Proceedings of the International Seminar on Mineral Processing Technology - 2006,
Chennai, India. pp. 254 - 264.

Gas Dispersion Measurements in Coal Flotation Cells

G. Harbort and **D. Alexander**

JKTech, Isles Road, Indooroopilly Qld 4068, Email: g.harbort@jktech.com.au

Abstract

Coal flotation across the world has undergone major changes over the past thirty years. In a number of new coal flotation plants, the traditional mechanical flotation cells have been replaced by pneumatic flotation cells, such as the Jameson Cell and Microcel column cells. Significant steps have also been taken in the understanding of what happens "beneath the froth". New performance evaluation technology has been developed as part of the Australian Mineral Industries Research Association (AMIRA) P9 project. This involves the measurement of gas dispersion characteristics, such as gas hold-up, superficial gas velocity and bubble size in industrial flotation cells. A good understanding of these characteristics leads to improvements in coal recovery and reduction in ash content to the final product.

This paper describes the variation of gas dispersion characteristics between different flotation machines and looks at a number of case studies within the Australian coal industry. The studies have allowed plant personnel at each coal operation to identify optimum operating conditions for their flotation cells as well as provide information on future plant capacity increases.

COAL FLOTATION TECHNOLOGY IN AUSTRALIA

In the last thirty years significant changes have occurred in coal flotation in Australia. The widespread use of continuous mining methods has resulted in a substantial increase in minus 0.5mm material being treated in coal preparation plants. In addition, the recent increases in coal prices has placed significant value on this fine coal, where flotation represents the only viable recovery route. A recent survey by the authors of coal operations in Australia shows that almost 50% of coal treatment plants now utilise flotation.

In addition to the increased use of flotation in coal processing, the type of flotation machines used in the Australian industry has changed dramatically. Sanders and Williamson (1996) found that in the 1970's coal flotation machines were almost exclusively of the mechanical sub-aeration variety. This typically involved a roughing bank, with a single reagent addition, or roughing and scavenging, with multiple reagent additions. In some cases separate flotation banks were used for fine and coarse flotation (Nicol and Bensley, 1988). As shown in Figure 1, the dominance of mechanical flotation cells continued until the 1990s, at which time the technology used in coal flotation underwent a fundamental change. In 1987, a trial 1.7m diameter flotation column was installed in the Riverside Coal Preparation Plant (Bensley et al, 1988). This was followed in 1989 by the installation of a coal slimes Jameson Cell flotation circuit at the Newlands Coal Mine (Jameson et al, 1991). Another milestone in Australian coal flotation occurred in 1995, with the introduction of the Microcel flotation column to the Peak Downs Coal Preparation Plant (Stone et al, 1995). The technology now used in coal flotation is very different to what it was, with 80% of installed flotation capacity being either flotation columns (Microcels) or Jameson Cells.

The increased importance of coal flotation, and the wide variety of flotation machines in use has required a greater understanding of their fundamental operation, in order to optimise performance.

GAS CHARACTERISATION

One of the most important factors in developing this understanding is measurement of the hydrodynamic conditions (or gas dispersion characteristics) within flotation cells. This is known to directly influence the flotation efficiency (Schubert and Bischofberger, 1978; Gorain et al, 1995). Gas dispersion measurements, such as bubble size, gas hold-up and gas velocity, can be used to characterize the hydrodynamic conditions in the pulp phase of a particular flotation cell. In simple terms, gas dispersion is defined as how well the air entering a flotation cell is dispersed throughout the entire volume of the cell. These parameters have been measured in a large number of cells of different types using techniques developed as part of the Australian Mineral Industries Research Association (AMIRA) P9 project.

