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Selection of the best route for column configuration in an existing copper circuit

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Abstract: This study was aimed to utilize column flotation to obtain much cleaner concentrate in the Cu circuit. However, the numbers of equipment and the proper streams for column application should be the key for successful operation. Therefore, the effects of some operational parameters such as wash water rate, airflow rate and froth height were investigated on the streams of namely Cu first cleaner concentrate, Cu rougher concentrate and Cu third cleaner concentrate in terms of mineral recoveries and selectivity. Distribution of wash water rate to products was also determined by a tracer test method. Optimum operating conditions and accordingly performance of the column were determined by simulation studies. According to the results, the suitable streams for industrial scale flotation column are advised as the rougher concentrate and/or first cleaner concentrate. With series installation of columns, it is possible to obtain two different concentrates which include 22% Cu, 4% Zn and 17% Cu, 8% Zn without any decrease in overall recovery of plant.

Keywords: column flotation, sulphide ores, distribution of wash water, airflow rate, froth height

1. Introduction

The flotation process is often referred to as a highly complex process because it is affected by many parameters at different rates. Selectivity of chemical regime, appropriate circuit design and usage of most efficient equipment are some of these parameters, which have a profound effect on performance of flotation process. As the properties of ores become more complex and difficult to process, the most proper optimization solutions are inevitable when metallurgy and economics are taken into consideration.

For the past six decades, mechanical flotation machines have been the standard equipment utilized for flotation. However, increased energy cost and fast changing technology have led to the development of much more efficient and appropriate equipment for the relevant process. It is well known that a major problem with mechanical cells is the recovery of hydrophilic particles by mechanical entrainment within the water, reporting to the concentrate. Trahar (1981) and Dionne (1989) have shown that the amount of entrainment increases as the particle size decreases. Due to this feature, mechanical flotation machines have proven to be inefficient particularly in final cleaning stages of concentration and consequently several additional cleaning stages are required to achieve the desired upgrading. As this fact makes the process more difficult and costly, the flotation columns are admitted attractive particularly for applications involving cleaning stages. Flotation columns are generally accepted for small capacity cleaner roles in worldwide base metal industry, while they have more popularity in coal, phosphate and iron industries particularly in Australia, China, USA and Brazil respectively (Harbort and Clarke, 2017). The main advantages include, improved separation performance (higher grade), less plant space requirement, lower energy consumption and adaptable to complex process control systems.

Since the first column installed in Noranda's Les Mines Gaspé (Cienski and Coffin, 1981), the effects of operational parameters such as feed flow rate, airflow rate, wash water rate, froth height, etc., are

being investigated by many researchers. For example, Yianatos et al. (2008) represents the effect of feed tonnage on bubble loading in which the bubble load increased significantly by increasing feed tonnage. Gas hold up, which is a function of gas rate and bubble size, may have a positive effect on recovery if it is increased up to certain level depending upon feed characteristics and reagent regime (Rubinstein, 1995). Operating parameters have also considerable effects on entrainment which is known as the major factor in flotation of fines. In a previous study, Stevenson (2007) shows an alternative point of view for entrainment and concluded that particle size does not have an effect on entrainment due to the assumption that the water content and bubble size remains constant in froth zone. This conclusion did not find much support as it has been experimentally found that entrainment is a strong function of particle size, as well as being dependent on other cell operating parameters such as froth depth and air rate (Neethling and Cilliers, 2009). The influence of operating variables including superficial gas velocity, slurry density, frother dosage and frother type on flotation rate was also studied by Massinaei et al. (2009). They found that the increase in superficial gas velocity and frother dosage enhanced the flotation rate, while the increase in slurry solids content reduced the flotation rate. Dey et al. (2015) also stated that the effect of superficial air velocity is more dominant than collector dosage for recovery at low froth height. The interactive effects of froth height and superficial air velocity on grade and recovery have also investigated with different type of minerals (Şahbaz et al., 2017; Dey et al., 2015). It is known that as the wash water rate increases, the concentrate grade increases by the drainage of hydrophilic particles in the froth phase. However, in parallel to that the recovery of the hydrophobic particles may also decrease to some extent. The uncontrolled variation in the amount of water recovered from time to time, would change the total recovery due to the variations in entrainment (Gülsoy and Ersayın, 1998). In some other studies, it became an evident that despite of an elevation in the grade, the recovery does not decrease much (Finch and Dobby, 1990; Goodall and O'Connor, 1992; Groppo and Parekh, 1990; Tao et al., 2000).

This study was performed in a circuit treating a volcanogenic massive sulphide ore that includes copper and zinc minerals such as chalcopyrite, bornite, chalcocite, covellite and sphalerite. There are two types of ores; although the overall mineralogy of them is similar, the main difference is due to the complexity in texture and Zn content, which makes it difficult to obtain Cu clean concentrate. The copper flotation circuit had four staged cleaner units operated by conventional, mechanical flotation cells after rougher stage and the average copper concentrate was used to be composed of 15-17% Cu and 7-10% Zn. It is known that such a zinc content is rather high for a copper concentrate for smelting considerations. Due to previous plant studies done, it was stated that the ~15% of Zn was lost in Cu final concentrate by entrainment via -20+10 μm size fraction with almost 60% liberation degree of sphalerite mineral. Therefore, the column flotation operation was preferred to eliminate this problem, however; the selection of columns for the appropriate stream(s) was the key for successful operation. In this scope, implementation of columns in Cu circuit was investigated by applying the tests at three different streams such as first cleaner concentrate, third cleaner concentrate and Cu rougher concentrate with a pilot scale column. Data evaluation was conducted based on the effects of operating parameters such as airflow rate, froth height and wash water rate on the selective flotation of copper minerals from sphalerite and pyrite (Altun, 2011).

