Investigating Entrainment Levels in Lumwana and Kansanshi Ores using the Froth Stability and Water Recovery Methods

S. Sondashi, L. K. Witika and J. H. Masinja

The University of Zambia, Lusaka, Zambia

Corresponding author: bchemss@zamnet.zm

Investigations of flotation characteristics of Lumwana and Kansanshi ores using formulated frothers were carried out. Of the six frothers tested, two came from the alcohol family, two from the glycol family and last two were formulated products. The initial work involved determining the optimum mesh of grind and frother dosage for Lumwana and Kansanshi ores. Further work involved carrying out surface tension, bubble size and froth stability measurements. Finally, water recovery tests were conducted at Lumwana and Kansanshi mine sites.

For froth stability tests, six frothers were tested on a two-phase (water–air) system using the Bikerman column flotation cell, while water recovery tests were conducted using a total of seven frothers, including the standards for each plant. The results of the testwork showed that (i) although a stable froth is essential for optimum recovery of valuable minerals, a higher molecular weight frother, like Dowfroth 250, caused poor selectivity when used on fine ores and (ii) a lower molecular weight frother was suited for Lumwana ore, while a mid to higher molecular weight formulated product was suitable for Kansanshi sulphide ore.

INTRODUCTION

Investigations of flotation characteristics of Lumwana and Kansanshi ores using formulated frothers were carried out. The initial work of this project involved determining the optimum mesh of grind and frother dosage for Lumwana and Kansanshi ores. Further work involved carrying out surface tension, bubble size and froth stability measurements. Finally, water recovery tests were conducted at Lumwana and Kansanshi mine sites.

In order to investigate the gangue entrainment levels in the Lumwana and Kansanshi sulphide ores, two well-known methods (froth stability and water recovery) were used. Firstly, froth stability tests were conducted using six frothers, two from the glycol family (Dowfroth 200 and Dowfroth 250), two from alcohol family (MIBC and pine oil) and other two from the formulated family (Betafroth 20 and Betafroth 245), at the University of Cape Town's Centre for Mineral Research (CMR) laboratories. Froth formation and stability measurements were conducted using the Bikerman column flotation cell.

Water recovery tests were carried on Lumwana and Kansanshi sulphide ores at the respective plant sites. The same six frothers plus the plant standards for each mine were tested on each ore. The frothers used as standards were Oreprep F515 and Aerofroth 68 for Lumwana and Kansanshi ores, respectively.The water recovery tests were conducted using a WEMCO flotation machine and 2.5 L cells, using the respective plant's process water (natural pH) in duplicate. Three concentrate samples were obtained for each float test. The three concentrate samples and tailings were wet- and dry-weighted in order to establish the water recovered to each concentrate before copper analysis was determined. Further grade–recovery curves were plotted for each frother tested.

The results obtained from the test frothers in both tests are discussed in such a way as to draw up some conclusions on the effect of froth stability on gangue recovery (entrainment levels) in the concentrates produced.

BACKGROUND TO FROTH STABILITY AND GANGUE ENTRAINMENT

Froth Stability

Creation of a stable froth is of paramount importance in the flotation process. The creation of a stable froth is promoted by employing a frother during the flotation process. Fine particles or slimes content in the ore help to stabilise the froth. In order to appreciate the froth properties of any frother, it is essential to subject the frother to the froth stability tests. These tests can be carried out using the Bikerman flotation column. By varying frother concentrations and recording the resulting froth height and collapse rate or reaction time, a lot of information on the frothing properties of the frother can be obtained. The information so obtained can then be used to plot graphs of frother concentration against froth height, and froth height against reaction time. However, for one to understand the performance of any frother, the rate of froth collapse needs to be determined. The rate of froth collapse, according to Laughlin et al. (1993) can be modeled using a modified first-order rate equation:

$$\frac{\mathbf{dH}}{\mathbf{d(t-ø)}} = -\mathbf{kH} \qquad [1]$$

where:
H is froth height (cm);
t is the elapsed time from termination of air flow in the column (s);
ø is the induction time (s), and
k is the froth "decay constant" (s^{-1}).

Integrating of the above equation [1] for Ho (initial froth height) to H and ø to t yields:

$$\ln[\frac{H}{H_o}] = -kt \qquad [2]$$

A plot of $\ln[\frac{H}{H_o}]$ vs. (t) may produce a straight line with slope, k, being the froth "decay constant" (rate of froth collapse).

