Solving challenges in copper cleaning circuits with the Jameson Cell

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ABSTRACT

Flotation is a separation process that exploits the hydrophobicity of particles and the buoyancy of air bubbles to recover valuable minerals from liquid-solid suspensions. Flotation is a complex multifaceted process that can be separated into three main areas: ore, chemistry and machine. This paper will focus on factors associated with the machine.

Bubble generation and mixing for bubble-particle contact are fundamental aspects of any flotation machine and different technologies on the market have varying ways of achieving this. The Jameson Cell technology is a robust and efficient high intensity flotation technology with attributes that make it ideal for recovering fast floating liberated mineral particles. It is proven to achieve very high upgrade ratios to produce final grade concentrates in a single stage of flotation.

This papers describes how it can be used to transform traditional flowsheet designs and shows how it has been successfully used to solve capacity and grade issues, associated with non-sulfide gangue and penalty elements, in a number of major copper concentrators around the world. Case studies include operations in Australia (Telfer), Laos (Phu Kham) and Zambia (Lumwana).

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INTRODUCTION

Flotation is a complex multifaceted process that can be separated into three main areas: ore, chemistry and machine, as shown in Figure 1. To solve plant issues it is important to understand how each of the areas and then the different factors within these areas affect and control flotation performance for one's system. Factors within the ore and chemistry areas are dynamic so needs to be dealt with by plant personnel in normal plant operations. However, factors associated with the machine used are generally set as it relates to the fundamental design of the technology. The most important characteristics of any technology is how it generates air bubbles and the size of these air bubbles, as this controls flotation kinetics, and it also dictates the carrying capacity of the machine. The other crucial component is how the machine effects collision and contact between air bubbles and particles.

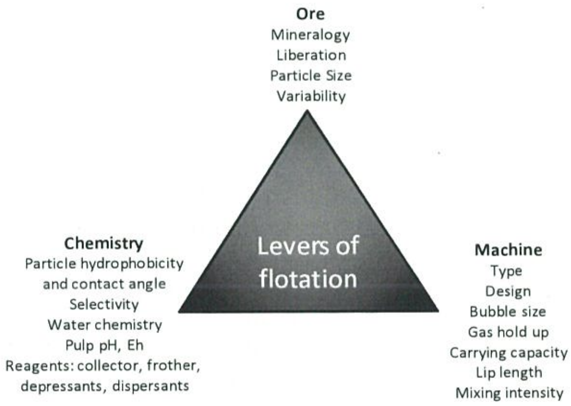

Figure 1 Flotation 'triangle' showing the different factors affecting and controlling performance in all systems

Currently, the majority of the world's copper operations have cleaner circuits use either multi-stages of all mechanical cells or a combination of mechanical cells and flotation columns. The former generally struggles to produce high grade and clean concentrates because of undesirable entrainment of gangue. Upgrade ratios are generally low requiring multiple stages of cleaning to achieve the target grade. The latter circuit suffers from high circulating loads due to the low unit recoveries of columns, exacerbated by spargers (the bubble generation device) that are not properly maintained.

In recent years, the Jameson Cell has been utilised to transform traditional copper cleaner circuits. It is best utilised to recover fast floating liberated mineral particles and is able to produce final grade concentrates in a single stage of flotation (Young et al., 2006). This paper will discuss the fundamental aspects of the Jameson Cell that make it ideal for retrofitting into existing copper cleaner circuits to increase capacity, and for solving issues in plants that are struggling to produce final grade concentrates that have acceptable levels of non-sulfide gangue and/or penalty elements such as uranium, fluorine or mercury.

JAMESON CELL DEVELOPMENT

The Jameson Cell is a high intensity flotation technology jointly developed in the mid-1980s between Mount Isa Mines (MIM, now Xstrata) and Professor Graeme Jameson from the University of Newcastle. What started as a research project to improve the sparger design in the column cleaner cells installed in MIM's zinc circuit culminated into the development of a completely different bubble-generation device called a downcomer, which was originally designed to replace spargers in columns cells. When it discovered that in addition to being a bubble generation device bubble-particle collisions required to effect flotation also occurred inside the downcomer, it became apparent that the large residence time and hence, volumes required for the collection zone in columns was no longer needed. This meant that the downcomers can be placed in much smaller tanks.

