RECOVERY INTERACTIONS BETWEEN THE FROTH ZONE, PULP ZONE AND DOWNCOMER WITHIN A JAMESON CELL

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ABSTRACT

The work reported in this paper shows that the primary area of coal recovery within the Jameson Cell is the downcomer, where the air and pulp are dispersed into a dense foam of fine bubbles. This creates an intense collection zone for bubble-particle collision and coal collection.

Historically, coal recovery in the Jameson Cell has not differentiated between recovery in the downcomer, pulp zone or the froth zone. As such, attempts to optimise the recovery of coal in one zone can result in non-optimum performance of another. A major flotation programme has been undertaken to measure coal recovery in the three zones of the Jameson Cell, separate from each other. The findings from this work should allow, upon completion, recovery in each zone to be individually optimised to give maximum overall coal recovery, from a size by size perspective.

INTRODUCTION

The Jameson Cell was a joint development between Mount Isa Mines and Prof. Graeme Jameson of the University of Newcastle (Jameson, 1988). Since its invention in 1986 there have been 94 Jameson Cells installed in the coal industry, both in Australia and overseas.

Jameson Cell operation

The principles of Jameson Cell operation have been discussed by numerous authors, including Jameson et al (1988), Evans et al (1995) and recently by Harbort et al (2002). The Jameson Cell can be divided into three main zones, as described with reference to Fig. 1.

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. Due to a high mixing velocity and a large interfacial area there is rapid contact and collection of particles.
2. The tank pulp zone is where secondary contacting of bubbles and particles occurs and bubbles disengage from the pulp. The aerated mixture exits the downcomer and enters the pulp zone of the flotation tank. The velocity of the mixture and large differential between it and the remainder of the pulp in the tank results in recirculating fluid patterns, keeping particles in suspension without the need for mechanical agitation.
3. The froth zone is where entrained materials are removed from the froth by froth drainage and/or froth washing.

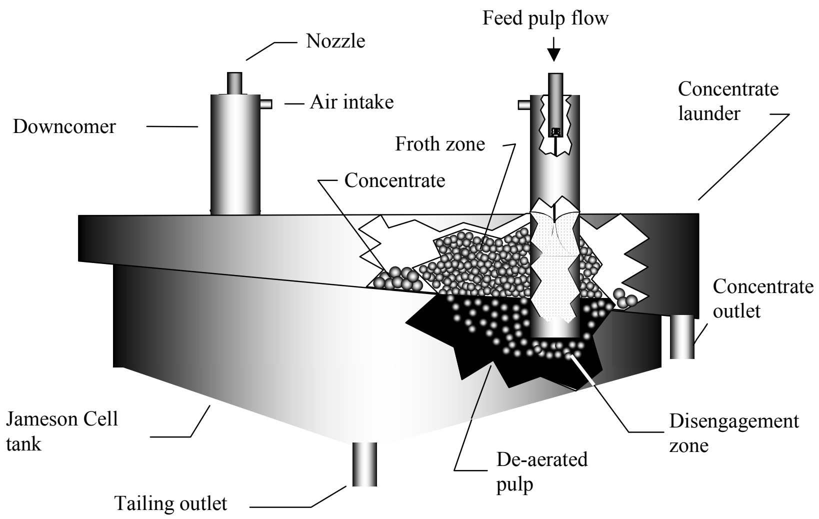

Figure 1.
Jameson Cell operation

Recovery interactions

Although a number of studies have been conducted on the effect of operating variables on the Jameson Cell (eg, Mohanty and Honaker, 1999) they have reported total Jameson Cell recovery, rather than the recovery in the three specific zones of the Jameson Cell.

The total recovery in a Jameson Cell is a function of the recovery gain in the downcomer, recovery loss or gain in the pulp zone and recovery losses in the froth zone.

