Z1600 JAMESON CELL TEST RIG – FROM RENTAL TO REVENUE

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ABSTRACT

A Z1600 Jameson Cell Test Rig was rented for test work at Vale's Clarabelle Mill operation. This paper discusses the evolution of renting the unit for test purposes to owning the unit and operating it as a revenue generating process component.

The paper focuses on three aspects of the Z1600 project; the initial rental and installation, the test work performed in the cleaning circuit, and the business factors which led to the unit being permanently incorporated into the copper circuit.

KEYWORDS

Jameson, copper, nickel, flotation, cleaning

INTRODUCTION

Clarabelle Mill is located in Sudbury Ontario (approximately 350 km north of Toronto) on the southwest rim of the Sudbury basin a meteoric impact crater that is 62 km long and 30 km wide. The result of the meteoric impact was concentrated nickel (Ni), copper (Cu) and platinum group metal (PGM) ore bodies in the outer perimeter of the basin; described in more detail by Hanley (1957). Vale currently has seven operating mines in the Sudbury basin, from which nine distinct ore types are mined. Ores are also received from two QuadraFNX mines. Clarabelle Mill processes all of these ores for the Ontario Operations of Vale.

The mill, commissioned in 1971, was originally built as one of four mills operated by then Inco Limited. Between the late 70's and the early 90's process changes were made to consolidate the Sudbury Operations milling processes into a single operating mill, Clarabelle Mill. In 1990, the SAG mill was installed resulting in peak mill throughput of 11.9 million short tons per annum (Mstpa), with typical throughputs of ~10 Mstpa. Mill average feed grades were 1.4% Cu and 1.2% Ni. During the resources boom, plans were developed to increase the mill capacity at Clarabelle Mill in stages to a final capacity of 13.5 Mstpa. The project known as the Clarabelle Mill Expansion and Recovery Project (CMERP) included expansion and reconfiguration of the grinding and flotation circuits. The first stage was a planned increase in grinding capacity with the reallocation of existing mills, the existing flotation capacity would be required to treat higher throughput until the new flotation circuit was constructed.

During the years preceding the expansion studies the development of the Ontario Life of Mine Plan had identified the ores for the increased capacity. These ores were more complex, with an increased proportion of hexagonal pyrrhotite. Hexagonal pyrrhotite is non-magnetic and thus not recovered to the magnetic separator concentrate, floating in the rougher stages and diluting the concentrate. The proposed flotation circuit expansion was designed to handle the load of pyrrhotite in the roughers however the interim expansion with existing flotation capacity would be bottlenecked in the rougher cleaner stage. An opportunity was identified to test a Jameson Cell to debottleneck the cleaner stage by scalping a moderate amount of concentrate from the B cleaner feed to reduce concentrate loadings to acceptable levels during the period preceding the flotation circuit expansion.

CURRENT CIRCUIT CONFIGURATION

Clarabelle Mill receives run of mine ore by truck and railcar which is dumped into the tipple bin, a sub-surface storage bin. Clarabelle has a conventional crushing process as well as a SAG grinding circuit. The flow sheet for the crushing and grinding process is described by Bom, Taylor, Barrette and Lawson (2009). Primary ball mill cyclone overflow reports to the flotation circuit, shown in Figure 1 and described below.

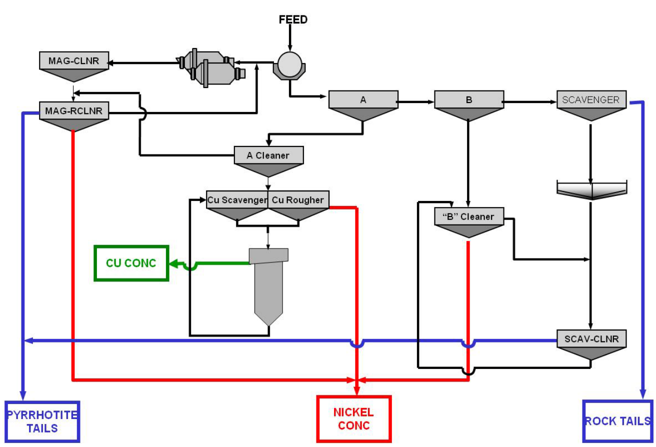

Figure 1 – Flotation flow sheet overview

The flotation circuit produces two concentrates (a Cu and a Ni concentrate) and two tailings (a rock (Rk) tails and a pyrrhotite (Po) tails). There are four distinct circuits in the flotation flowsheet shown in Figure 1; the magnetic pyrrhotite rejection circuit, the main flotation circuit, copper separation circuit and the non-magnetic pyrrhotite rejection circuit. The primary ball mill discharge passes over magnetic drum separators to remove the magnetic, or monoclinic, pyrrhotite particles from the main feed. The magnetic material, equalling approximately 20% of the feed, is reground in two 1500 kW mills operated in series to liberate any pentlandite (Pn) and chalcopyrite (Cp) particles from magnetic pyrrhotite. The liberated minerals are then floated through two stages of flotation, the concentrate reporting to Ni concentrate and the tails reporting to Po Tails.