JAMESON CELL PRINCIPLE OF OPERATION

The fundamentals of Jameson Cell operation has been described by other authors such as Evans, Atkinson & Jameson (1993). To summarise, in a Jameson Cell feed slurry is first pumped through a restriction (the slurry lens orifice) to create a high pressure jet which then enters into a cylindrical device called a downcomer. The jet of liquid shears then entrains air from the atmosphere. Removal of air into the jet causes a vacuum to be generated inside the downcomer. When a hydraulic seal is formed at the bottom of the downcomer, the vacuum causes a column of slurry to be drawn inside the downcomer. The jet of slurry plunges on the surface of liquid and the high kinetic energy of the jet breaks the entrained air into very fine bubbles. In this zone, the high intensity of the system creates a very favourable environment for the bubbles and particles to collide and attach. The air bubbles and mineral particles move continuously down the downcomer until it exits into the tank. The particle laden bubbles then float to the top to form the froth whilst the hydrophilic mineral particles remain in the pulp phase to be removed as tailings. To ensure consistent operation, tailings recycle is employed. Tailings recycle dampens feed fluctuations to the cell allowing the downcomer to operate at a constant feed pressure and flowrate. The high rate of mixing from the high pressure jet and the fact the air is self aspirated, allows for the Jameson Cell to have no moving parts aside from the feed pump. No agitators or compressors are required.

Due to rapid kinetics and a separate contact zone in the downcomer, the tank is not sized for residence time, so tank volumes are much smaller than equivalent mechanical and column cells.

BUBBLE SIZE

Bubble size is one of the most important factors in any flotation system as it has a strong influence over flotation kinetics. Fine bubbles increase the flotation kinetics across *all* particle sizes (Diaz-Penafiel & Dobby, 1994; Ahmed & Jameson, 1985) and not only improve the recovery of fine particles as often hypothesised. However, fine particles do exhibit slower flotation kinetics (resulting in poorer recovery and selectivity) so the influence of fine bubbles to improve fine particle recovery is, perhaps, more noticeable than for coarse particles which generally floats faster anyway. Fine bubbles improve the separation of minerals as they intensify the difference in the flotation kinetics of the valuable minerals from the gangue minerals, thus allowing higher grade concentrates to be produced. It also increases the carrying capacity (often measured as the tph of concentrate per m^2 of surface area of the flotation machine) as there is more bubble surface area per volume of air added for mineral particles to attach.

The Jameson Cell is able to produce fine bubbles via by the shear action of a plunging jet (Evans, Jameson & Atkinson, 1992). It is this fundamental characteristic that allows the Jameson Cell to float particles quickly, attain superior selectivity and have high productivity (carrying capacity). The latter is particularly beneficial when high mass pulls are required, such as recleaning in metals applications, and in the flotation of metallurgical coal where mass pulls (yield) can exceed 80%.

The air bubbles generated by the Jameson Cell are in the range of 300 to 700 μm (Sauter mean diameter, D_{32}) (Evans, Atkinson & Jameson, 1993). Figure 2 compares the bubble size of a range of industrial mechanical and columns cells (Nesset, Finch & Gomez, 2007; Nesset, 2009) to that of the Jameson Cell (Osborne et al., 2013). All results collated in Figure 2 were determined by the same bubble size measurement technique as developed by McGill University and described by Chen, Gomez & Finch (2001) and Gomez & Finch (2007).

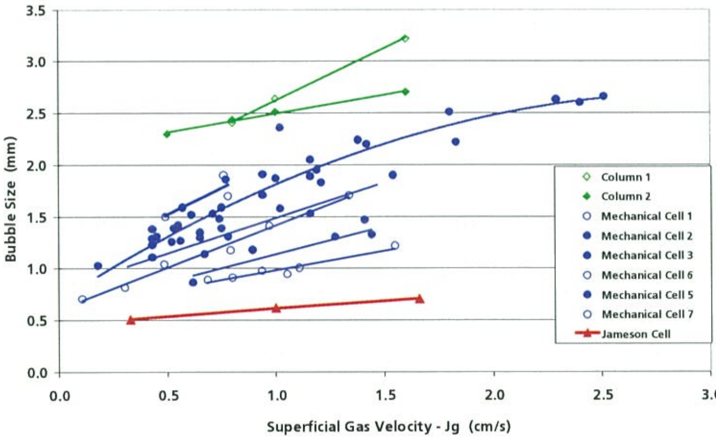

Figure 2 Bubble size as a function of Jg (measure of air flow rate) for different flotation technologies

Gas holdup, ε_g, is defined as the volumetric fraction of gas in the pulp. The gas holdup in a Jameson Cell downcomer is generally in the range of 40 to 60% while gas holdup in the separation zone (tank) is in the 20% to 40% range. In comparison, the gas holdup in conventional machines is found to be much lower and in the range of 10 to 20% (Yianatos et al., 2001; Grau & Heiskanen, 2003). Jameson Cells typically operate between 0.5 to 2 cm/s J_g (superficial gas velocity).

