

# **DESIGN AND PERFORMANCE ASPECTS OF COAL FLOTATION – EXPERIENCES WITH THE JAMESON CELL**

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## **ABSTRACT**

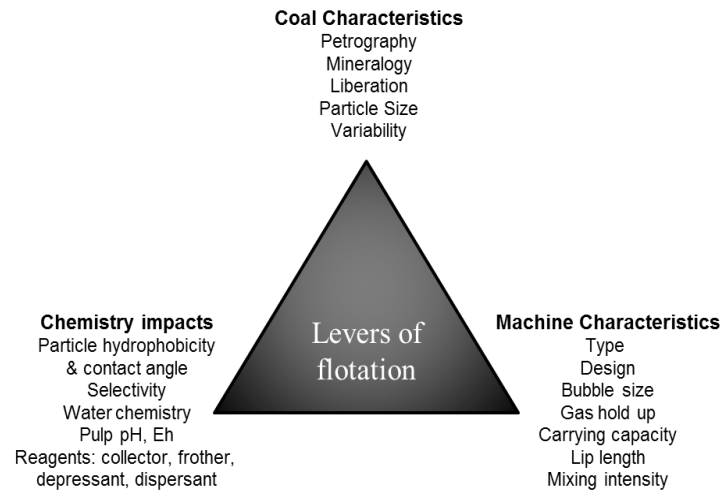
Flotation is commonly used to treat fine coal (typically below 500 microns in size) and is a complex, three-phase process that is controlled by factors which can be divided into three facets: coal, chemistry and machine. It is most often used for treating metallurgical coal fines where the value of the product can justify the added treatment cost of cleaning and dewatering the product component. However, because of improvements in flotation technology and the dewatering of both the product and the tailings this avenue is becoming increasingly attractive for treating thermal coals.

The Jameson Cell technology is an established robust and efficient high intensity flotation technology which has been continuously developed and improved over two decades. Its high capacity, small footprint and low maintenance requirements have made it more or less a standard flotation technology in the Australian coal industry.

This paper will review how the fundamental characteristics of a flotation machine translate to economic benefits. The performance of the Jameson Cell and continued operational challenges of fine coal circuits will also be discussed.

## **INTRODUCTION**

Flotation is a complex multifaceted process that can be separated into three main areas: the coal, the chemistry and the machine, as shown in Figure 1. To solve plant issues it is important to understand how different factors within these areas affect and control flotation performance for a particular system. Factors within the coal and chemistry areas are dynamic and hence need to be dealt with by personnel on an ongoing basis in normal plant operations. However, factors associated with the machine are generally a characteristic of the machine type itself as this relates to the fundamental design of the technology. One of the most important characteristics of any flotation technology is air bubble generation and the size of air bubbles produced as this controls flotation kinetics and also, it dictates the carrying capacity of the machine. Another crucial component is how the machine effects collision and contact between air bubbles and particles.



**Figure 1: Flotation ‘triangle’ showing the factors affecting performance.**

The Jameson Cell technology was first introduced in the late 1980s to overcome the design and operating inadequacies that were being experienced with column and conventional flotation cells. From the first commercial installation at Mt Isa in 1989, which was for sulphide treatment followed by the first coal installation at Newlands in 1990, it has been continuously developed and improved to improve performance and make it more robust and easier to use. Over 150 Jameson Cells are now operational in coal applications worldwide, with the current largest installation being at Wesfarmer’s Curragh Mine in Central Queensland which treats over 5 million tonnes of coal fines per year using twelve cells. Long-established coal-producing countries like Kazakhstan and South Africa are realising the benefits of the Jameson Cell over conventional cells and emerging coal regions such as Mozambique and Mongolia are now beginning to use the Jameson Cell for metallurgical coal applications.

The paper explains how fundamental characteristics of a flotation technology translate into an economic advantage. The performance of the Jameson Cells and ongoing operational challenges in flotation and fine coal circuits will also be discussed.