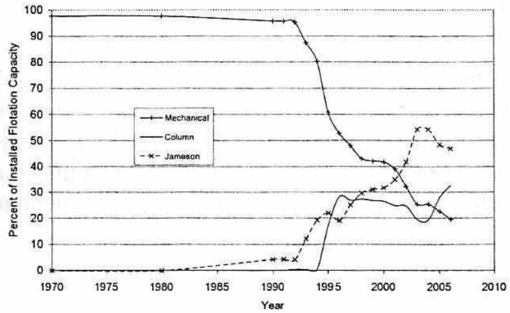

Fig. 1: Flotation Technology Used in the Australian Coal Industry

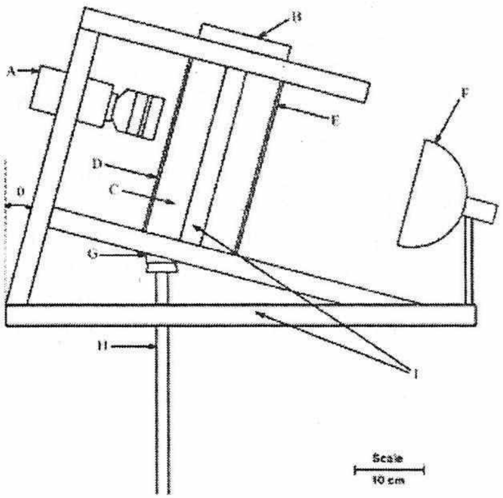

Fig. 2: Schematic of the Mcgill Bubble Viewer. A: Digital Camera, B: Filling Cap, C: Viewing Chamber, D: Front Window, E: Back Window, F: Lamp, G: Bubble Viewer

Bubble Size

In general terms, smaller bubbles result in improved flotation kinetics (Diaz-Penafiel and Dobby, 1994). Methods for measuring bubble size has been developed at the McGill University within the AMIRA P9 project (Chen et al, 2001). A sample of bubbles from the pulp phase is introduced into a viewing chamber made of clear PVC, where photographs can be obtained using a digital camera (Figure 2). Images are then analysed to determine the mean bubble size.

Gas Hold-Up, ε_G

Gas hold-up is the volume fraction of air within a flotation cell. Increasing gas hold-up values, to a certain point, results in improved flotation kinetics due to a greater number of bubbles per unit volume (Ahmed and Jameson, 1989). However, values greater than 30% indicate reduced cell capacity and thus reduces the cell residence time.

Gas hold-up is measured by taking a sample of aerated slurry within the pulp phase of a flotation cell (Power et al, 2000). The gas hold-up probe is a vertical cylinder with valves at the top and bottom of the cylinder. The probe is lowered into the pulp phase of the cell and the valves are opened to allow pulp and bubbles to pass through the probe. After 30 seconds the valves are closed and the volume of pulp collected is measured. This volume (V_p) is then used to calculate the gas hold-up using Equation 1:

$$\varepsilon_g = \frac{V_d - V_p}{V_d} \tag{1}$$

where V_d is the total volume of the tube between the valves.

Superficial Gas Velocity, J_g

Superficial gas velocity is a measure of the aeration ability of a cell and has a direct influence on flotation kinetics (Ahmed and Jameson, 1989). The general definition of J_g is:

$$J_g = \frac{Q}{A} \tag{2}$$

where Q is the volumetric air flow rate into the cell and A is the cell cross-sectional area. Too high a J_g can result in increased entrainment into the froth, and reduce the stability of the pulp-froth interface. Measurement of J_g at various locations within a cell has shown to be a good indicator of the efficiency of gas dispersion in the pulp phase of a cell (Gorain et al, 1996).

Superficial gas velocity is measured using a J_g probe (Gorain et al, 1996; Power et al, 2000). It comprises of a Perspex tube with a valve at the lower end and a water inlet and an air outlet line on the upper end (Figure 3). The probe is placed in the cell and the lower valve is closed. The water inlet and air outlet valves are opened to fill the tube with water, before both valves are closed. The lower valve is then opened to allow the air in the cell to move up the tube, displacing water. The time taken for the water level to fall a known distance, L (between two marks) is measured and the J_g calculated from Equation 3:

$$J_g = \frac{L}{t} \tag{3}$$

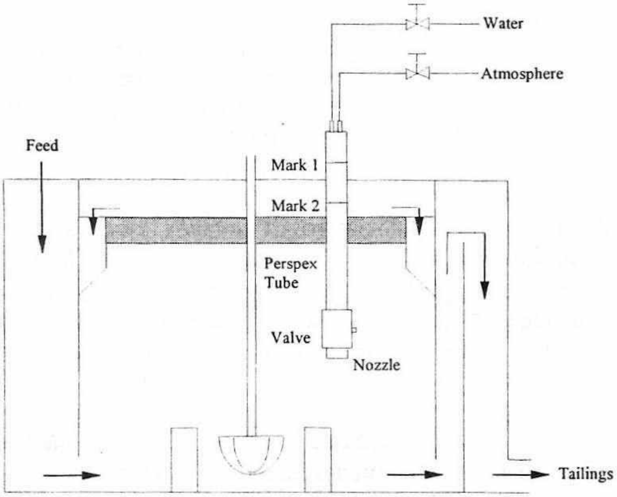

Fig. 3: Schematic of Superficial Gas Velocity (J_g) Probe

Adjustments are then made to account for the pressure difference between the location of sampling (lower valve) and water displacement (Perspex tube).

