Commissioning a HydroFloat® in a Copper Concentrator Application

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Abstract

There are great demands on miners to reduce their environmental footprint. Currently, more than 3% of the world's electricity is consumed in the grinding process to liberate valuable minerals, much of that produced from non-renewable sources (Ballantyne et al, 2012). The fine gangue from these processes requires large tailings facilities for waste storage and represents the largest water loss in mining, and an existential threat for mining companies and local communities. The competition for water resources puts miners in conflict with agricultural users and local populations, especially in metal-rich mining regions. As demand for a wide variety of metals for the green economy is rising, new and existing resources have lower grades. Coupled with social and environmental factors, the resource extraction intensity is driven to; improving energy efficiency, reducing water consumption, increasing the long-term safety of tailing facilities, and minimizing losses of valuable pay-metals. A number of technologies are being developed to address each of these drivers individually, for example, more efficient grinding technologies, improved techniques to de-water and minimize evaporative losses, and better designs and maintenance for tailing facilities, such as filtered and dry-stacked tailings. One technology that can contribute to improving all of these is Coarse Particle Recovery (CPR).

Coarse Particle Recovery (CPR) can be used in any flowsheet that requires flotation, and it provides an opportunity to improve recovery, energy efficiency and water use intensity by recovering minerals at a particle size 2-3 times coarser than conventional flotation processes. The first commercial applications using the HydroFloat for coarse flotation of sulphide minerals focused on scavenging coarse losses from flotation plant tailings. This demonstrated the suitability of the HydroFloat for harsh, 24/7 mining applications. The next step in the development of the technology is to use the technology to reject gangue

earlier in the process, where the benefits of energy efficiency (less energy in grinding and less energy in de-watering) and water reduction can be achieved.

The successful introduction of innovative new technology requires a close multidisciplinary and collaborative approach to pilot, scale-up, design, de-risk and operate.

Anglo American, in collaborative partnership with technology partner Eriez, have developed the world's largest HydroFloat unit application and applied it in an early gangue rejection mode at its El Soldado operation in Chile, South America. The plant was commissioned in Q1-Q3 of 2021. The commissioning and scalability of Hydrofloat in a coarse gangue rejection mode on a sulphide copper ore is discussed.

Introduction

Coarse Particle Recovery (CPR) using the Eriez HydroFloat has been used industrially for the last twenty years. The HydroFloat is effective for floating coarse particles, compared with conventional flotation because it uses a counter-current aerated fluidized bed and zero-order froth (Mankosa et al, 2012). This results in low shear, a plug-flow residence time distribution, and minimization of the drop-back phenomenon reported by Falatsu (Falatsu and Dobby, 1989). The application in base metal sulphides is more recent, and the early application in sulphides flotation was in tail scavenging. The HydroFloat works well in tail scavenging because conventional flotation typically is not effective for floating coarse semi-liberated particles in the tailing streams of conventional flotation plants (Wasmund et al, 2019). Pilot testing at multiple sites has shown that typically 60% of semi-liberated coarse mineralized ore in tails can be effectively scavenged in a single stage using the HydroFloat.

The three main advantages of tail scavenging of coarse particles are improved global recovery, typically 3-6%, the potential to increase the grind size of the mill circuit, and the de-coupled nature of the CPR plant with respect to the main concentrator. These benefits are significant enough to justify the business case to add a CPR circuit to the tail of a conventional concentrator. However, there are more significant benefits that may be realized by coupling CPR with the concentrator mill circuit and generating a coarse barren tail, the so called “Coarse Gangue Rejection” (CGR) application. A recent analysis using Capstone Mining’s Cozamin plant as a case-study showed that that the CGR application could reduce the amount of ball mill energy by 30-50%, produce a final tail where 30% of the stream was 2-3 times coarser than the conventional tail size distribution, and reduce the required capacity of conventional flotation by 40% (Regino et al, 2020).

Anglo American and Eriez began discussing the design and operation of a full-scale CGR demonstration plant in 2017, in order to confirm the potential identified to increase copper production with improved energy efficiency and water use intensity using CGR. Four design considerations were emphasized by Anglo; the plant should be designed as a module, so that after it was commissioned and de-bugged, it could be quickly replicated and installed anywhere else in the world (using the philosophy of “design once build many” vs the “stick build” approach), the HydroFloat units should be scaled for the maximum capacity, to minimize ancillary equipment, the HydroFloat units should be built with a reduced height requirement, which would minimize the structural and installation costs, especially in seismically sensitive areas, and finally the design should have sufficient process flexibility to execute a step-by-step commissioning plan, defined by Anglo American, aimed at minimizing production risk to existing operations during commissioning and ramp up. The aim being to evaluate the CGR flowsheet with a wide range of feed properties, including a range of size distributions and volumetric flow rates.

