ROLE OF COARSE PARTICLE FLOTATION IN THE DEVELOPMENT OF MORE EFFICIENT CONCENTRATOR PLANTS

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ABSTRACT

A paradigm shift is underway globally in energy generation and consumption, focusing on a transition to electrification and energy sources that do not create green-house gases (GHG). This new economy will increase the demand for minerals such as copper, nickel, graphite and lithium, among others. While the demand for these minerals is expected to increase, grades of mineral deposits and reserves are decreasing every day, and some of these deposits are located in areas of high social conflict with opaque governance structures that make mining development difficult and problematic. The search is on for innovative and more efficient ways of extracting and processing mineral resources. One of these is coarse particle flotation (CPF), which was first used at industrial scales for sulfide ores using the Eriez HydroFloat® at Newcrest's Cadia Valley in 2018.

There are two main families of CPF applications; the first being "Tail Scavenging" (TS) where the HydroFloat is used to recover an additional 3-6% of the total milled mineral and to increase the throughput for a brownfield application. The second is "Coarse Gangue Rejection" (CGR), where the HydroFloat system is inserted in the mill circuit and allows reduction in mill power, and the production of significantly coarser sized tails, typically 2-3 times than conventional mill tails. It is this latter application that has the potential to greatly reduce power and water consumption, as well as improve metallurgical efficiency. An industrial-scale CGR application was installed at Anglo American's El Soldado concentrator in Chile in 2019, and a recent paper explained the design concept, operation and benefits, largely de-risking the application for future practitioners. In this paper, some of the considerations for implementing CGR applications in world-scale concentrators of the future will be discussed including test-work and scale-up, the reduction in electrical energy, net-water consumption and the improvement in metallurgical efficiency.

1 INTRODUCTION

The HydroFloat is a fluidized-bed coarse particle flotation machine that overcomes the limitations of conventional stirred tanks flotation machines to allow for flotation of particles that are 2-3 times coarser, as shown in a copper example in Figure 1. The HydroFloat achieves these break-through results by overcoming buoyancy and froth recovery restrictions through up-current water velocity and plug flow conditions (Mankosa *et. al.,* 2016). Coarse semi-liberated material is inherently present in the size distribution of the grinding mill output, and it is not floated by conventional mechanical cell flotation units. This allows Coarse Particle Flotation (CPF) to typically recover an additional 3% to 6% of the mineral contained in the run of mine (ROM) mill feed of copper concentrator plants. CPF was successfully introduced in the base metals industry in the "Tail Scavenging" (TS) application at Newcrest's Cadia Valley Operation in New South Wales in 2018 which was reported by Vollert et al (2019). Since then, practitioners have discovered additional benefits by considering the "Coarse Gangue Rejection" (CGR) application, where the CPF system is added further upstream so that it can generate a coarse barren tail and increase the grinding endpoint. A quantitative process and economic comparison was made by Regino *et. al*., (2020) of a TS flowsheet and a coarse gangue rejection (CGR) flow-sheet, which compared both options at the Cozamin Cu-Ag-Pb-Zn concentrator in Mexico. At this site, the TS case could recover an additional 2%, 9%, 16% and 11% for Cu, Ag, Pb and Zn respectively, while CGR could reduce the ball mill grinding power by 30-50%, reduce conventional flotation capacity by 40% and deliver 30% of the tail at an average size 2-3 times coarser than the conventional plant. A further analysis reported by Pyle *et. al.* (2022) on a copper ore showed that CGR implementation could reduce total power in a SAGBM circuit by 24%, which includes the re-grind energy for the HydroFloat concentrate. Other studies have been conducted in several copper concentrators in South America (Concha *et. al*., 2021).

The first commercial application of CGR was reported by Anglo American at their El Soldado concentrator in Chile by Arburo *et. al.* (2022). This paper reported a number of innovative "firsts", including the first industrial CGR application, the first CPF application to use two stages of cyclones as feed preparation, and the first site to use the Eriez 5-meter diameter HydroFloat. This paper also demonstrated that the 5-meter HydroFloat could be scaled up from the results in a 150 mm test unit. Since this installation, it appears more certain that CGR applications throughout the world will enable miners to produce more metal more sustainably and profitably. McKinsey has recently reported that CPF is a "key technology for reducing the copper supply gap" (Crooks *et. al*., 2023).