Bubble Surface Area Flux, S_b

The bubble surface area flux is a measure of the rate of bubble surface area rising through the cell per unit cross-sectional area (Gorain et al, 1997). This parameter combines the superficial gas velocity and bubble size into a single quantity, according to Equation (4):

$$S_b = \frac{6J_g}{d_{32}} \tag{4}$$

S_b is considered to be an important parameter as it links gas dispersion to flotation performance directly, as described by Gorain et al (1997). As shown in Figure 4 there is a strong linear correlation between flotation rate constant and bubble surface area flux. This linear correlation seems to be independent of impeller type, cell type and cell size.

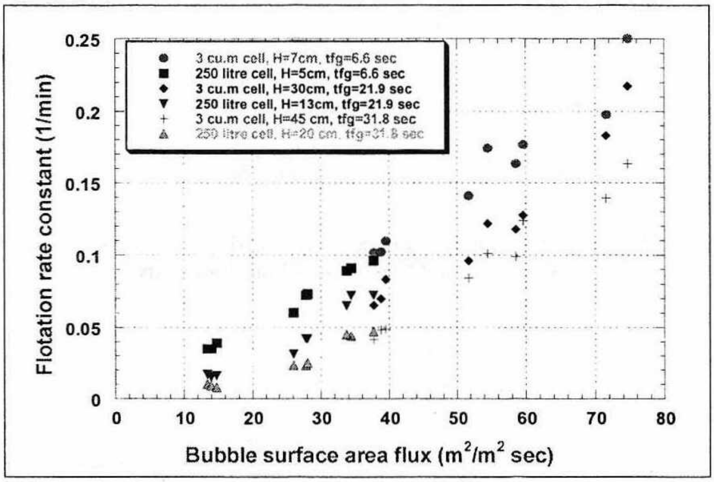

Fig. 4: Relationship between S_b and Flotation Rate Constant

PARAMETERS DATABASE

Gas dispersion measurements have been conducted in over 1100 flotation cells of different types and sizes by researches from the Julius Kruttschnitt Mineral Research Centre (JKMRC) and JKTech. A large database has been developed and discussed in some detail by Schwarz and Alexander (2005).

The database has been used for many applications, but the main use is in benchmarking a flotation cell operation. Many plant metallurgists question if their cells are operating in the 'typical' range for that particular cell type and duty, and this database has been invaluable in providing that information.

Figure 5 through to Figure 8 give frequency distributions of gas dispersion measurements that were observed across all cell sizes, duties and minerals for mechanical flotation cells and flotation columns. The purposes of these graphs are for illustrative purposes, with global grouping of equipment having limited use for equipment engineering.

Globally, the distribution of superficial gas velocity (Figure 5) shows that the majority of mechanical flotation cells operate in the range between 0.5cm/s and 1.0cm/s. The distribution of superficial gas velocities for columns show two distinct operating ranges – between 1.0cm/s and 1.5cm/sec and between 2.0cm/s and 2.5cm/s.

The distribution of bubble size (Figure 6) shows that the majority of mechanical flotation cells operate in the range between 1.0mm and 1.5mm. In contrast, flotation columns have, in general, larger bubble sizes with a distribution between 2.0mm and 2.5mm.

Both flotation columns and mechanical flotation cells operate with a similar distribution of air hold-up (Figure 7), with the majority of air hold-up measurements being between 10% and 15%.

A review of the bubble surface area flux measurements (Figure 8) shows that the majority of mechanical flotation cells operate in a broad range from $20s^{-1}$ to $60s^{-1}$. Flotation columns operate between $20s^{-1}$ to $40s^{-1}$.

