



The effect of varying pulp reagent chemistry on the flotation performance of a South African PGM ore



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ARTICLE INFO

Article history:

Received 5 April 2016

Revised 27 June 2016

Accepted 2 July 2016

Available online 7 July 2016

Keywords:

Flotation reagents

Froth flotation

Froth phase

Ionic strength

Pulp chemistry

ABSTRACT

The pulp chemistry plays a pivotal role during the extraction of commodities in the PGM industry as they employ the froth flotation separation process, which is based on the selective alteration of surface properties between the valuable minerals and undesired gangue. The chemical environment is intricate owing to the multiple and various surface reactions occurring at the mineral surface, and the increased ionic concentrations due to the practice of water recycling. Thus, a holistic understanding of the pulp chemistry is sought. By conducting bench scale flotation tests at varying concentrations of flotation reagents and typical ions present in plant water, it is possible to better understand the role of pulp chemistry on metallurgical plant performance. The effects of such variations, which modify the chemical environment of the pulp and impact plant performance, are discussed in this paper.

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1. Introduction

The South African Bushveld Igneous Complex, which consists of three main ore bodies, namely the Merensky, the UG2 and the Platreef, hosts the largest PGM reserves on a global scale (Cawthorn, 1999; U.S. Geological Survey, 2015). The Platinum Group Minerals (PGM), together with the Base Metal Sulphides (BMS) present in the ores, are extracted by the froth flotation separation technology which relies heavily on the surface chemistry of the valuable mineral particles and gangue. With the ever increasing demand for precious metals for applications in catalysis, medicine, fuel cells and other industries (Gupta et al., 2014), and the depletion of high-grade ores, it is imperative to gain a fundamental understanding of the process in an effort to optimise the metallurgical circuits for a better performance.

The chemistry of the pulp is of crucial importance as it determines the particle surface properties which are essential for a successful separation between the valuable mineral particles and gangue. Collectors are added to selectively impart/enhance hydrophobicity onto the valuable mineral particles, and depressants are added to render the gangue particles hydrophilic. Upon attachment to the air bubbles, the collector-coated valuable mineral particles are transported to the froth phase and recovered, and the gangue particles remain submerged in the pulp and disposed in the tailing stream. Of particular importance is a stable

froth, which is sought, for successful transportation and recovery of the valuables, and this is achieved by addition of frothing agents.

Due to the complexity of the process owing to multiple surface reactions taking place, competitive and interactive effects among the reagents, as well as secondary effects in addition to the primary roles of the reagents, it is often imperative to take a holistic approach in evaluating the behaviour of reagents in flotation (Bradshaw et al., 2005). Moreover, depending on the nature and adsorption characteristics of a reagent in question, pulp conditions can affect its adsorption onto the mineral surface. Therefore change in chemical pulp conditions owing to the practice of water recycling, which leads to build-up of pollutants such as organics, reagent residuals, and dissolved ions in the process (Chen et al., 2009; Levay et al., 2001; Rao and Finch, 1989), at concentrator plants can affect the behaviour of the flotation reagents. From the onset, UCT developed synthetic plant water (SPW) containing only inorganic ions, with total dissolved solids (TDS) of 1023 mg/L, to mimic industrial plant water and to understand the behaviour of reagents under such conditions when conducting laboratory scale experiments (Wiese et al., 2005). The concentration of the ions in the process steadily increases with time, and it is thus important to understand the behaviour of the reagents under elevated concentrations of the ions.

Therefore this is a flotation chemistry study that seeks to gain a holistic understanding of the pulp chemistry and its influence on the metallurgical performance of a PGM-bearing ore from the Merensky reef, with particular emphasis on the dosages of the

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chosen flotation reagents; collector, depressant and frother, and the ionic strength of the plant water.

2. Experimental details

Shown in Table 1 are the two synthetic plant water types; 1 SPW, the standard synthetic plant water, which was used as the base plant water, and 5 SPW, the higher ionic strength plant water used to simulate accumulation of ions in the plant water. They were prepared by dissolving various chemical salts in distilled water to achieve the concentration of the ions as shown in the table.

A sample of a typical Merensky ore was obtained from the Bushveld Igneous Complex of South Africa in the North West province. The bulk sample was crushed, blended, riffled and split using a rotary splitter into 1 kg portions. The 1 kg samples were milled in synthetic plant water (at the required ionic strength), with the collector added to the mill, using an Eriez laboratory stainless steel rod mill at 66% solids to achieve a grind of 60% passing 75 μm . This grind was chosen on the basis that it matches the primary rougher grind at operations processing this type of ore (Wiese, 2009). The milled slurry was transferred to a 3 L modified Leeds batch flotation cell, and synthetic plant water (at the required ionic strength) was added to achieve a pulp density of 35% solids. The cell was fitted with a variable speed drive and the pulp level was controlled manually by addition of synthetic plant water. The impeller of the flotation cell was set to a speed of 1200 rpm. Air was then introduced into the cell, at a flow rate of 7 L/min, which was sustained throughout the test. A constant froth height of 2 cm was sustained throughout the test by addition of synthetic plant water at the required ionic strength. Concentrates were collected into a pan by scraping off the froth at intervals of 15 s for collection times of 2, 4, 6 and 8 min. A feed sample was drawn before and a tails sample was drawn after each test. Water usage was monitored throughout the test. Feeds, concentrates and tails were filtered, dried and weighed before analysis. All batch flotation tests were conducted in duplicate in order to minimise the error, and the reproducibility was found to be within acceptable limits as required by the UCT standard batch flotation procedure (Manono, 2012).

