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# The effect of energy input on the flotation of a platinum ore in a pilot-scale oscillating grid flotation cell

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ABSTRACT

This study investigates the effect of energy/power input on the flotation of a platinum ore in a pilot-scale oscillating grid flotation cell. Oscillating grids generate near ideal hydrodynamic environments, characterised by turbulence which is relatively homogeneous and isotropic. Secondary rougher feed and primary cleaner tail streams were floated in a pilot-scale oscillating grid flotation cell at power inputs from 0 to 2.5 W/kg, using 0.71 and 1.47 mm bubbles. From this study one may conclude that the effect of energy/power input on the flotation rate is strongly dependent on the particle and bubble size. For large bubbles (1.47 mm), increasing energy input generally leads to an increase in the flotation rate for finer particles (−25 µm) and an optimum flotation rate for intermediate (+25–53 µm) & coarse particles (+53–75 µm). For small bubbles (0.71 mm), increasing energy input leads to a decrease in the flotation rate for all conditions. Optimum conditions for PGM flotation are using small bubbles at low energy inputs, or large bubbles at higher energy inputs.

## 1. Introduction

Energy/power input in a flotation cell is an important parameter which, if optimised, can increase the flotation rate. The optimum energy input within a flotation cell is still a matter of conjecture and there is a need to better understand the effect of this quantity on flotation kinetics. For successful flotation to occur, three processes must take place i.e. solids suspension, gas dispersion and particle-bubble contacting. In a mechanical flotation cell energy/power input affects all these processes simultaneously due to the action of the impeller. In addition, turbulence is highly inhomogeneous and anisotropic, with power intensities near the impeller orders of magnitude higher than those found elsewhere in the cell (Koh and Schwarz, 2003; Schubert, 2008; Tabosa, 2012; Meng et al., 2014). These limitations have resulted in the development of novel cells for the investigation of energy input.

Anderson et al. (2009) developed a novel oscillating baffled cell (OBC) which had the benefit of decoupling solid suspension, bubble generation and energy input. It was found that the unique bulk oscillatory motion of the fluid in the cell had a strong effect on flotation kinetics at very low power intensities. This cell has potential for industrial applications but is limited as a research tool due to the complex nature of the fluid flow. Changunda et al. (2008) used a novel oscillating grid cell (OGC), based on the design of Bache and Rasool (2001). The OGC decouples the processes of solid suspension and bubble generation as well as producing relatively homogeneous and isotropic turbulence. Due to the near ideal nature of the turbulence generated, oscillating grids have been used in many areas of research including mixing across density layers (McDougall, 1979), combustion (De-Silva and Fernando, 1994), sedimentation (Huppert et al., 1995), coagulation (Brunk et al., 1998), resuspension (Orlins and Gulliver, 2003), precipitation (Mokgethi, 2010), turbulence and the gas transfer processes (Herlina and Jirka, 2008). Oscillating grids provide a potentially ideal environment for investigating the effects of energy input on flotation kinetics, which cannot be achieved in impeller stirred cells.

The work of Changunda et al. (2008) was however limited to relatively low power intensities (< 0.60 W/kg). Massey et al. (2012) used the design of Changunda et al. (2008) to develop an oscillating grid flotation cell capable of operating at high power intensities of up to 5 W/kg. Both Changunda et al. (2008) and Massey et al. (2012) investigated the effect of energy on the flotation of quartz only. Safari et al. (2016) used an oscillating grid flotation cell to investigate the effect of energy/power input on the flotation kinetics of sulphide minerals (galena, pyrite & pentlandite) and oxide minerals (apatite, hematite & quartz). Results showed that the effect of energy input on the flotation rate is strongly dependent on particle size, bubble size, collector dosage and mineral type. The work of Changunda et al. (2008), Massey et al. (2012) and Safari et al. (2016) were for the flotation of pure minerals in a laboratory oscillating grid flotation cell. The aim of this study is to investigate the effect of energy/power input

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on the flotation of an industrial platinum ore in a pilot-scale oscillating grid flotation cell. Results are compared to the sulphide flotation data of Safari et al. (2016) as platinum is generally treated as a sulphide float.

## 2. Energy input in flotation

### 2.1. Theoretical findings

Energy/power input is considered to influence all of the sub processes of particle-bubble collision, attachment and detachment. The flotation rate is a function of the collision frequency, collision efficiency, attachment efficiency and detachment efficiency. Increasing energy input results in an increase in the collision frequency due to an increase in turbulence (Schubert, 1999). Models for turbulent collision suggest that the rate of flotation is proportional to the energy input, or turbulent energy dissipation rate, to the power of between 0.50 and 0.75 (Deglon, 2002). Increasing energy input has no/minimum effect on the collision efficiency. Increasing energy input results in an increase in the attachment efficiency since a higher energy input helps to overcome "the energy barrier" to particle-bubble attachment (Yoon and Mao, 1996). However, increasing energy input results in an increase in the detachment efficiency, especially for coarser particles. Here, the destabilizing influence (probability of detachment, stress on aggregate, detachment force) has been shown to be proportional to the energy input to the power of between 0.66 and 1.0 (Deglon, 2002). Several studies have combined the various theoretical models for particle-bubble collision, attachment and detachment in simulations of agitated flotation cells (Saint Amand, 1999; Koh and Schwarz, 2003; Pyke et al., 2003; Sherrell and Yoon, 2005). These studies have demonstrated that increasing energy input generally increases the rate of flotation to an optimum which is strongly dependent on the particle size, particle density, bubble size and contact angle.