## **JAMESON CELL PRINCIPLE OF OPERATION**

The fundamentals of Jameson Cell operation have been previously described by a number of other authors including 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 a cylindrical device called a downcomer. The jet of liquid first shears and 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 up inside the downcomer. The jet of slurry plunges onto the liquid surface and the high kinetic energy of the jet then disseminates 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 before exiting into the tank. The particle laden bubbles then float to the top to form the froth whilst the hydrophilic rock and mineral particles remain in the

pulp phase to be removed as tailings. To ensure consistent operation, tailings recycle is employed. This 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 coal laden slurry jet and the fact that the air is self aspirated, allows the Jameson Cell to have no moving parts other than 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 tend to be very much smaller than equivalent capacity mechanical and column cells.

## BUBBLE SIZE

### Flotation Kinetics

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 just recovery of fine particles as has often been hypothesised. This is clearly demonstrated in Figure 2 which shows the flotation rate of two different systems: silica and pyrite particles, which are floated at three different bubble sizes. The bubble sizes in this investigation (1 to 2 mm) are more or less the same as those encountered in many current industrial machines. In coal flotation, fine bubbles also improve separation as they intensify the difference in the kinetics of the coal from non-coal particles, thus allowing concentrates with lower ash content to be produced without loss in yield.

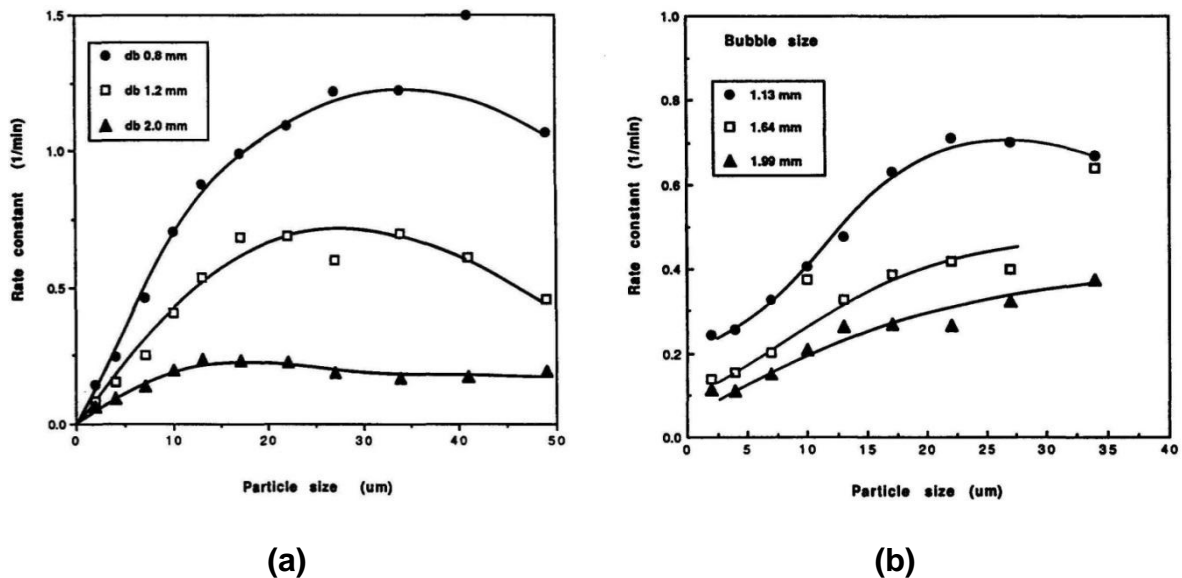


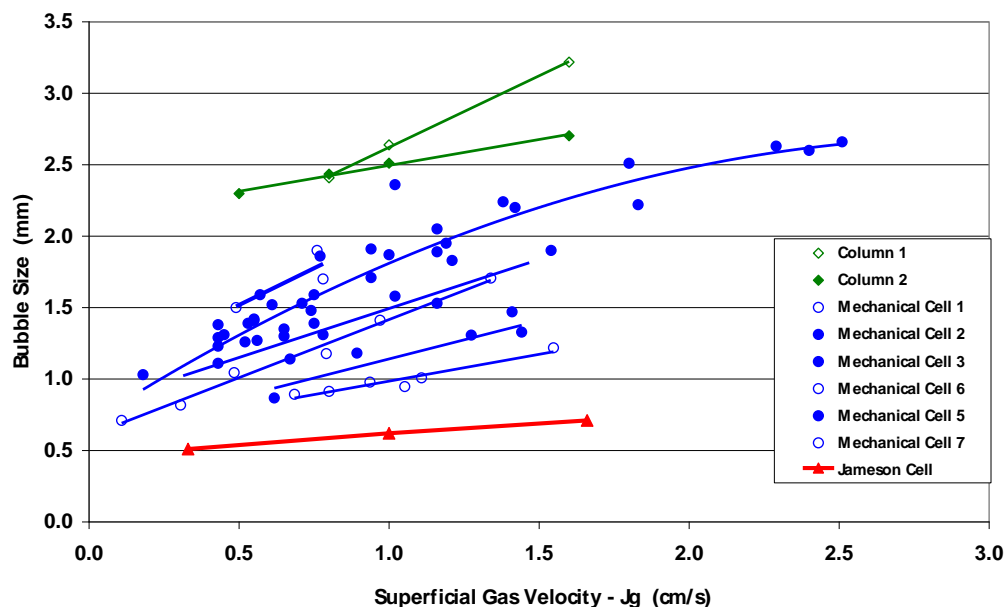
Figure 2: Rate constant as a function of particles size, for three bubble sizes at constant  $J_g$  of 1.53 cm/s: (a) Silica and (b) Pyrite (from Diaz-Penafiel & Dobby, 1994).

## Carrying capacity

Bubble size dictates the carrying capacity of a flotation machine. Finer bubbles increase the carrying capacity (often measured as the mass flow rate (tonne/h) of concentrate per  $\text{m}^2$  of surface area of the flotation machine) as there is more bubble surface area per volume of air added for particles to attach. Essentially, this means that if two different types of flotation machine are used to float the same coal using the same amount of air, the one generating air bubbles (measured as a distribution) that is half the size of the other machine will have double the bubble surface area available for flotation. This is therefore a very important consideration, especially for coal feeds offering very high potential yields, i.e., up to 80-90% mass; so the more bubble surface area that is available from the machine, the lower will be the cross-sectional area required and fewer cells will be required to recover all the coal.

