# How process water variables affect the management of gangue in flotation for a selected Cu-Ni-PGM Ore

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The issue of process water quality has become one of critical importance for many concentrators processing Cu-Ni-PGM sulfide ores in Southern Africa. There is an increasing demand to recycle and re-use onsite water with very little or no dependence on municipal water owing to several key considerations which are, inter alia, legal compliance, water scarcity, environmental protection, mine closure requirements, production penalties, and socio-political pressure. It is therefore a necessity for the mining and resources industry's R & D thrust to focus on the reduction of freshwater consumption, the removal of contaminants from mine water seepages and effluent, and the realisation of highly water efficient processing plants. However, for these foci to be realised, it is important to understand how certain aspects of flotation such as gangue management are affected by process water variables such as inorganic electrolytes, increased ion concentrations, ionic strength ($I$) and total dissolved solids (TDS). This paper presents a bench scale investigation of the behaviour of gangue, its floatability and entrainability, in process water of various inorganic constituents, ionic strength, and TDS for a selected Cu-Ni-PGM ore in the absence and presence of carboxy methyl cellulose as a depressant. Findings of this study will benefit Cu-Ni-PGM ore concentrators towards gaining a better understanding of the effects that various process water constituents have on gangue management, and thereby make informed decisions on process water quality control for the desired value recoveries and grades.

**Keywords:** Divalent ions, entrained gangue, floatable gangue, ionic strength, water quality

## INTRODUCTION

Froth flotation is the most commonly used method to selectively separate valuable sulfides from non-sulfide gangue in sulfidic Cu-Ni-PGM ores. While reagents used in flotation may be well understood in process water of low ionic strengths (fresh water), the effects of these reagents in flotation in degrading water quality of high ionic strengths are not well understood (Manono *et al.*, 2018a). The scarcity of water has become a serious problem for the mining sector as many mineral and metallurgical processes such as flotation are water reliant. To circumvent the scarcity of water, processing plants are using onsite water recirculation schemes, the consequence of which is the degradation of water quality with every cycle. The recycled water can be problematic in that its ion concentration, dissolved solids, and biological constituents may be different from fresh water and these uncommon quality variations may impact process plant performance. Examples of the effect of water recirculation on the quality of water and the resulting impact on plant performance are reported in the literature on how the recycling of process water has been reported to cause increases in the ionic strength ($I$) of process water; this has in turn had implications for the flotation performance as it pertains to recoveries and grades (Corin and Wiese, 2014; Slatter *et al.*, 2009). Ions such as calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$), nitrate ($NO_3^-$), sulfate ($SO_4^{2-}$) and chloride ($Cl^-$) are seen to accumulate within the recirculated water in mineral processing (Harrison *et al.*, 2018.; Rao and Finch, 1989; Slatter *et al.*, 2009; Wang and Peng, 2014).

These ions present in recirculated water may affect the hydrophobicity of minerals through interactions occurring at the mineral surface (Manono *et al.,* 2018a) and therefore flotation performance is affected negatively in recoveries and grades. Synthetic plant water containing some of the aforementioned ions has been used to mimic plant operating conditions in order to determine the effect of degrading water on flotation performance for Cu-Ni-PGM ores.

The majority of the studies which have used this approach have shown that much of the effects seen on flotation performance affect the behaviour of gangue and consequently the grades of the concentrates (Corin *et al.,* 2011; Dzingai *et al.*, 2021, 2020; Manono *et al.,* 2018b, 2012; Moimane *et al.,* 2016). Selected specific ions have been studied on the behaviour of gangue and froth stability for a selected Cu-Ni-PGM ore without a depressant (Manono e*t al.,* 2020). Specific ion effects on entrainment may also have a significant effect on the concentrate grade. Therefore, it is important to understand the floatability and entrainability of gangue under specific ions in process water. The effects of process water variables such as ion type and concentration on solids and water recoveries, floating gangue, entrained gangue, and valuable mineral recoveries and grades are important aspects to consider to better understand the consequences of onsite water recirculation on flotation performance. Such fundamental knowledge is critical in ensuring that plant operators make informed decisions in terms of interventions that would need to be made on the recirculated water without affecting plant performance.

**Materials and Methods**

A sample of a Platreef Cu-Ni-PGM ore was split into 1 kg samples, crushed, blended, and riffled. Using synthetic plant water (SPW) and single salt solutions (NaCl and $CaCl_2$) of an ionic strength of 0.0723 M, 66% solids slurry samples were milled in a laboratory scale stainless steel rod mill to 60% of the product grind passing 75 µm. The composition of the SPW and single salt solutions is shown Table I.

