*Physicochem. Probl. Miner. Process. 51(2), 2015, 511−519*

Physicochemical Problems of Mineral Processing

www.minproc.pwr.wroc.pl/journal/

ISSN 1643-1049 (print)
ISSN 2084-4735 (online)

*Received January 20, 2014; reviewed; accepted June 23, 2014*

# THE EFFECTS OF AIR-TO-PULP RATIO AND BIAS FACTOR ON FLOTATION OF COMPLEX Cu-Zn SULPHIDE ORE IN THE JAMESON CELL

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**Abstract:** The air-to-pulp ratio and bias factor are important operating parameters in the Jameson flotation cell. These parameters have significant effect on micro-events taking place between particles and bubbles in flotation, and hence on flotation performance. In this study, the possibilities of obtaining a Cu-Zn rich bulk concentrate from complex sulphide ore from the Cayeli region (Turkey) were investigated using the lab-scale Jameson cell. The effect of air-to-pulp ratio and bias factor on flotation recovery were also studied. The ore has problematic flotation behaviour due to very fine liberation size and oxidation. The results showed that the Cu-Zn rich bulk concentrate can be obtained from the ore with satisfactory grade and recovery. It was determined that the air-to-pulp ratio and bias factor have significant effect on the flotation recovery. The optimum values of air-to-pulp ratio and bias factor in flotation of rather fine sized minerals were determined to be within the range of 1-1.5 and 0.70-0.95, respectively.

***Keywords:*** *air-to-pulp ratio, bias factor, Jameson cell, flotation, hold-up*

## Introduction

The Jameson flotation cell, differing from other conventional flotation devices with its structural character and working principle, is an enrichment device. It was successfully used in beneficiation of difficult-to-float fine sized minerals (Jameson, 1999; Cinar et al., 2007; Sahbaz et al., 2013). The Jameson flotation cell, which first appeared in mineral processing in 1989, is used with different capacities in over 200 ore concentration plants. Nowadays, it is widely used in enrichment of fine coals and finely liberated complex sulphide ores, due to its higher flotation performance compared to other flotation devices (Evans et al, 1995; Jameson and Goel, 2012; Sahbaz et al., 2013). The most important basic reason for this is its ability to produce fine bubbles (200-1000 μm), which play an effective role in the particle-bubble collision. This feature arises from its design and its working principle.

http://dx.doi.org/10.5277/ppmp150212

The Jameson cell ability to create hydrophobic particle-bubble aggregates in flotation is connected initially to two separate sequential micro-events. The first one is the possibility of encountering the particle and bubble due to the gas hold-up (Oteyaka, 1993; Oteyaka and Soto, 1995), the second one is directly proportional to the particle size and inversely proportional to the bubble size (Sutherland, 1948; Gaudin, 1957; Schulze, 1993; Oteyaka, 1993; Oteyaka and Soto, 1995). The second micro-event plays an extremely important role in flotation of fine particles and directly affects the flotation recovery. The collision probability of fine particles with bubbles is related to the presence of fine bubbles in the cell. The absence of fine bubbles causes low flotation recovery (Reay and Ratcliff, 1975; Trahar and Warren, 1976; Fuerstenau, 1980; Yoon and Luttrell, 1989; Ahmed and Jameson, 1985; Miettinen at al., 2010). In conventional flotation cells, the flotation efficiency is low due to the fact that fine air bubbles cannot be produced at the appropriate size for fine particles. The Jameson flotation cell produces finer than one mm air bubbles due to its working principle. The fine bubbles cause the increase in possibility of collision, and therefore the Jameson cell is appropriate for flotation of fine size liberated ores. Furthermore, flotation in the Jameson cell is shorter than in the conventional flotation devices and hence it eliminates the number of used flotation banks (Miettinen et al., 2010).

There are important parameters that affect the flotation performance in the Jameson cell and other flotation devices. These parameters are superficial gas velocity, feed flow rate, jet length, bias factor, air-to-pulp ratio, and gas hold-up. The optimum values of these parameters change according to the particle size (Evans et al., 1995; Tasdemir, 2006; Tasdemir et al., 2007, 2011; Gursoy, 2007; Sahbaz, 2010). The air-to-pulp ratio is an important parameter, which not only determines the number and diameter of bubbles in the downcomer but also determines the flow regime (laminar or turbulent flow) and the gas hold-up value (Tasdemir, 2006; Sahbaz, 2010). Consequently, the air-to-pulp ratio is a parameter which influences the micro-events between particles and bubbles and directly affects the flotation performance. Another important operating parameter is the bias factor, which influences the concentrate grade and recovery. The bias factor ($J_b$) is calculated as (Mohanty and Honaker, 1999; Patwardhan and Honaker 2000; Ucar et al., 2013):

$$J_b = (Q_T - Q_F)/Q_{WW} \tag{1}$$

where, $Q_T$, $Q_F$ and $Q_{WW}$ are flow rates of tailing, feed and wash water, respectively. In general, a positive bias factor is maintained to limit entrainment of fine hydrophilic particles into the froth.