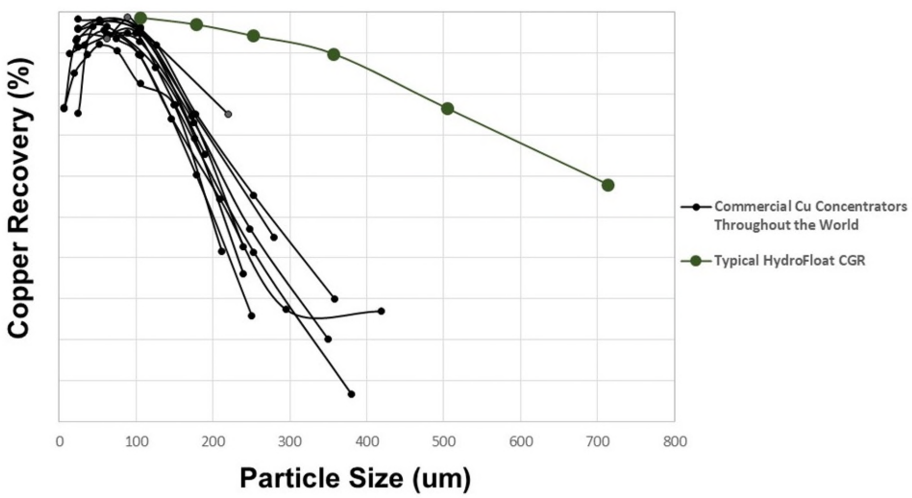

Figure 1. Recovery by size for different copper concentrator plants vs recovery at HydroFloat CPF in a CGR application (d80=400um) showing the extension of flotation efficiency in the coarse size range.

2. DISCUSSION

2.1 Coarse Particle Flotation Test-Work

A typical CPF project starts with a desktop analysis, followed by laboratory test-work and piloting, if required. **Figure 2** and **Figure 3** show laboratory and pilot HydroFloat CPF configurations, respectively.

The HydroFloat® CPF laboratory system consists of a HF-150 (Ø150mm) cell, where underflow discharge control and bed level control are performed by an automatic control valve which is connected to a pressure transmitter and a PLC integrated with a digital panel. Fluidization water and flotation air are measured by digital flowmeters. The system has also a tank that collects the water recovered from the HydroFloat® concentrate, which is recirculated as fluidization water. The laboratory CPF system allows semi-continuous test work, closely simulating the production mode.

Figure 2. HydroFloat® CPF laboratory system

On the other hand, the HydroFloat® CPF pilot plant consists of a HF-400 (Ø400mm) cell, a feed classification system (which could be a custom Weir cyclone pilot plant and/or CrossFlow separator), feed system, reagents skid, and fluidization water system. The pilot plant is fully automated, using a PLC & HMI station for feedback control.

These test systems, together with validated procedures allow accurate metallurgical scalability. For copper ores, Arburo *et. al.*[6] recently presented data showing accurate metallurgical scalability from a HydroFloat CPF lab unit to a 5-meter industrial HydroFloat at El Soldado. Similar results have been presented by Kohmuench *et al*.[12] for a phosphate CPF plant. A straightforward and intuitive scale-up procedure provides confidence in implementing CPF flowsheets at commercial levels.

Figure 3. HydroFloat® CPF pilot plant

2.2 CGR Flowsheet

The generalized CGR circuit is shown below as Figure 4. A number of variations are possible; however, the basic theme is that a classified stream is taken from the mill circulating load and fed to a HydroFloat at a significantly coarser size than conventional flotation. The resulting underflow product is an effectively barren tail, which is removed from the flowsheet prior to conventional flotation. In the case of the El Soldado plant, the feed for the CPF plant is the SAG product, and the classification consists of two stages of cyclones[4]. It should be noted that either cyclones, screens or hydraulic classifiers like the CrossFlow® can be selected for this role and the final decision will depend on equipment scale and the desired classification characteristics. The fine streams from the classification units can be recombined to constitute a stream suitable for conventional flotation.

