Start-up, commissioning and optimization of the gravity circuit at Atlantic Gold’s Moose River Project in Eastern Canada

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ABSTRACT
A discussion of the design, challenges and successes associated with the commissioning of the gravity recovery circuit at Canada’s newest open pit gold mine - Atlantic Gold’s Moose River Consolidated Project in Nova Scotia in Canada is presented.

An overview of the project, its historical significance and overall flowsheet is provided with special focus given to the design and selection of the gravity circuit equipment including the scalping screen, gravity concentrators and the novel intensive leaching technology selected for the project.

The performance of the gravity circuit is benchmarked against the feasibility study process design specifications and the outcomes are discussed. Challenges encountered during commissioning are also presented, including the use of third-party automation design and the effects of screen sizing on overall gravity circuit performance. Mechanical modifications made to the Sepro Leach Reactor (SLR) for the Moose River project are also discussed.

A detailed technical review of the mechanical and operational aspects of the Sepro Leach Reactor is provided with key operational data on leach times, recoveries, reagent usage, solid liquid separation, pregnant solution quality and its influence on bullion purity.

INTRODUCTION
Atlantic Gold Corporation’s Moose River Touquoy Mill in Nova Scotia, Canada was commissioned in the fourth quarter of 2017 with commercial production declared in March of 2018. The 2 Mtpa process plant uses a conventional, gravity-CIL process.

This site was previously mined in the 1870s. Interest waned in the early 1900s but resumed in the 1930s and the mine was brought back into production in 1935 until an underground mine collapse in 1936. This mining district became famous after CRBC radio commenced a ground breaking, around the clock, broadcast of the rescue operations. Over 100 million people listened to the broadcast from Canada, the United States and the United Kingdom. These broadcasts changed radio, transforming it from a medium for music to on the spot, breaking news reporting.

The mill was designed and constructed by Ausenco in the historic Moose River gold mining district, 95 km north-east of Halifax by road. The mill will process ore from the adjacent Touquoy pit for the first 5+ years of operation; after the Touquoy reserves are exhausted, the mill will process ore from the Beaver Dam deposit for an additional 5 years.

Currently, plans are in place to construct two satellite process plants at the neighbouring Fifteen Mile Stream and Cochrane Hill deposits to produce gravity and flotation concentrates to be trucked for final leaching and refining at the Moose River processing facility.

The Moose River process plant was designed with a nameplate capacity of 2 Mtpa or 250 t/h based on 91% availability. As of Q2 2018, the mill throughput has been increased, surpassing 300 t/h and exceeding 2.2 Mtpa over the first 12 months of commercial production.
Process Description

Crushing Circuit
The modular three stage crushing circuit consists of a primary jaw crusher and secondary and tertiary cone crushers producing a -14 mm ball mill feed. The circuit was designed to process approximately 400 t/h at 60% availability in order meet the designed mill throughput.

Grinding Circuit
The -14 mm mill feed is processed through one single pinion, 5.0 m x 8.1 m, 3.5 MW ball mill in a closed circuit with hydrocyclones producing a leach feed with design P_{80} = 150 µm. Unique to the Moose River mill is the absence of a pre-leach thickener. The cyclone overflow reports directly to the leach circuit; therefore, the cyclones must control grind size and % solids density. This creates added complexity to milling and gravity circuit optimization.

Gravity Circuit
A portion of the cyclone underflow is fed to the gravity circuit. The fully automated gravity circuit consists of one 1.5 x 3.6 m vibrating scalping screen, two Falcon SB1350B concentrators and one SLR3000 intensive leach reactor. Pregnant solution from the leach reactor is transported to a dedicated electrowinning circuit in the gold room.

Leach Circuit
The leach feed / cyclone overflow is fed to a 1.5 x 3.6 m vibrating trash screen with the underflow reporting to the leach feed box where it is conditioned with lime before flowing by gravity into the leach tank where cyanide is added. The leach circuit consists of one leach tank and six adsorption tanks each with a live volume of 1300 m³. Retention time is approximately 20 hours, with most of the leaching completed by leach tank #5. Currently, the leach tank cyanide concentration is 60-65 ppm with 40-45 ppm free cyanide remaining in the last leach tank. The low cyanide consumption (0.17 kg/t) is due to the clean ore, free of cyanide consuming metals.
**Elution Circuit**

The elution circuit is a COMO™ packaged pressure Zadra™ circuit. It includes a 6 tonne HCl acid wash column and a 6 tonne elution column. The elution circuit operates at 1.5-2% NaOH and 500 ppm cyanide. The operating temperature is 140-145 °C with average efficiencies ranging from 96-99%.

**Detox & Tailings Circuit**

The detox circuit consists of two 375 m³ tanks in series employing the INCO SO₂/Air process. For reagent addition there are two options: copper sulphate added to the first tank and sodium metabisulfite (SMBS) which can be added to the first and second tanks. With the low cyanide concentrations, the detox circuit only operates with SMBS addition to the first tank. The detox circuit targets, and achieves, less than 1.00 ppm CN WAD in the tailings discharge.