Gangue Entrainment

Recovery of gangue mineral particles, particularly fines, during flotation into the froth layer or concentrate, according to Pratama (2013) depends (i) on the carry-over off gangue minerals into the froth by attachment to air bubbles (true flotation), and (ii) suspension of gangue minerals in the water trapped between the bubbles (entrainment).

Similarly, Kirjavainan and Leapas (1988) stated that recovery of mineral particles into froth product is generally seen to be caused by two different mechanisms. Hydrophobic particles are recovered to the froth phase due to their affinity for air, generally induced by addition of some reagents, while hydrophilic particles are recovered by mechanical transportation or entrainment by water. The particle size dependency of the entrainment of gangue minerals has a strong and disadvantageous effect on the selectivity (or final concentrate grade) in the beneficiation of finer materials.

Frother Characteristics and Applications
Table I illustrates the characteristics of the six frothers tested in this work.

Table I. Frother characteristics. (Source: Crozier, 1992)

Frother	Froth characteristics	Applications/comments/solubility in water
Pine oil	Viscous stable froth	Recovery problems with sulphides/not soluble
MIBC	Fine textured froth	Good for fine ores/insoluble in water/ not soluble
D200	Fine and fragile/brittle froth	Good for platinum/fine ores/soluble in water
D250	Persistent froth	Good for sulphide/copper recoveries/soluble
Bf245	Smaller bubble froth	Selective sulphide flotation/95% soluble in water
Bf20	Larger bubbles froth	Less-selective, cheap cost/not soluble in water

EXPERIMENTAL PROCEDURES

Sample Mineralogical Analysis
The analyses of Lumwana and Kansanshi sulphide ore samples obtained for research testwork were conducted at Alfred H Knight (Zambia) Ltd and the mineralization was confirmed as follows:

- More than 85% of the total copper in Lumwana ore sample was derived from mostly chalcopyrite, with bornite and chalcocite being responsible for lesser amounts.
- The acid-soluble copper was minor, around 13% in the form of malachite and chrysocolla.
- The major gangue constituents were mainly quartz and feldspar (62%) with micas at 34%.
- The bulk of the total copper (~88%) in Kansanshi sulphide ore is acid-insoluble and is drawn mostly from chalcopyrite. Bornite is a minor contributor to the acid-insoluble copper.
- The acid-soluble copper (~11%) is minor and is accounted for by malachite.
- The gangue is composed of mostly quartz and feldspars (77%) and comparatively minor micas (12%) and carbonates (6%). The other constituents are negligible.

Froth Stability Testwork Procedure
Froth formation and stability measurements were conducted at the University of Cape Town using the Bikerman column flotation cell. The measurements were conducted on the two-phase (water–air) system at frother concentrations of 50 ppm, 100 ppm, 150 ppm, 200 ppm, 250 ppm and 300 ppm. The froth height achieved with each dosage was recorded and the time it took for the froth to collapse. Thereafter, plots of dosage against froth height, dosage against collapse/reaction time and froth height against collapse/reaction time were drawn.

Water Recovery Testwork Procedure
In order to compare the frothers, water recovery flotation testwork was conducted on Lumwana and Kansanshi sulphide ores. The flotation work involved testing each frother at optimised flotation conditions of 60 g/t frother dosage and a grind of 65% and 80% passing 150 µm for the Lumwana and Kansanshi ores, respectively.

Ore Preparation
The ore samples were received at 100% passing 6mm sieve size. The ore samples were split, using a Jones riffle sampler, into 1 kg sub-samples. Each 1kg sample was milled at 66% solids pulp by mass.

Flotation Procedure
Milled ore sample was transferred into a 2.5 L WEMCO cell. The cell mechanism was started and the cell filled with tap water to required level. The mechanism was adjusted to 850 rpm and the air pressure maintained at 5 bar. Xanthate (SIBX) was added at 100 g/t. The frother was then added at 60 g/t for both ores and conditioned for 2 minutes. The concentrates were collected after one minute, two

minutes and five minutes, by scraping the froth after every 15 s. The wet and dried products were weighed and recorded. Total copper analysis was by atomic absorption spectrophotometry.

RESULTS AND DISCUSSION

Froth Stability

The results obtained during froth stability testwork are presented in Figure 1. Of the six frothers tested, Dowfroth 250 gave the highest froth heights at all concentrations tested. The highest froth height was 17 cm, achieved when the frother was used at a concentration of 300 ppm. Betafroth 245 was a distance second, achieving a maximum froth height of 5 cm when used at 300 ppm concentration. Betafroth 245 was followed by Betafroth 20 which achieved a maximum froth height of 4 cm at 150 ppm concentration. The remaining frothers (D200, MIBC and pine oil) achieved maximum froth heights of 2.5 cm each at a concentration of 300 ppm.