Froth zone recovery

It is generally recognised (Vera, 1999) that recovery within the froth zone of any flotation machine is a function of the froth zone residence time τ, which in turn is determined by the aeration rate, Q_a, concentrate pulp flow rate, Q_c, the cell cross sectional area, A, and the froth depth, h. As such,

$$R_f = f.\tau$$
$$= f.A.h/(Q_a + Q_c)$$

Where f is a frothability factor effected by reagents and particle size.

Pulp zone recovery

Flotation equipment such as mechanical flotation cells and flotation columns are commonly designed to provide even dispersion of bubbles within the pulp zone of the tank. This dispersion results in pulp zone recovery becoming primarily a function of the residence time any one particle has in the pulp zone. In terms of operation within the Jameson Cell, tank void fraction 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 void 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, all of which affect the pulp zone recovery.

Downcomer recovery

The recovery that occurs within the downcomer is an area that is still under active investigation. Downcomer recovery is thought to be governed by a number of factors including the air-to-pulp ratio, turbulence, residence time and the amount of the mixing zone contained within the pipe.

Experimental procedure and equipment

The study was conducted using the Jameson Cell continuous recycle procedure as developed in 1992 by Cheng and associates (Manlapig et al, 1993). Two versions of this procedure are used by industry, these being the Simple Test, which approximates AS4156.2.1and the Coal Characterisation Test, which approximates AS4156.2.2. This test work used the Simple Test.

An experimental rig was used at the University of Queensland, which included:

- a 150mm diameter Jameson Cell, with a 25mm I.D. downcomer, fitted with a 3.8mm orifice plate
- a 100 litre capacity sump with stirrer
- a variable speed pump
- a Magnahelic flow meter measuring the Jameson Cell feed stream
- a pressure gauge on the feed line
- an air flow rotameter and a vacuum gauge on the Jameson Cell air line

As supplied coal contained material up to five millimetres in size. To prevent orifice plate blockage, coal greater than one millimetre was screened from the sample. The size distribution of the flotation feed coal is shown in Table 1, together with size fraction ash. At an overall ash of 15.6% the sample was considered a relatively clean flotation feed.

Table 1.
The size distribution and ash content in size fractions for the flotation feed.

Size range (µm)	Retained (%)	Cum. Retained (%)	Fractional Ash (%)	Cum. Ash (%)
-63 + 0 micron	52.01	52.01	18.84	18.84
+63 - 125 micron	13.30	65.31	11.98	17.44
+125 - 250 micron	10.33	75.64	12.55	16.77
+250 - 500 micron	12.47	88.11	11.19	15.98
+500 - 1000 micron	11.88	100.00	12.43	15.56

The sump was filled with 40 litres of water and approximately one kilogram of fine coal, to achieve a percent solids of 2.5%. The low percent solids was specifically chosen to minimise ash and coal entrainment and also to prevent any distortion of results through carrying capacity limitations. A diesel addition equivalent to 160g/t was added and conditioned for five minutes. An MIBC addition equivalent to 16ppm frother volume to fresh feed volume was added and conditioned for a further five minutes. No further reagents were added during the tests. As the Bowen Basin site, which supplied the feed sample, did not use wash water in its flotation operations no wash water was used in these trials.

Slurry was then pumped to the Jameson Cell at a rate of 14.1*l*pm. All tailing was continuously recycled back to the feed sump and pumped back to the Jameson Cell. The concentrate was collected at one, three, seven and fifteen minute intervals and then dried and analysed. In total 27 tests were conducted. The cumulative ash versus cumulative recovery curve for all tests is shown in Figure 2. This shows a sharp increase in combustibles recovery to 90%, with only a marginal increase in ash in concentrate. The maximum combustibles recovery achieved was 93% at a concentrate ash of 5.3%. The close grouping of results along the curve indicates that samples used for the varying tests was representative and exhibited similar flotation kinetic rates. All tailing and concentrate samples were sized at 63µm, 125µm, 250µm and 500µm. Ash and combustibles recoveries for the size fractions were then determined.

