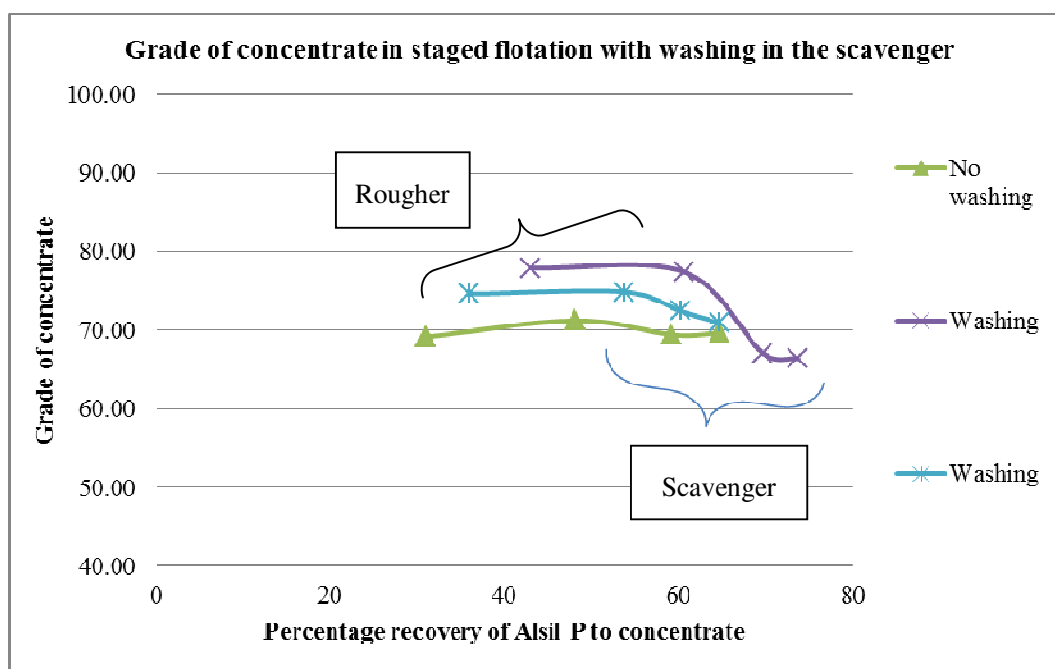


Figure 55: Grade of the concentrate compared to the percentage recovery of Alsil P with froth washing in the scavenger. Frother addition was 50g/ton in the rougher and 20g/ton in the scavenger.

Froth washing in the scavenger with frother dosages of 50g /t frother in the rougher and 20g /t frother in the scavenger showed no significant improvement compared to the run with no washing in Figure 55.

A final permutation was tried, in which the washing was applied in the rougher stage, using 50g/t frother dosage in the rougher stage and 10g/t frother dosage at the scavenger stage.

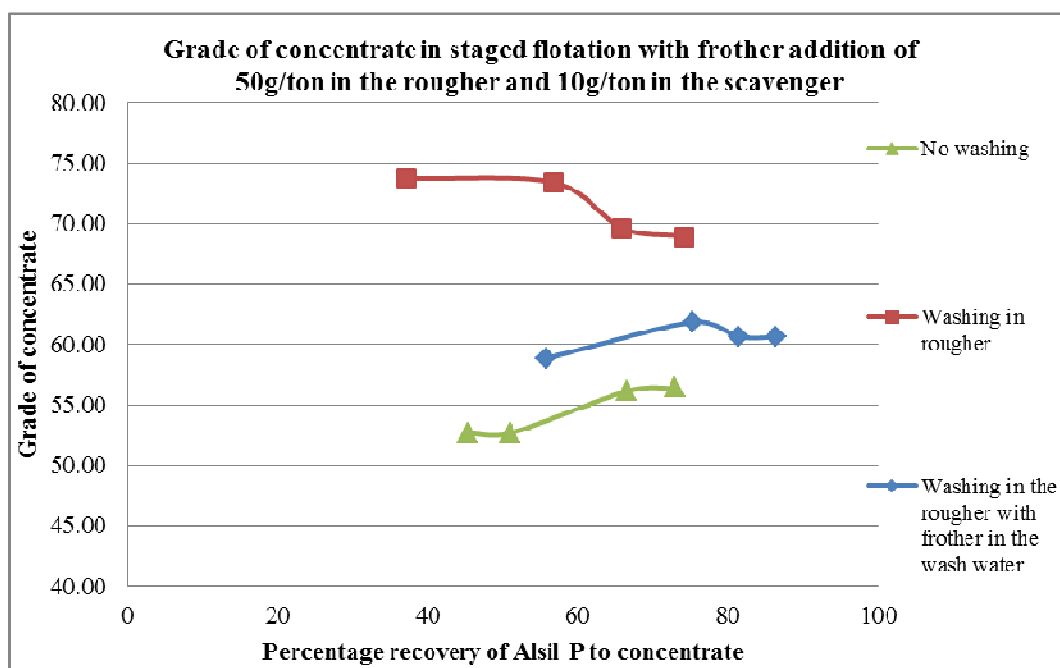


Figure 56: Grade of concentrate compared to the percentage recovery of Alsil P with froth washing in the rougher only. Frother addition was 50g/ton in the rougher and 10g/ton in the scavenger.

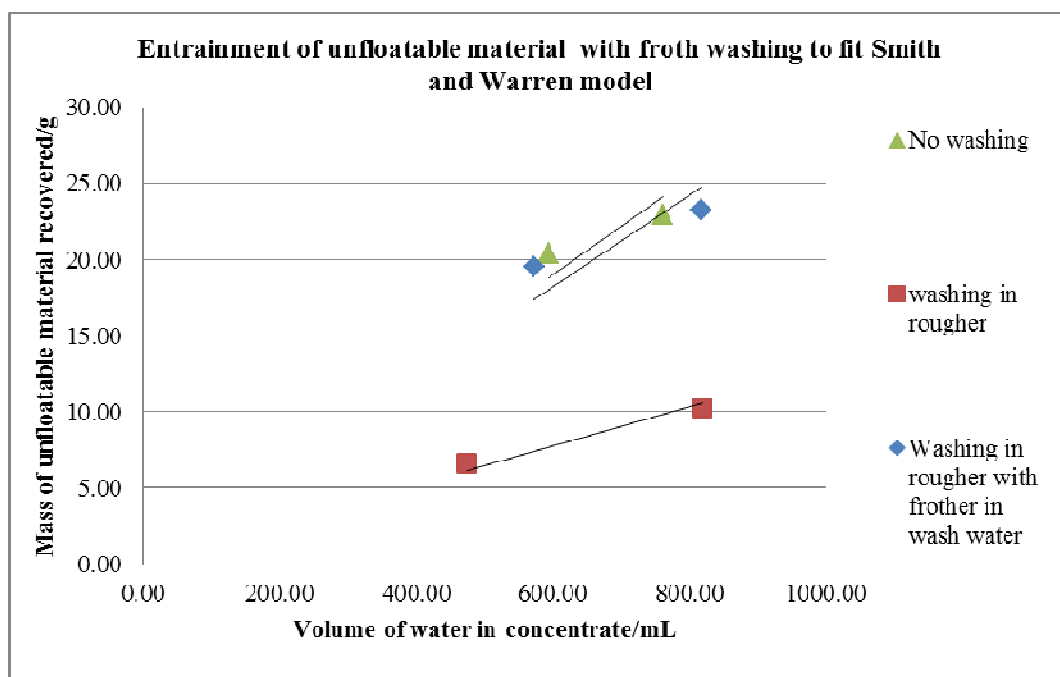


Figure 57: Graph to show fit of scavenger stage flotation tests with froth washing in the rougher to the Smith and Warren model. (Frother dosage of 50g/ton in the rougher and 10g/ton in the scavenger)

Table 10: Entrainment factor e_g and R^2 values for the relationship between entrainment and water recovery with zero intercept for rougher stage flotation when using a frother dosage of 50g/ton in the rougher and 10g/ton in the scavenger

Run	Entrainment factor e_g	R squared
No washing	0.0317	0.9872
Washing in rougher	0.0129	0.9518
Washing in rougher with frother in wash water	0.0303	0.978

Results in Figure 48 indicate that froth washing was beneficial with regards to the Alsil P recovered. Both washing with water and washing with frother in the wash water showed an improvement on no washing in the rougher. Although on comparison of the rougher results in figure 56 the washing and no washing run achieved approximately the same percentage of Alsil P recovery, the run with washing achieved a lower limestone entrainment. Washing in the rougher also resulted in a lower entrainment factor than no washing in the rougher stage. There could be benefit from washing in the rougher stage; further investigation is required to confirm this.

4.9. Water Bias

The suitable water bias for mechanical cell flotation is still unclear and therefore a positive, zero and negative bias were tested on the Alsil P with froth washing in the scavenger stage. In a batch cell, a positive bias implies an increase in the pulp level. This is necessary anyway, as the froth gradually became less stable as the Alsil P was depleted. Figure 58 shows results for a washing with a positive, negative and zero bias. From the graph it is clear that a positive bias produces the best results. One would expect that the negative bias would produce the lowest recovery of Alsil P however it is the zero bias that results in the lowest recovery. It is possible that the higher air flow required in maintaining the froth depth with decreasing water due to the negative bias results in a higher recovery of Alsil P.

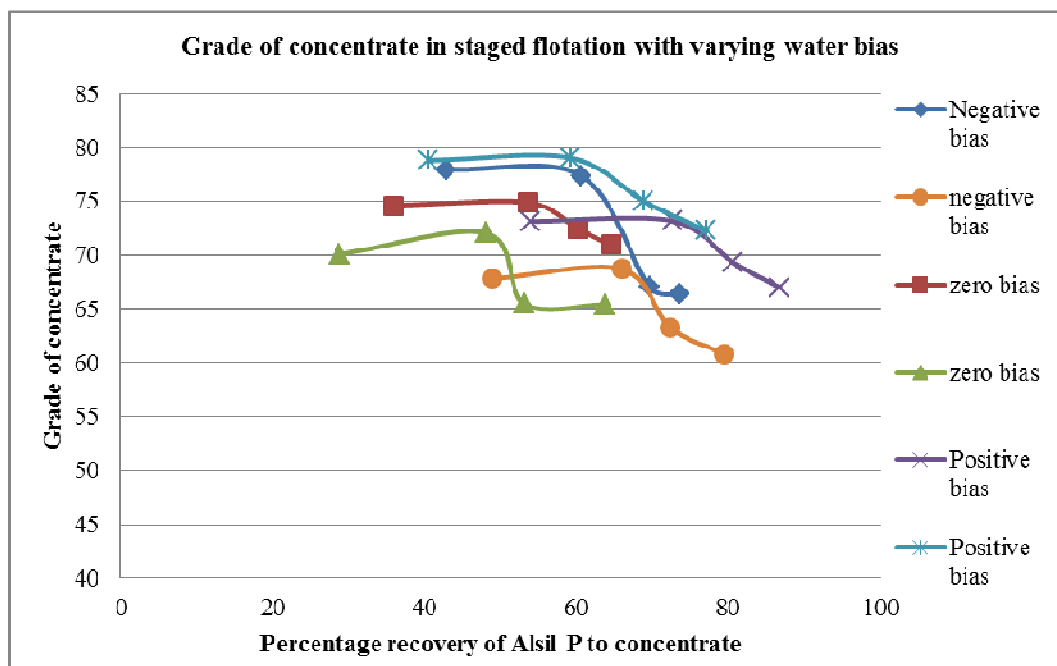


Figure 58: Effect of varying water bias on the grade and recovery of floatable material with froth washing at the scavenger stage. The frother addition was 50g/t in the rougher and 10g/t in the scavenger.

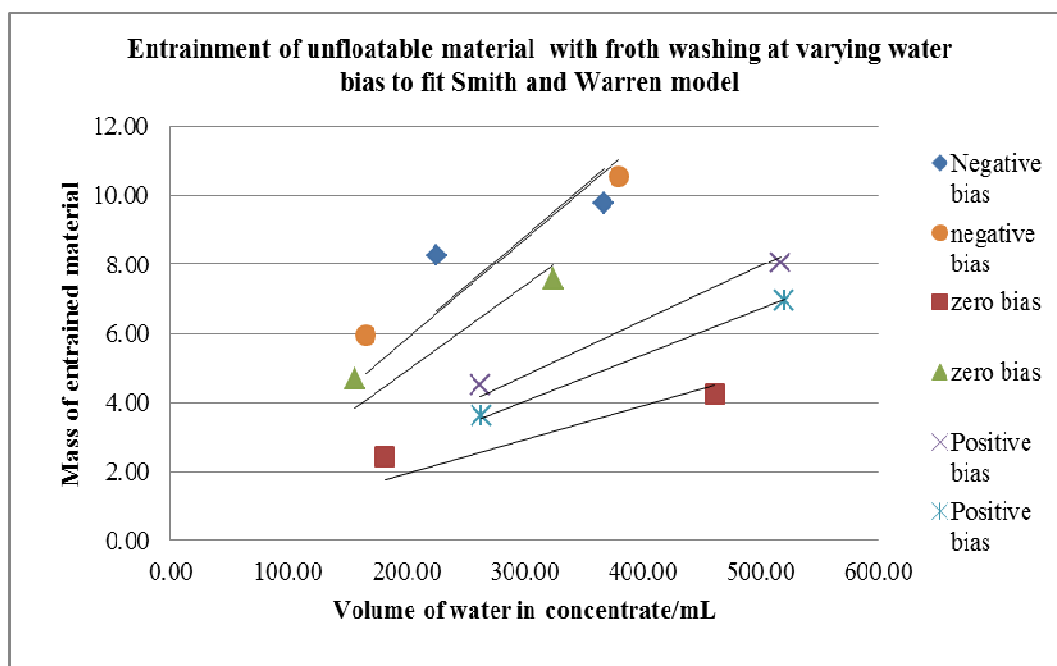


Figure 59: Graph to show fit of scavenger stage flotation tests with froth washing in the scavenger at varying water bias to the Smith and Warren model. (Frother dosage of 50g/ton in the rougher and 10g/ton in the scavenger)

Table 11: Entrainment factor e_g and R^2 values for the relationship between entrainment and water recovery with zero intercept for scavenger stage flotation at varying water bias when using a frother dosage of 50g/ton in the rougher and 10g/ton in the scavenger

Run	Entrainment factor e_g	R squared
Negative bias	0.0294	0.934
Negative bias	0.0291	0.9739
Zero bias	0.0098	0.9422
Zero bias	0.0245	0.9692
Positive bias	0.0159	0.9957
Positive bias	0.0134	0.995

Comparison of the entrainment factor obtained for washing at varying biases in table 11 shows that the lowest entrainment factor was achieved with washing at zero bias. However the repeatability of results for zero bias is poor. Washing with a negative bias produced the largest entrainment factor and the positive bias produced the lowest repeatable entrainment factor. This confirms the finding in figure 58 that washing with a positive bias was most effective.

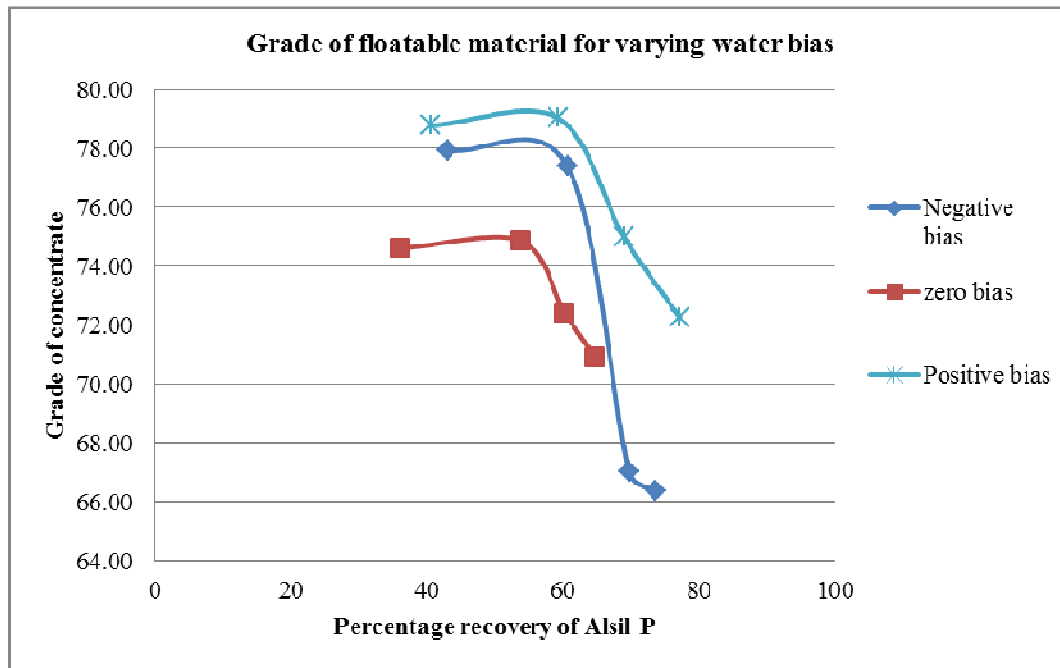


Figure 60: Comparison of floatable material grade and recovery for froth washing with a positive, negative and zero water bias

Figure 60 shows that the initial stages of washing are unaffected by the water bias in terms of recovery of floatable material, (note the first 2 points of the graphs) however as the amount of floatable material in the froth decreases the increased water levels assist in the recovery of Alsil P. The final grade of concentrate achieved is highest when washing with a positive bias.