2. Materials and methods

2.1. Materials

The ore consists of primary and secondary Cu minerals within mostly pyrite and other gangue minerals, particularly silicates. The typical mineralogical compositions of the flotation feed streams of two ore types namely A and B are determined by MLA (Mineral Liberation Analyser) analysis. Ore type A is much abundant than ore type B in the deposit and shows much difficult processing trend due to its high Zn content and fine grain size texture. Although the study was conducted on both ore types, the results of ore type A are presented here. The mineralogical composition and elemental analysis of the flotation feed stream are given in Table 1 and Table 2 respectively.

Table 1. The mineralogical composition of the flotation feed

Mineral	Ore A (%)
Chalcopyrite	7.71
Bornite	0.38
Sphalerite	12.24
Pyrite	58.59
Galena	0.47
Others	20.61
Total	100.00

Table 2. The elemental analysis of the flotation feed

Element	%
Al	0.91
Ba	2.77
C	0.47
Ca	0.72
Cu	2.91
F	0.00
Fe	31.47
H	0.02
K	0.27
Mg	0.11
Na	0.07
O	8.90
P	0.01
Pb	0.41
S	38.84
Si	3.80
Ti	0.09
Zn	8.21
Total	99.99

2.2. Experimental method

A pilot scale flotation column having 4 m height and 0.5 m diameter was used in this study. It consisted of flanged column body section, feed and underflow piping, wash water assembly, base support, cavitation tube sparger system, cavitation pump speed control and a control panel. As the proper replacement of column after rougher stage was investigated, some trial tests were performed to reveal the limitations and the response of operating parameters such as airflow rate, froth height, wash water rate and location of wash water rig. After several trial tests, it is seen that the flotation column improved the concentrate grade significantly in single stage thus, using the data obtained from the tests, the base operating conditions were determined and the values that would be modified in comparison tests were decided to be as in Table 3.

Table 3. Standard operating conditions for three parameters

	Range	Standard
Wash water rate, m ³ /h	0.84-1.2	0.96
Airflow rate, m ³ /h	8-14	12
Froth height, cm	20-50	30

As column test procedure was conducted for cleaning purpose, hence only 5 g/t frother (MIBC) was used as a reagent. The feed to the column cell was being pumped by a peristaltic pump from the pump sump of the relevant stream. The tests were planned and conducted based on one parameter at a time method. When a parameter was changed in the column, before sampling procedure, time duration of 45 minutes was left to reach steady state conditions. Then, sampling from the feed, concentrate and tail was commenced and repeated three times in about 20 minutes. The samples were filtered, dried and weighed to obtain the dry mass and determine the pulp density (w/w). Each sample was then split into two sections for Cu, Zn, Fe head and size-by-size assays. The particle size of flotation feed was measured as p_{80} : 36 μm therefore, the size fractions of +20 μm , -20+9 μm and -9 μm were chosen for analysis and obtained by a cyclosizer. The assay results and solid percentage values were mass balanced to determine the volumetric and solid flow rate and metal recoveries on a size-by-size basis by using JKSimFloat 6.4 software.

There are two water sources in the operation, one of them is the water flowing from the feed stream, and the other one is the wash water. Determining distribution of wash water that flows to concentrate can give an idea about the characterization and importance of wash water in column flotation. In order to determine the wash water split to products, a tracer method has been used. Tracer is an identifiable substance which can be pursued through the course of a process providing information on the pattern of events in the process. Tracers are a kind of simulator, which must be similar in behaviour to the material, which is going to be traced, but they must be different to be identifiable (Breitenbach, 1982). For this purpose, wash water prepared with a certain concentration of tracer was fed to column and the filtrate samples taken from the products were analysed by UV visible spectroscopy to determine the wash water split ratio.

3. Results and discussions

Column flotation is widely used at final stage cleaning right after conventional rougher and cleaner units to facilitate the removal of entrained gangue minerals. For this purpose, Cu first cleaner Concentrate, which is the main targeting stream, and Cu third cleaner Concentrate streams are used to perform pilot scale tests. Although the pneumatic type flotation cells are designed for final cleaning purposes, the usage of these cells as a rougher-cleaner is being widespread if the performance results satisfy the required conditions. With respect to this trend, it is agreed to try out the flotation column with Cu Rougher Concentrate stream in the same conditions with the other two streams. The tests were firstly conducted on Cu first cleaner concentrate stream in detail and then, the other two streams were studied with the best conditions to compare the results obtained from those.

3.1. Cu first cleaner concentrate

The purpose of using column for Cu first cleaner Concentrate (p_{80} :20 μm) was to obtain a final product by omitting two more stage cleaning. The possible flowsheet after flotation column installation is given in Fig. 1.

3.1.1. Airflow rate

Airflow rate affects both mass pull and water recovery. High water recovery and mass pull results in low concentrate grade due to increased gangue recovery by entrainment. The laboratory scale tests show that water entrainment along the froth increases almost proportional to the air rate increase in the range of 1-2 cm/s (Yianatos et al., 1998). However, the columns should be operated at a certain airflow rate to maintain a stable froth phase and optimum copper recovery in case of this ore. Hence, effects of airflow rate were investigated between 8 m^3/h and 14 m^3/h considering the preliminary test results.

The standard airflow rate was found as 12 m^3/h which is equal to 1.70 cm/s as superficial gas flow rate. The volumetric feed flow rate, wash water rate and froth height kept constant to obtain the best operating condition for the pilot scale column at optimum airflow rate. As the airflow rate increases, the solid and water tonnages that is being transferred to concentrate stream increases, but when the airflow rate exceeds 12 m^3/h , the increment in water tonnage compared to solid is almost five times. This shows that excess airflow rate increases the water recovery thus the amount of fine particles carried

by hydraulic entrainment. The Fig. 2a shows the overall performance obtained at different airflow rates. It is clear that the recovery of chalcopyrite mineral increases by increasing airflow rate but the concentrate grade decreases gradually. However, with the single stage cleaning by a column cell, the copper content of the Cu first cleaner concentrate stream, which is the column feed, could be increased from about 12% Cu, up to 25% Cu with about 45% recovery and 22% Cu with 55% recovery. The zinc content of the concentrate was decreased from 9% Zn down to 7% Zn. The influence of airflow rate on the selectivity is shown in the form of chalcopyrite (Cp) recovery vs. sphalerite (Sp)/pyrite (Py) recoveries (Fig. 2b). At lower airflow rates, separation becomes much selective but the overall chalcopyrite recovery remains below 50%. At 14 m³/h airflow rate, sphalerite recovery reaches to its maximum recovery while 12 m³/h air amount brings the maximum recovery for chalcopyrite and less recovery for sphalerite.