The remaining 80% of the feed is non-magnetic and reports to the main flotation circuit. This circuit consists of five parallel lines of 38 m^3 U-shaped cells. Each line of flotation is comprised of eight cells, two 'A' rougher cells, two 'B' rougher cells and four scavenger cells (two 'C' and two 'D'). The intention is to separate sulphides from rock. Any material that does not float in this circuit reports to the tailings deposition area or is pumped underground to be used in the backfilling process at one of the mines. The concentrate from the 'A' cells feeds the Cu/Ni separation circuit. The material recovered in the 'B' roughers and the scavengers reports to the Non Magnetic Po rejection circuit.

Cu Separation, commissioned in October 2006, is described by Xu and Wells (2009). Cu separation is performed on 'A' concentrate, which has the highest concentration of Cu in the flowsheet. Cp is a rapidly floating mineral and over 80% of the Cu in feed reports to the 'A' concentrate. An 'A cleaning' stage of flotation was implemented in April 2011and is described in another paper concurrently being written for the CMP by Barrette, Taylor, Doucet, Shelegey, Sullivan & Lawson (2012). The cleaning stage reduces entrained rock and decreases overall rock content in the Nickel concentrate. The Cp in the cleaned 'A' concentrate is separated from the Pn in two stages. The final copper concentrate is cleaned by columns that are at maximum mass pull capacity.

The non-magnetic Po rejection circuit is used to separate any remaining valuable minerals from the highly floatable non-magnetic pyrrhotite using diethylenetriamine (DETA) and sodium sulphite as pyrrhotite depressants. The circuit consists of the 'B' Cleaners (Dorr Oliver 8 m^3 cells) and the Scavenger Cleaners (100 ft^3 Denver cells). Concentrate from the B Cleaners reports to the Nickel concentrate, tails report to the Scavenger Cleaners. The concentrate from the Scavengers Cleaners reports to the B Cleaners. The final tails from this circuit are high in Po and report to the total Po tails to be deposited in the tailings area. It is this circuit in which the Z-1600 test work and data collection were performed.

JAMESON CELLS

Jameson Cells are a relatively new technology with fundamental work starting in 1985. The technology was developed as an alternative to column flotation cells; with which Mount Isa was having operational difficulties and increased maintenance costs, as discussed by Harbort, Jackson & Manlapig (1994). The work, which was a collaboration between Professor GJ Jameson and Mount Isa Mines Limited led to large scale test work in 1987 followed by the installation of the first production scale model in 1989. Additional cells were installed in 1998 and 2002 the former in a lead scalper duty similar to the proposed installation of the Z1600 at Clarabelle (Anderson, Pease, Barnes & Young, 2006).

Jameson Cells are high intensity flotation cells where bubble/particle attachment occurs rapidly (6–10 seconds) in the downcomer. The venturi effect created as the feed is pumped through the slurry lens at the top of the downcomer generates small bubbles (0.3-0.5 mm) through naturally aspirated air. The main volume of the cell is used for bubble slurry separation. Due to the design the main wear parts are the feed pump and the level control valve (Anderson, Pease, Barnes & Young, 2006). Figure 2 shows a general schematic of the Jameson Cell, the feed to the cell is stabilized through an internal recycle generated by the design of the feed sump in relation to the tails box. As new feed flow drops off, tailings are recycled to the feed sump allowing for a stable flow to the downcomer. This internal recycle allows for both increased recovery capability and helps to stabilize new feed fluctuations from upstream processes.