*Table I. Composition of SPW, $CaCl_2$ and NaCl*

| 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) | $CO_3^{2-}$ (mg/L) | TDS (mg/L) | Ionic Strength [M] |
|---|---|---|---|---|---|---|---|---|---|
| **SPW** | 240 | 210 | 459 | 861 | 720 | 528 | 51 | 3069 | 0.0727 |
| **$CaCl_2$** | 971 | - | - | 1718 | - | - | - | 2690 | 0.0727 |
| **NaCl** | - | - | 1671 | 2577 | - | - | - | 4249 | 0.0727 |

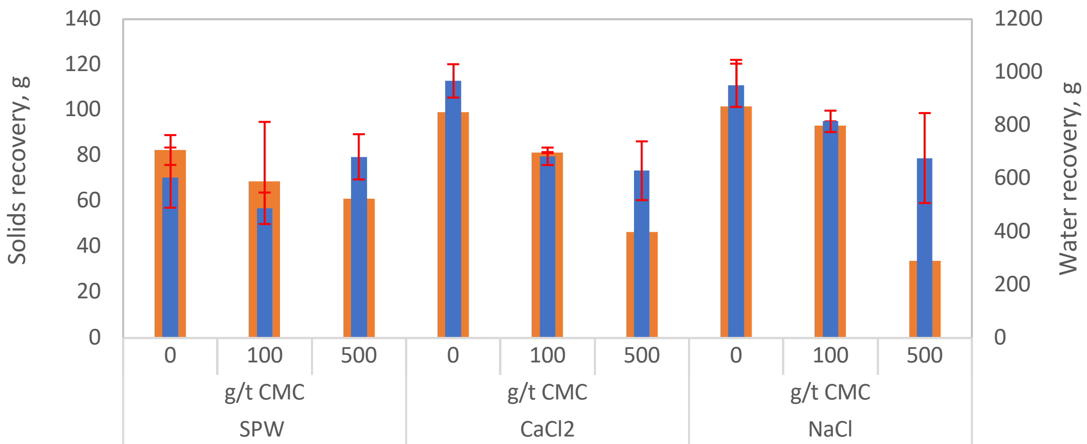
A 3 L Barker flotation cell was used with a volume of 35% solids by adjusting the slurry from the mill using either SPW or single salts solutions. The pulp level was controlled manually with the cell operating at a variable speed drive and an impeller speed of 1200 rpm. A constant airflow of 7 L/min was sustained throughout as well as a constant froth height of 2 cm. The cell's slurry height was corrected to 2 cm by the addition of the respective water solution continuously. The froth was scraped into a collecting pan every 15 s at the respective times of 2, 6, 12 and 20 min to collect four concentrates. Water usage was monitored throughout the experimental test work. Feed and tailings samples were collected at the start and end of each experimental test respectively. After flotation the collected feed, tailings and concentrates were filtered, dried, and weighed before each analysis. Cu and Ni assays from the collected concentrate, feed and tailings samples were determined using an Olympus Vanta Handheld-XRF Analyser. Each flotation test was conducted in duplicates for reproducibility. The standard error was generally within 5%.

Sodium isobutyl xanthate (SIBX) of a purity of 97%, supplied by Senmin, was used as a collector at a dosage of 150 g/t and was dosed directly into the mill prior to milling. DOW 200, supplied by Betachem, was used as a frother, and was added into the flotation cell at a dosage of 40 g/t. A polysaccharide in the form of sodium carboxy methyl cellulose (CMC), Depramin 267, supplied by AKZO Nobel, was used as a depressant, dosed into the flotation cell at 100 and 500 g/t while other tests were carried out in the absence of CMC. The inorganic salts used in preparing SPW and single salt solutions, supplied by Merck, were of analytical grade.

## RESULTS AND DISCUSSION

*Effect of SPW, $CaCl_2$ and NaCl on Solids and Water Recoveries*

Figure 1 illustrates the effect of synthetic plant water, $CaCl_2$ and NaCl on solids and water recoveries under various depressant dosages.




| | SPW 0 | SPW 100 | SPW 500 | CaCl2 0 | CaCl2 100 | CaCl2 500 | NaCl 0 | NaCl 100 | NaCl 500 |
|---|---|---|---|---|---|---|---|---|---|
| Total Solids rec, g | 82,54 | 68,69 | 61,22 | 99,11 | 81,41 | 46,63 | 101,80 | 93,33 | 34,00 |
| Total Water rec, g | 603,66 | 488,19 | 681,82 | 967,77 | 683,87 | 629,54 | 951,15 | 815,45 | 677,28 |