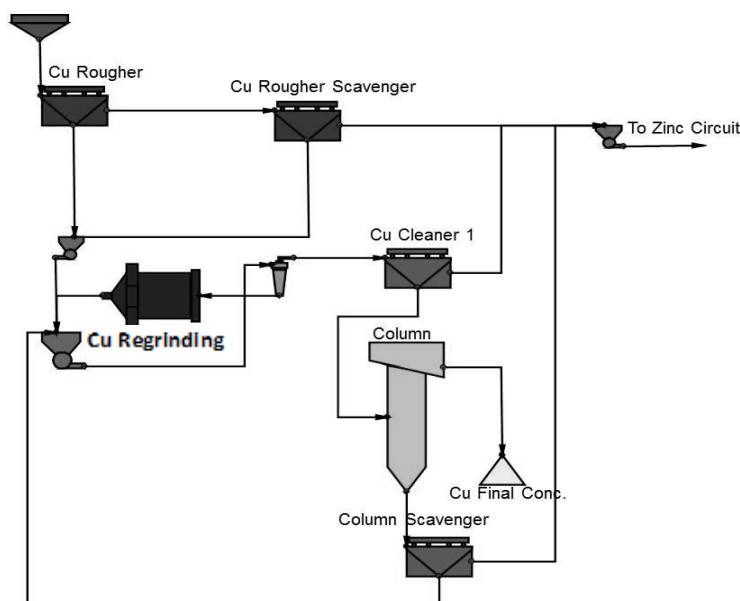


Fig. 1. Possible flowsheet after column installation for Cu First Cleaner Concentrate

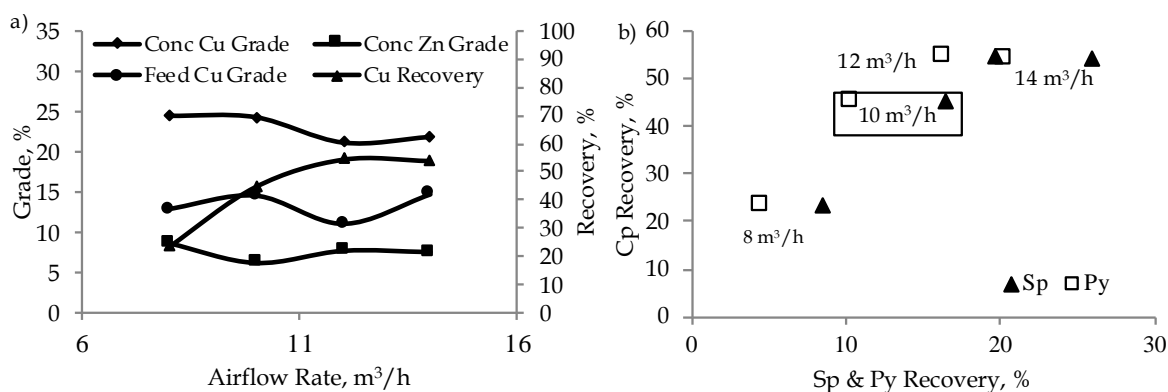


Fig. 2. Performance (a) and selectivity (b) at different airflow rates (30 cm froth height and 0.96 m³/h of wash water rate)

Chalcopyrite and sphalerite analyses on size basis were also performed at different airflow rates (Fig. 3a and 3b). The recovery of coarse particles was lower than the other size fractions at all of the airflow rates, except 8 m³/h. This could be due to higher drop back of coarse particles in the froth zone. Unlike the airflow rates between 10-14 m³/h, the recovery of the fine particles (-9 μm) at 8 m³/h, the lowest airflow rate, was lower than the medium size range presumably due to inadequate gas hold-up under this condition. Gas rate was measured as 1.70 cm/s for the standard airflow rate (12 m³/h) while it was only 1.13 cm/s for 8 m³/h. Therefore, decrease in gas rate could be the reason for lower recovery as it is directly proportional to gas hold up rate. As for sphalerite, the recovery values were different from

chalcopyrite. As the airflow rate was increased, the overall sphalerite recovery increased in all size fractions. However, in the airflow rates between 10 m³/h and 14 m³/h, the lowest recovery values were obtained at -20+9 μm fraction, indicating the most effective drainage of sphalerite at this size fraction. The higher recoveries in the coarse size fraction could be attributed to the recovery of locked particles with chalcopyrite, and in the fine size fractions to inadequate drainage.

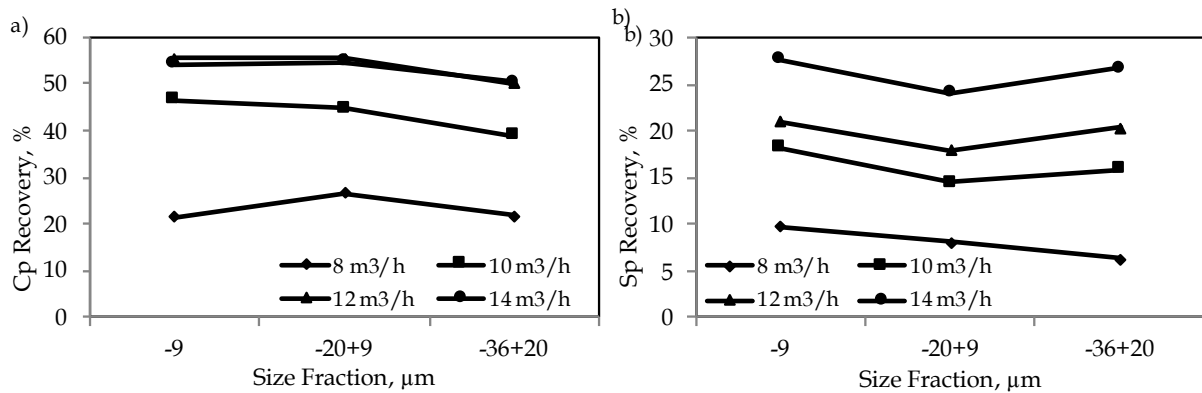


Fig. 3. Size by size chalcopyrite (a) and sphalerite (b) recoveries at different airflow rates (30 cm froth height and 0.96 m³/h of wash water rate)