This method of test evaluation produces a series of curves of cumulative flotation time versus cumulative combustibles recovery. Although it provides a test of high reproducibility it does not directly equate to the performance of downcomers in production Jameson Cells. Production Jameson Cells operate with continuous new feed, where only a portion of tailing is recycled back to the feed sump. To determine how the continuous recycle test results equated to operation of production sized Jameson Cells a single pass test without recycle was conducted to a allow a recycle factor, f_r to be calculated, where

$$f_r = t_{st1} / (V_s/Q)$$

t_{st1} is the time required in the continuous recycle test for the cumulative combustibles recovery to equal the combustibles recovery achieved in the single stage flotation test, V_s is the sample volume treated in the single stage operation and Q is the volumetric flow through the orifice plate.

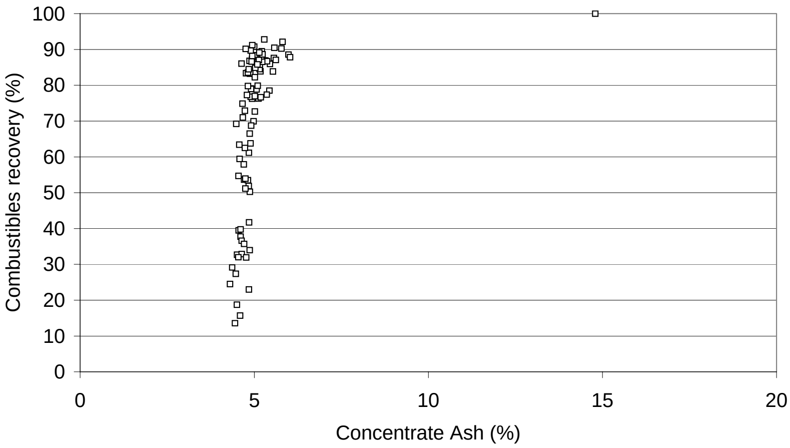

Figure 2.
Cumulative ash versus cumulative combustibles recovery.

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For example single stage operation during this test program achieved a combustible recovery of 71%. With reference to Figure 3 this equates to 4.4 minutes of continuous recycle operation. With a volume of 40 litres and a flow of 11lpm, fr = 1.2. An fr < 1.0 would indicate material is short circuiting and potentially being preferentially floated while an f_r = 1.0 represents a uniform flow distribution and f_r > 1.0 represents a non uniform flow distribution. The f_r was calculated for different size fractions was 1.2 +/- 0.05, indicating various coal sizes were floated in a similar manner.

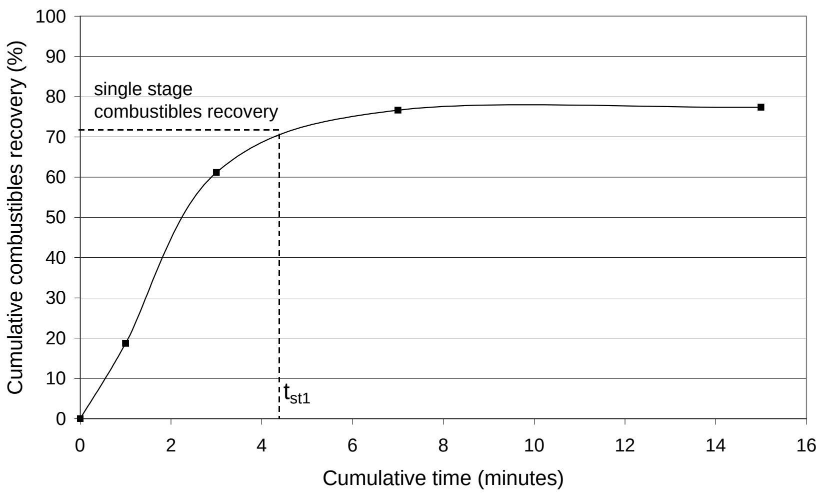

Figure 3.
Correlation between single stage and continuous tailing recycle.

