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Interactive effects of the type of milling media and $CuSO_4$ addition on the flotation performance of sulphide minerals from Merensky ore Part II: Froth stability

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Abstract

The limitations of pulp chemistry measurements in the flotation of a platinum group mineral (PGM) bearing Merensky ore were demonstrated in Part 1 of this article. In this paper the importance of the contribution of the froth structure due to changing froth stability is analysed using the batch flotation data. The effects of mild steel (MS) and stainless steel (SS) milling media and the addition of copper sulphate on the flotation performance of the sulphide minerals in Merensky ore have been evaluated in relation to the changes in stability of the froth phase. The effects of pulp chemistry and froth stability on the flotation of sulphide minerals were distinguished by using two different rate constants (k_t and k_w). The rate constant (k_w) calculated as a function of cumulative water recovery was used to describe characteristics of froth phase and k_t was calculated as a function of flotation time. The results revealed that the type of grinding media and copper sulphate addition had an interactive effect on the froth stability. While mild steel (MS) milling increased the froth stability due to the presence of hydrophilic iron hydroxides and colloidal metallic iron, the addition of copper sulphate reduced the stability, especially with stainless steel (SS) milling. Copper sulphate addition had a dual role in the flotation of Merensky ore in that it caused destabilisation of the froth zone as well as activation of selected sulphide minerals. The dominant effect was found to depend on the type of milling media and floatability of the mineral in question and this work has demonstrated the importance of using a combination of measurements to evaluate flotation performance holistically.

Keywords: milling media; copper sulphate; sulphide minerals; froth stability

1. Introduction

Flotation is well known to be complex with many interactive sub-processes occurring in the pulp and froth phases. However, most explanations of the behaviour of sulphide minerals in the literature have been based on pulp phase phenomena with little consideration of process in the froth phase and its interactive effects on overall flotation performance. Misleading conclusions can be drawn by considering only the pulp phase and omitting froth characteristics. The froth phase behaviour can have an overriding effect which can lead to the wrong interpretation of a change to pulp chemistry. For example, adding a new collector or changing the type of milling media changes the hydrophobicity of the minerals in the

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Table 1
The calculated rate and ultimate recovery values as a function of flotation time for batch flotation tests with Merensky ore with MS and SS milling media, in the presence and absence of 50 g/t copper sulphate

Test conditions	k_t (min^{-1})			k_w (l^{-1})			R_t (%)		
	Copper	Nickel	Iron sulphides	Copper	Nickel	Iron sulphides	Copper	Nickel	Iron sulphides
$SSCuSO_4$	0.48	0.26	0.23	10.79	6.39	5.63	81.8	73.4	75.8
SS	1.57	0.86	0.85	10.94	6.56	5.49	81.0	67.5	35.8
$MSCuSO_4$	1.68	1.74	0.94	10.99	11.40	6.50	82.8	76.5	67.4
MS	0.84	1.39	0.63	5.08	7.69	3.82	77.9	68.5	32.4

pulp and the pulp chemistry, which not only changes bubble-particle attachment in the pulp phase but also changes the stability of the froth phase, which affects overall performance. Bradshaw et al., 2004 showed that the increased mineral hydrophobicity achieved with a stronger collector, also lead to decreased froth stability, which, under certain conditions lead to reduced overall performance. Therefore, it is crucial to distinguish the effects of any changes in operational conditions in flotation to pulp and froth phase and evaluate these effects separately on flotation performance.

The role of froth phase is to provide a zone where hydrophobic material is upgraded. The zone should be stable enough to provide transfer of the hydrophobic particles out of the flotation cell. The froth phase should also provide selective drainage of entrained minerals back into the pulp, and thus contribute considerably to the total selectivity of the process. In addition to affecting the hydrophilic entrained particles, the structure and stability of the froth phase can also affect flotation behaviour of hydrophobic particles. Saturation of the bubble surfaces by the minerals may occur in the froth phase and lead to froth overloading and a decrease in the flotation rate and recovery of certain classes of the hydrophobic particles (Dippenaar, 1978; Harris, 1982; Lynch et al., 1981). Dudenkov (1967) showed that well dispersed hydrophobic particles could break froths, presumably by accelerating the coalescence of bubbles particularly in the froth. It has been proposed that fine hydrophobic precipitates, formed by the reaction of the collector with metal ions in solution, destabilised the froths. Moreover, Dippenaar and Harris have reported that strongly hydrophobic particles of all sizes can destroy froths independent of the frother used (Dippenaar, 1978; Harris, 1982). Therefore, stability of the froth phase has a critical importance in the selectivity and flotation rate.

At constant aeration rate and froth height, the recovery of water depends on the stability of the froth phase (Engelbrecht and Woodburn, 1975). The stability of the froth phase is determined by the stability of liquid lamellae between gas bubbles, which in turn affects the froth water content (Banford et al., 1998; Neethling and Cilliers, 2002). Therefore the water recovery of the concentrate can be used as a parameter to evaluate the stability of a froth zone.

In sulphide mineral flotation, the type of milling media employed influences the pulp chemistry and thus the final flotation behaviour of the mineral particles. The use of mild steel (MS) milling media in place of stainless steel (SS) milling media has the effect of creating a more reducing pulp environment with reduced dissolved oxygen content (Subrahmanyam and Forssberg, 1995). The corrosion of mild steel releases iron into solution and at alkaline pHs iron hydroxy species are formed. These hydrophilic species may coat the mineral, reducing floatability (Forssberg et al., 1993). Mineral surface oxidation and thiol collector oxidation are also influenced by pulp potential, and hence by type of milling media. However, in addition to the effects of milling media on chemistry of the pulp, the presence of hydrophilic colloidal metal hydroxides has been reported to affect the stability of froth zone (Bikerman, 1953; Van Deventer, 1998; Freeman et al., 2000).

The majority of the research in the literature conducted to investigate the effects of type of milling media and addition of $CuSO_4$ has been carried out with sulphide ores containing more than 50% sulphide minerals (Ekmekçi et al., 2003; Leppinen et al., 1998; Yuan et al., 1996). In contrast, Merensky ore with only 1% sulphide mineral content and a much higher gangue percentage has different characteristics. The effects of milling media and copper sulphate addition on pulp chemistry have been discussed in Part I of this paper (Bradshaw et al., 2005). The objective of Part II of this paper is to emphasise the importance of froth stability in analysing batch flotation data and to examine the use of water recovery in place of flotation time in the first order rate equation to describe the froth phase effects. The effects of mild steel (MS) and stainless steel (SS) milling media and the addition of copper sulphate on the flotation performance of the