COARSE GOLD RECOVERY USING FLOTATION IN A FLUIDIZED BED

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ABSTRACT

A number of technologies are in practice for selectively removing coarse gold from conventional grinding circuits. These circuits are often designed so that the grinding mill output is size classified, with large (or high density) particles being removed before the tails are returned to the mill. Because of the high relative SG of gold, and the fact that some forms of gold such as free gold do not break apart during conventional grinding, coarse gold can accumulate in the circulating load, and eventually be lost.

Eriez has developed a flotation cell that uses fluidized water to enhance flotation of coarse particles. More than 40 units have been sold in industrial minerals, and we are now exploring applications for the HydroFloat® in the gold industry.

Mineros S.A currently produces approximately 120,000 oz of gold per year by gravity concentrating alluvial gold ore with a mean particle size of 330 microns, followed by further concentration using a Falcon separator. A 400 mm diameter pilot-scale HydroFloat® was added to the tails of the Falcon to test whether additional gold could be captured. Enrichments of 50-600 times and recoveries normally in excess of 95% were achieved. This allowed direct smelting of the gold concentrate. Metallurgical results and operating parameters such as water addition and power will be discussed during the presentation.

This result opens the possibility that the HydroFloat® could be used directly in the grinding circuit, for removing coarse gold in the circulating load. This work also shows the possibility that the HydroFloat® can produce a throwaway tail, which will reduce the size of the circulating load stream and the grinding requirements of the circuit.

KEYWORDS

Flotation, fluidization, gravity concentration, gold

INTRODUCTION

Mineros S.A. is the largest gold producer in Colombia. In 2012, the company produced approximately 120,000 ounces of gold from its two operations: one alluvial, and the other an underground mine, both located in the province of El Bagre, Antioquia, Colombia.

Mineros S.A. is known not only for being the largest gold producer in Colombia, but also for being a socially and environmentally responsible company. In 2011, it received a Responsible Mining Award from the Government of Antioquia and the Calidad Corporation. In early 2012, as part of its environmental policy, Mineros S.A. began work on an ambitious project called 'No Mercury'. The 'No Mercury' project aimed to eliminate completely the use of mercury in all of its production processes.

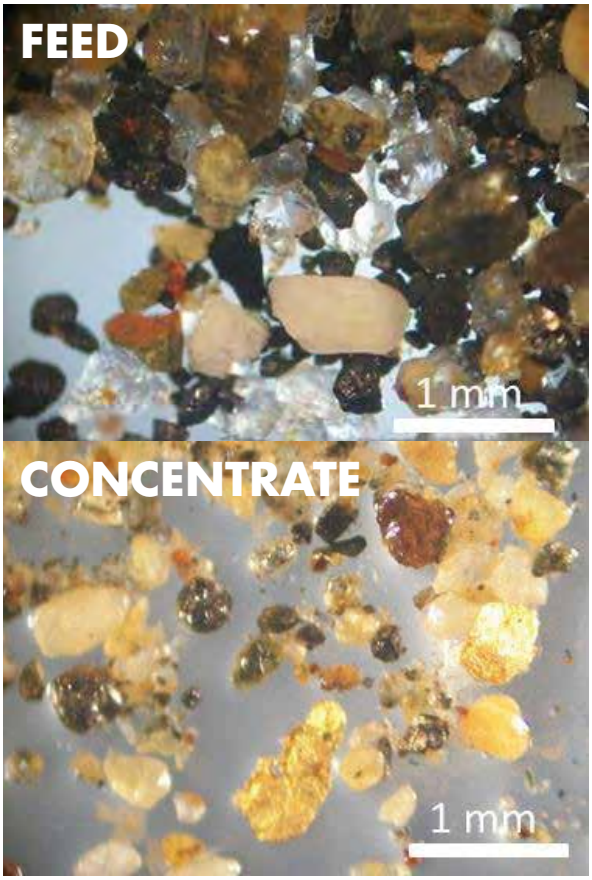

FIGURE 1
Optical photomicrographs of the head sample (left) and concentrate (right) used in the laboratory tests

FIGURE 2
Photograph of the Eriez HydroFloat® HF-400 pilot cell at Mineros facilities

Mineros S.A. has now eliminated mercury from its operations, employing instead a combination of gravimetric equipment to perform the concentration. However, significant amounts of gold have been observed in the tailings produced by the gravimetric process in the final concentration process in the Beneficio Plant at El Bagre, quantities varying between 5 g/t and 47 g/t Au.