4.10. Three component system

Flotation of platinum minerals and base minerals is often not as simple as simulated in a two component system. Selected sulphide minerals are made hydrophobic by addition of reagents while other minerals, such as talc, may be depressed at some stage in the recovery process. A few tests were conducted on three component system made up of chalcopyrite, Alsil P and limestone. In order to achieve the highest grade of chalcopyrite the Alsil P and limestone must be sufficiently depressed to reduce the mass to be smelted. From the literature survey it is thought that talc has a stabilising effect on the froth and may in fact aid in the recovery of valuables.

Initial rougher/scavenger tests were conducted with no froth washing and varying depressant dosages in order to see the effect that the Alsil P had on the recovery of the chalcopyrite. Figure 51 shows that the poorest recovery of chalcopyrite was achieved with no depressant.

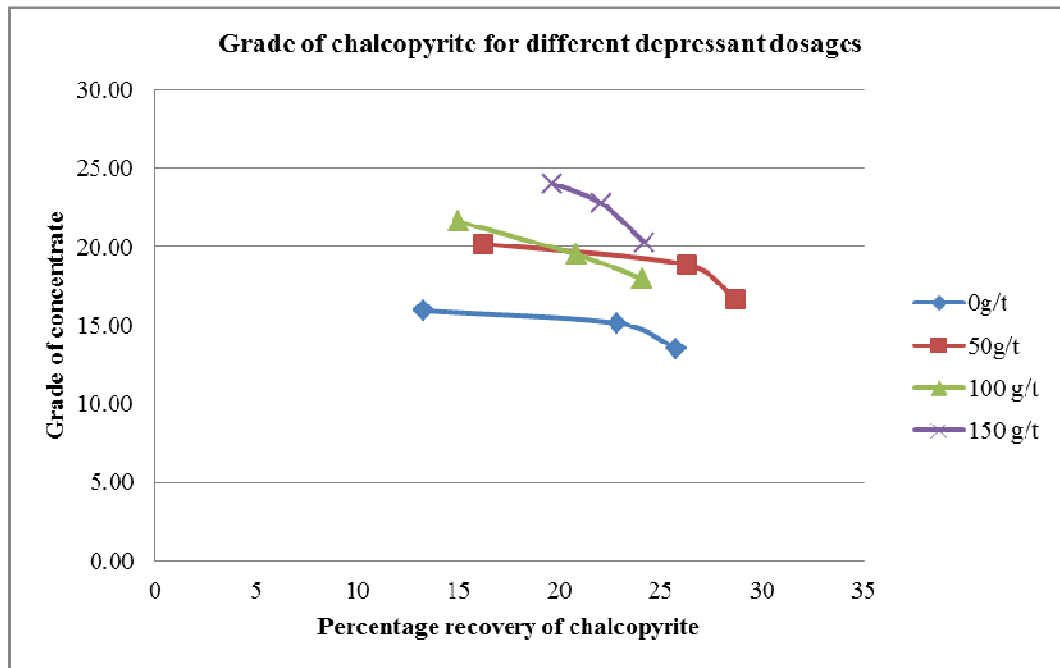


Figure 61: Recovery of chalcopyrite in a 3 component system for different depressant dosages

This was expected as the Alsil P and the chalcopyrite would initially compete for space on the bubbles. Samples were taken in 2 minute intervals and Figure 61 shows that there was no significant increase in recovery of chalcopyrite occurs after 6 minutes. This was the point at which the froth was observed to contain minimal if any chalcopyrite (dark grey colour). The recovery of chalcopyrite improves with the addition of depressant at the highest dosage of 150g/t the percentage of chalcopyrite recovered is lower than that at a dosage of 50g/t, but the grade of the concentrate is higher. The higher recovery of chalcopyrite in the presence of talc may indicate a positive influence of talc on floatation of the valuable material.

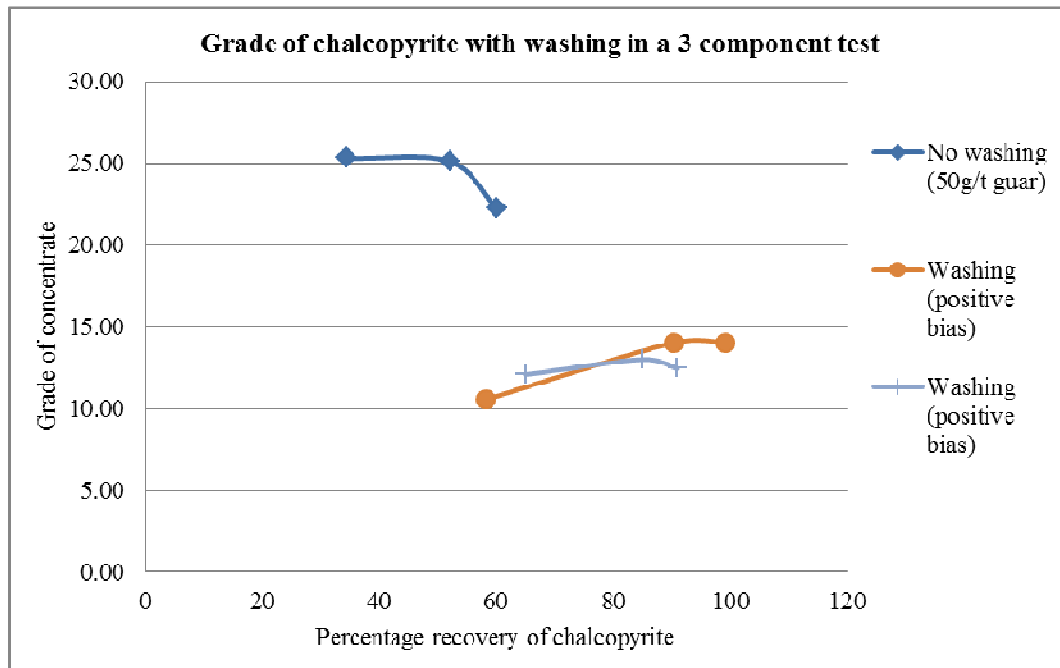


Figure 62: Recovery of chalcopyrite in a three component system with washing with a positive bias. All experiments had Guar at 50g/t.

Froth washing in the scavenger was tested on the 3 component system with a positive and negative bias. Figure 62 shows that washing with a positive bias increases the amount of chalcopyrite recovered, but mass recovery was significantly larger, due to a progressive raising of the pulp level. The results for froth washing with a negative bias in figure 63 below shows no significant difference to the run with no froth washing. This data is combined in Figure 64.

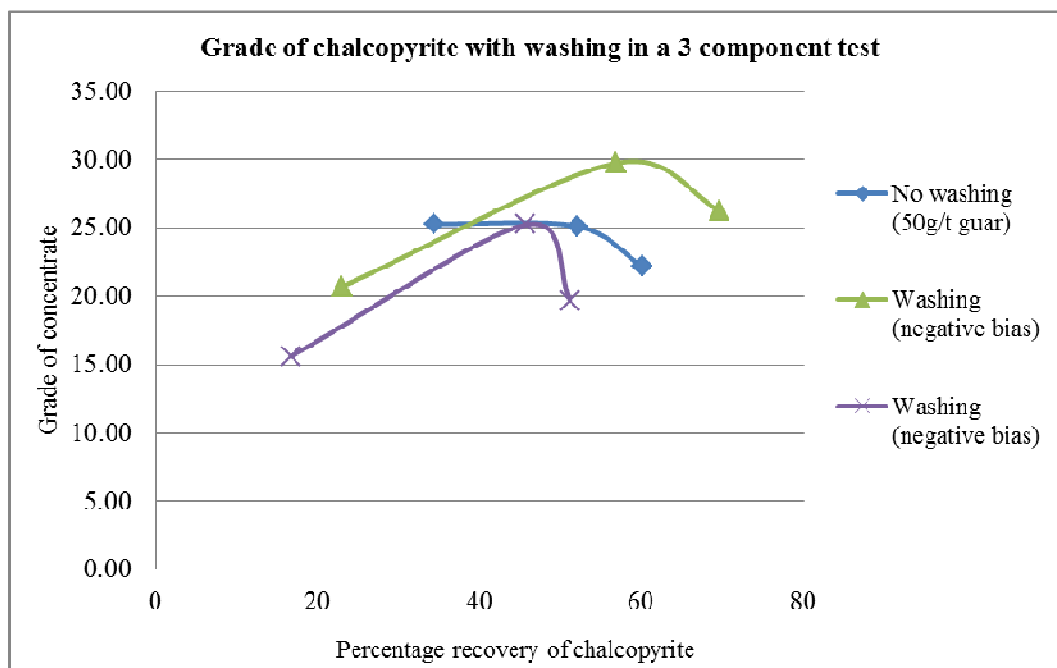


Figure 63: Recovery of chalcopyrite in a three component system with washing with a negative bias

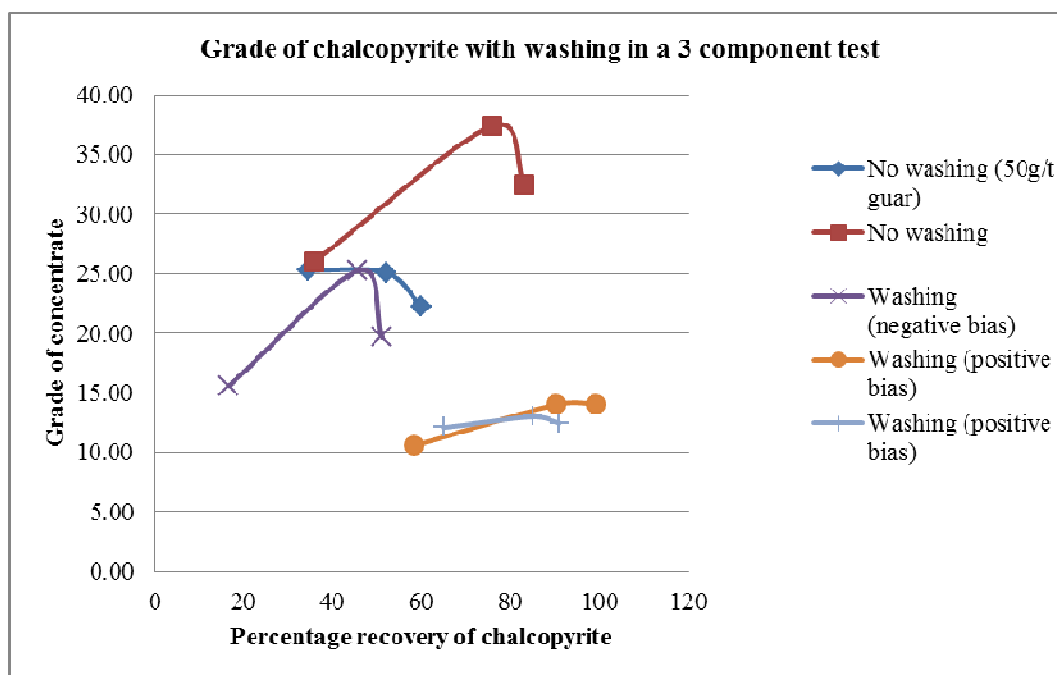


Figure 64: Comparison of recovery of chalcopyrite in a 3 component system washing with positive and negative bias

The depressant dosage was then increased to 100g/t to investigate whether further depressing the Alsil P would result in a higher recovery of chalcopyrite when using a positive bias. It is evident in Figure 65 that no significant improvement in recovery was achieved with increased depressant.

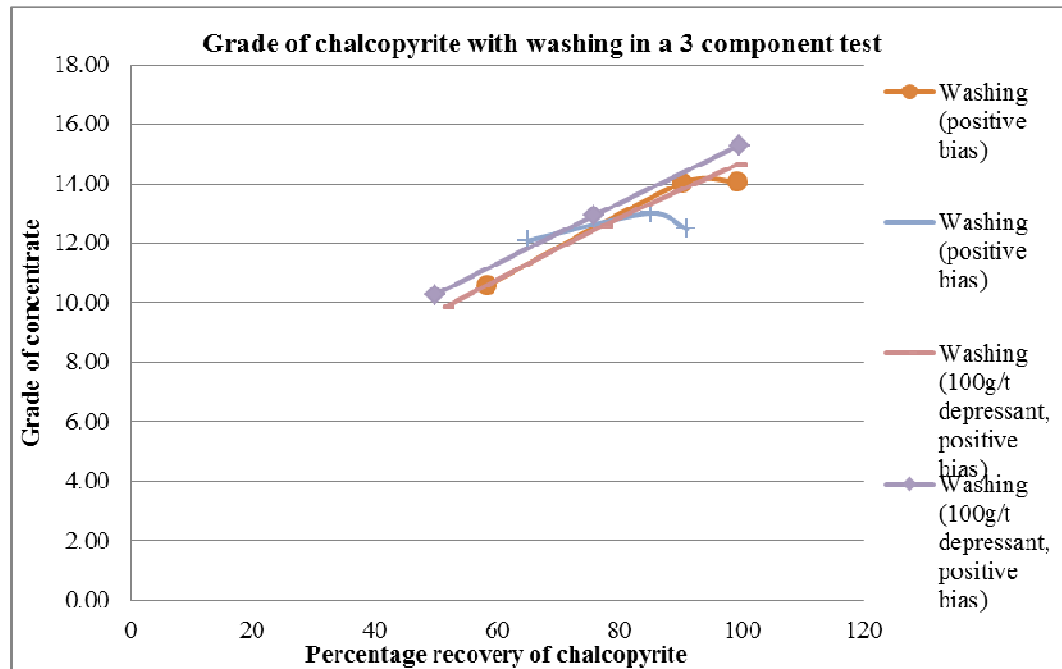


Figure 65: Comparison of recovery of chalcopyrite with varying depressant dosages at a positive bias

Figure 66 shows an alternative way of plotting the results for the three component system. Some benefit is indicated for washing with a negative bias.

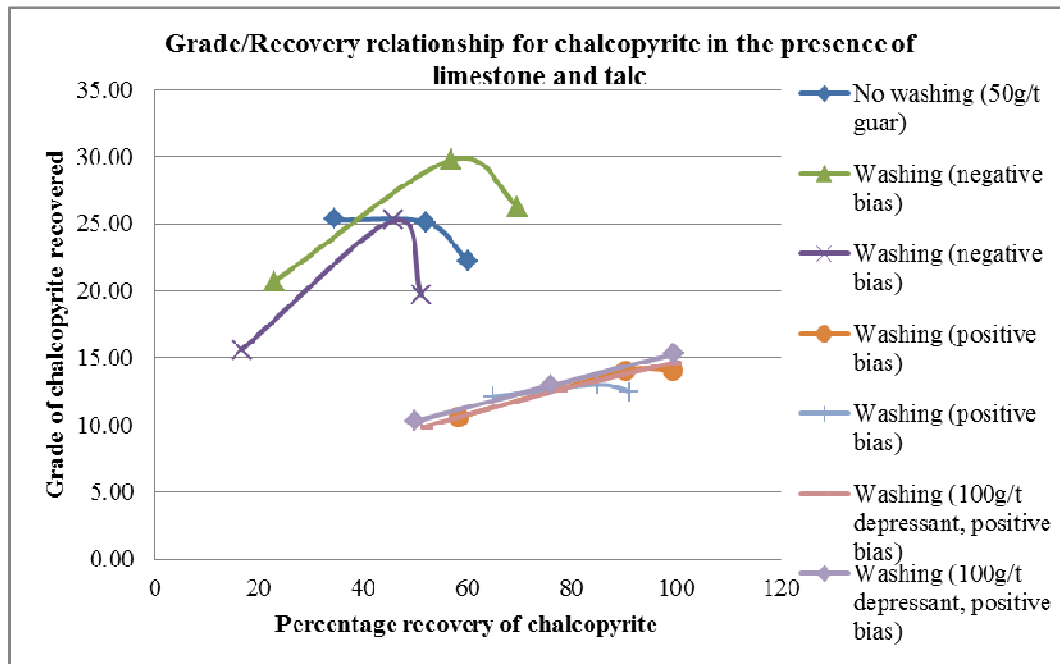


Figure 66: Grade of chalcopyrite recovered in froth washing tests

Although the 3 component system showed no real benefit to froth washing the best way to test the effects of froth washing was on an industrial scale flotation cell.

4.11. Industrial Flotation Tests

A froth sampling device was built in the workshop at UKZN, which allowed froth washing to be conducted on a portion of an industrial cell. The sampler was designed to fit over the lip of the cell and it is possible to vary the wash position horizontally and vertically. Figure 67 below shows how the device fitted over the lip of the cells on which the washing tests were carried out.



Figure 67: Froth sampling device on industrial cell lip

Since the froth sampler was designed and built at UKZN for use at a Lonmin Platinum flotation plant several difficulties were encountered when the flotation tests were carried out. The slot width and size of the bucket could only be accommodated in cleaner cells and due to the lack of time available for tests; the sampler could not be modified for testing on other cells. Plant tests were carried out on a cleaner, a secondary cleaner and a recleaner. Three timed samples were taken for each condition. The base case tests (no washing) were followed with tests with the wash water added at the laboratory optimum position (15cm from the lip and at the froth surface) and tests further from the lip (30cm), at the lip of the cell, and finally at the pulp-froth interface. The laboratory optimum was equated to halfway between the lip of the cell and the furthest washing position possible with froth sampler.

The PGM grade was improved in all three types of cells, namely the cleaner, cleaner-scavenger and the re-cleaner. Figure 68 shows the results for the cleaner cell. The PGM grade was improved, but the mass flow was reduced, which could result in a loss in recovery. Since the froth in the cleaner is usually deep, this proves that allowing the washing water time to penetrate the froth has the potential to improve the grade of the concentrate. Although laboratory tests showed washing at the pulp froth interface to be ineffective, it was decided to test this possibility in the industrial cleaner cell. Washing at the lip of the cell and washing at the pulp froth interface were also tried in the cleaner cell.