The tailings management facility consists of a conventional rock dam, decant tower to return process water to the mill and an effluent treatment plant (ETP). The ETP is designed to treat effluent water for arsenic and other heavy metals and collect them in Geobags prior to water discharge in a polishing pond followed by an engineered wetland.

**GRAVITY CIRCUIT OVERVIEW**

The gravity circuit is fed cyclone underflow and was designed to process 300 t/h or 33.3% of the circulating load. The gravity circuit split of the cyclone underflow flows by gravity to the 1.5 x 3.6 m vibratory scalping screen with the oversize being recombined with the remaining cyclone underflow.

Two knife gate valves on the screen underpan control the flow to the parallel Falcon SB1350B concentrators. Dilution water is added to the screen feed to improve screening efficiency and regulate the concentrator feed density. The concentrator tailings are recombined with the remaining cyclone underflow and are returned to the ball mill. The concentrates from the Falcon concentrators are discharged approximately once per hour and flow by gravity to the concentrate storage cone of the intensive leach reactor for periodic transfer to the reactor vessel.

**Sepro Leach Reactor Process Description**

The Sepro Leach Reactor (SLR) is a batch, intensive leach reactor specifically designed to rapidly leach high-grade gravity concentrates with high concentration cyanide solution. The SLR uses an agitated leach vessel for increased leach kinetics and Sepro’s patented filtration system to produce clear pregnant solution for direct electrowinning. A brief overview of the mechanical and operating principals of the Sepro Leach Reactor is provided in the following process description.
Concentrate Transfer (0.5 hours)
Gravity concentrate, periodically discharged from the Falcon concentrators, is collected in the concentrate storage cone and allowed to settle. Five minutes prior to each Falcon concentrate dump, a decant valve at the top of the storage cone opens. This decant step allows excess water to be discharged and creates enough freeboard within the cone to accept the next concentrate dump without risk of losing gold to the overflow. In the case of process disruptions or other situations that lead to a high proportion of slime within the concentrate cone, an optional de-slime step can be implemented to remove the slimes by elutriation.

Weight sensors on the concentrate cone track the solids content until a full batch of concentrate is collected. Once the cone is full, the concentrate is transferred by peristaltic pump into the leach reactor. Using weight sensors to track concentrate production provides more accurate data than the batch counting methods employed by other technologies.

The bottom of the cone is isolated with a knife gate valve. Prior to the knife gate valve opening high-pressure water is injected at the base of the cone to fluidize the coarse, dense gravity concentrate. If the cone discharge rate slows down or plugs during the concentrate transfer, the PLC will initiate a back flush sequence by closing the knife gate and agitating the concentrate with more fluidization water before resuming the transfer. When the weight sensors indicate the cone is empty, the transfer is complete and the cone resumes collecting concentrate.

Reagent Addition (0.75 hours)
Upon completion of the concentrate transfer, the leach reactor is topped up with process water or barren leach solution to submerge both impellers on the leach tank agitator. The agitator starts before sodium hydroxide is added to the reactor to raise the pH to safe levels and ensure sufficient conductivity for the subsequent electrowinning stages. When the pH is greater than 11.5 the control room operator is prompted to confirm cyanide addition. Upon confirmation, cyanide is added into the mix tank to commence the leach. Hydrogen cyanide (HCN) gas levels are
monitored by a static HCN sensor on the top of the leach tank, a strobe and siren alert operators and the control room if the levels become unsafe.

**Leach Cycle (13 hours)**
During the leach cycle, the pH of the slurry is monitored continuously and sodium hydroxide is automatically added to maintain safe pH levels. The dissolved oxygen (DO) content is monitored with a DO probe and hydrogen peroxide is added, as needed, to maintain a dissolved oxygen concentration between 16-20 mg/L.

**Solution Transfer (3 hours (4 x 0.75))**
Shortly before the leach timer expires, flocculant is added to the reactor. After one minute of mixing, the agitator gradually comes to a stop over two minutes. This gradual ramp down creates a stratified bed with the coarsest particles at the bottom and the finest, impermeable “slimes” at the top.

After allowing the concentrate bed to settle for five minutes the vertical well points are “flushed” by pumping pregnant solution through them and back into the top of the reactor for one minute. Next, the well point valves are closed and the tank bottom screens are opened; solution is recirculated from the tank bottom screens to the top of the tank for four minutes until the solution becomes clear. The well points act as a “shortcut” for the solution to bypass the impermeable slimes layer. As the bottom of the well points are closed, the solution is drawn from the well points on the peripheries of the tank through the “sand filter” created by the stratified bed and through the screens at the base of the tank. An illustration of this novel drainage and filtration process is presented in Figure 3.

![FIG 3 – Sepro Leach Reactor drainage process](image)

After four minutes of recirculating, when the solution is clear, the recirculation valve is closed, the valve to the pregnant solution tank is opened and pregnant solution is transferred to the gold room. When the reactor level sensor reaches the drain level setpoint, the reactor is refilled with process water and the agitator is started. After five minutes of mixing, the same agitator ramp down and recirculation procedure is repeated before the solution from the first rinse is transferred to the pregnant solution tank in the gold room. Once the pregnant solution tank is full, the remaining rinse solution is discharged to the CIL circuit.
A second and third rinse is performed, in order to achieve acceptably low cyanide discharge levels using a similar procedure. As the remaining solution is being discharged to the leach circuit where residual gold is recovered, clear solution is not required and the remaining solution is drained with both the tank bottom screens and well points open.

