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Steady-State Simulations and Commissioning To Improve Gold and Silver Recovery in A Grinding And Flash Flotation Circuit

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Abstract - In "La Plata" mine (located in Zacatecas, Mexico), low gold recovery (21±5%) in the flash flotation cell was identified. This also has the consequence that, even when including the flash cell and the complete flotation circuit (rougher, scavenger, and cleaner cells), the global gold recovery does not exceed 78±5%. In the present work, an evaluation of the concentration process efficiency in the "La Plata" was carried out. This was done by process sampling, ore characterization, and steady-state simulation. For the adequate determination of the mass balance and the model´s adjustment, an appropriate sampling strategy was proposed to get representative information about the process. This was particularly difficult in plants that do not have automatic control systems. Additionally, a repetition algorithm was developed to evaluate various operating conditions through steady-state simulation. Mineralogical characterization shows that quartz, feldspar, clay, silicates, and pyrite are the most common ores in fresh feed. Gold and silver appear as electrum, native gold, and acanthite (Ag_2S). These valuable minerals are liberated below 100 microns. After the sampling and simulation work (where a regrinding circuit was evaluated), modifications were made to the process and the best simulation results were commissioned. Daily monitoring was carried out for 41 days of operation, evaluating variables such as grade and recovery for gold and silver of the entire process and specifically of the flash flotation cell. The increase of gold recovery in the flash cell was 27% and the global gold recovery was close to 12%. Also, silver recovery was improved (5.5% in flash cell and 6% in global silver recovery).

***Keywords*:** Gold and Silver Recovery; Flash flotation Cell; Regrinding; Commissioning

1. Introduction

"La Plata" is a concentrator plant located in Zacatecas, Mexico (Fig. 1), has a nominal processing capacity of 375 t/d, with 5.27±1.60 g/t Au and 58.65±16 g/t Ag.

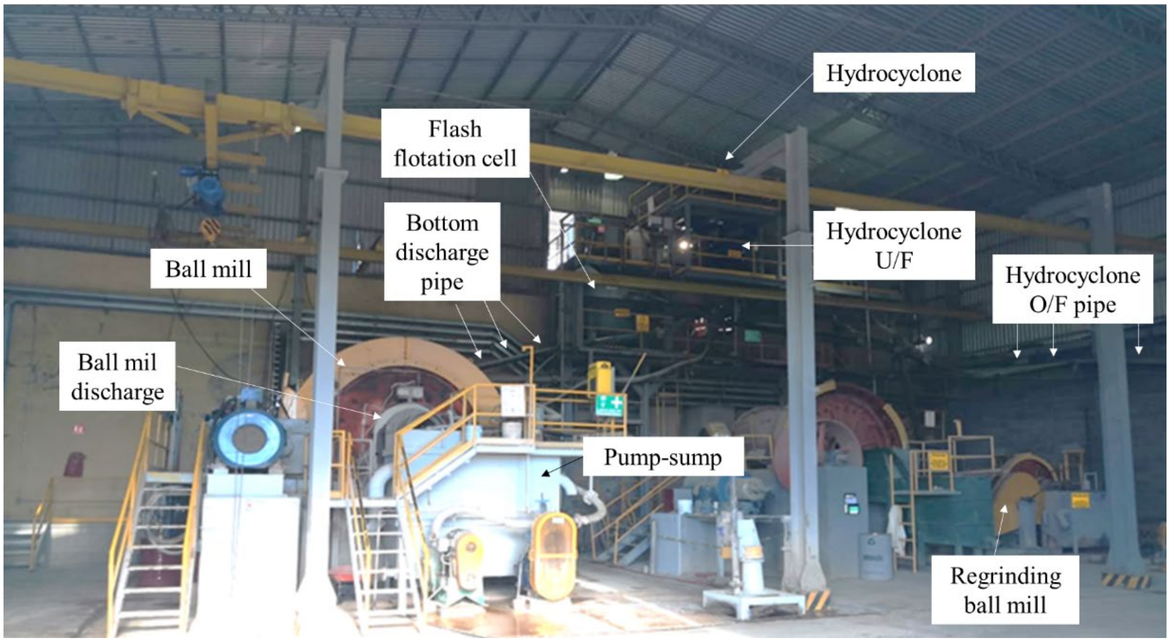

Fig. 1: "La Plata" grinding, classification and flash cell layout

When the mineralogy or textural properties of the minerals to be floated, particularly the grain size, change during the operation of the plant, operational problems arise in the flash flotation cell. Fig. 2 compares the particle-size distribution with the gold recovered in the flash flotation cells concentrate of two mining operations (Kannan Belle gold mine in Australia [1] and "La Plata" mine in Mexico). At the Kanowna Belle gold mine, 50% of the gold recovered in the flash cell concentrate has a size greater than 300 µm. This means that the flash cell fulfils the function of floating coarse particles, in that case auriferous pyrites.

