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The effect of the reagent suite on froth stability in laboratory scale batch flotation tests ☆

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ABSTRACT

In batch flotation tests conducted on ores from the Merensky reef, changes in froth stability invariably occur with variations in the reagent suite. The main reagents are collectors (primary and secondary), activators, depressants and frothers. Since the particles entering and leaving the froth in a batch flotation system are continuously changing, the stability of the froth can vary. Under these conditions the simplest measure of froth stability is the measure of water recovery at a fixed froth height. The batch flotation system developed at UCT allows for the separation of gangue which is entrained relative to gangue which is floated. It has been found that the presence of naturally floatable gangue (NFG) leads to froth stabilisation, whereas the presence of hydrophobic sulfide minerals may lead to destabilisation of the froth depending on the hydrophobicity (contact angle) of the sulfide minerals. This can vary with ore type since particle shape and amount of particles present can influence the extent of destabilisation. At low depressant dosages sodium isobutyl xanthate (SIBX) always results in lower froth stability than sodium ethyl xanthate (SEX). The frothing nature of dithiophosphate leads to increased froth stability and the addition of copper sulfate results in destabilised froths. Increasing depressant dosage reduces the stabilising influence of NFG and the depressant type (guar gum or CMC) also affects froth stability. Frother can be used in an attempt to overcome the destabilising effects of high depressant dosage. This work examines the effect of variations in the reagent suite and uses water recovered at a fixed froth height as an indication of froth stability in order to analyse these effects on the recovery of sulfide minerals, floatable gangue and entrained gangue.

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1. Introduction

Flotation is a selective physico-chemical process utilising the differences in surface properties to separate valuable and unwanted minerals. The process consists of two distinct phases, the pulp phase in which mineral recovery occurs and the froth phase from which the concentrated valuable minerals are separated from the bulk (Wiese, 2009). In the pulp phase reagents are added to the system to enhance the differences in mineral surface properties. These properties are affected by chemical changes using reagents such as collectors, activators and depressants to promote successful attachment of the valuable hydrophobic mineral to the bubble at the same time as preventing or reducing bubble–particle attachment with the unwanted or gangue minerals by rendering their surfaces hydrophilic. The mineral laden bubbles are transported into the froth phase. The rising bubbles, however, due to the thickness of the liquid films formed in the froth, allow the unselective transport of finer particles into the froth phase by entrainment. The role of the froth phase in flotation is to facilitate the upgrading of the valuable mineral without any loss of these valuables and to convey the concentrate to the next processing stage. The formation of froth requires the addition of a surface-active agent to the pulp phase to enhance the distribution of the air throughout the pulp and to form a relatively unstable froth that would break down rapidly for further treatment. In addition, in sulfide mineral flotation the type of surface-active agent used should not significantly interact with the solids particles in the pulp phase. The continuous breakage of the froth lamellae allows water and entrained solids to drain back into the pulp without inducing detachment of the valuable minerals from the liquid–air interface. The final grade of the valuable mineral is strongly dependent on the stability of the froth since the recovery of entrained gangue is directly proportional to water recovered (Engelbrecht and Woodburn, 1975; Zheng et al., 2006a,b; Neethling and Cilliers, 2002). However, too low a froth stability can lead to a loss of valuable minerals and inability to transport the material for further processing.

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Froth stability can therefore be affected by changes in the solution chemistry such as frother concentration and water quality. However, the stability of the froth can also be affected by the size and nature of the hydrophobic particles attaching at the air–water interface. Consequently the addition of activators, collectors and depressants can also have a significant influence on the stability of the froth. Studies have shown that increasing particle hydrophobicity increased froth stability up to a certain intermediate contact angle (Bikerman, 1953; Johansson and Pugh, 1992) and at higher contact angles particles were destabilising, depending on the concentration, leading to collapse and drainage of the froth. (Dippenaar, 1982; Hatfield et al., 2004). Weakly hydrophobic particles can stabilise froths by attaching at both interfaces of the draining lamella and, if sufficiently close-packed, physically prevent further draining of the film and eventual rupture. On the other hand, strongly hydrophobic particles can destabilise froths by bridging the froth films and allowing the rapid movement of the interface across the particle surface resulting in a collapse of the bubble. As long as these particles remain attached at the air–water interface they can repeatedly act as froth breakers and therefore be extremely effective destabilisers.

Batch flotation tests have long been used to optimise reagent performance for application to large scale plants. However, these have often found to be of limited value since it is seldom that the result of batch flotation tests can be correlated with the behaviour of the particular reagent in pilot or full-scale plant trials. One of the main reasons is that, very often, in batch flotation tests the changes in the froth stability brought about by change in the reagent suite are not taken into account. The challenge in any batch flotation system is establishing what measure can be used to assess froth stability. Since the particles entering the froth during flotation are changing continuously it is difficult to measure such parameters as equilibrium froth height, froth drainage rates and dynamic froth index accurately during the limited time of collection. However, if the flotation cell is operated at a constant froth height the water recovered for each concentrate can be measured and used as an indication of and variations in froth stability during the test. The measurement of the water recovered has another advantage in that the entrained mass is directly related to the water mass recovered and can therefore be used to decouple the gangue reporting to the concentrate by entrainment from that recovered by true flotation.

