JAMESON CELL DEVELOPMENTS AT PHILEX MINING CORPORATION

by

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ABSTRACT

The Philex concentrator represents the first time Jameson Cells have been used in a cleaner scavenger application or to replace mechanical flotation cells in roughing and scavenging. It also represents the first concentrator to operate wholly with Jameson Cells. This necessitated a major change in Jameson Cell design as well as a change in operating philosophy within Philex.

This paper provides an update on cleaner circuit performance, together with refinements that were required for cleaner scavenger, roughing and scavenging operation. The extended commissioning period and operation to date are reviewed in respect to operating difficulties, changes in operational philosophy and metallurgical results. Comparisons of operating, costs are provided as are residence time and flotation area, together with scale up information leading to the final production cell design. Metallurgical results in relation to gold and copper recoveries are reviewed, with special attention given to direct comparisons between Jameson and mechanical flotation banks, size by size analysis and mineralogical performance.

INTRODUCTION

The Jameson Cell combines a novel method for air and slurry contact where a contained plunging jet naturally entrains air achieving high voidage and intimate particle bubble contact. The fundamentals have been described by numerous authors, including Jameson and Manlapig (1991) and are not discussed further here.

Philex Mining Corporation is one of the largest gold producers in the Philippines and a leading exporter of copper, gold and silver in the Far East today. The mine site is located at the southern tip of the Central Cordilleras of Luzon Island, 17 kilometres from Baguio City, Figure 1. Mining operations commenced in 1958 at a rate of 800 tpd. Plant expansions have increased tonnage to over 20,000 tpd with typical head grades of 0.3% copper and 0.5g/t gold, (Philex Mining Corporation, 1992).

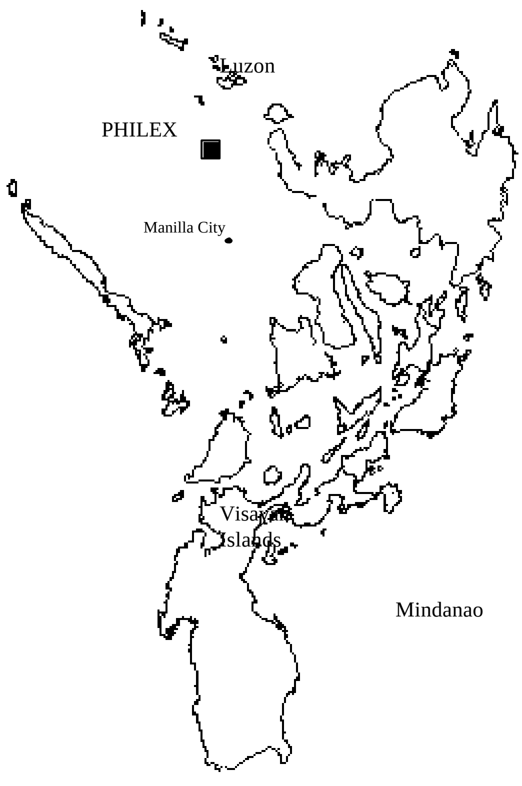

Figure 1. The Philippines

During 1992 Philex Mining Corporation conducted a major evaluation of their flotation circuit, Figure 2. This led to the conversion of their column/mechanical cell cleaner circuit to Jameson Flotation Cells in 1993. Following successful operation in cleaning further test work was conducted in 1993 in roughing and scavenging areas indicating additional metallurgical improvements could be made. In 1994 their mechanical cleaner scavenger circuit was replaced with Jameson Cells to provide floor area for a proposed rougher scavenger circuit. A phased introduction of Jameson Cell rougher and scavenger lines commenced in late 1994 and was completed in early 1996, producing the current Jameson Cell circuit, Figure 3.

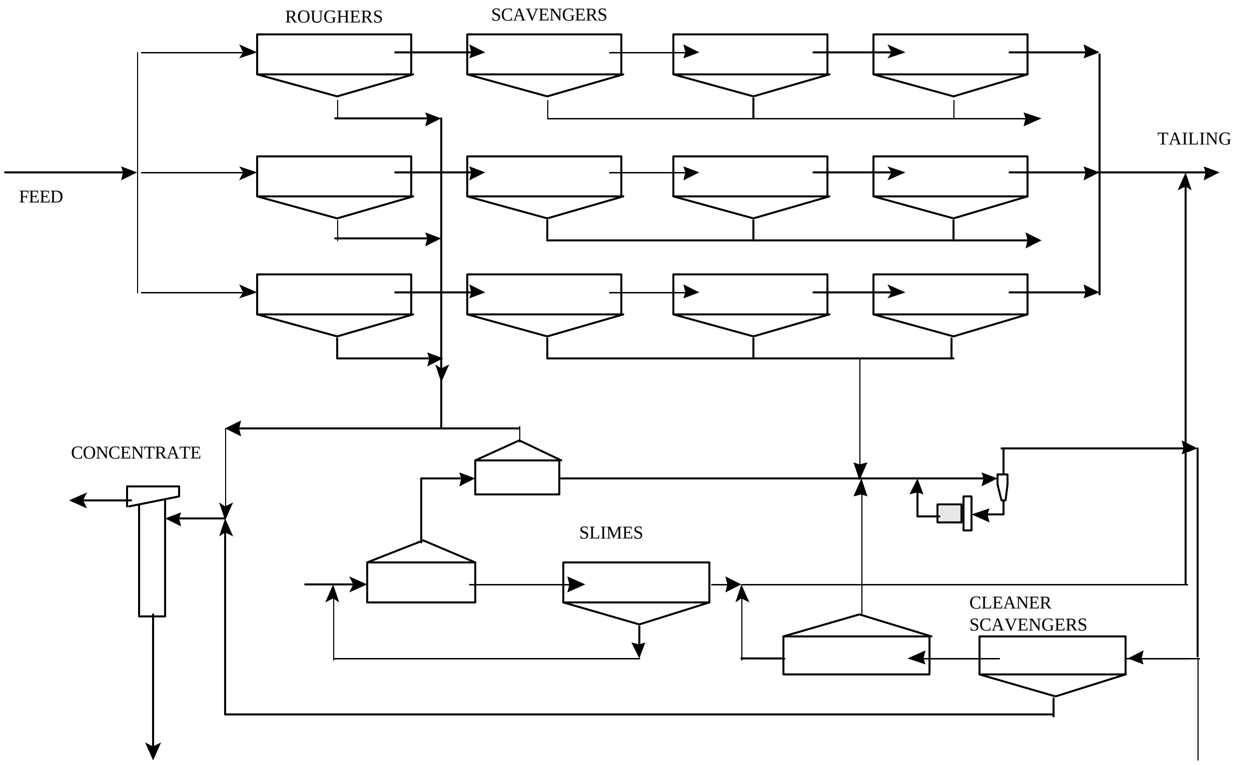

Figure 2. Philex Mining Corporation flotation circuit, 1992.