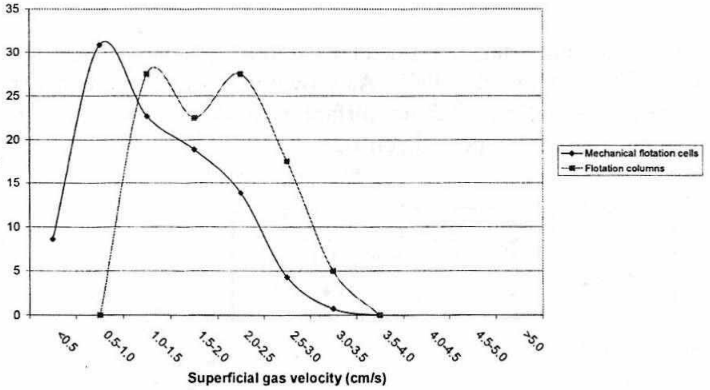

Fig. 5: Frequency Distribution of Superficial Gas Velocity Measurements Obtained from Flotation Columns and Mechanical Flotation Cells

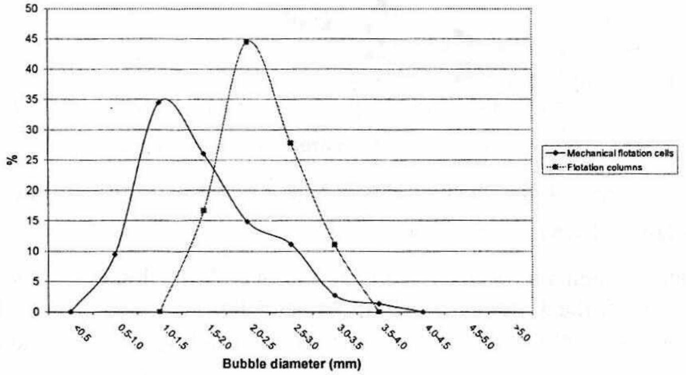

Fig. 6: Frequency Distribution of Bubble Size Measurements Obtained From Flotation Columns and Mechanical Flotation Cells

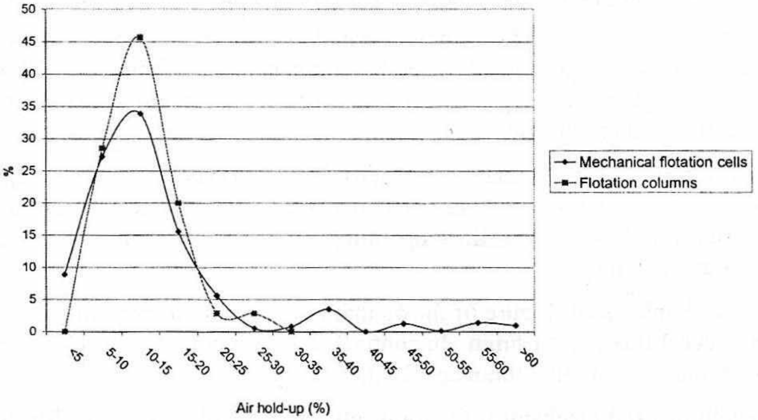

Fig. 7: Frequency Distribution of Air Hold-Up Measurements Obtained From Flotation Columns and Mechanical Flotation Cells

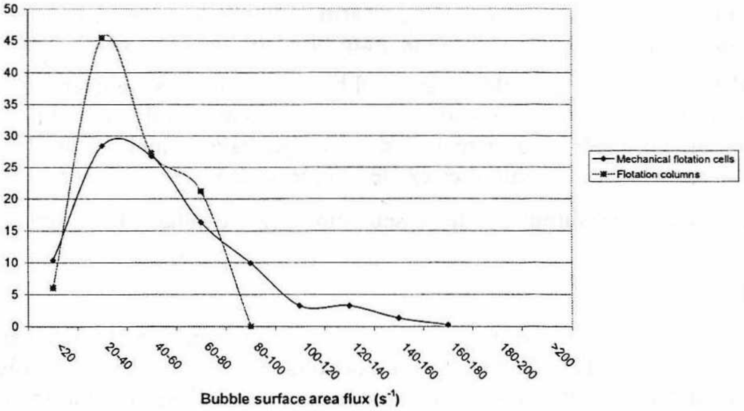

Fig. 8: Frequency Distribution of Bubble Size Measurements Obtained From Flotation Columns and Mechanical Flotation Cells

THE JAMESON CELL

The principles of Jameson Cell operation have been discussed by numerous authors including Jameson (1988) and Harbort et al (2002). The Jameson Cell can be divided into three main zones as described with reference to Figure 9.