3.1.2. Froth height

One of the most important features in column flotation is the availability of higher froth depth compared to conventional mechanical flotation cells. In addition to the airflow rate, grade and recovery can also be controlled by adjusting the froth height during the operation. The overall performance at different froth height is given in Fig. 4. The chalcopyrite recovery dropped dramatically from about 55% to 20% as the froth height was increased from 30 cm to 40 cm. This was in parallel with the decrease in solid recovery. The copper grade of the concentrate increased from about 12% Cu up to 23% Cu at one stage of column flotation. However, the difference between the minimum and maximum froth height values was small. The Zn grade of the concentrate decreased from 6.5% Zn to about 5% Zn and the effect of increasing the froth height from 20 cm to 50 cm seemed to have slight influence on the Zn grade of the Cu concentrate. This could be due to the decrease in the recovery of chalcopyrite in parallel to sphalerite and pyrite in the concentrate and 5% Zn content is already very low and further improvement in the zinc content is very difficult.

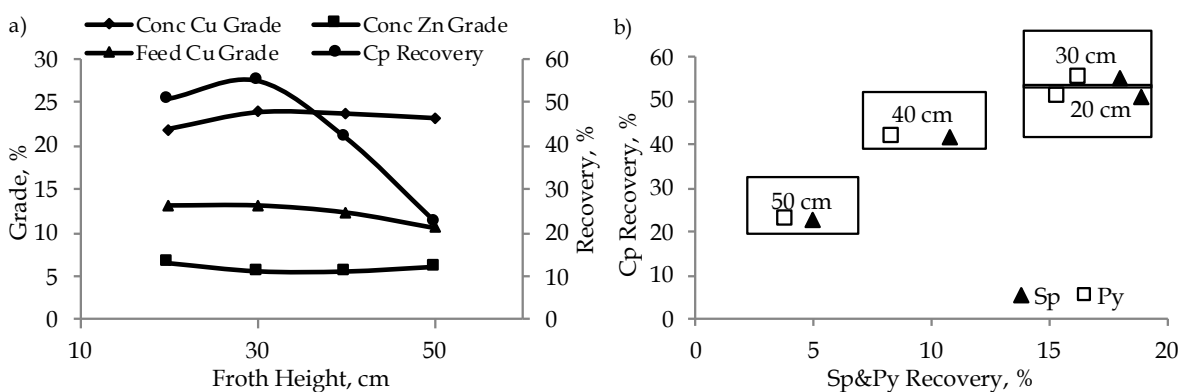


Fig. 4. Performance (a) and selectivity (b) at different froth heights (0.96 m³/h wash water rate and 12 m³/h airflow rate)

The selectivity between chalcopyrite and sphalerite/pyrite is illustrated in Fig. 4b. The results showed that the selectivity between chalcopyrite and pyrite was better than sphalerite. The lower chalcopyrite recovery is attained in 50 cm froth height with lowest sphalerite and pyrite recovery. As the froth depth gets lower, the recovery values increases but at 20 and 30 cm froth height the

chalcopyrite recovery becomes almost the same whereas sphalerite and pyrite have the highest recovery values.

Size by size analyses of chalcopyrite and sphalerite recoveries are given in Fig. 5a and 5b respectively. Chalcopyrite recovery decreased gradually at all sizes as the froth height increases from 20 cm and 40 cm. However, the recovery decreased considerably when the froth height was increased to 50 cm. In spite of that, the sphalerite recovery decreased substantially as the froth height was increased from 20 cm to 30 cm. Difference in the size fractions was observed at 20 cm and 30 cm froth heights for chalcopyrite. The recovery at medium size range was slightly higher than the other size fractions. As for sphalerite, the situation was opposite for 30 cm and 40 cm froth heights. Better gangue drainage was obtained at high froth depths. However, there is an upper limit for the maximum attainable froth height, as the froth stability decreases considerably after a certain value. The results given in this section showed clearly that inhibited flotation conditions were observed at 50 cm froth depth. Therefore, the optimum froth height was determined to be 30 cm based on the grade and recovery of copper and zinc grade in the concentrate.

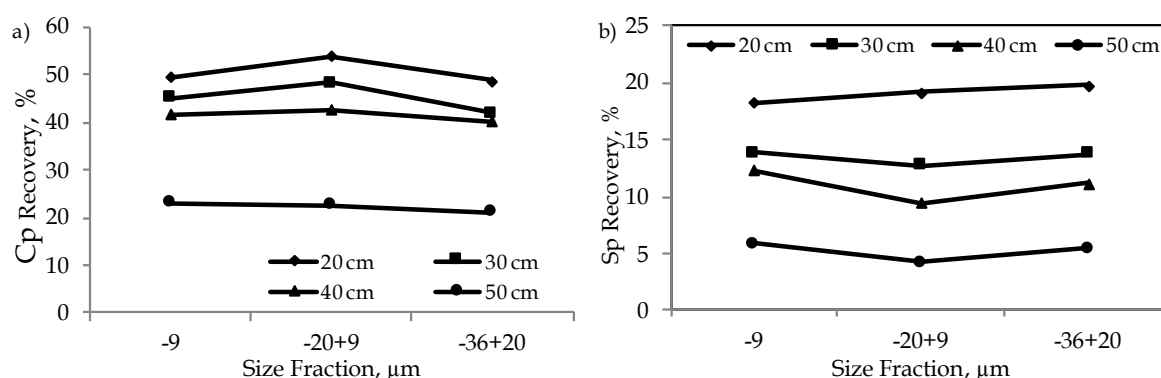


Fig. 5. Size by size chalcopyrite (a) and sphalerite (b) recovery at different froth heights (0.96 m³/h wash water rate and 12 m³/h airflow rate)

3.1.3. Wash water rate

The rate of wash water plays an important role on the quality and efficiency of concentration process. The increase in wash water rate resulted in a decrease in both water and solid flow rates to the concentrate. Between 1.08-1.20 m³/h wash water rate, there is a slight increase in the tonnages but this could be due to the fluctuation in Cu grade of the feed stream.

