APPLICATION OF THE WOODGROVE STAGED FLOTATION REACTOR (SFR) TECHNOLOGY AT THE NEW AFTON CONCENTRATOR

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ABSTRACT

The New Afton concentrator was commissioned in June 2012, reaching the design milling rate in September 2012. By late 2013, through a campaign of optimization and de-bottlenecking, it was recognized that the installed plant was capable of greatly exceeding the design throughput of 11,700 tpd. Because the value of the metal contained (by increasing the plant feed rate) exceeded the offsetting losses of copper and gold recovery (as the operation moved to a coarser grind), the concentrator feed rate was strategically increased with support of New Gold, while the operations team was given a mandate to evaluate, and then implement, flow sheet options that could re-establish the original design criterion grind target and achieve the corresponding improved recovery. Broadly, the two options implemented were the addition of a tertiary grinding stage consisting of Metso Vertimill® prior to rougher flotation (in order to address the grinding required at increasing throughput by increasing the power), and the addition of three Woodgrove Staged Flotation Reactors (SFR) added to the cleaner circuit after regrind of the rougher concentrate (to address the increased mineral loading to the cleaner circuit). Through test work, it was anticipated that the SFRs would be capable of achieving final concentrate grade in a single pass without the integration of recirculating loads, a strategy sometimes referred to pre-cleaning. This paper describes the expectations generated for the Woodgrove SFR unit operation through pilot plant testing on site, and compares those results with the performance of the expanded circuit that exceeded the original design criterion of P80 160 µm, which was commissioned in the second quarter of 2015.

KEYWORLD

Vertimill®, grinding, gold, copper, recovery, circuit, pilot plantt testing, design

INTRODUCTION

The New Afton concentrator, located near Kamloops, BC Canada, commenced operation in June 2012. The mill achieved the design throughput of 11,000 tonnes per day average during the month of September 2012 and, following various operational optimization efforts (O'Hara et al, 2015), achieved the design p80 grind size of 160 µm at the design milling rate in July 2013.

During August 2013, trials were carried out to determine the throughput rate limits of the mill circuits and to evaluate mill metallurgical performance at higher rates. Milling rates up to 15,500 dmt per 24 hours were achieved during this trial, demonstrating potential capability for sustained milling rates exceeding the nominal design capacity. As was expected, the higher milling rates resulted in a coarsening of the grinding circuit product size, and resulted in marginally lower recoveries in the rougher flotation circuit. Despite the lower recoveries, the higher milling rates resulted in higher metal production and the financial analysis favored running at rates of at least 13,000 tonnes per operating day, with the higher cash flow in the near term offsetting the value of metal production loss at the end of the mine life (due to the short term increase in the rate of reserve depletion). Milling rates were sustained above 13,000 tonnes per day through the second half of 2013, and increased above 14,000 tonnes per day by mid-2014 (Figure 1).

The coarser grind size and lower recoveries at the higher milling rate presented the potential opportunity to install a tertiary grinding circuit in order to return the grind size, and recoveries, back to or better than the design values. To evaluate this opportunity and develop flowsheet options, a conceptual study and pre-feasibility study for a "Mill Expansion Project" were carried out in the second half of 2013.

In parallel with the engineering studies, a pilot plant test program was carried out to evaluate potential opportunities to integrate the Woodgrove Staged Flotation Reactor (SFR) into the Mill Expansion Project design. The concentrate grades produced during the first 12-months of operation only averaged 22.7% copper compared to the 28% copper specified in the project design, which was based on the original mine feasibility study metallurgical test program (Figure 2). While a large proportion of pyrite dilution was rejected by implementing pH control in the existing cleaner circuit in mid-2013, non-sulfide gangue entrainment continued to limit final concentrate grades below 25% copper. Residence time in the cleaner was also identified as a limiting factor, as the mass loading increased due to higher throughput at similar grades.

The conceptual design study flowsheet for the mill expansion project included a significantly expanded cleaner flotation circuit using numerous additional conventional flotation cells to handle increase mill throughputs and improve concentrate grades. The functional attributes of the Woodgrove SFR cells indicated that they could improve final concentrate grades and circuit capacity, with a much lower capital and operational cost than conventional tank cells. The key opportunity of the SFR cells was the lower footprint area, which could avoid the need to add a second mill expansion building needed to house additional conventional cells. The test program and analysis which ultimately led to the installation of Woodgrove SFRs in the Mill Expansion Project are detailed in the subsequent sections of this paper.