**Tailings Discharge (0.75 hours)**

After the third rinse, the residual cyanide levels are safe to return to the grinding circuit and the reactor is filled with process water and agitated. After five minutes, the tailings transfer pump starts and the tank bottom valve is opened to discharge the leach residue back to the ball mill discharge sump. The reactor level is maintained for 30 minutes by periodic addition of process water to ensure complete discharging of the leach tailings. Upon completion of the tailings discharge, the reactor is ready to receive the next batch of concentrate.

<table>
<thead>
<tr>
<th>Step</th>
<th>Time (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentrate Transfer</td>
<td>0.5</td>
</tr>
<tr>
<td>Reagent Addition</td>
<td>0.8</td>
</tr>
<tr>
<td>Leaching</td>
<td>13.0</td>
</tr>
<tr>
<td>Solution Transfer</td>
<td>3.0</td>
</tr>
<tr>
<td>Tailings Transfer</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>18.0</strong></td>
</tr>
</tbody>
</table>

**TABLE 1 – Sepro Leach Reactor cycle timeline**

**GRAVITY CIRCUIT PERFORMANCE**

The Moose River ore is uniquely characterized by its high gravity-recovery-gold (GRG) content despite its relatively low grade. Gravity-recoverable-gold testing during the feasibility stage of the project indicated that the Moose River ore has GRG values ranging from 50-70% depending on sample head grade.

This high GRG content was recognized early in the planning stages and the feasibility study included a total of 33 gravity tests on various composites with an average recovery of 61.0%. The bulk of the metallurgical test work was conducted on the TAM master composite, which had an average gravity recovery of 60.9%. A metallurgical test program to evaluate the benefits of a gravity circuit concluded that a gravity circuit would yield a 78% decrease in residue grade (0.113 g/t to 0.025 g/t Au) and a 30% decrease in cyanide consumption (Lycopodium, 2006).

**Feasibility**

The GRG value is said to be the theoretical maximum recovery by gravity that can be approached but never achieved. Typically, these laboratory values are de-rated to 30-80% of the GRG value when modelling expected plant recoveries. Aside from the GRG value, the GRG size distribution, cyclone efficiency and percentage of circulating load to be treated are the most important factors in estimating actual plant recoveries. Based on the feasibility gravity results (Scott et al., 2015), the design throughput and the expected gravity circuit flowsheet; a detailed model of the gravity circuit was produced. The inputs and outputs of the gravity circuit model based on the feasibility study is presented in Table 2.
<table>
<thead>
<tr>
<th>Inputs</th>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh Feed (t/h)</td>
<td>Recovery (%)</td>
</tr>
<tr>
<td>Circulating Load (%)</td>
<td>Recovery (% GRG)</td>
</tr>
<tr>
<td>Head Grade (g/t)</td>
<td>Recovery (g/hr)</td>
</tr>
<tr>
<td>CUF to Gravity (%)</td>
<td>Con. Grade (g/t)</td>
</tr>
<tr>
<td>GRG (%)</td>
<td></td>
</tr>
<tr>
<td>Stage Recovery (%)</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 2 – Gravity circuit modelling based on feasibility parameters

The modelling exercise predicted that 52.6% of the gold would report to the gravity concentrate with a grade of approximately 1600 g/t Au. Given the expected life of mine (LOM) recovery of 94.2%, this equates to approximately 4,000 ounces per month and 55.8% of total gold production.

**Gravity Circuit Audit**

In late January 2018, after four months of commissioning, a gravity circuit audit was conducted in order to benchmark circuit performance and identify potential areas for improvement. Samples of the mill feed, cyclone overflow, cyclone underflow/Falcon feed and Falcon tailings were collected over the course of a 12-hour day shift.

A three stage GRG test, conducted on the mill feed sample, produced a GRG value of 58.7% which reconciled well with the life of mine GRG value of 61.0%.

A size-by-size assay was conducted on the cyclone overflow sample, which is essentially the gravity circuit tailings. The cyclone overflow had a $P_{80} = 81 \mu m$ and a grade of 0.57 g/t Au. To date, the grinding circuit has exceeded design capacity (>300 t/h compared to 250 t/h) while producing a significantly finer leach feed (75-80 µm compared to 150 µm $P_{80}$ design) which has allowed the mill to consistently exceed both design throughput and overall recovery.

A size-by-size assay of the cyclone underflow, which is the feed to the gravity circuit, had a $P_{80} = 862 \mu m$ and a grade of 8.96 g/t Au. Of note was that over 20% of the underflow was finer than 38 µm, this high fines content reporting to the concentrators can have a negative effect on SLR drainage times. Upon further investigation, it was found that larger apexes were being trialled and they were nearly worn out and near the end of their service life.