The aim of this research is to investigate the effect of air-to-pulp ratio and bias factor to obtain a bulk Cu-Zn concentrate from a fine grained complex sulphide ore by using the Jameson flotation cell.

## Experimental

The ore was obtained from Cayeli Region of Turkey. Mineralogically, the ore consists of chalcopyrite, sphalerite, and pyrite, along with small quantities of bornite and tetrahedrite. The main gangue minerals are barite, quartz, cerussite and clay. The microscopically determined liberation size of chalcopyrite and sphalerite minerals from the gangue minerals is approximately 38 µm. The liberation degree for chalcopyrite and sphalerite minerals is about 75-80%. Therefore, the ore was ground down to $d_{80}$=38 µm in a controllable manner. The ore contains 2.75% Cu, 6.15% Zn, 24.81% Fe, and 23.33% S. The particle size analysis of the ore was carried out using a Malvern Mastersizer 2000 (Fig. 1).

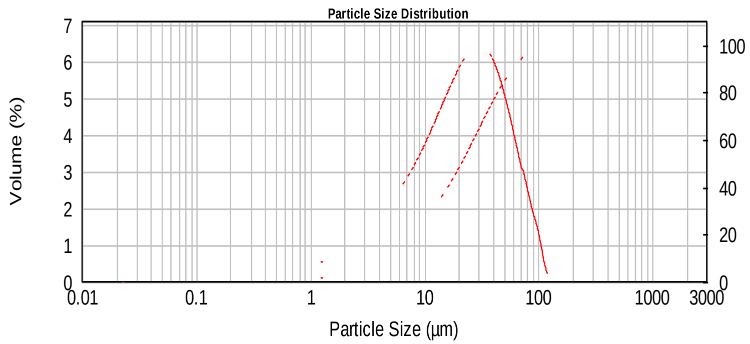


Fig. 1. Distribution of particle size of ore used in experiments

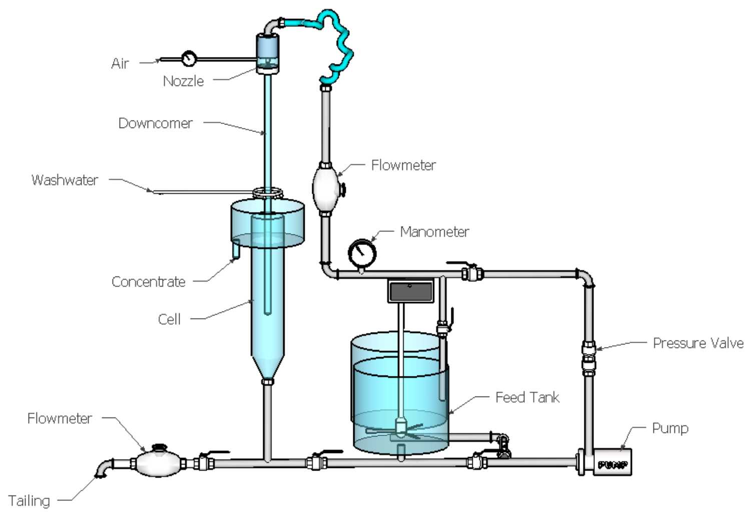


Fig. 2. Jameson flotation cell (Gursoy, 2012)

A 100 g/Mg of Aerophine 3418A (produced by Cytec in the Nederland) was used as a collector, 20 g/Mg of MIBC (methyl isobuthyl carbinol) was used as a frother, and CaO was used as a pH regulator. The experiments were carried out at pH 11.8 for pyrite depression. It is known that the surface of pyrite consists of hydrophilic ferric hydroxide at high hydroxyl concentrations (pH > 11) (Goktepe, 2002; Bulatovic, 2007). The experiments were carried out using a laboratory scale Jameson flotation cell (Fig. 2).