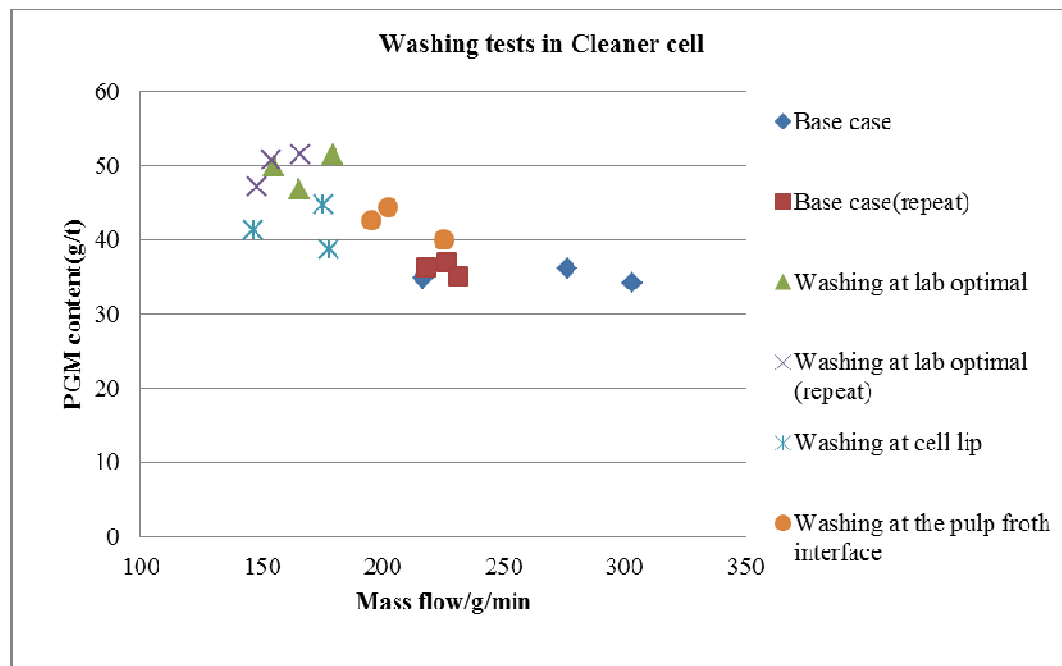


Figure 68: Industrial flotation tests in a Cleaner cell

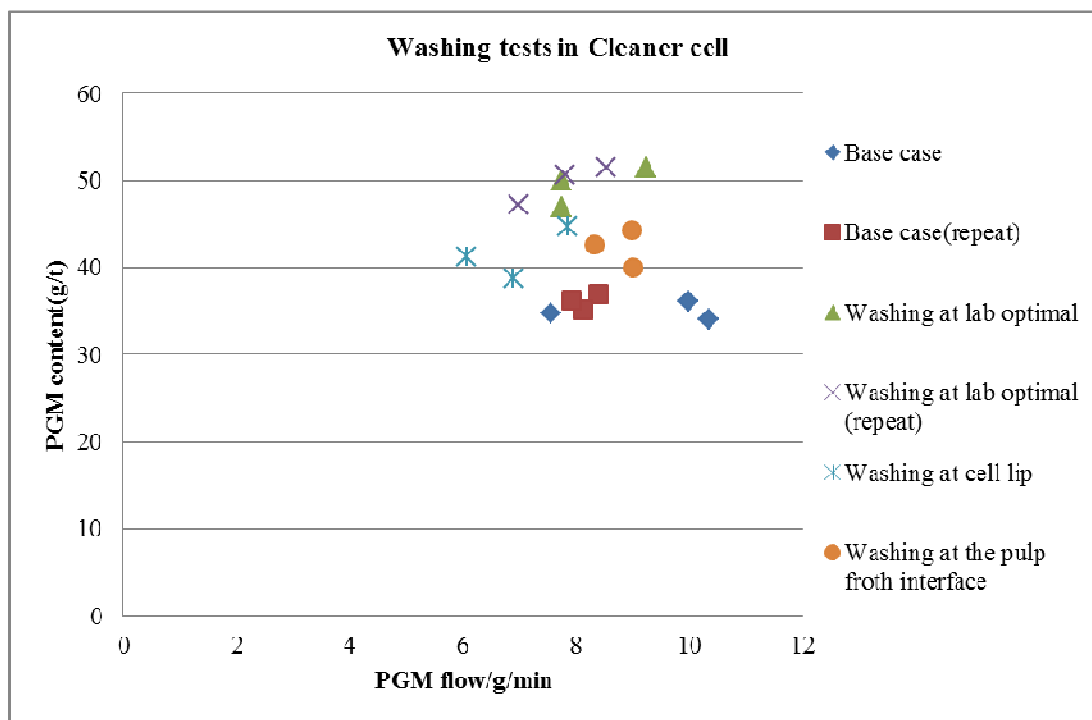


Figure 69: Industrial flotation tests in a cleaner cell

Figure 69 shows an alternative way of plotting the data, in which the flow of PGMs was calculated, which is a direct measure of PGM recovery. Washing produced higher grades, as previously noted, but, on average, there was a reduction in PGM recovery at the (laboratory) optimum position. The froth washing device caused an obstruction to the flow of froth and reduced PGM recovery. Washing at the pulp-froth interface, 3cm from the lip resulted in higher PGM grade at approximately the same PGM mass flow as the base case.

Results for the cleaner-scavenger in Figure 70 show similar findings to that of the cleaner. The placement of the wash bar at the upper surface of the froth reduced the PGM flow, (at the cell lip as well as at the lab optimal). The repeat test of washing at the lab optimal shows an increase in PGM flow and the PGM content, but this could have been due to a change in PGM content of the ore.

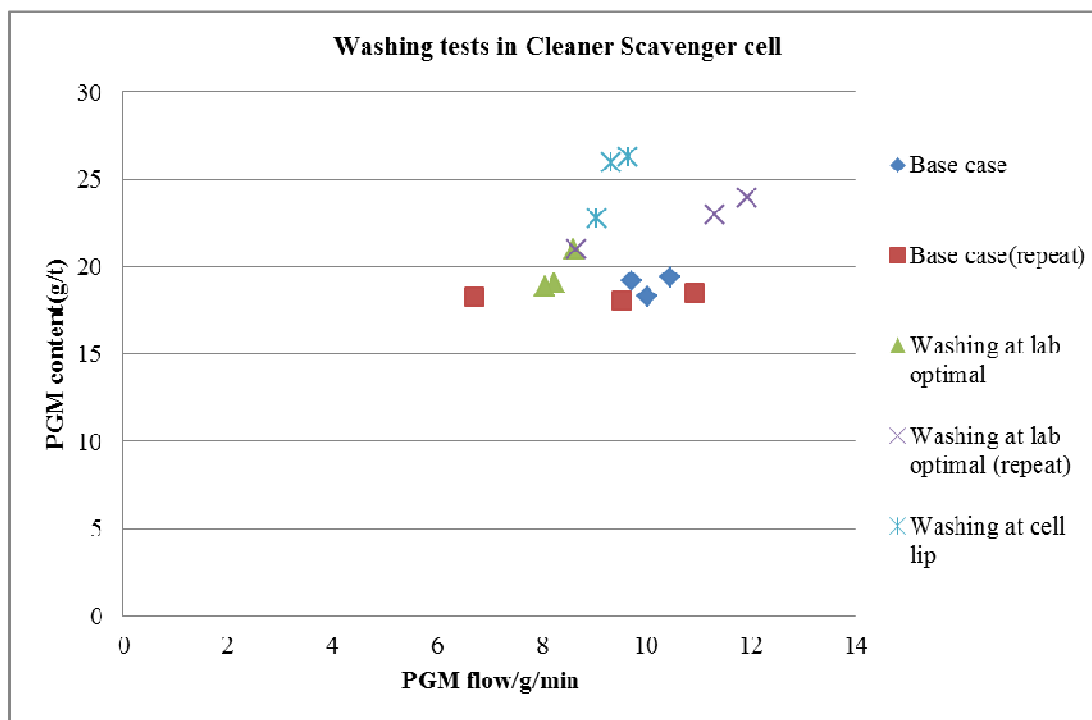


Figure 70: Industrial flotation tests in a cleaner scavenger cell

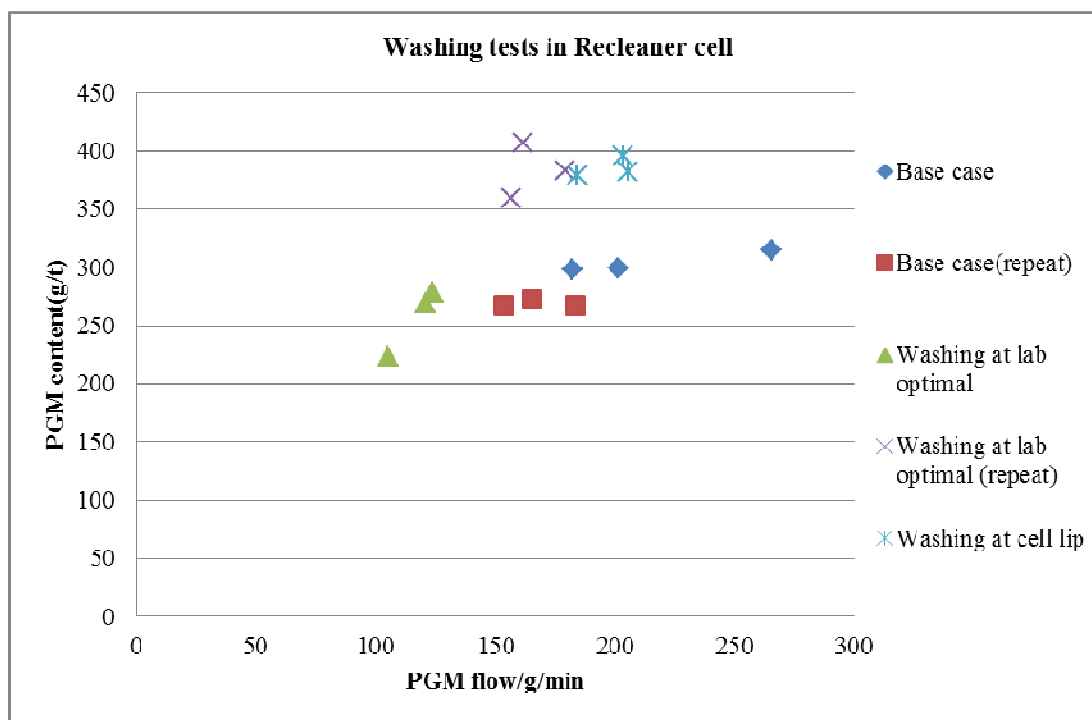


Figure 71: Industrial flotation tests in a recleaner cell

Figure 71 shows that similar reductions in PGM recovery were obtained in tests on the re-cleaner cell, when the wash bar was placed at the surface of the froth. Unfortunately, further tests on the use of a submerged wash bar were not done. Ideally this test should be repeated to confirm the positive results of the froth washing. Repeat tests for washing at the lab optimal position do not correlate well therefore no reliable conclusion can be made from the increased PGM content observed in repeat run.

Although the results of the re-cleaner may be unreliable, duplicate tests for the cleaner and cleaner scavenger show good correspondence. The standard deviations for these repeat tests range between 0.5 and 1.9.

The results obtained from the froth washing tests at Lonmin Platinum have demonstrated that there is potential for froth washing in flotation.

5. Conclusions and recommendations

Preliminary tests were performed on samples of Alsil P and limestone to establish the extent to which Alsil P floated and the entrainment of limestone in water (and frother). The froth structure on tests with Alsil P was voluminous and unstable. However, all subsequent tests were performed using a mixture of the above samples, to simulate platinum ore (5% floatable mineral). The presence of the limestone stabilized the froth, which then looked similar to the froth obtained in flotation tests at UKZN on platinum ore (UG2). It is concluded that the presence of limestone particles, in the lamellae of the froth, hindered bubble coalescence.

Initial tests on the effects of depressants were performed in a pilot-scale flotation cell (43L). The froth was allowed to flow naturally, (with no scraping), as the effectiveness of water injection had to be tested with a flowing froth. Comparative flotation tests between the depressants Guar gum and CMC revealed that Guar gum was the more effective depressant for Alsil P. Various depressant dosages were tested using the two component system and a dosage of 50g/t of ore was found to be most suitable. This depressant dosage resulted in a stable froth with an even appearance in terms of bubble size and structure. Flotation plants add some depressant in the rougher and scavenger to minimise the water in the froth and reduce the entrainment.

The data for recovery of limestone was fitted to a simple entrainment model by Smith and Warren (1989). It showed that entrainment was proportional to water recovery and that the entrainment factor decreased with increasing depressant dosage. This is attributed to the reduction in the amount of floatable material which trapped the gangue minerals into the concentrate.

The main focus of the investigation was on the application of froth washing. In view of difficulties in the operation of the pilot-scale cell (spillage and disposal of large amounts of material), all subsequent tests were performed in 5L cells. The effect of cell type, the type of washing device, the position of the froth washing, frother dosage, the stage of flotation and the water bias were tested. The following conclusions were reached:

- i. The PVC cell design was the preferred choice, as the pulp level and froth could be observed. The recovery and grade of floatable material was slightly better in this cell, compared to the standard Denver metal cell.
- ii. Two diameters (13 and 25mm internal diameter) of washing device were tested. No significant differences were observed and the smaller one was chosen, as being more appropriate.
- iii. The addition of dye provided some evidence of the movement of wash water through the froth, and indicating a preferred froth washing position near the cell impeller housing. However, subsequent analysis of the recovery of floatable material and mass of concentrate showed that a position 3cm from the lip yielded better results.

- iv. The addition of salt to the wash water made it possible to quantify the displacement of water by wash water. The wash water was added with zero bias, keeping the pulp level constant. Results of these tests showed that only about 40 percent of the wash water entered the concentrate.
- v. The combined effects of washing and frother dosage at 50g/t and 60g/t were tested. Recovery of both the floatable and un-floatable material was increased at the higher frother dosage. Washing reduced recovery. A plot of grade of concentrate versus recovery of Alsil P showed that the selectivity for floatable material was not improved by washing. At a frother dosage of 50g/t to the pulp the entrainment factor was reduced from 0.0310 (without washing) to 0.0227 with froth washing. However, more water was recovered, and hence there was no net benefit. It is concluded that the entrainment factor can be confusing; when water recovery is changed by washing (the concentrate had higher moisture content). The recovery versus mass plot is more useful method of assessing the overall effects of test variables. The entrainment factor analysis has been used on subsequent test data, but it is not used extensively in conclusions that follow below.
- vi. Since flotation occurs in stages, froth washing was tested in the rougher and scavenger stages of laboratory flotation tests. The focus was initially on the scavenging stage, where most of the floatable material has been removed and the concentrate contains a significant proportion of entrained material. The effect of froth washing was tested using a frother dosage of 50g/t in the rougher and an additional 10g/t in the scavenger. The data Figures 47 and 49 show that some of the scatter in the results is due to the rougher stage, where the test conditions are identical. Nevertheless, it can be concluded that washing produces a significant improvement in selectivity in the scavenger stage. The lines diverge and if the rougher stage is superimposed, an increase in recovery of about 5 per cent may be estimated.
- vii. Then the frother dosage in the rougher was increased to 60 g/t, washing in the scavenger stage was ineffective (Figures 51 and 52). It was also ineffective when the frother dosage in the scavenger was increased to 20g/t (Figure 55).
- viii. A final permutation of washing in one stage was tried, with washing in the rougher stage only. It may be concluded that this option is much more effective, with a substantial improvement in selectivity or recovery. The data in Figure 56 also confirmed results on scavenger washing, that addition of frother to the wash water had adverse effects.
- ix. The effect of bias (of wash water flow, versus water flow leaving in the concentrate) was tested in the scavenger stage. It is concluded that negative bias resulted in loss of recovery (the pulp level dropped), while a positive bias resulted in improved recovery, but a progressive increase in entrainment.

- x. A few flotation tests were done using a three component system of Alsil P, limestone and chalcopyrite, the latter representing the valuable sulphide mineral to be recovered. The results obtained from these tests showed that froth washing had no benefit.
- xi. Industrial flotation tests conducted at Lonmin Platinum resulted in an improvement of the PGM grade in all three types of cells tested, namely the cleaner, cleaner-scavenger and the re-cleaner but there was a reduction in PGM recovery. Observations and results showed that the positioning of the wash bar at the upper surface of the froth inhibited its flow. Positioning of the wash bar at the pulp/ froth interface produced encouraging results. The PGM content was increased by 19 percent when compared to the run with no washing, with minimal decrease of PGM flow. Due to time constraints repeat tests were not able to be performed.

The following is recommended for future work on froth washing:

- i. Entrainment is greatly dependent on particle size, unfortunately due to the size range of the material used particle size analysis was not possible in the chemical engineering laboratory at UKZN and the number of samples requiring size analysis made it impractical to be sent away for analysis. It is recommended that further froth washing tests be subjected to sized analysis.
- ii. More test work on froth washing in the rougher is required to realise if there is any benefit, it is recommended that tests with frother in the wash water be repeated to check results obtained in this project. The positioning of washing in the rougher should also be varied as a position further from the cell lip may be beneficial as this froth is much deeper than scavenger cell froth and will require more time to penetrate to the pulp-froth interface.
- iii. Further tests should be conducted at zero wash water bias as nothing conclusive can be said from the tests conducted regarding washing with a zero bias. Difficulties arose in predicting the exact amount of water to be replaced with wash water that was removed from the pulp into the concentrate. It is recommended that a volume marked tray be used and monitored during the run.
- iv. Additional tests should be conducted on a 3 component system. Difficulties arose in flotation of chalcopyrite which requires a collector whilst depressing Alsil P with the aid of froth washing. The three components require more detailed study to fully understand how they interact with each other in order to optimise the use of froth washing.