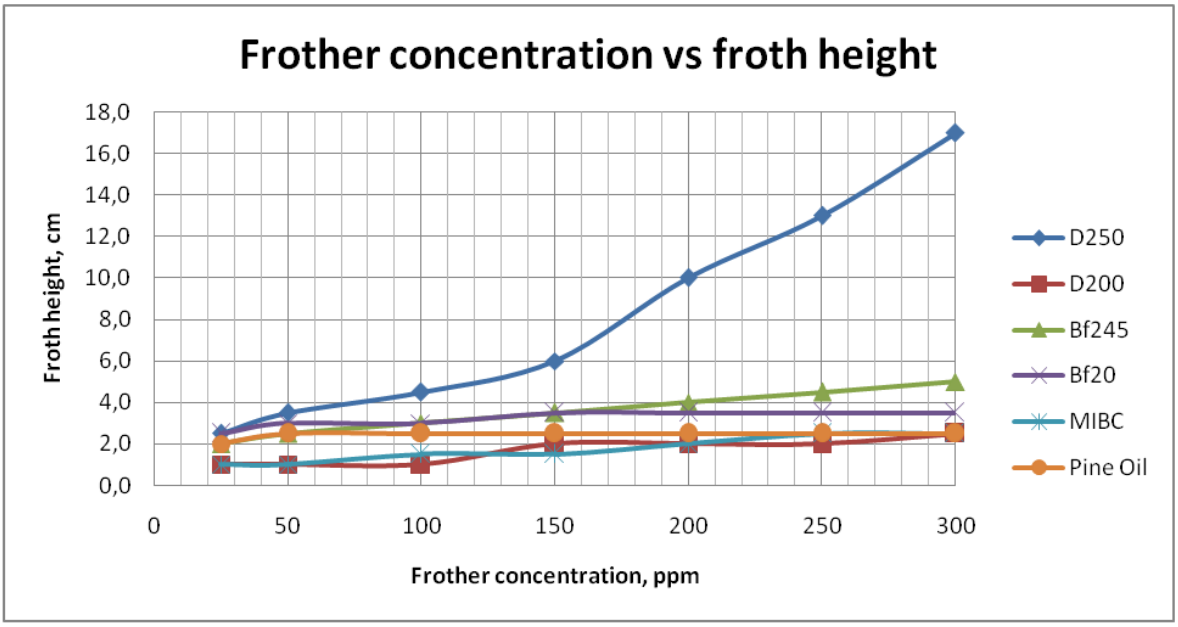

Figure 1.Response of froth height to frother concentration.

Figure 2 shows that when frother concentrations were recorded against the time it took for the froth to collapse (reaction time), Dowfroth 250 gave the highest reaction time, achieving a maximum of 10.5 s for the froth to completely collapse from dosage of 300 ppm. Dowfroth 250 was followed by Betafroth 245, which gave the maximum reaction time of almost 4.5 s at the same concentration. The rest of the frothers (Dowfroth 200, Betafroth 20, MIBC and pine oil) achieved a reaction time of 3 s each.

Similarly, when froth height was plotted against the reaction time (collapse rate) (by best fit of Figure 3 lines), it can be seen that Dowfroth 250, followed by Betafroth 245, achieved the highest reaction times of 6 s and 4.5 s, respectively, from a froth height of 40cm. Betafroth 20 gave the lowest reaction time of 2.5 s.

Water Recovery

The results obtained during water recovery testwork are presented in Figures 4 and 5. Figure 4 shows that on Lumwana ore, a lower molecular weight frother, Dowfroth 200, followed by pine oil recovered the least amount of water. On the other hand, the plant standard frother F515 and a higher molecular weight frother Dowfroth 250 recovered the largest amount of water, when compared with other tested frothers.