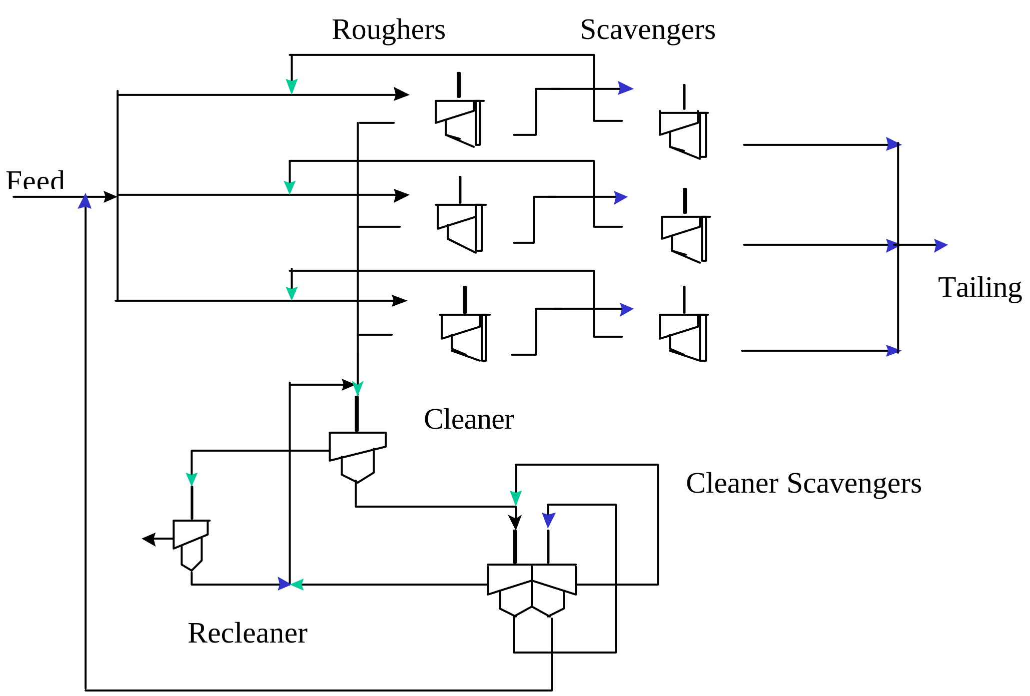

Figure 3. Philex Mining Corporation Jameson Cell flotation circuit, 1996.

CLEANER SCAVENGER INSTALLATION.

Motivation

Additional floor space created by the installation of the cleaner/recleaner cells had been used to increase cleaner scavenger residence time by sixty percent, through additional mechanical cells. As such, there had initially been no plan to replace the existing mechanical cleaner scavengers with Jameson Cells.

Following six months successful Jameson Cell cleaner/recleaner operation Philex's confidence in Jameson Cell technology was such to begin planning of a rougher/scavenger installation. This original proposal required a phased replacement of the mechanical banks, in their existing location, with Jameson Cells. A one third loss in plant capacity would have resulted at each equipment change over. In early 1994 a review of the rougher/scavenger proposal indicated that this entire circuit could be placed in the area where the mechanical cleaner scavengers were currently installed, without affecting production. This provided the motivation for a change of the cleaner scavenger circuit to Jameson Cells.

Design Considerations

Two major difficulties with this change over existed:

1. The only cleaner scavenger test work conducted (Harbort, 1992), was done with the aim of increasing circuit recovery with the addition of one Jameson Cell acting as a scalper. Scale-up calculations had shown that a four metre diameter cell with sixteen downcomers (4000/16) was required for this duty and initial cell design had been commenced. Typically it was to produce a concentrate of 15% Cu at a copper recovery of 60%. This compared with a new requirement to produce a recovery of 90% or better.
2. Available floor space was limited to an area 6.0m by 6.0m.

Alterations to initial design

The limited test work had indicated that recovery was very dependent on superficial air velocity, (Jg), with an increase in Jg from 0.4cm/sec to 0.8cm/sec giving a copper recovery increase from 60% to 70%. A further increase in Jg to 1.2cm/sec was expected to further improve recovery to 80%, still less than the new requirement, indicating that two stages of Jameson Cell treatment were required for the new application.

Until this installation Jameson Cell design had largely increased Jg by increasing the air to pulp ratio, (APR). Experience in other applications indicated that low APR values would not affect recovery provided the Jg was maintained. Later work at the University of Newcastle by Evans, Atkinson and Jameson (1995) subsequently confirmed theoretical aspects. Lower APR values would allow tank diameters to be reduced, and also allowed operation with lower frother addition. Reduction of APR from an initial value of 0.3 to 0.2, while maintaining Jg at 1.2cm/sec allowed the diameter required to be reduced from 4.0m to 2.75m.

Two 2.75m cells were still unable to fit into the allowable space. To overcome this problem the 4000/16 design was altered to produce a cell capable of two stages of flotation in the one shell. This was achieved by the use of additional baffles in the feed distributor, tank, internal and external launder - creating the 4000/16 2 stage Jameson Cell, Figure 4.

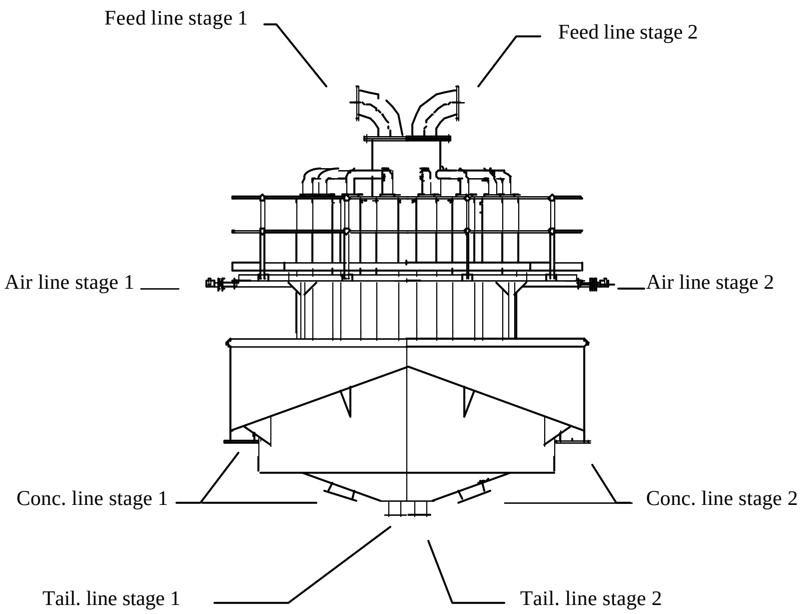

Figure 4. 4000/16 two stage Jameson Cell.

