HOME

Responding to the Challenge – Necessity Driving Circuit Change

A Taylor[1], V Lawson[2] and R Barrette[3]

ABSTRACT

Over the last year at Clarabelle Mill, three circuit reconfigurations were implemented. One circuit reconfiguration, 'A Cleaning', was initiated due to a furnace failure at the smelter complex, and two of the circuit reconfigurations, 'increased copper (Cu) separation' and the 'Interim IsaMill™ circuit', were seen as opportunities to increase cash flow through the mill. A Cleaning and the Interim IsaMill™ circuit took advantage of engineering design already completed for a major capital project. The engineering for each was modified, as needed, and construction of the required portions of the capital project was fast tracked. The increased Cu separation circuit change used existing test and plant equipment to increase the plant Cu concentrate production. Implementation of the projects required teams that included operations, maintenance, technical support, project management and capital project resources. This paper discusses the business reasons driving the changes and the forethought or synergies with other work, which made them a success, and what was learned through each project.

INTRODUCTION

Vale is the world's second largest diversified mining company; having interests in iron mining and production, base metal mining and finishing, logistics, fertilisers as well as in the energy sector. Vale has production plants and assets in 38 countries worldwide, employing approximately 119 000 people. Clarabelle Mill is part of Vale's nickel business within the Ontario Operations of the North Atlantic business group. Ontario Operations includes mines, a mill, smelter, matte processing plant, nickel refinery and a cobalt/precious metals refinery.

Clarabelle Mill is located in Sudbury, Ontario, Canada (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) orebodies in the outer perimeter of the basin, described in more detail by Hanley (1957). Clarabelle Mill currently processes the 80 to 90 orebodies that are mined at Vale's six operating mines in the Sudbury basin. Toll ores are also received from two KGHM (formerly QuadraFNX) mines at the mill.

The mill, commissioned in 1971, was originally built as one of four mills operated by then Inco Limited. Between the late 1970s and the early 1990s process changes were made to consolidate the Sudbury Operations milling processes into a single operating mill – Clarabelle Mill. In 1990, a semi-autogenous grinding (SAG) mill was installed, resulting in peak mill throughput of 11.9 million short tons per annum (Mst/a). In 1992, typical throughputs were ~10 Mst/a. Mill average feed grades through the 1990s and into the early 2000s were 1.4 per cent Cu and 1.2 per cent Ni.

There are two flow sheets for Clarabelle Mill that are central to this paper. The current flotation flow sheet and the challenging ore recovery (CORe) flow sheet, which will be fully commissioned by spring 2013. The next two sections of the paper are descriptions of these flow sheets. Both flotation circuits are designed to create four product streams: Cu concentrate, Ni concentrate, Po tails and rock tails. Cu concentrate is sold to market. Ni concentrate is processed thought the Ontario Operations to produce finished Ni and Co and produce a PGM concentrate to be further processed in other Vale operations. The Po tails are acid generating tails and are disposed of in the tailings area. Rock tails are used for mine backfill and tailings damn construction, as well as other tailings management processes.

Current circuit configuration

Clarabelle Mill receives run-of-mine ore by truck and railcar into the tipple bin, a subsurface 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 *et al* (2009). Primary ball mill cyclone overflow reports to the flotation circuit (Figure 1).

The feed to the mill is a combination of three sulfide minerals: chalcopyrite (Cp), pentlandite (Pn) and pyrrhotite (Po), with the balance being siliceous rock. Pyrrhotite is an iron sulfide floatable gangue, of which there are two crystal structures (monoclinic and hexagonal) present within the Sudbury ores, making it a more complex ore to deal with. Monoclinic Po is magnetic, and is essentially the only magnetic material in the ore, which historically drove the use of magnetic separators to separate this portion of the Po into a magnetic flotation feed.

1. Senior Engineer Metallurgy, Vale Ltd, Copper Cliff, Ontario, Canada. Email: andrew.taylor@vale.com

2. MAusIMM(CP), Manager – Mineral Separations Technology, Vale Ltd, Copper Cliff, Ontario, Canada. Email: virginia.lawson@vale.com

3. Section Leader – Mineral Separation Technology, Vale Ltd, Copper Cliff, Ontario, Canada. Email: renee.barrette@vale.com

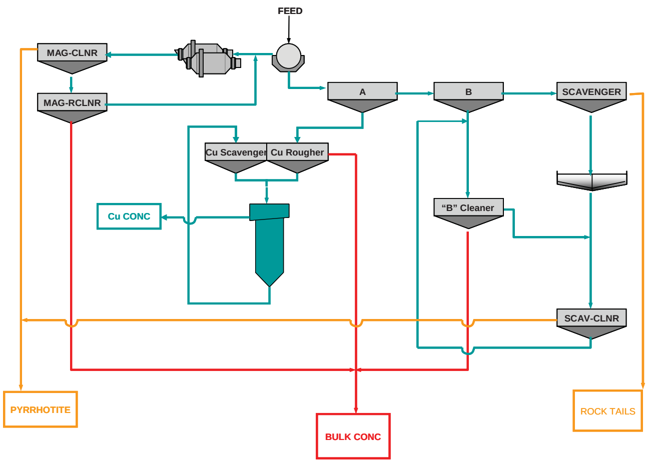

FIG 1 - Flotation flow sheet overview.