Results obtained from this study show that there is a potential for froth washing in flotation, particularly in rougher and scavenger flotation cells, where the flow of wash water does not increase pulp flow significantly. Due to the limitations of laboratory batch tests, particularly the

changing stability of the froth, it is recommended that further studies on froth washing should be conducted on a continuously operating pilot-plant or a full-scale PGM flotation plant. The device used in this study for plant tests, proved to be convenient to use and the results were repeatable. It should be modified, so that it fits plant rougher and scavenger flotation cells.

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Appendix A: Product Information Sheets

I ALSIL P

PRODUCT INFORMATION SHEET



PRODUCTION PLANT:	IDWALA INDUSTRIAL MINERALS, BENONI OPERATION (certified ISO 9001)		
DESCRIPTION OF THE PRODUCT:	A micronised pyrophyllite, sourced from mineral deposits, North West Province		
		Typical Values	
SPECIFIC PRODUCT DATA:	Fineness:		
	Residue on 75 µm screen	0,5 %	
	Residue on 45 µm screen	5 %	
	Y-Colour Co-Ordinate (Dry)	80 %	
	Yellowness (Dry)	5 %	
GENERAL PRODUCT DATA:	Chemical analysis:		
	SiO ₂	53 %	
	Al ₂ O ₃	33 %	
	Fe ₂ O ₃	0,1 %	
	Other parameters:		
MAIN APPLICATIONS:			
- paint industry as an extender			
- ceramic industry frits and glazes			
- chemical industry as a component in adhesives			
CONTACT DETAILS:			
Marketing Services Manager			For Gauteng
Idwala Carbonates & Idwala Industrial Minerals			ISD Benoni, Tel: (+27) 011 914 2600
Tel: (+27) 031 579 3355			For KwaZulu Natal:
Email: queries@idwala.co.za			ISD Durban, Tel: (+27) 031 579 3355
Website: www.idwala.co.za			For Cape:
			ISD Cape Town, Tel: (+27) 021 637 8155

The information contained in the Product Information Sheet relates only to the specific material described herein and does not relate to usage of the material in combination with any other material or in any other process.

The information on this Product Information Sheet has been determined from numerous measurements and is for guidance only. No guarantee is given or implied. Consequently, the Company disclaims any liability for damage or consequential loss arising from reliance on this Product Information Sheet.

Revision 1
July 2009

KULU-40

PRODUCT INFORMATION SHEET



PRODUCTION PLANT:		IDWALA CARBONATES, UMZIMKULU OPERATION, PORT SHEPSTONE (certified ISO 9001, ISO 14001)	
DESCRIPTION OF THE PRODUCT:		A calcium carbonate powder, manufactured from a white marble (limestone)	
		Typical Values	Test Method
CHEMICAL ANALYSIS	CaCO ₃	91.5 %	XRF
	MgCO ₃	3.5 %	XRF
	SiO ₂	4.0 %	XRF
	Fe ₂ O ₃	0.12 %	XRF
	Al ₂ O ₃	0.1 %	XRF
SPECIFIC PRODUCT DATA:			
Fineness:			
Residue on a 250 µm sieve		2 %	ISO 7877
Top cut (d98%)		250 µm	Malvern Mastersizer
Mean particle size (d50%)		40 µm	Malvern Mastersizer
Particles < 40 µm		50 %	Malvern Mastersizer
Whiteness:			
Brightness (Ry)		85.5 %	Elrepho 450
Moisture ex works		< 0.2 %	ISO 7872
GENERAL PRODUCT DATA:			
Packed bulk density		1.5 g/ml	ISO 78711
pH value		9	ISO 7879
Relative density		2.7 g/ml	
Hardness (Moh's)		3	
Refractive index		1.6	
PARTICLE SIZE DISTRIBUTION (Malvern Mastersizer)			
MAIN APPLICATIONS:			
Chemical			
- Ceramics			
- Grouting			
- Animal feeds			
- Fertilisers			
- Detergents			
CONTACT DETAILS:			
Marketing Services Manager		Idwala Sales & Distribution	
Idwala Carbonates & Idwala Industrial Minerals		ISD Benoni, Tel: (+27) 011 914 2600	
Tel: (+27) 011 799 6670		ISD Durban, Tel: (+27) 031 579 3355	
Email: queries@dwala.co.za		ISD Cape Town, Tel: (+27) 021 637 8155	
Website: www.idwala.co.za			

The information contained in the Product Information Sheet relates only to the specific material described herein and does not relate to usage of the material in combination with any other material or in any other process.

The information on this Product Information Sheet has been determined from numerous measurements and is for guidance only. No guarantee is given or implied. Consequently, the Company disclaims any liability for damage or consequential loss arising from reliance on this Product Information Sheet.

REVISION: 001/2008
KULU-40.doc (www.product-information.dwala.co.za)



MATERIAL SAFETY DATA SHEET

This MSDS conforms with General Administrative Regulations dated 6 Sept. 1996. (ISO-11014/ANSIZ400.1.1996)

NAME: ALSIL 2, P, VRE, ALPITCH, PYROFIL, SAND

SECTION 1. IDENTIFICATION OF THE SUBSTANCE/PREPARATION

NAME: ALSIL 2 (PYROPHYLLITE) HYDROUS ALUMINIUM SILICATE

C.A.S. No.: N/A E.C. No.: N/A E.C. LABEL: N/A ECOCHEM REF.: 34.06.01

UN/SIN No.: N/A HAZCHEM: INERT

HAZARD RATING: SAPMA: 3-H-B

IN EMERGENCY CONTACT: NITA RAMLUTCHMAN AT 011 799 6670 or 0834436994

SECTION 2. COMPOSITION/INFORMATION ON INGREDIENTS

EC CLASSIFICATION: NOT CLASSIFIED

OEL.TWA: 10/1 mg Total/Respirable dust

NO OTHER HAZARDOUS SUBSTANCES PRESENT

SECTION 3. HAZARDS IDENTIFICATION

SAPMA HEALTH RATING: 3-SLIGHT - Irritation or minor reversible injury possible.

INHALATION: Excessive exposure to dust can cause lung damage.

SKIN: Direct contact to be avoided.

EYES: Particulates may scratch eye or cause mechanical irritation.

INGESTION: No direct hazard expected but exercise caution.

NO CARCINOGENIC, MUTAGENIC OR GENETIC EFFECTS ESTABLISHED

Not considered dangerous to the environment.

SECTION 4. FIRST AID MEASURES

INHALATION: Move to fresh air until dust subsides.

SKIN: Always wash after being in contact with chemical substances.

EYES: Rinse immediately with plenty of water. Get medical attention if discomfort persists.

INGESTION: Seek medical advice in case of discomfort.

SECTION 5. FIRE FIGHTING MEASURES

Non-combustible.

SECTION 6. ACCIDENTAL RELEASE MEASURES - SEE ALSO SECTIONS 5,8 & 13

Can make floors slippery when wet.

Contain & collect.

SECTION 7. HANDLING AND STORAGE

Inert substance with no special requirements for hazard containment.

OELs derived from OHS Act Regulations for Dangerous Chemical Substances dated 25 August 1995 (EH-42)

SAPMA Rating - South African Paint Manufacturers Association Guide to Health Hazards (SABS ARP 006:1991).

SECTION 8. EXPOSURE CONTROLS/PERSONAL PROTECTION

OEL.TWA: 10/1 mg TYPE: Total/Respirable dust

SAPMA RATING: 3-H-B PPE: Dust mask

INHALATION: Avoid breathing dust - use a mask.

SKIN: Observe the rules of hygiene. Wash before eating, drinking or smoking.

EYES: Avoid contact with dust. Use goggles. Never touch eyes with dirty hands or gloves.

INGESTION: Observe the rules of hygiene. Wash before eating, drinking or smoking.

Appropriate hand protection and protective clothing must always be used

SECTION 9. PHYSICAL AND CHEMICAL PROPERTIES

CHEMICAL CLASS: FILLER/EXTENDER APPEARANCE: WHITE POWDER
pH: 7.7 DENSITY: 2.83

FLASH POINT: N/A

SOLUBILITY:- WATER: Insoluble

SECTION 10. STABILITY AND REACTIVITY

STABILITY: Stable if stored under normal conditions.

SECTION 11. TOXICOLOGICAL INFORMATION

NO CARCINOGENIC, MUTAGENIC OR GENETIC EFFECTS ESTABLISHED

LD50 ORAL: N/E

SECTION 12. ECOLOGICAL INFORMATION

Not considered dangerous to the environment.

SECTION 13. DISPOSAL CONSIDERATIONS

Minimal hazard. No problems contemplated in disposal. Exercise caution when disposing of used containers.

SECTION 14. TRANSPORT INFORMATION

UN No.: N/A Not considered hazardous for transport.

SECTION 15. REGULATORY INFORMATION

EC INDEX No.: N/A EEC LABEL No. (EINECS/ELINCS): N/A

S22 Do not breathe dust

S38 In case of insufficient ventilation, wear suitable respiratory equipment

NOT CLASSIFIED IN CHIP2

SECTION 16. OTHER INFORMATION

IN CASE OF ANY DISCOMFORT ALWAYS SEEK MEDICAL ADVICE.

IN EMERGENCY CONTACT: Marketing Services Manager (+2731 579 3355/083 443 6994)

KULU

**15, 40, 45, 200C, AGRIT C, AGRAN,
CRC, CRR**

MATERIAL SAFETY DATA SHEET



SECTION 1. IDENTIFICATION OF THE SUBSTANCE/PREPARATION

NAME: KULU 15, 40, 45, 200C, AGRIT C, AGRAN, AGSUP, CRC, CRR. LIMESTONE FILLER

C.A.S. No.: N/A E.C. No.: N/A E.C. LABEL: N/A ECOCHEM REF.: 32.02.01

UN/SIN No.: N/A HAZCHEM: INERT

HAZARD RATING: SAPMA: 4-H-B

IN EMERGENCY CONTACT: JAN VAN DUYKER at 011 7996670 or 083 455 8897

SECTION 2. COMPOSITION/INFORMATION ON INGREDIENTS

EC CLASSIFICATION: NOT CLASSIFIED

HAZARDOUS AND/OR OTHER RELEVANT COMPONENTS

CALCIUM CARBONATE 90% OEL 10/5 mg Total/Respirable dust

MAGNESIUM CARBONATE 5% OEL 10mg Total dust

SECTION 3. HAZARDS IDENTIFICATION

SAPMA HEALTH RATING: 4-HB -SLIGHT - Irritation or minor reversible injury possible.

INHALATION: Nuisance particulate.

SKIN: Direct contact to be avoided.

EYES: Particulates may scratch eye or cause mechanical irritation.

INGESTION: No direct hazard expected but exercise caution.

NO CARCINOGENIC, MUTAGENIC OR GENETIC EFFECTS ESTABLISHED

Not considered dangerous to the environment.

SECTION 4. FIRST AID MEASURES

INHALATION: Move to fresh air.

SKIN: Always wash after being in contact with chemical substances.

EYES: Rinse immediately with plenty of water. Get medical attention if discomfort persists.

INGESTION: Seek medical advice in case of discomfort.

SECTION 5. FIRE FIGHTING MEASURES

Non-combustible.

No direct explosion hazard expected.

SECTION 6. ACCIDENTAL RELEASE MEASURES - SEE ALSO SECTIONS 5,8 & 13

Contain & collect.

SECTION 7. HANDLING AND STORAGE

Inert substance with no special requirements for hazard containment.

SECTION 8. EXPOSURE CONTROLS/PERSONAL PROTECTION

OEL.TWA: TYPE: Mixture See Section 2

SAPMA RATING: 4-HB PPE: Dust mask

INHALATION: Avoid breathing dust - use a mask.

SKIN: Observe the rules of hygiene. Wash before eating, drinking or smoking.

EYES: Avoid contact with dust. Use goggles. Never touch eyes with dirty hands or gloves.

INGESTION: Observe the rules of hygiene. Wash before eating, drinking or smoking.
Appropriate hand protection and protective clothing must always be used.

OELs derived from OHS Act Regulations for Dangerous Chemical Substances dated 25 August 1995 (EH-42)

SAPMA Rating - South African Paint Manufacturers Association Guide to Health Hazards (SABS ARP 006:1991).

SECTION 9. PHYSICAL AND CHEMICAL PROPERTIES

CHEMICAL CLASS: FILLER/EXTENDER APPEARANCE: WHITE POWDER

pH: 9 DENSITY: 2.7

FLASH POINT: N/A

SOLUBILITY: WATER: Insoluble

SECTION 10. STABILITY AND REACTIVITY

STABLE IF STORED UNDER NORMAL CONDITIONS.

SECTION 11. TOXICOLOGICAL INFORMATION

NO CARCINOGENIC, MUTAGENIC OR GENETIC EFFECTS ESTABLISHED

LD50 ORAL: N/A

SECTION 12. ECOLOGICAL INFORMATION

Not considered dangerous to the environment.

SECTION 13. DISPOSAL CONSIDERATIONS

Minimal hazard. No problems contemplated in disposal. Exercise caution when disposing of used containers.

SECTION 14. TRANSPORT INFORMATION

UN No.: N/A not considered hazardous for transport.

SECTION 15. REGULATORY INFORMATION

EC INDEX No.: N/A EEC LABEL No. (EINECS/ELINCS): N/A

S22 Do not breathe dust.

NOT CLASSIFIED IN CHIP2.

SECTION 16. OTHER INFORMATION

IN CASE OF ANY DISCOMFORT ALWAYS SEEK MEDICAL ADVICE.

All information is given in good faith but without guarantee in respect of accuracy.

No responsibility is accepted for errors or omissions or the consequences thereof.

These recommendations were extracted from the EcoChem database using the HAZMAN programme.

IN EMERGENCY CONTACT: Marketing Services Manager (083 443 6994)

Appendix C: Salt conductivity calculations

Salt was added to the wash water, to facilitate the calculation of the efficiency of displacement of the water in the concentrate by wash water. The amount of salt in the concentrate was related to the concentration of salt in the wash water. The amount of salt was measured by conductivity. In order to relate the conductivity measure to a salt concentration a conductivity calibration chart was drawn up (See Figure below).

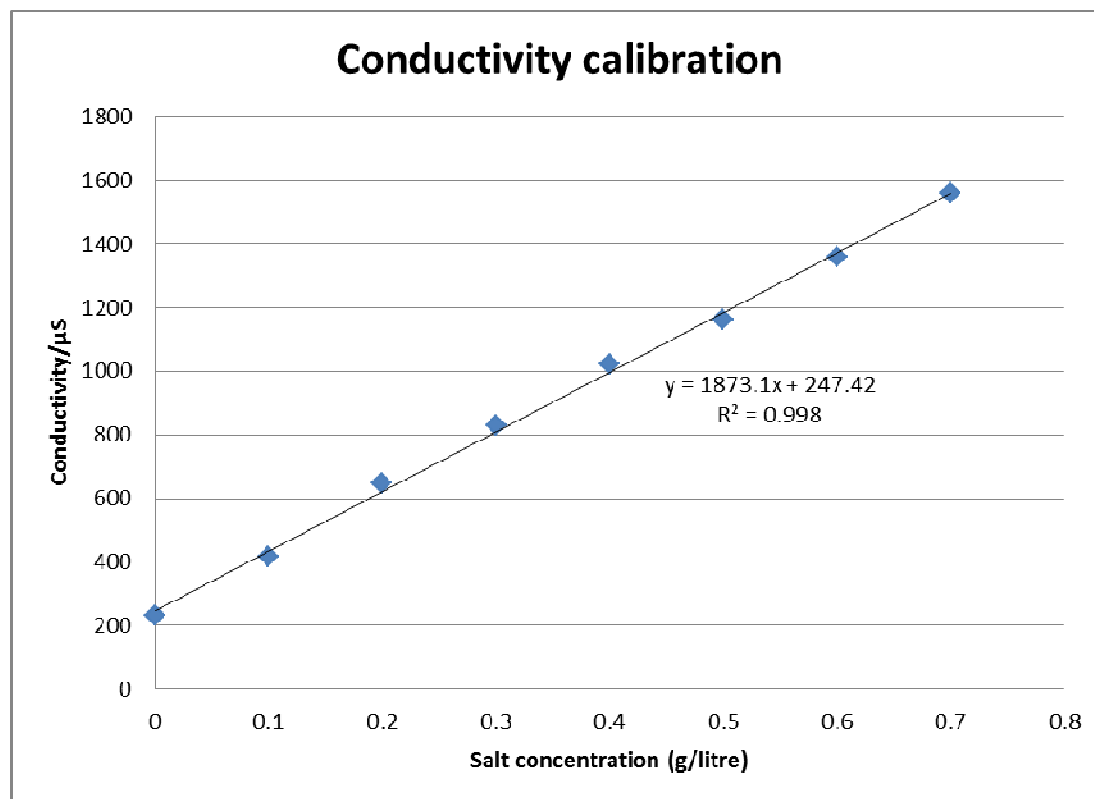


Figure 72: Conductivity calibration for runs conducted with salt in the wash water.

The conductivity of the wash water, concentrate and pulp were measured during these runs. The amount of wash water that went directly into the concentrate was calculated as follows:

Raw data (Washing applied to the scavenger stage):

The wash water was added manually via a funnel mounted above the flotation cell. The amount of wash water added during each time period and its conductivity was recorded.

Table 12: Raw data of wash water during salt runs

Wash water		
Time	Water added/ml	Conductivity/ μ S
4.00	375	-
8.00	250	-
12.00	250	1558
16.00	250	1558

Once the run was completed the concentrate samples were agitated and the conductivity was measured and the volume of water noted.