Anglo American selected El Soldado Copper plant in Chile as the testing ground for a full-scale demonstration plant of a world first HydroFloat design in a world first CGR mode of operation. The unique configuration of the El Soldado circuit allowed for the co-mingling of different streams to produce customized feeds for the CGR HydroFloat Demonstration Plant. Another factor in the selection of El Soldado for this demonstration plant was that it had been used in the past as a testing site for new technology, and there is a strong culture of innovation among the staff and management.

The El Soldado simplified flowsheet, prior to application of CGR, is shown as Figure 1. In this flowsheet, the primary crusher discharge is split to feed multiple grinding circuits. Approximately 55% of the feed reports to a SAG mill grinding circuit while the remaining 45% is fed to secondary & tertiary crushing which subsequently feeds four conventional ball mill grinding lines. The SAG mill operates in closed circuit with a cluster of cyclones. The conventional grinding includes 4 lines; line 1 & 2 each have three independent stages of grinding, line 3 & 4 have 2 independent stages of grinding followed by a shared tertiary ball mill, called Molino 2000. All of the combined cyclones (SAG mill, Molino 2000 and lines 1 & 2) overflow to feed the conventional flotation circuit.

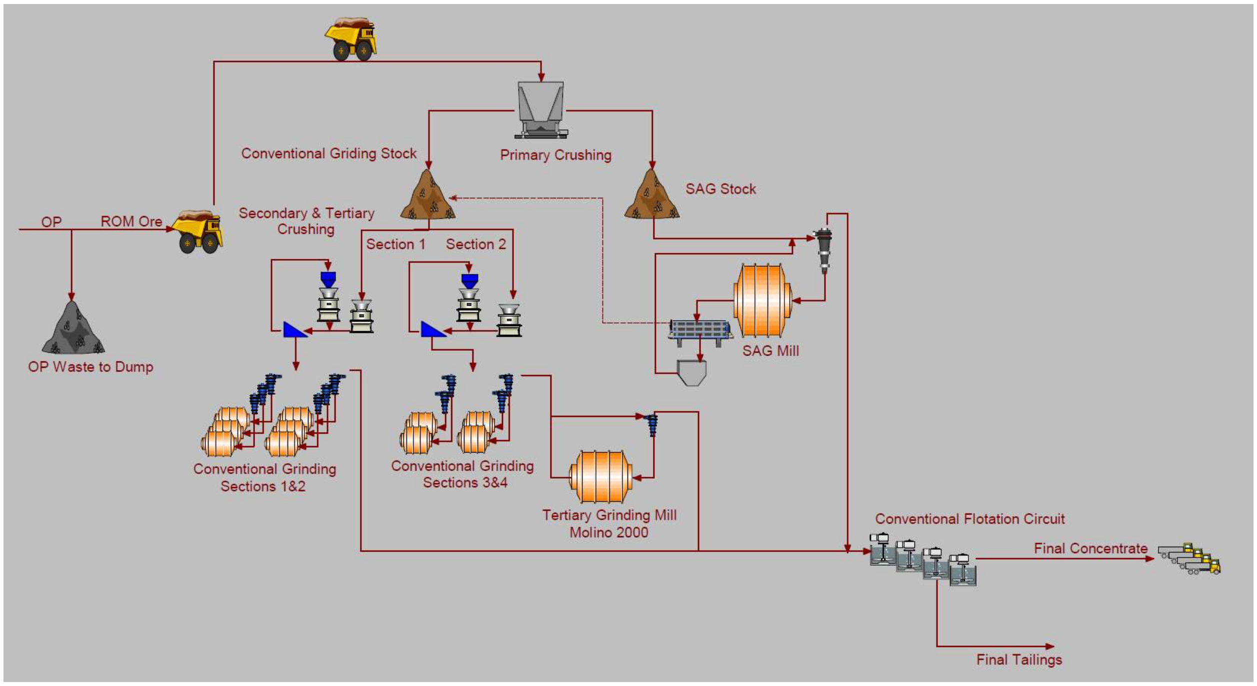

Figure 1: El Soldado Concentrator Simplified Flowsheet

CGR Demonstration Plant Description and Commissioning Plan

The CGR Demonstration Plant is installed between the grinding and conventional flotation at El Soldado concentrator. It is designed to process approximately 80 percent of El Soldado throughput, operating in integration with the existing conventional plant. Figure 2 show the CGR Demonstration Plant location at El Soldado Concentrator.