In March 1993 the Jameson Cell for the cleaner scavenger circuit was ordered. Fabrication of downcomer parts was done in Australia with steel work being built in the Philippines. The tank and platform were fabricated in two halves to allow movement into the concentrator. Equipment arrived on site in early August, 1994, with installation being completed three weeks later.

Commissioning

Commissioning commenced on August 30, and a number of problems, as detailed below were encountered.

- Height restrictions resulted in the cell being installed one metre lower than envisaged. This caused tailing pipe runs being close to the horizontal with subsequent sanding and restricted tailing flow, with pulp overflowing to concentrate, (Harbort, 1994).
- Bubble probes installed for tank level control were affected by larger than anticipated density fluctuations. They were replaced with float type level indicators.
- An instrumented control for feed pump box level control resulted in pump boxes and the Jameson Cell being hydraulically linked. Pump box level control was later achieved by placing tailing into a junction launder, one end of which flowed into the pump box, maintaining a constant level, the other end being directed to tailing.
- By mid September, after several modifications, recoveries across both stages was still only 50%, Figure 5. Investigation showed the problem was caused by the irregular trial use of a chemical defoamer. Used to suppress tenacious froth it resulted in severe loss of froth formation and extremely unstable Jameson Cell operation. Its use was discontinued and copper recovery increased to 75%.
- Several days later, corrosion in the recleaner feed box required running repairs to be conducted, limiting recoveries in the cleaner. After repairs were completed the cleaner scavenger copper recovery was increased to 85%.
- Reduced elevation had resulted in internal launders being too low to feed to respective areas of the plant and had been closed off. This caused dead zones to develop in the froth on the inner area of the cell. To overcome this piping was installed between the internal and external launder. This resulted in an eight percent increase in copper recovery to 93%, which was above the targeted value.

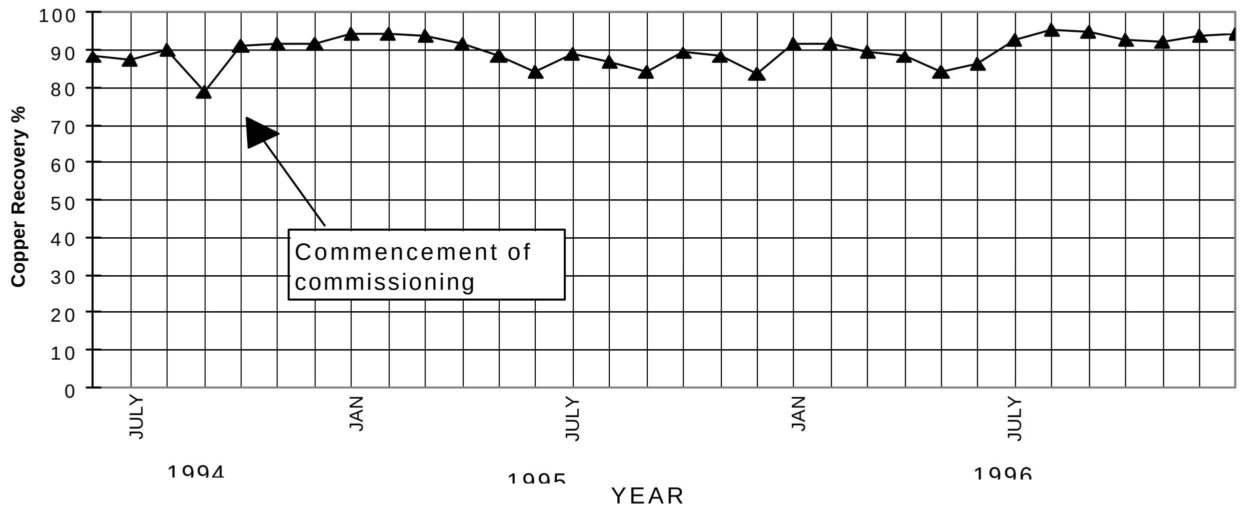

Figure 5. Cleaner scavenger copper recovery.

Size by size analysis

Figures 6 and 7 detail size by size recoveries of copper and gold across the 4000/16 Jameson Cell. The highest recoveries for both were achieved in the minus 74 micron fraction, being 93.4% for copper and 92.5% for gold. Recoveries decreased only marginally with increasing coarseness. At the coarsest size of plus 300 micron, copper recovery was 82.5% with gold recovery of 82.3%. An aberrant drop in recovery for both copper and gold was noted at the 149 micron size. The d_{80} of feed material was 75 micron.

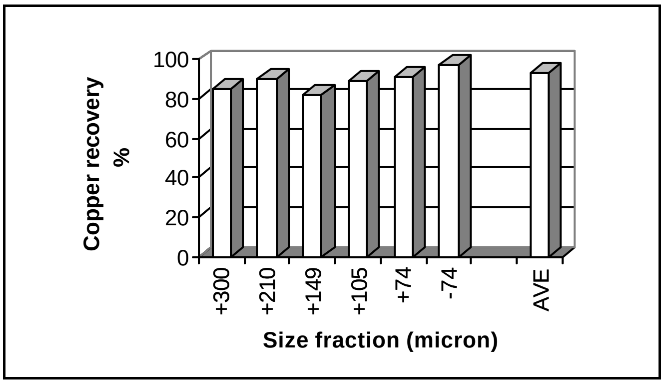

Figure 6. Cleaner scavenger copper size by size recovery.

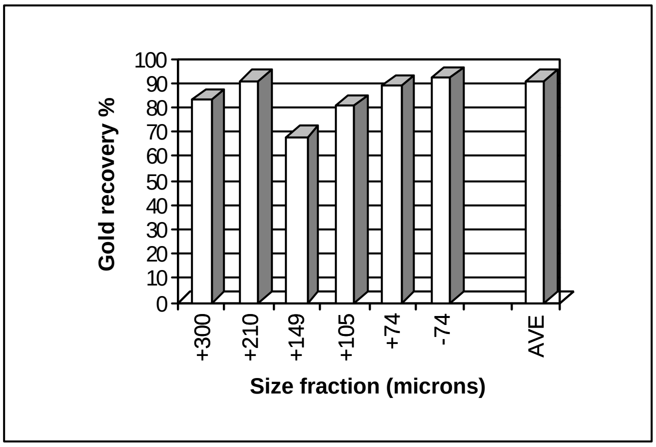

Figure 7. Cleaner scavenger gold size by size recovery.

Jameson Cell and mechanical cell comparisons

Table 1 details key comparisons between the Jameson and mechanical cleaner scavenger circuits. As previously discussed the major justification for replacement of the mechanical cleaner scavenger was to create sufficient area for the replacement of the main roughers and scavengers. The Jameson Cell cleaner scavenger circuit achieved equivalent metallurgical performance, operating with eight percent of footprint area and 9.4% of the residence time of the mechanical circuit.