In 2012, Mineros S.A. contacted the Eriez Flotation Division to conduct flotation tests with the aim of optimizing gold recovery, specifically to recover the gold that gravimetric equipment was not able to recover. To this end, the Eriez Flotation Division carried out laboratory scale tests at its Research Centre and Test Lab in Erie, Pennsylvania, USA. The promising results obtained from these tests led to two series of pilot tests being carried out at the Mineros S.A. Beneficio plant at El Bagre, Antioquia, Colombia. The results of these tests are presented in this paper.

ORE CHARACTERISTICS

The gravimetric equipment used at the Mineros Beneficio plant are not efficient at recovering certain particles such as fine free gold and some free gold laminar particles which have natural buoyancy characteristics. For this reason, Mineros S.A. searched for a clean alternative process for recovering gold from the tailings generated by the gravimetric process. Flotation was selected for further investigation.

The feed for the flotation tests was the tailings from a production gravimetric process, in this case a Falcon. These tailings are composed of alluvial sand, with particle size varying between less than 0.15 mm and greater than 2.00 mm (0.150 x 2.00 mm).

At Mineros, the tailings from the gravimetric process of the Beneficio Plant (El Bagre) are classified into groups: low grade tailings with a grade varying between 5 and 10 g/tonne; and high grade tailings with a head grade varying between 33 and 47 g/tonne.

The laboratory tests and the phase 1 pilot test work were carried out with the low grade ore, while the pilot 2 tests were performed with both types of ore. Figure 1 shows optical images of the feed ore and concentrates from the laboratory tests.

ERIEZ HYDROFLOAT®

The technology chosen to conduct the flotation tests was the Eriez HydroFloat®. The laboratory tests were carried out in the HydroFloat® HF-150 (150 mm diameter), and the pilot tests were performed in the HydroFloat® HF-400 (400 mm diameter). Figure 2 shows the HydroFloat® HF-400 pilot cell at the Mineros S.A. Beneficio plant.

The operating principle of the HydroFloat® cell has been fully discussed (Mankosa and Kohmuench, 2003; Kohmuench et al., 2007; Kohmuench et al, 2010; Kohmuench et. al.,2013). In this paper we present a summary of the operation of this cell.

FIGURE 3
Simplified diagram of the HydroFloat® cell

The HydroFloat® carries out the concentration process based on the combination of two principles:

- Fluidization: Which creates a high density particulate bed with good contact between bubbles and particles, and a fluidization medium that creates an upward bias which assists in the selective removal of bubble-particle aggregates
- Flotation: The bubble-particle aggregate, formed by the selective adhesion of the hydrophobic ore onto the air bubble, has an effective SG which imparts buoyancy

To effect the concentration of a particular ore, the HydroFloat® cell uses fluidization water which has been aerated with micro-bubbles of air.

Figure 3 is a cutaway diagram of the HydroFloat® cell, showing two main parts: the upper part, in which separation takes place, and the lower part (cone) in which dewatering takes place.

The feed (pulp) is added into the upper part of the cell, while the fluidization water is added through a system of pipes in the lower part of the cell. The key is to create a uniform flux of the fluidization water. Compressed flotation air and small quantities of frother are added to the fluidization water. The hydrophobic ore particles are carried by the air bubbles through the fluidized bed and into the freeboard. The freeboard is a quiescent laminar zone where detachment and "drop-back" of collected ore particle is minimized. The bubble-particle aggregates, along with the majority of the fluidization water, are collected from the launder. The tailings are extracted through the lower part of the cell through a control valve which controls the bed level.

