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The Effect of Water Circulation on Bulk Flotation Performance of a Polymetallic Sulphide Ore

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Abstract **-** In this paper, the effects of water circulation on flotation performance of a polymetallic sulphide ore containing, chalcopyrite, galena, sphalerite and magnetite was investigated. The study evaluated the effectiveness of recycling process water in 15 flotation cycles and how the different water constituents affect the recovery and grade of the valuable metals in particular copper, lead and zinc as a way of solving the problems associated with water supply and discharge in mining industries particularly in the metallurgical plants. The flotation experiments were conducted using : pH of 4.5, 1200 rpm, 0.025 g of SEX, 0.025 g of Cu_2SO_4, 0.025 g of CaO , 2.5 drops of MIBC, conditioning time of 2 minutes and flotation time of 5minutes. The flotation test results indicated that the grade of both Cu and Pb increased from 0.19 to 0.36 % and 3.17 to 4.14 % respectively. The recoveries were 82.44% Cu and 81.82% Pb. Zn grade decreased from 3.90 to 1.14% at a recovery 45.48%. All the studied parameters that affect water quality have increased as the number of flotation cycles increased except for pH which decreased as a result of sulphuric acid added and they all significantly influenced the performance of the flotation process. The pH decreased from a value of 6.4 down to a range of 3.42-3.81 while the electrical conductivity increased from 0.23 to a range of 2.78-4.92 mS/cm. The total suspended solids and total dissolved solids increased from 72-968 mg/L and 115.5-2460 mg/L respectively whilst the Mg and Ca contents increased from 7.19-33.1 mg/L and 13.41-97.75 mg/L respectively. Process water can be circulated several cycles in a flotation process of a polymetallic ore before it can significantly affect the flotation performance.

Keywords**:** Black Mountain ore, Flotation, Water chemistry, Process water, Polymetallic ore

1. Introduction

The discharge and consumption of water have increasingly become a problem in mineral processing operations particularly in processes such as flotation. The high consumption of fresh water in mineral processing plants contributes towards the world's ongoing problems of fresh water shortage. The discharge of waste water from mining operations is a huge contribution factor to environmental pollution and fresh water resources/streams contamination. Therefore, researchers are on the lookout for alternative ways that can help prevent these problems [1]. This research study focused on investigating the impact of water circulation on flotation performance of a polymetallic sulphide ore from the Black Mountain mine for the recovery of copper, lead and zinc bulk concentrates as one of the alternative ways that will help to reduce the high consumption of fresh water and high discharge of wastewater in mineral processing operations.

Black Mountain (BM) is a polymetallic base metal mine division of Anglo Operations Limited which comprises two underground shafts (the Deeps and Swartberg Shafts) together with the Gamsberg project located 110 km East of Springbok (Aggeneys) in the Northern Cape province of South Africa [2]. The mine has been blessed with high grade economic ore for many years and it operates a processing plant that primarily produces copper, lead, and zinc concentrates together with silver as a by-product contained in copper and lead concentrates. The mine has been in existence since 1978 and it is the only mine in South Africa that produces copper, lead, and zinc concentrates together with silver. Black Mountain mine mainly uses flotation process for its mineral's separation and concentration [2].

Flotation is a method of concentration used in mineral processing to separate desired minerals from their ores by altering their surfaces to a hydrophobic or hydrophilic condition that will allow the surfaces to either be repelled or attracted by water [3]. There are large quantities of water required for the fulfilment of flotation process and mining industries are under expanding pressure to manage the use of freshwater effectively and reduce the discharge of mining operations process water. It is well known that flotation process is generally effective when performed using fresh or clean water which is not always readily available and hence, metallurgists are on the lookout for water quality that is consistent in order to ensure that the flotation reagent regimes are developed and applied consistently [4].

Recycling and reusing the process water or sourcing other water streams (i.e., water recovered from the tailings dam) is one of the alternatives that are considered but the chemistry of the recycled or reused flotation process water differs from that of treated or fresh water due to the number of different reagents that are used in flotation process and the various elements or contaminants that are found in the process water [5]. The difference in the chemistry of the process water from that of the freshwater may result in complications to the operating conditions of the flotation process which in turn negatively or positively affect the performance of the overall flotation process [4]. The different reagents that are used during flotation process that alter the chemistry of the flotation process water are classified as follows: collectors/promoters, activators, frothers, depressants, pH regulators and sulphidizers [3] and the various water factors that are considered in this research study are Total Dissolved Solids (TDS), Total Suspended Solids (TSS), pH, Electrical conductivity (EC), Magnesium (Mg) and Calcium (Ca) contents.