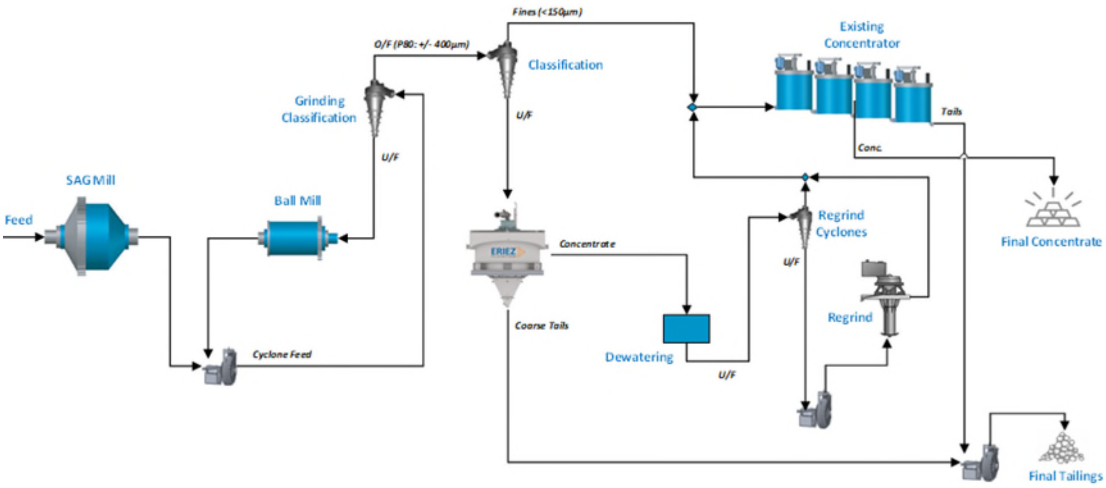

Figure 4. Coarse gangue rejection simplified flowsheet.

2.3 Benefits of CGR CPF

2.3.1. Milling energy reduction

The reduction in grinding power that is allowed by a coarser grind size can be used to reduce the overall power consumed at the same throughput, or it can be used to increase the mill throughput at the same level of power. In the reported Cozamin case study [3], which was a polymetallic sulfide, it was estimated that the ball mill energy could be decreased by 30-50%. For the copper sulfide example reported by Pyle *et. al.* [4], it was estimated that the total grinding energy for a SAGBM circuit could be reduced by 24%.

2.3.2 Production of coarse tails

The geotechnical stability of fine tails, especially when impounded in water, has been a major concern for mining companies, investors, governments, and communities at large. Fine particle slurries have rheological properties that make impoundments costly to maintain and unpredictable in their long-term performance. The implementation of a CGR circuit allows for the removal of a portion of the tail as a separate stream of coarse particles, typically 2-3 times coarser than the conventional tail. In the Cozamin study[3], approximately 30% of the mill product was removed, with a d80 size of 600 microns and without fine particles, compared with the conventional tail d80 of 230 microns and broad particle size distribution. At 600 microns and without fine particles, its hydraulic conductivity makes this stream easy to de-water and suitable as a stable building material that does not need to be impounded.

Another new approach is to combine the separate coarse and fine tail streams in an engineered system to recover water more effectively. Anglo American has recently published information about their technology, called "Hydraulic Dewatered Stacking" (HDS) [8,9]. This system uses interleaved layers of coarse and conventional tailings, with the coarse layers "wicking away" water from the fine layers. HDS has also been piloted at El Soldado with a 250,000 cubic meter impoundment. Using a 3-D network of alternating coarse and fine deposits with drainage channels, early results have achieved 80% water recovery, and the target is to reach 85%. Since water contained in tails is the major source of water loss in mineral processing, this approach is a major step forward in the goal of net-zero water consumption.

2.3.3 Higher recovery because of differences in milling

Overgrinding and the production of fines is one of the major losses in commercial flotation. An examination of metal deportment by size in two world-scale copper porphyry plants (one in North America and one in the Andean region) showed a significant fraction of the pay-metal losses in the size class below 53 microns (Wasmund *et. al*., 2019), shown as Figure 5. These results confirm poor recovery of fine particles by conventional flotation. Target minerals often also have significantly higher densities than the accompanying gangue, and also lower work indices, so there is evidence that liberated high density ores can be trapped in a mill circuit closed by cyclones, and when this happens, they will be preferentially overground, lessening their chances of being recovered in the subsequent flotation step (Sherman, 2023). One of the advantages of CGR is that shifting (coarsening) the endpoint of grinding reduces the production of fines. In the Cozamin study, the simulated CGR flowsheet was able to reduce the mill circulating load from the base-case of 186% to 50% when CGR was introduced [3]. Reducing the circulating load should reduce the overgrinding of target minerals under these circumstances.