Although Po is a gangue mineral, a portion is recovered to maintain the heat balance in the flash furnaces at the Copper Cliff Smelter.

There are four distinct circuits in the flotation flow sheet as shown in Figure 1: the magnetic Po rejection circuit, the main flotation circuit, Cu separation circuit and the non-magnetic Po rejection circuit. The flow sheet is described in more detail by Taylor *et al* (2012). Typically 20 per cent of the mill feed reports to the Magnetic Po rejection circuit, the remaining 80 per cent reports to the main flotation circuit feed.

Challenging ore recovery circuit configuration

During the 2007 and 2008 resources boom, plans were developed to increase the mill capacity at Clarabelle Mill in stages to a final capacity of 13.5 Mst/a. Vale's life-of-mine plan (LOMP) for the Sudbury Operations identified ores for 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. A project was implemented to create a new flow sheet, allowing for the increased throughput and the processing of higher amounts of hexagonal pyrrhotite. The project, known as the Clarabelle Mill enhancement and recovery project (CMERP), was the base for the CORe flow sheet (Figure 2). The progression of the flotation circuits is described in detail by Lawson and Xu (2011).

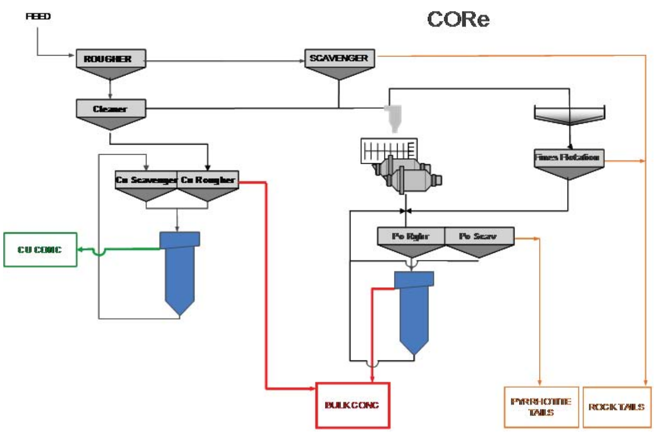

FIG 2 - The challenging ore recovery flow sheet as it will be completed in 2013.

The development of the CORe flow sheet is important to this paper because the engineering and construction schedule enabled the implementation of two of the projects discussed in this paper. Without the work performed in the early stages of development of the CORe project, the engineering and design required for A Cleaning and the Interim IsaMill™ circuit would have increased. Increased design and engineering would increase schedule and costs nullifying the benefits of the projects.

A CLEANING

In February 2011, the failure of a tapping block on the northeast wall of the #2 Flash Furnace (one of only two furnaces) at the Copper Cliff Smelter resulted in a period of 16 weeks of reduced nickel production. The expected resultant nickel lost was estimated to be five per cent of annual Vale production, (Barrette *et al*, 2012). In order to mitigate the production loss a series of actions were taken to maximise the nickel production from the mines and from Clarabelle Mill. With the total furnace throughput cut in half, a plan was developed to increase the nickel concentrate grade feeding the smelter. The fastest way to increase the nickel content in the nickel concentrate was to increase the mill feed nickel grade. To use ore blending to maintain high-concentrate grade, plant data were analysed to understand the mill feed grade versus concentrate grade and recovery trade-offs. The optimum feed grade was determined to be higher than 1.3 per cent Ni to maintain Ni concentrate grades of 16 per cent equivalent nickel reporting to the smelter. Reducing the pyrrhotite level in feed too low would simply replace pyrrhotite in the concentrate with rock that has zero nickel value. Consequently, the Po:Ni ratio needed to be controlled to ensure that dilution of the concentrate with pyrrhotite was minimised. Equivalent nickel grade is the Ni grade of the concentrate with the Cp mathematically removed.

$$EqNi = \frac{\%Ni}{\left(100 - \left(\%Cu \times 2.886\right)\right)}$$

As an example, a concentrate grade that is ten per cent Ni and 11 per cent Cu has an EqNi of 14.6, so does a concentrate that has nine per cent Ni and 13 per cent Cu.

Based on these criteria, a new mine plan was created and the workforce was reassigned across Vale's Sudbury mines to mine designated orebodies to create a blended ore, which met the division's requirements for the smelter. The change in ore blend resulted in an immediate increase in the mill concentrate grade. With essentially no change in flotation circuit parameters the concentrate grade was increased by two equivalent nickel points from 14 to 16 due to the higher feed grades of good quality ore.