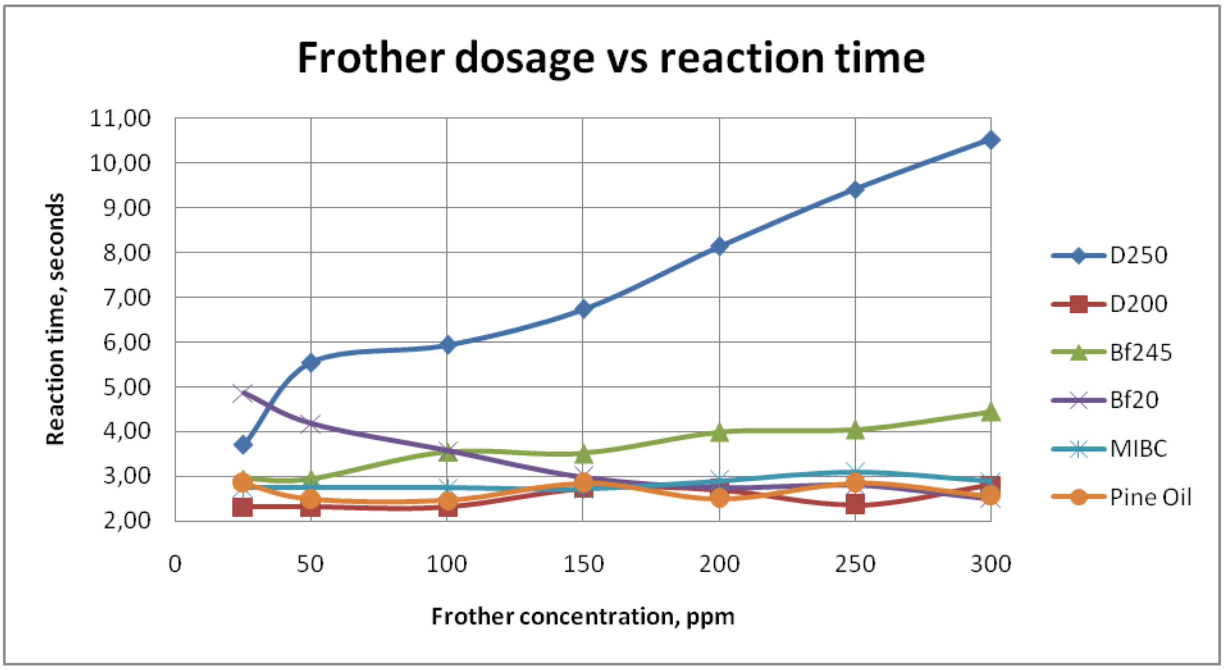

Figure 2.Relationship between frother concentration and collapse rate (reaction time).

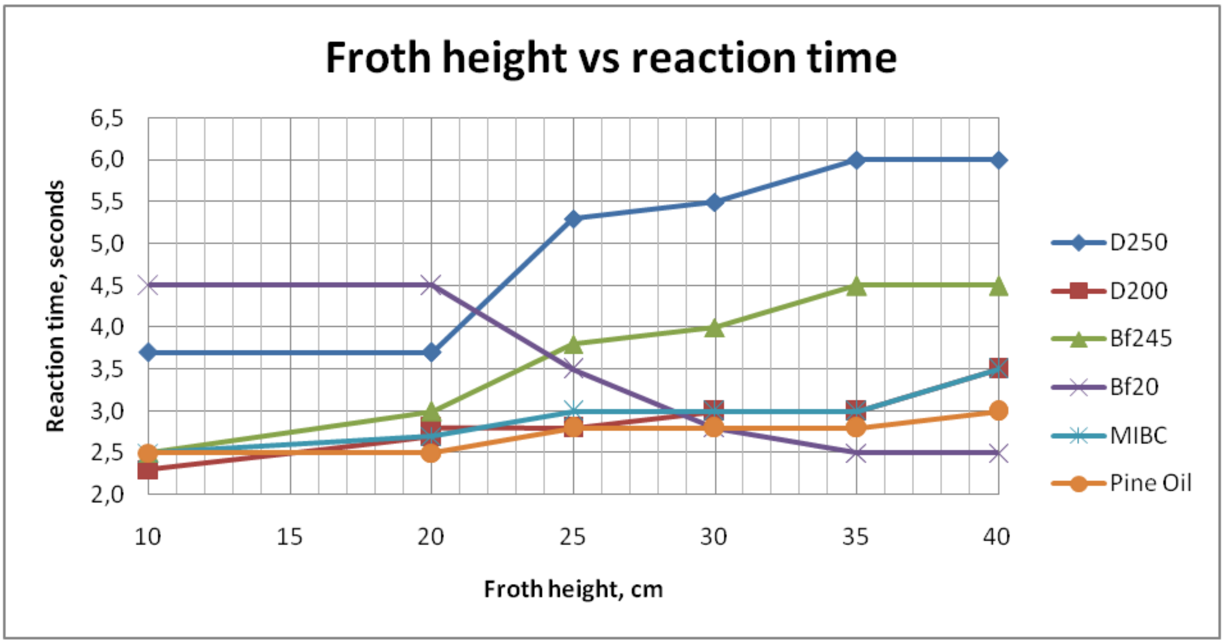

Figure 3. Relationship between froth height and collapse rate (reaction time).