A size by size assay of the Falcon tailings returned a calculated grade of 5.84 g/t Au with $P_{80} = 882 \mu m$. This equates to a Falcon stage recovery of 34.8%, slightly lower than the 40% value used in the feasibility modelling exercise. The size-by-size Falcon stage recovery, calculated as the difference between the Falcon feed and tailings, is presented in Table 3.
As expected with a high g-force, centrifugal gravity concentrator, the highest stage recoveries were observed in the -850 / +106 µm size fractions. The stage recovery of approximately 35% was in line with expectations for a concentrator installed within a grinding circuit being fed tonnage in excess of design capacity.

Based on the values obtained from the audit and plant operating parameters from January 24th, a second model was constructed to benchmark the circuit’s current performance. The model inputs and outputs are compared with the actual production results from January 2018 in Table 4.

The results above show that the gravity circuit performance was close to that predicted by the feasibility model. The gravity circuit was recovering approximately 46% of the gold in the mill feed and 78% of the GRG. While these results were satisfactory, the audit identified numerous areas for potential improvement, the most prominent being improving cyclone separation efficiency and reducing SLR batch times. It was assumed that reducing the amount of fines reporting to the gravity circuit would reduce equipment loading, improve feed grade and minimize the number of fines reporting to the leach reactor, which can have a significant effect on solution drainage rates.

### Table 3 – January 24th, 2018 Falcon concentrator stage recovery by size fraction

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Falcon Feed (CUF)</th>
<th>Falcon Tailings</th>
<th>Stage Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wt. (%)</td>
<td>Au (g/t)</td>
<td>Dist. (%)</td>
</tr>
<tr>
<td>2,000</td>
<td>7.3</td>
<td>0.81</td>
<td>0.7</td>
</tr>
<tr>
<td>1,180</td>
<td>5.6</td>
<td>0.76</td>
<td>0.5</td>
</tr>
<tr>
<td>850</td>
<td>4.9</td>
<td>4.71</td>
<td>2.6</td>
</tr>
<tr>
<td>600</td>
<td>7.3</td>
<td>7.65</td>
<td>6.4</td>
</tr>
<tr>
<td>425</td>
<td>12.1</td>
<td>9.95</td>
<td>13.7</td>
</tr>
<tr>
<td>300</td>
<td>12.6</td>
<td>13.22</td>
<td>18.9</td>
</tr>
<tr>
<td>212</td>
<td>11.3</td>
<td>14.87</td>
<td>19.1</td>
</tr>
<tr>
<td>150</td>
<td>6.8</td>
<td>16.09</td>
<td>12.4</td>
</tr>
<tr>
<td>106</td>
<td>3.9</td>
<td>16.69</td>
<td>7.4</td>
</tr>
<tr>
<td>75</td>
<td>2.5</td>
<td>17.24</td>
<td>4.9</td>
</tr>
<tr>
<td>53</td>
<td>2.1</td>
<td>17.14</td>
<td>4.2</td>
</tr>
<tr>
<td>38</td>
<td>2.0</td>
<td>16.88</td>
<td>3.9</td>
</tr>
<tr>
<td>-38</td>
<td>20.2</td>
<td>2.33</td>
<td>5.3</td>
</tr>
<tr>
<td>Total:</td>
<td>100.0</td>
<td>8.83</td>
<td>100.0</td>
</tr>
</tbody>
</table>

### Table 4 – January 24th, 2018 Gravity circuit modelling vs. actual plant performance

<table>
<thead>
<tr>
<th>Model Inputs</th>
<th>Model Outputs</th>
<th>January Plant Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh Feed (t/h)</td>
<td>300</td>
<td>Recovery (%)</td>
</tr>
<tr>
<td>Circulating Load (%)</td>
<td>400</td>
<td>Recovery (% GRG)</td>
</tr>
<tr>
<td>Head Grade (g/t)</td>
<td>1.13</td>
<td>Recovery (g/hr)</td>
</tr>
<tr>
<td>CUF to Gravity (%)</td>
<td>33.3</td>
<td>Con. Grade (g/t)</td>
</tr>
<tr>
<td>GRG (%)</td>
<td>58.7</td>
<td>Average SLR Batch (hr)</td>
</tr>
</tbody>
</table>

The results above show that the gravity circuit performance was close to that predicted by the feasibility model. The gravity circuit was recovering approximately 46% of the gold in the mill feed and 78% of the GRG. While these results were satisfactory, the audit identified numerous areas for potential improvement, the most prominent being improving cyclone separation efficiency and reducing SLR batch times. It was assumed that reducing the amount of fines reporting to the gravity circuit would reduce equipment loading, improve feed grade and minimize the number of fines reporting to the leach reactor, which can have a significant effect on solution drainage rates.
Recent Performance
Since the start of commissioning, there has been a steady increase in gravity recovery from 32% in November 2017 to 58% in June 2018. The gravity circuit production results since the declaration of commercial production on March 1st, 2018 are presented in Table 5.

