World Academy of Science, Engineering and Technology
International Journal of Chemical and Molecular Engineering
Vol:4, No:9, 2010

An Investigation into the Effect of Water Quality on Flotation Performance

Edison Muzenda

***Abstract*—**A study was carried out to determine the effect of water quality on flotation performance. The experimental test work comprised of batch flotation tests using Denver lab cell for a period of 10 minutes. Nine different test runs were carried out in triplicates to ensure reproducibility using different water types from different thickener overflows, return and sewage effluent water (process water) and portable water. The water sources differed in pH, total dissolved solids, total suspended solids and conductivity. Process water was found to reduce the concentrate recovery and mass pull, while portable water increased the concentrate recovery and mass pull. Portable water reduced the concentrate grade while process water increased the concentrate grade. It is proposed that a combination of process water and portable water supply be used in flotation circuits to balance the different effects that the different water types have on the flotation efficiency.

***Keywords*—**Flotation, mass pull, process water, thickener overflows, water quality.

I. Introduction

THIS Water represents 80 to 85% of the mineral pulp processed in flotation circuits [1]. In many areas water is scarce and its control has become an increasing requirement. This has led to the use of relatively impure primary water supplies and high proportions of recycle from tailings dams, thickener overflow, dewatering and filters products in minerals processing. It is well known that there are now minerals processing operations in which zero water release is required by environmental regulations. Primary water supplies from bore holes containing high levels of salinity including calcium, magnesium and iron salts as potential precipitates are being used in several areas in minerals processing operations. Treated sewage effluent water with relatively high levels of total organic carbon is being used at some sites for make – up water supply. In many cases recycling waters within flotation plants is advantageous as; it lowers the need to receive new waters into the system, it lowers the amount of discharge and it allows retention of some reagents, lowering reagent consumption.

Water as a transport and process medium is essential to most metallurgical processes, as it may have a direct impact on the efficiency of the processes and thus a good understanding on the effects of water on various processes is required. On the majority of occasions water quality is found to have an effect on the process of ore flotation, but precise reasons for these effects are not known. It is speculated that the detergents, organic hydrocarbons, dissolved solids, reagents and dissolved oxygen present in sewage effluent and recycle water affect the natural hydrophilic qualities of the gangue materials present with the ore so that the gangue is activated and floats in the ore concentrate.

The flotation results of various studies have shown that the quality of the process water in general, and recirculating water in particular, can have an adverse effect on the flotation selectivity of complex sulphide minerals This is mainly due to one or more of the following factors; residual xanthates and their oxidation products which absorb selectively on most sulphides, metallic ions such as Cu^{2+}, Pb^{2+} and Fe^{2+}, which cause inadvertent activation, alkaline earth metals which may activate the non sulphide gangue and variation in the slurry pH and pulp potential in both the milling and the flotation circuit.

E. Muzenda is with the Department of Chemical Engineering, Faculty of Engineering and the Built Environment, University of Johannesburg, Doornfontein, Johannesburg 2028, phone: 0027115596817; Fax: 0027115596430; e-mail: emuzenda@ uj.ac.za.

II. Effects of Recycle Water on Flotation

Recycle waters are sourced from tailings dams and classification ponds (long recycle or external recycle waters) [1], and thickener overflows, dewatering and filtration units directly connected to the concentrator (short recycle or internal recycle waters) [1]-[3]. Typical contaminants in tailings are $SO4^{2-}$, Cl^-, F^-, Mg^{2+}, Ca^{2+}, Na^+, K^+, sulphide, thiosalts, base metals, collectors, frothers, activators, depressants, colloidal materials (silicates, clays and iron hydroxides), and natural organic material [4]. In some processes metal ions may be found in tailings water but they will precipitate where lime is added to the tailings dams [5]. For tailings waters time effect is crucial due to the delay in water being returned to the plant [5] As a result of oxidation processes in the pond, tailings return water have low oxygen potentials and low oxygen contents. Higher conductivities in recycle waters are caused by evaporation and this may decrease due to dilution during high rainfall and snow melt seasons. Problems connected to the use of recycled water are related to process chemical residues and various oils which may accumulate in tailings return dams [5]. In internal recycle waters, the flotation reagents have not had enough time to decompose resulting in plant decreased reagent usage. However on the other hand suspended solids levels tend to be high and this has a negative impact on flotation [6]. Optimum recycling of water from metallurgical plant processes occurs when there is maximum removal of water from each product streams and returned to the processing plant [2]. In general ore dissolution and reagent addition cause various elements or compounds to accumulate in solution and this alters the chemistry of the system as discussed in [6].