The Jameson Cell is able to produce fine bubbles via the shearing 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 air bubbles generated by the Jameson Cell are in the range of 300 to 700  $\mu\text{m}$  (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) 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 3: Bubble size as a function of  $J_g$  (superficial gas velocity, a measure of air flow rate) for different flotation technologies.**

## FROTH WASHING

A flotation technology that has froth washing capabilities has advantages over those that do not, as froth washing is one of the most effective methods employed to reduce entrainment thereby enabling concentrates with the lowest ash content to be produced. The amount of wash-water used is therefore an important process variable so the system must be able to be operated over the desired flowrate range for that sized flotation cell based on the designed concentrate tonnages and solids content of the concentrate. Wash-water addition is commonly measured as a ratio with the water in the concentrate. A wash-water ratio of 1.0 means that, theoretically, all the 'dirty' water in the concentrate containing the entrained ash particles is replaced by clean wash-water. In practice, the wash-water addition is dependent on the process operation and in particular, factors such as the structure and stability of the froth which in turn is influenced by factors such as particle size and hydrophobicity of the particles recovered in the froth, and on frother concentration. A stable froth allows froth washing to be effective in producing a clean concentrate without having a detrimental effect on combustibles recovery.

Jameson Cells are installed with either wash-water ring or tray systems. Design considerations include the hole size, distribution of the holes to ensure water is spread across the entire surface of the flotation cell, placement of the system at an appropriate distance above the cell lip, and most importantly, the robustness and ease with which it can be maintained as the quality and cleanliness of the water used for froth washing in most plants is often poor which can lead to frequent blockages.

## PROJECT ECONOMICS

To be of value for any project the fundamental characteristics of a flotation machine must translate into actual economical benefits. Common measures are capital, operating and maintenance costs. Capital costs must not only include the flotation machine, but also auxiliary equipment (such as pumps, blowers and compressors), structure, piping, civil works and electrical items. Table 1 lists summarises the fundamental characteristics and cost components associated with different flotation technologies.