Figure 5 shows that on Kansanshi sulphide ore, an aliphatic alcohol frother, MIBC, followed by a glycol-based formulated frother, Betafroth 245, recovered the least amount of water. The higher molecular weight glycol frother, Dowfroth 250, followed by the plant standard frother, Aerofroth 68, recovered the largest amount of water.

From the water recovery tests, one can deduce that, on Lumwana ore, a lower molecular weight glycol frother Dowfroth 200, performed better, while higher molecular weight glycol frother Dowfroth 250 followed by plant standard frother F515, recovered the largest amounts of water out of all seven frothers tested. However, on Kansanshi sulphide ore, middle to higher molecular weight glycol-based formulated frother Betafroth 245 and an aliphatic alcohol frother MIBC performed better by recovering the least amounts of water and therefore lower entrained gangue. Again, Dowfroth 250 recovered largest amount of water, and therefore more entrained gangue.

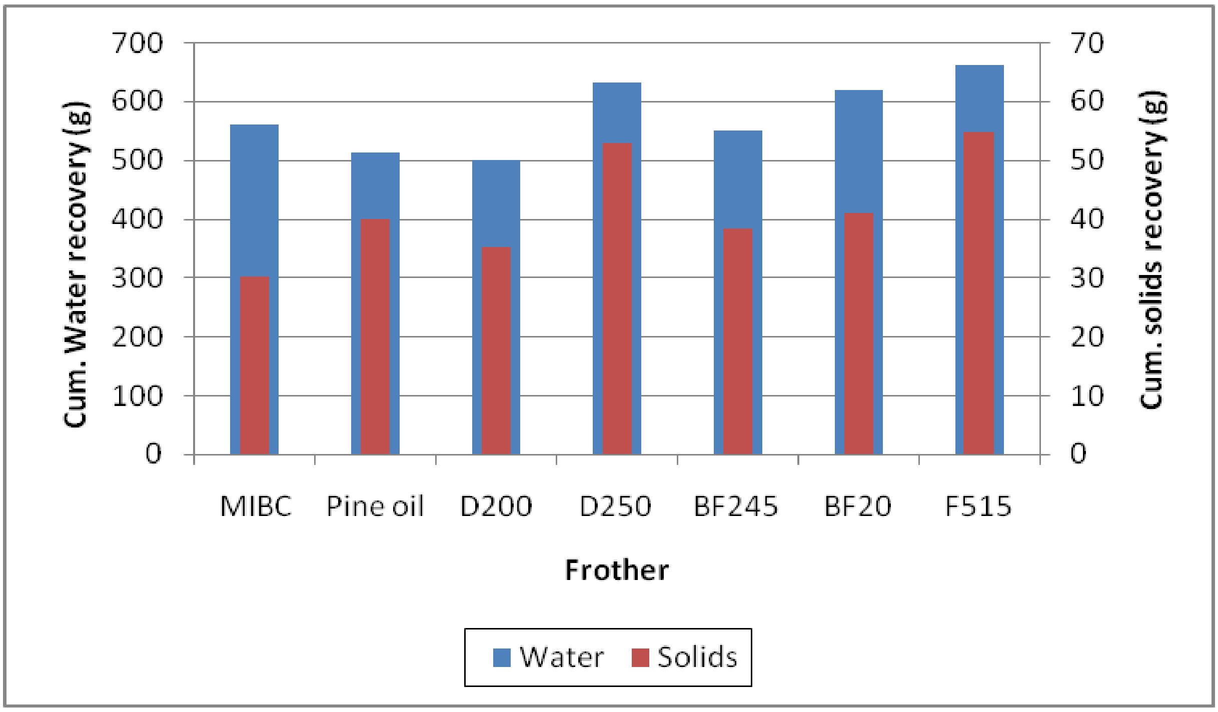

Figure 4. Water recovery testwork results for Lumwana ore.