Recycled waters in general have increased levels of total dissolved solids (TDS) which result in an increase in the specific gravity (SG) of the water which affect slurries [7]. If the SG of the plant is kept constant while that of water is increased it will in lower solids percentage throughput within the plant. With increasing electrolyte concentration due to particle to particle segregation, the slurry viscosity may increase affecting mineral floatability plus classification and pumping [7]. Flotation of minerals from gangue and from each other depends on their different surface properties [8]. These surface properties are affected by solution components such passivation of mineral surfaces which may occur due to ion precipitation. This has huge negative effect on flotation as the surface chemistry of the mineral is changed. This can be overcome by making use of reagents which modify surface properties [4].

Compared to portable water, when water from the process is reused reagent consumption may be reduced by almost 50% [5]. One major drawback with this water is that it can lead to the formation of stable froth. When the froth is stable and has high water content, selectivity tend to be reduced. Flotation in high salinity waters causes little or no mineral dissolution, indicating little surface alteration [9].

III. RELEVANT PREVIOUS STUDIES

An investigation on the effects of synthetic waters on synthetic minerals indicated that the adsorption of calcium into pentlandite and pyrrhotite surfaces increases the minerals hydrophilicity and thus more xanthate is required to induce hydrophobicity of the minerals [10]. The studies of Kirjavainen et al [11] on Enonkoski drill core samples showed that the addition of calcium and thiosulphate ions improved copper and nickel sulphide floatability after grinding in a steel mill as activation due to galvanic interactions occurred. The same study showed that grinding in a ceramic mill with added calcium and thiosulphate ions caused depression. Smart et al. [12] found that substituting soda ash for lime decreases the amount of calcium in the process which increases value recovery as calcium tends to precipitate on the mineral surface causing depression.

Reference [13] studied the effect of water quality on the flotation kinetics of chalcopyrite. A comparative study on the flotation of low grade, zinc – rich, copper sample from Benambra was made using Melbourne, Benambra, deionised and recycled water. The results show different flotation characteristics with water from different sources. Benambra water improved the flotation recovery in flotation run-of mine ore. The copper was lower with Melbourne water. Deionised water resulted in reduced copper grade and recovery compared to Melbourne and Benambra. Three Benambra water recyclings, after successive improvements, gave a steady state flotation rate. The run-of-mine ore reached steady state kinetics after four recycling of Melbourne and deionised water.

Haran et al. [14] conducted a batch rougher flotation study on copper tailings from Benembra to compare flotation kinetics at optimised condition, using Melbourne, mine deionised and recycled waters. The results showed an enhanced copper grade and recovery when deionised water was used compared to when Melbourne, mine or recycled waters. This greater rate of flotation was attributed to the near absence of dissolved organic and inorganic species. Fresh mine water gave better copper grade and recovery and an enhanced flotation rate as compared to Melbourne water. Improved flotation kinetics in the first recycling of Melbourne and recycled waters were observed. Three recycles of mine water in the flotation process indicated a steady-state rate of copper tailings. This was not the case for Melbourne and deionised waters where flotation was inhibited by three water-recycles. Organic species such as thio-phosphates and carbamates released from residual reagents in water and inorganic species from tailing samples that dissolve were responsible for water quality and hence flotation kinetics.

The impact of water type on borate ore flotation was investigated by [15]. Flotation results obtained from tests with use of tap water, demineralised water and artificial water prepared with Ca^{2+} and Mg^{2+} cations deliberately added into demineralised water were compared to each other in optimal flotation conditions.

Williams and Phelan [16] showed that the presence of zinc ions (in the region of 200ppm) in the circulating water (pH 3) in the mill affected the recovery of sphalerite in the subsequent zinc circuit (pH 5) at the Woodlawn Mines. This was caused by the presence of the colloidal oxide on the surface of the mineral. The adverse effect of zinc ions on the flotation recovery of sphalerite was eliminated by treating the process water to remove zinc ions before the water entered the mill. Du Preez [17] conducted a survey on the composition of the water from different streams at the Rosh Pinar Mine where water from the thickener is the main source of process water for milling and lead flotation circuit.