**Table 1: Fundamental characteristics and cost components of different flotation technologies.**

Component	Jameson Cell	Column Cell	Conventional Cell
<b><u>Fundamental</u></b>			
Bubble Size	0.3 – 0.7 mm	2 – 3 mm	1 – 2 mm
Carrying capacity	High	Low	Low
Mixing intensity	High	Low	Medium

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### **Capital Costs**

Equipment	Single cells. Numbers of cells as required to suit tonnage and flows	Single cells. Numbers of cells as required to suit tonnage and flows.	Installed in banks. Number of banks as required to suit tonnage and flows.
Structure & Civil Works	Cell sits on a steel structure at a high level to allow concentrate and tails to gravity flow. Small volume tanks. Integrated into plant.	Due to big volume and weights, need large amount of concrete and foundations for structural support. Need to sit outside plant due to large heights (10 -17 m).	Requires large footprint. Integrated into plant.
Auxiliary Equipment	Feed pump.	Air Compressors and/or recirculation pumps. May need feed pump.	Agitators and Blowers. May need feed pump.

### **Operating Costs**

Power	Feed pump.	Air compressors and recirculating pumps. Feed pump.	Agitators, rotors and blowers. Feed pump.
Reagents	Same across different technology		

### **Maintenance Costs**

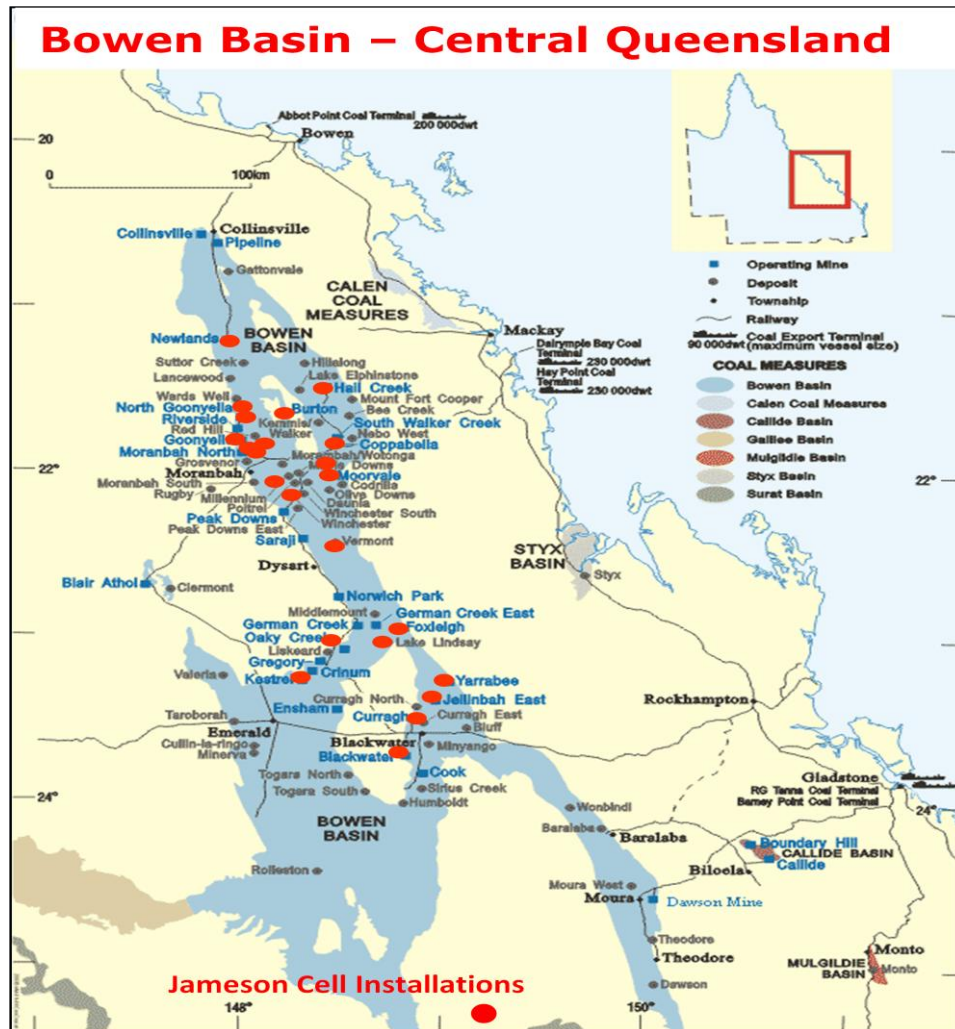
Labour	Low. No moving parts.	Medium/high. No moving parts but spargers and compressors to maintain.	High. Rotors, stators and motors to maintain.
Wear part/spares replacements	Highest wear part (slurry lens orifice) lasts 10 years in operation.	Variable. Spargers may need replacing 6 months to 5 years depending on the column technology used.	Variable. Rotors and stators may need replacing 2 - 4 years depending on the make and model of cell.