The frother Dowfroth 250, a polyglycol ether frother of molecular weight 264 g/mol which was supplied by Betachem in concentrated form, was added at dosages of 50 and 60 g/t. The polysaccharide depressant, guar gum (Sendep 348) with molecular weight 239,000 g/mol and 92% purity, was added at dosages of 100 and 300 g/t, and was supplied by Senmin. A xanthate collector, sodium isobutyl xanthate (SIBX) with molecular weight of 171.1 g/mol and purity of 90%, which was also supplied by Senmin was dosed at 50 and 150 g/t.

Copper and total nickel analysis of all samples was carried out using a Bruker S4 Explorer X-ray Fluorescence (XRF) spectrometer. Sulphur analysis was carried out using a LECO DR423 sulphur analyser. It should be noted that the analytical technique for the nickel content measurement measures the total nickel present in the ore, and owing to the significant amount of nickel associated with the gangue, the recovery of nickel as an indication of the sulphide mineral pentlandite cannot be entirely accurate. However this value can be used when comparing sulphide nickel recoveries for the

same ore. It has also been assumed that the analysis of the sulphide minerals; chalcopyrite and pentlandite, recovered in the concentrates serves as a proxy to the PGM recovery due to the strong association of the sulphides with PGMs in these type of ores (Wiese et al., 2005).

3. Results and discussion

This section presents results and discussion of the effects of varying pulp chemistry on the solids, water, copper and nickel recoveries and grades. It should be noted that the test conditions on the graphs (Figs. 1–3) are in chronological order, i.e., the test condition 50 SIBX, 100 Guar, 50 D250, 1 SPW, designates test condition 1, and that they are abbreviated for ease of reference. For example, 50 SIBX refers to 50 g/t of the collector sodium isobutyl xanthate, 100 Guar refers to 100 g/t of the depressant guar gum and 50 D250 refers to 50 g/t of the frother Dowfroth 250.

3.1. The effect of varying the pulp chemistry on solids and water recoveries

It is clear from Fig. 1 that generally, under 1 SPW, increasing the collector dosage decreased both solids and water recoveries. Water recovery at a fixed froth height gives an indication of the change in froth stability (Wiese, 2009). Thus it is evident from the figure that under 1 SPW increasing the collector dosage from 50 g/t to 150 g/t decreased the stability of the froth (as seen by reduction in water recovery), and ultimately reduction in solids recovery. The effect of particle hydrophobicity is well documented in literature, and it has been consistently reported that highly hydrophobic (contact angle: $\theta > 90^\circ$) particles have an impact of destabilising the froth phase (Bradshaw et al., 2005; Hadler et al., 2005; Schwarz and Grano, 2005; Johansson and Pugh, 1992; Dippenaar, 1982), and ultimately may lead to reduction in valuable mineral recovery. It can thus be postulated that increasing the collector dosage from 50 g/t to 150 g/t led to particle hydrophobicity above the optimum particle hydrophobicity (90°), after which point any further increase in particle hydrophobicity starts causing bubble rupture – froth destabilisation. Although the collector-coated particles were observed to destabilise the froth, as seen by the reductions in both solids and water recoveries, as a result of increasing the collector dosage under 1 SPW, the effect was less prominent at higher frother dosage of 70 g/t. This is an indication of a competitive phenomenon between the frother molecules and collector-coated particles on the froth, as the role of the former is to stabilise the froth, while the latter have the ability to act as froth breaking agents, when “too” hydrophobic. Therefore at sufficiently high frother concentration in the pulp, a froth stable enough to resist the effect of the highly hydrophobic particles can be induced, and consequently bubble rupture will be minimal, and hence adequate recovery of particles can be achieved.

On the contrary, generally, both solids and water recoveries were seen to increase when the collector dosage was increased under high ionic strength plant water, 5 SPW, as shown in Fig. 1. This indicates that the destabilisation effect of the resultant highly hydrophobic collector-coated particles on the froth was minimised or counteracted. Thus under 5 SPW the froth was sufficiently stable to resist any change (destabilisation) owing to the dynamic forces

Table 1

The concentration of the ions present in the two synthetic plant waters used in this study.

Plant water	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 (ppm)
1 SPW	80	70	153	287	240	176	–	17	1023
5 SPW	400	350	765	1435	1200	880	–	85	5115

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