The variations in froth stability described above have been observed in batch flotation studies on Merensky reef ores carried out in the Reagent Research Facility at UCT. This has resulted in the development of a methodology to include the effects of reagents on froth stability in the understanding and assessment of the performance of reagents such as depressants, collectors and activators.

The Platinum group elements (PGE) in the Merensky reef are strongly associated with the sulfide minerals chalcopyrite, pentlandite and pyrrhotite, which are present in the ore at a concentration of about 1%. Following the recovery of copper and nickel gives a reasonable indication of the valuable mineral performance (Brough, 2008; Wiese et al., 2009: Wiese, 2009). Invariably polysaccharide depressants are used to reduce the naturally floatable gangue minerals (NFG) present. Although present at levels between 0.5% and 5%, talc has a disproportionate effect on flotation performance since it occurs along pyroxene grain boundaries and can result in large amounts of NFG reporting to the concentrate (Becker et al., 2006). It has been shown that, using a high depressant dosage (500 g/t) all NFG can be depressed and the only gangue reporting to the concentrate is in the form of entrained gangue (Wiese, 2009). Consequently, an entrainment factor (mass per unit water) for the particular ore, grind and pulp density can be established. This entrainment factor can then be used at lower depressant dosages to determine the amount of NFG reporting to the concentrate by flotation.

This paper describes some of the froth stability variations that were observed using various reagents and how the data can be used to better understand reagent performance.

2. Experimental details

Three ores from the southern section of the Merensky reef in the Bushveld Igneous Complex, South Africa were prepared at UCT (Wiese, 2009) for use in batch flotation tests. All batch flotation tests were conducted using synthetic plant water, whereby distilled water is modified by the addition of various chemical salts, supplied by Merck, to contain total dissolved solids of 1023 ppm (Wiese, 2009).

Batch flotation tests were conducted using a method developed at UCT (Wiese, 2009). 1 kg portions of the ore samples were milled at 66% solids in synthetic plant water to achieve a grind of 60% passing 75 μm using a laboratory scale stainless steel rod mill. The milled slurry was transferred to a modified 3 L Leeds flotation cell. The volume in the cell was made up to produce 35% solids using synthetic plant water. The flotation cell was fitted with a variable speed drive and the pulp level was controlled manually by the addition of synthetic plant water. The impeller speed was set at 1200 rpm.

2.1. Reagents used during the batch flotation tests of the three ores were as follows

Ore A: The collectors were sodium ethyl xanthate (SEX) and sodium isobutyl xanthate (SIBX) at a dosage of 50 g/t. Three different CMC depressants were used at dosages of 100 g/t. The depressants have different Degrees of substitution (DS) (charge) and different molecular weight (MW). Depramin 186: DS 0.86, MW 260 000; Depramin 267: DS 0.67, MW 325 000; Depramin 158: DS 0.58, MW 443 000.

Ore B: The primary collector used was SIBX, together with a secondary collector, Senkol 5 (dibutyl dithiophosphate) at a combined dosage of 50 g/t. Stypres 504, a modified guar gum, and Depramin 267, a CMC, were used as depressants at dosages of 100, 200 and 300 g/t. Copper sulfate ($CuSO_4 \cdot 5H_2O$) at a dosage of 40 g/t was used as an activator. DOW 200 at a dosage of 40 g/t was used as a frother.

Ore C: The collector used was SIBX at a dosage of 150 g/t. Stypres 504, at a dosage of 0, 250 and 500 g/t was used as a depressant. The frother was DOW 200 at dosages of 40, 50, 60 and 70 g/t.

DOW 200 was supplied by Betachem. The collectors were supplied by Senmin and were added to the mill prior to grinding. $CuSO_4$ was added to the flotation cell i.e. after the collector, and conditioned for 5 min. Depressants were conditioned for 2 min and the final reagent, frother, was conditioned for 1 min. The modified guar gum, Stypres 504, was supplied by Chemquest, and the CMC depressants were supplied by Akzo Nobel functional Chemicals.

The air supply to the flotation cell was maintained at a flow rate of 7 L/min in all tests and the froth height was kept constant at 2 cm throughout. Four concentrates were collected at 2, 6, 12 and 20 min of flotation time by scraping the froth into a collecting pan every 15 s. A feed sample was taken before and a tailings sample was taken after each test. Water recoveries were measured for each test. Feeds, concentrates and tails were filtered, dried and weighed before analysis. All batch flotation tests were conducted in duplicate. Error bars showing standard error between duplicate tests, are included in figures. Copper and total nickel analysis of all samples was done using a Bruker S4 Explorer XRF. Sulfur analysis was carried out using a LECO sulfur analyser.

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