Jameson Cells are generally very cost-competitive in most cost components as the only auxiliary equipment required is a feed pump so the tie-in to a plant is simple and power use is low. The cell has no moving parts making it easy to operate and with minimal spares requirement it is also economical to maintain.

## **JAMESON CELL PERFORMANCE**

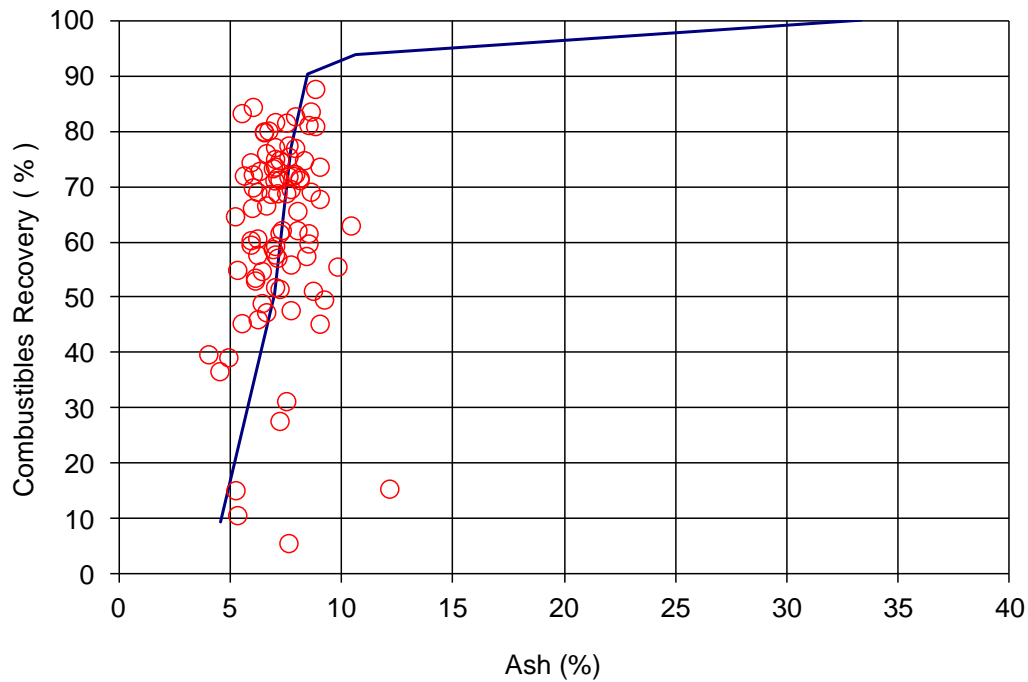
The Jameson Cell has become a standard in the Australian coal industry as it has been proven to be able to consistently produce low ash concentrates and achieve high combustibles recovery whilst being tolerant of commonly encountered variations in feed type and quality variations (Harbort, Manlapig & Jackson, 1992; Atkinson,

Conway & Jameson, 1993; Manlapig et al., 1993). There are over a hundred Jameson Cells installed in the coking coal region of the Bowen Basin in Central Queensland (Figure 4) and also in the Hunter Valley region of New South, where thermal coal preparation plants are more dominant.



