PULP RHEOLOGY IN THE FLOTATION OF SERPENTINISED ULTRAMAFIC NICKEL SULFIDE ORE AND ITS EFFECT ON FLOTATION

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ABSTRACT

In this paper, a correlation between the rheological properties of flotation pulp and the flotation response was investigated through a series of rheological and batch flotation tests. The experiments, which have been carried out with very finely ground serpentinised ultramafic nickel sulfide ore, confirmed that the flotation performance of this particular ore strongly depends on pulp density. As rheological measurements revealed the viscosity/yield stress of the studied pulps, the system that contains needle-like particles, at solids contents of 15-20% (wt) is prohibitively high. This high solids content affects the flotation process: concentrate yield increases and concentrate grade dramatically declines with increasing pulp density. The observed "boiling" in the flotation tests at a high pulp density (15-20 % wt.) is likely the result of a high viscosity. The concentrate grades consistently decrease at the Casson yield stress higher than 1.5-2 Pa.

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INTRODUCTION

In a flotation process, mineral particles collide with bubbles; flotation kinetics thus deals with interactions between particles and bubbles (Figure 1). The particles are classified as floatable if they successfully attach to air bubbles and are lifted by them to a froth layer. In the reaction

$$\text{solid particle} + \text{bubble} = \text{particle-bubble aggregate} \qquad (1)$$

the rate of removal of the solid particles from a cell is commonly assumed to be the first-order relation and it depends on several sub-processes.

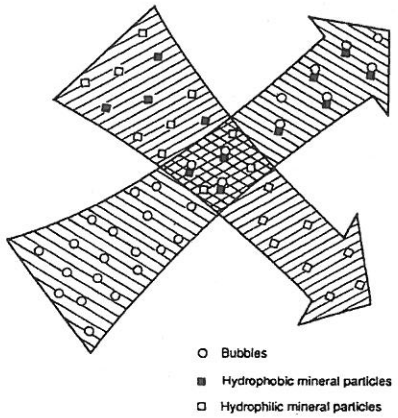


Figure 1 - Separation of hydrophobic from hydrophilic particles in flotation

A more complex picture of this process takes account of the probabilities of these sub-processes.

$$P = P_c P_a P_s \qquad (2)$$

where P is the probability of flotation, P_c is the probability of particle-bubble collision, P_a is the probability of particle-bubble attachment, and P_s is the probability of formation of a stable particle-bubble aggregate that can resist shearing environment is a flotation cell.

Several equations which have been derived allow calculation of these probabilities. They all show that the viscosity of the medium in which the process takes place, that is the pulp viscosity, affects strongly particle-bubble collision and attachment. It is also likely that it affects the probability that the formed particle-bubble aggregates will survive the conditions they are subjected to in the flotation cell.

Klassen and Mokrousov [1] pointed out that the increased viscosity of the pulp hinders aeration and rise of mineralized bubbles into the froth. Schubert [2] indicated that many researchers who found beneficial effect of dispersing agents on flotation attributed these results entirely to the removal of slime coatings while obviously the other important and neglected factor is reduction of apparent viscosity of the system. Every effect caused by dispersants also involves reduction of the pulp viscosity and thus directly

increases the collision rate and improves the flotation kinetics. But also turbulence intensity is reduced when viscosity increases and so – as pointed out by Schubert – the finer are the solid particles, or the higher is the solids concentration, that is the higher is apparent viscosity of the pulp the sharper is a decrease in the size of turbulent zone around impeller. This "turbulence dumping" effect is reduced when the pulp viscosity is lowered.

The sulfide nickel ore tested in this project contained some fibrous gangue minerals (chrysotile) which affect very strongly rheological properties of these flotation systems, and the objective of this paper was comparison of the rheological properties of the flotation pulp with the flotation response.

EXPERIMENTAL

Materials

The nickel sulfide ore (0.5% Ni) used in these tests contained pentlandite, millerite and violarite as the main nickel bearing minerals. The serpentinised ultramafic gangue predominantly contained lizardite together with significant quantities of antigorite and chrysotile; the other gangue minerals included talc, chlorite, brucite, magnesite, magnetite and pyroaurite. The ore typically assays 40% MgO [3]. Because of its needle-like fibrous structure the mineral of interest in this suite was chrysotile. The flexible fibrous structure of this mineral is generally believed to be the cause of the ore problematic behaviour and it this aspect that poses a major challenge in processing the ore.

Methods: 1 kg batches of the ore pre-crushed below 3 mm was placed with 1.5 L of the process water (48.2 g/L of NaCl, 24.4 g/L of $MgSO_4.7H_2O$ and some minor additions of potassium and calcium chlorides) in a steel rod mill. The time of grinding was adjusted such that 80% of the grinding product was below 125 µm. Washing out with another 1.5 L of the process water resulted in the pulp with 25% solids content. The products of four grindings combined together were classified using a C700 Mozley cyclone rig at a cut point of 25 µm. The yields of underflow and overflow were about 45 and 55%, respectively. The overflow was left to decant and after 4 hours a clear supernatant was siphoned off. The sediment after decantation contained about 30% solids.