Total Solids rec, g　Total Water rec, g

*Figure 1. Total solids and water recoveries for all conditions tested.*

From Figure 1, it can be seen across solution type that increasing the depressant dosage resulted in a decrease in solids and water recoveries. A trend of this nature is expected since the presence of a depressant such as CMC in increasing dosages, destabalises the froth by depressing some of the froth stabilising non-sulfide naturally floatable gangue (NSNFG). At 0 g/t CMC (that is, in the absence of CMC), $CaCl_2$ and NaCl resulted in similar solids and water recoveries, however these were much lower than the recoveries seen with synthetic plant water (SPW). at 100 g/t CMC dosage, solids and water recoveries were in the order SPW>$CaCl_2$>NaCl. This trend could be attributed to findings in the literature which have shown that in the presence of CMC, solutions containing divalent cations such as $Ca^{2+}$ and $Mg^{2+}$ result in a greater depression of gangue and hence SPW which contains $Ca^{2+}$ and $Mg^{2+}$ in solution would result in lower solids and water recoveries compared to $CaCl_2$ and NaCl and hence $CaCl_2$ would also yield much lower solids and water recoveries compared to NaCl.

For a CMC dosage of 500 g/t, solids recoveries were in the order SPW>$CaCl_2$>NaCl whereas the water recoveries were in the order SPW>NaCl>$CaCl_2$. It is worth mentioning that at this CMC dosage, it is expected that all NSNFG is depressed and that any gangue reporting to the concentrate does so by way of entrainment (Wiese 2019, Corin *et al.*, 2011, Manono *et al.*, 2012). It is known in literature that monovalent cations such as $Na^+$ result have a lesser froth stabilising effect compared to divalent cations such as $Ca^{2+}$; this phenomenon could explain the lower solids recoveries in NaCl compared to SPW and $CaCl_2$ at 500 g/t of CMC.

*Effect of SPW, $CaCl_2$ and NaCl on Copper Recoveries and Grades*

Figure 2 illustrates the effect of synthetic plant water, $CaCl_2$ and NaCl on Cu recoveries and grades under various depressant dosages.