In Q1 2014, following the completion of the SFR pilot plant test programs and the Mill Expansion Project feasibility study, approval was received to proceed with the project. The project scope included the installation of a Metso VTM-3000 Vertimill® for the tertiary grinding circuit and installation of three SFR cells to improve cleaner circuit capacity and performance. The SFR cells were installed between the existing concentrate regrind circuit and first-cleaner flotation circuit. In that configuration, concentrate from the SFR cells is pumped directly to the final concentrate thickener (Figure 3) as pilot testing had indicated that could be achieved. All of the new equipment was installed in a single building annexed onto the side of the existing concentrator building.

Detailed engineering commenced in March 2014, and construction commenced on site in June 2014. Circuit commissioning took place through April 2015, with the tertiary grinding circuit and Woodgrove SFRs circuit operational by April 17 and May 1, 2015, respectively.

During the first five months following the start-up of the Mill Expansion Project, the average copper and gold recoveries increased 4.5% and 3% respectively, compared to the first three months of 2015. Concentrate copper grade increased 3.5% during the same period, while the average milling rate was marginally higher (+0.5%).

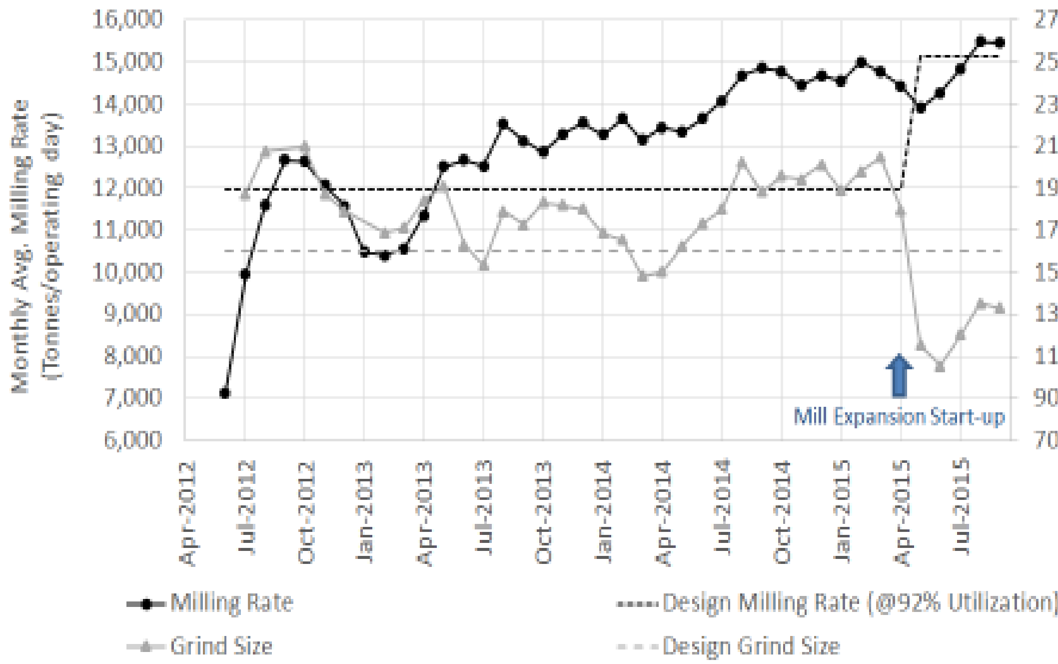

Figure 1 - Milling Rate and Grinding Circuit Product Size (p80, µm)