**Figure 4: Jameson Cell installations in the Bowen Basin region of Central Queensland, Australia.**

Jameson Cells are designed to be able to operate across the entire ash/yield curve for any coal type treated as demonstrated in Figure 5. The solid line is a coal characterisation test, such as the 'tree flotation test' (ISO 8858-2) widely used in Australia, or the 'release analysis' (ISO 8858-1) which is perhaps more commonly used in other regions of the world. The data points shown in Figure 4 come from operating shift samples collected from a plant over a six month period. The points overlap the characterisation curve indicating the Jameson Cell is producing a concentrate with the desired or expected, ash content. The large variations in combustible recovery are due to operation of the cell. The low combustibles range is probably due to insufficient reagent additions but clearly, high combustibles recovery, at the knee of the curve, is possible if the process is properly optimised.

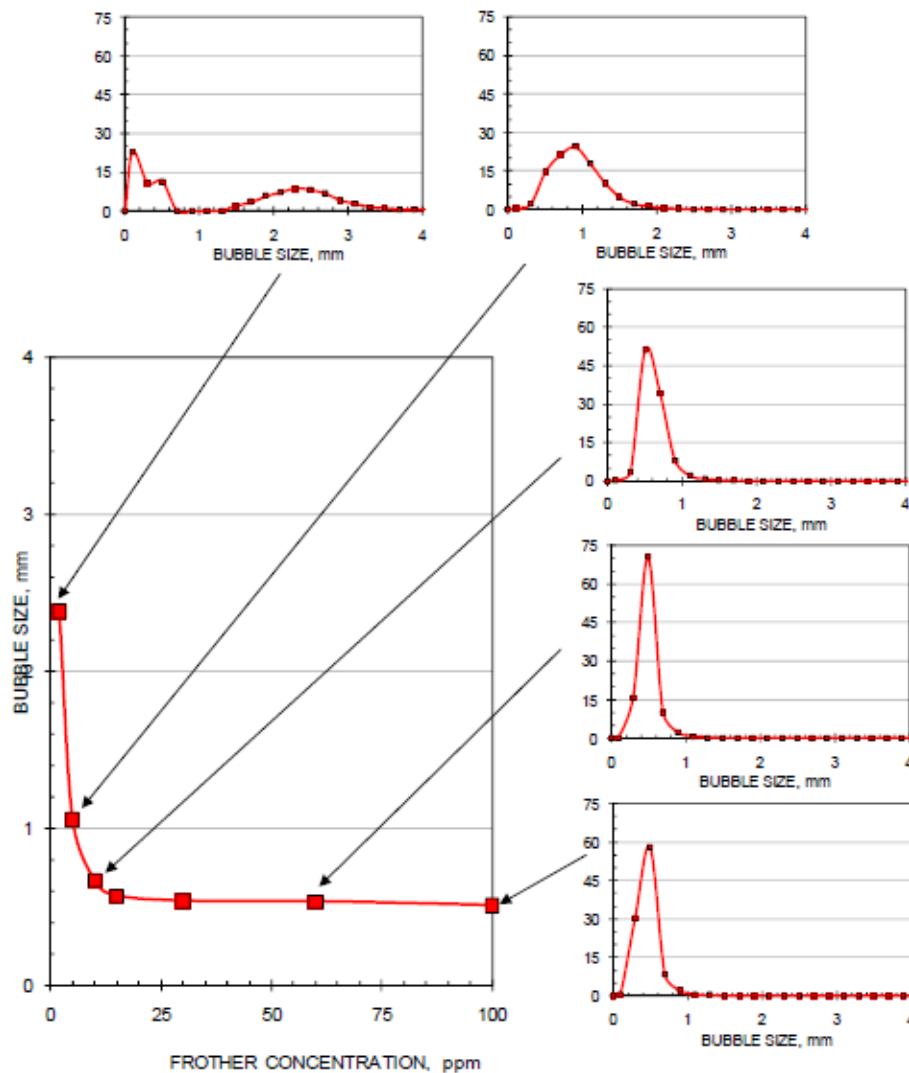


**Figure 5: Jameson Cell performance from an operating plant showing its ability to operate across the entire ash-yield curve.**