FROTH WASHING

The ore bodies mined today are more complex, lower grade and often need to be ground finer to liberate the value mineral particles. It is well known that effective separation of fine particle systems via flotation is far more challenging compared to coarser ones as fine particles exhibit slower flotation kinetics, oxidise more quickly and require more reagents to float due to larger surface areas, and entrainment of non-floating gangue, which typically occurs below 50 microns (Johnson, 2005), is always a problem.

Froth washing is one of the most effective methods employed to reduce entrainment and allow high grade clean concentrates to be produced. Washwater systems must be designed correctly: have the right hole size, provide good distribution of the water across the entire surface of the flotation cell, be placed at an appropriate distance above the cell lip, and most importantly be robust and easy to maintain as the quality and cleanliness of the water used for froth washing in most plants are poor leading to frequent blockages.

An example of the effect of froth washing on gangue rejection and hence, selectivity, is shown in Figure 3. Data is taken from Jameson Cell pilot plant trials at a site where the cleaner feed stream has a D_{80} of 20-25 μm. The decrease in the recovery of non-sulfide gangue (NSG) with addition of wash water is dramatic and results in a completely different selectivity curve. For any flotation system, the effect of washwater is highly dependent on the properties and structure of the froth. The froth must be stable if the water added is to penetrate through the froth to remove entrained gangue particles to attain a high grade product, whilst minimising its effect on value particles attached to the air bubbles affecting recovery.

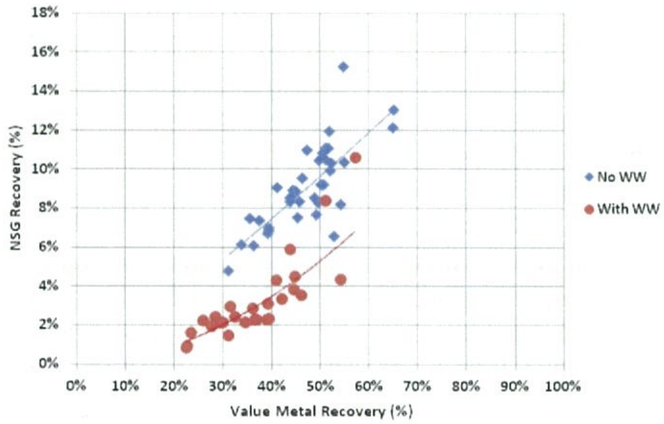

Figure 3 Demonstration of a flotation system in the absence and presence of washwater (WW) to minimise the entrainment of fine non-sulphide gangue (NSG)

RECENT INSTALLATIONS AND CASE STUDIES

The ability of the Jameson Cell to produce high grade clean concentrates have seen it successfully utilised as a cleaner scalper cell (at the head of existing cleaner circuits) in more and more operations. The recovery achieved in a single cell is dependent on the quantity of liberated material in the feed but typically ranges from 40% to 90%. Final grade concentrates are dependent on copper mineralisation in the feed and ranges from 28-32% Cu for chalcopyrite systems to 45-60% Cu for ores containing secondary copper minerals (chalcocite, bornite). Three specific case studies are discussed in this paper.

Case Study 1: Phu Kham

Phu Kham is a 12 Mtpa copper-gold concentrator owned by PanAust and is located approximately 100 km east of the capitol of Laos. Plant feed grades are 0.75% Cu, 0.33 g/t Au and 3.8 g/t Ag. The process plant comprises of a SAG and ball mill grinding circuit followed by rougher flotation. Rougher concentrate is reground using a M10,000 IsaMill and three stages of conventional cleaning is used to achieve a final concentrate grade of 25 % Cu, 7 g/t Au and 60 g/t Ag as described by Bennett, Crnkovic & Walker (2012).