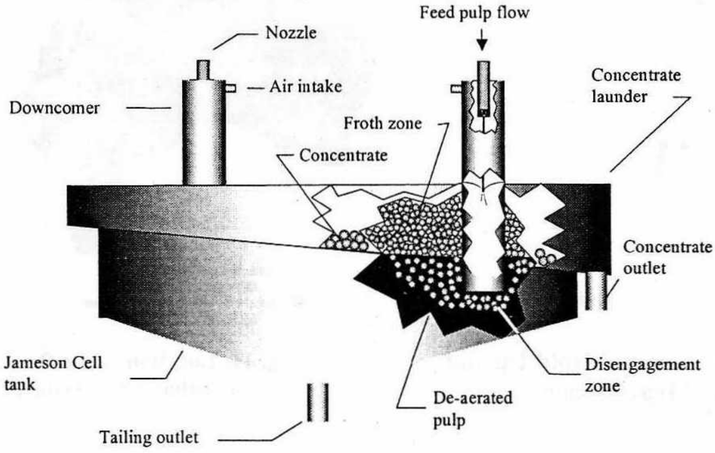

Fig. 9: Jameson Cell Operation

1. The downcomer is where primary contacting of bubbles and particles occurs. Feed pulp is pumped into the downcomer through an orifice plate, creating a high-pressure jet. The plunging jet of liquid shears and then entrains air, which has been naturally aspirated.
2. The tank pulp zone is where secondary contacting of bubbles and particles occurs and bubbles disengage from the pulp.
3. The tank froth zone is where entrained materials are removed from the froth by froth drainage and/or froth washing.

Whereas flotation equipment such as mechanical flotation cells and flotation columns are commonly designed to provide even dispersal of bubbles within the pulp zone of the tank, the Jameson Cell is not. Measurements show that bubble patterns in general form a central, air swept cone surrounding each downcomer (Harbort et al, 2003). The Jameson Cell tank contains areas of high, localised air hold-up throughout the pulp zone. The rising swarm of bubbles is governed by a number of factors including recirculating patterns within the tank, pulp flow volumes and air flow volumes.

To determine the average J_g, air hold-up and bubble size values, a number of measurements were taken across the horizontal cross section around one downcomer, as illustrated in Figure 9. This data was entered into the OriginPro 7.5 statistical software package, which allowed contour maps to be generated to evaluate whether irregularities existed in the aeration.

The gas characterisation measurements discussed below were conducted 300mm below the froth/pulp interface.

SITE DETAILS

Experimental work was conducted at two coal preparation plants in the Bowen Basin, in Central Queensland (Figure 11). The Bowen Basin contains Australia's most significant Permian coal deposits in an area 600km long and up to 250km wide. Coal seams within the basin can show significant variations in rank and quality, depending on their history. Coals vary in rank from anthracite to low volatile bituminous coal in the north to low ash non-coking coals in the south (Mutton, 2003). Typical treatment consists of heavy media separation with flotation of the minus 250μm size fraction.

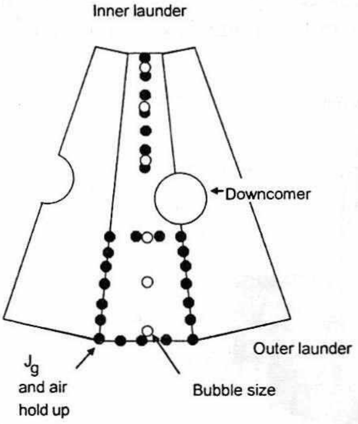

Fig. 10: Location of Jg, Air Hold Up and Bubble Size Measurements

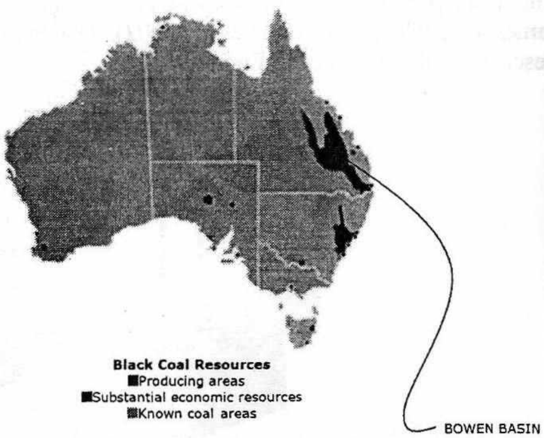

Fig. 11: Location of the Bowen Basin (Australian Coal Assoc., 2005)

DISCUSSION

Table shows the average J_g, air hold-up, bubble size and S_b for plants A and B respectively. A detailed analysis of gas characterisation measurements is given below.