The adoption of new milling circuits also promises to increase the efficiency of CGR by reducing fines as a mill product. The combination of high-pressure grinding rolls (HPGR) and vertical stirred mills can produce less fines than more common combinations such as crushing and ball milling. A South American copper ore was used as the comparison by Weir Minerals, who subjected the ore to milling by HPGR and a vertical stirred mill (Swiss Tower Mill, STM) vs 3-stage crushing /ball milling, while targeting the same P80. Swiss Tower mills are ideally suited for reducing fines because of their multi-compartment design and the selective grinding feature allowing operation in open circuit. Figure 6 shows the resulting size distributions, showing approximately 33% more minus 38-micron material in the 3-stage crushing/ball mill product. The pay elements within this size fraction are difficult to recover by conventional flotation, so the combination of coarsening the grind and selecting grinding technologies that produce less fines will improve the loss of fine material by conventional flotation in a CGR circuit.

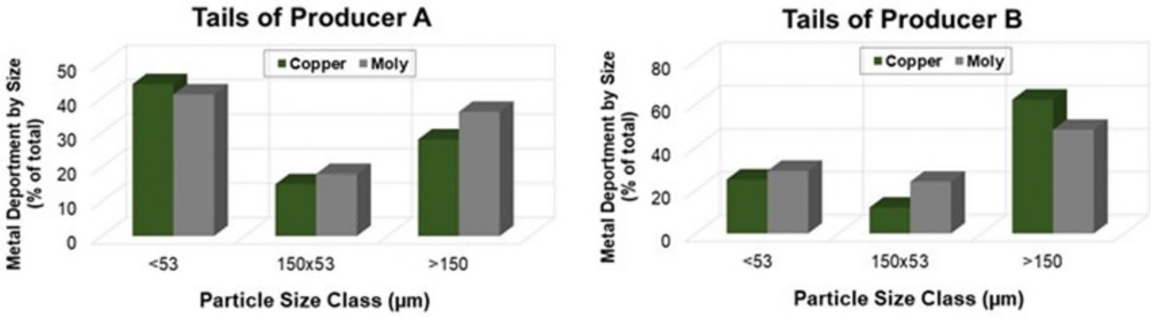

Figure 5. Copper and molybdenum deportment by size for the final tails from two copper porphyry concentrators in the Americas, each greater than 100,000 tonne per day [8]

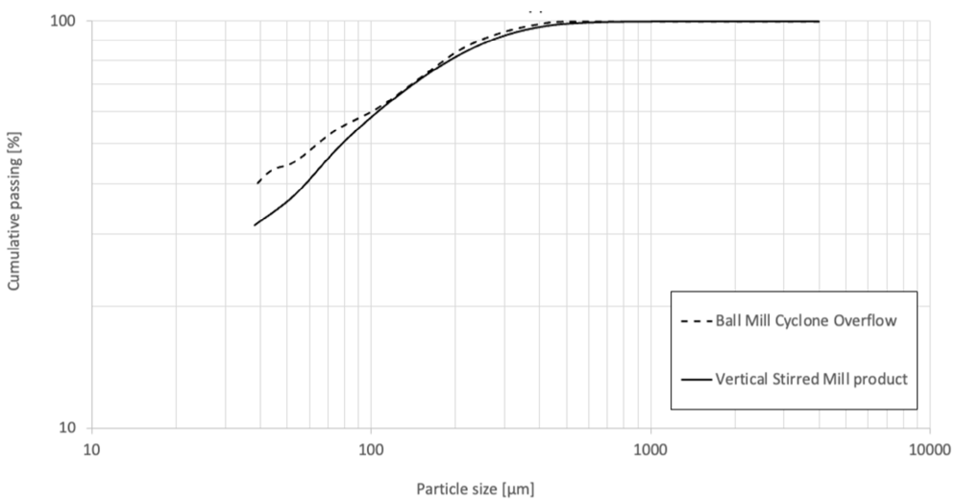

Figure 6. Copper ore from South America, subjected to 3-stage crushing/Ball mill circuit and HPGR/Vertical stirred mill product

3. CONCLUSION

This paper highlights the most recent developments of the coarse gangue rejection (CGR) application of coarse particle flotation, including techno-economic studies, test-work, and results from commercial implementation. The benefits of CGR include reduction in: grinding energy, conventional flotation requirements, the loss of fine particles resulting from overgrinding, and the production of unstable and potentially dangerous tails. Additionally, CGR circuit can be employed to maximize improvements in plant throughout and water recovery. Further improvements in CGR are accessible when using less traditional grinding circuits such as the combination of HPGR and vertical stirred mills.

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