2. Experimental

2.1 Design of flotation experiments

A Box-Behnken design type of the Response Surface Methodology (RSM) design tool found in Minitab software was used to optimize the running of experiments for the purpose of this study. The three factors that were chosen to optimize the response (% recovery) are flotation time, collector dosage and pulp pH as indicated in Table 1 and this resulted in a total of 15 tests or experiments to run.

Table 1: RSM design factors and levels

FACTORS	LEVELS			UNITS
	Low (-1)	Standard (0)	High (+1)	
Pulp pH (X_1)	2,5	4,5	6,5	A-dimensional
Collector dosage (X_2)	15	25	50	mg
Flotation time (X_3)	2	5	10	Minutes

2.2 Materials and Methods

A Black Mountain ore from the Northern Cape Province, South Africa was used as the feed material for the purpose of this project. Upon receiving the ore, it went through a series of sample preparation which included crushing, milling/grinding, sampling, and pulverizing. The pulverized sample was used for characterization purposes using XRF and XRD techniques and an unpulverized sample was used for SEM analysis. After sample preparation and characterization, the Black Mountain ore sample was taken through a grinding section where wet milling was done for further size reduction and determination of the milling time that would help achieve 80 % passing 75 µm, which is the time that was then used to mill the rest of the samples prior to flotation process.

500 g each of the milled sample was immediately taken through to the flotation cell after milling and a total of 15 flotation tests were conducted while circulating the process water from one flotation test to the next in order to investigate the effects of circulating process water on the performance of the flotation process. Sodium Ethyl Xanthate (SEX) collector, Methyl Isobutyl Carbinol (MIBC) frother, Copper Sulphate (Cu_2SO_4) activator, Lime (CaO) depressant and Sulphuric acid pH regulator were the flotation reagents used in the flotation process for the purpose of this study following optimum conditions (reagents addition kept at a constant of 0.025 g, pulp pH of 4,5 and flotation time of 5 minutes). Upon completion of the flotation process, the products (both concentrates and tailings) were filtered, dried and weighed and prepared for post flotation analysis using XRF technique. Representative samples of water were collected for each test conducted and analysed to determine the pH, electrical conductivity (EC), total dissolved solids (TDS), total suspended solids (TSS), Mg and Ca contents present and these are the potential water factors that affect the performance of the flotation process.

3. Results and discussion

3.1 Characterization results

Table 2 shows the elemental composition of the raw BM ore pulverized sample obtained using XRF analysis. The main abundant element present in the ore is iron (Fe) with a composition of 31.56 % which is often associated with copper minerals in most ores according to existing literature [6]. BM ore is a primary host of copper, lead and zinc sulphides [4] and therefore, there are significant quantities of Cu, Pb and Zn elements present in the ore with percent compositions of 0.19, 3.17 and 3.90 respectively. The ore also contains significant quantities of Al, Si, S and Mn with the main gangue being Si. The significant amount of silicon found in the raw Black Mountain ore sample is in correspondence to what was discovered by [6] and the rest of the XRF results below corresponds to what has already been discovered in existing research.

Table 2: Elemental composition of the pulverized Black Mountain ore

Elements	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti
%	0.00	0.16	1.61	9.18	0.11	6.69	0.02	0.16	0.33	0.11
Elements	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Pb	Bi
%	0.03	4.05	31.56	0.03	0.02	0.19	3.90	0.02	3.17	0.03

3.2 Mineralogical composition of the raw BM ore

Fig.1 is an illustration of the relationship between intensity (cps) and the angle 2-theta (degree) of the main minerals present in the BM ore as indicated on the spectrum. The main minerals present in the ore are Zinc sulfide, Chalcopyrite, Magnetite, Galena, Pyrite, Sillimanite, Jacobsite and Quartz. The highest peak from the XRD patterns mainly occur between 25 and 30 degrees on the horizontal axis which is where the minerals Quartz and Sillimanite are found. This then goes to prove that the Black Mountain ore used in this project has high quantities of crystalline silicon which is in correspondence to what has already been discovered from the XRF results above and from the study conducted by [6]. As it is already known from literature that Black Mountain ore is a primary host of copper, lead and zinc sulphide minerals , the second highest peak on the graph occurs where the minerals galena (sulphide host of lead) and chalcopyrite (sulphide host of copper) are found represented by the letters D and C and there are also visible peaks of the letter A indicating a sulphide host of the zinc metal.