Table 1: Average Gas Characterisation Measurements

Measurement	Plant A	Plant B
J_g (cm/s)	1.33	1.9
Bubble Size (mm)	1.63	1.44
Air hold-up (%)	28.5	38.5
S_b (s^{-1})	49	79

Superficial Gas Velocity, J_g

The average J_g measured for the Plant A Jameson Cell was 1.33cm/s, which is within the lower region for typical operation for flotation columns. The average J_g measured for the Plant B Jameson Cell was 1.90cm/s, which is near the upper region for typical operation for flotation columns.

The J_g contour map for the Plant A Jameson Cell (Figure 12) shows a reasonably even air dispersion. The J_g varied from 1.7cm/s to 2.7cm/s. It was characterised by high J_g values in the vicinity of the inner and outer launders and lower J_g values away from the launders. The higher J_g regions may result in increased ash entrainment to the froth. With these areas being close to the concentrate launders there is reduced time for wash water to clean concentrate and higher ash concentrate can result. The lower J_g region away from the launders generate a lower pressure region when compared to the high J_g region and bubbles entering the froth zone may, for a time, travel away from the concentrate launders, generating a slower moving, stagnant area of froth. This profile appears to be a function of the bubble dispersion mechanism connected to the downcomer.

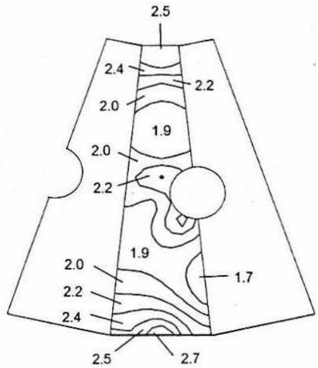

Fig. 12: J_g Contour Map for Plant a Jameson Cell

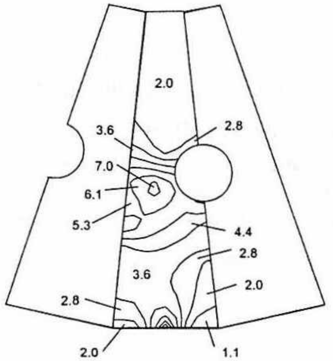

Fig. 13: J_g Contour Map for Plant B Jameson Cell

The J_g contour map for the Plant B Jameson Cell (Figure 13) shows a significant variation in air dispersion. The J_g varied from 1.1cm/s to 7.0cm/s. It exhibited a very high J_g in the immediate vicinity of the downcomer, generally decreasing towards the inner and outer launder. This has a number of benefits:

1. The high J_g, high froth ash region has the maximum distance to travel with a high chance of entrained ash being washed out
2. The pressure differential between high and low J_g regions will result in an increased horizontal velocity in the direction of the concentrate launders

The J_g near the downcomer was considered high. This may result in bursting of froth in this area.

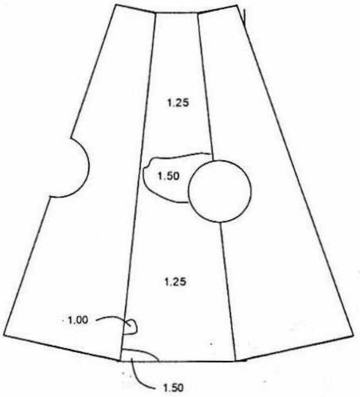

Fig. 14: Bubble Size Contour Map for Plant a Jameson Cell

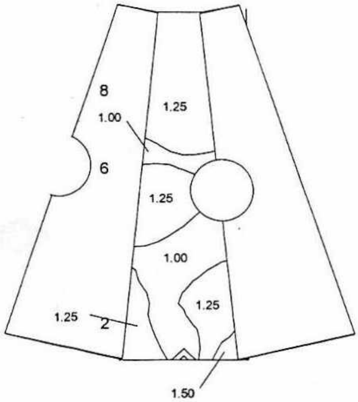

Fig. 15: Bubble Size Contour Map for Plant B Jameson Cell

Bubble Size

The average bubble sizes measured for the two flotation plants were 1.63mm and 1.44mm, respectively. This places them near the typical operating range for mechanical flotation cells.