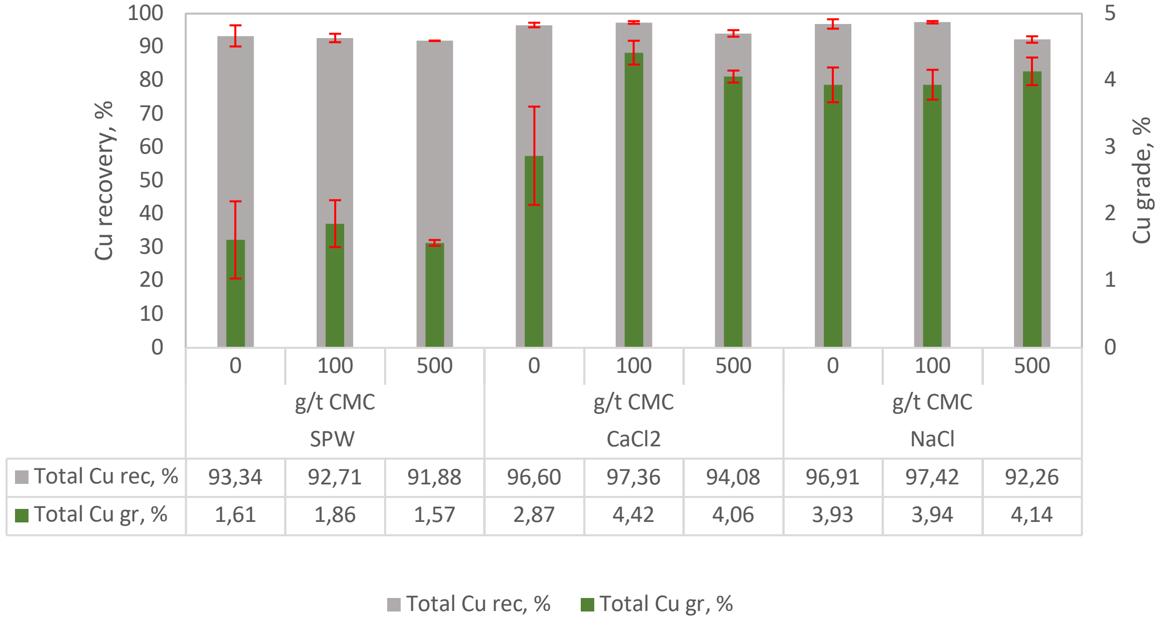


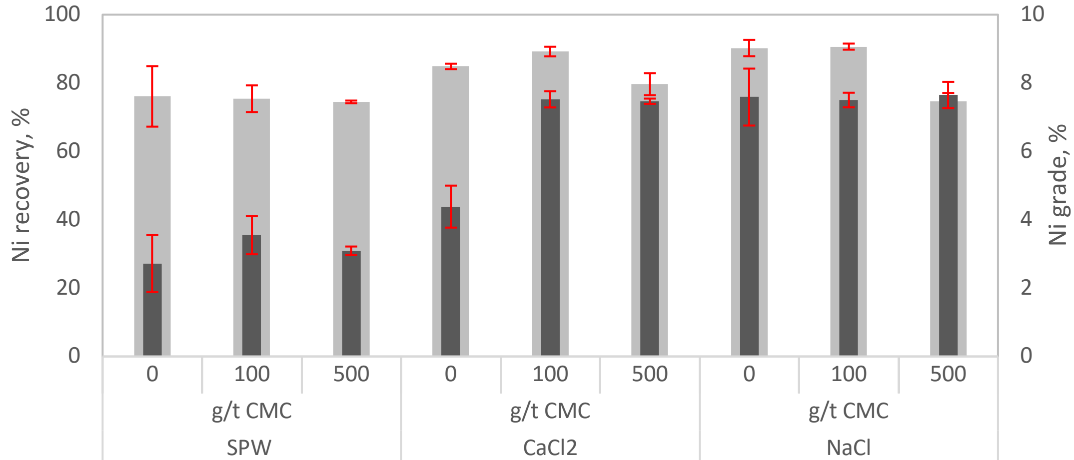

*Figure 2. Total Cu recoveries and grades for all conditions tested.*

From Figure 2, it can be seen across solution type that increasing the depressant dosage to 500 g/t resulted in a slight decrease in Cu recoveries, though this decrease may not be statistically significant. However, it is apparent that the recoveries for Cu were the lowest in SPW compared to $CaCl_2$ and NaCl, while $CaCl_2$ and NaCl resulted in similar Cu recoveries for each corresponding CMC condition. SPW also resulted in lower Cu grades compared to both $CaCl_2$ and NaCl. This trend is counter-intuitive in that SPW resulted in lower solids and water recoveries compared to both $CaCl_2$ and NaCl; it would thus have been expected that the grades of the concentrates would be higher in SPW.

In the absence of CMC, Cu recoveries were in the order SPW<$CaCl_2$≅NaCl whereas the grades were in the order SPW<$CaCl_2$<NaCl. It is generally expected that at a depressant dosage of 500 g/t, Cu grades would be higher compared to those obtained for a CMC dosage of 100 g/t, however this study's results have, for both $CaCl_2$ and NaCl, not shown differences in the Cu grades. This could suggest that for this given ore under these water quality conditions, the depression of NSNFG has already reached its full capacity at 100 g/t CMC such that further increases in CMC dosage would not yield better results in the concentrate grades.

*Effect of SPW, $CaCl_2$ and NaCl on Nickel Recoveries and Grades*

Figure 3 illustrates the effect of synthetic plant water, $CaCl_2$ and NaCl on Ni recoveries and grades in varying depressant dosages.




| | SPW 0 | SPW 100 | SPW 500 | CaCl2 0 | CaCl2 100 | CaCl2 500 | NaCl 0 | NaCl 100 | NaCl 500 |
|---|---|---|---|---|---|---|---|---|---|
| Total Ni rec, % | 76,10 | 75,42 | 74,49 | 84,86 | 89,21 | 79,68 | 90,24 | 90,65 | 74,75 |
| Total Ni gr, % | 2,72 | 3,55 | 3,09 | 4,39 | 7,52 | 7,47 | 7,59 | 7,50 | 7,65 |



*Figure 3. Total Ni recoveries and grades for all conditions tested.*

From Figure 3 it can be seen across solution type that increasing the depressant dosage to 500 g/t resulted in a slight decrease in Ni recoveries. It could be said that the higher CMC dosage of 500 g/t may have led to a depression of pentlandite-gangue composites which have been reported in the literature for ores similar to those used in this study (Becker *et al.*, 2009; Corin *et al.*, 2011). Ni recoveries were the lowest in SPW compared to $CaCl_2$ and NaCl – this trend is in line with the lower solids recoveries in SPW seen in Figure 1.

In the absence of a depressant, Figure 3 shows that both Ni recoveries and grades were in the order of SPW< $CaCl_2$<NaCl. In the presence of CMC at a dosage of 100 g/t, Ni recoveries were also in the order of SPW<$CaCl_2$<NaCl whereas the Ni grades were in order of SPW<$CaCl_2$≅NaCl. For the CMC dosage of 500 g/t, Ni recoveries were in the order of SPW≅NaCl<$CaCl_2$ whereas the Ni grade was in the order of SPW< $CaCl_2$≅NaCl.

