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The effect of ionic strength of plant water on valuable mineral and gangue recovery in a platinum bearing ore from the Merensky reef ☆

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ABSTRACT

As the restrictions on water usage become more prevalent throughout the world, mining operations are required to understand the impact that water recycling will have on them. Not only owing to operational needs, but also from an environmental stand point. As would be expected recycling is likely to lead to increased dissolved ions, increasing the ionic strength, which may impact plant performance. By conducting flotation tests under varying degrees of ionic strength of synthetic plant water it is possible to better understand the effect that water recycling could have on the recovery of a mining operation. The effect of such an increase in ionic strength is discussed.

1. Introduction

Researchers have long been aware of the possible effects that ions present in recycled water may have on the flotation operation (Rao and Finch, 1988). Most of the studies have been concerned with the possible interaction of these recycled ions with the collector thereby reducing the efficiency of the operation. The majority of studies have been directed to oxide mineral systems where a fatty acid collector, which is usually used, can react with the calcium and magnesium ions present in the recycle water. Giesekke and Harris (1984) found that at calcium and magnesium ion concentrations above 10 mg/l reaction with the fatty acid collector would be occurring and generally, in apatite and fluorite flotation operations, the levels of these ions are far in excess of this value. Similarly, in sulphide mineral flotation systems the presence of ions in the recycle water such as copper and lead can lead to collector sequestration and activation of other minerals. Levay et al. (2001) has conducted a much more in depth analysis of the circuit water quality, the variability of the different water sources and various methods of upgrading the water quality. However, little has been done on the affect of ions such as calcium and magnesium on the recovery of sulphide minerals and nothing has been done on the effect these ions may have on the recovery of naturally floatable gangue (NFG) minerals. NFG is generally accepted to be talc; however Becker et al. (2009) have shown that a minor amount of talc, in the form of partial talc rims on the surface of orthopyroxene, is responsible for the natural floatability of composite orthopyroxene/talc particles.

Platinum group elements (PGE) are recovered from the Merensky reef in the Bushveld complex, South Africa, by flotation in a number of operations. Each operation has developed a unique reagent suite, yet all include the use of a polysaccharide depressant to reduce the amount of NFG, present in all sections of the reef, reporting to the concentrate. Merensky reef ores contain approximately 1% sulphide minerals in the form of chalcopyrite, pentlandite and pyrrhotite and the PGE's are strongly associated with these sulphides. Although talc/serpentine is present in small quantities (<5%) it has a disproportionate effect as it is found along pyroxene grain boundaries and leads to significant quantities of NFG reporting to the concentrate (Gottlieb and Adair, 1991; Becker et al., 2006). As a result rougher concentrates consist of over 90% gangue minerals composed of NFG and entrained material. The Reagent Research Facility (RRF) was set up at UCT in 1999 to specifically develop an understanding of the mechanism and interaction of depressants, such as modified guar gum (guar) and carboxy methyl cellulose (CMC), with the gangue and sulphide minerals and to optimise the application of these types of reagents. From the outset it was realised that the presence of ions such as calcium and magnesium would have an influence on the flotation behaviour so synthetic plant water (containing inorganic ions only) was developed to mimic the typical water analysis of one of the concentrators. This water, with a TDS (total dissolved solids) of 1023 mg/l (Wiese et al., 2005) was then used for all further studies on depressant interactions.

Over the last 5 years it has become evident that there has been a steady increase in the amount of dissolved ions present in the tailings dams and recycled water and that the use of a standard plant

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water of 1023 mg/l was no longer typical of most PGE concentrators. This study was therefore undertaken to assess the influence of increasing the ionic strength of the water, by doubling and tripling the level of ions in the standard plant water, on the sulphide and NFG recovery at various depressant dosages using a guar depressant. The batch flotation technique at UCT has shown that the use of a high depressant dosage (500 g/t) can be used to decouple the amount of entrained gangue from the amount of NFG (Wiese et al., 2009) as all NFG is depressed at this dosage and therefore, at lower dosages of 0 or 100 g/t, the amount of NFG reporting to the concentrate and the effect of the ionic strength thereon can be established. An entrainment function is obtained from the slope of the plot of total gangue vs. water recovery. This entrainment function is multiplied by the water recovery to give the amount of entrained gangue recovered to the concentrate. The mass of entrained gangue as well as the sulphide mass recovered is subtracted from the total mass of the concentrate obtained to give the NFG recovered.

2. Experimental details

An ore typical of the Merensky reef was acquired from one of the Merensky processing operations. The bulk sample was crushed, blended, riffled and split using a rotary splitter into 1 kg portions.

Standard plant water (Wiese et al., 2005) was used as the base water quality (1Plant) and the levels of the ions doubled or tripled (2Plant or 3Plant) for the higher ionic strength flotation tests as shown in Table 1. In addition, some tests were done using the Cape Town Tap water which has a very low TDS of 69 mg/l.

