

To Recycle or Not? A Bench Scale Simulation of Water Recirculation in Sulfidic Cu-Ni Ore Flotation

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Abstract

The mining industry recycles and re-uses its process water as a way of responding to the global scarcity of water. The recycling of water may increase the salinity of process water. Residual reagents may also be present in the recirculated water. It is thus important to mimic water recycling so as to investigate the effect that water recirculation and residual reagents will have on flotation performance. This work showed increases in the electrical conductivity of recirculated water suggesting an accumulation of ions in the recirculated water. This in turn resulted in an increase in the amount of water and solid particles reporting to the concentrate. Cu and Ni recoveries remained unchanged showing that the increase in solids recoveries was due to increases in gangue recovery which in turn led to a minimal decrease in the concentrate grades. Furthermore, there was an increase in residual xanthate and CMC with each recirculation.

Keywords: Coagulation, Electrolytes, Flotation, Polysaccharides, Water quality

Introduction

Flotation as a process through which valuable minerals are separated from non-valuable minerals uses water as a transport medium. With water being an essential part of the flotation process, it stands to reason that its quality or chemistry is of paramount importance in the concentration of Cu-Ni-Pt sulfide ores since interactions between reagents and solid particles in flotation pulps depend on the surface chemistry of the pulp phase. Given the high water usage in flotation circuits, water conservation efforts such as process water recirculation are being proposed. This however presents a challenge in that increased use of recycled water in flotation may effect the process owing to an accumulation of inorganic and organic species which may interfere with important aspects of flotation. These species may inadvertently activate gangue and thereby decreasing the grade of the concentrate (Rao and Finch, 1989). It is for this reason that flotation circuit optimisation efforts must consider the effect of water recirculation on the quality of water as well as the resulting effect on the selectivity of the process. These efforts should be targeted towards ensuring that optimal recoveries of the targeted minerals are achieved without

the dilution of the concentrates. It is also reported that water recirculation may be advantageous in several aspects beyond just enhancing water use efficiency, but could potentially reduce operating costs and increase the profitability of the plant through a reduction in reagent dosing since recycled water may contain residual reagents such as collectors, depressants and frothers which are very important to flotation. This benefit may also arise from the fact that reagents such as frothers could be reduced in their dosages for as long as the water contains inorganic electrolytes enough to inhibit bubble coalescence and in turn yield the desired froth stability at lower or no frother dosages (Manono et al., 2018, 2012; Slatter et al., 2009). This action of inorganic electrolytes on the stability of the froth rises from the fact that recirculated water may contain high concentrations of divalent ions such as Ca^{2+} , Mg^{2+} and SO_4^{2-} which are said to compress the electrical double layer and increase the efficiency of the particle-bubble attachment process by reducing the electrostatic repulsion between the bubble and particle (Liu et al., 2013). Not only can these divalent compress the electrical double layer, but they can favour the formation of

smaller stable bubbles, thereby increase the bubble particle collision rate (Liu et al., 2013). It is however said that despite the advantages of using recycled water, there may well be drawbacks in using recycled water in that if there is no proper control of water quality and reagents dosing, residual reagents and excessive amounts of inorganic electrolytes in recirculated water may cause overly stable froths which may in turn reduce the selectivity and result in decreased concentrate grades (Slatter et al., 2009; Rao and Finch, 1989). Furthermore recirculated water may contain high concentrations of oxyhydroxyl species, carbonate and sulphate precipitates. These may coat the surface of the sulfide mineral meant to be floated and thereby hinder the interaction of the collector with the mineral surface (Bruckard et al., 2011; Ikumapayi et al., 2010; Levay et al., 2001; Ma et al., 2009). This in turn would decrease the sulfide mineral recoveries.

Thus this study considered a bench scale simulation of water recirculation in a sulfidic Cu-Ni ore flotation. The study aimed at investigating how long it would take for solids in the tails to settle such that a supernatant of recyclable quality can be obtained in order to mimic and assess the recyclability of water from the tailings ponds. The amounts of residual depressant and collector present in the recyclable liquid supernatant (water) were also considered. Furthermore, the clear supernatant was analysed for its inorganic content present in the recycled water by measuring the pH and electrical conductivity. The effect of recirculation was examined on key flotation measurable outputs, namely, the recoveries and grades of valuable (Cu and Ni) sulfide minerals