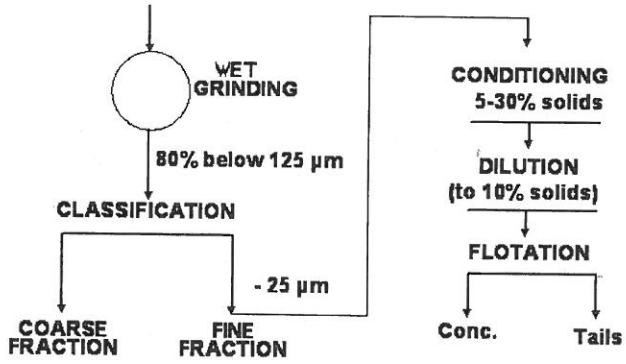


Figure 1b - Flow diagram of the tests

Rheological tests were conducted in a controlled rate co-axial rheometer Haake Viscotester 550. The samples of the slurry were taken from the flotation pulp just before aerating the pulp to initiate flotation. All measurements were conducted using a MV-1P bob and cup fixture where P indicates a ribbed surface to reduce errors associated with wall slip. Rheograms were generated in the shearing rate range between 0 and 200 s^{-1} for 1 minute to obtain complete curves. The flow curves were modeled by using either Bingham or Casson equations. The Casson model was found to better describe the experimental data.

RESULTS

The results of the flotation tests are shown in Figure 2. As this figure demonstrates the curves shift to the left with increasing pulp density. Thus, the same recovery requires higher concentrate yields when pulp density increases. The increasing concentrate yield translates into higher entrainment and this is what Figure 3 shows.

For these pulps the measured Casson yield stress depends strongly on the solids content (Figure 5). These pulps become very viscous and very non-Newtonian when the solids content exceeds 15 %(wt), and the grade of the flotation concentrates clearly deteriorates under such conditions (Figures 5 and 6).

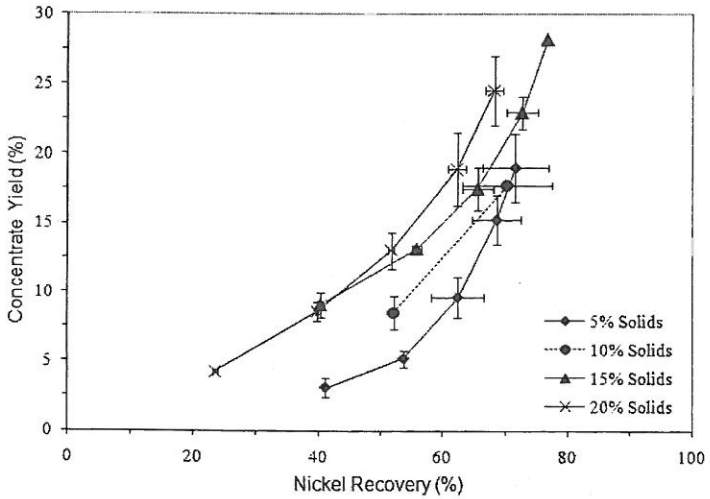


Figure 2 - Effect of pulp density of the flotation feed on the concentrate yield - nickel recovery curves

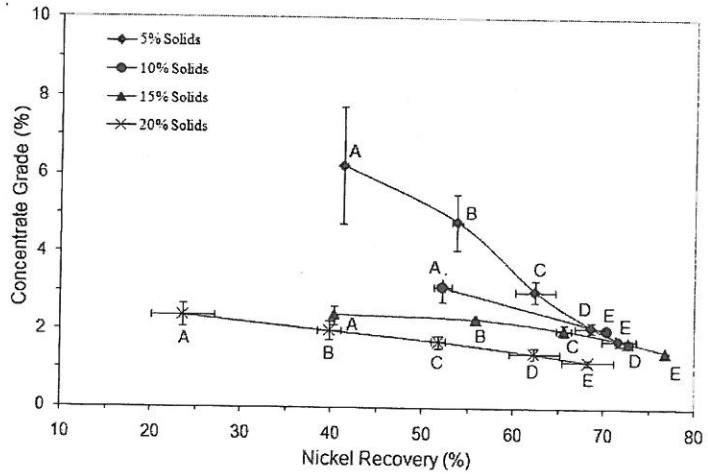


Figure 3 - The grade – recovery curves for flotation tests carried out at varying solids content. The flotation concentrates were collected after 2 minutes of flotation (point A), 5 minutes of flotation (point B), 10 minutes of flotation (point C), 20 minutes of flotation (point D) and 30 minutes of flotation (point E)