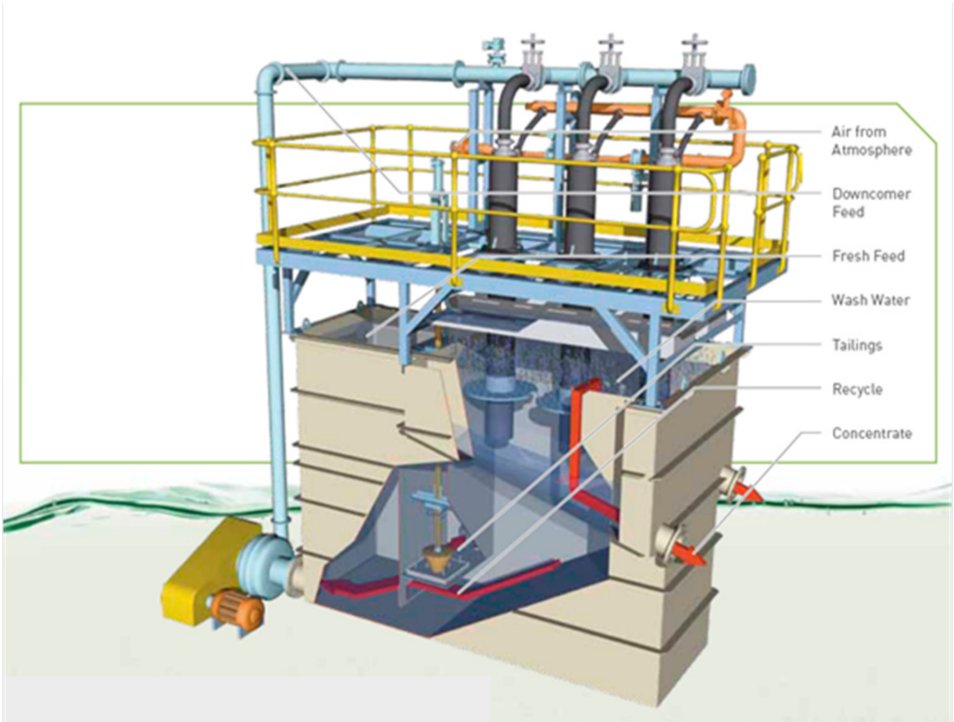

Figure 2 – Jameson Cell schematic (www.jamesoncell.com)

Z1600 TEST RIG RENTAL

In July 2008 an agreement between Xstrata Technology and Clarabelle Mill was reached for the rental of the Z1600 test rig with an option to purchase. The intention was to investigate the feasibility of a Jameson cell to debottleneck the B cleaners. The increasing tonnage due to the CMERP project and the increase in the amount of hexagonal pyrrhotite collectively resulted in a recognized bottleneck. The research data obtained operating the cell was to be used for design criteria for proposed new equipment and the new process flowsheet.

The unit was shipped from Australia via sea container and then by truck to site. Once the unit arrived on site the installation location was identified and the engineering for installation commenced. The installation of the Z1600 was more complex than initially presumed. The execution of the installation project culminated in the removal of a section of exterior wall and using a mobile crane to lift the cell through the wall and into place. Other aspects included modifications to the cell so that it met with plant safety and Canadian building and electrical codes. Power supply had been identified early in the process; however the hand railing height required modification for safe use in the plant. Australian Code is 100cm (39.4") while Canadian code for hand railings is 42".

Final installation of the unit was completed in October of 2010. More extensive engineering, the global financial crisis and a work stoppage in Vale's Ontario operations all contributed to the delay in installation and commissioning of the cell.

B CLEANING TEST WORK

The Z1600 Jameson cell was to be used to determine if a production sized Jameson cell could scalp a high grade concentrate and debottleneck the B Cleaners. In December 2008 the global financial crisis changed the operating plans of many mills including Clarabelle. The project was sufficiently advanced that, although the B Cleaners would not be a bottleneck, test to show that this technology could be used as a scalping cell was continued.

Figure 3 below shows the location of the test rig in the plant flowsheet. The concentrate from the Jameson Cell flows to the final Ni Concentrate while the tails flow back to the feed of the B Cleaner circuit. This creates a circulating load of the Jameson tails back to the feed of the circuit that the mill metallurgist determined would help to increase overall nickel recovery from the cleaner circuit.

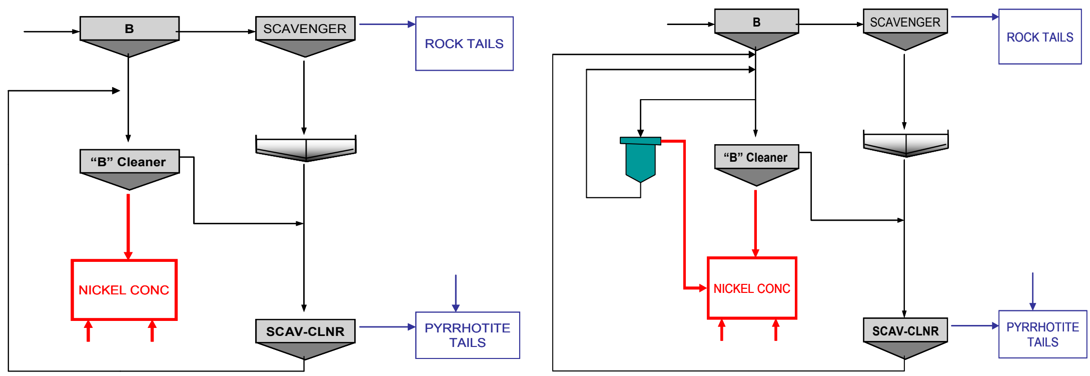

Figure 3 – The B Cleaner circuit flowsheet without and with the Jameson test rig

Test Plan

The test plan for the cell was to determine the grade recovery curve of the Jameson Cell in the B Cleaning circuit and to compare it to the B Cleaner grade recovery in daily use. This would determine if a Jameson Cell could be used as a scalping cell to debottleneck the B cleaner circuit. Cell operating variables would be used to create the grade recovery curve for the cell.