It is important for coal preparation plant operators to be trained to understand that flotation needs to be treated differently to gravity concentration processes because it is based on surface properties of coal and non-coal particles, so reagents are essential to the process. Collectors are necessary to render the coal particles hydrophobic. Too little and some coal particles will not float and too much will result in reduced selectivity leading to a concentrate with a higher than desired ash content. Frothers have a completely different function. They are required to prevent the bubbles generated from a flotation machines from coalescing. Regardless of the technology used, frothers should be used at dosages above the critical concentration of coalescence (CCC), as this is the minimum concentration required to prevent coalescence (Finch, Nessel & Acuna, 2008).

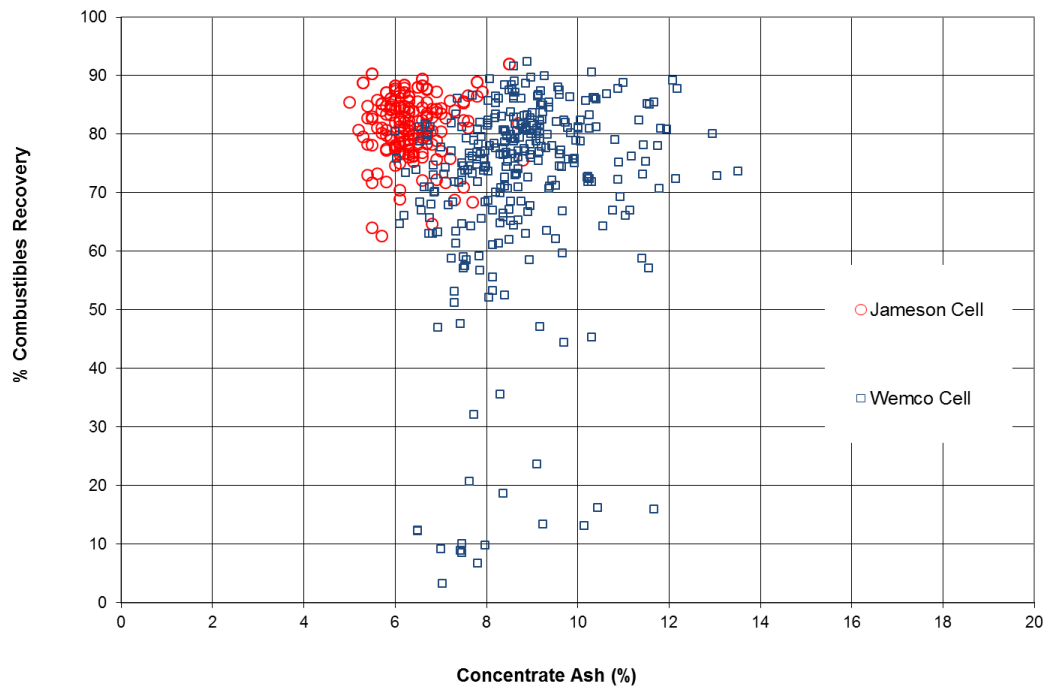
The graph in Figure 6 shows bubble size as a function of frother concentration for the commonly used MIBC (methyl isobutyl carbinol) where the CCC is about 15 ppm. Whilst the CCC is a property of the frother, the actual minimum bubble size generated is dependent on the machine as shown in Figure 3. In operation, the use of reagents should always be investigated ahead of process parameters such as air flowrate and froth depth as these variables are secondary to controlling performance compared to reagents. In addition, froth washing should only be used if target concentrate quality cannot be achieved. It is not mandatory to the flotation process itself but simply an additional tool, albeit an extremely effective one, that can be utilised purely for controlling concentrate grade.