IV. MATERIALS AND METHODS

A. Overview

Water samples were taken from different thickener overflows and analysed for pH, Total Suspended Solids (TSS), Total Dissolved Solids (TDS) and Conductivity (Eh). This was done to determine the quality of water to be used in batch flotation. The experimental test work comprised of batch flotation tests being done using Denver flotation cell for a period of 10 minutes. Nine different test runs were carried out on different water types. For each test run, three tests were carried out in order to ensure reproducibility. The individual concentrate masses of the respective test runs were composited in order to obtain the minimum masses required for analysis.

B. Sample Preparation

The sample used in the flotation tests was the fresh feed taken from the primary mill in four 20 L buckets. The samples were dried and crushed to about 3.5mm using a cone crusher.

Although the samples were taken from the same location they were recognised as four independent samples.

C. Bulk Blending

The four crushed samples were combined and bulk blended using the bulk blending standard procedure as illustrated in figure 1 below. The four sub samples were then combined to give one final blended sample. The final blended sample was divided into 27 small samples of 1 kg each. A grind test was done to determine the time required for 80% of the 1kg sample to pass the 75µm screen. The 1kg samples were then milled and filtered for flotation purposes.

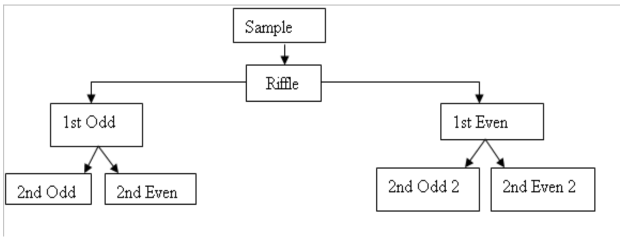

Fig. 1 Bulk blending procedure

D. Flotation Procedure

The 1kg sample was put into the flotation cell and the rotor of the cell was lowered into the cell. The air intake valve was closed, the cell was filled with water up to the 1.3 L mark. The rotor was started to agitate the solids and to eliminate any possible air pockets. The rotor was stopped to make sure that the level was at 1.3L mark. 8 ml of SIBX and 2.3 ml of $CuSO_4$ were added. This was conditioned for 2 minutes. 1 ml of Sendep 30E and 1ml of frother were added and conditioned for 2 minutes. Flotation was started by opening the air intake valve and this was timed using the stop watch. The froth was collected into the concentrate pans over 15 seconds intervals for 10 minutes. After flotation, the concentrates and the tailings were put in the oven at 90^0C.

E. Post Flotation Sample Preparation

The dry samples were removed from the pans taking special care to avoid wastage and contamination of the fine material. The concentrates and tails were placed into small plastic bags. The bags were marked and weighed for dry mass determination

V. Resluts and Discussion

A. Post Flotation Sample Preparation

Recirculating water samples were taken from the production site directly. The recirculating water samples were settled for some time in order to remove precipitated solids and then the upper liquor was taken as flotation experimental water. Recycle water after treatment can be used as process water due to little solid and suspended particles. The analysis results of water are shown in Table 1 below.

TABLE I
AMANDELBULT CONCENTRATOR RECIRCULATING MINERAL PROCESSING WASTEWATER

Type of Water Sample	PH	TDS (ppm)	Conductivity (µs / cm)	TSS (ppm)
Portable water	7.1	0	100	0
High rate thickener	9.91	2200	3200	70
Thickener #2	7.16	2200	3200	62
UG2 #1 Thickener	7.15	200	2700	59.5
Merensky Thickener	7.17	1900	2800	129
Cloudt dam	7.5	2300	2700	44.5
Thickener #1	7.08	2400	2900	13
Return water	7.82	2400	3400	30
Sewage effluent	7.34	1200	1600	23

From the above results it is clear that the water quality in terms of (pH, total dissolved solids, conductivity and total suspended solids) of water vary. To evaluate the effect of recycling mineral processing wastewater on flotation of Platinum Group Metals (PGM's), flotation experiments were conducted and the results are presented in Table 2 and figures 1 – 5.

