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The effect of cell hydrodynamics on flotation performance

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A B S T R A C T

It is clear that along with gas dispersion characteristics, the energy dissipated by the impeller is process determining in flotation, and its effect on flotation kinetics has been widely studied. However, turbulent conditions inside a flotation cell have usually only been changed by varying impeller speed or air flowrate or both. Therefore, there is a need to investigate not only these variables but also how changes in impeller/stator mechanism size and design, cell aspect ratio and cell design affect turbulence. This should lead to a better understanding of the effect of cell hydrodynamics on flotation performance. The aim of this work was to evaluate the role of flotation cell hydrodynamics on flotation performance in a fully instrumented 3 m^3 cell. The cell was operated at a copper concentrator in Australia with different combinations of airflow rates, impeller speeds and sizes and cell aspect ratio providing a wide range of hydrodynamic conditions. An analysis of the flotation cell performance showed that the overall copper recoveries were very similar for the conditions tested. However, by decoupling pulp effects from froth effects it was possible to determine whether the changes made affected the pulp zone and/or froth zone responses. The analysis showed that the overall recovery had the potential to be up to 10% higher if not limited by froth recovery. Comparing the metallurgical performance of the cell with the different hydrodynamic conditions it was found that the collection zone flotation rate was not directly related to overall energy dissipation, as is commonly observed at laboratory scale, where energy is usually only changed by varying impeller tip speed. Results suggest that it is the size of the turbulent zone, rather than just energy input, that affects flotation recovery.

1. Introduction

Three distinct zones can be identified within a mechanical flotation cell: the turbulent, quiescent and froth zones. It is known that the highly turbulent zone is responsible for the key sub-processes (Schubert and Bischofberger, 1978, 1979; Schubert et al., 1982; Schubert, 1985, 1986, 1999, 2008; Weiss and Schubert, 1988; Weber et al., 1999):

- Suspension of the particles in the pulp;
- Feeding and dispersion of the air into bubbles;
- Mixing of the aerated pulp for better reagent distribution and conditioning; and
- Promotion of particle-bubble collisions (the basic requirement for particle-bubble attachment).

Too much turbulence can have an adverse effect on flotation because it results in the detachment of particles from bubbles as they rise in the pulp, as well as causing destabilisation and loss of recovery within the froth phase. Thus, a quiescent zone, less energy intensive than the turbulent zone, provides conditions for detaching entrained or entrapped gangue particles from aggregates created in the turbulent zone. The quiescent zone is believed to be important for flotation as it minimises the detrimental effects of turbulence on the froth phase.

Turbulence in mechanical flotation cells has been quantified by impeller speed or power input by many researchers (Ahmed and Jameson, 1985; Deglon et al., 2000; Schubert and Bischofberger, 1979; Schubert, 1985, 2008; and many others), but few have considered the parameters necessary for a more comprehensive characterisation of turbulence.

Exceptions are Jordan and Spears (1990); Pyke et al. (2002, 2003) and Duan et al. (2003) who measured turbulence parameters such as turbulent fluctuating velocities and energy spectra in batch flotation cells and incorporated these results into micro-kinetic models for flotation in agitated systems. The authors considered the turbulent microenvironment in the flotation cell to have a significant impact on both bubble breakup and bubble-particle contact.

Schubert and Bischofberger (1978) found that an increase in recovery occurred with increasing impeller speed and hence established optimum power inputs for different particle size fractions in a cassiterite flotation plant. An optimum in the flotation rate as a function of impeller speed, particle size, density, and bubble size was found by Ahmed and Jameson (1985).

Other similar studies, showing an increase in flotation rate of fine particles with an increase in impeller speed, can be found in the literature for different ore types: galena (Spears and Jordan, 1989), chalcopyrite (Jordan and Spears, 1990) and coal (Cheng et al., 1995).

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The energy dissipation, or specific power input (ε), may be considered equal to the average energy dissipation in a flotation machine (Schubert, 1986, 2008), which is related to the power input (P) of the impeller into the total mass of the fluid system (m) by:

$$\varepsilon = \frac{P}{m} \tag{1}$$

This equation shows that achieving high local energy dissipation rates in the impeller stream is dependent on the power input to the impeller. The degree of turbulence is at a maximum in the impeller region and is significantly reduced in the quiescent zone above the impeller (Wu and Patterson, 1989; Rutherford et al., 1996; Pyke et al., 2002, 2003; Newell and Grano, 2007). Schubert and Bischofberger (1979) suggest that, in the highly turbulent zones of the cell, values of ε may be 5 to 30 times higher than the average value.

The impeller-stator system area and its immediate vicinity represent the high intensity zone, where air is sheared and bubbles are generated, and significant turbulence and air void fraction are present. This zone also represents the area where particles and bubbles come into first contact. These factors suggest this zone presents the highest probability of collision, and thus the highest flotation kinetics (Koh et al., 2000). Hence, high collision rates necessitate the use of an efficient impeller-stator system (Schubert, 2008).

The effect of the high intensity turbulence on flotation recovery has been widely studied by Schubert and co-workers (Schubert et al., 1982; Schubert and Bischofberger, 1998; Schubert, 1999; and others). They investigated recovery in the high intensity zone by means of high-speed photography, showing that particle-bubble collection occurs almost solely in this zone of high local energy dissipation.