<table>
<thead>
<tr>
<th>Month</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity Recovery (%)</td>
<td>42%</td>
<td>40%</td>
<td>54%</td>
<td>58%</td>
</tr>
<tr>
<td>Gravity Production (Oz)</td>
<td>3,942</td>
<td>3,021</td>
<td>4,414</td>
<td>4,387</td>
</tr>
<tr>
<td>SLR Batches</td>
<td>28</td>
<td>31</td>
<td>33</td>
<td>35</td>
</tr>
</tbody>
</table>

TABLE 5 – Gravity production data since March 1, 2018

In May, a significant improvement in gravity recovery was observed. This was primarily attributed to improvements made to the control of the grinding circuit, which improved concentrator feed quality and led to an increase in the SLR drainage rate. A particle size distribution conducted on the cyclone underflow indicated that the proportion of -38 µm material reporting to the gravity circuit had been reduced to 13%. The increased drainage rate is the largest single factor in reducing the average batch time from 21.7 hours to 18.1 hours allowing more batches to be processed per month. Figure 4 illustrates the clear correlation between number of batches treated and gravity recovery.

Since May 1st, the gravity circuit has been responsible for an average of 59% of total gold production for an average of 4,401 ounces per month. The average gravity recovery of 56% has matched the expected recoveries from the feasibility study and represents 92% of the theoretical maximum established by the GRG value of 61%. The average SLR batch time has been reduced to 18.1 hours compared to 21.7 in January and in excess of 24 hours early in the commissioning process.

GRAVITY CIRCUIT COMMISSIONING
While the Moose River gravity circuit is performing consistently today, the commissioning of a gravity circuit utilizing a new intensive leach reactor technology with third party automation was not without its challenges. Some gravity circuit deficiencies noted during commissioning and their respective solutions are discussed in the following sections.
Gravity Circuit

Scalping Screen
The 5’ x 12’ (1.5 m x 3.6 m) scalping screen was undersized to treat >320 t/h of cyclone underflow at 75% solids. Upon start-up the screen was able to handle 1/6 cyclones or approximately 160 t/h of the circulating load. When a second cyclone was directed to the gravity circuit, in order to reach the design tonnage of 1/3 of the circulating load, the screen was overwhelmed with a 2” thick layer of material reporting to the oversize launder and only the finest material reporting to the gravity concentrators.

This poor screening efficiency restricted tonnage reporting to the Falcon concentrators. Having primarily fines reporting to the gravity circuit significantly reduced concentrator efficiency and the resulting “slimy” gravity concentrate resulted in slow drainage times in the SLR. While plans are currently being evaluated to install a larger scalping screen, the short-term solution was to dilute the screen feed to 60-65% solids with the addition of approximately 75 m³/hr of process water and to replace the recommended 2 mm slotted screen panels with 3 mm panels.

![FIG 5 – 2 mm screen apertures at 75% solids (left), 3 mm apertures at 60% solids (right)](image)

While these modifications resulted in a major increase in screening efficiency it is well documented that larger scalping screen apertures lead to an exponential increase in high g-force gravity concentrator wear rates. A 3 mm spherical particle weighs 3.4x as much as a 2 mm sphere; under high G conditions (60-150Gs) the impact forces in the concentrator bowl are drastically increased.

Concentrator Feed Arrangement
The concentrator feed arrangement from the screen underpan was less than ideal with two 6” knife gate valves installed with no concentrator bypass. The SB1350B concentrator is designed to process 50-150 t/h. Currently when both machines are online they are each processing 160-170 t/h. Having no bypass means that when one concentrator goes into a rinse cycle, the feed to the other concentrator increases to well over 300 t/h. This significantly reduces recovery efficiency while increasing machine wear. Plans are underway to modify the feed arrangement to include a gold trap free bypass.

Another issue that was encountered was the absence of feedback position sensors on the knife gate valves that control feed to the concentrators. Consequently, when a concentrator was scheduled to rinse, a signal would be sent to the knife gate to close before the concentrator would slow down and enter a rinse cycle. Occasionally, the knife gate would fail to close and the 160 t/h of feed would continue to flood the machine and pass directly to the concentrate storage cone in the SLR. At the end of the rinse cycle, the Falcon concentrators would manage to spin back up and resume operation; however, the concentrate storage cone would be diluted with feed grade
material. The installation of open and close limit switches on the knife gate valves to ensure the feed has stopped before the concentrator rinses has been an effective solution to this issue.

**Sepro Leach Reactor**

The SLR3000 at Moose River was the first unit of the second generation Sepro Leach Reactor as well as the only SLR installation using third party automation. As Sepro’s in-house automation team had programmed all previous SLR installations, the control philosophy provided to the third party programmer was not comprehensive. This resulted in a number of issues being encountered during commissioning; fortunately, they all had solutions that were addressed through close cooperation between Sepro, Atlantic Gold, and Ausenco personnel.

In October 2017, commissioning of the gravity circuit was critical in order to maximise gold recovery. The first batches of “gravity concentrate” were extremely fine and slimy; this was due to the grinding circuit operating with non-optimised cyclone components resulting in a high circulating load and compounded by the screening issues mentioned previously.

**Concentrate Transfer**

After a few days of intermittent operation, the concentrate hopper was full and the first batch was ready for leaching. During the concentrate transfer, the vertical tank pump was prone to air locking and required frequent operator intervention to both adjust the pump dilution water and regulate the feed rate to prevent the concentrate from overflowing and being lost to the floor and sump.