Soon after the plant was commissioned in 2008, a debottlenecking project was initiated to look at ways to increase cleaner capacity as the recovery across this circuit was seen to drop off significantly when the cleaner feed exceeded 150 tph. The study concluded that the best option was to install additional cleaner capacity as the head of the cleaner circuit. A B6500/24 model Jameson Cell was chosen for this duty and installed in March 2011. The simple tie-in of the Jameson Cell to the rest of the plant meant minimal disruption to normal production and commissioning only required one week. The Jameson Cell produces a high grade concentrate typically around 26-28% Cu at 50-60% recovery and has allowed the overall cleaner circuit at

Phu Kham to maintain a consistently high recovery when the cleaner feed tonnage increases from 150 to 300 tph. Tests conducted with the Jameson Cell online and offline in February 2012 showed that the benefit of having the Jameson Cell was an overall plant increase of 0.8% copper recovery (Bennett, Crnkovic & Walker, 2012).

Case Study 2: Telfer

Telfer is a 21 Mtpa copper-gold concentrator owned by Newcrest and located in the South Western area of the Great Sandy Desert in Western Australia. As described by Seaman, Manton & Griffin, 2011, ore is mined from open pit and underground sources which have significant variations from mainly chalcocite in the open pit to chalcopyrite in the underground ore. The concentrator is set up so that these two different ores are treated in two parallel trains. Train 1 treating a blend of open pit and underground ore and Train 2 which only treats open pit ore. The ore is processed in different configurations. One of the most common configurations is sequential flotation where copper concentrate is produced first, then re-activation and flotation of pyrite followed by cyanide leaching to recover gold. Typical head grades are 0.1 to 0.2 % Cu, 1 to 2 g/t Au, 1 to 5 % Sulphur. Gold is present as free gold and also contained within copper minerals and pyrite.

Review of historical data showed that a large proportion of the liberated, non-sulfide non-floating gangue was being recovered to the copper concentrate by entrainment (Seaman et al., 2012). Dilution batch tests were performed to assess the NSG rejection potential of plant cleaner feed streams. Modelling of different cleaner circuit configurations predicted that with Jameson Cells (the chosen technology and whose selectivity performance was simulated by the dilution batch tests) installed at the head of the existing cleaner circuit copper concentrate grades could be increased to 20-25% Cu (from 16-18% Cu) by rejecting half the NSG that is currently reporting the to the concentrate. Removing the load off the circuit allows operation of the existing cleaner cells at lower wt% solids and addition of water to control pulp density, to allow better cleaning in the mechanical cells. With mineralogical circuit analysis, dilution cleaning tests and modelling outputs, pilot plant testing were considered unnecessary and capital expenditure was approved to install one Jameson Cell per train (Seaman et al. 2012).

Two E3432/8 model Jameson Cells were ordered in May 2011 and the project was fast-tracked to allow commissioning in November 2011. Performance of the cells matched the results from dilute batch flotation tests carried out during the project development phase. The Jameson Cells produces copper concentrate with 20 to 25 % Cu and is able to maintain these high grades up to 80% recovery, which exceeded the design of 50% copper recovery. Recovery by size data shows the Jameson Cell can achieve good recovery of copper (and gold) across all size fractions and has good gangue rejection down to very fine fractions below 10 microns. The payback for the project was found to be between two and seven months (Seaman et al. 2012).

Case Study 3: Lumwana

Lumwana is a 20 Mtpa copper concentrator owned by Barrick and located in Zambia's Mwinilunga District, 65 km from the provincial capital of Solwezi in the North Western Province of Zambia and approximately 660 km from the country's capital, Lusaka. Lumwana has two major copper deposits: Malundwe and Chimiwungo. Copper mineralization includes chalcopyrite, bornite and chalcocite. In addition to copper, these deposits also contains the penalty element, uranium (U) contained in vein hosted and disseminated uranite. The processing plant consists of SAG and ball milling for primary grinding. The flotation plant consists of two parallel train of rougher/scavenger followed by a single train of two stages of conventional cleaning. A ball mill is used for rougher concentrate regrind.

Soon after commissioning in early 2009, it was discovered the installed cleaner circuit could not produce final grade copper concentrates with uranium levels below acceptable limits. Studies showed the fine liberated U particles were recovered into the froth by entrainment. Based on the successful application of the Jameson Cell to reject fluorine, another penalty element, at Prominent Hill (Barns, Colbert & Munroe, 2009), Lumwana operations trialled the Jameson Cell on various cleaner streams at their site. Several weeks of continuous pilot plant testing (in November 2009) using a L500 Jameson Cell rig clearly demonstrated that the majority of U particles in the cleaner feed stream can be rejected allowing final grade copper concentrates with acceptable U levels to be consistently produced. Figure 4 shows the resulting copper/uranium selectivity curve produced from these tests. After piloting, a full scale B5400/18 model Jameson Cell was installed in a cleaner scalper duty in the plant with commissioning occurring in July 2011. Addition of the Jameson Cell has allowed Lumwana operations to produce a clean and saleable copper concentrate that has U levels below acceptable limits. This is particularly impressive given the varying nature of the copper mineralogy and uranium content of the plant feed. Although designed for a cleaner scalper duty, operational issues with the recleaner cells at Lumwana has forced reconfiguration of the cleaner circuit and the duty of the Jameson Cell altered to recleaning. The plant is still producing final clean concentrates below target U levels. A project is underway to optimise the cleaner capacity at Lumwana (Araya et al., 2013).