The second change to increase the Ni content in the Ni concentrate was to improve the rejection of entrained gangue from the Ni concentrate. This was done in two ways:

1. The first change was a modification of the frother control strategy to the main roughers, and the second was the A Cleaning flow sheet modification. The frother addition rate was initially tied to the plant feed tonnage and not based on a target rougher concentrate grade. Changing this control philosophy resulted in a reduction in the variability of the frother addition rate and thus concentrate grade.
2. The flow sheet modification to clean the rougher concentrate required capital funding and time to design, construct and commission the new circuit. The decision to implement cleaning of the primary rougher concentrate was made within two weeks of the furnace failure. The CORe project team had already designed an interim flow sheet that converted the required cells for A Cleaning from their current rougher/scavenger duty to a primary cleaner duty. At the time of this change CORe was in

detailed design engineering so most of the risks associated with design had already been addressed.

The flow sheet design change that was implemented involved the installation of a new pumpbox and duty/standby pumps, complete with required instrumentation. Due to the lack of procurement time the decision was made to reuse redundant pumps from the plant. This was seen as the largest technical risk. The pumps were not capable of the duty required and needed to be replaced. The conversion of a single line of flotation banks, consisting of eight 38 m^3 cells, was also completed. The flotation line required new launder piping and a redirection of the tails line back into the process for the new flow sheet configuration. The modifications are shown in Figure 3. To enable the construction to proceed rapidly, all the process decisions were made within a week of the decision to make the flow sheet change. Process options were considered using an empirical model in a Microsoft Excel simulation tool, based on existing plant data and CORe flow sheet design data. One major concern related to the potential of high Ni losses from the A Cleaner tail if the stream was incorrectly configured. This was mitigated by redirecting the rougher cleaner tail into the magnetic circuit Po re-cleaner cells. The rationale for this decision was based on the following assumptions:

- The material would have another opportunity to float before seeing an exit stream.
- The magnetic re-cleaner capacity exceeded current plant requirements.
- The pipe route was a simple gravity and direct run with no need for pumping.

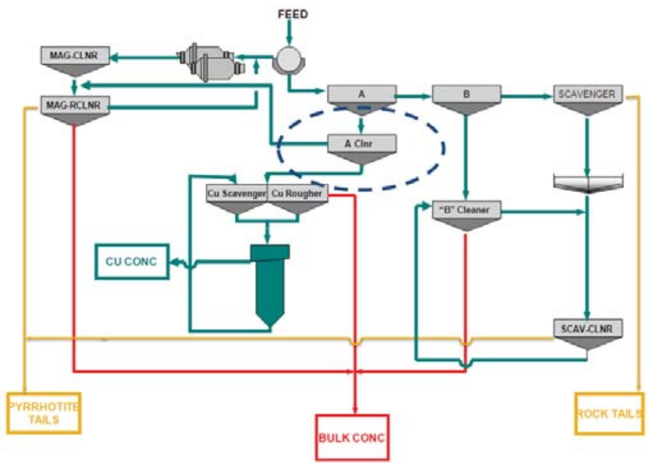

FIG 3 - Clarabelle mill flow sheet post A Cleaning.

Process results

The flow sheet change was commissioned on schedule, four weeks after construction mobilisation, and the improvement was immediate. Figure 4 shows that Stage 1 of the project (the process manipulations) did not shift the variability in the percentage of rock reporting to the Ni concentrate, but did shift the amount of entrained rock reporting on average from ~13 per cent to just over 11 per cent. In Stage 2, the addition of the rougher cleaning stage made further reductions from 11 per cent to ~9 per cent in the overall Rk recoveries to Ni concentrate, and reduced the variability of the Rk reporting to the smelter.

Lessons learned

There were three key learnings from this project:

1. The highest technical risk to the project was the pumping system. The time line did not allow for the procurement

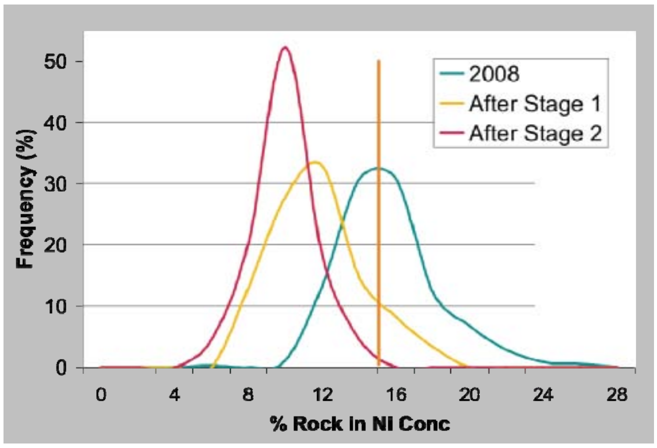

FIG 4 - Rock rejection from nickel concentrate.

of pumps specified for the pumping system. Two decommissioned pumps from the plant had been identified as suitable for the service, based on pump curves and an estimated dynamic head of the piping. The risk was not communicated well to the plant personnel and there was a general perception that bad engineering design was the reason that the pumps failed to perform as planned. Better communication with plant personnel about the projects at the commissioning stage was deemed to be required.
2. A second learning was around typical standard engineering materials used at the mill. Clarabelle Mill uses rubber lined pipe for all slurry piping for wear protection. Due to the urgency of the project the field run piping was measured and fabricated in several days then sent out for rubber lining. The initial measurements did not take into account the rubber overlap of the pipe ends. This resulted in sections of pipe having to be fabricated on-site and field fit without rubber lining. The learning from this was that a single spool piece from any section of line should be left to fabricate as a final field fit in the piping run.
3. During the commissioning process, troubleshooting was ineffective because the process information was not being collected by the data historian used at Clarabelle Mill, called PI from OSIsoft. There were also some misunderstandings as to the specific goals of the commissioning and ramp-up and what data was necessary to show the success of the project. A formalised system has now been developed to prevent this type of occurrence at Clarabelle Mill.