Table 13: Raw data of concentrate during salt runs

Concentrate		
Time	Volume of water/ml	Conductivity/ μ S
4	319.70	
8	213.90	
12	160.20	827
16	212.50	874

Due to the fragility of the conductivity meter probe the conductivity of the pulp could not be measured during the run. Calculation of the amount of wash water reporting to the concentrate in the first 4 minute interval of froth washing was calculated as follows:

$$\text{Conductivity } (\mu\text{S}) = 1873.1 \left(\text{salt concentration } \left(\frac{\text{g}}{\text{l}} \right) \right) + 247.42 \quad \dots \text{eqn (6)}$$

$$\text{Mass of salt in water (g)} = \text{Salt concentration } \left(\frac{\text{g}}{\text{l}} \right) \times \text{Volume of water (l)} \quad \dots \text{eqn (7)}$$

Mass of salt in 3rd concentrate (at 12 minutes) = 0.0160g

Mass of salt in wash water added = 0.1660

Therefore 0.15g of salt enters the pulp from the wash water. Assuming that this salt mixes evenly into the pulp, the amount of salt that goes into the concentrate from the pulp over the next time interval can be calculated as follows:

Initial conductivity of the pulp was taken as 233 μ S (that of tap water).

Therefore mass of salt in pulp at the beginning = 0.0004g

Mass of salt in pulp =

Mass of salt in wash water added – mass of salt in concentrate +

Mass of salt in pulp at beginning

... eqn (8)

Mass of salt in pulp = 0.1190g

Volume of water in pulp =

initial volume of pulp + wash water added – water in concentrate

... eqn (9)

Volume of water in pulp = (4200.00 + 375.00 + 250.00 + 250.00 – 319.70 – 213.90 – 160.20) ml = 4.3810l

Concentration of salt in pulp = $\frac{\text{Mass of salt in pulp}}{\text{Volume of pulp}}$... eqn (10)

Concentration of salt in pulp = 0.02714 g/l

Mass of salt in concentrate from pulp =

Concentration of salt \times Volume of concentrate

... eqn (11)

Mass of salt in 4th concentrate entering from pulp = 0.0058g

As calculated for the 3rd concentrate,

Mass of salt in wash water = 0.1660g

Mass of salt in concentrate = 0.0681g

Therefore,

Mass of salt in concentrate from wash water = Mass of salt in concentrate

Mass of salt from pulp

Mass of salt in concentrate from wash water = 0.0623

*Percentage of salt in wash water reporting to the concentrate =
(Mass of salt in concentrate from wash)/(mass of salt in wash water)*

Percentage of salt in wash water reporting to concentrate = 33.06%

Therefore percentage of wash water reporting directly to the concentrate = 33.06%

Appendix D: Flotation test data

Table 14: Flotation test data for limestone and Alsil P system

										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	377.40	23.60	17.55	3.58	13.92	17.55	3.58	13.92	79.33	27.85	0.40	207.05
8.00	160.90	14.20	8.15	1.27	5.81	25.70	4.85	19.73	76.76	39.46	0.54	71.05
12.00	153.50	10.40	4.35	1.02	2.64	30.05	5.88	22.37	74.43	44.73	0.65	68.15
			30.05	5.88	22.37							
	40225.00											
air	16.00	17.00										
(Time/min)	0.00	4.00								40225.00		
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	-	31.90	25.85	9.29	19.33	25.85	9.29	19.33	74.78	38.66	1.03	
8.00	163.40	12.10	6.05	1.35	4.22	31.90	10.64	23.55	73.82	47.10	1.18	75.65
12.00	216.20	12.50	6.45	1.92	4.35	38.35	12.56	27.90	72.75	55.80	1.40	128.75
			38.35	12.56	27.90							
		(froth washing at pulp-froth interface)										
	1.00			40227.00								
air	14.00	16.00	19.00	21.00								
(Time/min)	0.00	2.50	6.00	10.00						40227.00	1.00	
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	340.70	23.30	17.25	6.28	12.21	17.25	6.28	12.21	70.80	24.43	0.70	170.65
8.00	206.40	15.00	8.95	2.61	6.44	26.20	8.89	18.65	71.19	37.30	0.99	115.75
12.00	193.90	12.70	6.65	2.14	4.08	32.85	11.04	22.74	69.21	45.47	1.23	106.25
			32.85	11.04	22.74							
	2.00	(froth washing		40227.00								

		above froth)										
air	14.00	16.00	19.00	21.00								
(Time/min)	0.00	2.50	6.00	10.00						40227.00	2.00	
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
6.00	401.80	30.40	24.35	9.25	16.60	24.35	9.25	16.60	68.15	33.19	1.03	224.65
9.00	156.70	11.30	5.25	1.57	3.28	29.60	10.81	19.88	67.16	39.76	1.20	69.75
14.00	184.90	12.40	6.35	2.03	4.18	35.95	12.84	24.05	66.91	48.11	1.43	97.55
			35.95	12.84	24.05							
	40231.00	(froth washing above froth)										
air	14.00	16.00	19.00	21.00								
(Time/min)	0.00	2.50	6.00	10.00						40231.00		
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	401.80	30.40	24.35	7.29	18.55	24.35	7.29	18.55	76.18	37.10	0.81	224.65
8.00	156.70	11.30	5.25	1.37	4.06	29.60	8.66	22.61	76.39	45.22	0.96	69.75
12.00	184.90	12.40	6.35	2.01	4.27	35.95	10.67	26.88	74.78	53.77	1.19	97.55
			35.95	10.67	26.88						Total	391.95
	40232.00	(froth washing above froth)										
air	16.00	18.00	24.00									
(Time/min)	0.00	4.00	11.00							40232.00		
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	0.00	31.40	23.50	7.68	16.50	23.50	7.68	16.50	70.20	33.00	0.85	0.00
8.00	224.90	17.90	10.00	2.53	7.66	33.50	10.21	24.16	72.12	48.32	1.13	133.20
12.00	172.50	13.40	5.50	1.63	3.48	39.00	11.84	27.64	70.87	55.27	1.32	86.00
15.00	172.40	13.50	5.60	2.68	3.15	44.60	14.52	30.78	69.02	61.57	1.61	115.50
			39.00	11.84	27.64							
	40233.00	(froth										

		washing above froth)										
air	17.00	19.00										
(Time/min)	0.00	4.00								40233.00		
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	359.60	29.10	21.20	3.31	15.90	21.20	3.31	15.90	75.00	31.80	0.37	185.60
8.00	163.10	14.30	6.40	1.56	4.37	27.60	4.86	20.27	73.43	40.53	0.54	75.00
12.00	338.30	21.10	13.20	7.47	8.50	40.80	12.33	28.76	70.49	57.52	1.37	244.10
			40.80	12.33	28.76						Total	504.70
	40234.00	(froth washing above froth)		75g/t Dowfroth								
air	16.00	18.00										
(Time/min)	0.00	4.00								40234.00		
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	807.10	59.20	51.30	24.82	32.15	51.30	24.82	32.15	62.66	64.29	2.76	603.00
8.00	229.50	16.40	8.50	2.76	6.06	59.80	27.59	38.21	63.89	76.42	3.07	139.30
12.00	167.80	12.30	4.40	1.24	2.49	64.20	28.83	40.70	63.39	81.39	3.20	82.40
16.00	183.30	13.10	5.20	2.05	3.01	69.40	30.88	43.71	62.98	87.41	3.43	126.80
			64.20	28.83	40.70						Total	951.50
	40235.00	No washing		50g/t dowfroth								
air	16.00	19.00										
(Time/min)	0.00	4.00								40235.00		
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	432.80	33.50	25.60	8.31	18.77	25.60	8.31	18.77	73.32	37.54	0.92	254.40
8.00	223.20	19.80	11.90	3.38	9.19	37.50	11.69	27.96	74.56	55.92	1.30	129.60
12.00	213.50	16.20	8.30	2.99	5.97	45.80	14.68	33.93	74.09	67.86	1.63	124.20
			45.80	14.68	33.93							
	40235.00	No washing		75g/t dowfroth								

air	16.00	19.00										
(Time/min)	0.00	4.00								40235.00		
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	731.20	49.70	41.80	15.31	31.34	41.80	15.31	31.34	74.98	62.68	1.70	536.60
8.00	380.10	22.00	14.10	4.94	10.74	55.90	20.25	42.08	75.27	84.15	2.25	284.30
12.00	254.90	15.40	7.50	2.92	5.22	63.40	23.18	47.29	74.59	94.59	2.58	166.40
			63.40	23.18	47.29							
	40235.00	No washing		75g/t dowfroth								
air	16.00	19.00										
(Time/min)	0.00	4.00								40235.00		
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	684.90	44.40	36.50	13.52	26.27	36.50	13.52	26.27	71.97	52.54	1.50	495.60
8.00	274.70	17.50	9.60	2.74	6.99	46.10	16.26	33.26	72.15	66.52	1.81	183.40
12.00	254.40	14.50	6.60	2.17	4.08	52.70	18.43	37.34	70.85	74.68	2.05	166.80
			52.70	18.43	37.34							
	40240.00	no washing		50g/t dowfroth	30g/t guar							
air	16.00	18.00	22.00									
(Time/min)	0.00	4.00	10.00							40240.00		
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	278.40	37.10	29.20	6.44	22.26	29.20	6.44	22.26	76.24	44.52	0.72	96.40
8.00	205.30	21.10	13.20	3.34	9.98	42.40	9.78	32.24	76.04	64.48	1.09	110.40
12.00	210.60	17.20	9.30	3.16	6.46	51.70	12.94	38.70	74.85	77.40	1.44	120.30
			51.70	12.94	38.70							
	40241.00	Froth washing above froth with larger device in perspex cell				50g/t dowfroth						

air	16.00	18.00										
(Time/min)	0.00	4.00								40241.00		
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	563.80	34.60	26.70	8.28	19.43	26.70	8.28	19.43	72.79	38.87	0.92	384.30
8.00	296.70	17.80	9.90	2.65	7.52	36.60	10.93	26.96	73.65	53.91	1.21	205.10
12.00	277.40	14.90	7.00	2.49	4.62	43.60	13.43	31.58	72.43	63.16	1.49	189.40
			43.60	13.43	31.58						Total	778.80
	40241.00	No washing in perspex cell				50g/t dowfroth						
air	15.00	16.00	19.00	20.00								
(Time/min)	0.00	4.00	8.00	10.00						40241.00		
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	495.30	37.50	29.60	10.49	21.00	29.60	10.49	21.00	70.96	42.01	1.17	312.90
8.00	229.20	19.80	11.90	3.64	8.69	41.50	14.13	29.70	71.56	59.39	1.57	135.60
12.00	198.70	16.10	8.20	2.53	5.45	49.70	16.66	35.15	70.71	70.29	1.85	109.50
			49.70	16.66	35.15							
	40242.00	Froth washing above froth with larger device in perspex cell				50g/t dowfroth						
air	15.00	17.00	21.00									
(Time/min)	0.00	4.00	10.00							40242.00		
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	399.90	27.60	19.70	4.63	14.40	19.70	4.63	14.40	73.08	28.79	0.51	227.40
8.00	202.00	13.30	5.40	1.46	3.49	25.10	6.10	17.89	71.27	35.78	0.68	114.90
12.00	215.20	11.80	3.90	1.14	2.20	29.00	7.23	20.09	69.28	40.18	0.80	130.30
15.00	164.10	11.10	3.20	1.13	1.60	32.20	8.36	21.69	67.36	43.38	0.93	79.90
			29.00	8.36	21.69						Total	552.50

	40242.00	Froth washing above froth with larger device in perspex cell				50g/t dowfroth						
air	15.00	17.00										
(Time/min)	0.00	4.00								40242.00		
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	388.40	26.30	18.40	5.08	13.47	18.40	5.08	13.47	73.21	26.94	0.56	217.20
8.00	218.80	14.00	6.10	1.78	3.85	24.50	6.85	17.32	70.68	34.63	0.76	131.00
12.00	258.80	14.80	6.90	2.19	4.27	31.40	9.04	21.59	68.75	43.18	1.00	170.90
			31.40	9.04	21.59						Total	519.10
	40245.00	Froth washing above froth with smaller device (with controlled number of holes) in perspex cell										
air	15.00	18.00				50g/t dowfroth						
(Time/min)	0.00	4.00								40245.00		
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	563.10	38.70	30.80	9.80	23.00	30.80	9.80	23.00	74.69	46.01	1.09	379.50
8.00	211.70	12.00	4.10	1.38	2.25	34.90	11.18	25.25	72.36	50.51	1.24	125.90
12.00	266.30	12.40	4.50	1.85	2.42	39.40	13.03	27.67	70.23	55.34	1.45	180.80
			39.40	13.03	27.67						Total	686.20
R1	40246.00	Froth washing above froth with smaller device (with controlled number of										

		holes) in perspex cell 6cm from lip										
air	15.00	17.00				60g/t dowfroth						
(Time/min)	0.00	4.00								40246.00		
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	594.90	46.60	38.70	11.86	28.19	38.70	11.86	28.19	72.84	56.38	1.32	403.40
8.00	250.90	16.10	8.20	2.42	5.86	46.90	14.28	34.05	72.60	68.10	1.59	161.00
12.00	221.60	12.40	4.50	1.63	2.58	51.40	15.91	36.63	71.27	73.27	1.77	136.10
			51.40	15.91	36.63						Total	700.50
R2	40246.00	Froth washing above froth with smaller device (with controlled number of holes) in perspex cell 3cm from lip										
air	16.00	18.00				50g/t dowfroth						
(Time/min)	0.00	4.00								40246.00		
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00		38.20	30.30	8.66	21.88	30.30	8.66	21.88	72.22	43.77	0.96	-183.10
8.00		17.20	9.30	2.61	6.67	39.60	11.28	28.55	72.10	57.11	1.25	-91.00
12.00	250.60	15.20	7.40	2.19	4.72	47.00	13.47	33.27	71.50	68.00	1.50	162.20
			47.00	13.47	33.27							
R1	40248.00	Froth washing above froth with smaller device (with controlled number of holes) in										

		perspex cell 6cm from lip										
air	16.00	18.00				60g/t dowfroth						
(Time/min)	0.00	4.00								40248.00		
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	756.70	54.10	46.20	16.29	33.00	46.20	16.29	33.00	71.42	65.99	1.81	557.70
8.00	261.30	15.80	7.90	2.65	5.53	54.10	18.94	38.52	71.21	77.05	2.10	171.70
12.00	261.10	13.00	5.10	2.18	2.95	59.20	21.12	41.48	70.06	82.95	2.35	175.00
			59.20	21.12	41.48						Total	904.40
R2	40248.00	Froth washing above froth with smaller device (with controlled number of holes) in perspex cell 6cm from lip										
air	16.00	18.00				60g/t dowfroth						
(Time/min)	0.00	4.00								40248.00		
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	818.90	49.60	41.70	16.07	27.00	41.70	16.07	27.00	64.75	54.00	1.79	624.40
8.00	312.40	14.30	6.40	2.20	4.20	48.10	18.28	31.20	64.86	62.39	2.03	224.30
12.00	359.10	15.90	8.00	2.32	3.50	56.10	20.59	34.70	61.85	69.39	2.29	270.10
			56.10	20.59	34.70						Total	1118.80
	40249.00	Froth washing above froth with smaller device (with controlled number of holes) in perspex cell										