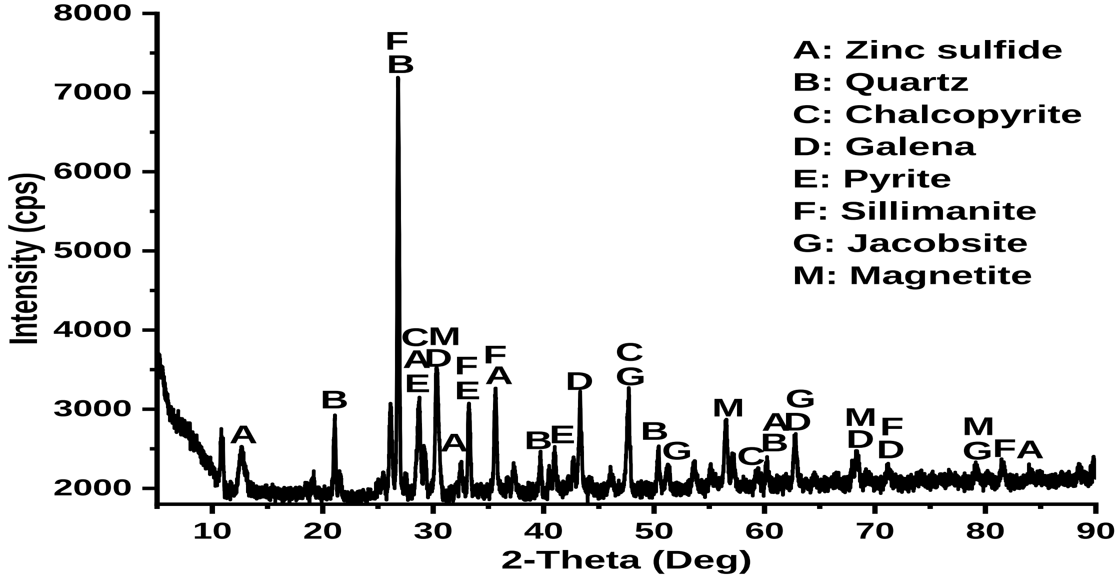
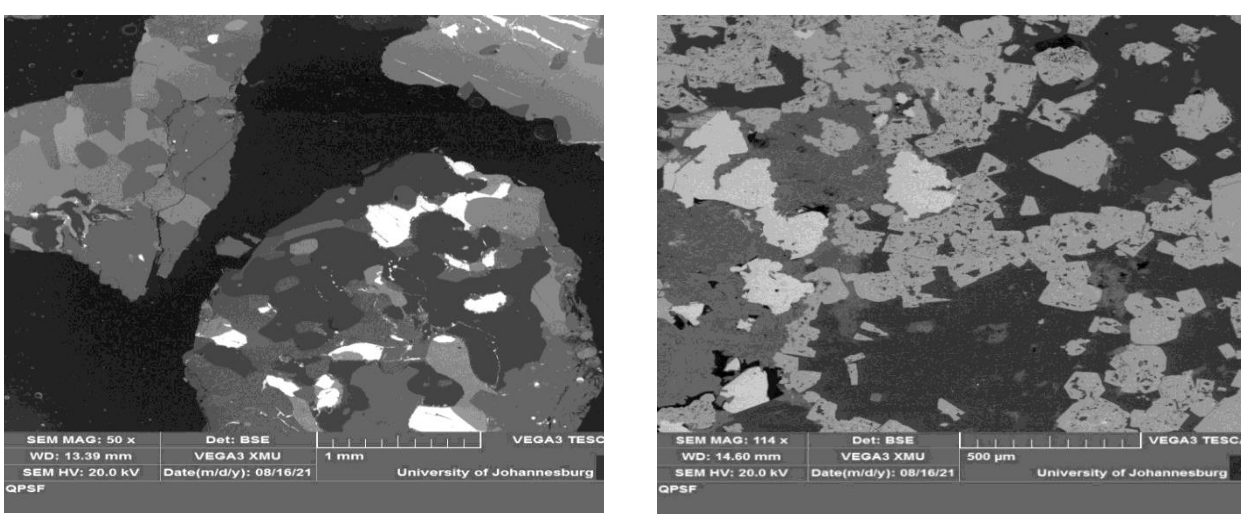