Successes

Within days of the furnace failure a plan to mitigate losses from the Ontario division was established. The initial change to the operating control was completed within two days of the failure. Within one week the plan to move forward with the circuit reconfiguration was made. It took less than a month to get all approvals, tender the work and select a construction firm to perform the work. In just over six weeks the contractor received the approval, mobilised the workforce and completed construction of the new circuit. The time line presented in Figure 5 shows the nine-week span for the project.

The rejection of entrained gangue that was realised through both the process control changes and the addition of rougher cleaning, allowed the mill to supply the smelter with higher-grade Ni in concentrate with minor to no Ni losses. The changes allowed for the Ontario Operations to put in effect a mine plan to produce ore and produce finished Ni at an acceptable rate for the company's customers.

Since the completion of the rebuild of #2 Flash Furnace, the continued operation of rougher cleaning has allowed for

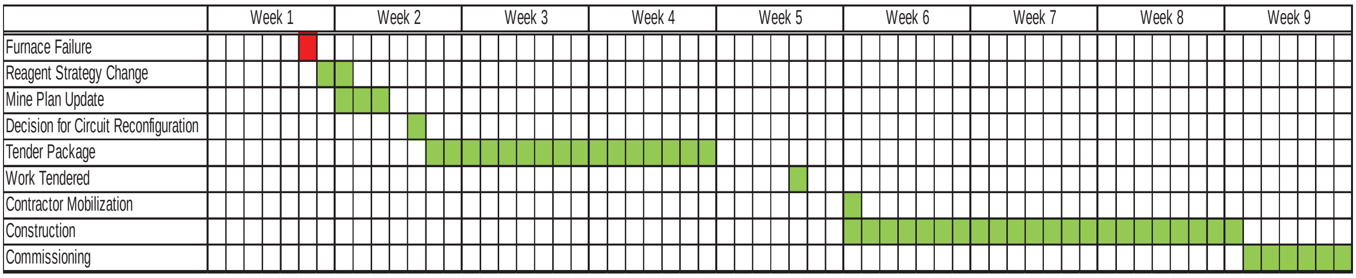

FIG 5 - A Cleaning project timeline.

less entrained rock in Ni concentrate reporting to the smelter, which increases the energy efficiency of the smelting process.

INCREASED COPPER SEPARATION

Clarabelle Mill's execution plan for 2011 included a 50 per cent reduction in the variability in the Ni concentrate quality targets, Cu:Ni ratio, equivalent Ni grade and Po grade, as previously explained by Barrette *et al* (2012). At the same time the feed to the mill Cu:Ni ratio was increasing, which, in turn, was causing higher variability in the daily Cu:Ni ratio. The average feed Cu:Ni ratio increased from 1.1 to 1.5 in the last five years. As the copper removal capacity is bottlenecked by the flotation columns, an increase in feed Cu:Ni ratio at a fixed copper removal resulted in an increase in Cu:Ni ratio in the Ni concentrate. To remain on spec for Cu:Ni ratio in the Ni concentrate, the feed tonnage was reduced. A fundamental requirement for a quality organisation is the ability to manipulate feed metal units (using mill throughput) in order to maintain concentrate quality to the customer. This is shown in Figure 6, taken from Taylor *et al* (2012), where the mill tonnage capacity is plotted for varying Cu:Ni ratios in the feed at several Cu:Ni ratios in Ni concentrate with varying Cu concentrate production capability. An example is that for a Cu:Ni ratio of 1.5 in the feed if the Cu concentrate tonnage constraint is moved from 650 to 800 st/h (590 to 725 mt/h) the potential mill throughput to remain on-spec increases from 21 000 st/d to 26 000 st/d for a Ni concentrate Cu:Ni ratio of 0.5. This represents a significant increase in value generation from the mill for the 2011/2012 mine plan.

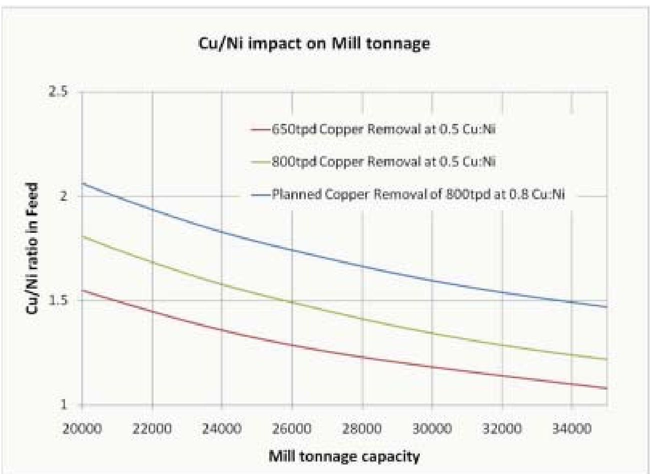

FIG 6 - Mill throughput capability based on feed quality.