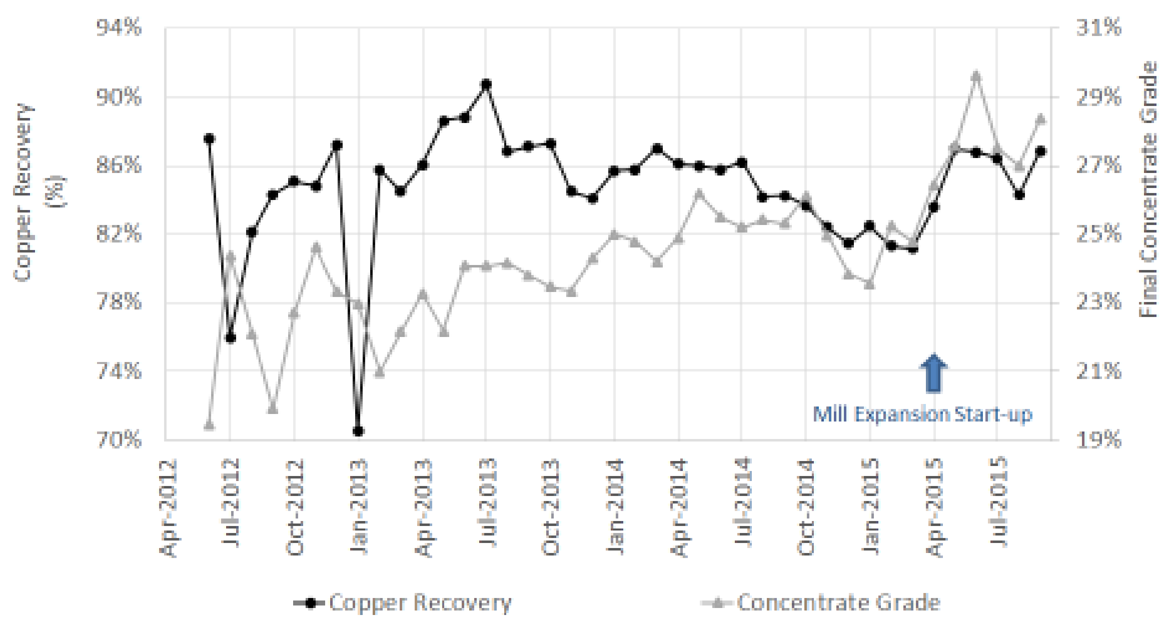

Figure 2 - Copper Recovery and Copper Concentrate Grade

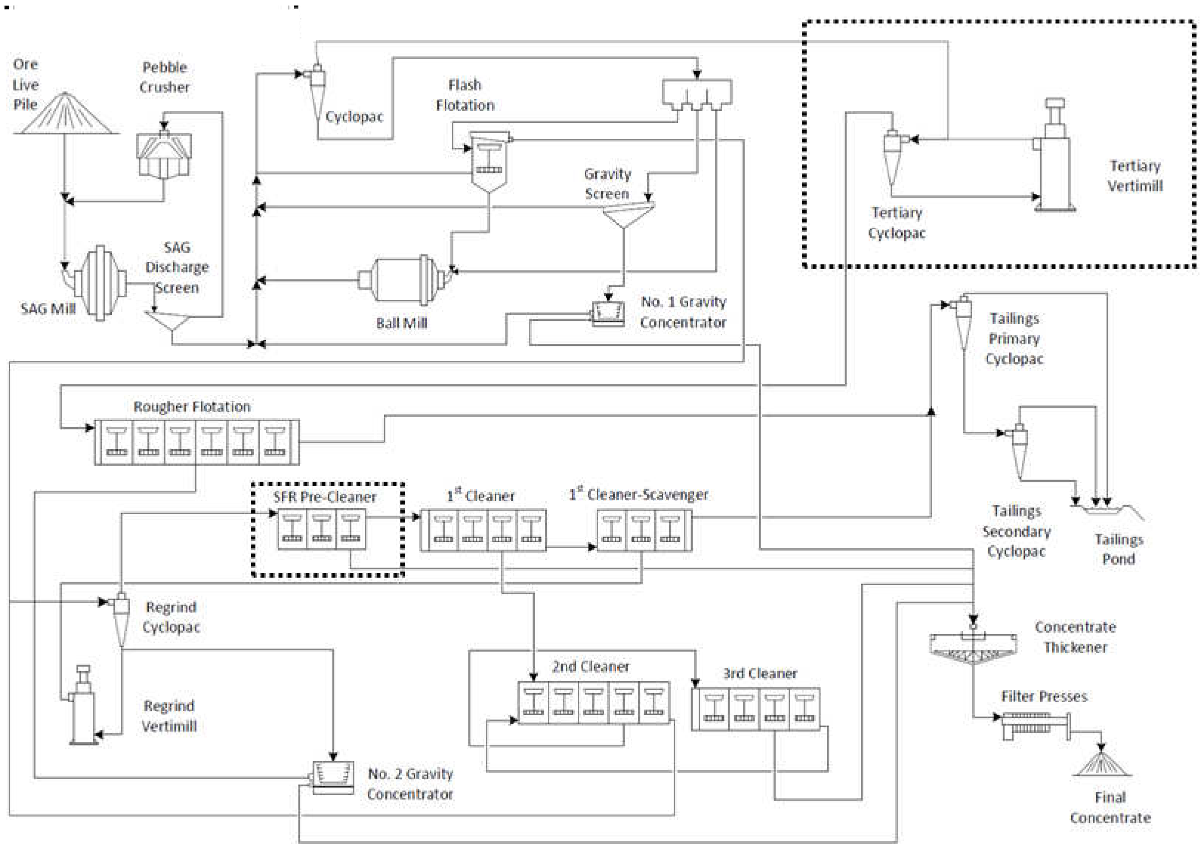

Figure 3 - New Afton Concentrator Flowsheet, with Mill Expansion Project tertiary grinding and SFR Pre-cleaner circuits highlighted