Results

Upon initial start up of the cell the new feed flow was too erratic to reach and maintain steady state operation of the cell. Investigation found that there were multiple factors contributing to the fluctuation. The initial feed line was sized at 6" with a 6" pinch valve for manual control of the flow. The 6" feed line was a lateral off of a 12" feed line to the B Cleaner cells. The flow in the main line was very erratic and the flow variation (up to 1000 usgpm) was much greater than the upper feed requirement to the cell of 330 usgpm. To reduce the peak flow to the cell the 6" control valve was only opened 5-10%. To remedy this a 3" sleeve was installed into the pinch valve and the pump feeding the circuit was operated in manual speed control rather than variable pump speed for pump box level control. Figure 4 below shows the reduction in flow variation between the initial start-up and the final configuration. In both instances a flow of 190 usgpm was being targeted to feed the cell.

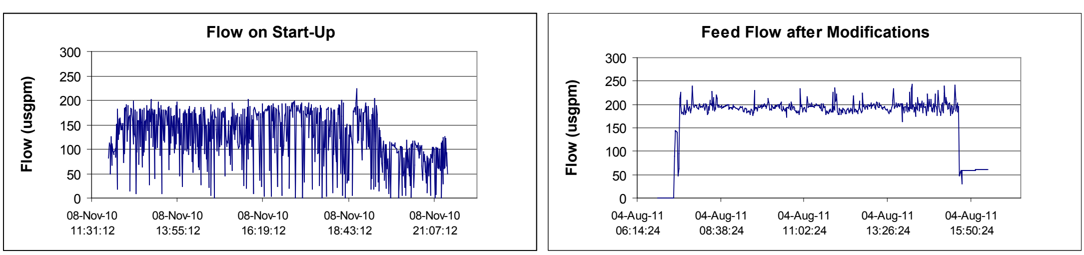

Figure 4 – New feed flow to cell before and after modifications. Data over 9.5 hour at 1 min increments.

Bubble Size

The Vale Base Metals Technology Development (VBMTD) Minerals Processing department has a bubble size measurement device developed by McGill University which was used to measure the bubble size from the Jameson Cell and the B Cleaner Cells. Figure 5 shows a diagram of the bubble size analyzer. Bubbles travel up the sampling tube, the angled viewing window is used to help create a single layer of bubbles to photograph. The back lighting and filter help to delineate the bubble water interface for analysis. Bailey (2004) describes the apparatus and analysis method in more detail. Using the apparatus a series of 50 pictures is taken and then analysed by McGill's Image Processor software using reference measurements taken with each set of pictures to create a bubble size distribution. As expected the Jameson Cell produced smaller bubbles. The images in Figure 6 are two of the pictures used for the analysis. During the bubble sizing the Jameson was operating at 70% level (froth depth - 20"), 160 kPa and 55% recycle. The Dorr Oliver cells were operating at 130 scfm air and 23% level.

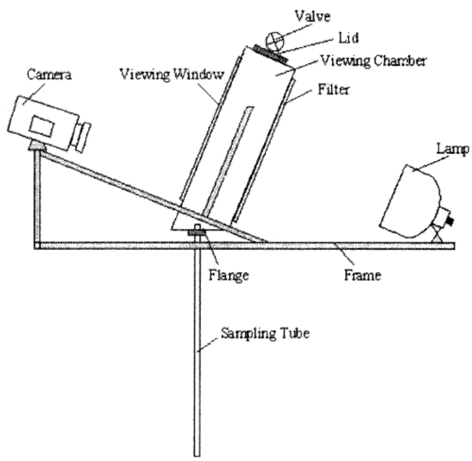

Figure 5 – Depiction of the bubble size measurement apparatus, (Bailey 2004)

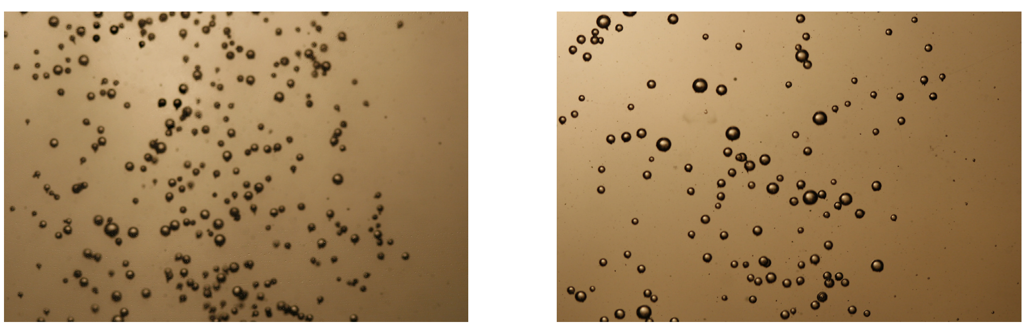

Figure 6 – Bubble sizing pictures. (Left – Z1600, Right – B Cleaners)

Table 1 – Bubble size analysis

	D10	D32	D20	D30
Z1600	0.73	1.01	0.80	0.86
B cleaner	0.84	1.17	0.91	0.99
% Difference	**15.1**	**15.8**	**13.8**	**15.1**

The table above shows that the B Cleaner cells are producing on average 15% larger bubbles across the D10 to D32. In 2004 size by size analysis test work at Clarabelle Mill showed that the largest loss of Pn from the B Cleaning circuit was ultra-fine liberated Pn lost to tails. Increased recovery through the circuit was theorized to come from recovery of the fine Pn by smaller bubbles produced in the Jameson Cell.