Fig. 6a shows that Cu grade of the concentrate increased to about 27% Cu at 1.08 m³/h and 1.20 m³/h wash water rate. In these tests, the zinc grade of the concentrate decreased down to 3.88% Zn. However, the improvement in the grade of the concentrate causes recovery loss in the order of 20%. Comparison of the effects of the three operating parameters showed that wash water rate was the most effective parameter to control the quality of the concentrate. The points on the lower left part of the selectivity graph (Fig. 6b) represent the recovery values obtained at 1.08 and 1.20 m³/h wash water rate. The sphalerite recoveries are the same but the pyrite recovery drops further due to the increasing in wash water rate from 1.08 to 1.20 m³/h.

Fig. 7a shows the effect of wash water rate on chalcopyrite recovery at size fractions. The recovery of the coarse chalcopyrite particles was lower than the other size fractions due to the easy detachment from air bubbles. Similar behaviour was observed with sphalerite particles as well (Fig. 7b). The drainage of coarse sphalerite particles was higher than the fine particles.

The effects of wash water on the grade and recovery of chalcopyrite, sphalerite and pyrite were discussed above. It is clear that wash water creates a counter current flow in the froth zone and improves drainage of hydrophilic gangue particles. However, there is not enough data in the literature about the distribution of the wash water in the column cell. Therefore, a tracer test was performed to determine the distribution of wash water to concentrate and tail products.

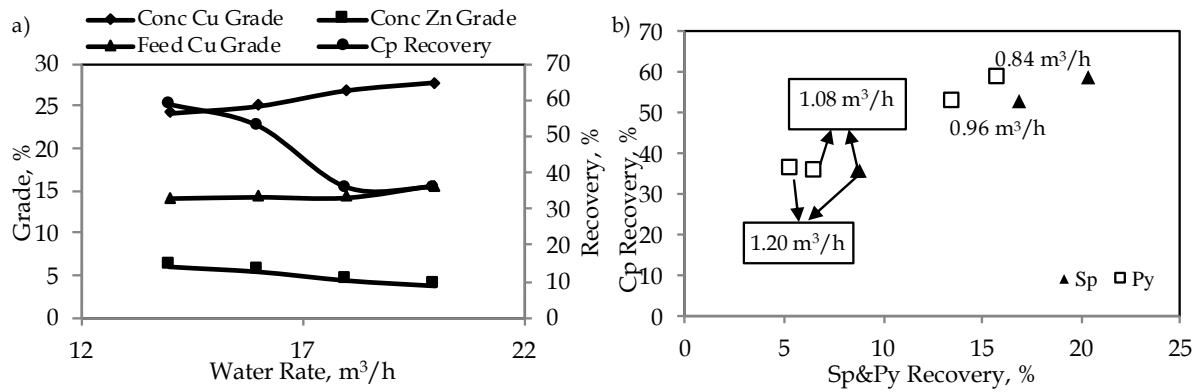


Fig 6. Performance (a) and selectivity (b) at different wash water rates (30 cm froth height and 12 m³/h airflow rate)

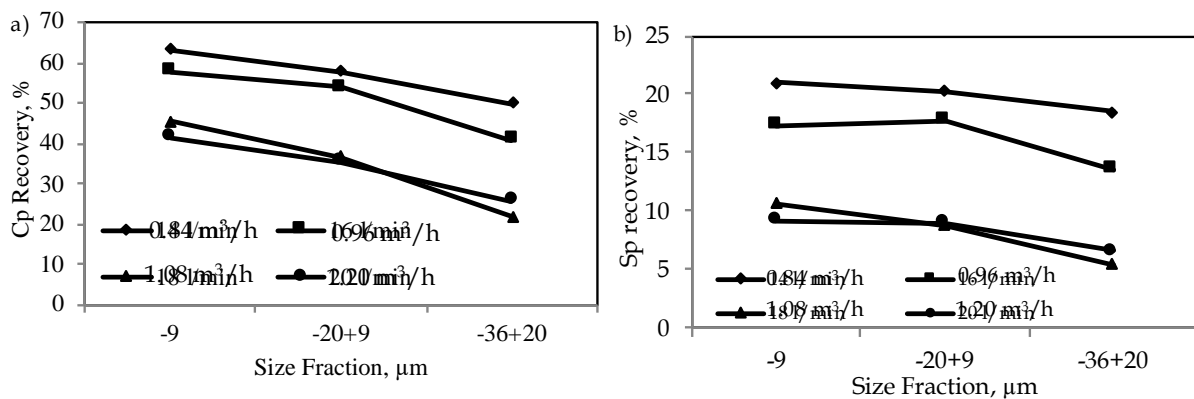


Fig. 7. Size by size chalcopyrite (a) and sphalerite (b) recovery at different wash water rates (30 cm froth height and 12 m³/h airflow rate)

3.1.4. Distribution of wash water

Two set of tests were performed to reveal the difference between high and low wash water rate. Cu first cleaner concentrate stream was used in the tests with 30 cm froth height, 10 cm of wash water rig level and 12 m³/h airflow rate. These parameters kept constant during the entire study. Two barrels of wash water were prepared including 1 ppm chemical tracer in each, with an adjustable peristaltic pump; the volumetric flow rate was arranged.