As shown in Figure 14 and Figure 15, both had a very narrow range in bubble size. Both Jameson Cells operated with a bubble size that varied from 1.0mm to 1.5mm. There was a tendency for bubbles to be at their minimum size at a J_g of 1.4cm/sec, with a minor increase in bubble size as the J_g increased or decreased from this point.

Air Hold-Up

The average air hold-up measurements for the two flotation plants cells were 28.5% and 38.5%, respectively. These values are substantially higher than the typical operating range for both mechanical flotation cells and flotation columns.

The Pant A Jameson Cell exhibited a relatively narrow range of air hold up values (Figure 15). Air hold-up measurements varied from 16.3% to 32.5%. The Plant B Jameson Cell, by comparison, exhibited substantial variation in air hold-up values (Figure 16). The Plant B air hold-up values were proportional to the J_g and varied from 18.1% to 61.9%.

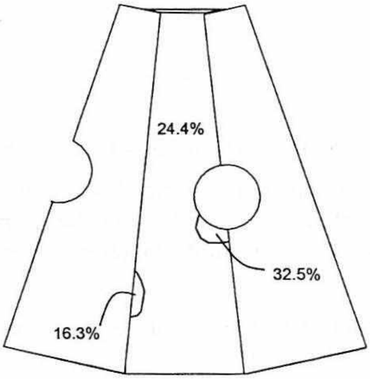

Fig. 16: Air Hold-Up Contour Map for Plant a Jameson Cell

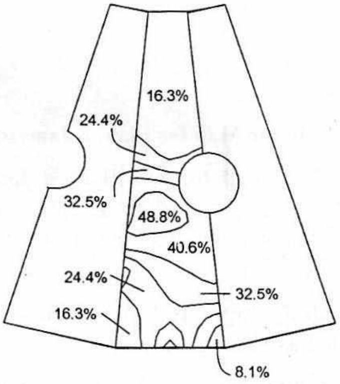

Fig. 17: Air Hold-Up Contour Map for Plant B Jameson Cell

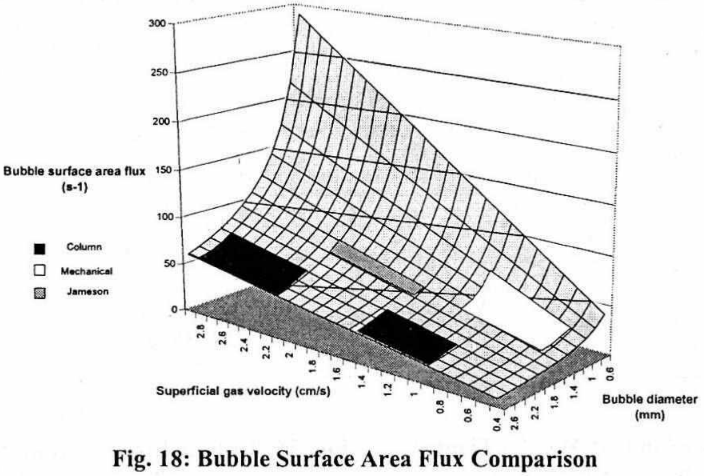

Fig. 18: Bubble Surface Area Flux Comparison

Bubble Surface Area Flux

The average bubble surface area flux calculated for the Plant A Jameson Cell was $49s^{-1}$. This is in the upper region for typical operation for mechanical flotation cells. The average bubble surface area flux calculated for the Plant B Jameson Cell was $79s^{-1}$. This is substantially higher than the typical operating ranges for either flotation columns, or mechanical flotation cells, Figure 18.

These measurements indicate that significant scope exists in Plant A for increasing combustibles recovery, through increasing the aeration rate. Conversely, the high bubble surface area flux measured in Plant B indicates that only limited potential exists for increasing combustibles recovery.

CONCLUSIONS

Gas characterisation measurements including the superficial gas velocity, bubble size and air hold-up have been measured in several Jameson Cells. These measurements highlight areas of high ash within the froth, as well as stagnant zones that may result in low combustibles recovery. They provide an excellent diagnostic tool for plant trouble shooting

Compared with a data base of flotation equipment the measurements show that the Jameson Cell J_g was near the upper J_g region for flotation columns; the average bubble sizes was near the typical operating range for mechanical flotation cells; air hold-up values were substantially higher than the typical operating range for both mechanical flotation cells and flotation columns.