**Figure 6: Bubble size as a function of frother concentration (Zou, 2010).**

When a Jameson Cell is optimised with respect to the three facets shown in Figure 1, very consistent performance can be produced as shown in Figure 7. The data used in this example are from a plant performance survey carried out at the Goonyella (1,800 tonne/h plant) coking coal operation in Central Queensland and owned by BHP Billiton Mitsubishi Alliance (BMA) (Caretta, Graham & Dawson, 1997). The graph shows a comparison of the performance of the Jameson Cell with the original mechanical cell circuit it replaced and illustrates that the Jameson Cell can consistently produce a lower ash concentrate at a high combustible recovery. In comparison, the mechanical cells produced a higher ash product and the scatter in the data indicates more inconsistent performance. In this plant, replacement of the 32 mechanical cells with 8 Jameson Cells contributed to an overall plant yield increase of ~3.5% and was reported to have led to production records (Caretta, Graham & Dawson, 1997).



**Figure 7: Full scale Jameson Cell performance at BMA's Goonyella mine compared to old mechanical (Wemco) cell circuit.**

## CHALLENGES IN COAL FLOTATION AND FINE COAL PROCESSING

As mentioned earlier, the flotation machine is only one of three facets important to the overall process, but it tends to be the one that often receives the most attention, so it is often blamed when performance of the fines circuit is poor. However, the variability of the coal feed and flotation reagent control are two factors which are perhaps surprisingly often overlooked.

The greater the number of different coal seams and/or sources that are treated, the more challenging is the task of achieving effective flotation and the targeted qualities and recoveries. Operators must therefore be properly trained to respond to changes in tonnage, particle size distribution and flotation behaviour of the different coal types and make the necessary adjustments to reagent dosages and process variables to optimise performance. Also the provision of adequate sampling facilities and effective controls for reacting to changes that are occurring will make the operation much more capable of achieving expected outcomes.

In many plants, monitoring of flotation performance is irregular and often a 'knee-jerk' change is made when performance has clearly deteriorated. Furthermore, in many plants it may be very difficult and sometimes impossible to conduct surveys because sample points do not exist for the feed, concentrate and tailings. Even in the more modern (recently built) plants, the flotation feed often cannot be easily collected as it usually consists of more than one stream which flows by gravity into a large inaccessible collecting sump. In several Jameson Cell installations, operators have often been observed to unknowingly collect the downcomer feed, and use the result from a "rapid ash" analysis together with a two-product formula to calculate yield and

combustibles recovery. This is erroneous as the downcomer feed is an internal stream. Sampling points are an essential part of good design practice of the fines circuit.

Even though flotation is the 'separation process', the overall fines circuit performance is often dictated by concentrate and/or tailings dewatering or treatment capacity as this often proves to be the bottleneck in the process. Many flotation circuits have to be 'scaled back' to suit the capacity of the dewatering device leading to large losses in coal fines which in turn may then lead to issues in the tailings thickener. Another area to address is the type of dewatering device used for concentrate dewatering. The technology chosen needs to carefully consider the particle size and type of coal treated and not use capital cost as the driver for decisions. Many flotation feeds are becoming much finer in size distribution and therefore the demands in the flotation technology increase. Jameson Cells have been applied effectively to raw coal tailings streams with  $D_{80}$  (80% passing) values of as low as 50 microns. Clearly, such challenges can only be met by flotation processes that offer very small bubble sizes.

## CONCLUDING REMARKS

The Jameson Cell is a proven, robust and efficient high intensity flotation technology that has been continuously developed and improved over two decades. It is already regarded as a standard in the Australian coal industry and interest is growing in many other coal producing countries. In the coal industry, flotation continues to be a challenge in many coal preparation plants as it does not 'fit' into what is essentially a gravity separation flowsheet. Operators need to have a sound understanding of the flotation process in order to trouble-shoot and optimise the performance of the whole plant. The importance of reagents to the flotation process has to be realised. Fines circuit operation continues to be an ongoing challenge for coal producers and in too many plants, concentrate dewatering is a bottleneck preventing flotation circuits to be operated to their full potential.

Until such time that all the levers available for the flotation circuit can be fully controlled and measured, the expectancy of adding a desired flotation concentrate component to the product will not be realised. It is therefore essential to focus on flotation as the first priority and ensure that the feed can be controlled and concentrate and tailing treatment are both adequately catered for.

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