SFR Pilot Plant Testing

To evaluate the potential application of the SFR technology for use in the New Afton mill, a "semi-continuous" SFR pilot plant was brought to site to carry out test campaigns. Three SFR pilot campaigns were conducted on New Afton regrind cyclone overflow between October 2013 and March 2014. The pilot plant consisted of a single SFR cell operated at 18 to 20 liters/minute throughput rate, and two 100-liter feed/tails tanks. Samples of the regrind cyclone overflow were collected in the pilot plant feed tank and then continuously processed through the SFR, thereby simulating a copper pre-cleaner circuit. The SFR tailings were collected, then re-processed though the SFR up to four times, to replicate up to four SFRs operating in series.

The primary metallurgical target set for the test program was to demonstrate that a 29% copper concentrate grade could be achieved at a minimum 45% recovery. Ultimately, this would determine if a second building extension could be avoided by adding SFR pre-cleaners to the New Afton cleaner circuit. If the metallurgy supported this option, the smaller footprint of the SFR made it possible to locate three units within the committed footprint for the tertiary grinding mill building extension.

Figure 4 describes the overall pilot SFR grade/recovery relationship produced from the pilot plant data (SFR-PP). Superimposed on this graph is the SFR pre-cleaner concentrate target (29% copper), and the grade/recovery relationship of the existing first, second, and third cleaner circuits (C1, C2, C3) for three surveys (A, B, C) carried out in October and March while the SFR pilot program was conducted.

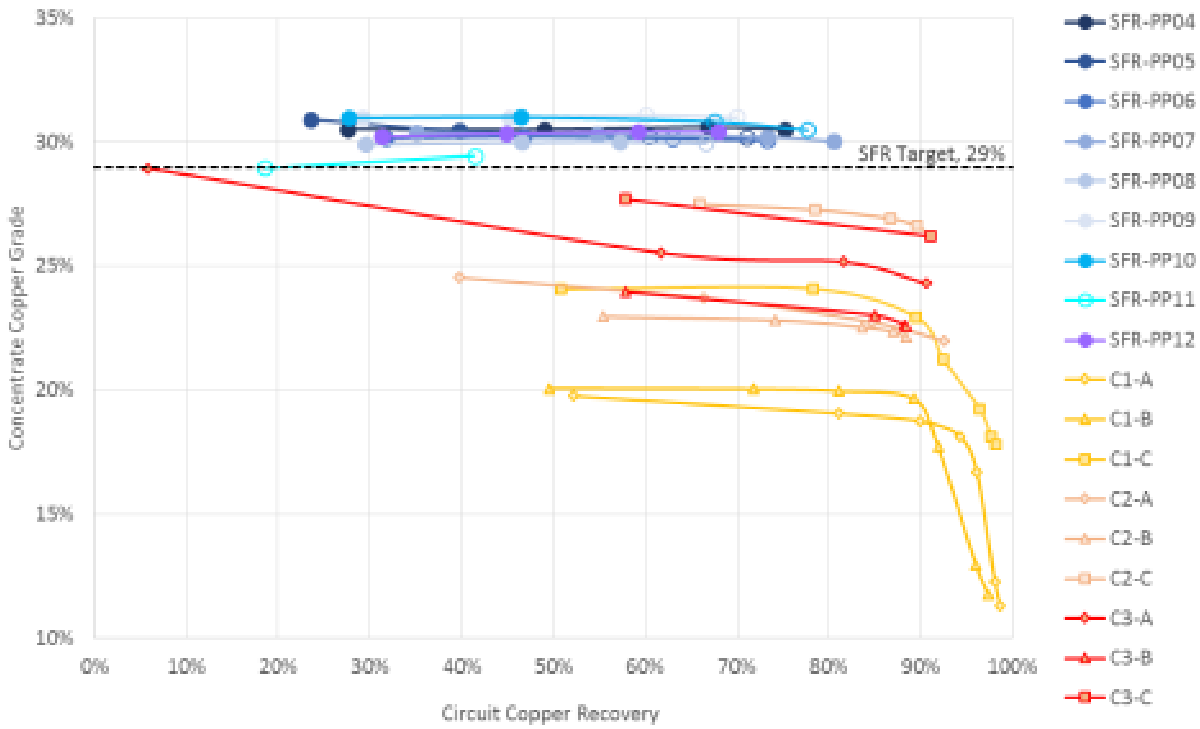

Figure 4 - Copper Grade/Recovery correlations for the SFR pilot plant (SFR-PP), and the existing mill Cleaner stages