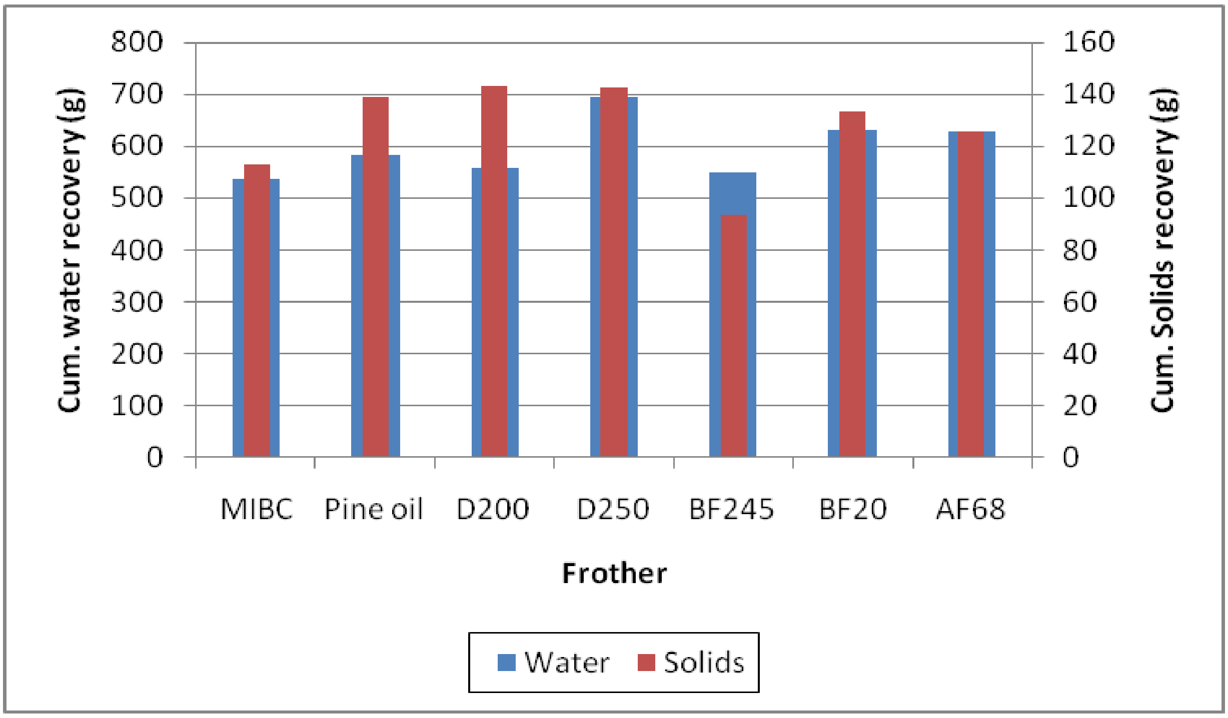

Figure 5. Water recovery testwork results for Kansanshi sulphide ore.

When concentrate grades and copper recovery from water recovery testwork are plotted as shown in Figure 6, the frother that gave the most superior grade–recovery curve by far was the aliphatic alcohol frother, MIBC. Plant standard frother, Oreprep F515, gave the lowest grade–recovery curve, an indication that the frother promoted recovery of significant amounts of gangue due to its higher water recovery properties.