Fig. 1: Mineralogical composition of the Black Mountain ore

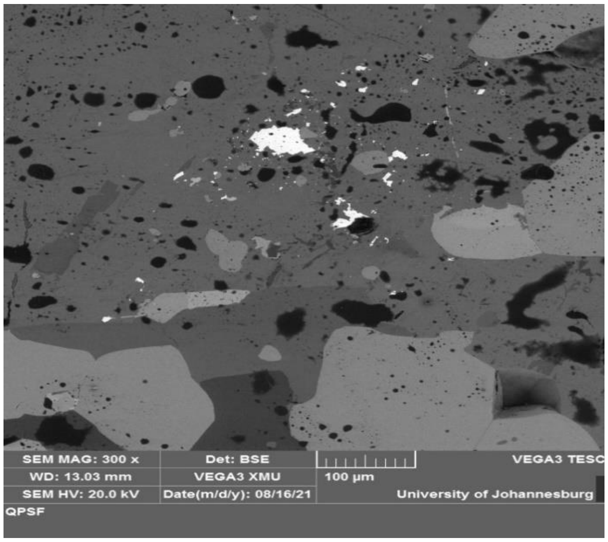
3.3 Surface topography of the raw BM ore

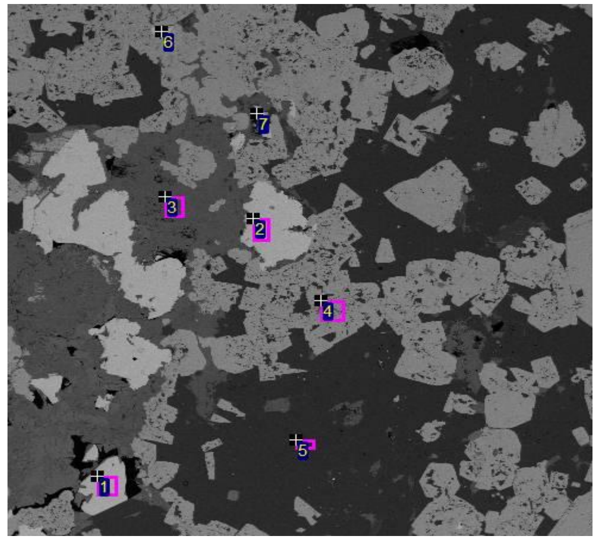
Fig. 2 shows the surface topography of the raw Black Mountain ore sample tested under different magnifications (i.e., 50x, 114x, and 300x) using Scanning Electron Microscopy (SEM) analysis. The SEM micrograph shows a mosaic distribution of minerals on the ore surface characterized by several contrasts covering from dark to bright spots. The bright spots are characterized by minerals with higher molecular weight and absorbing much energy. Therefore, spots 1, 2, 6 and 7 on image (d) illustrate the probable existence of pyrite and sphalerite. Simultaneously, the dark greyish spots lying on lower molecular weight represents quartz as revealed in spot 5 and the light greyish color due to a higher and lower molecular weight mixture is indicated by spot 4.



(a) Micrograph at 50 x magnification

(b) Micrograph at 114 x magnification





(c) Micrograph at 300 x magnification

(d) Minerals distribution image

Fig. 2: Surface topography of Black Mountain ore under different magnifications.