Power consumed by the Jameson Cell circuit at 197.8kW is half of the previous circuit. This is slightly above the anticipated power (Garcia, 1993), however the more stable operation produced has reduced the cleaner/recleaner power from its original consumption of 150kW, (Garcia, Sevilliano, Smith, 1995) to 112.7kW (Malicse, 1996), a fall of 37.3kW.

Orifice plate usage had initially been predicted at two sets of ceramic per year. The initial steel orifice plates, with an anticipated life of two months remained in service for nine months and the first set of ceramic orifice plates have been in use for 24 months.

Table 1. Comparison of Jameson and mechanical cell cleaner scavengers.

Comparison	Jameson Cells	Mechanical Cells
Power consumption - kW	198	393
Foot print area - sq metres	30	375
Residence time - minutes	2.9	30

CLEANER CIRCUIT UPDATE

The commissioning of the Jameson cleaner and recleaner cells have been discussed elsewhere (Harbort et al, 1993; Harbort, Sevilliano, Chui, 1994) and this paper presents an update on operation, since commissioning in 1993.

Froth formation

The first Jameson Cells installed at Philex were generally very well accepted by operators. One initial operational difficulty was the difference in froth formation between the Jameson Cells and the column/mechanical cells they replaced. The Jameson Cell cleaner and recleaner produce a fine froth, typically with bubble diameters no more than 5mm at the overflow lip. The replaced column by comparison had bubbles of 25mm diameter at the overflow lip. Operators often interpreted the small bubble size as meaning low grade concentrate, when this was not the case. Usual action was to first decrease the air rate to "improve" grade. As found by Atkinson and Espinosa-Gomez (1992) reduction of the air within a Jameson Cell causes an increase in vacuum within the downcomer and typically causes bubble size to get smaller. Visually, reducing air rates made the froth appear even "lower grade". The next action was to increase wash water to "improve" grade. This produced a "wetter", faster flowing froth, again interpreted as lowering grade, when in fact the opposite occurred.

The targeted concentrate grade of 25% copper, with equivalent pre-installation recoveries continued to be achieved until June 1995, 18 months after commissioning (Smith, 1996). In June 1995 both a drop in concentrate grade and cleaner circuit recovery occurred, Figure 8. Initial attempts to correct the fall concentrated on improvement in shift operation. This did arrest the fall, but a return to previous levels was not achieved. A detailed audit was then conducted around the Jameson Cells which highlighted a number of possible causes for the deterioration, (Harbort, 1995).

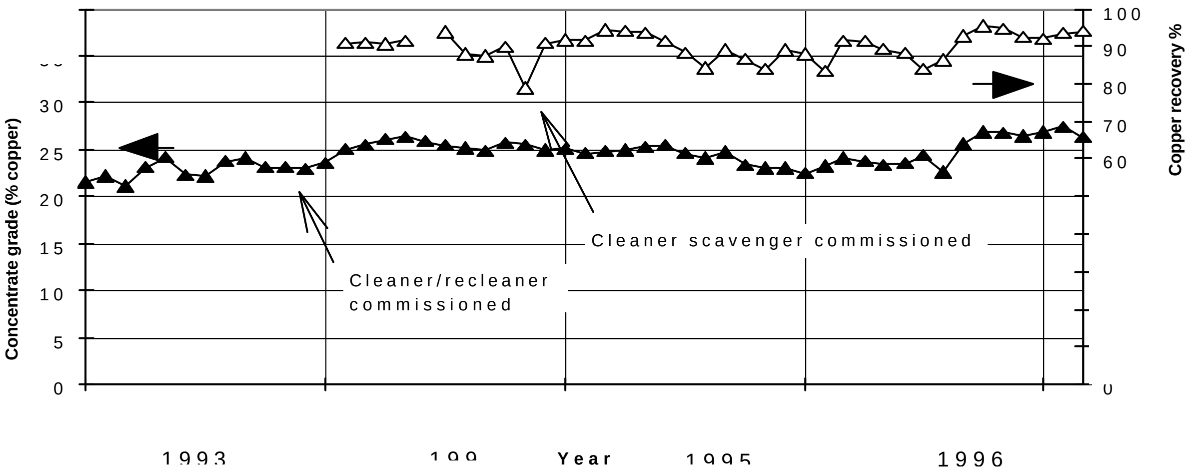

Figure 8. Cleaner circuit copper recovery and concentrate grade.

Feed flow rates

The recleaner cell had been designed to treat a flow of $51m^3$ per hour. The actual operating flow had increased to 99.5 m^3 per hour through a combination of lower percent solids, lower cleaner concentrate grades and higher metal content. To cope with this increased flow the recleaner feed pump had been increased in speed and the orifice plate size increased. An investigation of the recleaner showed that a column of pulp was forming between each downcomer and the outer tank wall, giving inefficient froth/pulp separation. Jameson Cell modelling studies by the CSIRO, (Schwarz, 1992) had predicted this could happen, although this was the first time the phenomena has been observed in practice. To overcome the problem the downcomers were relocated inward toward the cell centre.

Carrying capacity

Froth carrying capacity limitations, causing a gradual copper build up in the cleaner circuit, was also considered a possible problem. Initial design indicated a recleaner carrying rate of 12.76g/min/cm^2. This value was routinely exceeded, (Manlapig, 1994), without a deterioration in recleaner performance. Indications from January 1995 were that even at 14.75 g/min/cm^2 carrying capacity was not limited. Although carrying limitations did not cause a high load system to develop, when one existed it did increase the time it took to remove copper from the circuit. Modifications to the cleaner cell were conducted to allow high grade concentrate to be removed from one downcomer area direct to final concentrate. This provided a rapid method for removing copper from the cleaner circuit.

Frother addition

Excessive frother was also diagnosed as a problem. Frother consumption had been gradually increasing over 1995, partly in an attempt to increase recovery and partly due to concerns on frother quality. In November 1995 frother addition to the rougher circuit was decreased by 25% and some improvement in cleaner circuit performance was observed. As the only frother addition was to the rougher circuit there were concerns that decreases in addition to improve concentrate grade would decrease overall recovery and no further reductions were conducted for several months. In July 1996 frother was again decreased by 25%. Within sixteen hours of the reduction cleaner circuit copper recovery improved from 85% to 95% and concentrate grade improved by approximately three percent copper.

A review of frother consumption over 21 months shows a direct relationship between increasing frother consumption and decreasing grade and recovery, Figure 9. Unlike mechanical cells where over addition of frother decreases concentrate grade without affecting recovery, in the Jameson Cell, under certain conditions, recovery can be affected. This was recognised earlier, (Harbort, 1993), but had typically only applied to small test cells. In the Philex cleaner circuit frother saturated feed had caused a "blurring" of the pulp/froth interface causing level indicators to drift. Since the reduction of frother the cleaner circuit has continued to produce record concentrate grades and recoveries.