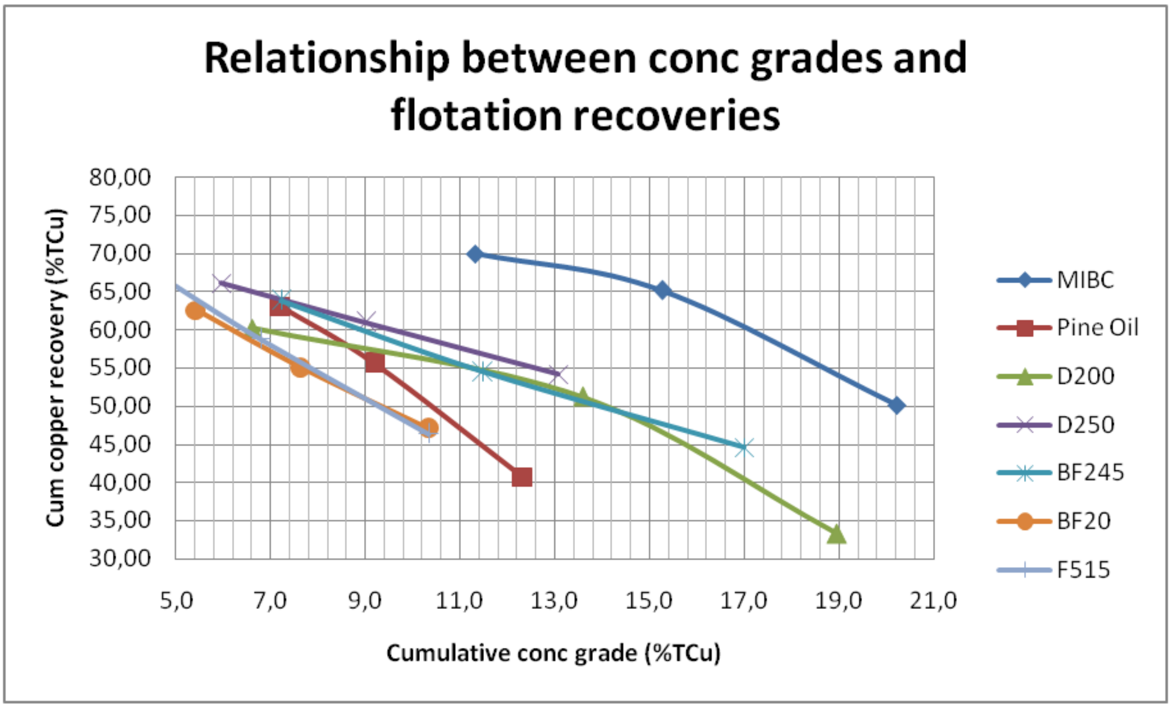

Figure 6. Grade-recovery curves for Lumwana ore using different frother types.

Water recovery tests on Kansanshi sulphide ore showed (Figure 6) that the aliphatic alcohol frother, MIBC, and glycol-based formulated frother, Betafroth 245, gave superior grade–recovery curves. However, the higher molecular weight glycol frother, Dowfroth 250, gave one of the inferior grade–recovery curves. This can be attributed to the fact that frother Dowfroth 250 gave a more stable froth (as shown in Figure 7) and recovered significant amounts of finer clay particles in the concentrate, thus diluting its final concentrate grade.

From the results obtained from froth stability tests, it can be deduced that the high molecular weight glycol frother, Dowfroth 250, formed a highly stable froth compared with all other five frothers tested. But this high stability leads to high water recovery and therefore resulting higher entrained gangue. However, the froth formed by Betafroth 245 was much "drier", as seen in Figures 4 and 5. Hence, frother Betafroth 245 recovered less water compared with Dowfroth 250, and consequently this frother gave higher concentrate grade-copper recovery curves, particularly on Kansanshi ore (Figure 7). Therefore, recovery of valuables and good concentrate grades are strongly dependent on the stability of the froth phase within the flotation system.

Discussion of Froth Stability Water Recovery Test Results

While a frother giving a stable froth is desirable for good valuable mineral recovery, it is possible for the same frother to recover large amounts of water too. This is true for Dowfroth 250, in that apart from giving higher copper recoveries during water recovery tests, it also recovered large amounts of water compared with Betafroth 245, MIBC and Dowfroth 200. On the other hand, for Lumwana ore, though Dowfroth 250 performed better than it did on Kansanshi ore however, an aliphatic alcohol frother MIBC and a lower molecular weight glycol frother Dowfroth 200 out-performed it in terms of recoveries and concentrate grades (Figure 7). This confirms that Lumwana ore has some higher levels of floatable gangue, such as mica, which is mainly rejected by the two lower molecular weight frothers (MIBC and Dowfroth 200). This is consist with Leja (1982), who stated that frothers MIBC and Dowfroth 200 when used in flotation produce fine, fragile froth which is good for rejection of fine gangue.