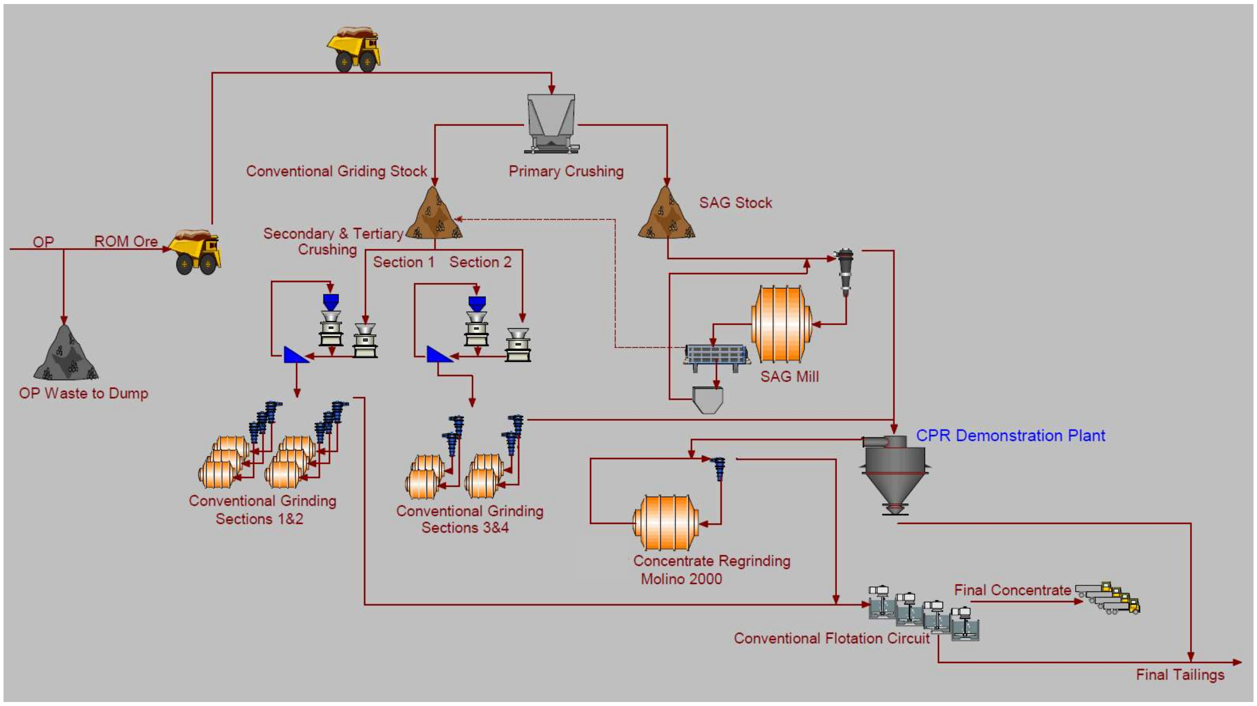

Figure 2: CGR Demonstration Plant location at El Soldado Concentrator.

The CGR Demonstration Plant can process the overflow from SAG and conventional grinding lines 3 & 4. The feed to the CGR circuit is processed in two-stages of cyclones splitting this feed into two streams. The fine size fractions from both cyclone stage overflows are combined and sent directly to conventional flotation. The coarse size portion of the first stage of classification is sent to the second stage and the second stage coarse size portion is sent to the HydroFloat for coarse flotation. Concentrate from the HydroFloat is reground before being sent to the conventional flotation feed. Recovered water from the concentrate is recycled internally in the CGR Demonstration Plant. The CGR tailings from the HydroFloat are combined with the conventional flotation tailings. Figure 3 shows the CGR Demonstration Plant flowsheet.