B. Flotation Results

TABLE II
PERCENT MASS PULLS FOR VARIOUS WATER TYPES

Type of Water Sample	% Mass Pull
Portable water	65
High rate thickener	24.6
Thickener #2	23.6
UG2 #1 Thickener	25.4
Merensky Thickener	34.3
Cloudy dam	26
Thickener #1	24
Return water	24.3
Sewage effluent	24.9

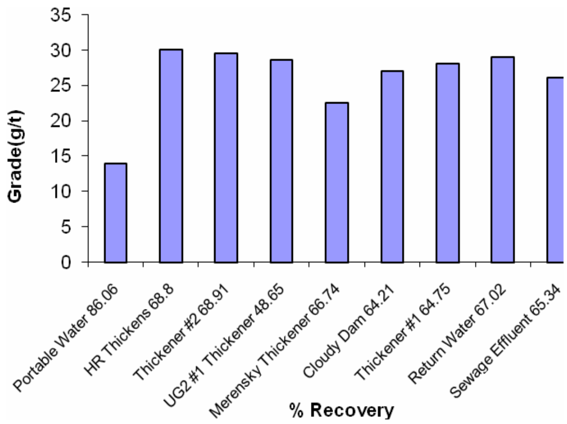

Fig. 2 Grade versus Recovery for different types of water

As expected, fig 2 shows that water quality does have an adverse effect on flotation performance. It is clear that the grade of the concentrate was the lowest (13.7) with the use of portable water when compared with the grade of the thickened water, return water and sewage effluent water. However, the recovery of the concentrate was the highest (86.06%) with the use of portable water when compared to the thickened water, return water and sewage water. The increase in grade with the use of thickened water might be due to the presence of residual reagents in the water which enhances the flotation of valuable minerals.

The low concentrate grade and high recovery in portable water flotation is due to a higher percent mass pull. Since portable water is not contaminated with residual reagents, the flotation of Platinum Group Metals (PGM's) depends only on the reagent dosages. The presence of residual reagents (depressants in particularly) in thickened water might have had a depressant effect on the gangue which resulted with a higher concentrate grade and low recovery.

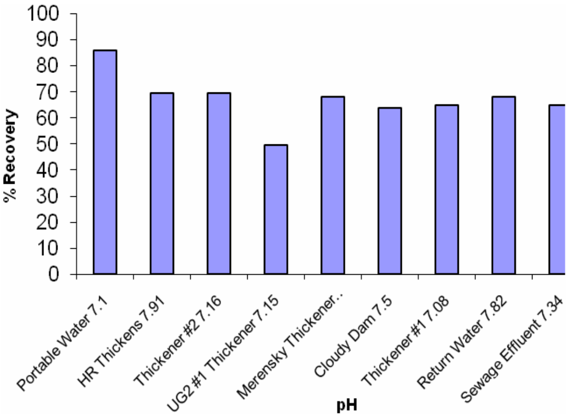

Fig. 3 The plot of Recovery versus pH

Fig 3 shows that portable water with a pH of 7.1 had the highest recovery (86 %). For pH values greater than 7.1 as in the other water types (thickened, return and sewage effluent) the concentrate recovery decreased to values ranging between 64 to 68 %. This shows that an increase in pH (>7) reduces the concentrate recovery. The reduction of recovery at high pH values is due to the formation of precipitated species (zinc hydroxide with some copper hydroxide) which cause high mineral coverage of sulphide minerals. It is clear that different kinds of water have different effects on flotation of PGM's. Therefore, in the recycling of the mineral processing wastewater, the origin of wastewater must be taken into account.

Fig 4 shows that the presence of dissolved solids in mineral processing wastewater decreases the concentrate recovery. Portable water with negligible dissolved solids gave the highest recovery of 86%. The highest amount of total dissolved solids (2400 ppm) was in thickener number 2 and return water and this gave a concentrate recovery of 65 %. Dissolved solids are present in recycling water as colloidal particles and these may remain dispersed or attached to mineral particles as hydrophilic surface layers. Hence the surface valuable mineral particles become hydrophilic and they are carried over with gangue thus reducing recovery.