Advance planning and engineering

The Cu Separation circuit at Clarabelle Mill was commissioned in 2006. The engineering design for the building, services and equipment allowed for a future expansion of the capacity, if needed. The original design capacity for commissioning in 2006 was 150 000 Mt/a of Cu concentrate or 485 Mt/d. Maximum design capacity with the expansion to four columns was estimated at 370 000 Mt/a. The circuit has successfully operated at up to 590 Mt/d capacity since commissioning. In 2009 and 2010, the Larox filter capacities were expanded by 40 per cent by installing four extra plates to each filter, as per the original design, which would allow for the full design throughput to be filtered. With the expansion of the filters completed the only limitation to throughput was flotation capacity. As the column surface area was the bottleneck the only way to increase production from the circuit was to install more flotation capacity.

In July 2008, an agreement between Xstrata Technology and Clarabelle Mill was reached for the rental of a Z1600 Jameson Cell test rig. The Z1600 is a single downcomer production sized Jameson Cell, which the Mineral Separation Technology group was going to use for research on several plant streams. Although the Z1600 is a semi-mobile unit, it could not be easily moved throughout the plant due to space limitations. Prior to the selection of the optimal Jameson Cell location, a test work was created; flotation capacity in Cu separation was one of the scenarios. The location and detailed engineering design for the installation took into account these factors so that continued test work could be performed with minimal future engineering requirements.

In December 2010, proposals for increasing Cu column capacity were investigated. The review included examining all current project studies completed, and identified several additional options. The options and details on the analysis are summarised by Taylor *et al* (2012). Based on the analysis, it became clear that the conversion of the Jameson Cell was low-risk, low-capital and quick to implement. The total project flow sheet included the addition of the Jameson Cell and the ability to bypass concentrate from the first Cu scavenger cell to Cu concentrate. The proposed modified flow sheet is shown in Figure 7.

Based on the project time line requirements, as well as the production forecast for Q3 2011 and into 2012, the project

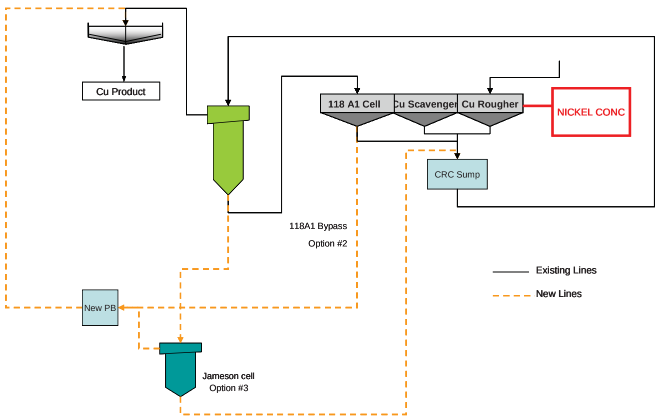

FIG 7 - Increased Cu separation flow sheet.

required rapid movement through the stages for a capital project. Figure 8 shows a high-level Gantt chart of the project time line. The project was 54 in duration from concept to commissioning. The construction phase, which was 18 weeks long, was driven by the delivery time of the control valves and instrumentation required to convert the Jameson Cell from a manually operated test cell to an automated cell.

Process results

The requirement for the removal of Cu from the circuit was changed late in the construction phase by a change in Vale's mine production forecast for 2012. The increased Cu production was no longer part of the 2012 mining plan. This change impacted the commissioning of the increased Cu circuit time line due to a lack of Cu units entering the plant. The lack of Cu units was detrimental to commissioning as the lower Cu units would affect the quality of both the Ni and Cu concentrates.

The Jameson Cell was operated for metallurgical ramp-up at intervals when the Cu head-grade was high enough to run the new process. The current average production rate from the two 3.8 m SGS Minnovex columns is 590 Mt/d; the Z1600 shows a maximum capacity of approximately 112 - 115 Mt/d (based on mass pull surveys). Based on these numbers the columns have a mass pull rate of 1.19 Mt/h/m^2, while the Jameson Cell has been able to pull 2.31 Mt/h/m^2.

Metallurgically the Jameson Cell performed on par with the columns in its ability to make Cu concentrate that was within customer specification. Figure 9 shows that both the Jameson Cell, and the columns, are operating with the same upgrade capability for Cu and rejecting Ni in the same capacity. Figure 10 is a plot of the mass pull of concentrate in Mt/m^2/h, calculated for both the Jameson Cell and the columns. The data from the columns is for 207 operating days from October 2011 through to the beginning of May 2012. The data for the Jameson Cell is based on 13 operating days where surveys were taken for analysis. Roughly 57 per cent of the time the columns operated at or above 1.1 Mt/m^2/h, while the Jameson Cell has operated 83 per cent of the time at or above the 1.1 Mt/m^2/h rate. The Jameson Cell reached a higher maximum mass pull rate than the columns: 2.44 t/m^2/h versus 1.43 Mt/m^2/h respectively.