		6cm from lip										
air	16.00	18.00				60g/t dowfroth						
(Time/min)	0.00	4.00								40249.00		
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	723.70	50.40	42.50	14.29	28.21	42.50	14.29	28.21	66.37	56.41	1.59	528.40
8.00	267.30	14.90	7.00	2.84	4.16	49.50	17.13	32.37	65.39	64.74	1.90	178.60
12.00	251.60	16.50	8.60	3.50	2.77	58.10	20.63	35.14	60.48	70.28	2.29	162.00
			58.10	20.63	35.14						Total	869.00
		Froth washing above froth with smaller device (with controlled number of holes) in perspex cell 6cm from lip										
	40253.00											
air		16.00	20.00			65g/t dowfroth						
(Time/min)		0.00	8.00									
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	779.70	55.20	47.30	16.09	31.21	47.30	16.09	31.21	65.98	62.42	1.79	579.60
8.00	251.50	14.30	6.40	1.71	4.69	53.70	17.80	35.90	66.85	71.79	1.98	163.40
12.00	269.40	13.60	5.70	1.57	4.13	59.40	19.38	40.02	67.38	80.05	2.15	182.70
			59.40	19.38	40.02						Total	925.70
		Froth washing above froth with smaller device (with controlled number of holes) in perspex cell 6cm from lip										
	40255.00											

air		15.00	18.00	20.00	21.00	60g/t dowfroth						
(Time/min)		0.00	6.00	8.00	10.00							
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	661.40	46.30	38.40	17.46	20.94	38.40	17.46	20.94	54.53	41.88	1.94	470.20
8.00	266.00	15.60	7.70	0.43	7.27	46.10	17.89	28.21	61.19	56.41	1.99	176.60
12.00	300.30	14.50	6.60	2.02	4.58	52.70	19.92	32.78	62.21	65.56	2.21	212.70
			52.70	19.92	32.78						Total	859.50
	40255.00	No washing										
air		15.00	19.00	20.00		60g/t dowfroth						
(Time/min)		0.00	6.00	8.00								
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00		53.70	45.80	15.03	30.77	45.80	15.03	30.77	67.17	61.53	1.67	-198.60
8.00	256.10	19.60	11.70	3.53	8.17	57.50	18.56	38.94	67.72	77.88	2.06	162.70
12.00	303.00	17.30	9.40	3.40	6.00	66.90	21.97	44.93	67.17	89.87	2.44	212.60
			66.90	21.97	44.93							
	40255.00	No washing with scavenging										
air		15.00	19.00	20.00		60g/t dowfroth						
(Time/min)		0.00	6.00	8.00								
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	747.40	58.00	50.10	19.51	30.59	50.10	19.51	30.59	61.06	61.19	2.17	544.50
8.00	249.40	18.40	10.50	4.26	6.24	60.60	23.76	36.84	60.78	73.67	2.64	157.20
12.00	256.90	17.50	9.60	5.57	4.03	70.20	29.34	40.86	58.21	81.73	3.26	166.30
16.00	174.70	12.30	4.40	1.77	2.63	74.60	31.10	43.50	58.31	86.99	3.46	119.00
			74.60	31.10	43.50							
	40261.00	Washing at scavenging										

		stage										
air		15.00	19.00	20.00		60g/t dowfroth						
(Time/min)		0.00	6.00	8.00								
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	608.70	47.60	39.70	12.78	26.92	39.70	12.78	26.92	67.80	53.83	1.42	416.20
8.00	298.40	22.30	14.40	3.85	10.55	54.10	16.64	37.46	69.25	74.93	1.85	202.30
12.00	288.70	19.50	11.60	7.08	4.52	65.70	23.71	41.99	63.91	83.97	2.63	196.10
16.00	192.70	12.50	4.60	2.25	2.35	70.30	25.96	44.34	63.07	88.67	2.88	136.80
			70.30	25.96	44.34							
	40262.00	No washing				R	S					
air		15.00				50g/t dowfroth	20g/t dowfroth					
(Time/min)		0.00										
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	421.20	30.30	22.40	6.91	15.49	22.40	6.91	15.49	69.16	30.99	0.77	246.00
8.00	254.60	19.30	11.40	2.81	8.59	33.80	9.71	24.09	71.26	48.17	1.08	161.50
12.00	242.80	16.70	8.80	3.30	5.50	42.60	13.01	29.59	69.45	59.17	1.45	153.00
16.00	154.90	11.80	3.90	1.10	2.80	46.50	14.11	32.39	69.65	64.77	1.57	99.70
			46.50	14.11	32.39							
	40262.00	Washing at scavenging				R	S					
air		15.00				50g/t dowfroth	20g/t dowfroth	250ml water				
(Time/min)		0.00										
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	417.10	35.50	27.60	6.09	21.51	27.60	6.09	21.51	77.94	43.02	0.68	236.70
8.00	260.80	19.50	11.60	2.77	8.83	39.20	8.86	30.34	77.40	60.68	0.98	167.50
12.00	320.00	20.70	12.80	8.28	4.52	52.00	17.14	34.86	67.04	69.72	1.90	226.20
16.00	195.60	11.40	3.50	1.51	1.99	55.50	18.65	36.85	66.40	73.71	2.07	140.80
			55.50	18.65	36.85						S	367.00

											Total	771.20
	40263.00	Washing at scavenging				R	S					
air		15.00				50g/t dowfroth	20g/t dowfroth	400ml water				
(Time/min)		0.00								40253.00		
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	400.40	32.00	24.10	6.12	17.98	24.10	6.12	17.98	74.61	35.96	0.68	223.50
8.00	263.70	19.70	11.80	2.90	8.90	35.90	9.02	26.88	74.87	53.76	1.00	170.20
12.00	268.20	13.60	5.70	2.45	3.25	41.60	11.47	30.13	72.44	60.27	1.27	181.50
16.00	334.80	11.90	4.00	1.79	2.21	45.60	13.26	32.34	70.92	64.68	1.47	279.50
			45.60	13.26	32.34						S	461.00
											Total	854.70
	40263.00	No washing				R	S					
air		15.00				60g/t dowfroth	20g/t dowfroth					
(Time/min)		0.00								40253.00		
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	567.80	42.10	34.20	10.93	23.27	34.20	10.93	23.27	68.05	46.55	1.21	380.80
8.00	347.70	25.40	17.50	4.24	13.26	51.70	15.17	36.53	70.66	73.06	1.69	248.50
12.00	279.00	16.00	8.10	4.08	4.02	59.80	19.25	40.55	67.81	81.10	2.14	189.90
16.00	204.50	13.00	5.10	1.68	3.42	64.90	20.93	43.97	67.75	87.94	2.33	148.10
			64.90	20.93	43.97							
	40266.00	washing				R	S					
air		15.00				60g/t dowfroth	20g/t dowfroth	200ml water				
(Time/min)		0.00										
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	555.90	42.00	34.10	10.20	23.90	34.10	10.20	23.90	70.08	47.79	1.13	369.00
8.00	219.50	16.80	8.90	2.21	6.69	43.00	12.41	30.59	71.14	61.18	1.38	128.90
12.00	247.90	13.00	5.10	3.32	1.78	48.10	15.73	32.37	67.29	64.73	1.75	161.80
16.00	178.00	10.60	2.70	0.94	1.76	50.80	16.68	34.12	67.17	68.25	1.85	124.00

			50.80	16.68	34.12						S	285.80
											Total	783.70
WEEK 8/04												
	40276.00	washing NO depressant				0.00	S					
air		15.00				50g/t dowfroth	20g/t dowfroth					
(Time/min)		0.00										
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	530.00	47.10	41.10	8.23	32.87	41.10	8.23	32.87	79.97	65.74	0.91	336.10
8.00	455.90	28.50	22.50	6.52	15.98	63.60	14.75	48.85	76.80	97.69	1.64	351.70
12.00	372.40	27.40	21.40	16.78	4.62	85.00	31.53	53.47	62.90	106.93	3.50	270.00
16.00	299.70	21.20	15.20	11.18	4.02	100.20	42.71	57.49	57.37	114.97	4.75	233.20
			100.20	42.71	57.49						R	687.80
											S	503.20
	40277.00	Washing				R	S				Total	1191.00
air		15.00				50g/t dowfroth	10g/t dowfroth					
(Time/min)		0.00								40253.00		
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	507.90	30.70	24.70	8.17	16.53	24.70	8.17	16.53	66.94	33.07	0.91	330.40
8.00	303.60	19.00	13.00	3.38	9.62	37.70	11.54	26.16	69.39	52.32	1.28	208.90
12.00	268.50	18.30	12.30	8.27	4.03	50.00	19.81	30.19	60.38	60.38	2.20	175.20
16.00	254.30	18.30	12.30	8.23	4.07	62.30	28.04	34.26	54.98	68.51	3.12	190.70
			62.30	28.04	34.26						S	365.90
											Total	905.20
	40277.00	No Washing				R	S					
air		15.00				50g/t dowfroth	10g/t dowfroth					
(Time/min)		0.00								40253.00		
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	464.00	28.70	22.70	6.89	15.81	22.70	6.89	15.81	69.64	31.62	0.77	288.50

8.00	258.70	17.70	11.70	2.45	9.25	34.40	9.34	25.06	72.84	50.11	1.04	165.30
12.00	270.20	22.20	16.20	11.81	4.39	50.60	21.16	29.44	58.19	58.89	2.35	173.00
16.00	228.40	15.80	9.80	6.62	3.18	60.40	27.77	32.63	54.02	65.26	3.09	167.30
			60.40	27.77	32.63							
	40280.00	Washing at scavenging				R	S					
air		15.00				60g/t dowfroth	0g/t dowfroth					
(Time/min)		0.00										
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	627.40	36.50	30.50	11.83	18.67	30.50	11.83	18.67	61.21	37.34	1.31	444.10
8.00	265.60	16.80	10.80	3.00	7.80	41.30	14.83	26.47	64.10	52.95	1.65	173.10
12.00	271.80	19.60	13.60	10.62	2.98	54.90	25.45	29.45	53.64	58.90	2.83	177.20
16.00	233.30	17.20	11.20	8.14	3.06	66.10	33.58	32.52	49.19	65.03	3.73	170.80
			66.10	33.58	32.52							965.20
	40280.00	No Washing				R	S					
air		15.00				60g/t dowfroth	0g/t dowfroth					
(Time/min)		0.00										
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	643.70	39.00	33.00	15.02	17.98	33.00	15.02	17.98	54.49	35.97	1.67	457.90
8.00	299.00	17.50	11.50	3.49	8.01	44.50	18.50	26.00	58.42	51.99	2.06	205.80
12.00	215.90	13.10	7.10	4.35	2.75	51.60	22.86	28.74	55.70	57.49	2.54	127.80
16.00		11.80	5.80	3.48	2.32	57.40	26.34	31.06	54.11	62.12	2.93	-57.10
			57.40	26.34	31.06							
	40281.00	Washing for roughing and scavenging				R	S					
air		15.00				50g/t dowfroth	10g/t dowfroth					
(Time/min)		0.00										
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass	Mass	Mass talc	Cumulative	Cumulative	cumulative	Grade %	Talc	Limestone	water

			recovered	Limestone		tot	lime	talc				
4.00	463.80	26.60	20.60	6.16	14.44	20.60	6.16	14.44	70.08	28.87	0.68	290.40
8.00	310.30	18.90	12.90	3.20	9.70	33.50	9.36	24.14	72.05	48.27	1.04	215.70
12.00	244.90	13.20	7.20	4.69	2.51	40.70	14.06	26.64	65.46	53.29	1.56	156.70
16.00	227.80	14.20	8.20	2.86	5.34	48.90	16.92	31.98	65.40	63.96	1.88	168.30
			48.90	16.92	31.98						R	506.10
											S	325.00
	40282.00	Washing for roughing and scavenging				R	S				Total	831.10
air		15.00				60g/t dowfroth	0g/t dowfroth					
(Time/min)		0.00										
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	613.00	34.70	28.70	10.06	18.64	28.70	10.06	18.64	64.94	37.28	1.12	431.50
8.00	323.60	18.00	12.00	2.90	9.10	40.70	12.96	27.74	68.16	55.48	1.44	229.90
12.00	265.30	19.40	13.40	9.99	3.41	54.10	22.95	31.15	57.58	62.31	2.55	170.90
16.00	222.90	14.30	8.30	4.98	3.32	62.40	27.92	34.48	55.25	68.95	3.10	163.30
			62.40	27.92	34.48						R	661.40
											S	334.20
	40283.00	Washing at scavenging				R	S				Total	995.60
air		15.00				50g/t dowfroth	10g/t dowfroth					
(Time/min)		0.00										
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	474.70	31.10	25.10	8.50	16.60	25.10	8.50	16.60	66.12	33.19	0.94	296.80
8.00	265.90	18.00	12.00	3.53	8.47	37.10	12.03	25.07	67.57	50.14	1.34	172.20
12.00	212.70	12.60	6.60	2.84	3.76	43.70	14.87	28.83	65.98	57.66	1.65	125.10
16.00	243.40	13.70	7.70	4.67	3.03	51.40	19.54	31.86	61.99	63.73	2.17	184.40
			51.40	19.54	31.86						S	309.50
											Total	778.50
	40283.00	Washing at scavenging				R	S					
air		15.00				60g/t dowfroth	10g/t dowfroth					

(Time/min)		0.00										
			Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Recovery		mass
Time	Wet Mass	Dry Mass								Talc	Limestone	water
4.00	780.70	45.20	39.20	18.51	20.69	39.20	18.51	20.69	52.78	41.38	2.06	588.70
8.00	313.70	18.90	12.90	4.44	8.46	52.10	22.95	29.15	55.96	58.31	2.55	219.10
12.00	284.80	13.90	7.90	4.08	3.82	60.00	27.03	32.97	54.95	65.94	3.00	195.90
16.00	244.50	13.00	7.00	3.83	3.17	67.00	30.86	36.14	53.95	72.29	3.43	186.20
			67.00	30.86	36.14						S	382.10
											Total	1189.90
	40284.00	No washing				R	S					
air		15.00				60g/t dowfroth	10g/t dowfroth					
(Time/min)		0.00										
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	694.70	46.40	40.40	14.57	25.83	40.40	14.57	25.83	63.93	51.65	1.62	501.50
8.00	284.90	18.90	12.90	3.91	8.99	53.30	18.49	34.81	65.32	69.63	2.05	190.30
12.00	252.00	15.10	9.10	4.50	4.60	62.40	22.99	39.41	63.16	78.82	2.55	161.90
16.00	172.00	11.40	5.40	2.20	3.20	67.80	25.19	42.61	62.85	85.22	2.80	115.30
			67.80	25.19	42.61							
	40289.00	washing at scavenging				R	S					
						60g/t dowfroth	10g/t dowfroth					
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	738.50	45.00	39.00	16.88	22.12	39.00	16.88	22.12	56.72	44.24	1.88	546.70
8.00	289.50	18.30	12.30	3.65	8.65	51.30	20.53	30.77	59.98	61.54	2.28	195.50
12.00	262.80	12.70	6.70	2.98	3.72	58.00	23.51	34.49	59.47	68.99	2.61	175.10
16.00	246.20	12.40	6.40	3.88	2.52	64.40	27.39	37.01	57.47	74.02	3.04	188.50
			64.40	27.39	37.01						S	363.60
											Total	1105.80
	40290.00	Washing for roughing and scavenging				R	S					

						50g/t dowfroth	10g/t dowfroth					
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	532.70	31.80	25.80	8.57	17.23	25.80	8.57	17.23	66.80	34.47	0.95	354.10
8.00	297.00	16.60	10.60	2.39	8.21	36.40	10.96	25.44	69.90	50.89	1.22	204.70
12.00	244.70	12.80	6.80	2.42	4.38	43.20	13.37	29.83	69.04	59.65	1.49	156.90
16.00	199.40	11.20	5.20	1.56	3.64	48.40	14.93	33.47	69.15	66.94	1.66	142.90
			48.40	14.93	33.47						R	558.80
											S	299.80
	40290.00	No washing				R	S				total	715.70
						60g/t dowfroth	10g/t dowfroth					
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	548.60	33.40	27.40	9.92	17.48	27.40	9.92	17.48	63.81	34.97	1.10	368.40
8.00	274.30	17.20	11.20	3.28	7.92	38.60	13.20	25.40	65.81	50.81	1.47	181.40
12.00	227.40	13.50	7.50	2.66	4.84	46.10	15.86	30.24	65.60	60.49	1.76	138.90
16.00	199.90	11.50	5.50	1.87	3.63	51.60	17.73	33.87	65.64	67.74	1.97	143.10
			51.60	17.73	33.87							
	40291.00	Washing for roughing and scavenging				R	S					
						60g/t dowfroth	10g/t dowfroth					
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	820.70	48.90	42.90	19.52	23.38	42.90	19.52	23.38	54.51	46.77	2.17	625.00
8.00	274.10	12.30	6.30	2.23	4.07	49.20	21.75	27.45	55.80	54.91	2.42	186.10
12.00	237.70	11.10	5.10	2.04	3.06	54.30	23.79	30.51	56.19	61.02	2.64	151.60
16.00	127.50	7.90	1.90	0.70	1.20	56.20	24.49	31.71	56.43	63.43	2.72	74.30
			56.20	24.49	31.71							811.10
												225.90

	40291.00	No washing				R	S					962.70
						60g/t dowfroth	0g/t dowfroth					
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	789.70	49.10	43.10	20.39	22.71	43.10	20.39	22.71	52.69	45.42	2.27	593.80
8.00	255.60	11.30	5.30	2.52	2.78	48.40	22.91	25.49	52.66	50.97	2.55	168.60
12.00	198.70	16.90	10.90	3.10	7.80	59.30	26.01	33.29	56.14	66.58	2.89	106.80
16.00	216.20	11.30	5.30	2.16	3.14	64.60	28.17	36.43	56.40	72.87	3.13	159.60
			64.60	28.17	36.43							
	40297.00	Washing at scavenging with frother in wash water				R	S					
						60g/t dowfroth	0g/t dowfroth					
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	637.10	43.40	37.40	10.37	27.03	37.40	10.37	27.03	72.27	54.05	1.15	446.90
8.00	275.00	18.40	12.40	3.54	8.86	49.80	13.91	35.89	72.06	71.77	1.55	180.90
12.00	236.00	19.60	13.60	11.74	1.86	63.40	25.66	37.74	59.53	75.48	2.85	141.40
16.00	194.70	16.90	10.90	9.33	1.57	74.30	34.99	39.31	52.91	78.62	3.89	132.50
			74.30	34.99	39.31							273.90
												901.70
	40297.00	Washing throughout with frother in wash water				R	S					
						60g/t dowfroth	0g/t dowfroth					
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water

4.00	686.30	41.00	35.00	11.16	23.84	35.00	11.16	23.84	68.13	47.69	1.24	498.50
8.00	295.60	14.80	8.80	2.77	6.03	43.80	13.93	29.87	68.20	59.74	1.55	205.10
12.00	226.60	15.40	9.40	7.44	1.96	53.20	21.36	31.84	59.84	63.67	2.37	136.20
16.00	210.10	13.20	7.20	5.44	1.76	60.40	26.80	33.60	55.62	67.19	2.98	151.60
			60.40	26.80	33.60							703.60
												287.80
	40298.00	Washing at scavenging (new washer). With frother in wash water				R	S					839.80
						50g/t dowfroth	10g/t dowfroth					
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	479.70	32.80	27.10	8.69	18.41	27.10	8.69	18.41	67.94	36.82	0.97	299.80
8.00	276.20	18.40	12.70	3.52	9.18	39.80	12.21	27.59	69.33	55.19	1.36	181.80
12.00	238.40	11.70	6.00	2.70	3.30	45.80	14.91	30.89	67.45	61.78	1.66	151.40
16.00	219.70	10.40	4.70	2.48	2.22	50.50	17.39	33.11	65.56	66.21	1.93	163.70
			50.50	17.39	33.11							315.10
												796.70
	40298.00	Washing at scavenging (new washer). With frother in wash water				R	S					
						60g/t dowfroth	0g/t dowfroth					
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	686.40	47.20	41.50	15.72	25.78	41.50	15.72	25.78	62.12	51.56	1.75	492.10
8.00	277.70	19.20	13.50	4.17	9.33	55.00	19.89	35.11	63.84	70.22	2.21	182.50
12.00	250.80	13.30	7.60	5.04	2.56	62.60	24.92	37.68	60.19	75.35	2.77	162.20