While originally an updated cleaner circuit consisting of 2 SFR's was planned during prior concept work, process design studies using the pilot data confirmed that three SFR's operating above the final concentrate grade target and producing at least 60% of the final concentrate copper would add significantly more cleaner circuit capacity than was required to handle expected near term increases in mill feed rate. The SFR concentrate target was set 3% higher than the final concentrate grade target because it would see the fastest floating material. The existing copper conventional cleaners would treat a lower grade and somewhat slower floating feed coming from the SFR tailings and could thus make a lower concentrate grade that, when blended with the SFR concentrate, was calculated to meet the grade target.

The grade/recovery relationship for the SFR pilot plant delineated in Figure 4 is not a curve; rather it is a linear correlation that extends surprisingly far along the copper recovery axis and predicts concentrate grades in the 30% range at up to 75% overall recovery by the fourth stage, and perhaps beyond 80% recovery for additional stages. In the end, three SFR's were chosen for two reasons:

1. This was the practical maximum that would fit into available floor space in the mill expansion building design (without a major increase building size and cost)
2. Three SFR's could be expected to reliably operate well above the pre-cleaner circuit three-stage recovery and grade targets demonstrated.

To further clarify point 2, the final process design studies suggested that the SFR pre-cleaners had to produce approximately 60% of the overall final concentrate copper mass. This is very different than the recovery required by the SFR circuit unit operation because the regrind cyclone overflow included second cleaner tailings and cleaner scavenger concentrate. Thus these circulating loads add copper mass to the incoming untreated rougher concentrate such that the SFR pre-cleaner actually only requires a 45% circuit recovery to generate 60% of the final concentrate copper mass. As illustrated from Figure 4, this circuit recovery is well within the capability of three SFR's.

While preliminary pilot tests were carried out without froth under wash water, the concentrate froth contained considerable entrained gangue, resulting in concentrate grades similar to that that typically observed on the first cell of the existing third cleaners (~26-28%). Further investigation by laboratory tests performed in a Denver float cell with very high water dilution indicated concentrate grades exceeding 28% should be attainable.

Subsequently pilot tests were primarily carried out with froth under-wash water added to the cell, in volumes ranging from 5 to 15% of the feed rate. The results of these tests (Figure 4) found that the SFR was able to consistently produce concentrate grades above 30% copper; recoveries ranged from 35% to 60% with two SFR stages, and from 60% to 80% with four SFR stages.

Woodgrove SFR Design

The following sections describe the systematic and reproducible method used by Woodgrove for designing flotation circuits, including the New Afton SFR pre-cleaner circuit. Table 1 lists the definitions for terminology and abbreviations for the components the SFR.

Table 1 - SFR Definitions

SFR	Staged Flotation Reactor
PCU	Particle Collection Unit; the agitated (smaller) tank where new bubble surface is continually generated and collection takes place.
BDU	Bubble Disengagement Unit; the bottom of the second, usually larger, and un-agitated tank. The BDU accepts aerated feed from the PCU and facilitates separation of gas bubbles from tailings slurry.
FRU	Froth Recovery Unit; sits on top of the BDU and is the location where a stable froth is formed. Froth under-washing is possible with all SFR's (roughers included).
Collection Zone	The volume required for turbulent mixing
Quiescent Zone	A stable, relatively non-turbulent zone created to allow bubble disengagement from the (tails) slurry.

The Woodgrove approach to flotation

Context to the following discussion on the SFR design is provided by first describing Woodgrove's approach to flotation as embodied by the SFR and how it differs from conventional mechanically agitated cells.