After attempting a number of different feed and dilution water arrangements to prevent airlocking with limited success, the 2” vertical tank pump was replaced with a 2” Canamix C50 Peristaltic pump. The peristaltic pump eliminated the airlocking issues and was found to be ideal for this duty because:

1. It can be directly piped to the concentrate cone discharge and provides constant suction to keep the concentrate flowing steadily
2. In the event of a pump, knife gate or power failure the pump acts as a valve, preventing the contents of the storage cone from being spilled on the ground
3. It is designed to pump very dense (>75%) solids slurries without requiring significant dilution water
4. Security is greatly improved as there is no longer residual gravity concentrate sitting in plain sight within the tank of the vertical tank pump

**Reagent Addition**

After the concentrate transfer was complete, the next steps were to start the agitator, top up the tank with process water and begin reagent addition. Initially, the automation program set the cyanide addition to occur before caustic addition. This mistake was caught immediately and caustic dosed manually before cyanide addition was resumed. Due to an incomplete control philosophy and insufficient communication, a number of automation issues were identified including interlocks that needed to be worked through over the course of the commissioning process. While Sepro strongly recommends that clients purchase the SLR with a full manufacturer programming and automation package, an updated, comprehensive, control philosophy was developed to prevent any future misinterpretations.

**Leach Cycle**

The leach cycle starts with hydrogen peroxide dosed periodically in order to maintain dissolved oxygen levels between 16-20 mg/L. The dissolved oxygen probe in the reactor had been stored for 6 months in the empty reactor vessel with the protective cap removed. As a result, the probe malfunctioned which resulted in overdosing of peroxide; turning the leach reactor into a cyanide destruction tank. During the early batches, peroxide addition was controlled manually by intermittently checking the dissolved oxygen content with a hand held DO probe and manually starting and stopping the peroxide dosing pump as required.
Along with replacing both the pH and dissolved oxygen probes, their position within the leach tank was raised to the mid-point of the vessel to prevent erroneous readings caused by sanded sensors.

A small amount of peroxide added to the reactor results in a rapid increase in dissolved oxygen levels; however, the DO sensor can take up to three minutes to catch up. To prevent overdosing, a programming change was made to add peroxide in short, five-second bursts followed by a four-minute delay; allowing the DO reading to stabilize before more peroxide is added.

**Solution Transfer**

After 16 hours of leaching with intermittent peroxide addition, the leach was stopped and the solids allowed to settle. The combination of a high fines content in the gravity concentrate and lack of flocculant dosing system resulted in very slow solution drainage and poor pregnant solution quality. The pregnant solution draining time under these suboptimal conditions was in excess of three hours.

While some ore types allow the SLR to drain properly without the use of flocculant, in all cases to date flocculant has both improved drainage rates and pregnant solution quality. At this stage in commissioning the flocculant dosing system was not yet operational. In haste, a standard anionic flocculant was procured and dosed manually; this improved pregnant solution clarity and reduced the average reactor drainage time to approximately 90 minutes. After contacting a flocculant supplier, a detailed flocculant screening program was conducted and a more effective non-ionic flocculant was obtained; this further improved pregnant solution clarity and reduced average drainage time to 75 minutes.

As the commissioning process of the rest of the grinding circuit progressed, the optimization of both the hydrocyclones and gravity scalping screen led to an improvement in gravity circuit feed quality with less fines reporting to the SLR. Since commercial production was declared on March 1st 2018, the reactor drainage time has averaged 42 minutes. As each leach batch requires the reactor to be drained a total of four times in order to achieve safe cyanide discharge levels, these modifications have reduced the average batch time by over 9 hours.

**Tailings Transfer**

After the pregnant solution had been drained and sufficient wash cycles had been completed to dilute the residual cyanide concentration to acceptable discharge levels, the tailings were returned to the ball mill. During the tailings transfer similar issues were encountered with the vertical tank pump airlocking and requiring frequent manual intervention. As with the concentrate transfer pump, the vertical tank pump for tailings discharge duty was replaced with a 2.5” Canamix C65 peristaltic pump. In addition, a manual knife gate valve was added between the tank bottom valve and the transfer pump to allow the pump to be isolated in the event the pump needs maintenance while the reactor is full.

At the end of the transfer, it was found that a significant portion of the solids had settled out and remained around the peripheries of the tank. The SLR was designed to discharge approximately 90% of the solid tailings after each batch leaving the densest 10%, containing any large unleached gold particles, within the leach tank for the next batch. During commissioning this residual load was found to be closer to 50%, which effected the capacity of the following batches. The initial tailings transfer sequence involved repulping the solids to fill the leach reactor, starting the agitator and opening the tank bottom valve to allow the slurry to feed into the tailings transfer pump. It was found that after the slurry level dropped below the second impellor the dense gravity concentrate settled out rapidly and would not drain through the tank bottom orifice.

In order to ensure more complete discharging of tailings after each cycle, the discharge sequence was modified to periodically add process water to the reactor, keeping both impellers submerged while pumping the slurry from the tank bottom discharge valve. After 30 minutes of pumping the agitated slurry, the water addition ceases and the tank is allowed to drain fully. This has resulted in residual loads near the design value of approximately 10%.

The final issue that was noted after the tailings transfer was poor sealing of the tank bottom valve. This was the result of coarse particles remaining between the valve head and gasket, and a poor
head and seal design. This was more of a concern before the tank pump was replaced with a peristaltic pump because when the valve did not seal properly there would be a constant drip of cyanide solution from the reactor during the leach cycle.