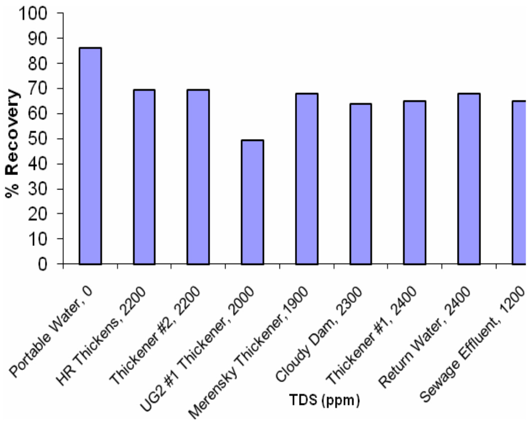

Fig. 4 The plot of Recovery versus TDS

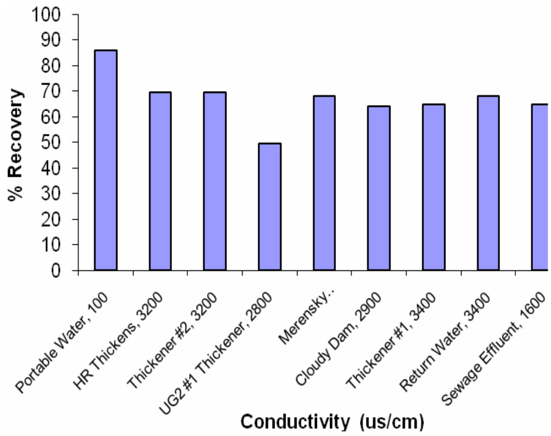

Fig. 5 The plot of recovery versus conductivity

Conductivity has an effect on concentrate recovery as observed in fig 5. The use of portable water with the lowest conductivity (100μs/cm) resulted in the highest concentrate recovery (86 %). UG2 #1 thickener water produced the lowest concentrate recovery and this can be attributed to the presence of alkali earth metal ions in particular Ca^{2+} and Mg^{2+} which may activate the non sulphide gangue thus reducing the concentrate recovery while increasing the concentrate grade.

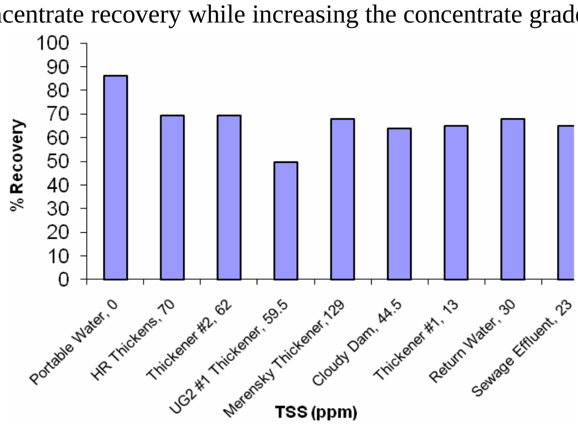

Fig. 6 The plot of recovery versus TSS

An increase in total suspended solids decreases the concentrate recovery as observed in fig 6. High amounts of total suspended solids result from ineffective dosages of flocculants. Residual level flocculants might have competitive action with other flotation reagents thus reducing the concentrate recovery. In many recycle streams, the recirculating load of precipitates, particularly calcium sulphate, magnesium carbonate, iron hydroxide and silica are the main contributions to the mineral surface contamination.

VI. CONCLUSION

The results obtained in this study indicate that the quality of water has an effect on flotation performance in particular recovery and grade. Batch flotation results indicate that portable can lead to high recovery and increased mass pull but a lower concentrate grade. The use of thickened, return and sewage effluent waters decrease mass pull. pH values closer to 7 improved concentrate grade while those above 7.15 resulted in lower recovery values. The presence of dissolved solids in mineral processing waste water can result in reduced recoveries but better concentrate grade. The conductivity of the water was found to improve concentrate grade while reducing the recovery. A high content of suspended solids in recirculating water lead to decreased concentrate recoveries. It can be concluded that water quality and origin have an impact on flotation performance. After this detailed study of the influence of water quality on flotation performance, it is recommended that a combination of process water and portable water supply be used in flotation circuits. This will balance the adverse effect that the different types of water have on the performance of mineral processing operations. It is important and cost – effective to ensure that the water reticulation system within a plant is optimised and the quality of the water used in flotation is kept constant. One of the major problems regarding water usage on metallurgical plants is its high level of fluctuation in quality. Flotation is sensitive to variations in water quality and it is recommended that water streams are managed in such a way as to minimise quality fluctuations and ensure consistency in quality. An optimum/consistent combination of water streams will also ensure process stability.

ACKNOWLEDGMENT

The author is indebted to the Department of Chemical Engineering of the University of Johannesburg for financial support. The authors wish to acknowledge his research group and colleagues in the Department of Chemical Engineering at the University of Johannesburg for their critical evaluations, suggestions and comments in the writing up of this article.

REFERENCES

[1] G. Levay, R. St. C. Smart, and W. M. Skinner, "The impact of water quality on flotation performance" *SAIMM. J.*, vol. 101, no. 2, pp. 69-75, April 2001.