Froth zone recovery

To determine the effect of the froth zone on combustibles recovery the depth of the froth zone was varied while other variables were held constant. The experimental conditions are shown in Table 2.

Table 2

Variables for froth zone recovery evaluation

Test no	Air-to-pulp ratio	Froth height (mm)	Froth residence time (min)
5	1.06	50	0.35
6	1.06	100	0.70
7	1.06	200	1.40
8	1.06	400	2.80

Pulp zone recovery

To determine the effect of the pulp zone recovery the air void fraction within the tank was varied. The air void fraction in the tank, ε was calculated by measuring the tank pulp volume without air addition, $V_{t(0)}$ and the tank aerated pulp volume immediately upon commencing air flow into the tank, $V_{t(1)}$, where:

$$\varepsilon = (V_{t(1)} - V_{t(0)})/ V_{t(0)}$$

The experimental conditions are shown in Table 3.

Table 3
Variables for pulp zone recovery evaluation

Test	Air-to-pulp ratio	Froth depth (mm)	Tank air void fraction (%)
16	0.90	100	2.59
15	0.90	100	5.17
14	0.90	100	7.76
13	0.90	100	10.34

Downcomer recovery

To determine the effect of the downcomer on combustibles recovery the air-to-pulp ratio and by association the downcomer vacuum were varied while other variables were held constant. The experimental conditions are shown in Table 4.

Table 4
Variables for downcomer recovery evaluation

Test no	Air-to-pulp ratio	Vacuum (kPa)	Froth Residence time (min)
4	0.22	18.5	0.70
3	0.45	15.5	0.70
2	0.90	10.5	0.70
24	1.06	3.5	0.70
23	1.06	0.75	0.70
26	1.06	0.5	0.70

The downcomer recovery was back calculated from the overall recovery, froth recovery and pulp zone recovery.

Results and discussion

Froth zone recovery

Figure 4 details the effect of varying the froth residence time on the recovery of the various size fractions. Linear lines of best fit have been inserted, which for size fractions above 63µm showed an r^2 correlation of 0.99. The slope of each line represents the rate of coal loss per unit time, with the Y axis intercept being the combined recovery of the downcomer and pulp zone. It can clearly be seen that loss in recovery in the froth zone for all size fractions is linearly proportional to the amount of time material spends within the froth. Typical Jameson Cells operating in coal flotation will operate with a froth residence time of approximately 1.5 minutes (Honaker et al, 1995). With reference to Figure 5, the rate of recovery loss versus average particle size it can be seen that particles less than 63µm in size are largely unaffected by froth residence time. Above 63µm the rate of coal loss increases dramatically, but then plateaus for particle sizes between 125µm and 1000µm.

The low recoveries at a residence time of zero for -63µm and 500µm to 1000µm particles are therefore an indication of lower pulp zone and downcomer zone recoveries for these size fractions.