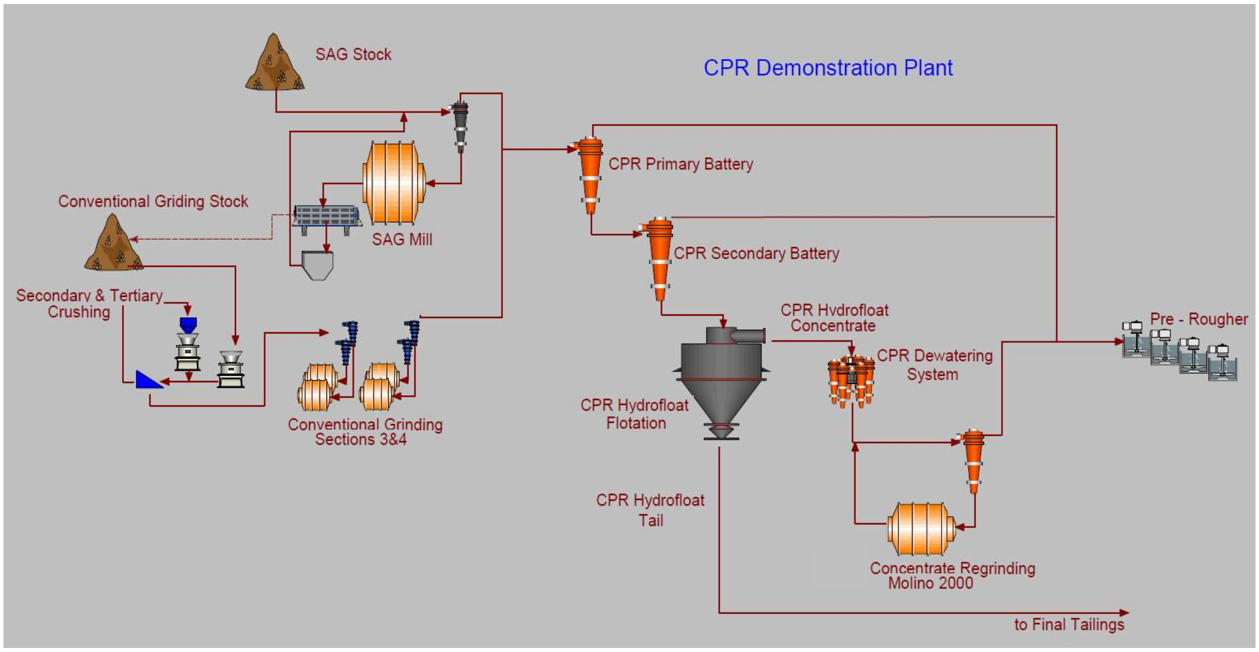

Figure 3: CGR Demonstration Plant flowsheet.

The CGR module that was designed and built had several new features, never seen before in relation with the design, engineering and operational strategy using the HydroFloat in base metal sulphides. Firstly, this is the first commercial CGR application, which allows the removal of a coarse barren tail at a size 2-3 times coarser than the grind size typically required to liberate and separate the same ore with conventional flotation. Secondly, this CGR Demonstration Plant is the first installation of a HydroFloat in sulphide flotation where the upstream classification process consisted of cyclones rather than a teeter bed size classifier. The use of cyclones allows for more operational flexibility in incrementally adjusting the feed flowrate after installation and reduces the installation height and structural costs. Thirdly, this CGR Demonstration Plant is the first application of the Eriez 5 metre diameter stepped cone HydroFloat design. This design increases the unit capacity of the HydroFloat by almost two times compared with the previous generation. It also reduces the relative height requirement by changing the aspect ratio compared with previous designs, which contributes to lower installation costs. Figure 4 shows a set of photos of the CGR Demonstration Plant. Finally, the CGR Demonstration Plant design incorporated the required flexibility to execute a three-step commissioning plan, defined by Anglo American, designed to control and minimize risk to the existing operations during commissioning, ramp up and operation.

The three-step commissioning plan, requiring three different flowsheet configurations, was as follows:

Step 1: Operating the CGR Demonstration Plant at the normal D80 of El Soldado Concentrator (~200 micron- base case), and a mass flowrate of 750 tonnes/hour, with feed from the SAG and Molino 2000 (lines 3 & 4 conventional grinding), while maintaining the throughput. CPR circuit products (concentrate and tailings) were recombined and delivered to the conventional flotation feed (no CPR product produced). This step was defined to commission and operate the circuit and to learn and optimize the HydroFloat operation, with minimal impact on the existing concentrator.

Step 2: The CGR Demonstration Plant configuration was changed to start producing separate concentrate and tailings streams with the tailing stream directed to plant tailings. The CGR Demonstration Plant was operated with a coarser feed (D80 ~280 micron) and a solid mass flowrate of 750 tonnes/hour. The SAG mill was operated at the same product size as conventional flotation feed (~200 micron- base case) whilst mill lines 3 and 4 were fed to the CPR circuit at a coarser product size to give a coarser feed size distribution of the combined feed stream. In this step, the Molino 2000 was reconfigured from its original duty as tertiary grinding in the conventional grinding circuit of sections 3 & 4 to a new duty as the HydroFloat concentrate regrind mill. This configuration allowed the evaluation of a step change towards coarser grinding, enabling commissioning of the Molino 2000 in its new capacity as a regrind mill and further to learn and optimize the HydroFloat operation before moving to step 3.

Step 3: Step 3 was achieved by operating the CGR Demonstration Plant at the design feed D80 (~330 micron) and a solids mass flowrate of 870 tonnes/hour. The same configuration and product size for Lines 3 & 4 were used as Step 2. The SAG Mill product size and throughput was increased to give the D80 feed size to the CPR circuit of ~330 microns. This step enabled a controlled increase in the module feed particle size and optimization of the HydroFloat and CPR circuit to reach the final and permanent operating condition defined for the project.

Figure 5 shows the cumulative size distributions to the CGR demonstration module for each step.