B Cleaner Circuit Flotation Testwork

During the test work there were two issues which hindered the operation of the Jameson Cell. The first and biggest issue was a limitation in froth removal from the launder. Due to the pipe runs required during installation of the cell froth backed up in the cell launder. This limited the amount of mass that could be pulled from the cell, constraining the cell level to 80% and lower (15" froth depth or deeper). The second limitation was in the amount of wash water that could be supplied to the ring. The upper flow to the wash water ring was limited to 80 lpm. The limited wash water flow did not generally allow for a positive wash water bias.

The feed to the B Cleaner circuit contains 3 floatable minerals; Cp, Pn and Po. The ratio of Cu to Ni in the feed and concentrate is one indicator which can be used to distinguish a difference in the performance of the cells. When comparing the Jameson to the B Cleaner Cells, the Jameson Cell had a higher upgrade ratio of Cp than the B Cleaners with respect to the Pn in the feed. As shown in Figure 7, for a given feed copper to nickel ratio (Cu:Ni) the concentrate Cu:Ni ratio was higher with the Jameson Cell. This selectivity is a benefit for operating the cell in the Cu cleaning circuit as discussed later in the paper.

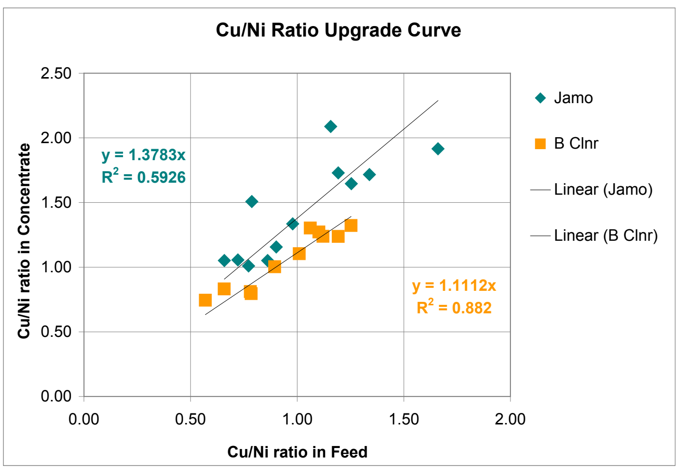

Figure 7 – Comparison of Cu/Ni upgrade.

Initially the Jameson Cu Upgrade vs. Recovery curves did not appear to trend as expected, which is a constant upgrade across % recycle. Further analysis showed that as % recycle increased the recycled tails lowered the feed grade in the downcomer. As the testwork was performed over a range of B cleaner feed grades (2 – 10% Cu) the range of upgrade was impacted. The upgrade ratio was recalculated based on the downcomer feed grade resulting in a more normal flat upgrade ratio was seen across the range of % recycle. The two graphs depicting this are shown in Figure 8. Based on the recalculated downcomer feed and the tests which had less than 50% recycle a shift to a higher Cu upgrade can be seen in Figure 9. The 3 points from tests with low recycle appear to be on a higher upgrade recovery curve but there is insufficient data to confirm this observation.

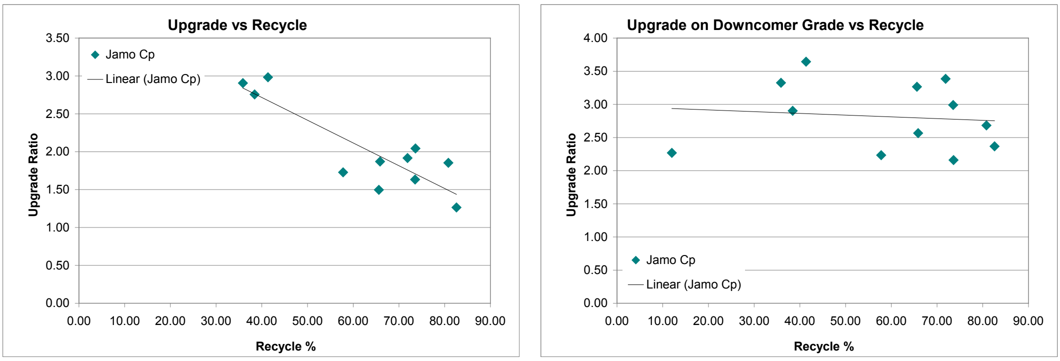

Figure 8 – Initial and downcomer upgrade relationship to % tails recycled.