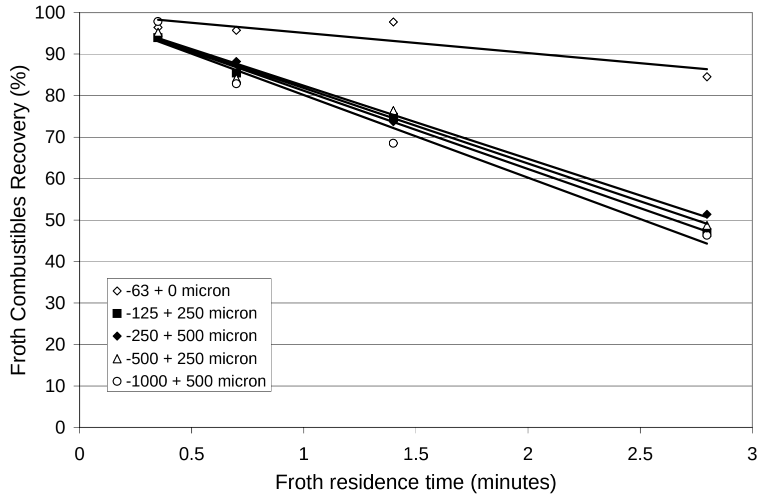

Figure 4
The effect of froth residence time on recovery in the froth zone

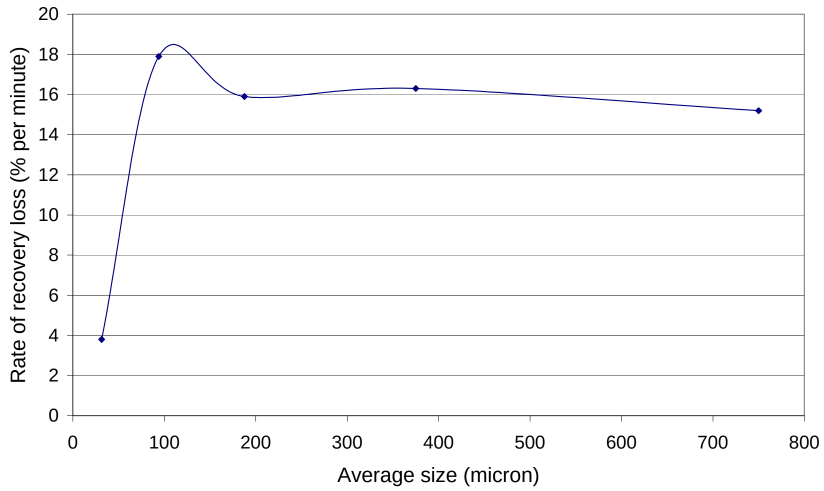

Figure 5
The effect of particle size on the recovery rate within the froth zone

Downcomer recovery

The effect of the downcomer air-to-pulp ratio on recovery can be described by with reference to the air-to-pulp ratio versus vacuum curve as shown in Figure 6. Below an air-to-pulp ratio of 0.2 the mixing zone within the downcomer is minor and the downcomer operates in what is essentially a bubbly flow regime. As the air-to-pulp is increased and vacuum decreases a distinct mixing zone is generated with high turbulence, followed by a pipe flow regime. A situation is eventually reached where attempts to increase the air-to-pulp ratio fail to entrain more air and only result in a decrease in vacuum. In this region the turbulent mixing zone dominates. For this paper evaluation of the downcomer will concentrate on the latter two areas.

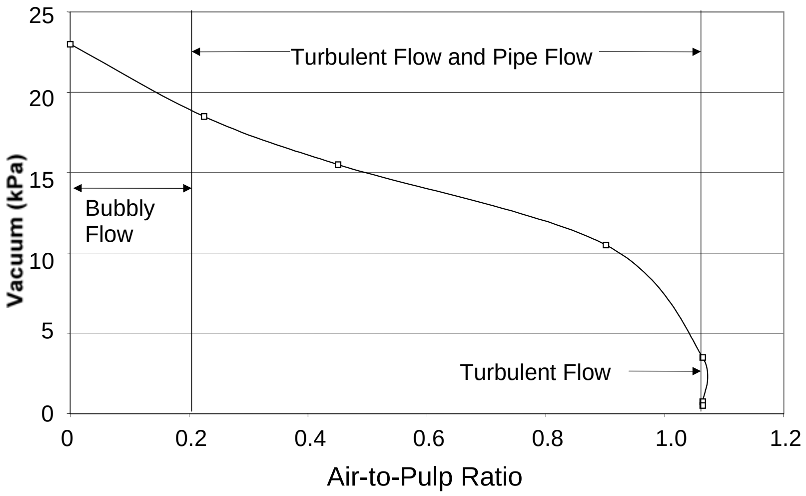

Figure 6
Flow regimes within the Jameson Cell downcomer

Figure 7 shows the change in downcomer recovery as the air-to-pulp ratio is increased from 0.22 to 1.06, but prior to the transition point where the vacuum falls suddenly. In this area the change in recovery per air-to-pulp ratio is approximately linear. Figure 8 details the average rate of recovery per change in air-to-pulp ratio over this range.