It is clear that along with gas dispersion characteristics, the energy dissipated by the impeller is process-determining in flotation. Its effect on flotation kinetics has been widely studied (Schubert and Bischofberger, 1978; Jameson and Ahmed, 1983; Deglon et al., 1999; Pyke et al., 2003; Newell and Grano, 2006).

Conventional mechanical flotation cell size has increased significantly over the last 20 years. However, as cell size has increased, most manufacturers have kept the aspect ratio of the cell constant to maintain geometric consistency. This has resulted in cells with a highly turbulent region near the impeller and very large quiescent zones, which potentially result in very little flotation recovery. There may be an opportunity to increase cell recovery rates by changing the volume ratio between the high and low turbulent zones in the cell.

Most of the studies performed to investigate the effect of energy on flotation response have usually only involved changing impeller speed and/or air rate. Only limited laboratory scale work has been reported in the literature evaluating the size of the high turbulent zone and the ratio between high and low turbulent (or quiescent) zones on flotation performance. Earlier studies (Hall and Dell, 1989; Morris and Matthesius, 1988) on the effect of the ratio of quiescent to turbulent zone volumes in batch tests concluded that turbulence appears to play an important role in promoting particle-bubble attachment, as well as the generally accepted roles of air diffusion and suspension of solids.

Both studies suggested that the ratio between high and low turbulent zones within a flotation cell affects performance. Hall and Dell (1989) showed that in a cell with a larger turbulent zone, i.e. a shorter cell, and at a certain optimum air rate, higher flotation rates were obtained. However, Morris and Matthesius (1988) found that for coarser particles (>150 μm) the beneficiation efficiency was enhanced when flotation was carried out in a cell double in height.

There would therefore seem to be opportunities to improve flotation recovery rate by optimising the distribution of turbulence in a flotation cell. The work described in this paper was performed to evaluate the role of flotation cell hydrodynamics on flotation performance in a fully instrumented 3 m^3 cell. The cell was operated with different combinations of airflow rates, impeller tip speeds and sizes and cell aspect ratio providing a wide range of hydrodynamic conditions. The objective was to gain a better understanding of how flotation cell operational variables, which change both the energy inputted to the flotation cell and how this energy is distributed, impact flotation recovery.

2. Methodology

2.1. The experimental rig and test work program

The experimental work was carried out in Metso's flotation test rig at the Northparkes copper/gold concentrator, located in the central west of New South Wales, Australia. The test rig consists of two modules that can be disassembled to facilitate transportation (Fig. 1). A 3 m^3 Metso RCS flotation cell is located on the upper platform, with concentrate and tailings being discharged via gravity to a product sump tank located on the bottom platform. The staircase and the grid mesh platform enable personnel to safely access the top of the cell, where different measurements can be carried out in the flotation cell.

The 170 cm diameter RCS flotation cell incorporated a variable sidewall height, allowing comparison of a standard aspect ratio cell (145 cm height), with a lower aspect ratio cell (110 cm height, 2.5 m^3 volume). By reducing the cell height, the ratio between high and low shear zones in the cell was increased. The cell geometries are illustrated in Fig. 2.

One of the main advantages of the Metso rig is that it incorporates easily accessible full stream sampling points and is fully instrumented to allow stable operation, essential requirements for metallurgical test work (Runge et al., 2007).

The rig can be operated in three modes: open circuit, full recycle and tailing recycle (Runge et al., 2007). The configuration used for this test work was full recycle mode, in which the concentrate and tailing streams are mixed in the product sump and then recycled back as new feed. In this case the cell operates with nominally unchanging feed properties. The measured feed flow is kept constant by controlling the product sump pump speed. Feed flow rate was maintained at 80 $m^3\,h^{-1}$ throughout the test work, resulting in a flotation residence time of 2.3 min which is typical of that observed in industrial flotation cells. A peripheral launder with froth crowder was used to collect the froth.

Slurry to fill the test rig was taken from the flotation feed of Module 1 of the Northparkes concentrator. Flotation feed typically assayed 0.3% Cu at approximately 30% solids by mass, with a P_{80} of 100 μm. When processing the flotation feed material, the reagent suite added to the test rig was identical to that used in the plant (PAX, frother, NaHS and promoter).

At the start of each day the rig was filled with fresh slurry from the plant. The rig was then operated at a series of different test conditions and measurements performed. A factorial design was used in which each of the following variables was tested at two or three levels:

- Cell aspect ratio (height:diameter): 0.85 and 0.65;
- Impeller design: RCS3 (standard impeller for a 3 m^3 Metso RCS flotation cell) and RCS5 (oversized impeller, i.e. impeller for a 5 m^3 Metso RCS flotation cell);
- Impeller tip speed: 3.5 m s^{-1} and 6.2 m s^{-1};
- Air flowrate: 100 and 140 $m^3\,h^{-1}$
- Froth depth: three different froth depths, (typically 5, 9 and 13 cm).

A total of 103 test conditions were evaluated during the test campaign. This included the 48 test conditions of every combination of the factor levels in a full factorial experimental design; and also reproducibility testing.

To change between aspect ratios, the current sidewall was unbolted, removed with a crane and replaced with a new sidewall. To change between impellers, the current impeller and stator had to be unbolted and the new combination bolted into place. These modifications were time consuming and difficult, logistically and therefore there