Lessons learned

The two key learnings that came from rapid implementation of this project include:

1. Several flush points and clean-outs were missed in design of the pipelines. The lack of ability to flush and dump the line resulted in several plugged lines, at a low point and upstream of an isolation valve. More regular field walkthroughs with operations personnel during construction would most likely have identified the appropriate locations based on the field run.
2. The airflow control valve and flowmeter were not of appropriate size or configuration for the naturally aspirated Jameson Cell. The undersized instrumentation was not apparent until the installation of the control valve and flowmeter was complete. This would have been rectified prior to installation if Xstrata Technology had been contacted for input into the instrumentation installed on the Jameson Cell. More input from vendors and the

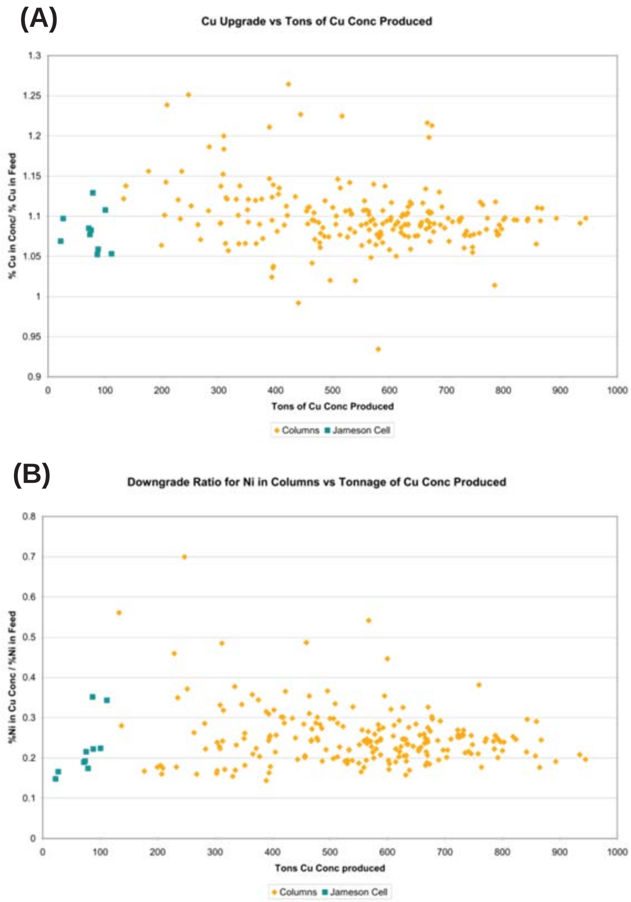

FIG 9 - Operational Cu upgrade and Ni rejection capabilities.

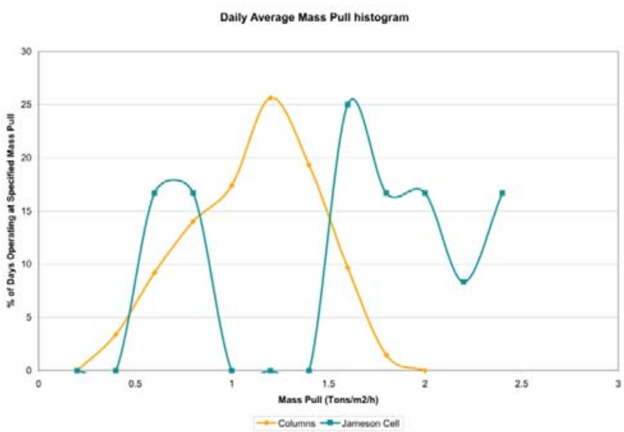

FIG 10 - Mass pull histogram for the columns and Jameson cell.

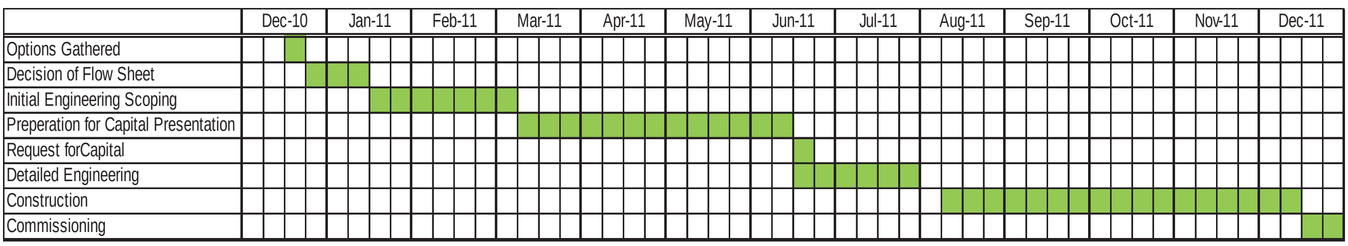

FIG 8 - Timeline for the increased Cu project.