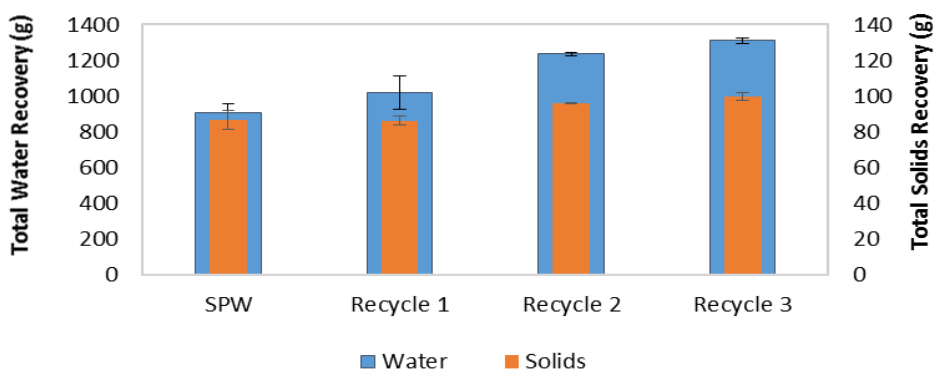
Methods

For each test, 3 kg of a Merensky ore was milled in a stainless-steel rod mill with the water being investigated. Sodium isobutyl xanthate (SIBX) was used as a collector and added to the mill at a dosage of 150 g/ton as is the general practice in most Cu-Ni-PGM concentrators. Milling was performed such that a grind of 60% passing 75 microns was attained. The milled slurry was transferred to an 8 L flotation cell, after which the relevant amount of water was added to the

cell such that the slurry contained 37.5% solids. The impeller speed of the 8 L cell was set to 1200 rpm. A feed sample of the slurry was taken from the float cell after which the slurry was conditioned with Depramin 267, a carboxymethyl cellulose (CMC) as a depressant at a dosage of 300 g/t. This was conditioned for 2 minutes after which DOW 200 was added as a frother at a dosage of 40 g/ton and allowed to condition for 1 minute. After all reagents had been conditioned, an air valve of the cell was opened to allow the froth to develop and the air flowrate was maintained at 12.9 L/min for all flotation tests conducted. Four concentrates were collected at time 2, 6, 12 and 20 minutes by scraping the froth into collection pans at 15 seconds interval. The froth height in the cell was controlled and maintained at 2 cm by topping up with water. After each flotation test, two tailings samples were taken. The water recovered in each of the four concentrates was measured and recorded. The four concentrates along with the feed and tailings samples were filtered, dried in the oven and weighed before they were sent for further analysis. The water recovered during the filtration of the concentrates was discarded. The bulk of the tailings from the flotation tests was filtered in the filter press and the water recovered was recirculated in the flotation system. A sample of the recirculated water was taken for analysis to determine the residual collector and depressant content in the water. All flotation tests were conducted in duplicates. The analysis of the Cu and Ni content in the concentrate, feed and tails samples was conducted using the Bruker X-Ray Fluorescence (XRF) S4 Explorer Spectrometer. For each of the concentrates, the difference between the total mass of valuable mineral (i.e. chalcopyrite and pentlandite) and the total mass of the concentrates was determined to be the mass of the gangue minerals. To determine the inorganic content present in the recycled water, a sample of the clear supernatant obtained after the filtration of the bulk tailings was analysed using an electrical conductivity (EC) and pH meter. The EC and pH meter were used as proxies to determine the ionic strength of the recyclable plant water. To mimic and assess the recyclability of water from the bulk tailings, a settling time test was conducted to determine

Table 1 Concentration of ions present in the fresh synthetic plant water (SPW).

Water type	Ca ²⁺ (mg/L)	Mg ²⁺ (mg/L)	Na ⁺ (mg/L)	Cl ⁻ (mg/L)	SO ₄ ²⁻ (mg/L)	NO ₃ ⁻ (mg/L)	NO ₂ ⁻ (mg/L)	CO ₃ ²⁻ (mg/L)	TDS mg/L	Ionic Strength [mol/L]
SPW	240	210	459	861	720	528	-	51	3069	0.0727

**Figure 1** Total solids and water recovery using SPW and recirculated water.

the time it takes for the solids to settle such that a supernatant of recyclable quality can be obtained. To determine the settling time, a tailings sample was drawn from the float cell into a 250 mL conical flask. The sample was agitated using a plastic stirring rod; prior to the timing of the settling began. The settling time of the solids was determined once the solids had settled and solids surface became visibly stagnant. The settling time of the solids was determined after each run of the flotation tests for both the original test and the duplicate, to determine if the implication of ion accumulation after each recycle would have an effect on the solids settling time. Supernatant samples were taken after the filtration of the bulk tailings to analyse the residual xanthate collector in the recirculated water. The concentration of residual xanthate in the recirculated water was determined using a UV/Vis spectrometer. To determine the residual CMC depressant present in the recyclable water, a similar procedure to that of the determination of the residual collector was followed in accordance to the du Bois method (du Bois et al., 1956). The concentration of ions present in the fresh synthetic plant water (SPW) is shown in Table 1.