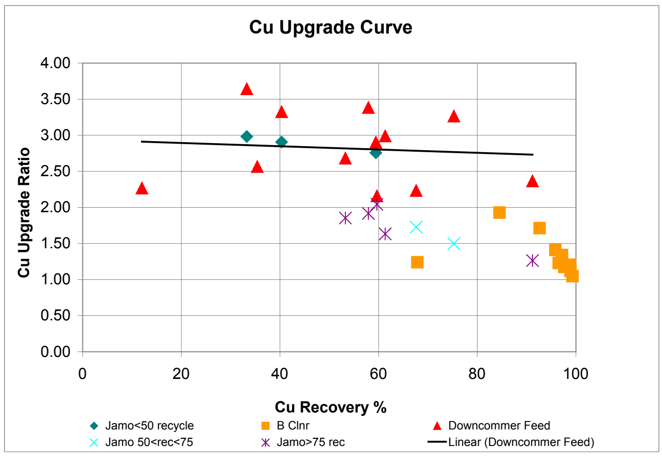

Figure 9 – Jameson downcomer corrected upgrade

The selectivity data for the Jameson Cell lie on the same selectivity curve as the B Cleaners. The Jameson Cell data sit on the lower end of the recovery curve as compared to the B Cleaners due to short residence time and deep froth depth. These Jameson Cell data are more scattered due to the large range in operating conditions tested. Figure 10 shows a compilation of selectivity curves. The selectivity of Cp over Rk shows that the negative wash water bias did not change rock rejection compared to B cleaning. Rock rejection would be enhanced in a scalper operation by correct wash water addition rates.

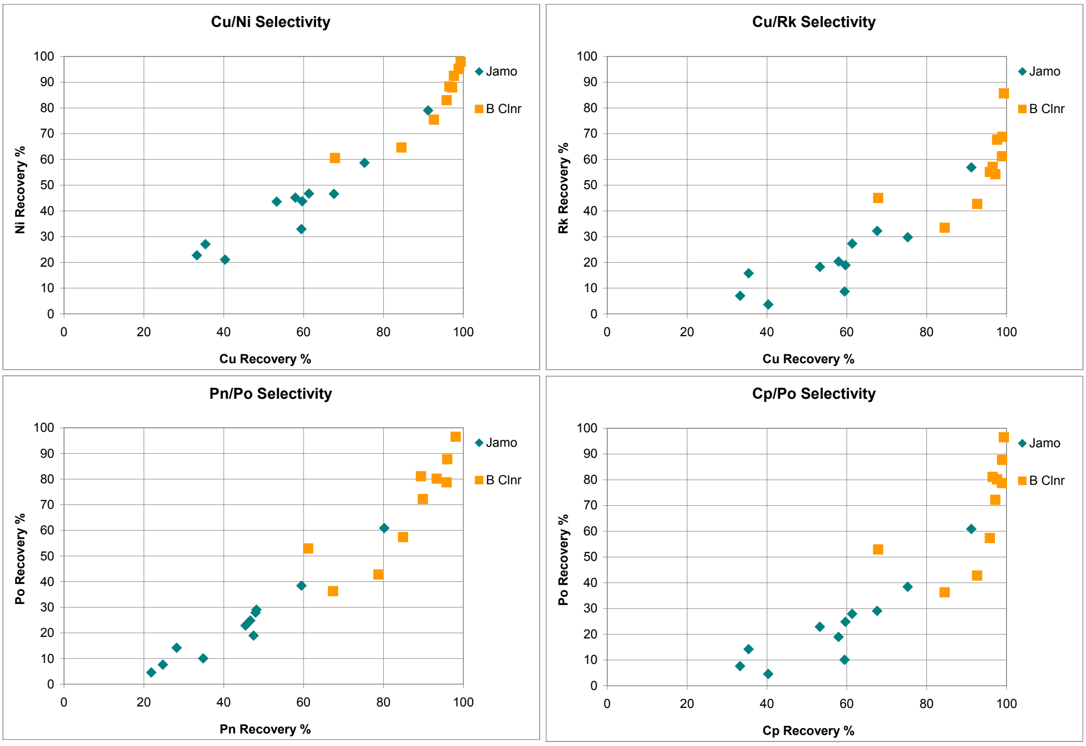

Figure 10 – Selectivity curves

Overall the Jameson Cell performed on the same grade recovery curve as the B cleaners. These data demonstrate that had this circuit become the plant bottleneck that additional capacity in the form of a Jameson Cell could have been successfully deployed. The B cleaners are currently operating well below the plant maximum mass removal of 1150 tpd or 0.75 t/hr/m lip or 0.75 t/hr/m^2 surface area. These numbers represent a discount on standard industry practice of 1.5 t/hr/m lip or 1.5 t/hr/m^2 area, however froths generated when using DETA and sodium sulphite are persistent and conservative numbers of 0.5 t/hr/m lip and 0.5 t/hr/m^2 surface area have previously been used for design purposes in similar circuits. The Jameson Cell was able to pull 1.43 t/hr/m or 0.57 t/hr/m^2 surface area even with the froth removal constraint of the launder piping.