Vale Instrumentation group is required moving forward to ensure that all components installed in new systems are compatible and will function properly within the mill's process network infrastructure.

Successes

The main purpose of the installation was to increase the plant's ability to maintain Ni concentrate grade specifications at maximum tonnage milled when Cu feed grades increased. The circuit has shown its capability to perform that duty, even though its required runtime is low. It will be used as a swing system, as required, being able to be started and shut down with relative ease and with little upset to the overall plant operation. Having the ability to increase Cu separation capacity means that the mill operations can react to fluctuations in the Cu:Ni ratio of the feed in a timely manner and not reduce throughput of the mill to maintain the product quality.

Taking from the lessons learned in the A Cleaning project, during the field run sections of pipe, key spool pieces were not measured for fabrication until the majority of the piping was completed. Although the construction phase was still rapid the implementation of this fabrication phase caused less re-work and construction time on the piping than was required in the A Cleaning project.

ISAMILL™ INTERIM CIRCUIT

In 2007, based on the Ni market, the #8 ball mill was converted from scavenger regrind service to a primary ball mill for increased throughput capacity. In 2010, the #11 regrind ball mill for B Rougher and scavenger concentrates had a catastrophic structural failure, which rendered it unusable. Both of these regrind circuits were in the non-magnetic pyrrhotite rejection circuit. The recovery opportunity, by replacing both regrind mills with an IsaMill™, was reviewed by the plant technical team. A plan to install an IsaMill™ to replace the 2250 kW of regrinding power with a M5000 (1.5 MW) IsaMill™ was presented to management who agreed to roll the work into the CORe project that was in front-end loading engineering Stage 3 (FEL3). As the rest of the CORe project was well underway the inclusion of the IsaMill™ was fast-tracked so that at the completion of FEL3 engineering was aligned.

Opportunity arises

As the IsaMill™ is new technology to Clarabelle Mill and to Vale, it was decided to start the IsaMill™ in an interim circuit. The ability to reinstate regrind capability to the B Cleaner feed was calculated to increase Ni recoveries by ~0.9 per cent by liberating Pn/Po binaries. A further benefit was that plant personnel could gain an understanding of the IsaMill™ operation prior to CORe commissioning. This included the training of operators on optimum mill operation, training mechanics on maintenance and training the instrumentation and electrical departments on the new equipment.

Design modifications

The work required to allow the IsaMill™ to operate in the interim B Rougher service, compared to its final Po regrind service in the CORe flow sheet, included:

- the modification of the last 50 ft of eight-inch discharge piping and two-inch lime addition piping to redirect the IsaMill™ discharge and lime addition to a different pump box than will be used in the CORe flow sheet
- rebuilding the interim circuit pump box and associated pumps
- rebuilding of the cyclone pack associated with the mill earlier than originally planned
- installing pH probes into the B Cleaner cells to control the lime addition flow
- ensuring that all existing piping to be recommissioned was fit for use.

Process results

Low-plant flows resulted in higher levels of recycle to the mill feed and the increased discharge temperature was a concern. By reducing the setpoint on the mill power draw, the discharge temperature was maintained in an acceptable range.

The initial configuration of the cyclones was not appropriate for the low flow rates in the circuit. A new apex and vortex finder combination was calculated and then installed. A control philosophy to reduce pressure variation in the cyclopack was created and implemented.

Overall, the performance of the IsaMill™ met design requirements. The target grind size for the circuit was a P_{80} feeding the B Cleaners of 25 µm, it was estimated that the P_{80} from the IsaMill™ would need to be microns, with a IsaMill™ P_{80} of ~40 µm required to attain this desired feed size. Although there was variation, for the 12 surveys completed, the P_{80} for B Cleaner feed and IsaMill™ discharge were 27 µm and 46 µm respectively (Figure 11).

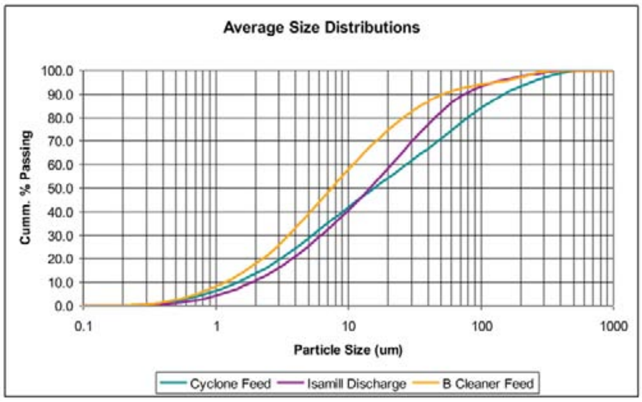

FIG 11 - Interim IsaMill™ circuit size distribution.

Lessons learned

There are two key learnings from this project:

1. The implementation of the Interim IsaMill™ circuit was a request of the CORe project team, by plant operations personnel. This required interaction of plant maintenance with an engineering procurement and construction management project. Planning work in the same area, using the same equipment was complex and at times became a scapegoat for both the project and plant for missed deadlines. Integrating the project team into the plant planning and scheduling system helped to remedy the situation.
2. The Interim IsaMill™ circuit was not part of the original tender package to the construction contractor. Because the Interim IsaMill™ was essentially replacing #11 Mill, some of the existing piping that would eventually be modified needed to remain intact. Unfortunately, some of the piping changes that were made were required for the interim circuit. The changes were caught early enough to be corrected before commissioning. There is another interim circuit that will be implemented; closer discussion with the contractor will be required to ensure that this is not repeated.