3.4 Flotation process results

The experimental results for the bulk flotation process that was performed for the recovery of copper, lead and zinc bulk concentrate are shown on Fig. 3. The results show the grade of the major elements (Cu, Pb, and Zn) present in the Black Mountain ore together with the gangue (Si) that reports to both the concentrates. It is evident from Fig.3 that the direct flotation process promoted an upgrade of Cu from a feed grade of 0.19 % to a range of 0.26 – 0.36 % together with that of Pb from a feed grade of 3.17 % to a range of 3.32 – 4.14 % in the concentrates. A study conducted by [1] recently found that the collector remaining in the flotation process water forms new lead xanthate species on the surface of galena which then promotes the flotation of galena and hence an upgrade of the lead metal. However, a poor grade of Zn was observed with a downgrade from 3.90 % to a range of 1.14 – 3.24 % except for test 5 that achieved Zn grade of 4.37 %. The grade of copper reporting to the concentrate is very low as compared to that of the other products for all the flotation tests and this was expected because the head grade or the grade of copper in the feed material was also low. The low copper grade as compared to the other products in the flotation circuit may also be accounted for by the inadvertent activation of sphalerite and pyrite by copper ions in the water according to previously done studies [2]. Si grade that reports to the tailings is higher than that in the concentrates and that of the products in the tailings which shows that the direct flotation process was efficient although Zn was downgraded.

Fig. 4 is a representation of the % recovery of the flotation products that reports to both the concentrates. The % recovery of both Cu and Pb in the concentrates are the highest with the ranges of 24.49 % to 82.44 % for Cu and 10.92 % to 81.82 % for Pb respectively while the % recovery of Zn is the lowest with a range of 4.20 % to 45.48 %. The low recoveries of Zn in the concentrates are accounted for by the excess use of Cu_2SO_4 during the flotation process and the inadvertent activation of unwanted minerals (such as pyrite) by metal ions that float together with sphalerite affecting its selectivity. The % recovery of all the valuable metals are above that of the gangue in the concentrates and below that of the gangue in the tailings which indicates that the direct flotation process was efficient. As already known from literature, a direct flotation process should favour the recovery of the valuable metals over that of the gangue in the concentrates [5].