Figure 4: CGR Demonstration Plant photo set

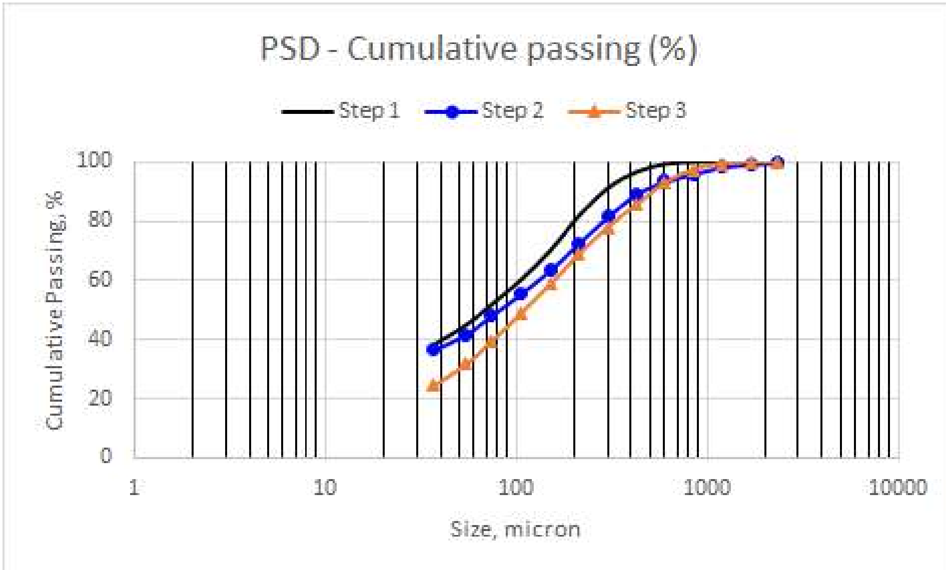

Figure 5: Nominal feed size distributions for feeding the CGR Module

The three step commissioning plan was executed in the period of Q1 to Q3 2021, completing successfully each of the defined steps described previously, despite the typical commissioning issues plus the additional COVID-19-pandemic factors that increased the complexity of accomplishing this challenge.

The increase of D80 and feed to the CPR circuit was achieved according to the plan, which generated the anticipated reduction in energy consumption and water use intensity. Figure 6 shows the monthly performance during 2021 of the SAG mill specific grinding energy, the D80 of the CPR circuit feed and the D80 of the conventional flotation feed. The change between June and Aug 2021 represents the transition to "step 3" and the coarsening of the grind, resulting in a decrease in grinding energy and decrease in P80 of the feed to conventional flotation.

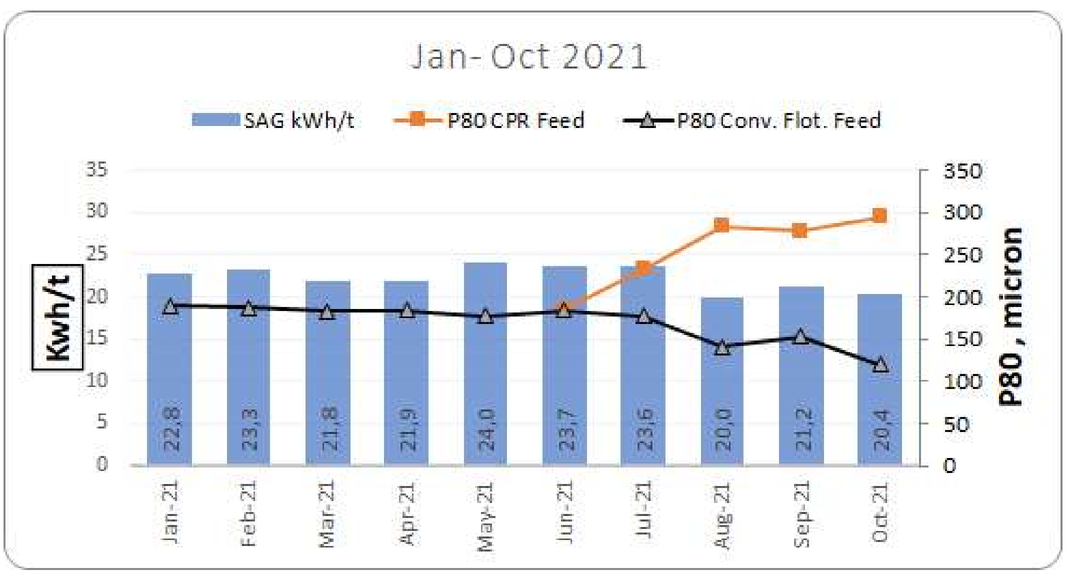

Figure 6: SAG kWh/t, P80 Feed to CPR and P80 Feed to Conventional Flotation, Jan. to Oct. 2021