The HydroFloat® cell has the following design characteristics:

- The process capacity is determined by the cross-sectional area: 20 tonnes/h-m^2 – 30 tonnes/h-m^2.
- There is a higher efficiency of flotation air consumption: approximately 10% of the air consumed by conventional flotation cells.
- Consumption of reagents is reduced: in some applications, following the installation of the HydroFloat®, it was possible to reduce the consumption of reagents (collector) by between 10 - 40%.
- Parts: conventional cells have internal moving parts (rotor and stator) which experience heavy wear through being in contact with course ore. The HydroFloat® cell does not experience this problem because it does not have internal moving parts.
- Particle size in the feed: the HydroFloat® is being employed industrially to float particles of up to 3,000 µm (phosphates). For optimum performance it is recommended to work within a distribution of particle size of 1:6.
- Percentage of solids: the HydroFloat® cell can work with pulps with percentages of solids between 40% and 80%. The tailings produced in the HydroFloat® emerge with a percentage of solids similar to the feed, due to the dewatering zone.

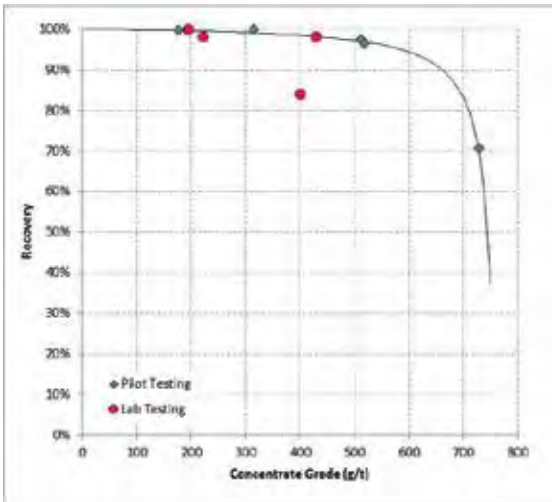

FIGURE 4
Relationship between concentrate grade (g/tonne Au) and recovery (Au %) in laboratory testing and the phase 1 pilot test

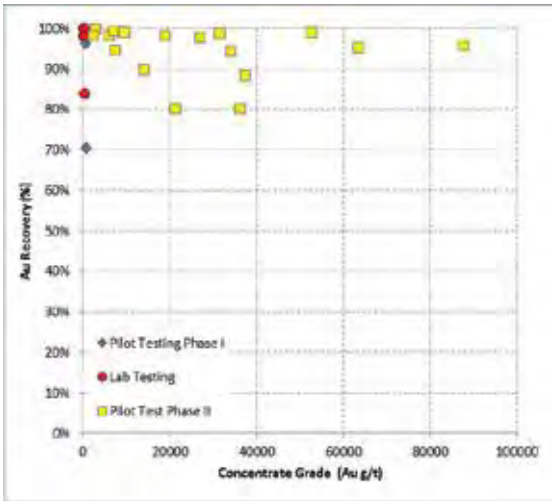

FIGURE 5
Relationship between concentrate grade (g/tonne Au) and recovery (Au %) in laboratory tests and the pilot tests phases 1 & 2

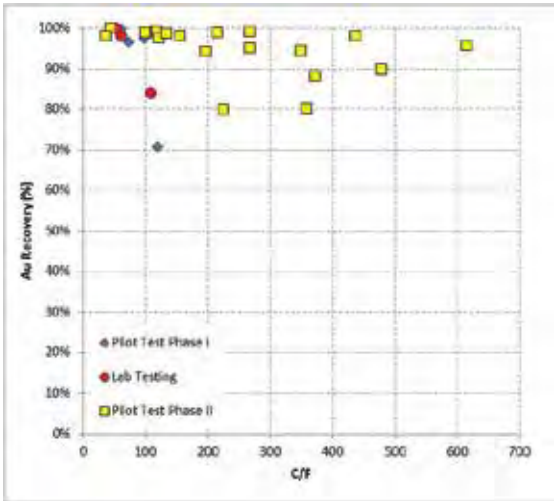

FIGURE 6
Relationship beteween ration (C/F) and recovery (Au %)