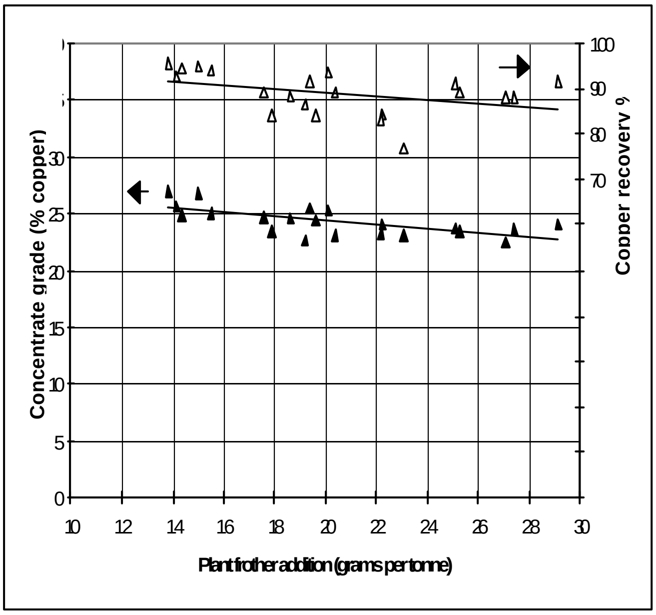

Figure 9. Effect of overall plant frother addition on cleaner circuit performance.

ROUGHER/SCAVENGER INSTALLATION

Design considerations

Where the cleaner scavenger cell required alteration to an existing design, the rougher scavenger Jameson Cells required a new design. Criteria for design included:

- ability to handle coarse feed
- sizing to incorporate space limitations
- efficient feed distribution to downcomers
- operator acceptance

The Philex concentrator operated with three parallel lines of rougher/scavengers and it was a site preference that the Jameson Cell installation would follow this layout. A number of installation options were reviewed.

1. *Six by five metre diameter Jameson Cells* (three for roughing/three for scavenging). This option failed the design criteria in terms of footprint area, lip length and froth travel distance, (Table 2).

2. *Twelve by 3.5 metre diameter cells*. There was operator resistance to this option in that circular cells were considered largely suitable for cleaning but it was felt that rougher/ scavengers should be rectangular.

3. *Twelve by R3330/8 cells*. Rectangular Jameson Cells had been operated at Newlands Coal Pty Ltd on coal fines, (Jameson, Goffinet, Hughes, 1991) and at the Philippine Smelting and Refining Corporation on copper slag scavenging, (Dawson, Harbort, 1996). However, these cells had operated at less than 20tph per cell, compared to the Philex requirement of 200tph per cell. Significant design work on rectangular cells for roughing duties had been done in 1993 Manlapig and this was further developed for the design of the R3330/8 model Jameson Cell for use at Philex.

Table 2. Jameson rougher/scavenger design criteria.

Model	Lip length/area ratio cm/cm^2	Maximum froth travel distance (mm)	Operator acceptance
5000/16	0.96	1000	medium
3500/8	1.46	625	medium
R3330/8	1.33	550	high
Target	>1.0	< 750	high

Design changes

Figure 10 shows a schematic of the R3330/8 Jameson Cell. Changes to the old design included:

- level control using a sand port and overflow weir
- use of a horizontal distributor, with reducing cross sections to maintain pressure
- vertical rather than horizontal feed inlet to downcomers
- use of ceramic at key locations within downcomers
- division of the downcomer into two contacting zones, separated by an aeration funnel that concentrates air around the plunging jet and reduces froth creep to minimise solids build up in air lines.

Twelve R3330/8 Jameson Cells were ordered by Philex in January 1995, with a staggered delivery and commissioning period.

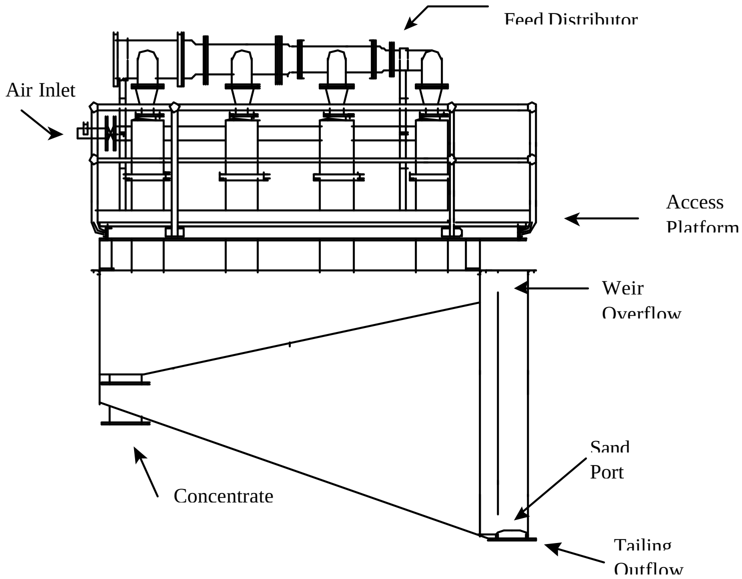

Figure 10. R3330 Jameson Cell.

Commissioning

Significant dates (Harbort, 1996), relating to commissioning were:

- December 7, 1994. Jameson bank C rougher commenced operation.
- February 14, 1995. Jameson Bank C scavengers commenced operation.
- June, 1995. Mechanical bank C de-commissioned.
- September 1, 1995. Jameson bank A commenced operation.
- October 10, 1995. Jameson bank B commenced operation.
- January, 1996. Mechanical banks A and B off line for refurbishment.
- September, 1996. Performance trial conducted showing the Jameson Cells were operating significantly better than predictions from test work.

A number of problems, as detailed below were encountered.

External Recycle Mechanism

Pump box level control to maintain steady feed pressures initially was via an instrumented control scheme. This was designed to keep feed pressures within +/- 10kPa of set points. Initial operation indicated that this was difficult. Jameson Cells operating in SX-EW duties had for several years made use of the Internal Recycle Mechanism (I.R.M.) to obtain stable pressures. (Dawson, Jackson, 1995). This concept was transferred to the rougher pump box at Philex to create the External Recycle Mechanism (E.R.M) as described by Harbort (1995) and Manlapig (1996). The E.R.M. is explained with reference to Figure 11. In simple terms it allows fluid in an intermediate box to flow into the main pump box, to maintain it at a constant level.