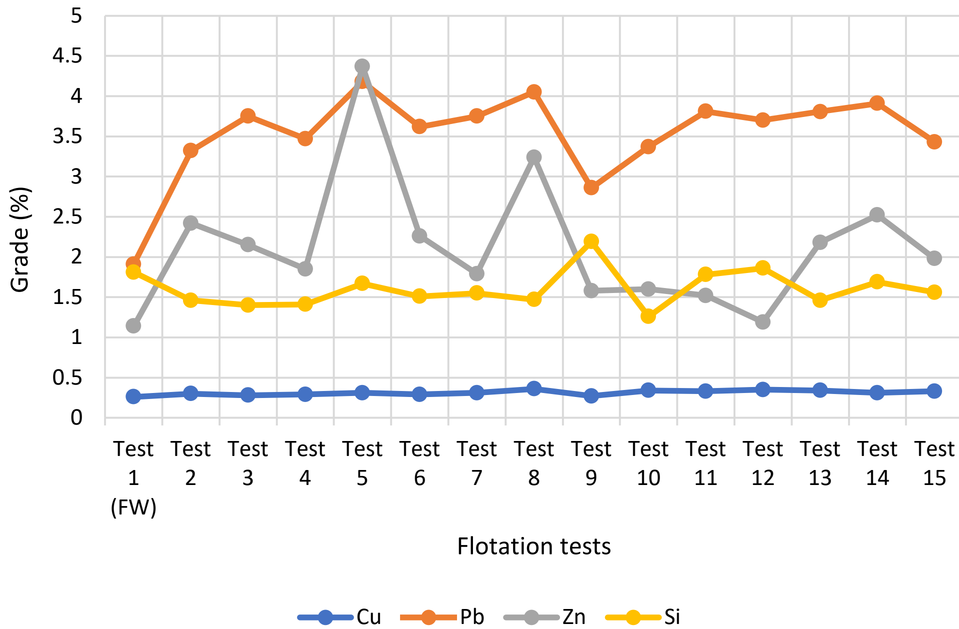


Fig. 3: Grade of the flotation products that reports to the concentrates

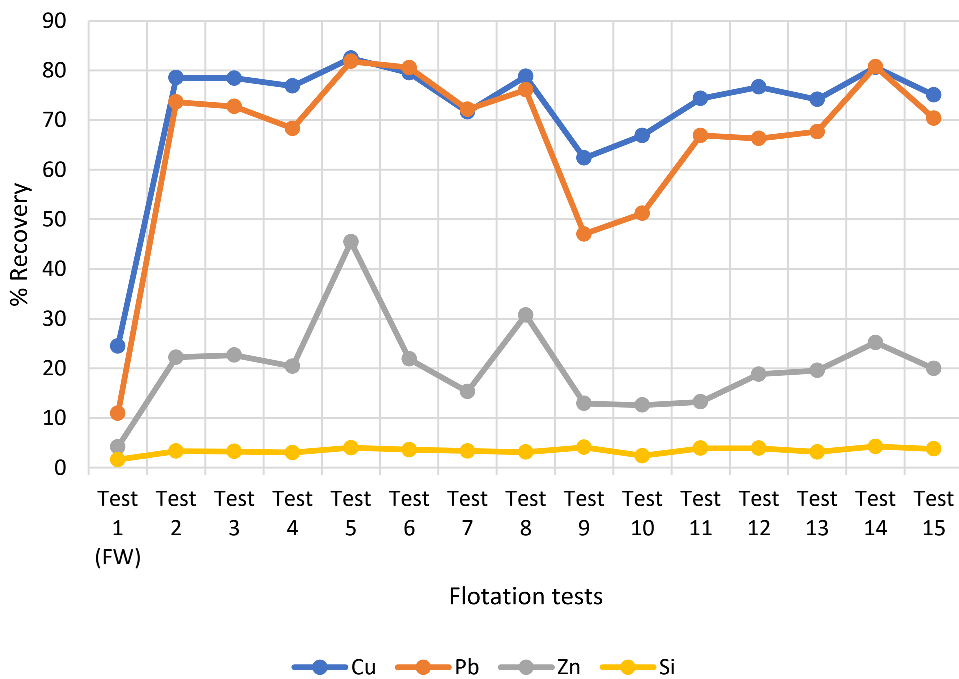


Fig. 4: % Recovery of the flotation products to the concentrates

3.5 Circulated process water analysis results

The pH and electrical conductivity of the circulated water was measured and the results are shown in Fig. 5. The results revealed that the pH of the circulated process water intensely decreased from 6.4 down to 3.42 and started to consistently move at round about similar values from test 2 up to 15. This decrease in pH was expected since the flotation tests were conducted in an acidic media through the addition of sulphuric acid. The electrical conductivity as seen on the graph below increased from 0.23 mS/cm to 4.92 mS/cm. The inverse relationship between the pH and the electrical conductivity of the recycled process water had no significant negative impact on the flotation performance but rather facilitated the flotation of the valuable products over that of the gangue and a similar observation was made in a previously conducted research [6].