Operational Performance and Scalability

To test the basis for the scale-up of the Eriez HydroFloat cell in a CPR application, Anglo American conducted test-work using an on-site 150 mm diameter laboratory HydroFloat cell receiving feed from the same HydroFloat feed stream as the full-scale module. Scale up of the HydroFloat is based on maintaining the same feed mass and fluidization water flux (i.e. tonnes feed/hour/m^2 and m^3 water/m^2 of unit cross-sectional area) while maintaining similar ratios of aeration and percent solids of the feed. Figures 7 and 8 show measures of metallurgical performance, comparing the results of the 150 mm diameter test unit and the 5 meter diameter unit; these are upgrade ratios versus mass pull and the copper recovery per size class for the Hydrofloat and conventional rougher flotation. These results indicate that the metallurgical performance obtained from tests in a HydroFloat lab unit can be reasonably reproduced in the largest unit of industrial scale. It also suggests that the test unit could be used to evaluate changes in ore type, size distribution or conditioning chemistry.

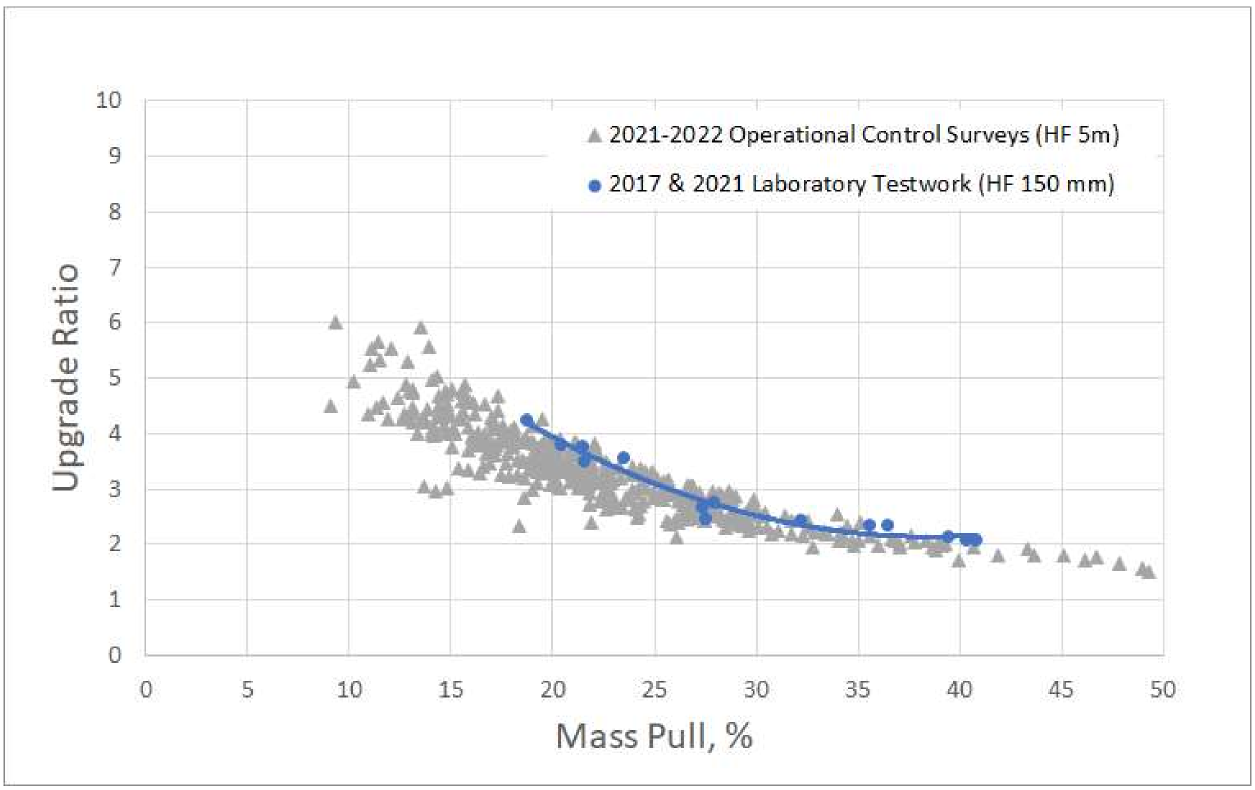

Figure 7: Upgrade Ratio versus Mass Pull comparing Laboratory and Full Scale HydroFloat units