In the first set, the wash water rate was adjusted to 0.96 m³/h and samples were taken around the pilot column in ten minutes time interval. At the end of thirty minutes, the wash water rate was adjusted to 0.48 m³/h but to obtain constant volumetric flow rate and retention time, 0.48 m³/h of water, without any tracer, was combined to feed stream. After thirty minutes, as the process was stable, the sampling started just as the same way done in the first set.

After the survey, the samples were filtered and the filtrates were collected to be analysed by UV visible spectroscopy. The solids were analysed for Cu, Zn and Fe. The mass balanced tonnages and elemental assays are given in Table 3.

In both test conditions, the specification of Cu first cleaner concentrate stream is almost the same. The water tonnages of the concentrate and tail stream in both tests were close to each other but the distribution of wash water was different (Table 4). Recovery and grade of the concentrate were significantly affected by the wash water rate. It was observed that both the recovery and grade of the unwanted minerals in the copper concentrate were lower at higher wash water rate.

The second effect of the change in wash water rate is the distribution of wash water. In the first set, in which the wash water rate was 0.96 m³/h, the per cent of wash water that passes to concentrate stream was 44% and the split of water coming from feed stream was 7.9%, but in the second set of test, it was found as 54% and 13.6% respectively. Thus, low amount of wash water rate increased the percent of

feed water that passes to froth zone that led to higher gangue recovery. By the aid of tracer tests, new information was obtained about the impact of wash water on column flotation process. As mentioned before, wash water rate is the easiest parameter to be adjusted in column flotation applications, yet the effects of such difference is not fully investigated and modelled. To have a better understanding, a detailed study should be done by using similar tracing methods, which would supply valuable data to characterize the behaviour of wash water.

Table 3. Performance values for tracer tests

STREAM	1 st set (0.96 m ³ /h wash water rate)				2 nd set (0.48 m ³ /h wash water rate)			
	tph Solids	tph Water	Cu %	Zn %	tph Solids	tph Water	Cu %	Zn %
Cu first cleaner Stream	0.43	0.85	11.65	10.74	0.45	1.40	11.49	9.78
Concentrate	0.15	0.41	22.00	6.76	0.21	0.46	19.23	7.25
Tail	0.28	1.35	6.36	12.77	0.24	1.45	4.79	11.97
Column Feed	0.43	1.76	11.65	10.74	0.45	1.91	11.49	9.78
Wash water		0.91				0.51		
	Recovery (%)				Recovery (%)			
STREAM	Copper	Zinc	Pyrite	Gangue	Copper	Zinc	Pyrite	Gangue
Concentrate	63.87	21.30	18.90	30.32	77.66	34.40	27.20	41.59
Tail	36.13	78.70	81.10	69.68	22.34	65.60	72.80	58.41
Column Feed	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 4. Distribution of wash water and feed water between the concentrate and tail

		Water tonnage flows		% Split of water flowing		Distribution of wash water (%)
		from feed stream		from feed stream		
1 st set (0.96 m ³ /h)	Concentrate		0.08		7.87	44.33
	Tail		0.94		92.12	55.67
2 nd set (0.48 m ³ /h)	Concentrate		0.19		13.64	55.96
	Tail		1.24		86.97	44.04

3.2. Cu rougher concentrate

Since the results obtained from Cu first cleaner concentrate stream are satisfactory, the idea of using the column flotation at the rougher stage has gained great importance. The tests were conducted to see whether the conditions met similar to first cleaner concentrate stream. The flowsheet given in Fig. 8 shows the possible circuit diagram when the copper rougher concentrate stream combined to a flotation column.

The overall performance of the column and the comparison of the standard condition with the modified one are presented in Fig. 9. In standard condition, copper content of the concentrate stream reached up to 21.8% with a recovery value of 62%. The zinc metal content of the concentrate remained almost the same with an average of 5.2%. When the wash water amount is increased, performance is not being that much affected, particularly the copper grade of the concentrate. Only 0.2% improvement in copper content is obtained with an increase in recovery about 3%.

The impact of modification in airflow rate is much higher than wash water rate. As the airflow rate adjusted to 2 m³/h less than the standard condition, the copper grade of the concentrate reached to 26.7%, which means 77% of the concentrate consists of chalcopyrite, with a recovery value of 20%. The copper grade is much higher than expected in a single stage operation done to copper rougher concentrate stream but as mentioned before the amount of material produced is very low compared to previous studies and this is clearly the main factor responsible of recovery suffering.