[2] N. W. Johnson, "Issues in Maximasation of Recycling of Water in a Mineral Processing Plant" *The Australian Institute of Mining and Metallurgy*, Publication Series No 6/2003, Oct. 2007, pp. 239 -245, [*Proc. Conf. Water in Mining*, Brisbane, Queensland, 2003].

[3] A. J. Roderick, and G. Dopson, "Factors Influencing Water Quality," *in Water Management and Treatment for Mining and Metallurgical Operations*, vol. 6, von Michaelis, H, Ed, Colorado, Randol International ltd, 1985, pp. 3052-3056.

[4] M. Smith, and L. D. Hertzog, "Seawater in flotation," *in Water Management and Treatment for Mining and Metallurgical Operations*, vol. 6, von Michaelis, H, Ed, Colorado, Randol International ltd, 1985, pp. 3163-3164.

[5] K. S. E. Forssberg, and M. I. Hallin, "Process Water Reticulation in a Lead-Zinc Plant and other Sulphide Flotation Plants," *in Proc, Symp. Challenges in Mineral Processing*, K. V. S. Sastry and M.C. Fuerstenau, Ed, Society of Mining Engineers, 1989.

[6] M. Rey, and P. Raffinot, "Flotation of Ores in Sea Water" *in Water Management and Treatment for Mining and Metallurgical Operations*, vol. 6, von Michaelis, H, Ed, Colorado, Randol International ltd, pp. 3167-3174, 1985.

[7] S. R. Rao, and J. A. Finch, "A Review of Water Reuse in Flotation" *Min. Eng. J.*, vol. 2, no. 1, pp. 65-85, 1989.

[8] B. J. Arnold, and F. F. Aplan, "The Effect of Clay Slimes on Coal Flotation, Part 11: The Role of Water Quality," *Int. J. Min. Process.*, vol. 17, pp. 243-260, 1986.

[9] N. J. Shackleton, V. Malysiak, and K. A. Slatter, "Effects of Water Quality and Surface Passivation on Flotation Behaviour," *in Proc. Anglo American Metallurgical Symp.*, Session 4, Paper 2, November 2001.

[10] V. Malysiak, N.J. Shackleton, and D. De Vaux, "Effect of Water Quality on Pentlandite-Pyroxene Floatability with an Emphasis on Calcium Ions," *in Proc. 22nd International Mineral Processing Cong.*, ISBN: 0-958-46092-2, 2003.

[11] V. Kirjavainen, N. Schreithofer, and K. Heiskanen, "The effect of calcium and thiosulphate ions on flotation selectivity of nickel-copper ores," *Min. Eng, J.*, vol. 15, pp. 1-5, August 2002

[12] R. St. C. Smart, W. M. Skinner, and G. Levay, "Process Water Quality and Treatment: Issues and Methodology," *Proc. WAMMO.*, pp. 226-235, 1999.

[13] N. P. Haran, E. R. Boyapati, C. Boontanjai, and C. Swaminathan, "The Effect of Water Quality on Flotation Kinetics of Chalcopyrite," Excellence in Chemical Enginneering: *in Proc. 24th Australian and New Zealand Chemical Engineering Conference and Exhibition*, Barton, ACT, *Inst. Eng. Australia*., vol. 3, pp. 77-82, 1996.

[14] N. P. Haran, E. R. Boyapati, C. Boontanjai, and C. Swaminathan, "Kinetics Studies on Effect of Recycled Water on Flotation of Copper Tailings from Benambra Mines, Victoria," *Developments in Chemical Engineering and Mineral Processing*, vol. 4, issue. 3-4, pp. 197 – 211, 2008.

[15] S. G. Ozkan, and A. Acar, "Investigation of impact of water type on borate ore flotation," *Water Research*, vol. 4, issue. 7, pp. 1773-1778, April 2004.

[16] S. R. Williams, and J. M. Phelan, "Process development at Woodlawn Mines," *in Complex Sulphides. Processing of Ores, Concentrates and By-products*, A. D. Zunkel, R.S. Boorman, A. E. Morris, and R. J. Wesely, Eds, Pennsylavania, *The AIME*, pp. 293-304, 1985.

[17] R. Brehenhamn, H. S. Du Preez, and G. Coetzer, "Influence of Water Resources and Metal Ions on Galena Flotation of Rosh Pinnar Ore," *Kumba Resources R&D*, Pretoria, South Africa, pp. 193 -207, 2001.