ACKNOWLEDGEMENTS

The authors would like to thank the staff and students of the AMIRA P9 project and its sponsors for the work and the funding, which developed the methodology and contributed greatly to the database. In addition, the authors wish to thank various site personnel who have also contributed to the database, especially Anglo American Research Laboratories, Rio Tinto, BHP Billiton and the BHP Billiton Mitsubishi Alliance. Finally, acknowledgement is given to the many JKTech personnel who have performed these measurements at the various sites around the world.

REFERENCES

[1] Ahmed, N and Jameson, GJ, 1989. Flotation kinetics, Mineral Processing and Extractive Metallurgy Review, 5, 77-99

[2] Australian Coal Association, 2005. http://www.australiancoal.com.au/resources.htm

[3] Bensley, C, Roberts, T, Nicol, S and Lamb R, 1988. Column flotation: the development of the Tower Flotation Cell, in Proceedings 4th Australian Coal Preparation Conference, Gladstone, (Eds:), Australian Coal Prep. Socierty, 153-169

[4] Chen, F, Gomez, CO and Finch, J, 2001. Technical note: bubble size measurement in flotation machines, Minerals Engineering, 14(4), 427-432

[5] Gorain, B.K., Franzidis, J.P. and Manlapig, E.V. (1995); "Studies on impeller type, impeller speed and air flow rate in an industrial flotation cell – part 2: effect on gas hold-up", Minerals Engineering, 8, 1557-1570.

[6] Gorain, B.K., Franzidis, J.P. and Manlapig, E.V. (1996); "Studies on impeller type, impeller speed and air flow rate in an industrial flotation cell – part 3: effect on superficial gas velocity", Minerals Engineering, 9, 639-654.

[7] Gorain, B.K., Franzidis, J.P. and Manlapig, E.V. (1997); "Studies on impeller type, impeller speed and air flow rate in an industrial flotation cell – part 4: effect of bubble surface area flux on flotation performance", Minerals Engineering, 10, 367-379.

[8] Harbort, G, De Bono, S, Carr, D and Lawson, V, 2003. Jameson Cell fundamentals—a revised perspective, Minerals Engineering, Volume 16, Issue 11, November 2003, 1091-1101 Harbort, GJ, Manlapig, EV, DeBono, SK, 2002. Particle collection within the Jameson Cell downcomer, Trans IMM, Sect C 111 / Proc AusIMM, 307, Jan-Apr, C1-C10

[9] Jameson, GJ, 1988. A new concept in flotation column design, Column '88, in Proceedings International Symposium on Column Flotation, SME, Phoenix, Az, 1988, (Ed: Sastry, KV), 281-289

[10] Jameson, GJ, Goffinet, M, Hughes, D, 1991. Operaing experiences with Jameson Cells at Newlands Coal Pty Ltd, in Proceedings Fifth Australian Coal Preparation Conference, Newcastle, NSW, (Ed: Lean, P J), Australian Coal Prep Society, pp 146-158

[11] Nicol, SK, Bensley, CN, 1988. Recent developments if fine coal preparation in Australia, in Proceedings Industrial Practice of Fine Coal Processing, Hidden Valley, Sept 25-28, 1988 (Eds: Klimpel, RR and Luckie, PT), SME-AIME – Colorado, pp147-152

[12] Power, A., Franzidis, J.P. and Manlapig, E.V. (2000); "The characterisation of hydrodynamic conditions in industrial flotation cells", Proceedings of the AusIMM 7th Mill Operators Conference, Australasian Institute of Mining and Metallurgy, Kalgoorlie, 243-255.

[13] Sanders GJ, Williamson, MM, 1996. Coal flotation – Technichal review, ACARP Report C4047

[14] Schubert, H. and Bischofberger, C. (1978); "On the hydrodynamics of flotation machines", International Journal of Mineral Processing, 5, 131-142.

[15] Schwarz, S and Alexander, D, 2005. Gas dispersion measurements in industrial flotation cells, Minerals Engineering (in press)

[16] Stone, RG, Brake, IR and Eldridge, G, 1995. Development of a new column flotation circuit for Peak Downs Coal Preparation Plant, in Proceedings 7th Australian Coal Preparation Conference, Mudgee 9-15 Sept 1995, (Ed: Smitham, J), Australian Coal Prep Society, 145-156