Results and Discussion

Figure 1 illustrates the effect of water recirculation on the total amounts of water and solids recovered during the flotation

of the selected Merensky ore. There is a general trend of an increase in solids and water recoveries as the water changes from fresh synthetic plant water to the 3rd recycle. This result could be due to an increase in the stability of the froth as the electrical conductivity and therefore ionic strength (IS) increased in the same order as shown in Figure 2. This trend is in line with previous findings which have shown that increases in IS stabilise the froth more, thereby resulting in increases water and solids recoveries. (Manono et al., 2018a)

Figure 2 shows the alkalinity and electrical conductivity of the fresh synthetic plant water and recirculated waters. It can be seen that as the number of recycles increases, the electrical conductivity of the water had a steady increase. The alkalinity of the water decreased with each recycle. These results suggest that the recirculation of water increased the amount of electrolytes in water. These are said to be in agreement with speculations made by previous authors and hence the premise of this work (Levay et al., 2001; Manono et al., 2018b; Muzenda, 2010; Rao and Finch, 1989; Slatter et al., 2009)

Figure 3 shows the residual SIBX collector present in the supernatant to be recycled after each flotation test. An increase in the residual collector is seen with each recirculation of process water. It is however clear that as the number of cycles increases, the change of

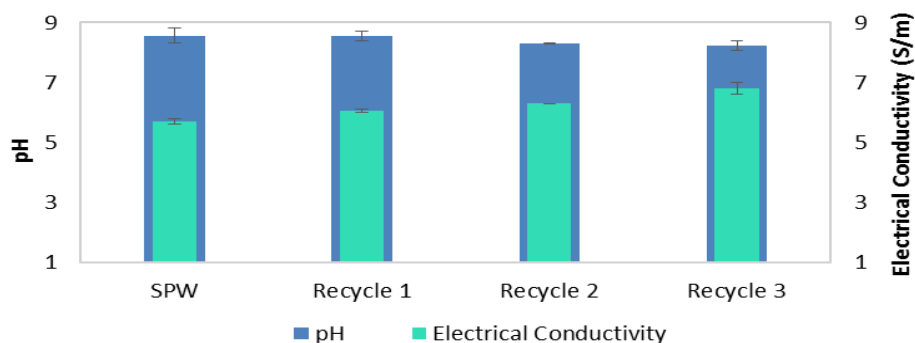


Figure 2 pH and Electrical Conductivity of SPW and recirculated water before flotation.

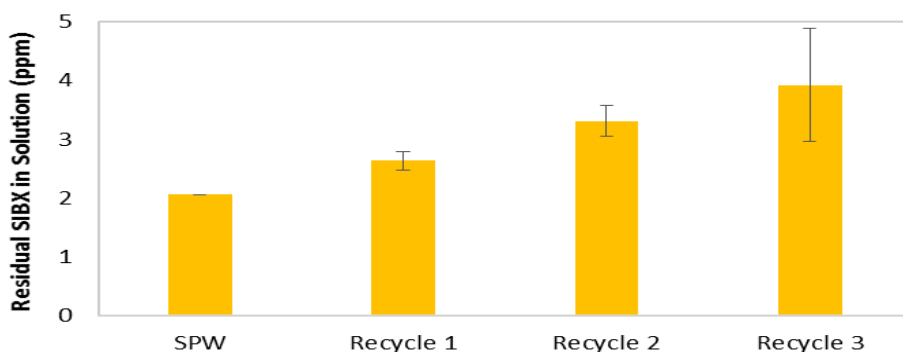


Figure 3 Residual concentration of SIBX in various waters after flotation.