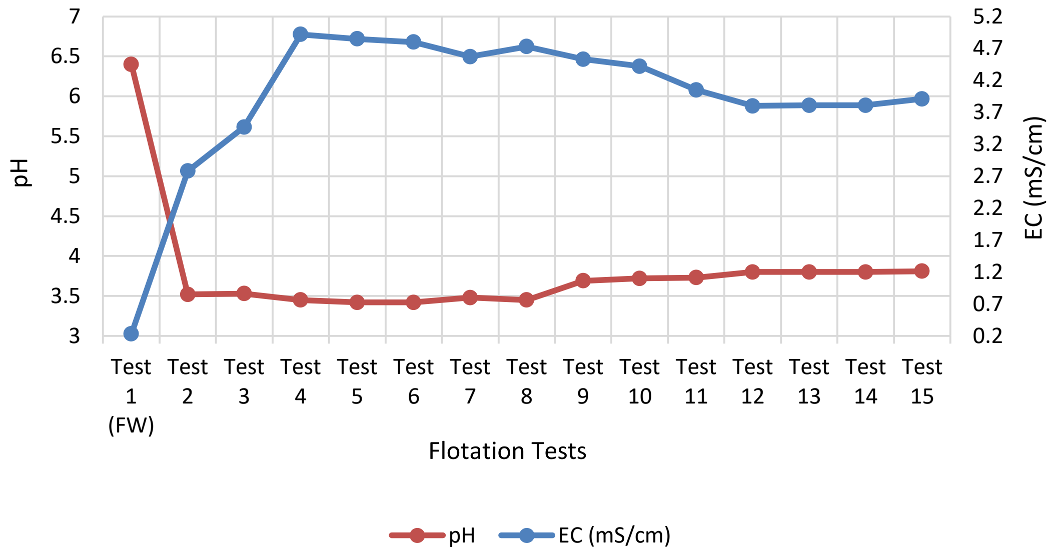


Fig. 5: pH and Electrical Conductivity (EC) measurements of the process water

3.5.2 Impact of process water circulation on Total Dissolved Solids and Total Suspended Solids

The impact of recirculating process water on TDS and TSS was investigated and the results are shown in Fig. 6. It can be observed that both TDS and t TSS in the flotation process water significantly increased from test 1 to the last. The TDS increased from 115.5 mg/L to a range of 1390-2460 mg/L for all tests conducted and the TSS increased from 72 mg/L to 968 mg/L as the flotation process took place and as the water was being circulated. A similar observation of increasing TDS in circulated flotation process water was observed in a study conducted by [6]. The increase in both the TDS and the TSS values shows that the two water quality factors have a directly proportional relationship with the addition of flotation reagents, the more the flotation reagents are added, the more both factors increase although the increase is not consistent. The increase in the accumulation of the cations and the anions or dissolved ions (TDS) in the process water had a negative impact on the selectivity of sphalerite during the flotation process resulting in lower recoveries of zinc over that of copper and lead.

3.5.3 The effect of process water circulation on Mg and Ca content.

The Magnesium and Calcium contents in the circulated process water inconsistently increased as the flotation process water was being circulated. The Mg content increased from 7.19 to 33.10 mg/L while the Ca content increased from 13.41 to 97.75 mg/L for all the flotation tests conducted. An increase in the Ca content is due to lime addition during flotation process which was used as a depressant for pyrite. An increase in the Mg and Ca contents in the flotation process water negatively influenced the overall performance of the process by inadvertently activating unwanted minerals, thus affecting selectivity of Sphalerite [5].

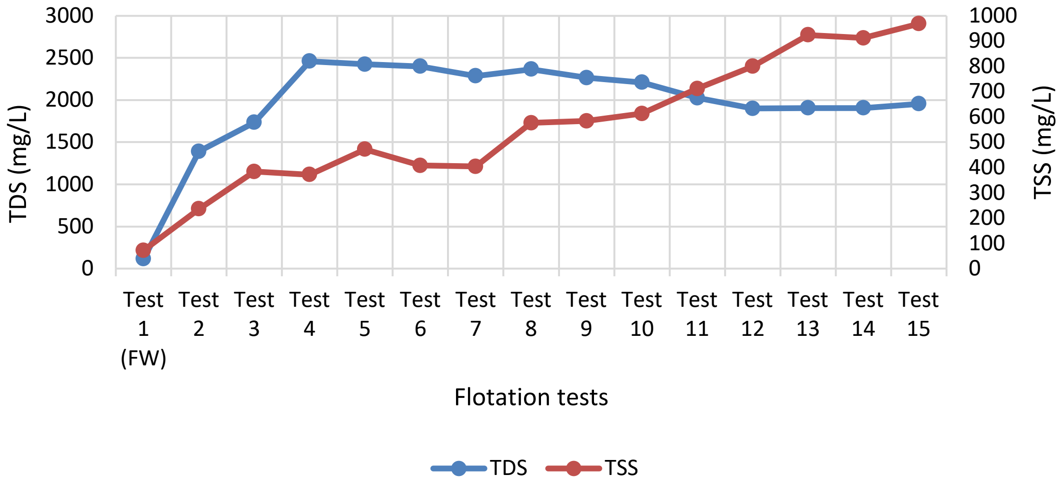


Fig. 6: TDS and TSS of the circulated process water

4. Conclusion

Process water circulation in flotation of a polymetallic sulphide ore favours the flotation of chalcopyrite and Galena over that of sphalerite. pH and EC changes significantly in the first few cycles but stabilises as the number of cycles increases. The inverse relationship between the pH and electrical conductivity has facilitated the flotation of the valuable metals while an increase in the TSS and TDS together with the accumulation of Ca and Mg contents throughout the water circulation has shown to decrease the selectivity of sphalerite mineral which resulted in low grade and recovery of the zinc metal. Therefore, recirculating the flotation process water in flotation operations is recommended for future implementations in order to reduce freshwater consumption and waste water discharge in mineral processing industries.

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