### 2.2. Experimental findings

There have been a large number of experimental studies investigating the effect of energy/power input (or agitation) on flotation rates/recoveries. These studies have generally demonstrated that increasing agitation improves the flotation of fine particles but has a detrimental effect on the flotation of coarser particles (Ahmed and Jameson, 1985; Jordan and Spears, 1990; Deglon, 2002; Pyke et al., 2003; Newell and Grano, 2006; Schubert, 2008). Most studies have shown that increasing agitation results in an increase in the flotation rate to an optimum. At energy/power inputs below the optimum, the relationship between the energy input and flotation rate can be described by $k \propto \varepsilon^N$. Here the exponent N and the optimum energy/power input have been found to be in the range of 0.7–1.0 and 0.05–5 kW/m$^3$ respectively. As with the theoretical models for particle-bubble contacting, this optimum has been found to be strongly dependent on the particle size, particle density, bubble size and contact angle. However, experimental studies have also indicated that this optimum is dependent on the mineral type.

## 3. Experimental

### 3.1. Pilot scale oscillating grid flotation cell

A pilot-scale oscillating grid flotation cell was designed and constructed, as shown in Fig. 1. Physical specifications for the cell are given in Table 1. The pilot scale OGC was operated as an entirely self-contained unit, using variable speed feed, recycle and tailing mono-pumps. The cell had a stack of 19 grids which were oscillated at various frequencies using a variable speed drive. Energy input was determined by measuring the force supplied to the grid stack using a load cell mounted in line with the drive shaft. The energy input was altered by changing the oscillating frequency which was manipulated by changing the rotational speed of the motor. Air was sparged into the cell either directly through porous sintered metal spargers or indirectly through cavitation tube spargers. These two methods of sparging produced two different bubble sizes, with significantly smaller bubbles from the cavitation tube spargers. In this study, bubble size was measured photographically with the Anglo Platinum Bubble Sizer (APBS). The recycle rate to the cavitation type spargers was measured using a magnetic flow meter. The air flow rate was controlled using a rotameter. A fixed amount of wash water was used to clean the froth launder during tests. Froth was removed from OGC using a conventional froth launder, fitted with a small froth crowder.

### 3.2. Materials and reagents

The flotation experiments were performed in the oscillating grid cell using feed taken directly from the Baobab Concentrator in the Limpopo province of South Africa. The feed to the Baobab Concentrator was Platreef Ore (PGM) from the nearby Mogalakwena Concentrator belonging to Anglo American Platinum. Feed to the OGC was obtained from different streams. Secondary rougher feed (SRF), primary cleaner tail (PCT) and secondary cleaner tail (SCT) streams were used as a feed for the OGC flotation experiments ($< 75$ μm). The feed SG varied depending on plant operation but on average was 1.13 t/m$^3$ for primary and secondary cleaner tail and 1.26 t/m$^3$ for secondary rougher feed. No additional reagents were added to the OGC. Sample preparation was conducted at the Baobab plant laboratory and CMR laboratory at the University of Cape Town. Samples were screened into three size fractions (−25, +25–53 and +53–75 μm) and sent to Anglo American Technical Solutions (Research) for 2E assay (Platinum and Palladium).

### 3.3. Experimental conditions and procedures

The flotation experiments were conducted in continuous mode using the conditions given in Table 2. Energy inputs were chosen to cover the range of power intensities typically found in industrial mechanical flotation cells. A typical flotation column superficial gas velocity of 1 cm/s was used. Two bubble sizes were used depending on the method of sparging. Bubble sizes from the porous sintered metal (1.47 mm) and cavitation tube spargers (0.71 mm) are towards the upper and lower ends of the range typically found in industrial flotation cells respectively. The experimental conditions used by Safari et al. (2016) are also shown in this table for comparative purposes. The bubble size distribution in the pilot-scale OGC is illustrated in Fig. 2.

To minimise froth recovery effects, a shallow froth depth of around 10 cm was maintained. The standard plant reagent scheme and dosages were used at the Baobab Concentrator. Feed was obtained directly from the plant and pumped through a 2 in. hose to a 1.5 m$^3$ agitated surge tank. Flotation tests were conducted over a period of 30–60 min to allow for steady state. Concentrate was collected continuously for 7–10 min. Increments of feed and tails were taken every 1 min for 7–10 min. Tails flow rates and SG's were measured at the start and end of each test. OGC operating conditions were monitored continuously during the test. The flotation rate was calculated using the standard first-order expression for a continuous flotation cell. Entrainment was assumed to be negligible due to the low water recovery (3.7% on average), relatively low percentage solids and the low percentage of ultrafine particles in the feed stream.

The experimental programme consisted of 27 flotation tests of which the majority were with the large bubble size (1.47 mm) and the remaining 10 tests were with the small bubble size (0.71 mm). The OGC flotation cell operated stably/consistently. However, there was variability in the nature of the feed to the cell. Variability was most significant between test campaign days, but occurred during the course of a day. The coefficient of variation (relative precision) for the variability in feed rate (due to changes in % solids) and feed grade (due to changes in quality) over the full test campaign was 7.03% and