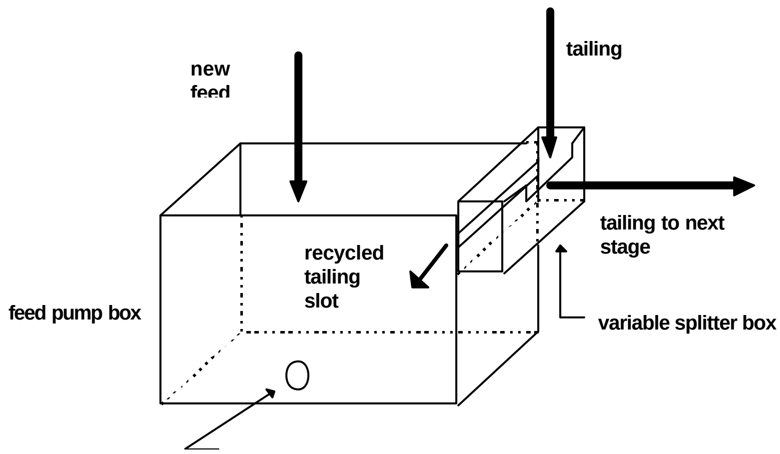

Figure 11. Schematic of External Recycle Mechanism (E.R.M.)

Operation with the E.R.M. commenced on December 16, 1994, with stable pump box level control being achieved with great success. Even wide fluctuations in flow were dampened allowing near constant feed pressures at all times. Figure 12 shows the beneficial effect of the E.R.M. in minimising flow fluctuations. At approximately 2am on September 12, 1996 operations were disrupted by cycloning problems in one of the ball mills. This resulted in varying flows to the flotation circuit, which continued until 11am when the problem was corrected. The short frequency of the flow disruptions resulted in mechanical cell level control being unable to stabilise, with consequential copper losses to tailing. By comparison, these fluctuations were adequately handled by the E.R.M., with no loss of recovery evident, even with manual adjustment on cell level control.

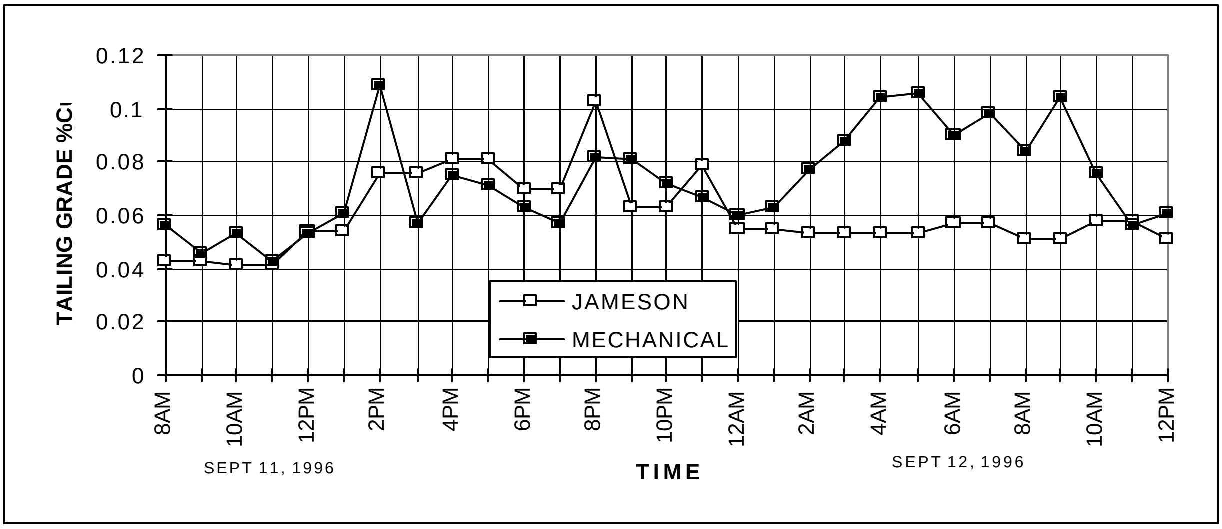

Figure 12. Minimisation of circuit disruptions with the E.R.M.

Froth formation

Once again the difference in froth formation between the Jameson and mechanical roughers was an area that caused some difficulty with operating personnel. Each bank of mechanical rougher/scavengers had a lip length of forty metres, with an average mass flow over the lip of approximately 0.29tph per metre of lip. By comparison, each bank of Jameson rougher/scavengers has a lip length of twenty six metres with an average mass flow over the lip of 0.65tph per metre of lip. Initially, experienced mechanical cell operators had a tendency to run Jameson Cells visually the same as the mechanical cells, with too low a mass pull, giving lower recoveries.

On going performance

Figure 13 shows the average operating performance in 1995/1996 compared with results from the mechanical banks. The difference between expected and actual tailing increases with increasing feed grade. A number of reasons appear to exist for this including improved copper oxide recovery, better scavenging ability and improved fine particle flotation.

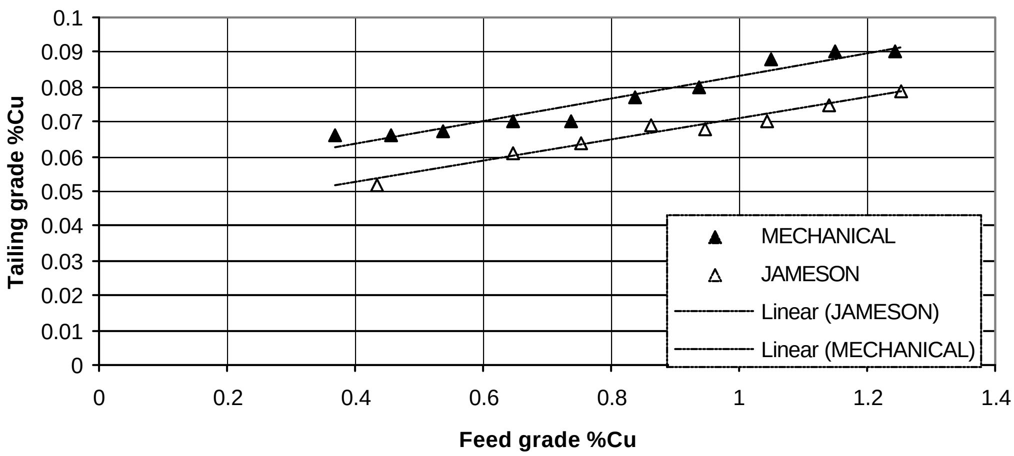

Figure 13. Comparison of Jameson and mechanical rougher scavengers.

Copper oxide content typically increases with increasing rougher feed grade. Immediately following commissioning it became apparent that the Jameson Cells were achieving higher recoveries of oxidised copper than the mechanical banks, Figure 14. During the initial tests feed material contained low copper oxide content and this advantage of the Jameson Cell was not apparent.