16.00	229.20	10.20	4.50	2.62	1.88	67.10	27.55	39.55	58.95	79.11	3.06	173.40
			67.10	27.55	39.55							335.60
												1010.20
	40301.00	Washing at roughing (new washer). With frother in wash water				R	S					
						60g/t dowfroth	0g/t dowfroth					
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	774.00	53.10	47.40	19.51	27.89	47.40	19.51	27.89	58.84	55.78	2.17	573.80
8.00	339.20	19.20	13.50	3.73	9.77	60.90	23.24	37.66	61.83	75.31	2.58	244.00
12.00	221.20	11.90	6.20	3.17	3.03	67.10	26.41	40.69	60.64	81.37	2.93	134.00
16.00	207.20	9.90	4.20	1.67	2.53	71.30	28.08	43.22	60.61	86.43	3.12	151.70
			71.30	28.08	43.22							817.80
												1103.50
	40304.00	Washing throughout (new washer). With frother in wash water				R	S					
						50g/t dowfroth	10g/t dowfroth					
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	551.00	45.20	33.80	10.38	23.42	33.80	10.38	23.42	69.29	46.84	1.15	364.40
8.00	288.00	23.30	11.90	3.23	8.67	45.70	13.61	32.09	70.21	64.18	1.51	194.40
12.00	267.10	20.70	9.30	5.50	3.80	55.00	19.11	35.89	65.25	71.78	2.12	176.80
16.00	202.60	17.10	5.70	3.21	2.49	60.70	22.32	38.38	63.22	76.75	2.48	145.60
			60.70	22.32	38.38							322.40

												881.20
	40304.00	Washing at scavenging (new washer). With frother in wash water				R	S					
						50g/t dowfroth	10g/t dowfroth					
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	304.00	38.70	33.00	8.83	24.17	33.00	8.83	24.17	73.24	48.34	0.98	118.20
8.00	278.80	18.70	13.00	3.27	9.73	46.00	12.10	33.90	73.70	67.81	1.34	184.10
12.00	299.70	14.40	8.70	4.80	3.90	54.70	16.90	37.80	69.11	75.60	1.88	210.00
16.00	222.30	11.60	5.90	3.57	2.33	60.60	20.47	40.13	66.22	80.26	2.27	165.10
			60.60	20.47	40.13							375.10
												677.40
	40308.00	Washing at scavenging. With frother in wash water				R	S					
						60g/t dowfroth	0g/t dowfroth					
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	723.90	53.50	47.80	20.72	27.08	47.80	20.72	27.08	56.66	54.17	2.30	523.30
8.00	310.00	19.70	14.00	4.21	9.79	61.80	24.92	36.88	59.67	73.75	2.77	214.30
12.00	297.80	15.70	10.00	7.26	2.74	71.80	32.19	39.61	55.17	79.23	3.58	206.80
16.00	246.30	11.80	6.10	4.28	1.82	77.90	36.47	41.43	53.18	82.86	4.05	188.90
			77.90	36.47	41.43							395.70
												1133.30
	40309.00	Washing at roughing and scavenging. With frother in wash				R	S					

		water										
						60g/t dowfroth	0g/t dowfroth					
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	880.40	61.00	55.30	20.13	35.17	55.30	20.13	35.17	63.60	70.35	2.24	672.30
8.00	334.70	17.30	11.60	3.73	7.87	66.90	23.86	43.04	64.34	86.09	2.65	241.40
12.00	234.70	11.80	6.10	3.07	3.03	73.00	26.93	46.07	63.11	92.14	2.99	147.60
16.00	256.00	11.90	6.20	3.21	2.99	79.20	30.14	49.06	61.95	98.12	3.35	198.50
			79.20	30.14	49.06							1259.80
	40323.00	No washing				R	S					
						50g/t dowfroth	10g/t dowfroth					
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	597.00	43.70	38.00	13.78	24.22	38.00	13.78	24.22	63.74	48.44	1.53	406.20
8.00	282.80	18.65	12.95	4.10	8.85	50.95	17.88	33.07	64.91	66.14	1.99	188.15
12.00	283.00	15.60	9.90	5.16	4.74	60.85	23.04	37.81	62.13	75.62	2.56	192.10
16.00	257.00	13.50	7.80	4.02	3.78	68.65	27.06	41.59	60.58	83.18	3.01	197.90
			68.65	27.06	41.59							
	40323.00	Washing at scavenging (Salt in wash water)				R	S					
						50g/t dowfroth	10g/t dowfroth					
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	526.20	33.70	28.00	9.51	18.49	28.00	9.51	18.49	66.05	36.99	1.06	345.40
8.00	283.70	18.00	12.30	3.70	8.60	40.30	13.21	27.09	67.23	54.18	1.47	189.70
12.00	344.60	19.60	13.90	8.88	5.02	54.20	22.09	32.11	59.25	64.23	2.45	249.70
16.00	325.00	15.50	9.80	4.91	4.89	64.00	26.99	37.01	57.82	74.01	3.00	263.90

			64.00	26.99	37.01							513.60
												1048.70
	40325.00	No washing				R	S					
						50g/t dowfroth	10g/t dowfroth					
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	496.80	27.70	22.00	9.17	12.83	22.00	9.17	12.83	58.32	25.66	1.02	322.00
8.00	279.30	16.40	10.70	3.83	6.87	32.70	13.00	19.70	60.24	39.40	1.44	186.90
12.00	255.10	13.10	7.40	4.07	3.33	40.10	17.07	23.03	57.42	46.05	1.90	166.70
16.00	222.40	12.00	6.30	3.02	3.28	46.40	20.09	26.31	56.70	52.62	2.23	164.80
			46.40	20.09	26.31							840.40
	40336.00	Washing in scavenger				R	S					
						50g/t dowfroth	10g/t dowfroth					
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	562.50	37.20	31.50	10.62	20.88	31.50	10.62	20.88	66.29	41.76	1.18	378.20
8.00	277.30	17.40	11.70	3.25	8.45	43.20	13.87	29.33	67.90	58.66	1.54	183.90
12.00	478.70	25.80	20.10	14.36	5.74	63.30	28.23	35.07	55.40	70.13	3.14	377.60
16.00	302.60	15.20	9.50	6.07	3.43	72.80	34.31	38.49	52.87	76.98	3.81	241.80
			72.80	34.31	38.49							1181.50
	40338.00	Washing in scavenger				R	S					
						50g/t dowfroth	10g/t dowfroth					
		repeat										
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	509.90	43.10	37.40	9.81	27.59	37.40	9.81	27.59	73.76	55.17	1.09	319.70
8.00	310.30	20.40	14.70	4.18	10.52	52.10	13.99	38.11	73.14	76.21	1.55	213.90
12.00	250.00	14.50	8.80	4.69	4.11	60.90	18.68	42.22	69.33	84.44	2.08	160.20

16.00	270.00	11.90	6.20	2.68	3.52	67.10	21.36	45.74	68.16	91.47	2.37	212.50
			67.10	21.36	45.74							906.30
	40339.00	Washing in scavenger				R	S					
		repeat				50g/t dowfroth	10g/t dowfroth					
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	605.90	41.80	36.10	11.62	24.48	36.10	11.62	24.48	67.81	48.96	1.29	417.00
8.00	298.50	17.70	12.00	3.44	8.56	48.10	15.06	33.04	68.70	66.09	1.67	204.80
12.00	256.10	14.80	9.10	5.94	3.16	57.20	20.99	36.21	63.30	72.41	2.33	166.00
16.00	273.40	13.90	8.20	4.63	3.57	65.40	25.62	39.78	60.83	79.56	2.85	213.90
			65.40	25.62	39.78							1001.70
	40339.00	Washing in rougher				R	S					
						50g/t dowfroth	10g/t dowfroth					
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	651.90	30.90	25.20	6.62	18.58	25.20	6.62	18.58	73.73	37.16	0.74	473.90
8.00	440.50	19.20	13.50	3.68	9.82	38.70	10.30	28.40	73.38	56.80	1.14	345.30
12.00	280.10	14.30	8.60	4.06	4.54	47.30	14.37	32.93	69.63	65.87	1.60	190.50
16.00	228.00	12.20	6.50	2.35	4.15	53.80	16.72	37.08	68.93	74.17	1.86	170.20
			53.80	16.72	37.08							1179.90
	40343.00	No washing				R	S					
						50g/t dowfroth	10g/t dowfroth					
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	562.90	45.50	39.80	11.77	28.03	39.80	11.77	28.03	70.44	56.07	1.31	370.30
8.00	288.00	19.00	13.30	3.52	9.78	53.10	15.29	37.81	71.21	75.62	1.70	193.00

12.00	310.50	20.00	14.30	9.35	4.95	67.40	24.64	42.76	63.44	85.52	2.74	215.20
16.00	243.60	16.10	10.40	6.62	3.78	77.80	31.26	46.54	59.82	93.08	3.47	181.90
			77.80	31.26	46.54							960.40
	40344.00	Washing at scavenging				R	S					
						50g/t dowfroth	10g/t dowfroth					
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	547.40	41.00	37.00	9.94	27.06	37.00	9.94	27.06	73.15	54.13	1.10	357.60
8.00	291.50	16.70	12.70	3.40	9.30	49.70	13.34	36.36	73.16	72.72	1.48	197.10
12.00	351.70	12.50	8.50	4.51	3.99	58.20	17.85	40.35	69.34	80.71	1.98	262.20
16.00	312.90	12.40	6.65	3.55	3.10	64.85	21.40	43.45	67.00	86.90	2.38	254.95
			64.85	21.40	43.45							1071.85
	40344.00	Washing in rougher				R	S					
						50g/t dowfroth	10g/t dowfroth					
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	747.30	34.80	29.05	8.41	20.64	29.05	8.41	20.64	71.06	41.29	0.93	565.45
8.00	490.50	19.20	13.45	4.43	9.02	42.50	12.84	29.66	69.79	59.32	1.43	395.35
12.00	293.90	15.90	10.15	4.25	5.90	52.65	17.09	35.56	67.54	71.12	1.90	202.75
16.00	245.20	13.90	8.15	3.54	4.61	60.80	20.63	40.17	66.07	80.34	2.29	185.75
			60.80	20.63	40.17							1349.30
	40351.00	Washing in scavenger with positive bias				R	S					
						50g/t dowfroth	10g/t dowfroth					
										Recovery		mass

Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	480.40	31.50	25.80	5.47	20.33	25.80	5.47	20.33	78.78	40.65	0.61	301.80
8.00	288.20	17.40	11.70	2.39	9.31	37.50	7.86	29.64	79.04	59.28	0.87	194.80
12.00	352.80	14.20	8.50	3.64	4.86	46.00	11.50	34.50	74.99	68.99	1.28	263.30
16.00	315.60	13.10	7.40	3.30	4.10	53.40	14.81	38.59	72.27	77.19	1.65	256.90
			53.40	14.81	38.59							1016.80
	40352.00	Washing in scavenger extra frother in ww				R	S					
						50g/t dowfroth	10g/t dowfroth					
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	462.70	34.60	28.90	4.58	24.32	28.90	4.58	24.32	84.14	48.63	0.51	281.00
8.00	306.30	18.00	12.30	2.57	9.73	41.20	7.15	34.05	82.64	68.09	0.79	212.30
12.00	416.70	19.50	13.80	8.95	4.85	55.00	16.11	38.89	70.72	77.79	1.79	321.90
16.00	334.80	14.00	8.30	4.42	3.88	63.30	20.53	42.77	67.57	85.54	2.28	275.20
			63.30	20.53	42.77							1090.40
	40355.00	Washing in scavenger extra frother in ww, no addn in sc				R	S					
						50g/t dowfroth	0g/t dowfroth					
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	574.60	38.80	33.10	8.41	24.69	33.10	8.41	24.69	74.59	49.38	0.93	388.70
8.00	297.30	17.60	11.90	2.40	9.50	45.00	10.81	34.19	75.98	68.38	1.20	203.70
12.00	337.40	19.60	13.90	10.23	3.67	58.90	21.04	37.86	64.27	75.71	2.34	242.50
16.00	306.10	13.10	7.40	4.06	3.34	66.30	25.11	41.19	62.13	82.38	2.79	247.40
			66.30	25.11	41.19							1082.30

	40360.00	No washing ~0 bias				R	S					
						50g/t dowfroth	0g/t dowfroth					
										Recovery		mass
Time	Wet Mass	Dry Mass	Mass recovered	Mass Limestone	Mass talc	Cumulative tot	Cumulative lime	cumulative talc	Grade %	Talc	Limestone	water
4.00	485.90	34.30	28.60	4.27	24.33	28.60	4.27	24.33	85.06	48.65	0.47	304.50
8.00	305.50	18.50	12.80	2.20	10.60	41.40	6.47	34.93	84.36	69.85	0.72	211.00
12.00	291.50	14.30	8.60	2.94	5.66	50.00	9.42	40.58	81.17	81.17	1.05	201.90
16.00	226.20	11.90	6.20	2.54	3.66	56.20	11.95	44.25	78.73	88.50	1.33	168.70
			56.20	11.95	44.25							886.10

Table 15: Three component system results

No washing																		
Dowfroth	50.00	pH	~8-9															
Guar	0.00																	
SIBX	15.00																	
									Cumul ative							Recove ry	mass	cumula tive
Time	Mass recover ed	Percent age chalco	Mass Limest one	Mass talc	Mass chalco	Total	Limest one	Talc	Chalco pyrite	Grade %		chalco	talc	Limest one	water		recover y	
1.50	41.60	15.93	11.10	23.8 8	6.63	41.60	11.10	23.88	6.63	15.93	4.16	13.25	23.88	1.23	91.60	91.60	2.18	250.00
4.00	33.80	14.19	7.04	21.9 7	4.79	75.40	18.13	45.84	11.42	15.15	7.54	22.84	45.84	2.01	133.20	224.80	5.35	250.00
7.50	20.10	7.30	4.88	13.7 6	1.47	95.50	23.01	59.60	12.89	13.50	9.55	25.78	59.60	2.56	194.70	419.50	9.99	280.00
No washing																		
Dowfroth	50.00	pH	~8-9															
Guar	50.00																	
SIBX	15.00																	
									Cumul ative							Recove ry	mass	cumula tive
Time	Wet	Dry	Mass	Mass	Percent	Mass	Mass	Mass	Total	Limest	Talc	Chalco	Grade		chalco	talc	Limest	water

	Mass	Mass	of fp	reco vere d	age chalco	Lime stone	talc	chalco		one		pyrite	%				one		
1.50	279.40	46.00	5.70	40.3 0	20.20	13.10	19.06	8.14	40.30	13.10	19.06	8.14	20.20	4.03	16.28	19.06	1.46	86.30	86.30
4.00	231.70	35.20	5.70	29.5 0	17.01	7.67	16.82	5.02	69.80	20.77	35.88	13.16	18.85	6.98	26.31	35.88	2.31	120.50	206.80
7.50	266.60	22.10	5.70	16.4 0	7.11	4.36	10.88	1.17	86.20	25.13	46.75	14.32	16.61	8.62	28.64	46.75	2.79	169.20	376.00
No washing																			
Dowfroth	50.00	pH		~8-9															
Guar	100.00																		
SIBX	15.00																		
									Cumul ative							Recove ry		mass	cumula tive
Time	Wet Mass	Dry Mass	Mass of fp	Mass reco vere d	Percent age chalco	Mass Lime stone	Mass talc	Mass chalco	Total	Limest one	Talc	Chalco pyrite	Grade %		chalco	talc	Limest one	water	
1.50	294.40	40.40	5.70	34.7 0	21.61	11.58	15.62	7.50	34.70	11.58	15.62	7.50	21.61	3.47	15.00	15.62	1.29	106.90	106.90
4.00	202.30	24.30	5.70	18.6 0	15.62	5.68	10.02	2.90	53.30	17.26	25.64	10.40	19.52	5.33	20.81	25.64	1.92	102.00	208.90
7.50	256.40	19.40	5.70	13.7 0	11.96	4.98	7.08	1.64	67.00	22.24	32.72	12.04	17.97	6.70	24.08	32.72	2.47	161.70	370.60
No washing																			
Dowfroth	50.00	pH		~8-9															
Guar	150.00																		
SIBX	15.00																		
									Cumul ative							Recove ry		mass	cumula tive
Time	Wet Mass	Dry Mass	Mass of fp	Mass reco vere d	Percent age chalco	Mass Lime stone	Mass talc	Mass chalco	Total	Limest one	Talc	Chalco pyrite	Grade %		chalco	talc	Limest one	water	
1.50	342.30	46.60	5.70	40.9 0	24.02	15.50	15.57	9.83	40.90	15.50	15.57	9.83	24.02	4.09	19.65	15.57	1.72	148.60	148.60
4.00	158.10	13.20	5.70	7.50 11.3 0	15.95	3.13	3.17	1.20	48.40	18.63	18.74	11.02	22.77	4.84	22.04	18.74	2.07	68.90	217.50
5.50	291.90	17.00	5.70		9.54	5.30	4.92	1.08	59.70	23.93	23.67	12.10	20.27	5.97	24.20	23.67	2.66	199.60	417.10
No washing																			