For the finer particle sizes, minus 125µm increasing the air-to-pulp ratio has a major affect on increasing recovery. Above this particle size the air-to-pulp ratio has a decreasing affect on recovery improvement, until the plus 500µm fraction where higher air-to-pulp ratios may in fact be causing combustible recoveries to fall marginally.

As one moves to the turbulent regime area of downcomer operation at the maximum air rate and low vacuums the rate of recovery is no longer linearly proportional to the air rate. To determine downcomer performance recovery is compared to the vacuum, Figure 9. For coal size fractions between -63µm to 500µm operation at low vacuums results in a loss of combustibles recovery. This may be due to the mixing zone no longer being contained within the downcomer and insufficient downcomer residence time for collection. The vacuum at which the drop in recovery occurs is dependent on the particle size, varying from 3.5kPa at –63µm to 0.75kPa at 500µm. It is interesting to note however that operation at a vacuum between 0.75kPa and 0.5kPa, or near the region of maximum turbulence, a substantial increase in combustibles recovery for plus 500µm coal particles occurs.

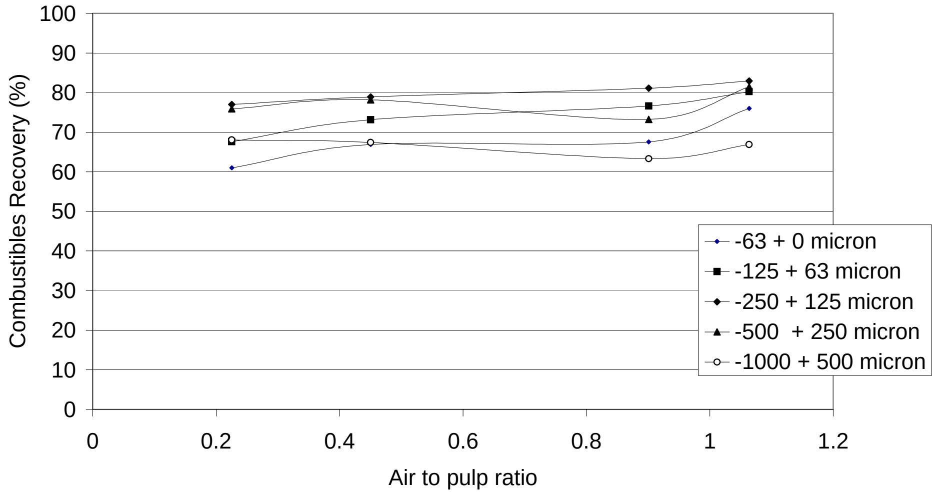

Figure 7
The effect of the downcomer air-to-pulp ratio on the downcomer combustibles recovery

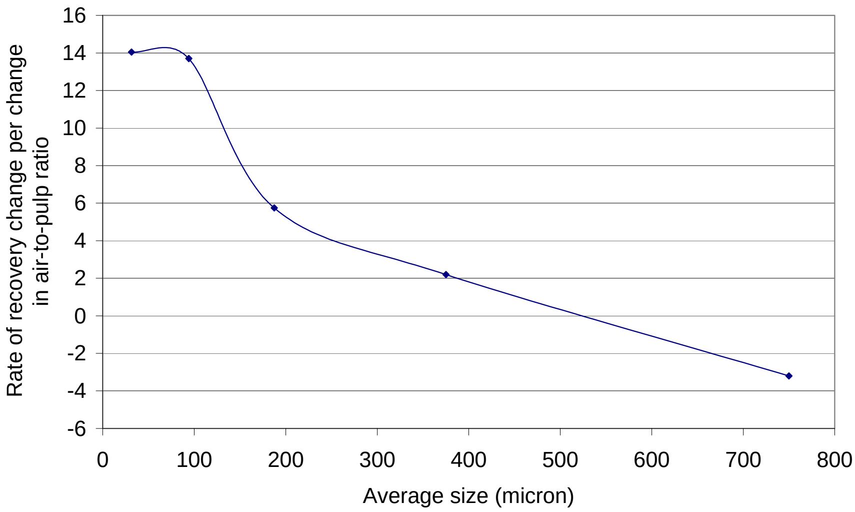

Figure 8
The effect of particle size on the rate of recovery within the downcomer