Woodgrove views mineral flotation as comprising three basic phenomena:

1. Particle collection
2. Bubble/slurry disengagement
3. Froth recovery

Conventional mechanical flotation cells employ a single tank with the agitator mounted in the centre–making it impossible to sequence these three flotation steps. In that case, aggressive agitation takes place side-by-side with tailings slurry de-aeration (deemed bubble/slurry disengagement in this paper) and froth recovery. It is important to note that of the three phenomena listed above: two require some form of a quiescent zone to function properly, while particle collection relies on turbulent mixing. To establish these two divergent conditions in the same tank prevents the single tank geometry from being optimized for each process, which in turn often contributes to lower stage recoveries and concentrate grades.

Early in the SFR concept phase, a substantially reduced flotation footprint was predicted if the agitator was relocated to a dedicated turbulent tank, leaving behind a quiescent tank for bubble/slurry disengagement and froth recovery. Footprint reduction would come in the form of fewer flotation stages due to improved froth (and hence, stage recoveries) and a smaller per-stage footprint. The former is a direct result of improved froth recovery on the back-end flotation cells where froth surface area can be tailored to maintain high solids flux (and control the resulting bubble loading).

Reduced per-stage footprint comes from a combination of a small quiescent zone and use of floor space within the curved area between tanks (typically unused and wasted space). In conventional mechanical cells, there is no tank wall separating the collection zone from the quiescent zone, so strong currents from the former can bleed into the latter. To compensate, the conventional cell quiescent zone needs to be larger so residual collection turbulence is sufficiently mitigated to ensure full deaeration of the tailings slurry.

By sequestering the agitator in a small tank designed for purpose (the PCU), no collection turbulence carryover to the quiescent zone occurs. Thus, in the SFR, the only remaining factor affecting the quiescent zone size is the downward velocity of deaerated slurry heading towards the tailings port. In the SFR, this velocity is maximized to minimize the BDU footprint. Further savings in floor space is achieved by tucking the smaller PCU into the curved dead space between successive BDU's (see Figure 5).

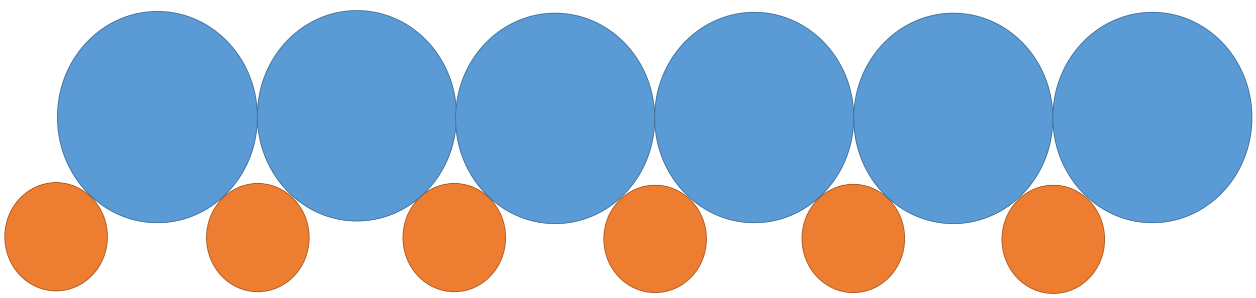

Figure 5 - Typical SFR layout (PCU in orange, BDU in blue)

SFR design criteria

Separating turbulent collection from bubble/slurry disengagement and froth recovery frees the process design team to tailor tank geometries and dimensions for the specific duty of each zone (collection, bubble/slurry disengagement, or froth recovery). In this section, we will describe the general process design approach used to size each SFR unit.

The PCU (multiple patents pending) is designed for one purpose only: to promote rapid and complete collection of valuable minerals. Design criteria include:

- Adequate slurry retention time for the probabilistic collection process to be sufficiently complete before advancing to the BDU
- Minimization of footprint by ensuring effective collection turbulence in cross section (i.e. no quiescent zone between the impeller tip and the PCU tank wall)
- Impeller designed for multiple slurry passes through the clearance between the impeller and the stators
- Minimum specific energy input to the slurry
- Impeller design and tip speed target

All of the above are based on pilot or laboratory testing supported by Woodgrove database information.

The BDU comprises the lower section of the quiescent tank. As the name suggests, the function of the BDU is to expedite the separation of gas bubbles away from tailings slurry after the aerated feed arrives from the PCU. Process design criteria here is to keep an even and gentle distribution of aerated slurry from the Particle Collection Unit.