REPEAT																		
Dowfroth	50.00	pH		~8-9														
Guar	150.00																	
SIBX	15.00								Cumul ative							Recove ry	mass	cumula tive
Time	Wet Mass	Dry Mass	Mass of fp	Mass reco vere d	Percent age chalco	Mass Lime stone	Mass talc	Mass chalco	Total	Limest one	Talc	Chalco pyrite	Grade %		chalco	talc	Limest one	water
1.50	282.60	39.70	5.70	34.0 0	22.15	11.00	15.47	7.53	34.00	11.00	15.47	7.53	22.15	3.40	15.06	15.47	1.22	95.80
2.50	147.20	13.80	5.70	8.10	12.25	2.31	4.79	0.99	42.10	13.31	20.27	8.52	20.24	4.21	17.05	20.27	1.48	57.40
6.00	310.20	18.50	5.70	12.8 0	7.97	3.38	8.40	1.02	54.90	16.69	28.67	9.54	17.38	5.49	19.09	28.67	1.85	216.40
No washing																		
Dowfroth	50.00	pH		~8-9														
Guar	150.00																	
SIBX	15.00								Cumul ative							Recove ry	mass	cumula tive
Time	Wet Mass	Dry Mass	Mass of fp	Mass reco vere d	Percent age chalco	Mass Lime stone	Mass talc	Mass chalco	Total	Limest one	Talc	Chalco pyrite	Grade %		chalco	talc	Limest one	water
1.50	325.40	54.20	5.70	48.5 0	23.27	16.32	20.90	11.29	48.50	16.32	20.90	11.29	23.27	4.85	22.57	20.90	1.81	124.10
4.00	214.60	23.60	5.70	17.9 0	18.29	6.04	8.59	3.27	66.40	22.35	29.49	14.56	21.93	6.64	29.12	29.49	2.48	115.00
6.50	210.10	14.50	5.70	8.80	12.62	3.81	3.88	1.11	75.20	26.17	33.36	15.67	20.84	7.52	31.34	33.36	2.91	120.30
No washing																		
Dowfroth	50.00	pH		~8-9														
Guar	50.00																	
SIBX	10.00																	
									Cumul ative							Recove ry	mass	cumula tive
Time	Wet Mass	Dry Mass	Mass of fp	Mass reco vere d	Percent age chalco	Mass Lime stone	Mass talc	Mass chalco	Total	Limest one	Talc	Chalco pyrite	Grade %		chalco	talc	Limest one	water
1.50	204.00	19.70	6.10	13.6 0	34.42	0.00	0.00	3.44	13.60	0.00	0.00	3.44	25.31	1.36	34.42	0.00	0.00	37.60

4.00	127.00	13.10	6.00	7.10	17.59	0.00	0.00	1.76	20.70	0.00	0.00	5.20	25.12	2.07	52.01	0.00	0.00	38.20	75.80
6.00	149.80	12.30	6.00	6.30	8.02	0.00	0.00	0.80	27.00	0.00	0.00	6.00	22.23	2.70	60.03	0.00	0.00	62.50	138.30
No washing																			
Dowfroth	50.00	pH		~8-9															
Guar	50.00																		
SIBX	10.00																		
									Cumulative							Recovery		mass	cumulative
Time	Wet Mass	Dry Mass	Mass of fp	Mass recovered	Percent age chalco	Mass Lime stone	Mass talc	Mass chalco	Total	Limestone	Talc	Chalco pyrite	Grade %		chalco	talc	Limestone	water	
1.00	222.80	19.90	6.10	13.80	35.93	0.00	0.00	3.59	13.80	0.00	0.00	3.59	26.04	1.38	35.93	0.00	0.00	56.20	56.20
3.00	126.90	12.60	6.10	6.50	40.00	0.00	0.00	4.00	20.30	0.00	0.00	7.59	37.40	2.03	75.93	0.00	0.00	38.70	94.90
6.00	140.30	11.40	6.10	5.30	7.26	0.00	0.00	0.73	25.60	0.00	0.00	8.32	32.50	2.56	83.19	0.00	0.00	54.00	148.90
Washing																			
Dowfroth	50.00	pH		~8-9															
Guar	50.00																		
SIBX	10.00																		
									Cumulative							Recovery		mass	cumulative
Time	Wet Mass	Dry Mass	Mass of fp	Mass recovered	Percent age chalco	Mass Lime stone	Mass talc	Mass chalco	Total	Limestone	Talc	Chalco pyrite	Grade %		chalco	talc	Limestone	water	
1.00	194.20	17.20	6.10	11.10	23.00	0.00	0.00	2.30	11.10	0.00	0.00	2.30	20.72	1.11	23.00	0.00	0.00	30.30	30.30
3.00	141.80	14.10	6.10	8.00	33.84	0.00	0.00	3.38	19.10	0.00	0.00	5.68	29.76	1.91	56.84	0.00	0.00	52.10	82.40
6.00	177.00	13.50	6.10	7.40	12.80	0.00	0.00	1.28	26.50	0.00	0.00	6.96	26.28	2.65	69.64	0.00	0.00	88.60	171.00
Washing																			
Dowfroth	50.00	pH		~8-9															
Guar	50.00																		
SIBX	10.00																		
									Cumulative							Recovery		mass	cumulative
Time	Wet Mass	Dry Mass	Mass of fp	Mass recovered	Percent age chalco	Mass Lime stone	Mass talc	Mass chalco	Total	Limestone	Talc	Chalco pyrite	Grade %		chalco	talc	Limestone	water	

1.00	200.10	16.80	6.10	10.70	16.69	0.00	0.00	1.67	10.70	0.00	0.00	1.67	15.60	1.07	16.69	0.00	0.00	36.60	36.60
3.00	145.60	13.50	6.10	7.40	29.01	0.00	0.00	2.90	18.10	0.00	0.00	4.57	25.25	1.81	45.70	0.00	0.00	56.50	93.10
6.00	184.00	14.00	6.10	7.90	5.46	0.00	0.00	0.55	26.00	0.00	0.00	5.12	19.68	2.60	51.16	0.00	0.00	95.10	188.20
Washing																			
Dowfroth	50.00	pH		~8-9															
Guar	50.00																		
SIBX	10.00																		
									Cumul ative							Recover y		mass	cumula tive
Time	Wet Mass	Dry Mass	Mass of fp	Mass reco vere d	Percent age chalco	Mass Lime stone	Mass talc	Mass chalco	Total	Limest one	Talc	Chalco pyrite	Grade %		chalco	talc	Limest one	water	
2.00	260.90	47.50	6.10	41.40	50.72	0.00	0.00	5.07	41.40	0.00	0.00	5.07	12.25	4.14	50.72	0.00	0.00	66.70	66.70
3.50	143.90	18.40	6.10	12.30	30.14	0.00	0.00	3.01	53.70	0.00	0.00	8.09	15.06	5.37	80.86	0.00	0.00	49.90	116.60
6.00	152.60	18.30	6.10	12.20	19.23	0.00	0.00	1.92	65.90	0.00	0.00	10.01	15.19	6.59	100.09	0.00	0.00	59.40	176.00
Washing																			
Dowfroth	50.00	pH		~8-9															
Guar	50.00																		
SIBX	10.00																		
									Cumul ative							Recover y		mass	cumula tive
Time	Wet Mass	Dry Mass	Mass of fp	Mass reco vere d	Percent age chalco	Mass Lime stone	Mass talc	Mass chalco	Total	Limest one	Talc	Chalco pyrite	Grade %		chalco	talc	Limest one	water	
2.00	372.40	61.30	6.10	55.20	58.32	0.00	0.00	5.83	55.20	0.00	0.00	5.83	10.57	5.52	58.32	0.00	0.00	164.40	164.40
4.00	183.80	15.30	6.10	9.20	31.98	0.00	0.00	3.20	64.40	0.00	0.00	9.03	14.02	6.44	90.30	0.00	0.00	92.90	257.30
6.00	195.80	12.40	6.10	6.30	9.00	0.00	0.00	0.90	70.70	0.00	0.00	9.93	14.05	7.07	99.30	0.00	0.00	108.50	365.80
Washing																			
Dowfroth	50.00	pH		~8-9															
Guar	50.00																		
SIBX	10.00																		
									Cumul ative							Recover y		mass	cumula tive
Time	Wet Mass	Dry Mass	Mass of fp	Mass reco	Percent age	Mass Lime	Mass talc	Mass chalco	Total	Limest one	Talc	Chalco pyrite	Grade %		chalco	talc	Limest one	water	

				vered	chalco	stone													
2.00	370.90	59.90	6.10	53.80	65.00	0.00	0.00	6.50	53.80	0.00	0.00	6.50	12.08	5.38	65.00	0.00	0.00	164.30	164.30
4.00	199.80	17.70	6.10	11.60	20.00	0.00	0.00	2.00	65.40	0.00	0.00	8.50	13.00	6.54	85.00	0.00	0.00	106.50	270.80
6.00	221.20	13.70	6.10	7.60	6.00	0.00	0.00	0.60	73.00	0.00	0.00	9.10	12.47	7.30	91.00	0.00	0.00	132.60	403.40
no Washing																			
Dowfroth	50.00	pH		~8-9															
Guar	100.00																		
SIBX	10.00																		
									Cumulative							Recovery		mass	cumulative
Time	Wet Mass	Dry Mass	Mass of fp	Mass recovered	Percent age chalco	Mass Lime stone	Mass talc	Mass chalco	Total	Limestone	Talc	Chalco pyrite	Grade %		chalco	talc	Limestone	water	
2.00	379.50	58.30	6.10	52.20	51.43	0.00	0.00	5.14	52.20	0.00	0.00	5.14	9.85	5.22	51.43	0.00	0.00	174.50	174.50
4.00	177.20	15.30	6.10	9.20	25.75	0.00	0.00	2.58	61.40	0.00	0.00	7.72	12.57	6.14	77.18	0.00	0.00	86.30	260.80
6.00	172.10	12.50	6.10	6.40	21.98	0.00	0.00	2.20	67.80	0.00	0.00	9.92	14.63	6.78	99.16	0.00	0.00	84.70	345.50
washing																			
Dowfroth	50.00	pH		~8-9															
Guar	100.00																		
SIBX	10.00																		
									Cumulative							Recovery		mass	cumulative
Time	Wet Mass	Dry Mass	Mass of fp	Mass recovered	Percent age chalco	Mass Lime stone	Mass talc	Mass chalco	Total	Limestone	Talc	Chalco pyrite	Grade %		chalco	talc	Limestone	water	
2.00	400.00	49.70	6.10	43.60	53.75	0.00	0.00	5.38	43.60	0.00	0.00	5.38	12.33	4.36	53.75	0.00	0.00	203.60	203.60
4.00	231.80	17.30	6.10	11.20	34.96	0.00	0.00	3.50	54.80	0.00	0.00	8.87	16.19	5.48	88.71	0.00	0.00	138.90	342.50
6.00	201.00	12.40	6.10	6.30	12.31	0.00	0.00	1.23	61.10	0.00	0.00	10.10	16.53	6.11	101.02	0.00	0.00	113.70	456.20
washing																			
Dowfroth	50.00	pH		~8-9															
Guar	100.00																		
SIBX	10.00																		
									Cumul							Recovery		mass	cumulative

									ative							ry			tive
Time	Wet Mass	Dry Mass	Mass of fp	Mass recovered	Percent age chalco	Mass Lime stone	Mass talc	Mass chalco	Total	Limest one	Talc	Chalco pyrite	Grade %		chalco	talc	Limest one	water	
2.50	398.90	54.70	6.10	48.60	49.95	0.00	0.00	5.00	48.60	0.00	0.00	5.00	10.28	4.86	49.95	0.00	0.00	197.50	197.50
4.00	159.30	16.20	6.10	10.10	25.97	0.00	0.00	2.60	58.70	0.00	0.00	7.59	12.93	5.87	75.92	0.00	0.00	67.50	265.00
6.00	311.20	12.60	6.10	6.50	23.68	0.00	0.00	2.37	65.20	0.00	0.00	9.96	15.28	6.52	99.60	0.00	0.00	223.70	488.70

Table 16: Industrial flotation test results

Test 1 - 6						
Cleaner						
Samples taken at 3 minute intervals						
Test 1						
No washing						
Sample Number	Mass of wet ore	Dry mass	Mass of water	Mass of ore	Mass flow of ore (g/min)	PGM / g/t
1	829.4	320.1	531.2	298.2	276.47	36.128
2	910.3	352.8	578.4	331.9	303.43	34.093
3	650.9	258.2	414.6	236.3	216.97	34.813
Test 2						
No washing repeat						
Sample Number	Mass of wet ore	Dry mass	Mass of water	Mass of ore	Mass flow of ore (g/min)	PGM / g/t
4	680.1	266.1	435.5	244.6	226.70	36.978
5	694.0	280.5	435.0	259.0	231.33	35.171
6	654.7	262.9	413.8	240.9	218.23	36.265

Test 3						
Washing at position furthest from lip						
Sample Number	Mass of wet ore	Dry mass	Mass of water	Mass of ore	Mass flow of ore (g/min)	PGM / g/t
7	496.2	182.0	335.3	160.9	165.40	46.862
8	465.1	171.0	316.0	149.1	155.03	49.95
9	538.3	192.0	367.8	170.5	179.43	51.505
Test 4						
Washing at position furthest from lip repeat						
Sample Number	Mass of wet ore	Dry mass	Mass of water	Mass of ore	Mass flow of ore (g/min)	PGM / g/t
10	462.7	154.6	329.6	133.1	154.23	50.635
11	443.9	151.1	314.5	129.4	147.97	47.201
12	498.0	177.8	341.8	156.2	166.00	51.463
Test 5						
Sample Number	Mass or wet ore	Dry mass	Mass of water	Mass of ore	Mass flow of ore (g/min)	PGM / g/t
13	526.9	169.4	379.0	147.9	175.63	44.65
14	440.2	156.2	306.1	134.1	146.73	41.29
15	534.3	187.0	368.4	165.9	178.10	38.72
Test 6						
Washing at the pulp froth interface						
Sample Number	Mass of wet ore	Dry mass	Mass of water	Mass of ore	Mass flow of ore (g/min)	PGM / g/t
16	674.9	247.8	448.3	226.6	224.97	40.04
17	585.4	215.8	391.0	194.4	195.13	42.604
18	607.7	227.9	401.2	206.5	202.57	44.309

Test 7 - 11						
Cleaner Scavenger						
Samples taken at 3 minute intervals						
Test 7						
No washing						
Sample Number	Mass of wet ore	Dry mass	Mass of water	Mass of ore	Mass flow of ore (g/min)	PGM / g/t
19	1615.2	594.5	1041.8	573.4	538.40	19.418
20	1520.1	559.5	981.6	538.5	506.70	19.168
21	1642.6	598.0	1066.2	576.4	547.53	18.309
Test 8						
No washing repeat						
Sample Number	Mass of wet ore	Dry mass	Mass of water	Mass of ore	Mass flow of ore (g/min)	PGM / g/t
22	1771.3	647.3	1147.8	623.5	590.43	18.49
23	1100.9	488.3	633.7	467.2	366.97	18.267
24	1578.5	574.7	1027.1	551.4	526.17	18.111
Test 9						
Washing at position furthest from lip						
Sample Number	Mass of wet ore	Dry mass	Mass of water	Mass of ore	Mass flow of ore (g/min)	PGM / g/t
25	1302.3	461.9	864.3	438.0	434.10	19.02
26	1285.9	447.4	861.7	424.2	428.63	18.812
27	1233.1	425.0	829.3	403.8	411.03	20.983
Test 10						
Washing at position furthest from lip repeat						

Sample Number	Mass of wet ore	Dry mass	Mass of water	Mass of ore	Mass flow of ore (g/min)	PGM / g/t
28	1241.4	437.6	827.2	414.2	413.80	20.949
29	1478.9	509.3	990.5	488.4	492.97	22.967
30	1493.8	491.1	1023.6	470.2	497.93	23.951
Test 11						
Washing near lip						
Sample Number	Mass of wet ore	Dry mass	Mass of water	Mass of ore	Mass flow of ore (g/min)	PGM / g/t
31	1192.2	394.3	819.2	373.0	397.40	22.783
32	1079.6	340.9	760.5	319.1	359.87	25.922
33	1100.9	399.6	724.0	376.9	366.97	26.32
Test 12 - 16						
Recleaner						
Samples taken at 3 minute intervals						
Test 12						
Sample Number	Mass of wet ore	Dry mass	Mass of water	Mass of ore	Mass flow of ore (g/min)	PGM / g/t
34	2531.4	1023.6	1529.5	1001.9	843.80	314.59
35	1835.9	738.9	1119.0	716.9	611.97	297.839
36	2021.0	822.7	1220.1	800.9	673.67	299.017
Test 13						
No washing repeat						
Sample Number	Mass of wet ore	Dry mass	Mass of water	Mass of ore	Mass flow of ore (g/min)	PGM / g/t
37	2055.7	834.9	1242.6	813.1	685.23	267.423

38	1822.9	738.0	1105.3	717.6	607.63	272.342
39	1724.8	699.8	1045.5	679.3	574.93	267.555
Test 14						
Washing at position furthest from lip						
Sample Number	Mass of wet ore	Dry mass	Mass of water	Mass of ore	Mass flow of ore (g/min)	PGM / g/t
40	1412.3	561.9	870.6	541.7	470.77	223.676
41	1345.7	543.9	822.5	523.2	448.57	269.699
42	1337.3	544.0	814.8	522.5	445.77	278.667
Test 15						
Washing at position furthest from lip repeat						
Sample Number	Mass of wet ore	Dry mass	Mass of water	Mass of ore	Mass flow of ore (g/min)	PGM / g/t
43	1405.4	568.5	858.5	546.9	468.47	382.621
44	1306.2	478.5	848.9	457.3	435.40	359.668
45	1195.0	536.0	680.1	514.9	398.33	406.612
Test 16						
Washing near lip						
Sample Number	Mass of wet ore	Dry mass	Mass of water	Mass of ore	Mass flow of ore (g/min)	PGM / g/t
46	1547.1	634.7	933.6	613.5	515.70	395.076
47	1613.4	648.6	985.9	627.5	537.80	382.135
48	1463.3	595.5	888.5	574.8	487.77	378.573