The 1 kg ore samples were milled in synthetic water (at the required ionic strength) at 66% solids, using a laboratory scale stainless steel rod mill, to achieve a grind of 60% passing 75 μm. The milled slurry was transferred to a 3 L Leeds flotation cell. The volume of the cell was made up to generate 35% solids using synthetic plant water (at the required ionic strength). The cell was fitted with a variable speed drive and the pulp level was controlled manually. The impeller speed was set to 1200 rpm. 1% sodium isobutyl xanthate (SIBX) collector solution and 40 g/t DOW 200 frother were used for all experiments. The polymeric depressant Stypres 504, a modified guar gum, was used. The guar was added at dosages of 0, 100 and 500 g/t. The collector solution was added to the mill, Wiese et al. (2005) showed this to have a significant effect on flotation performance.

The collector, SIBX, was supplied by Senmin. The Stypres 504 depressant was supplied by Chemquest. The frother, DOW 200, was supplied by Betachem. All the chemical salts used to make up the synthetic plant water solutions were supplied by Merck.

An air flow rate of 7 L/min was maintained for all flotation experiments and a constant froth height of 2 cm was sustained throughout. The cell height was constantly corrected to 2 cm by the addition of synthetic plant water at the relevant ionic strength. Concentrates were collected at 2, 6, 12 and 20 min respectively by scraping the froth into a collecting pan every 15 s. A feed sample was taken before and a tails sample after each flotation test. Water usage was monitored throughout. Feeds, concentrates and tails were filtered, dried and weighed before analysis. All batch flotation tests were conducted in duplicate and reproducibility was found to be within 5% mass recovery standard error. Copper and total nickel analysis of all samples was conducted using a Bruker XRF. Sulphur analysis was carried out using a LECO sulphur analyser. Assuming the stoichiometries for chalcopyrite and pentlandite to be $CuFeS_2$ and (FeNi)S respectively, the recovery of iron sulphides (including pyrrhotite) can be estimated from the copper, nickel, sulphur values for each concentrate. The recoveries of copper and total nickel can be used to estimate the recoveries of chalcopyrite and pentlandite respectively. Since some nickel is present in some gangue minerals the recoveries of total nickel are lower than the sulphide nickel recoveries. Nevertheless total nickel values can be used to compare the sulphide nickel response to ionic strength and depressant addition variations.

3. Results and discussion

In a flotation cell material reports to the concentrate in two ways, either via true flotation or entrainment. Ekmecki et al. (2003) and Wiese et al. (2007) showed, for a Merensky ore without copper activation, that when the guar dosage was increased to 300 g/t, the amount of naturally floatable gangue (NFG) was reduced close to zero. Increasing the guar dosage to 500 g/t ensures that no NFG is recovered allowing the determination of an entrainment factor from the linear nature of the mass per unit water curve obtained (Wiese et al., 2009). The values obtained and the final water recovered for the various ionic strengths used are shown in Table 2. It can be seen that there is a slight decrease in the amount of material entrained per unit water mass as the ionic strength is increased. This suggests that, as the solids density and particle size distribution remained constant for all tests, there is an increase in the coagulative nature of the ore due to the increased ionic strength presumably by the adsorption of calcium and magnesium ions onto the particle surfaces resulting in a lowering of the surface charge and causing a reduction in the entrained mass. However, the relative change in the amount of solids entraining is small in relation to the change in the amount of NFG reporting to the concentrate on the addition of depressant. It is also evident from Table 2 that increasing the ionic strength leads to a significant increase in the amount of water recovered. The final mass and water recoveries for the four ionic strength conditions and the three depressant dosages are shown in Fig. 1.

For each ionic strength condition it is evident that adding an increased amount of depressant results in a significant decrease in the amount of solids reporting to the concentrate. At the same time there is generally a decrease in the amount of water recovered for increased depressant dosage implying that there is a decrease in froth stability as the amount of NFG reporting to the concentrate is reduced. It is assumed that at a dosage of 500 g/t there is no NFG in the concentrate. However, if the effect of increasing the ionic strength is examined for a fixed depressant dosage it can be seen that for each depressant dosage the effect of increasing the ionic strength leads to an increase in water recovery or froth stability. Previous work has shown that the nature of the solids reporting to the concentrate have a significant influence on the stability of the froth (Dippenaar, 1982; Johansson and Pugh, 1992; Tao et al., 2000; Schwartz and Grano, 2005; Melo and Laskowski, 2007). The sulphide minerals, depending on their nature and the collector

Table 1
Ions present in synthetic water.

Water type	Ca^{2+} (ppm)	Mg^{2+} (ppm)	Na^{+} (ppm)	Cl^{-} (ppm)	SO_4^{2-} (ppm)	NO_3^{-} (ppm)	NO_2^{-} (ppm)	CO_3^{2-} (ppm)	TDS	Ionic strength (M)
Tap	19	1.5	12	12	19	17	–	–	68.5	0.0020
1Plant	80	70	153	287	240	176	–	17	1023	0.0241
2Plant	160	140	306	574	480	352	–	34	2046	0.0482
3Plant	240	210	459	861	720	528	–	51	3069	0.0723