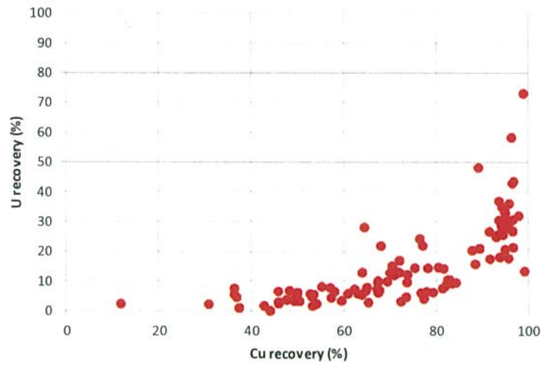

Figure 4 Selectivity of copper uranium recovery determined from Jameson Cell pilot testwork at Lumwana

CLEANER CIRCUIT DESIGN

The attributes that makes the Jameson Cell ideal for a cleaner scalper duty also make it ideal for final cleaning. An optimum cleaner circuit is shown in Figure 5. This design would allow higher plant final grade concentrates to be produced, whilst using lesser number of cells and in a smaller footprint, compared to an all conventional cell circuit. There are benefits in capital (less equipment), operational (less power) and maintenance (labour and spare parts). In fact, this circuit design with Jameson Cells has been operating at Northparkes (New South Wales, Australia) since 1994.

In addition to superior grade, a major advantage of using a Jameson Cell as a recleaner instead of conventional cells is that it may allow operations to diagnose 'online' plant liberation issues. That is, if the Jameson Cell cannot, in this duty, produce decent grade concentrates with froth washing to eliminate or minimise entrainment, then the value mineral particles recovered in this stream must not be sufficiently liberated.

Perhaps one could argue that other flotation technologies can be used instead of the Jameson Cell in the circuit proposed in Figure 5. Indeed this is possible, however it's important to match the attributes of different technologies for the different duties. Fast flotation kinetic and high carrying capacity afforded by the Jameson Cell are the main advantages, but practical considerations such as ability to control flotation performance, very fast response to process changes, whether they are deliberate or part of normal plant fluctuations, and rapid start-up and shut-down, may be just as important. Add to this its simplicity to maintain, it makes the Jameson Cell the best option.

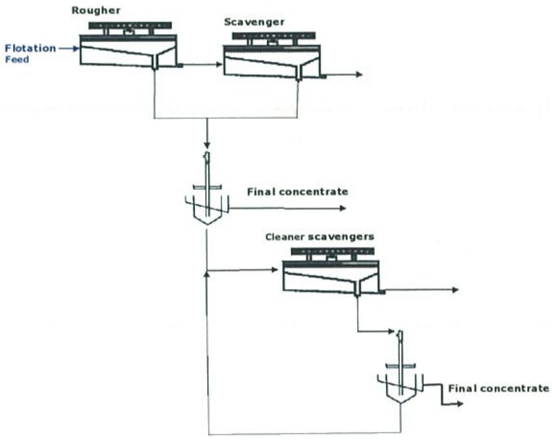

Figure 5 Ideal cleaner flowsheet using Jameson Cells in cleaner scalper and recleaner duties to produce final concentrate and mechanical cells only as cleaner scavenger

CONCLUDING REMARKS

The Jameson Cell has been used to successfully solve cleaner circuit issues in several major copper concentrators around the world. It is ideal for inclusion into existing circuits to increase cleaner capacity. Its small footprint, simple tie-in to existing structures and straight forward commissioning requirements means it can be easily incorporated into plants with minimal disruption to operations. It has found applications in existing operations where entrainment of gangue and/or penalty elements is an issue. The Jameson Cell produces clean concentrate in a single stage of flotation, through superior flotation selectivity and by applying froth washing.