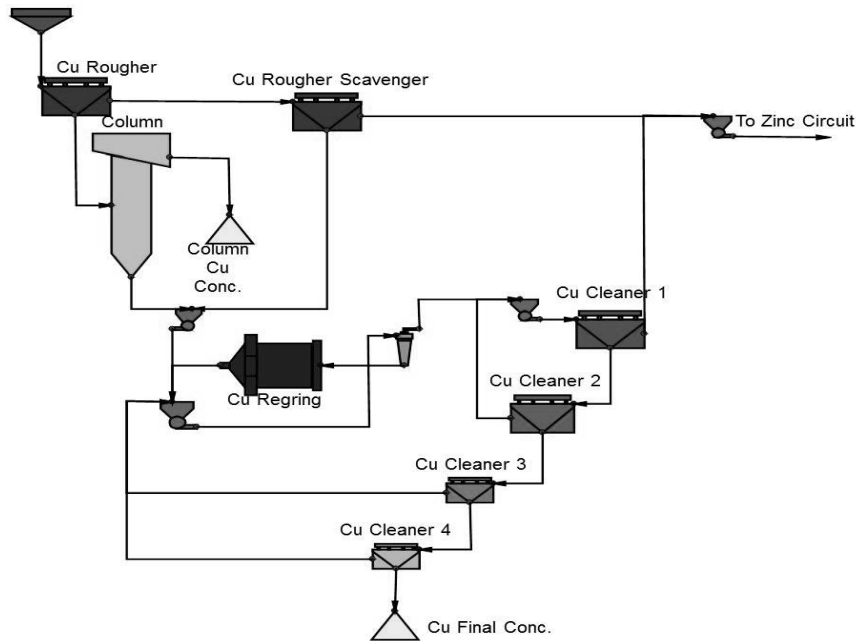


Fig. 8. Possible flowsheet after column installation for Cu Rougher Concentrate

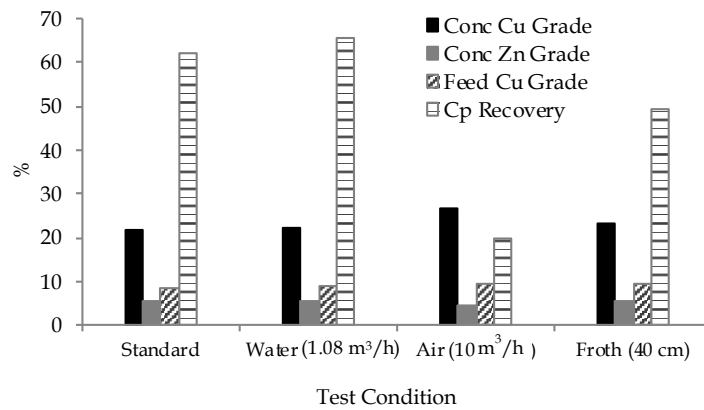


Fig. 9. Performance of column with Cu Rgh Conc stream at different operating conditions

The froth height, which is a major component in column flotation applications, was subjected to comparison test and showed a good correlation between froth height-concentrate grade and recovery values. Compared to standard condition, the copper content reached to 23.1% with 1.3% variation and recovery decreases down to 49% with a difference of 13%. Lower airflow rate reduces the chalcopyrite recovery due to less mass pull, so this parameter is out of consideration in this situation (Fig. 10a).

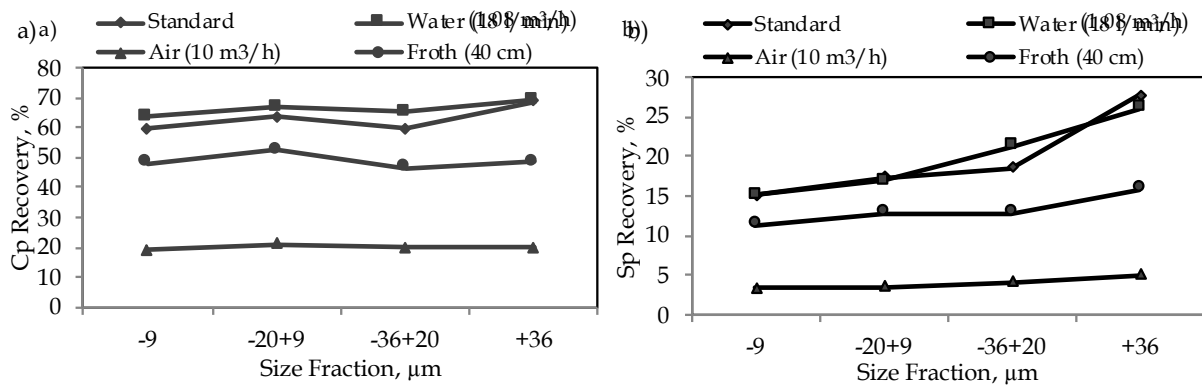


Fig. 10. Size by size chalcopyrite (a) and sphalerite (b) recovery at each condition

Recoveries in standard and wash water rate tests were almost the same for each size fraction (Fig. 10b). As mentioned before, the recovery in airflow rate test has the least value due to very low concentrate mass pull. The increase in froth height decreased the sphalerite recovery by 5% but it also reduced the amount of copper recovery by 10% and this did not provide a cleaner concentrate.

The tests done to copper rougher concentrate stream show that even in highly contaminated conditions, flotation column works effectively and removes most of the unwanted minerals compared to conventional cells.

3.3. Copper third cleaner concentrate

The concentrate of the third cleaner cell was combined to pilot column and the same test conditions in rougher concentrate stream were carried out (Fig. 11).

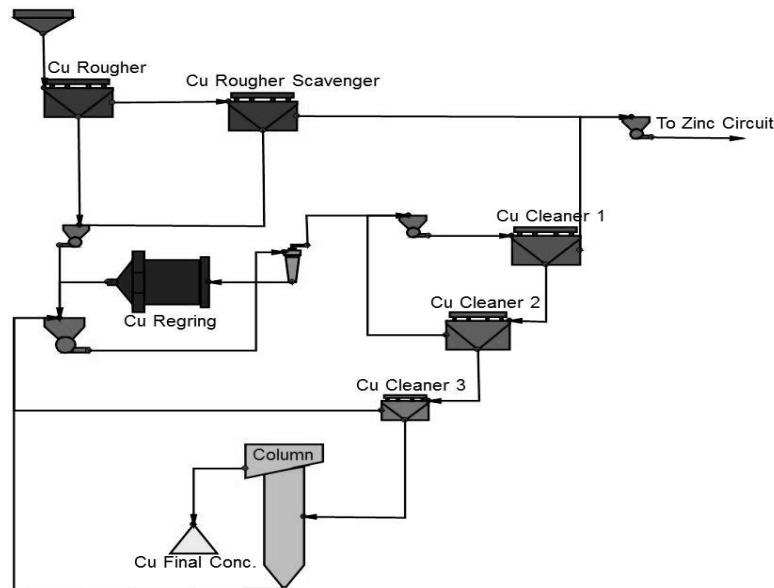


Fig. 11. Possible flowsheet after column installation for Cu Third Cleaner Concentrate

The results indicated that the best performance was acquired with standard operating conditions (Fig. 12). The performances obtained from higher wash water rate and lower airflow rate tests showed a similar relationship separately. As expected, due to low rate of concentrate flow, in the test with higher froth height the amount of recovered copper metal was placed to last position compared with other tests. The zinc grade of the froth height test had the greatest value while the copper content of this concentrate had the lowest measurement.