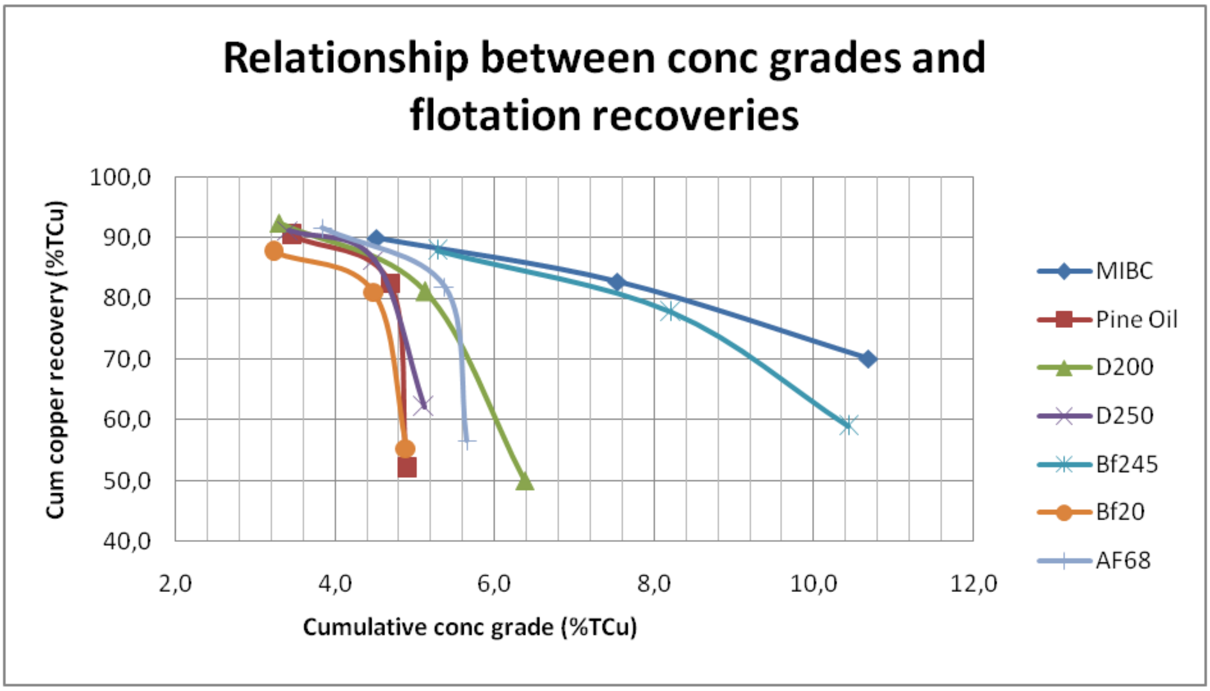

Figure 7. Grade-recovery curves for Kansanshi ore using different frother types.

CONCLUSIONS AND RECOMMENDATIONS

Froth Stability

The higher molecular weight glycol frother Dowfroth 250 was shown to produce a highly stable froth, followed by a mid to higher molecular weight formulated frother Betafroth 245. However, the froth produced by Dowfroth 250 was so stable that it affected froth drainage for both ores.

Water Recovery

On Lumwana ore, a lower molecular weight glycol frother Dowfroth 200 and aliphatic alcohol frother MIBC, recovered the least amounts of water (less entrained gangue) and achieved the highest grade–recovery curves, respectively, compared with the plant standard frother F515 and higher molecular weight frother, Dowfroth 250, that recovered largest amounts of water, resulting in higher levels of entrained gangue in the concentrates.

On Kansanshi ore, an aliphatic alcohol frother, MIB, and a mid to higher molecular weight glycol-based formulated frother, Betafroth 245, recovered the least amounts of water (less entrained gangue) and achieved the highest grade–recovery curves compared with the higher molecular weight glycol frother Dowfroth 250, that recovered largest amount of water, resulting in higher levels of fine gangue in the concentrate.

Recommendations
The lower molecular weight aliphatic alcohol frother, MIBC, is recommended for the Lumwana flotation circuit and the higher molecular weight glycol-based formulated frother, Betafroth 245, is recommended plant trial for Kansanshi flotation circuit.

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REFERENCES

CHEMINOVA A/S(2011).Flotation chemicals. Available from www.danafloat.com

Corin, K.C. and Wiese, J.G. (2013). Investigating froth stability: A comparative study of ionic strength and frother dosage. *Flotation 13*, Minerals Engineering International Conference presentation (unpublished then)., Cape Town

Crozier, R.D. (1992).*Flotation–Theory, Reagents, and Ore Testing*. Oxford, England: Pergamon Press.

Glembotskii, V.A., Klassen, V.I and Plaksin, I.N. (1963).*Flotation*. John Wiley & Sons, Ltd..New York.

Grobler, W.A, Sondashi, S. and Chidley, F. (2005). Recent developments in flotation reagents to improve base metal recovery. *Proceedings Base Metals Conference*, South African Institute of Mining and Metallurgy, Johannesburg. pp185-190

Harris, A., Venkatesan, L. and Greyling, M. (2013). A practical approach to plant-scale flotation optimisation. Journal of Southern African Institute of Mining and metallurgy, Johannesburg.pp 263-272

Jain, S.K. (1987).*Ore Processing*. A.A. Balkema, Rotterdam, Holland.

Kirjavainan, V.M. and Leapas, H.R. (1988).A study of entrainment mechanism in flotation. *Proceedings of the XVI International Mineral Processing Congress*, Stockholm, Sweden.

Laughlin, J.D.M., Quinn, P., Robertson, G. and Agas, G.E (1993). Frother evaluation. *Proceedings International Mineral Processing Congress*, 23-28 May, Sydney, Australia.

Leja, J. (1982).*Surface Chemistry of Froth Flotation*. Plenum Press, New York.

Pratama, P, P (2013) Froth flotation 2. Available from, www.frothflotation2.com