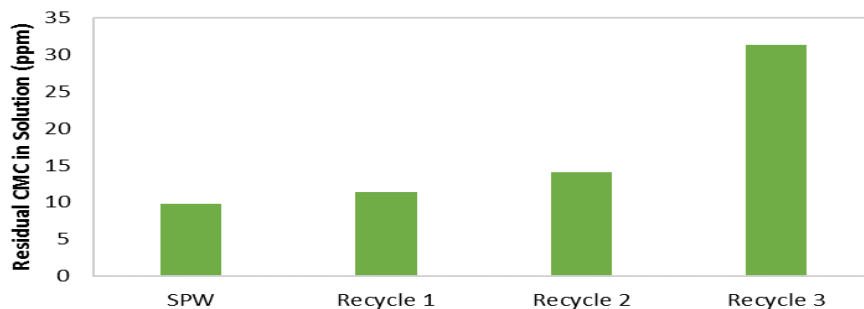


Figure 4 Residual CMC present in various waters after flotation.

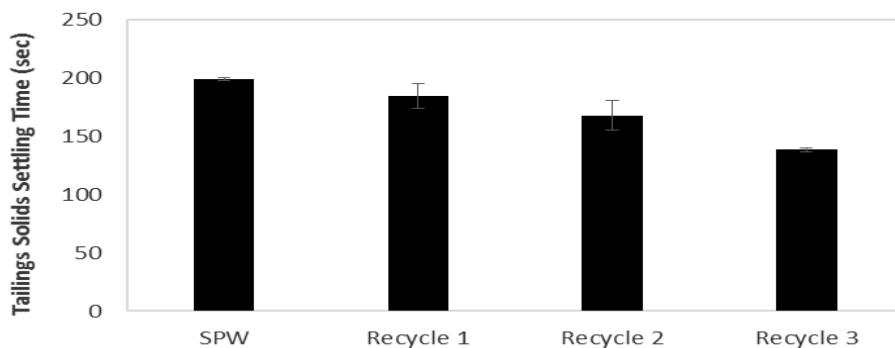


Figure 5 Settling time of solids in the tailings after flotation.

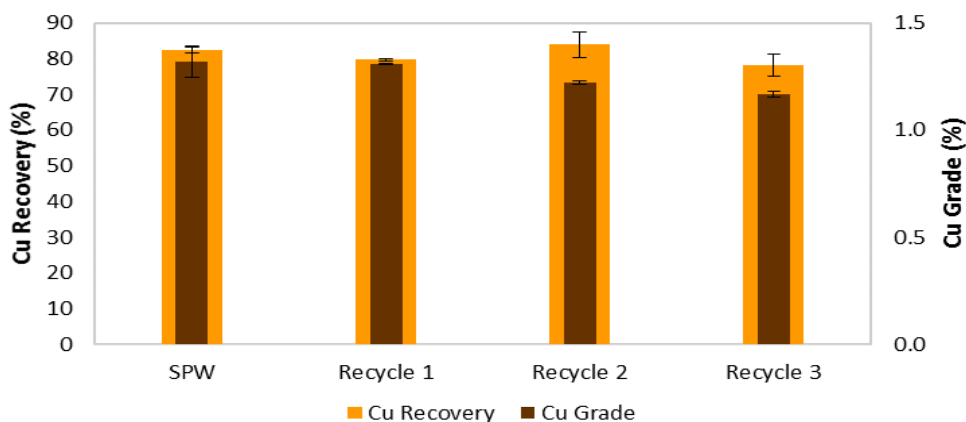


Figure 6 Copper recovery and grade in fresh SPW and recirculated water.

an increase in residual SIBX is lower than the 2 mg/L which remained after floating with fresh SPW in that the step change of an increase in SIBX concentration between SPW and Recycle 1, Recycle 1 and Recycle 2, and Recycle 2 and Recycle 3 is ≈ 0.6 mg/L on average. This may well imply that the interaction of the collector with the mineral surface in flotation is affected by the quality of the water used during flotation.

Figure 4 shows the concentration of the residual CMC present in each of the waters that were to be recycled from their flotation tails. A steady increase in the concentration of CMC in the recyclable supernatant is observed in that after floating with SPW as the water source, 9 mg/L of CMC remained in the tailings water and 31.4 mg/L CMC remained in the tailings water after flotation with Recycle 3.

Figure 5 illustrates the settling time of solids from the tails for the fresh synthetic plant water as well as the recycled waters after flotation. It can be seen that the settling time of solids decreased as the number of recycles increased. It is believed that the tails become more coagulated as the number of recycles increased owing to the reported increase in electrical conductivity as it has been shown that increases in the ionic strength of plant water results in increases in mineral particle coagulation especially when CMC is part of the system (Manono et al., 2018a).