The new peristaltic pump functions as a valve when not in operation; it prevents any leakage of cyanide solution during leaching and allows the water injection line, used for flushing the pump, to also be used to backflush the tank bottom valve while it closes. This combination of a redesigned valve head along with flushing of the valve during the closing sequence has eliminated the risk of leakage.

**Bullion Purity**

The SLR’s patented filtration process allows the solid-liquid separation step to be performed within the reactor, without the need for a clarifier, thickener or other filtration equipment. Under ideal conditions, the SLR will discharge high quality, clear pregnant solution which when electrowon and smelted produces high purity bullion. Initially, the bullion poured from the gravity circuit contained significantly more impurities than the bullion from the CIL/elution circuit. In particular, the first bar poured contained in excess of 30% impurities and 6-7% arsenic. A number of initiatives undertaken to improve gravity bullion purity were as follows:

1. The introduction of a generic anionic flocculant in mid-November dramatically increased bullion purity to 89.4% Au; however, arsenic contamination still was an issue. ICP analysis of the solution showed minimal dissolved arsenic but it instead appeared to be entering the electrowinning circuit as an ultrafine suspension.

2. The introduction of a short de-sludging step in the concentrate storage cone resulted in a further increase in bullion purity to 92.8% Au.

3. After optimization of the cyclone performance and scalping screen efficiency to minimize the amount of fines reporting to the gravity circuit, the average gravity bullion purity further increased to 94.4% Au.

Since commercial production was declared in March 2018, bullion produced from the gravity circuit has exceeded 94% Au with less than 2% impurities. Photographs of the high quality pregnant solution and resultant high purity bullion are presented in Figure 6.

**FIG 6 – SLR pregnant solution (left) and gravity bullion (right)**

**SEPRO LEACH REACTOR OPERATING DATA**

The benefits of processing centrifugal gravity concentrate by intensive cyanidation as opposed to conventional tabling are well documented. These benefits include significantly higher recoveries, improved bullion purity, increased safety, security, an overall reduction in mill cyanide consumption, and an increase in leach circuit throughput.

Since commercial production commenced in March 2018, the Moose River SLR has been operating as designed with minimal oversight and high availability. To date, the gravity-intensive
leach circuit has operated autonomously with no gravity operator, which was initially budgeted for in the feasibility study.

**Leach Performance**

The SLR operates at a cyanide concentration of 2% with hydrogen peroxide dosed periodically to maintain dissolved oxygen levels in the range of 16-20 mg/L. The high energy agitated leaching of the SLR has proven to result in rapid gold dissolution. On January 24th 2018, while conducting an evaluation of potential alternative oxidants, a number of rolling bottle leach tests were conducted on the Falcon concentrate produced on that day. A comparison between the industrial SLR leach profile and a rolling bottle leach is presented in Figure 7. This chart illustrates the difference in leaching rates between a high energy agitated leach and rolling bottle agitation. Both leaches were conducted on the same Falcon concentrate at 35% solids, 2% cyanide concentration with a target dissolved oxygen content of 16-20 mg/L maintained with periodic hydrogen peroxide addition.

![FIG 7 – Sepro Leach Reactor vs. bottle roll leach profiles](image)

After four hours of leaching, the SLR had achieved 76% Au recovery compared to 47% in the bottle roll. After thirteen hours, at the end of the SLR leach cycle, SLR recovery was 97%; the bottle roll recovery was 78%. A number of SLR leach profiles taken during the first half of 2018 are plotted in Figure 8.
With vigorous agitation, high cyanide and dissolved oxygen levels, leaching of the fine gold is rapid with an average recovery of 62% after just two hours. The presence of coarse gold flakes as large as 10 mm results in a levelling off of the leaching rate, still gold recoveries after six hours average 85%. Ultimate recoveries, after 13 hours of leaching, have all been in the range of 97.0-99.6% with an average of 98.6%.

Leach residue grades range from 8-59 g/t with an average of 22.3 g/t Au. Duplicate tailings assays have shown good repeatability indicating that the nugget effect has been minimized and the bulk of the unleached gold is likely locked in arsenopyrite.

Back calculated SLR feed grades range from 800-3000 g/t with an average of 1364 g/t Au. This means each 3000 kg batch contains an average of 131.6 ounces. Based on the average SLR recovery of 98.6% and an average of 1.09 batches per day, the average daily gravity gold production is 141.4 ounces.

**Operating Costs**

The SLR operates at a cyanide concentration of 2% with hydrogen peroxide dosed periodically to maintain dissolved oxygen levels between 16-20 mg/L. Flocculant is used to aid settling and filtration and is dosed at 100 g/t. The approximate operating costs per batch are outlined in Table 5.