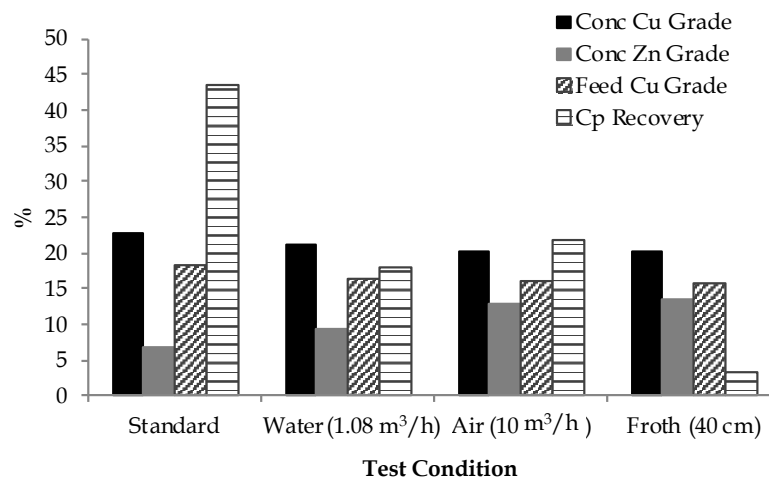


Fig. 12. Performance of column with Cu Third Cleaner Concentrate stream at different operating conditions

In term of recovery, Fig. 13a reveals that the standard test condition serves the best result for copper in all size fractions. Using higher wash water rate to obtain a cleaner concentrate from the column flotation, decreases the recovery of copper without improving the metal content. Size-by-size analysis of the froth height test shows that at each size fraction, the copper recovery remains below others. The recovery values of sphalerite (Fig. 13b) decrease as the parameters are set to comparative condition in both cases but the chalcopyrite recovery decreases in these circumstances either. Although the grade values and enrichment ratios are close to each other in all test conditions, the recovery values obtained in copper third cleaner concentrate stream with standard test condition seems the best result.

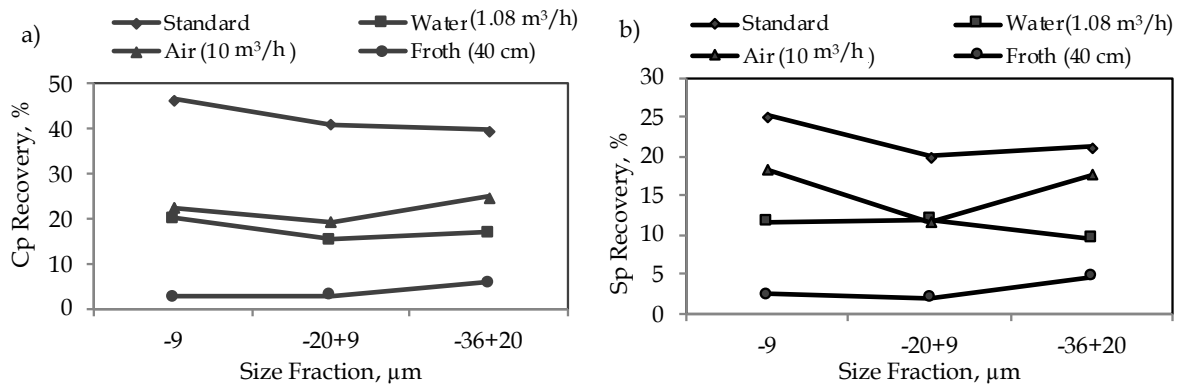


Fig. 13. Size by size chalcopyrite (a) and sphalerite (b) recovery at each condition

With these series of tests, the effects of froth height, wash water rate and airflow rate on flotation behavior were verified and the optimum parameters for modelling & simulation studies were provided. According to the test results; rougher concentrate and/or first cleaner concentrate streams were much suitable streams for column installation. However, recirculated streams as in real circuit design should be considered therefore, modelling and simulation studies were performed. Providing feedback of plant staff, the simulations were done for flotation column application in both rougher-cleaner concentrate streams and it is accepted to place two flotation columns to rougher concentrate stream and another two flotation columns to first cleaner concentrate stream in series. As a summary of simulation studies, two copper concentrates can be obtained which are including 22% Cu, 4% Zn (like typical concentrate of ore type B) and 17% Cu 8% Zn (like typical concentrate of ore type A) without any decrease in overall recovery of plant.

4. Conclusions

With this study, it is elucidated that column flotation is applicable in this copper circuit equipped with mechanical cells, and the relationship between the operating parameters and column performance are established. The effects of froth height, wash water rate, airflow rate on flotation behaviour were verified and the optimum parameters for modelling & simulation studies were provided. The results of the pilot scale tests indicated that, in the rougher and the first cleaner concentrate streams the beneficiation was much higher and the recovery values were high enough for a cleaner unit. The average production of plant used to be, 15-17% Cu and 7-10% Zn in ore type A, but with the columns installed in the circuit two different concentrates are being produced which are including 22% Cu, 4% Zn (like typical concentrate of ore type B) and 17% Cu 8% Zn (like typical concentrate of ore type A) without any decrease in overall recovery of plant. As a result of simulation studies, rougher concentrate and/or first cleaner concentrate streams are advised as the most suitable stream(s) that an industrial scale flotation column can be installed.

Additional tests were also done in this study for determining the distribution of wash water. The results indicated that the higher wash water rate reduced the amount of water passes from column feed to concentrate stream, thus entrainment. In addition, the effect of wash water on recovery and grade of copper was verified as the higher addition rate of wash water decreases the recovery of minerals but increases the grade of concentrate.

The column flotation is a widely used and common technique, which allows an effective cleaning in mineral processing, but it is not fully understood. The key feature of wash water addition and the effect of this parameter are still being investigated by researchers. Current simulation programs are lack of appropriate model for the unique component of flotation columns, wash water addition. Further studies should be done to have more data, for modelling the role of wash water in flotation column applications, which will provide better understanding while simulating the flotation conditions of plants.

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