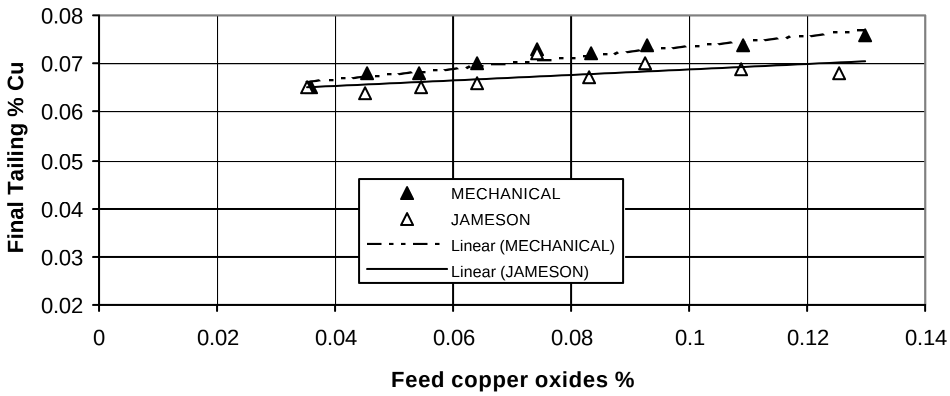

Figure 14. Effect of feed copper oxides on final flotation tailing.

Operation has shown that roughing performance was similar to test work and to that achieved by the mechanical cells. Scavenging in the Jameson Cells however shows a marked improvement over the mechanical cells. Figure 15 details the distribution of tailing results for September/October, 1996, with Jameson and mechanical banks having similar scavenger feed grades. Both operated for a similar period of time in the normal operating range, with the Jameson Cells performing better under minor upset conditions. Of major significance is that the Jameson Cells for twenty percent of the operating time produced a very low scavenger tailing, rarely achieved by the mechanical circuit at Philex. This is possibly due to the intense bubble/particle nature of contact which occurs in the downcomer. This is further highlighted by the fact that the Philex mechanical scavenging banks have twelve contacting stages compared to one for the Jameson scavengers.

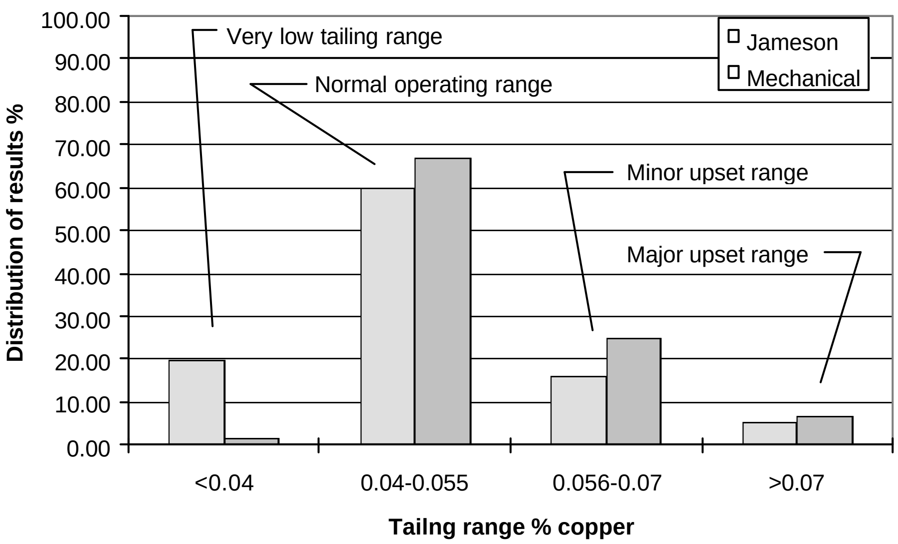

Figure 15. Distribution of tailing results for September/October, 1996.

Size by size analysis

Surveys have been conducted around the Jameson Cells and mechanical banks. These samples were sized by screening and cyclosizing and size fractions assayed to allow a size by size comparison of recoveries, Figure 16. The results show that the Jameson Cells and mechanical banks achieved similar recovery of copper in all size fraction greater than 14 micron. In the 10 micron to 14 micron size fraction the Jameson Cell achieved

2% additional copper recovery over the mechanical cells. For the minus 10 micron slimes fraction the Jameson Cells achieved 6.72% additional copper recovery. The samples were further analysed via QEM SEM, (CSIRO, 1996), showing losses of chalcopyrite to tailing in the +106 micron size range were as unliberated gangue binary composites. Liberated chalcopyrite up to 212 micron in size was observed in concentrate. By comparison, chalcopyrite losses in the 10 to 14 micron fraction were largely free particles, (60.2% of chalcopyrite lost), with 21.0% lost as composites with pyrite and only 16.8% being lost as gangue composites. It is likely that -10 micron material (unanalysed), would exhibit a similar form of loss. As such 20% of total copper losses were as free particles in the slimes fraction.

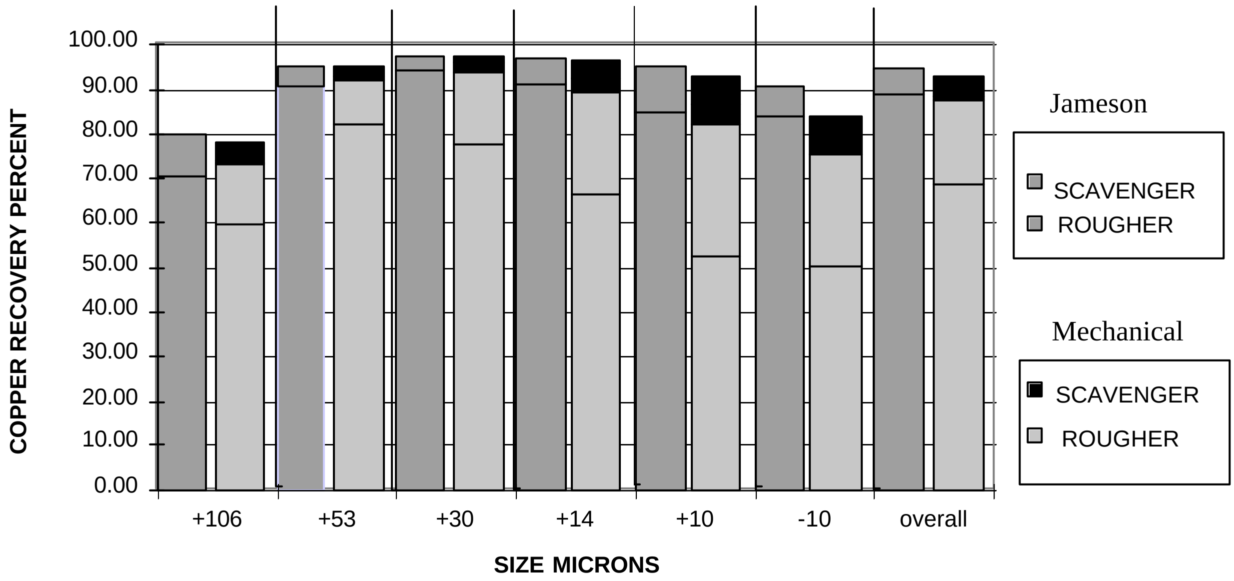

Figure 16. Copper recovery by size fraction.