Atop the BDU rests the Froth Recovery Unit (FRU) which is designed considering the following factors:

- Solids flux, expressed as tonnes of solids per square metre per hour (average and expected range)
- Maximum froth travel distance
- Lip length

Since there is no agitating mechanism, there is no external constraint on how small the FRU can be made. Conventional mechanical cells must support the motor, speed reduction system, and bearing housing above the cell while leaving enough open room at the top to allow for the impeller and stator to be removed via the overhead crane for maintenance. This limits the amount of crowding that can be done in the froth zone such that the back end stage recoveries for rougher or scavenger circuits are often low as a direct result of too much open area.

The FRU open area is sized for the anticipated concentrate solids mass flow such that solids flux values are acceptable, bubbles are well loaded and stable, and froth residence times are low. SFR stage recoveries at the back end of rougher and scavenger circuits are consequently much higher than their conventional counterparts and it is often possible to reduce the number of cells in a row by one or two, further reducing flotation circuit footprint.

In summary, footprint reductions in the order of 40% to 50% are therefore possible by:

1. Separating the turbulent collection process from the two quiescent processes (bubble/slurry disengagement and froth recovery), thereby ensuring the smallest quiescent zone possible and allowing each SFR unit to be sized specifically for its duty.
2. Minimizing BDU footprint.
3. Placing a portion of the PCU in the dead space between consecutive BDU's.
4. Reducing the number of cells in a row by increasing back end stage recoveries.

In addition, energy reductions in the order of 50% can be expected.

Application of Pilot Data in SFR Design

As with other SFR installations, the primary source of design information for the New Afton SFR pre-cleaners came from pilot programs conducted at site. Once analyzed, the collected data falls into two categories:

1. Data employed to generate an SFR-specific mass balance (grade/recovery performance, number of stages, selectivity, froth washing, % solids, flows, etc.). In addition to encapsulating direct piloting experience, this balance reflects the process design criteria supplied by the client.
2. Data used in combination with the mass balance for deriving cell geometries, sizes, and power (superficial gas rate, specific energy, specific power, agitator tip speed, Reynolds number, apparent viscosity, Kolmogorov micro turbulence, energy dissipation rate, etc.)

SFR Circuit Start-up and Operational Results

The SFR circuit started operation on May 1, 2015, two weeks after the start of the tertiary grinding circuit; the effect of the circuit start-up on concentrate grade is illustrated in Figure 6. The start-up of the tertiary circuit resulted in an immediate ~2% improvement in concentrate grade due to the increased liberation in the grinding circuit, and the resulting higher rougher concentrate grades and lower mass pull feeding the cleaner circuit.