*Effect of SPW, $CaCl_2$ and NaCl on the Entrainment of Gangue*

Figure 4 shows the amount of entrained gangue recovered for SPW, $CaCl_2$ and NaCl for a fixed depressant dosage of 500 g/t CMC. It must be stated that Wiese (2009), CMC dosages of between 300 and 500 g/t allow for a total inhibition of the floatability of NSNFG and that any gangue reporting into the concentrate would have done so by entrainment. This procedure ensures the determination of the degree of entrainment or the entrainment factor which can be reported as the amount of entrained gangue per unit water. This entrainment factor would thus be given by the slopes of the linear trends shown in Figure 4.

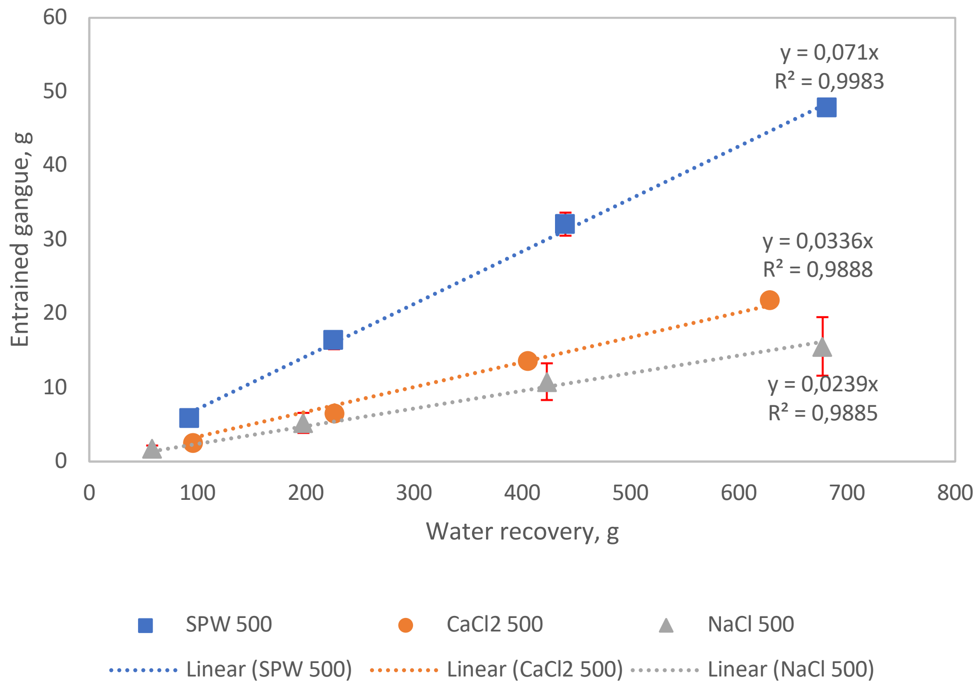



*Figure 4. Entrained gangue vs. water recovery for SPW, $CaCl_2$ and NaCl in 500 g/t CMC.*

Figure 4 shows the total amount of entrained gangue reporting to the concentrate for SPW, $CaCl_2$ and NaCl at 500 g/t CMC. SPW resulted in larger amounts of entrained gangue compared to $CaCl_2$, the recovery of gangue as well as the degree of entrainment was in the order of SPW>$CaCl_2$>NaCl. This therefore shows that the amount of entrained gangue per unit water was lower in NaCl compared to SPW and $CaCl_2$ for a fixed CMC dosage of 500 g/t. This trend is in agreement with the solids recoveries trend of SPW>$CaCl_2$>NaCl reported in Figure 1.

## CONCLUSIONS

Based on the results of this study, it was seen that for the selected ore:

- Solids and water recoveries were higher in $CaCl_2$ and NaCl compared to SPW, suggesting a greater stabilisation of the froth in both $CaCl_2$ and NaCl.
- Cu and Ni recoveries were higher in $CaCl_2$ and NaCl compared to SPW.
- Both Cu and Ni grades were higher in $CaCl_2$ and NaCl compared to SPW.
- The degree of entrainment was higher in SPW compared to $CaCl_2$, and NaCl resulted in the lowest degree of entrainment.

It is important to note that the effects of inorganic electrolytes seem to depend on two actions of inorganic electrolytes, namely, their action at the solid-water interface with a significant bearing on the ion-mineral particle-CMC interaction as well as their action at the air-water interface which significantly influences the stability of the froth. Both actions are of outmost importance in terms of the resulting influence on the mass pull.

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