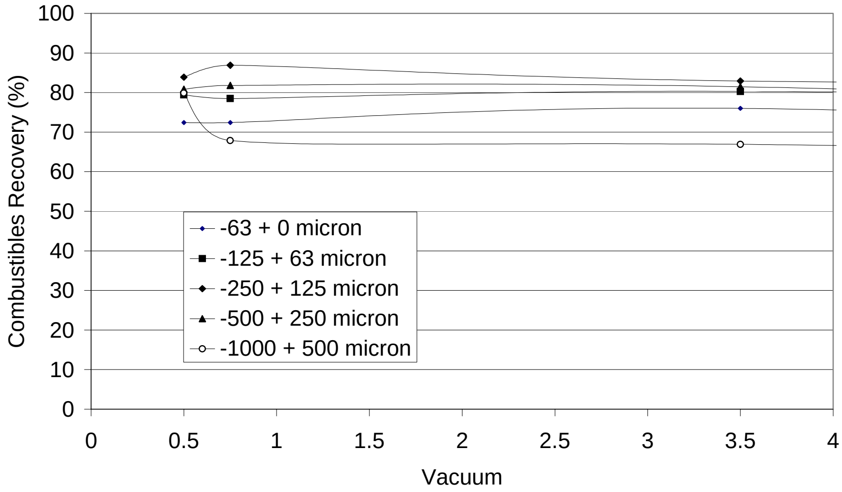

Figure 9
The effect of reducing vacuum on the downcomer combustibles recovery when operating at the maximum air-to-pulp ratio

Pulp zone recovery

It has generally been accepted that the pulp zone of a Jameson Cell does little more than maintain recovery generated within the downcomer. As evidenced in Figure 10 the pulp zone recovery is substantially less than the downcomer recovery and the downcomer must be considered the driving force for recovery within the Jameson Cell.

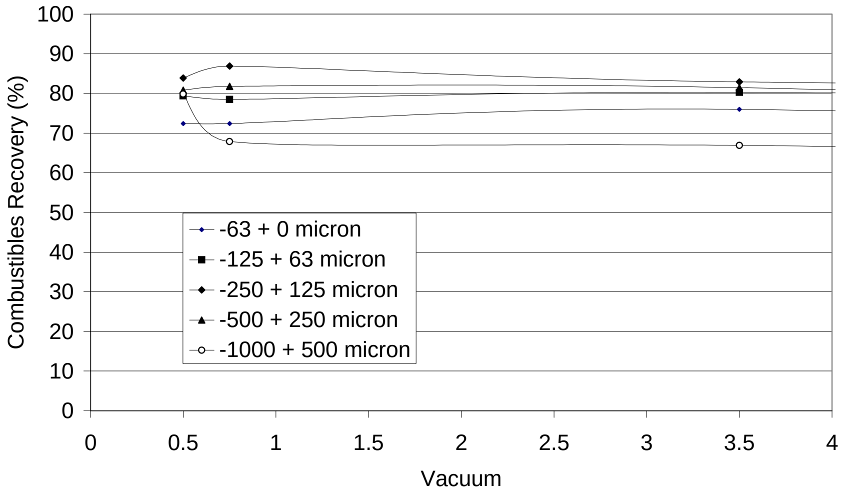

Figure 10
Pulp zone combustibles recovery

Although a full statistical analysis of pulp zone recovery is not possible due to the number of results available a brief review has been conducted. By reviewing data at an air-to-pulp ratio of 1.06, a vacuum of 3.5kPa, where the tank air void fraction was 10.3%, the following can be deduced:

1. For particle sizes above 125μm approximately 70% of coal lost in the froth zone is recovered in the pulp zone.
2. For particles below 125μm 90% of coal lost in the froth zone is recovered in the pulp zone.
3. For particle sizes between 63μm and 500μm approximately 17% of coal not recovered in the downcomer is recovered in the pulp zone.
4. For particles below 125μm approximately 12% of coal not recovered in the downcomer is recovered in the pulp zone.
5. There is no evidence of pulp zone coal recovery for particles greater than 500μm not recovered in the downcomer

Conclusions

1. The downcomer is the primary zone for combustibles recovery. Recovery of size fractions <500μm increase with increasing air-to-pulp ratios, while recovery of the >500μm fraction is either unaffected or decreases. At maximum air-to-pulp ratios the recovery of size fractions <500μm decreases with decreasing vacuum, while recovery of the >500μm fraction increases.
2. The pulp zone effectively recovers coal lost in the froth zone and to a lesser extent finer coal not initially recovered in the downcomer.
3. The froth zone recovery is linearly dependent of residence time within the froth.

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References

Australian Standards, 1994. AS4156.2.1 Coal Preparation: Part 2.1: Higher rank coal- Froth flotation- Basic test, Standards Association of Australia, Homebush, NSW, 1994.

Australian Standards, 1994. AS4156.2.2 Coal Preparation: Part 2.2: Higher rank coal- Froth flotation- Sequential procedure, Standards Association of Australia, Homebush, NSW, 1994.

Clarkson, C J, Manlapig, E V, Cheng, C Y, 1995. Pilot and laboratory scale trials on Jameson Cells

Harbort, G J, De Bono, S, Carr, D, Lawson, V, 2003. Jameson Cell fundamentals – a revised perspective. *Minerals Engineering*, Vol. 16, No. 11, Nov. 2003. Pp 1091-1101

Harbort, G J, Manlapig, E V, DeBono, S K, 2002. A discussion of particle collection within the Jameson Cell downcomer. Trans *IMM (Section C: Mineral Process. Extr. Metall*), 111 / *Proc. Australas. Inst. Min. Metall*., 307, January/April, 2002, ppC1-C10

Evans, G M, Atkinson, B W, Jameson G J, 1995. The Jameson Cell. *Flotation Sci. Eng*, 1995, pp331-363

Finch, J.A., Dobby, G.S., 1990, Column Flotation, Pergamon Press, Toronto, Canada.

Honaker RQ, Mohanta NK, Ho K, 1995. Comparison of Flotation Cells. *12th International Coal Preparation Exhibition and Conference. Lexington, KY, USA May 2 – 4, 1995. pp 175 - 189*

Jameson, GJ, Belk, M, Johnson, NW, Espinosa-Gomez, R, Andreaditis, JP, 1988. Mineral flotation in a high intensity column. *Chemeca 88, 16th Australian Conference on Chemical Engineering*. Sydney, 1988. pp 507-510

Jameson, GJ, 1988. A new concept in flotation column design. Column '88 – *Proceedings of an International Symposium on Column Flotation*, SME, Phoenix Az, 1988. Sastry, KV, ed. pp 281-289

Manlapig, EV, Jackson, BR, Harbort GJ, Cheng CY, 1993. Jameson Cell coal flotation in 10th International Coal Preparation Exhibition and Conference, May 4-6 1993, Lexington, Kentucky. pp 203-219

Mohanty, M K, Honaker, R Q, 1999. Performance optimisation of Jameson flotation technology for fine coal cleaning. *Minerals Engineering*, Vol. 12, No. 4, 1999. pp 367 – 381

Vera, M, 1999. The Froth Zone. *The Optimisation of Mineral Processing by Modelling and Simulation 1996 to 1999 Volume 2- Flotation*. AMIRA Project P9L. Pp 117 - 123