A recent investigation at the Wark Institute under the AMIRA P260 program benchmarked the flotation recovery of the HydroFloat® against a lab Denver cell for a well characterized sphalerite system and concluded that the HydroFloat® was much more effective for ore particles greater than about 400 µm (Awatey et. al., 2013; Awatey et. al., 2014).

RESULTS AND COMMENTARY

The first tests conducted were laboratory scale tests in which it was found possible to recover more than 98% of the gold content in tailings resulting from the gravimetric process. Having observed these promising results, Mineros S.A. decided to acquire a pilot HydroFloat® to carry out tests at their site in Colombia.

The relationship between the recovery (% Au) and the concentrate grade (g/tonne Au) of the laboratory scale and the first pilot campaign ("pilot phase 1 testing") is shown in Figure 4. It can be seen in this figure that the results of the first phase of the pilot tests show the scalability and reproducibility of the laboratory tests. That is, the pilot phase 1 results achieved recoveries of greater than 98% and concentrate grades between 180 g/tonne and 700 g/tonne.

In the laboratory tests and phase 1 pilot tests, the main aim was to determine if the flotation in the HydroFloat® cell could recover more than 95% of the gold content from the gravimetric tailings. Having confirmed the feasibility of achieving this level of recovery, Mineros S.A. decided to assess the high grade gravimetric tailings and determine if it was a possible to produce concentrates of a higher quality (greater than 5,000 g/tonne Au) so that the concentrate could be directly smeltable.

In the second pilot campaign, the main objective was to generate higher grade concentrates. Figure 5 shows the relationship between the recovery of gold and the grade of concentrates produced in all the tests, including the results of the pilot phase 2 tests. In the second phase of the pilot tests, most recoveries were found to be above 90%, with average recoveries of 95% Au, though at certain points recoveries were found to be greater than 98%. Furthermore, in the second phase of pilot tests it was found possible to produce much richer concentrates, with grades of up to 87,669 g/tonne Au.

The production of higher grade concentrates in the second phase of the pilot tests was partly due to the higher feed grade in comparison with the earlier tests, and partly due to the operational conditions of the HydroFloat®, which were optimized to increase selectivity. This is reflected in Figure 6, which shows that while the highest enrichment ratio in the laboratory and pilot 1 tests were 100 times; in the pilot 2 tests it was found possible to achieve enrichment ratios higher than 600 times. It is important to note that it was possible to achieve these high enrichment ratios without detriment to recovery.