The Jameson flotation cell is composed of 200 mm diameter cell, 26 mm diameter downcomer, and 5 mm diameter nozzle. The other flotation conditions and instrumental parameters are given as:

| | |
|---|---|
| - Particle size | : - 38 μm |
| - Bubble size | : 0.6 – 1.0 mm |
| - Solid ratio | : 2 % |
| - Frother | : MIBC (20 g/Mg) |
| - Collector | : Aerophine 3418A (100 g/Mg) |
| - Depressant (sphalerite) | : $ZnSO_4$ (1000 g/Mg) |
| - pH | : 11.8 |
| - Conditioning time | : 6 min |
| - Feed flow rate | : 11.5 $dm^3$/min |
| - Waste flow rate | : 14.3 $dm^3$/min |
| - Wash water flow rate | : 3 $dm^3$/min |
| - Air flow rate | : 9.1, 13.6, 17.5, 20.0, 21.7 $dm^3$/min |
| - Air-to-pulp ratio | : 0.79, 1.18, 1.52, 1.74, 1.89 |
| - Hold-up | : 0.38, 0.44, 0.49, 0.51, 0.52 |
| - Positive bias factor | : 0.43, 0.60, 0.77, 0.93 |
| - Feed pressure | : ~110 kPa |
| - Separation tank diameter and height | : 200 mm and 900 mm |
| - Downcomer diameter and length | : 26 mm and 1800 mm |
| - Nozzle diameter | : 5 mm |
| - Downcomer plunging depth | : 60 cm. |

Apart from the hold-up, values of the other parameters were directly measured from the variables given above. The hold-up value, as there was no suitable measuring apparatus, can be found by using the Tasdemir model (2006):

$$\varepsilon = 0.2183+0.00885V_J + 0.044\lambda - 0.0197D_N + 0.0028D_D + 0.0179L_J \text{ (for } \varepsilon \leq 0.4596),$$

$$\varepsilon = 0.2428+0.0031V_J + 0.066\lambda - 0.00225D_N + 0.0041D_D + 0.018L_J \text{ (for } \varepsilon > 0.4596),$$

where $\varepsilon$ is the hold-up (%), $V_J$ jet velocity at the end of downcomer (m/min), $\lambda$ air-to-pulp ratio, $D_N$ nozzle diameter (m), $D_D$ downcomer diameter (m) and $L_J$ jet length (m). In each experiment, the wash water tank (70 $dm^3$) and the cell were filled with tap water and then the frother was added. Then, the established study variables were set and operated with a by-pass (giving the concentrate and tailing launder back to the tank) until the pulp feed was started.

At the beginning of each experiment, the ore was conditioned in stirring tank for 6 minutes after adding the collector. The feed tank was filled with tap water and the conditioned ore was introduced to the feed tank until it reached 2% of the solid-to-liquid ratio. The pH of solid suspension in the feed tank was set to 11.8 by adding CaO. Then, the conditioned slurry was pumped (100–170 kPa) into the downcomer, which is the primary contacting zone of particles with bubbles. There is a nozzle on the top of downcomer to provide a high pressure water plunging jet. The air is drawn into the downcomer due to the Venturi effect of the plunging jet. The fine bubbles (400–700 μm) are quickly dispersed into the pulp and carried downward by the bulk fluid motion.

The three-phase mixture passed from the base of the downcomer into the separation tank, which has a much greater cross-sectional area than the downcomer. As a result, the downward superficial velocity of the mixture was reduced, allowing the hydrophobic particles–bubbles aggregate to rise to the surface and form a froth layer. Some hydrophilic particles, coming into the froth phase through hydraulic entrainment, were washed down by the addition of wash water. The concentrate product reported to launder, while the liquid phase and hydrophilic particles left through a valve at the base of the separation tank. The obtained concentrate and tailing were then dried, weighed, and chemically analysed using X-ray fluorescence spectrophotometer (XRF).

## Results and discussion

The air-to-pulp ratio (ratio of the air flow rate to the feed flow rate) was obtained by keeping the pulp feed flow rate constant, while changing the vacuumed air flow rate. The speed of vacuumed air to the downcomer is measured at the start of each experiment using an air flow meter. The air flow rate entering the downcomer can be calculated ($cm^3/s$) from the cross-sectional area of the downcomer and air speed. The flotation experiments were carried out at the air-to-pulp ratio values of 0.79, 1.18, 1.52, 1.74, and 1.89. The flotation recovery and concentrate grade versus air-to-pulp ratio values are given in Fig. 3.