Figure 17 details the effect of the Jameson Cell rougher installation on overall plant copper tailing. Early 1994 represents the plant's previous best performance in recent times where a tailing of 0.059% copper were achieved. The average tailing for the six months prior to Jameson C bank commissioning was 0.069% copper. Following completion of commissioning and during the early part of 1996 when mechanical banks were off line for refurbishment, the Jameson Cells, operating alone, achieved an average tailing of 0.064% copper. Peaks in tailing grade after this relate to periods where significant amounts of ROM spillage material was treated. Following normalisation of ore supply, tailing levels fell to 0.055% copper. With increasing confidence and expertise Philex have managed to reduce plant tailing further to an October 1996 average of 0.046% copper.

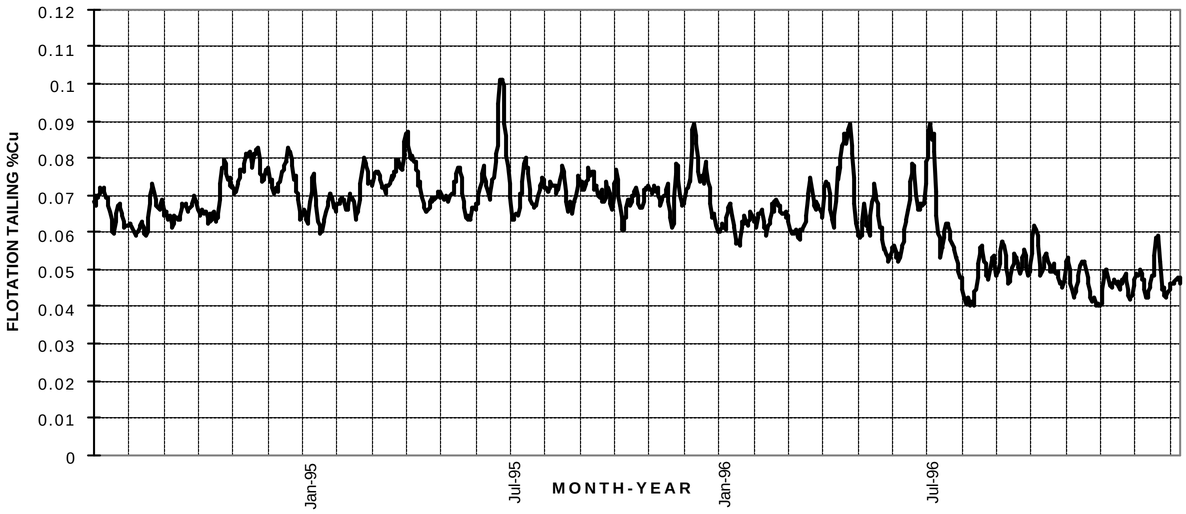

Figure 17. Plant copper final tailing.

In addition to improved copper recovery a significant increase in gold recovery, above that indicated by gold floating in sulphides, was observed. At typical plant recoveries the Jameson Cells improved gold recovery by approximately one percent. This appears in part due to elevated Jameson Cell recovery of free gold during plant upset conditions, Figure 18.

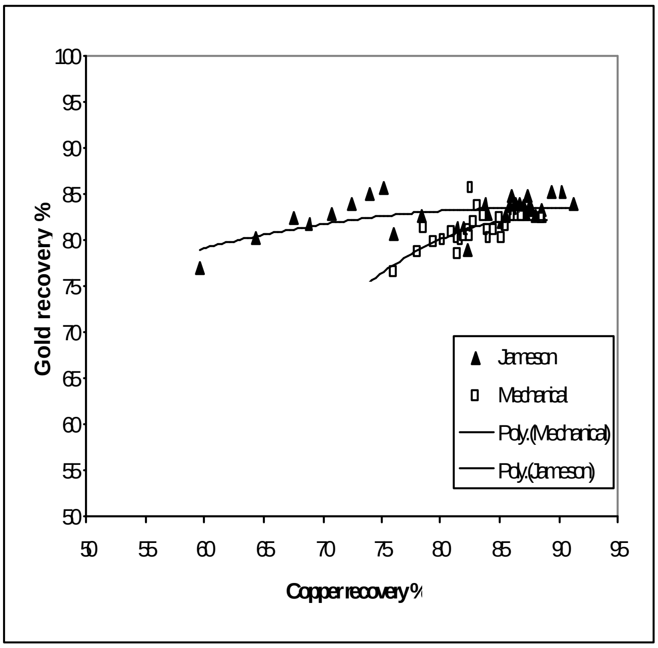

Figure 18. Copper recovery versus gold recovery.

Performance trial

The copper tailing grade achievable from test work was based on a sliding scale, largely governed by the copper feed grade to the roughers. In September 1996, a performance trial at rated capacity was conducted to confirm operating performance. For the trial, one Jameson bank was fed from milling line no 2, with milling line no 1 feeding to mechanical banks A and B, which acted as a control. Key parameters for the trial are shown in Table 3. (Harbort, Murphy, 1996).

During this trial the tailing achieved was 0.01% copper less than that anticipated.

Table 3. Performance trial key parameters

Parameter	**Line 1** **Control**	**Line 2** **Jameson A bank**
SIBX addition (g/t)	24.04	24.04
Frother addition (g/t)	18.35	15.2
Approx. pulp density (kg/*l*)	1.28	1.36
Grind (% passing 200#)	67.5	67.2

Jameson Cell and mechanical cell comparisons

Table 4 details other comparisons between the Jameson and mechanical rougher/scavenger circuits. The Jameson circuit occupies 60% less floor area and achieves equivalent results to the mechanical banks with 40% of their residence time. This is achieved with a power saving of 18%

Table 4. Comparison of Jameson and mechanical cell cleaner scavengers.

Parameter	Jameson Cells	Mechanical Cells
Power Consumption - kW	1396	1702.5
Foot print area - sq metres	360	900
Residence time - minutes	7.46	17.9

CONCLUSIONS

Philex Mining Corporation has successfully conducted a major installation of Jameson Cells into cleaner and rougher sections of their Banget concentrator. Indicated metallurgical improvements have been:

Cleaner/Recleaner
- 2.6% increase in copper concentrate grade
- 3.5% increase in plant copper recovery
- 2.6% increase in plant gold recovery

Cleaner Scavenger
- 1.5% increase in cleaner circuit copper recovery

Rougher/Scavenger
- 3.3% increase in copper recovery
- 4.5% increase in gold recovery

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