Figure 6 shows the recovery and grade of Cu after floating with fresh synthetic plant water and recirculated water. It can

be seen that Cu recovery in fresh SPW and recirculated waters was well within 80%. Both the 1st and 3rd recycled waters yielded the lowest Cu recovery ($\approx 78\%$) whereas the fresh SPW and the 2nd recirculation of water yielded the highest Cu recoveries averaging 83%. The concentrate Cu grade showed a slight decrease with each recirculation though it may not be statistically significant as the difference was well below 0.5%.

Figure 7 shows the recovery and grade of Ni after floating with fresh synthetic plant water and recirculated water. Both the fresh SPW and 2nd recycled waters yielded the lowest Ni recovery (41% and 42% respectively) whereas the 1st recirculated water and the 3rd recirculation of water yielded the highest Ni recoveries (of 45% and 44% respectively). It is important to mention that this trend is the opposite of the Cu flotation recoveries. The concentrate Ni grade remained fairly constant regardless of water recirculation.

Figure 8 shows a trend of a slight increase in the amount of gangue reporting to the concentrate with each recirculation. This provides reasons for the slight decrease in mineral grades with recirculated water.

This investigation has shown that as the water is recirculated, the electrical conductivity (EC) increases. This can be ascribed to an accumulation of ions. This suggests that with each recirculation, the ionic strength of the water increased. Although the recirculation of water increased the amount of water recovered owing to an increase in froth stability, the solids recovered showed

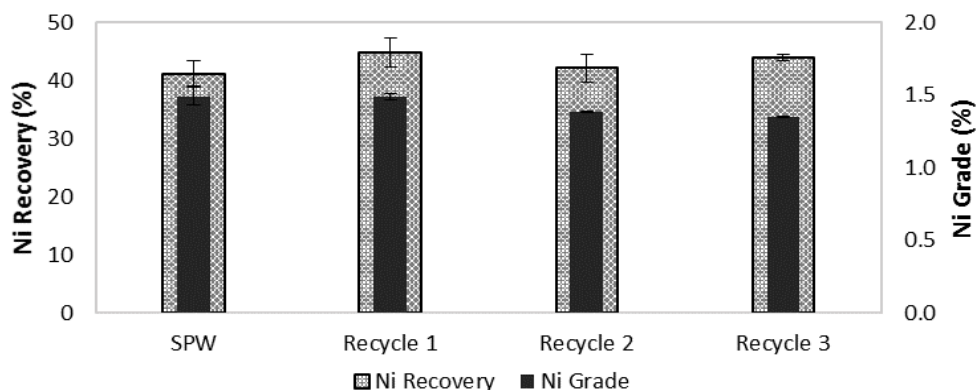


Figure 7 Nickel recovery and grade in fresh SPW and recirculated water.

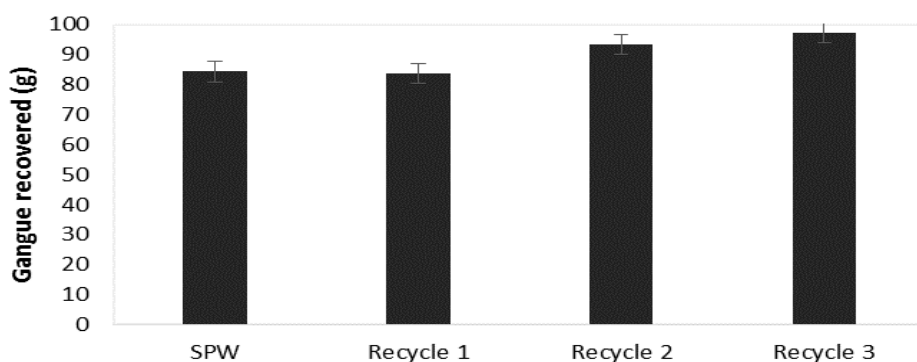


Figure 8 The amount of gangue recovered in fresh SPW and recirculated water.

very slight increases. The slight increase in solids recovered is due to a very minimal increase in gangue recovery as seen in Figure 8. The recirculation of water did seem to have a strong effect on the recoveries and grades of Cu and Ni. The increase in gangue recovery between the initial and final run was very minimal to effect the concentrate grades and therefore proves that in the current study, water recirculation had little or no effect on flotation performance.

Conclusions

It was shown that recirculating water increased the electrical conductivity of the process water as well as the amount of residual reagents. However, there was no evidence of a negative influence on the recoveries and grades of Cu and Ni. The slight increase in solids recovery is a result of a little more gangue being entrained and recovered into the froth owing to a more stable froth. On the

basis of the findings of this work, plant water recirculation may prove beneficial owing to increases in the inorganic electrolytes and residual reagents in the process water which seemed not to have affected flotation negatively.

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