The Jameson Cells are best utilised for cleaner scalper and recleaner duties. The ideal cleaner circuit design would see Jameson Cells used in these duties to produce all the final concentrate from a plant and mechanical cells used for cleaner scavengers only. These cleaner circuits would allow plants to produce the highest grades possible and achieve this using lesser number of cells and in a smaller footprint, compared to traditional designs.

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REFERENCES

Ahmed, N. & Jameson, G.J. (1985) 'The effect of bubble size on the rate of flotation of fine particles', *International Journal of Mineral Processing*, vol. 14, pp. 195-215.

Araya, R., Mwanza, A., Cordingley, G. & Huynh, L. (2013) 'Necessity driving change and improvement to the cleaner circuit at Lumwana Concentrator', *In preparation.*

Barns, K.E., Colbert, P.J. & Munro, P.D. (2009) 'Designing the optimal flotation circuit – The Prominent Hill case', *Proceedings of the Tenth Mill Operators' Conference,* AusIMM, Adelaide, South Australia, pp. 173-182.

Bennett, D., Crnkovic, I. & Walker, P. (2012) 'Recent process developments at the Phu Kham copper-gold concentrator, Laos', *Proceedings of the 11th Mill Operators' Conference*, AusIMM, Hobart, Tasmania, pp. 257-272.

Chen, F., Gomez, C.O. & Finch, J.A. (2001) 'Bubble size measurement in flotation machines', *Minerals Engineering*, vol. 14, no. 4, pp. 427-432.

Diaz-Penafiel, P. & Dobby, G.S. (1994) 'Kinetic studies in flotation columns: Bubble size effect', *Minerals Engineering*, vol. 7, no. 4, pp. 465-478.

Evans, G.M., Atkinson, B.W. & Jameson, G.J. (1993) 'The Jameson Cell', *Flotation Science and Technology*, Marcel Dekker, New York, pp. 331-363.

Evans, G.M., Jameson, G.J. & Atkinson, B.W. (1992) 'Prediction of the bubble size generated by a plunging liquid jet bubble column', Chemical Engineering Science, vol. 47, no. 13/14, pp. 3265-3272.

Gomez, C.O. & Finch, J.A. (2007) 'Gas dispersion measurements in flotation machines', *International Journal of Mineral Processing*, vol. 84, pp. 51-58.

Grau, R.A. & Heiskanen, K. (2003) 'Gas dispersion measurement in a flotation cell', *Minerals Engineering*, vol. 16, pp. 1081-1089.

Johnson , N.W. (2005) 'A review of the entrainment mechanism and its modelling in industrial flotation processes', *Proceedings of the Centenary of Flotation Symposium,* AusIMM, Brisbane, Queensland, pp. 487-496.

Nesset, J.E., Finch, J.A. & Gomez, C.O. (2007) 'Operating variables affecting bubble size in forced-air mechanical flotation machines', *Proceedings of the Ninth Mill Operators' Conference*, AusIMM, Fremantle, Western Australia, pp. 55-65.

Nesset, J.E. (2009) 'Flotation machine diagnostics', *Mineral Processing Systems Course*, Montreal, Canada.

Osborne, D., Huynh, L., Kohli, I., Young, M. & Mercuri, F. (2013) 'Two decades of Jameson Cell installations in coal', *Proceedings of International Coal Processing Congress*, Istanbul, Turkey, *In submission.*

Seaman, D.R., Burns, F., Adamson, B., Seaman, B.A. & Manton, P. (2012) 'Telfer processing plant upgrade – The implementation of additional cleaning capacity and the regrinding of copper and pyrite concentrates', *Proceedings of the 11th Mill Operators' Conference*, AusIMM, Hobart, Tasmania, pp. 373-381.

Seaman, D., Manton, P. & Griffin, P. (2011) 'Separation efficiency improvement of a low grade copper-gold flotation circuit', *Proceedings of Procemin 2011*, Gecamin, Santiago, pp. 263-272.

Yianatos, J., Bergh, L., Condori, P. & Aguilera, J. (2001) 'Hydrodynamic and Metallurgical Characterization of Industrial Flotation Banks for Control Purposes', *Minerals Engineering*, vol. 14 , pp. 1033-1046.

Young, M.F., Barnes, K.E., Anderson, G.S. & Pease, J.D. (2006) 'Jameson Cell: The Comeback in Base Metals Applications Using Improved Designed Flow Sheets', *Proceedings of the 38th Annual Meeting of the Canadian Mineral Processors*, Ottawa, Ontario, pp. 311-332 .