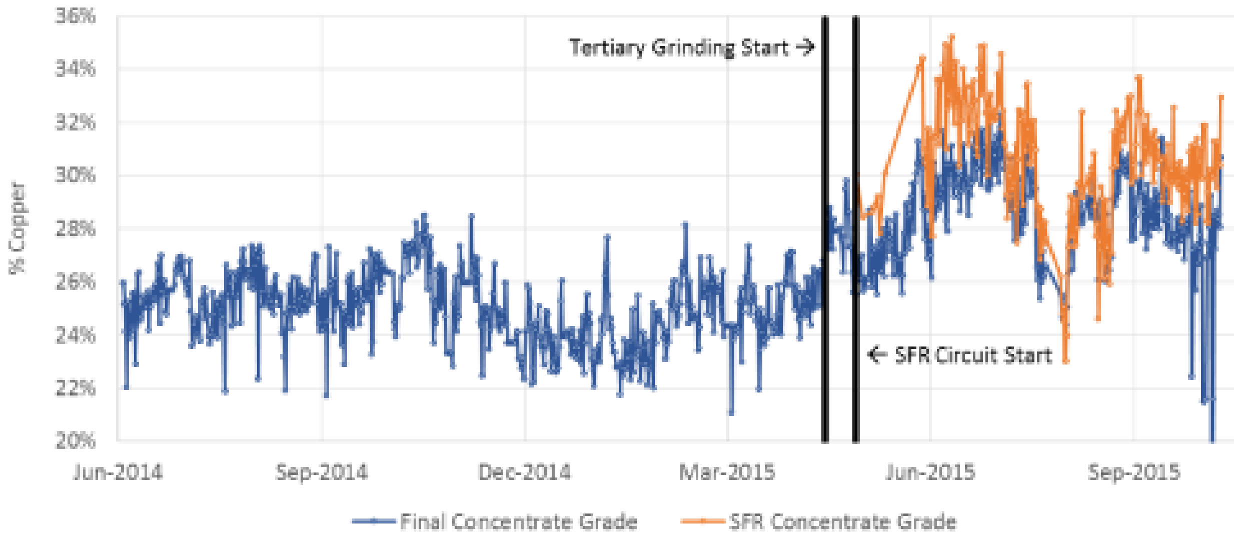

Figure 6 - Final Concentrate and SFR Concentrate Copper Grades

Upon starting the SFR circuit, the SFR cells produced a concentrate grade of around 29% copper; however, the overall final concentrate grade initially dropped by ~2%. The culprit was identified as excessive mass pull produced by the first SFR cell and the original cleaner circuit tank cells, resulting in excessive gangue entrainment and collection of low grade particles. Following changes to SFR make up-water from process water to fresh water, and adjusting the operating parameters in the original cleaner circuit to reduce mass pull, SFR concentrate grades exceeding 30% were consistently attained, and final concentrate grades over 29% were achieved. Over the month of June, the average SFR concentrate grade was 32.5% and the final concentrate grade was 29.6%.

The SFR circuit unit recovery during the first month of operation generally ranged between 50 and 70% (Figure 7); noting the proportion of total final concentrate produced from the SFRs is generally 5-10% higher than the unit recovery, due the re-circulating loads from the 2nd cleaner, 3rd cleaners and 1st cleaner scavengers. Operation of the cleaner and SFR circuit was impacted in late June and July due to modifications to the regrind cyclones, and scheduled and breakdown maintenance on the regrind Vertimill® causing high variability in the concentrate size distribution and resulting in variability in the recovery that was subsequently addressed in September.

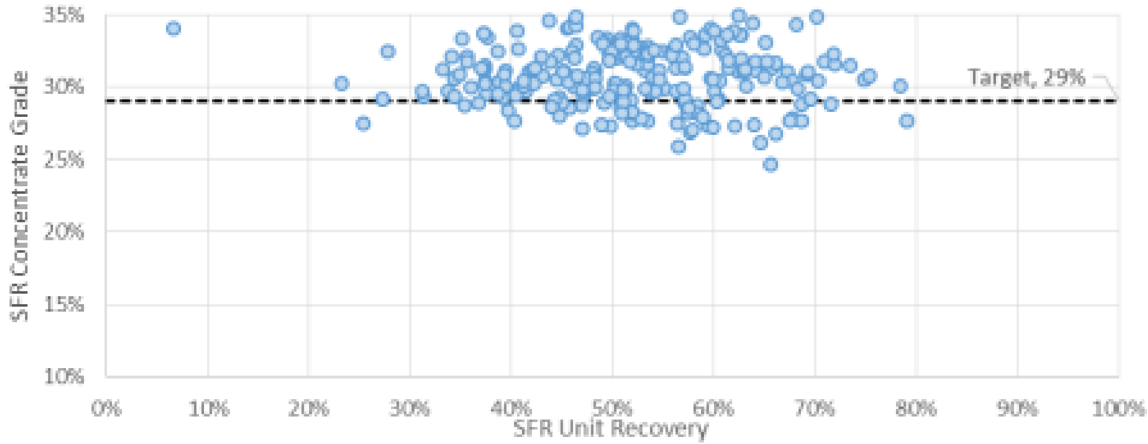

Figure 5 - SFR Circuit Grade/Recovery correlation; May 1 to Oct 9 mill actuals, excluding regrind mill downtime period in July/August

One of the key operational benefits of the SFRs in the New Afton circuit is the consistent mobility of froth through the FRU into the concentrate collection launders. The 1st cleaner tank cells were frequently hindered by poor froth mobility, which leads to either poor recoveries, or excessive pulping and circuit run-aways in an effort to get the froth flowing. This typically occurred around once per week, and more frequently with new operators. Froth on the SFRs has not been observed to have static areas; froth generally flows consistently across the entire open area at the top of the FRU regardless of operator skill.

Summary and Conclusions

The unique design of the Woodgrove SFRs results in a smaller foot-print to conventional tanks cells or other flotation technology. As well, the capability to produce high grade concentrates in a single circuit without recirculating loads was of particular benefit for simultaneously increasing capacity and concentrate grade in the New Afton concentrator. These features, combined with the results of the SFR pilot plant test program led to the decision to install three SFRs as part of the Mill Expansion Project.

The installation of the Woodgrove SFRs has proven to be a successful application of this relatively new flotation technology. The SFRs matched the performance of the pilot plant results and met the design target of 29% concentrate and 45% recovery within the first few days of operation. Following a few weeks of tuning the SFRs and the original cleaner cells, the new circuit ultimately contributed to a net increase of mill final concentrate grade of 3.5% copper.