Successes

The Interim IsaMill™ circuit was designed and implemented with minimal issues as part of a major capital project. In general the operating and control strategy worked as expected and where it did not changes were implemented in a timely manner to help facilitate the continued commissioning of the IsaMill™.

Table 1 shows the calculated operating work index (Wio), as calculated by Bond's law of comminution. The data used for #11 Mill was from a detailed survey performed in 2004, where size by size analysis was completed. The table shows that although the current feed to the circuit has a finer distribution, the Wio during both commissioning runs was higher than when #11 Mill was operating. During commissioning, the IsaMill™ did not reach the initial calculated Wio of 8.5, which is attributed to the lack of feed to the IsaMill™ causing recirculation of product sized material to the feed.

TABLE 1

Operating work index.

	Average power draw (KW)	Average (t/h)	f_{80}	p_{80}	Wio
#11 Mill (2004 data)	401	75	110	52	12.5
Commissioning run 1	659	62	92	20	9.6
Commissioning run 2	453	78	87	34	10.2

CONCLUSIONS

The A Cleaning project was driven by an emergency with necessary changes required to keep Ni losses to a minimum, while maximising the divisional throughput in a time when the smelter was the bottleneck due to the furnace failure. Process engineering was performed early on, but the project was executed with field engineering and a time and materials contract. There was daily monitoring of progress, hours worked and costs, all of which kept the Vale project management department and the time and materials construction contractor well aligned with the path forward.

Although the conversion of the Jameson Cell from test equipment to operational equipment in the plant was of the same monetary and engineering scale as the A Cleaning project and was also considered a fast tracked project, it still followed the normal path of engineering projects. Having full engineering piping runs, engineering design reviews and passing through management reviews before going for tender, all led to a longer project time line.

The Interim IsaMill™ circuit project was the largest and most complex of the three projects. In this project, plant management took advantage of an opportunity, due to the capital construction time line. The foresight to take advantage of the equipment with minimal economic outlay and physical work allowed the plant to regain recoveries lost due to a lack of regrind capability. Advancing the commissioning of the IsaMill™ outside of the complete flow sheet change allowed for plant personnel to gain an understanding of the IsaMill™ operation. The interaction of a capital construction project with portions of work required by plant personnel caused some complexity. Even with the complexity of the work to be performed, the plant was able to meet its commitments and have work completed in time for commissioning.

ACKNOWLEDGEMENTS

The authors would like to thank the Vale Canada Limited for permission to publish this paper. Moreover, the support and contribution of all personnel at Clarabelle Mill, the Mineral Separation Technology Group, the CORe Project and Vale Base Metals Research and Development should be recognised as instrumental in making these projects successful.

REFERENCES

Barrette, R, Taylor, A, Doucet, J, Shelegey, J, Sullivan, H and Lawson, V, 2012. Applying a customer-based approach at Vale's Clarabelle Mill, in *Proceedings 44th Annual Meeting of the Canadian Mineral Processors*, pp 36-52 (Canadian Institute of Mining, Metallurgy and Petroleum: Westmount).

Bom, A, Taylor, A, Barrette, R and Lawson, V, 2012. Implementation of expert control systems at Vale Inco's Clarabelle Mill, in *Proceedings 47th Conference of Metallurgists*, held in conjunction with *Nickel and Cobalt 2009* (Canadian Institute of Mining, Metallurgy and Petroleum: Westmount).

Hanley, J E, 1957. The Sudbury ores: Their mineralogy and origin, *Canadian Mineralogist*, 6(1):207.

Kerr, A, Barrett, R, Bouchard, A, Labonte, G and Truskoski, J, 2003. The mill redesign project at INCO's Clarabelle Mill, in *Proceedings 35th Annual Meeting of the Canadian Mineral Processors*, pp 29-49 (Canadian Institute of Mining, Metallurgy and Petroleum: Westmount).

Lawson, V and Xu, M, 2011. Float it, clean it, depress it – Consolidating the separation stages at Clarabelle Mill, *in Proceedings MetPlant 2011*, pp 589-601 (The Australasian Institute of Mining and Metallurgy: Melbourne).

Taylor, A, Doucet, J, Blanchette, M, Barrette, R and Lawson, V, 2012. Z1600 Jameson Cell test rig – From rental to revenue, in *Proceedings 44th Annual Meeting of the Canadian Mineral Processors*, pp 13-26 (Canadian Institute of Mining, Metallurgy and Petroleum: Westmount).

Xu, M and Wells, P, 2004. Development of copper/nickel separation at INCO, in *Proceedings 36th Annual Meeting of the Canadian Mineral Processors*, pp 15-28 (Canadian Institute of Mining, Metallurgy and Petroleum: Westmount).