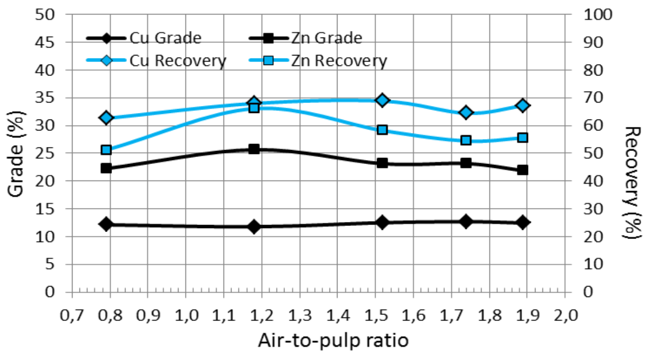


Fig. 3. Effect of air-to-pulp ratio on concentrate grade and recovery of Cu and Zn

According to the data presented in Fig. 3, the highest value of copper recovery was obtained when the air-to-pulp ratio value was 1.52. The copper content and recovery in the concentrate were respectively 12.51% and 68.83%, while the enrichment ratio was 4.55. It can also be seen that zinc also floated very easily. It could be explained by the presence of Cu ions from the oxidised copper minerals activating the sphalerite. To prove this point, the copper ore sample taken from the grinding process was filtered and NaOH was added to it. As a result a colour of solution changed to blue (turquoise) indicating the presence of $Cu^{+2}$ ions. Next $Cu(OH)_2$ was formed (Fig. 4).

Fig. 4. Addition of NaOH to filtered pulp sample (pH 5.5)

The bias factor is one of the variables that contribute to attain optimum performance by the Jameson cell. The bias factor is defined by the fraction of wash water flowing downward and entering to the tailing stream (Eq.1). The bias factor refers to the presence or absence of froth zones. In the case of negative bias there is no froth. The bias factor is also a significant parameter determining the fine hydrophilic particles in the froth zone. With increase in the bias factor, entrainment of particles decreases and hence the concentrate grade increases (Sahbaz et.al, 2008; Tasdemir, 2006). Therefore, in this work series of flotation studies with different bias factors (0.43, 0.60, 0.77 and 0.93) were carried out to determine the effect on the concentrate grade and recovery. The results are shown in Fig. 5.

According to Fig 5, with increasing bias factor, the concentrate grade tends to increase and conversely the recovery tends to decrease. This could be attributed to the fact of hydraulic entrainment of fine gangue particles into the concentrate decreases. However, the increase of Zn grade in the concentrate is due to the natural oxidation of the ore and no sphalerite depression. As a result, sphalerite surface is activated by $Cu^{+2}$ ions ($ZnS + Cu^{+2} = CuS + Zn^{+2}$) and its floatability increases with collector addition.

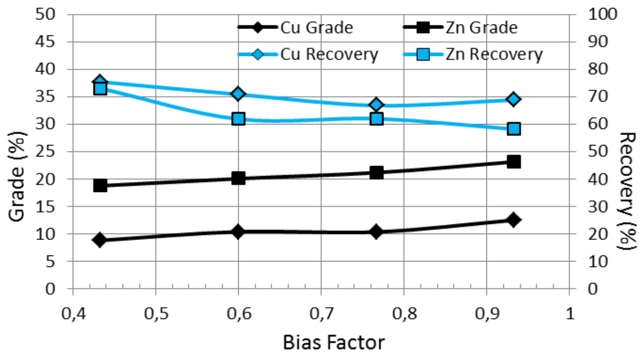


Fig. 5. Effect of bias factor on concentrate grade and recovery of Cu and Zn (for air-to-pulp ratio 1.52)

The results showed that acceptable bias factor value was 0.93 in terms of Cu grade. If cleaning stage was planned to apply after this stage, it would be performed with low bias factor in terms of recovery. As a result, greater bias factor for cleaning stage and smaller bias factor for rougher stage could be applied. The product containing 12.51% Cu, with the recovery of 68.83% was obtained by using lower bias factor, while the product of 8.80% Cu with the recovery of 75.41% was obtained with the bias factor of 0.43.

## Conclusions

The effect of air-to-pulp ratio and bias factor on the Jameson cell flotation performance of fine grained complex sulphide ore was studied. It was shown that the Jameson flotation cell can be successfully used in beneficiation of fine particle size copper sulphide ores from the Cayeli region (Turkey). It was found that the air-to-pulp ratio had a significant effect on the concentrate grade and recovery. It was observed that at the air-to-pulp ratio values of between 1.18 and 1.52, provided significant improvements in the concentrate grade and recovery. The flotation performance decreased at larger values of the air-to-pulp ratio due to increased bubble sizes since the possibility of particle-bubble collision decreased.

It was also determined that a bias factor value between 0.70 and 0.95 should be chosen to obtain the concentrate with high grade and recovery as required for rougher flotation.

A further research should be performed to eliminate the negative effect of $Cu^{+2}$ ions in the selective flotation of chalcopyrite and sphalerite.

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