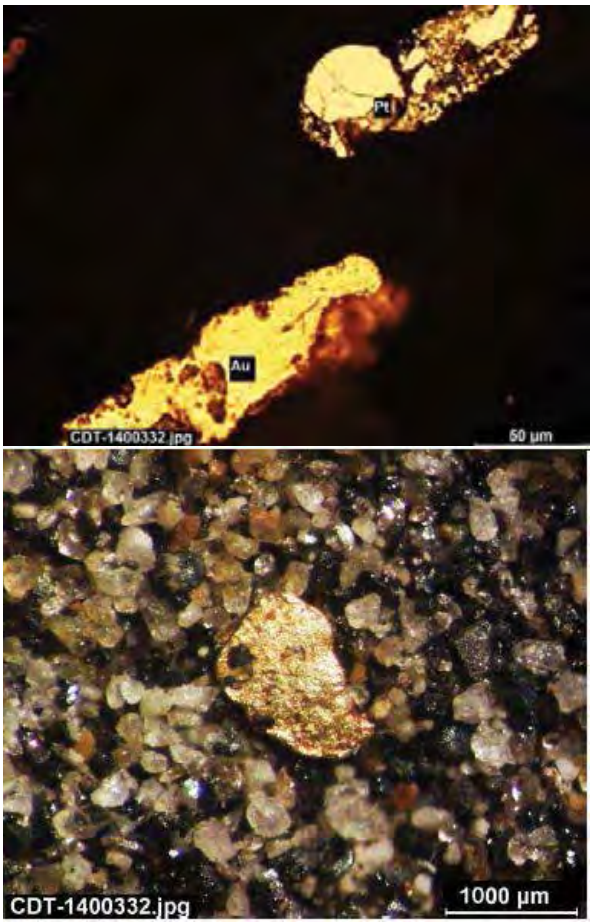

FIGURE 7
Microscopy of the HydroFloat® concentrates obtained in pilot test 2

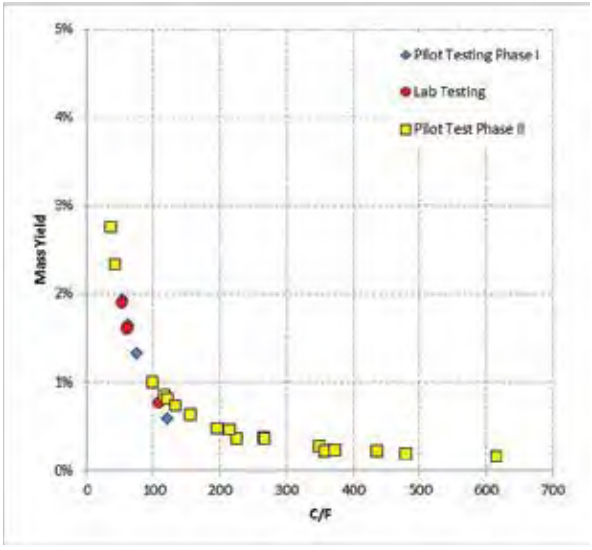

FIGURE 8
Relationship upgrade ratio (C/F) and mass yield

Mineros S.A. conducted an optical microscopy study of the concentrates in the second phase of pilot tests, some results are shown in Figure 7. It was found that the concentrates are mainly composed of minerals such as quartz, magnetite and zircon. Most of the gold particles are in free form – laminar, extended, in sizes varying between 0.3 mm and 1.0 mm. In addition to the free gold particles, some gold/silver associations were identified.

With the concentrates from the pilot 2 tests, Mineros S.A. conducted smelting tests, and determined that these concentrates can be directly smelted. This finding is very important, as the need to use other reagents and pollution-producing processes (eg. amalgamation or cyanidation) in the production of gold is eliminated.

Another important finding in the tests was that high recoveries (>95% Au) can be achieved with mass yield (mass pull) less than 3%. Figure 8 shows the enrichment ratio (C/F) vs mass yield. This relationship is important because from it we may determine the point at which we need to operate in order to obtain the required quality of concentrate.

CONCLUSIONS

The results of the laboratory and pilot tests show that the Eriez HydroFloat® cell is capable of efficiently recovering alluvial gold particles from tailings resulting from the gravimetric process such as tables, Falcon or Knelson concentrators. It has been found possible to obtain recoveries of 95% Au on average, and at several points recoveries were greater than 98% Au.

In the second phase of pilot tests it was found possible to produce concentrates with grades of up to 87,669 g/t Au, and concentration ratios of up to 615 times.

The results of the microscopy of the HydroFloat® concentrates showed that it was possible to float laminar gold particles with sizes of between 0.3 mm and 1.00 mm.

The quality of the concentrates obtained in the phase 2 pilot tests allowed them to be directly smeltable.

In summary, we can say that the HydroFloat® cell technology has been shown to be feasible and eco-efficient for the recovery and concentration of free gold.

Based on these positive results, the HydroFloat® is also being evaluated at other plants as a unit operation in gold and copper applications for treating the cyclone underflow from a conventional primary grinding circuit. Results will be reported in the near future.

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