INCREASED CU SEPARATION

Clarabelle Mill's execution plan for 2011 included a plan for a 50% reduction in the variability in the nickel concentrate quality targets. At the same time as the targets for concentrate quality were being tightened the variability in the feed, in particular an increase in the feed Cu:Ni ratio was occurring due to a strategic focus on copper production from Vale's Sudbury operations. The average feed Cu:Ni ratio has increased from 1.1 to 1.5 in the last 5 years. A constraint of the Cu:Ni ratio and the capacity for Cu removal is the inability to remain on-spec for Nickel concentrate quality without reducing mill feed tonnage. A fundamental requirement for a quality organization is the ability to manipulate feed metal units to the mill in order to maintain concentrate quality to the customer. This is shown in Fig 11 where the mill tonnage is plotted for varying Cu:Ni ratios in the feed for several Cu:Ni ratios in Nickel concentrate with varying Cu concentrate production capability. An example is that for a Cu:Ni ratio of 1.5 in the feed if the copper concentrate tonnage constraint is moved from 650 to 800 tph the potential mill throughput to remain on spec increases from 21,000tpd to 26,000tpd for a Ni concentrate Cu:Ni ratio of 0.5. This represents a significant increase in value generation from the mill if the feed from the Sudbury mines exists.

The copper separation circuit was installed as an addition to the Clarabelle Mill flowsheet in 2006 using a low technical risk flowsheet and proven flotation chemistry. The purpose of the circuit was to remove 150,000 tpa copper concentrate to release capacity in the Sudbury smelter to process concentrates from Voisey's Bay Nickel Limited. The circuit has successfully operated at or above design capacity since commissioning and has provided some mitigation to increased Cu:Ni ratios in feed. During the design phases of the copper separation circuit allowances had been made for expected expansion and where possible had been incorporated in the design. Inclusions that have already been capitalized on include expanding the Larox filters from 10 to 14 plates each, increasing the capacity for each filter by 40%.

One outcome of the copper separation circuit was an increase in the variability of Cu:Ni ratio in Ni concentrate to Vale's smelter complex. The reason for the increase in variability is the direct result of being constrained by flotation capacity of the copper flotation columns. On days when the copper head grades are high and the column capacity is at maximum all additional copper is recovered into the nickel concentrate stream. Installation of additional copper capacity will reduce variability of the Cu:Ni ratio in Ni concentrate as the constraint currently impacts increased variability.

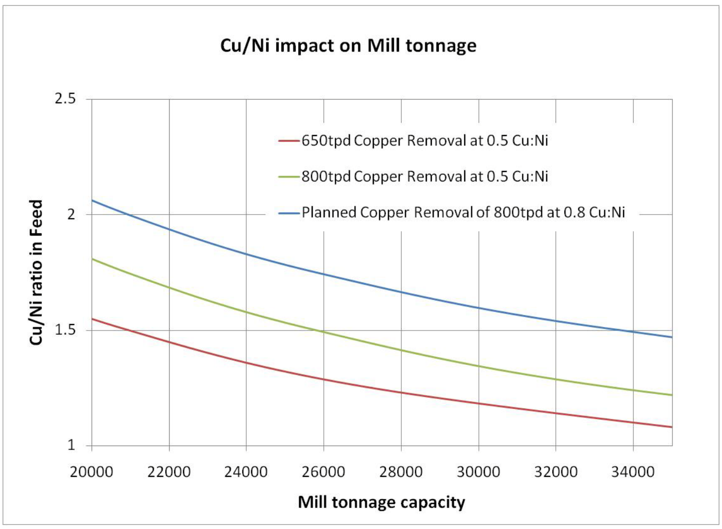

Figure 11 – Mill throughput capability based on feed quality

In December 2010 proposals for increasing copper column capacity were investigated. The review included examining all current project studies completed and identified several additional options. These are summarized below.

1. Increase copper circuit capacity by adding two additional flotation columns and required ancillary equipment from a previous 2008 study (pumps, compressors etc)
2. Increase capacity by open circuiting the copper scavenger flotation cells and new pump to transfer to copper concentrate
3. Converting the Z1600 pilot Jameson Cell to copper concentrate duty treating column tail and install a new pump to transfer Jameson Cell concentrate to copper concentrate
4. Installation of new Jameson Cell in copper building

Further analysis of these options allowed them to be ranked in terms of CAPEX $/tonne additional copper concentrate.

Table 2 – Cost ranking for increased Cu production

Option	CAPEX$/tonne conc	Time to implement
1. Additional columns and equipment	58	24 months
2. Open circuit Cu scavenger conc and pumping system	19	12 months
3. Jameson and pumping system	16	12 months
4. New Jameson cell	29	18 months
5. Combined options 2&3	11	12 months

Based on the analysis of options in Table 2 it became clear that option #2 was low risk, low capital and was quick to implement. The analysis showed the opportunity for an additional option (#5) of combining option #2 and #3, this reduced the $/ton by allowing an additional increment of Cu concentrate from the pilot Jameson Cell using the infrastructure required for the scavenger option with only additional pipe work and instrumentation. Option #5 was accepted and immediately an engineering request to commence was raised. The proposed modified flowsheet is shown in Figure 12.