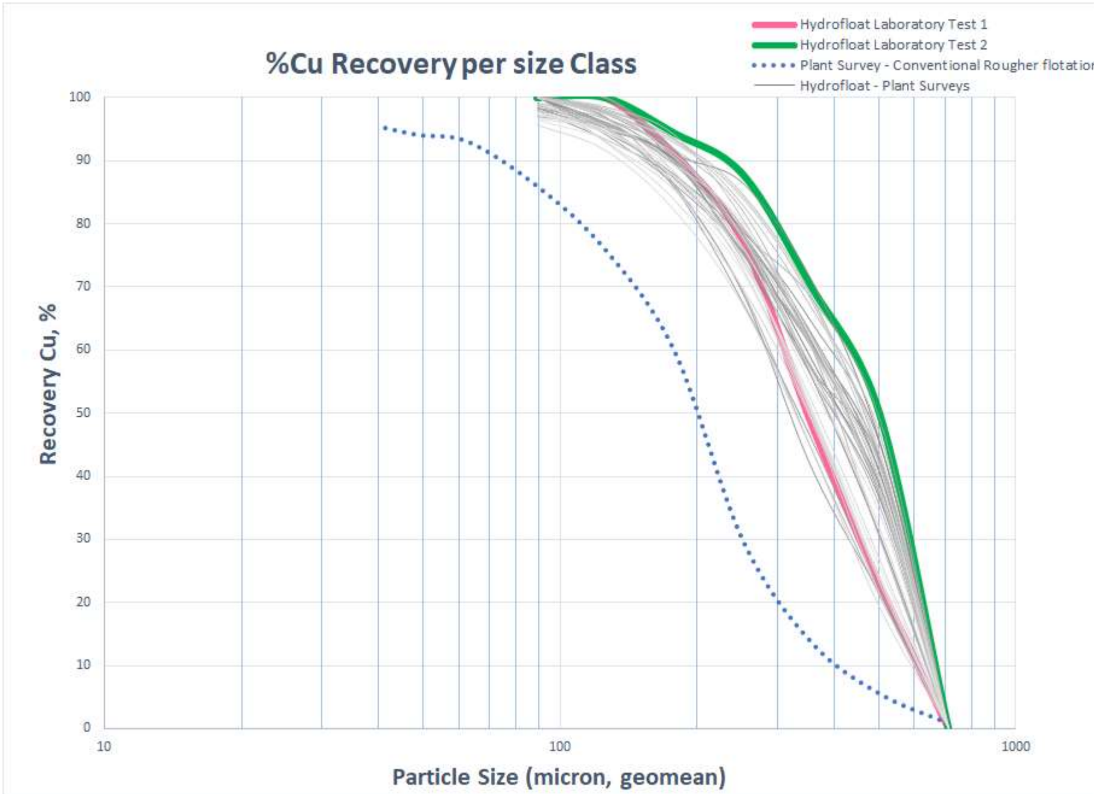

Figure 8: Cu Recovery per size class for HydroFloat laboratory and full-scale units compared with full scale Conventional Rougher Flotation.

Another important measure for the success of the HydroFloat operation and scalability is the Cu recovery by size class. Figure 8 shows the recovery by size class for conventional flotation (dotted blue line), and flotation using the HydroFloat at El Soldado. A number of plant surveys were conducted during step 3 of the operation to measure the performance of the HydroFloat under different operating conditions shown as solid grey lines. These are compared with the results of two HydroFloat laboratory tests under ideal conditions, shown as solid red and solid green lines. High variability in the plant performance can be explained by the different operating conditions tested and ore variability. Operating variables that contribute to HydroFloat performance include, teeter water rise rate, air to water ratio, bed density, bed level, feed rate, quantity of fines (<75 micron) in the HydroFloat feed, reagent conditioning and ore type. HydroFloat laboratory test 1 and HydroFloat laboratory test 2 were conducted on different days with different ore types and under different operating conditions. Most of the plant surveys fall within the range of variability expected due to ore type and changes in plant operating conditions and it is therefore concluded that the HydroFloat is performing as expected based on scalability on a t/h/m2 basis.

Figure 9 below shows the average (monthly) HydroFloat head grade and concentrate grade, where it is possible to appreciate the wide range of head grades that were processed in the HydroFloat industrial unit and the copper concentrate grade produced.