<table>
<thead>
<tr>
<th>Reagent</th>
<th>kg / batch</th>
<th>$ / kg</th>
<th>$ / batch</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCN</td>
<td>20.8*</td>
<td>2.79</td>
<td>58.03</td>
</tr>
<tr>
<td>NaOH</td>
<td>2.13</td>
<td>0.85</td>
<td>1.81</td>
</tr>
<tr>
<td>H₂O₂</td>
<td>13.18</td>
<td>1.10</td>
<td>14.50</td>
</tr>
<tr>
<td>Flocculant</td>
<td>0.30</td>
<td>5.85</td>
<td>1.76</td>
</tr>
<tr>
<td>*Consumed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Reagents Total:</strong></td>
<td></td>
<td></td>
<td><strong>76.10</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Electrical</th>
<th>kWhr / batch</th>
<th>$ / kWhr</th>
<th>$ / batch</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>67.98</td>
<td>0.08</td>
<td>5.44</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Spare Parts</th>
<th>Cost $</th>
<th>Batches</th>
<th>$ / batch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5730.76</td>
<td>330</td>
<td>17.37</td>
</tr>
</tbody>
</table>
The average operating cost per leach batch is $98.90. Based on the average gold production per batch, this equates to $0.77 CAD per ounce produced or $33 per tonne of gravity concentrate processed. It should be noted that while 104 kg of cyanide is dosed each batch, only around 20% of the cyanide is consumed by the process. After electrowinning, the residual 80% in the barren solution reports to the leach circuit where cyanide addition is reduced accordingly.

Ongoing Initiatives

Leach Duration

The current leach cycle time of thirteen hours was chosen early during the commissioning process in order to maximize SLR stage recovery. As the SLR tailings are returned to the milling circuit, any unleached gold should be ground finer and be recovered again by the Falcon concentrators or report to the CIL circuit. Given the clear relationship between the number of SLR batches and gravity gold production, it would likely be favourable, from both a gravity circuit and overall plant recovery perspective, to end the leach sooner.

By reducing the leach duration from thirteen to ten hours, the expected stage recovery would be reduced from 98.6%-95.0%. A 3.6% reduction in SLR recovery equates to an average of 4.7 ounces per batch; however, a three-hour reduction in batch time would allow for an additional 5.2 batches per month. Assuming that none of the unleached gold is re-recovered by the gravity concentrators and a logarithmic relationship between number of SLR batches and gravity production, as illustrated in Figure 4, an increase in gravity production of 364 Oz per month is expected.

Alternative Oxidants

Hydrogen peroxide was selected during the design phase as the preferred oxidant because it is a cost effective source of dissolved oxygen, easy to dose and there is no oxygen plant on site. While peroxide has proven to be an effective leach accelerant, there are drawbacks both from financial, metallurgical and health and safety perspectives. In small doses, peroxide is effective at maintaining high dissolved oxygen levels; however, when overdosed it can result in increased caustic consumption, destruction of cyanide and evolution of HCN gas.

A number of parallel bottle roll leach tests were conducted on the Moose River Falcon concentrate to compare the leach performance using pure oxygen, compressed air, hydrogen peroxide and Sepro Leach (a chemical oxidant). The results indicate that sparging pure oxygen results in the fastest leaching, with compressed air resulting in the slowest leaching and lowest recovery. After oxygen, hydrogen peroxide proved to produce the second fastest leaching over the first four hours. After four hours, the SeproLeach recoveries surpassed the peroxide leach and produced a lower tailings grade and higher overall leach recovery.

Plant trials are currently underway to evaluate the potential benefits of switching from hydrogen peroxide to SeproLeach. Chemical oxidants such as SeproLeach or LeachAid™ are ideal for intensive leach reactors as they can be batch dosed as dry pellets at the start of the leach as opposed to being sparged or dosed periodically when the dissolved oxygen levels drop. While the chemical oxidant is slightly more expensive, it is expected that the reduced cyanide consumption, increased recovery, simplified automation and minimized safety concerns will render it economically favorable.

Barren Solution Tank

Currently, the dedicated gravity electrowinning circuit in the gold room includes only a single pregnant/barren solution tank. At the end of each SLR leach cycle, when the SLR is ready to send pregnant solution to the gold room, the barren electrowinning solution from the previous batch must be discharged to the leach circuit to make room for the next batch.
The SLR can be configured to reuse a portion of this barren electrowinning solution as makeup solution. This is economically beneficial as it reduces cyanide consumption and in the event of poor electrowinning efficiency, will keep the majority of the residual gold within the SLR-gold room circuit instead of being discharged to the leaching circuit. While the current gold room layout makes the addition of a barren solution tank difficult, this will be considered in any future expansions or new gold room designs.

CONCLUSIONS
Since May 1st, the Moose River gravity circuit has been responsible for an average of 59% of total gold production, an average of 4,401 ounces per month. The average gravity recovery of 56% has matched the expected recoveries from the feasibility study and represents 92% of the theoretical maximum established by the GRG value of 61%. While commissioning of a new mill is never without its challenges, Atlantic Gold’s highly skilled and enthusiastic metallurgical team, working in close collaboration with Sepro personnel, have in short order achieved the gravity production goals set out in the feasibility study with future optimization projects expected to exceed this benchmark.

ACKNOWLEDGEMENTS
The authors wish to thank Atlantic Gold Corporation for their permission to publish this paper. Thanks are also given to the staff of the Moose River mill, the Ausenco commissioning team, consultants and engineers involved in this project.

REFERENCES