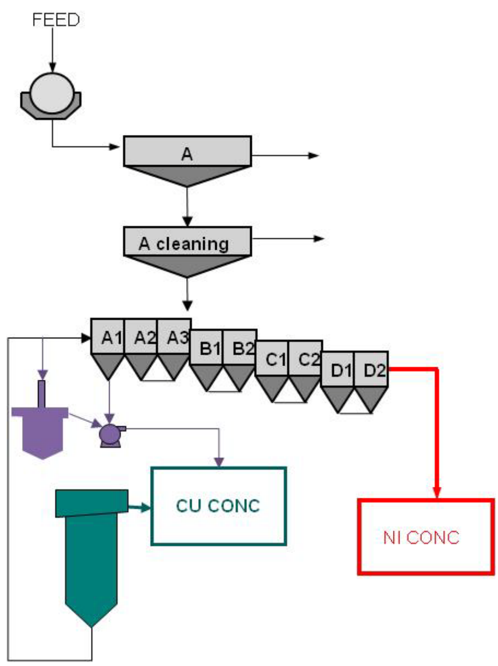

Figure 12 – Modified copper flowsheet

In February 2011 a sample campaign was performed to determine the grade and mass recovery of the A1 Scavenger Concentrate, option #2 in Table 2. Timed concentrate samples were taken so that a total mass recovery of concentrate could be calculated. Six sets of samples were taken during the month, of those only one did not meet the grade specifications for the customer. Using the mass recoveries from the test work, Cu concentrate tonnages ranged from 26 – 44 tonnes with an average tonnage of 31.5 tonnes. As can be seen from Figure 13 the copper losses to the nickel concentrate are bimodal. The intermediate fractions are well recovered but the coarse +106 micron and fine -20 micron are poorly recovered. The use of both the Jameson Cell with fine bubbles and a tank cell with measured success with coarse particles will enable the copper recovery to copper concentrate to be increased. This test work and plant data support the decision to combine the second and third options for increasing the Cu concentrate production. Commissioning is slated for November 2011 less than 12 months after presenting the project for approval.

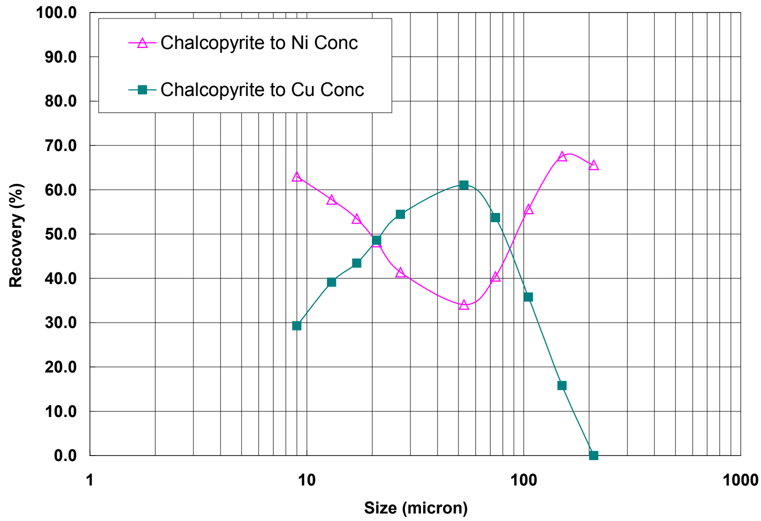

Figure 13 – Recovery of Chalcopyrite to copper and nickel concentrates

CONCLUSION

Brown field installations, even of test equipment, typically require concessions of one sort or another. In the case of the Z1600 installation the location led to delays as it was a large engineering project in a brownfield site. The location was very good for feed piping for both the B Cleaning test work and the subsequent Cu Separation Circuit modification but was not the most appropriate location for the tails piping run or concentrate launder piping. The cell became launder limited due to the lack of slope on the concentrate line, limiting the ability to push the cell into a higher mass pull zone of the grade-recovery curve. These improvements can however be easily configured for future installations.

The Jameson Cell was able to easily scalp 2.8 tph at 56% copper recovery at a froth removal rate that exceeded the B cleaners. The selectivity matched the existing circuit operation which is not unexpected given the similar bubble size and no froth washing. Due to changes in production forecasts and priorities, the debottlenecking cell was not required. These same changes have resulted in the need to convert plant circuits to increase copper removal instead.

Opportunities for increasing plant efficiency can be found in many locations. In the case of the Jameson Cell Z1600 test rig, a pilot plant scale piece of equipment was determined to be an economical improvement to the full scale plant flow sheet at the mill.

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