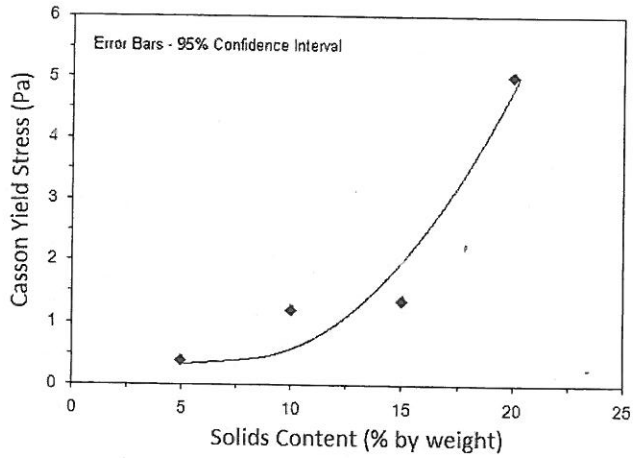


Figure 4 - Effect of solids content on the Casson yield stress measured for the suspensions of the finely ground nickel sulfude ore (the feed in the flotation tests)

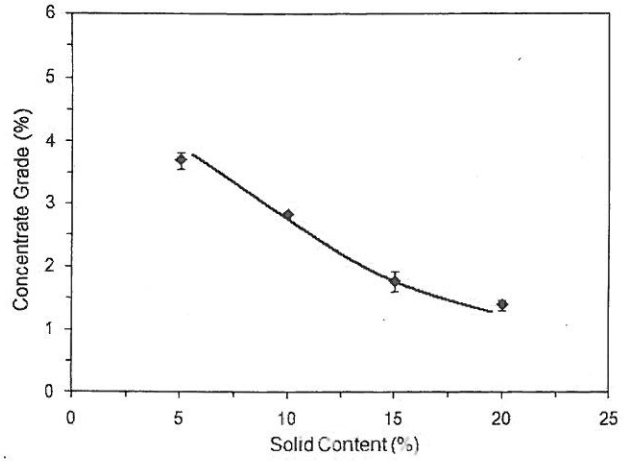


Figure 5 - The effect of pulp density on the grade of flotation concentrates.

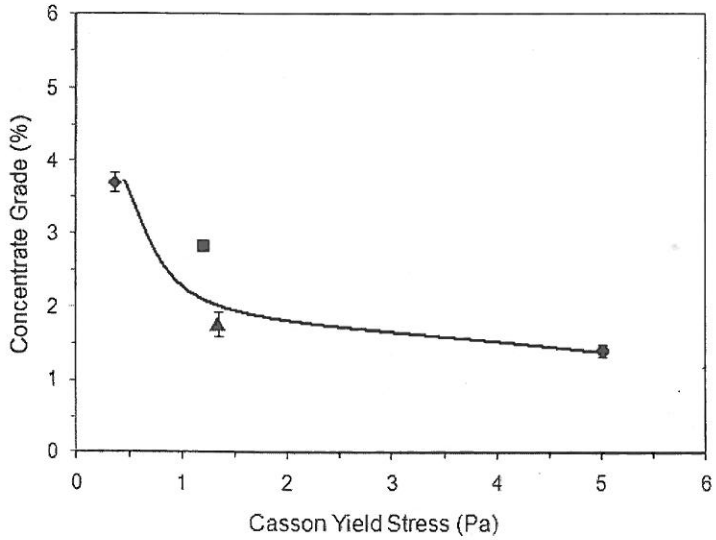


Figure 6 - The effect of the Casson yield stress on the grade of flotation concentrates. tent. 5% solid (♦), 10% solid (■), 15% solid (▲) and 20% solid (●)

DISCUSSION

Rheological properties of mineral suspensions depend on the size and concentration of solid particles. Also, rheology of such systems strongly depends on the shape of particles [4,5]. In these pseudoplastic systems as the shear rate increases so the particles begin to align with the flow and pack more efficiently. The flotation results clearly show that the flotation of the tested ore is affected when the Casson yield stress exceeds about 1.5-2 Pa. However, the tests also revealed the time-dependent rheological properties of the concentrated pulps of the studied finely ground nickel sulfide ore [5], and at this stage it was impossible to evaluate how such changing rheological properties could affect the flotation performance.

It is to be pointed out that in our flotation experiments "boiling" was observed when these tests were carried out at a high pulp density (15-20% wt). This likely results from a high viscosity of the pulp and the "dampening effect" described by Schubert [2]. The concentrate grades consistently decreased at the Casson yield stress higher than 1.5-2 Pa.

CONCLUSIONS

1. Flotation of the studied finely ground nickel sulfide ore is difficult. The obtained grade-recovery curves reveal that the concentrate grade is affected when pulp density is increased from 5 to 20% (wt.).

2. Rheological experiments carried out with the same pulps show dramatically increasing pulp viscosities when the solids content approaches 20 by weight (8% by volume). This indicates that the maximum packing fraction for this finally ground ore is around 8% by volume.

3. The concentrate grades consistently decrease at the Casson yield stress higher than 1.5-2 Pa and "boiling" was observed in the flotation tests carried out under such conditions.

ACKNOWLEDGEMENTS

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