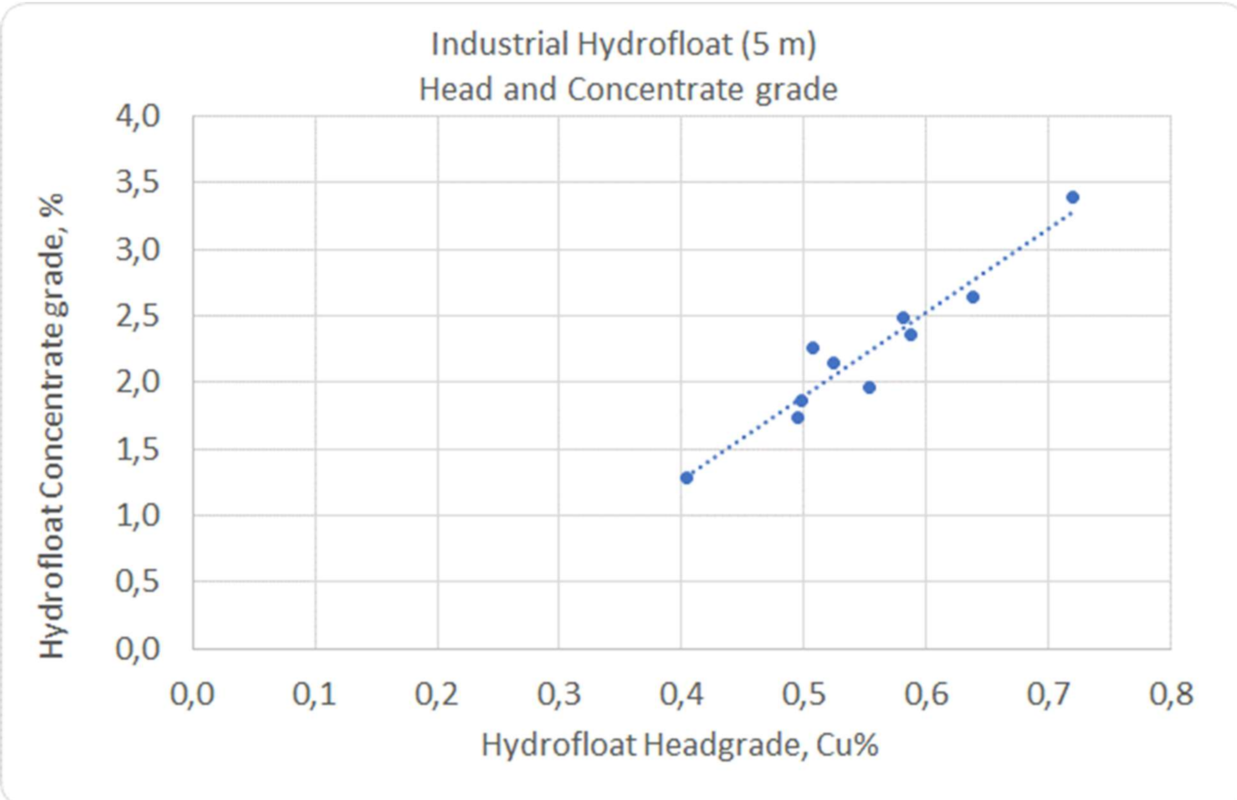

Figure 9: Monthly average HydroFloat feed and concentrate grades

Water saving benefits in combination with Hydraulic Dry Stack (HDS)

The reject streams arising from the adoption of Coarse Particle Recovery deliver opportunities for additional water recovery from the tailings and Hydraulic Dry Stack (HDS). HDS is a patented dry-storage technology, developed by Anglo American, which utilises the 'throw-away' free-draining sands slurry from the HydroFloat underflow stream and other processes. HDS delivers managed co-disposal, utilising the free draining CPR sands (ideally sized to be compatible with the total tailings) to accelerate the consolidation and dewatering of the full TSF (tailings storage facility). This significantly increases water recovery and recycling volumes, thereby reducing freshwater consumption, while creating stable, re-usable land instead of a traditional wet tailing storage facility. HDS is being demonstrated in two sites during 2022 - at El Soldado in a dedicated large scale demonstration facility, and at Mogalakwena, South Africa as a brownfield application. HDS facilities are under consideration for a number of other Anglo facilities and is likely to deliver a demonstrable improvement in water management and stewardship.

Conclusions

The successful scale-up and commissioning of this coarse particle recovery application at Anglo American's El Soldado Coarse Gangue Rejection (CGR) module represents a major step forward in the commercial adoption of sustainable process technologies. Firstly, it demonstrates the scale-up of the technology to a unit size that improves the economics for capital investment and large tonnage operations. The unit at El Soldado is the largest unit in the world, and this work has shown that simple scale-up rules based on flux apply. This means that the results from a well-planned test performed in a lab-scale 150 mm diameter unit can be used to size a unit for any given duty and to predict the metallurgical performance in a unit with more than 1000x the capacity. Secondly, it shows that the technology can be integrated into a conventional concentrator flowsheet to practically reduce grinding and generate a coarse 'throw away' tail which is 2-3 times coarser than conventional flotation tails. Thirdly, it shows the synergistic combination of new technologies, specifically the combination of coarse particle flotation technology with the Hydraulic Dry Stack technology, which allows rapid recovery of water with less energy, while storing tailings in a safe and stable format. Finally, this work shows the benefits of close and collaborative interactions between mining companies and vendors. As a result of this successful technology application, full scale plants are under construction at a number of Anglo American sites including Mogalakwena (PGMs), Quellaveco (Copper), and they are in the planning stage at a number of other sites across the Anglo American group.

Acknowledgements

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