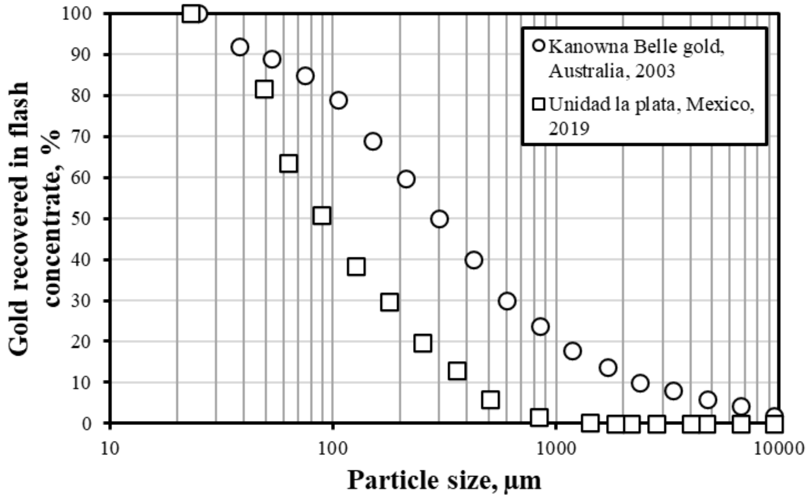

Fig. 2: Comparison of mineral processing with the use of flash cells.

On the other hand, in the "La Plata" mine, where the particle-size distribution was like that at the Kanowna Belle gold mine, currently a concentrate gold recovery is obtained where 50% of the particles have a size less than 90 µm. This results in a low gold recovery (21±5%) in the Mexican plant, since the flash cell is most effective in recovering gold when more than 50% of the concentrate particles have a coarse size. This also has the consequence that, even when including the flash cell and the complete flotation circuit (rougher, scavenger, and cleaner cells), the gold global recovery does not exceed 78±5%. This is a common problem in concentration plants, since the processing of large volumes of material has led to the depletion of large high-grade ore reserves and is increasing the need for the processing of minerals with more complex mineral associations.

The flash flotation cell was designed to recover coarse or fine particles with high density and rapid floatability, containing high grades of the mineral of interest. This cell is especially important in processes involving the recovery of precious minerals (such as gold and silver), because these very dense particles are classified as "coarse particles" and are returned to the ball mill as circulating load in a conventional grinding and classification circuit. The flash cell helps recover these valuable particles from the grinding station. In addition to the flash flotation cell design, it is well known that the recovery of coarse particles greater than 300 microns is favoured under very different conditions than the flotation of fine particles smaller than 75 microns [2-4]. For coarse particle flotation, a low froth depth is promoted, resulting in a low froth retention time. This is intended to prevent valuable coarse particles becoming detached from the bubbles and draining to the bottom of the cell [5]. A low stirring speed (sufficient to keep the pulp in suspension) and very high concentration of collector are also promoted, favouring the phenomena that occur in the collection zone: collision, adhesion, and stability [6-9]. In some cases, the stirring speed will not be enough to keep the pulp in suspension, so a by-pass of very coarse particles towards the bottom of the cell is identified [10]. The frother selection is a factor of great importance, and it is accepted that, to float coarse particles, large bubbles with greater hydration must be generated in the collection zone [11]. Therefore, a high molecular weight frother is preferred, favouring bubble hydration and froth stability [12-15].

Gold flotation is particularly important in this research, there is evidence that gold is oleophilic so it can absorb traces of oils or organic matter making it "naturally hydrophobic" or acquiring a certain degree of "natural floatability". There is evidence for xanthate adsorption on gold due to electrochemical reactions involving xanthate and oxygen ions. Chemisorption of ethyl xanthate on gold, silver, and gold-silver alloys has been studied using various methods by [16]. This work showed that ethyl xanthate was chemisorbed on the silver sites in the gold-silver lattice potentials below those at with silver ethyl xanthate was formed. Dithiophosphates (DTP) typified by sodium Aeroflot® are believed to act in similar way to xanthates. [17] investigate the selective adsorption of organic collectors on gold particles and electrum by ToF-SIMS and ToF-LIMS techniques identifying that silver has a marked effect on free gold flotation kinetics. Silver activates gold floatation and there is a strong correlation between the surface concentration of silver and the loading of certain collectors. Therefore, the recovery of particles with gold and silver in a flash flotation cell will depend on several physical and chemical factors. such as the design of the cell, the operating conditions, the size and density characteristics of the particles to float, and the chemical scheme used. In the present work, an adaptation strategy of a closed-circuit regrinding mill with the flash cell is proposed to increase the recovery of gold and silver, through steady-state simulation and subsequent commissioning on an industrial scale.

2. Materials and methods

2.1. Sampling

Five sampling campaigns were carried out (In Fig. 3 sampling points are presented). For each campaign, a composite of each sampling point was made, taking pulp every 15 minutes for two continuous hours. The mass required for size analysis was computed using the methodology of [18]. This provided sample confidence of 95%. The percentage of solids and the sieving using the √2 series were determined in each sampled stream. For the estimation of the metallurgical balance, the gold and silver were tested using fire assay at points 1, 3, 5, 7 and 8 (fresh feed, hydrocyclone fines, flash concentrate, final concentrate, and final tails). It is especially difficult to measure flash cell discharge flow. However, in the present study, the plant layout allowed the sampling of this stream with the same sampler used for the mill discharge. In streams that contained large quantities of coarse particles, the amount of sample used for size analysis was greater because of the large quantities of fine particles present. This achieved a confidence of 95%.

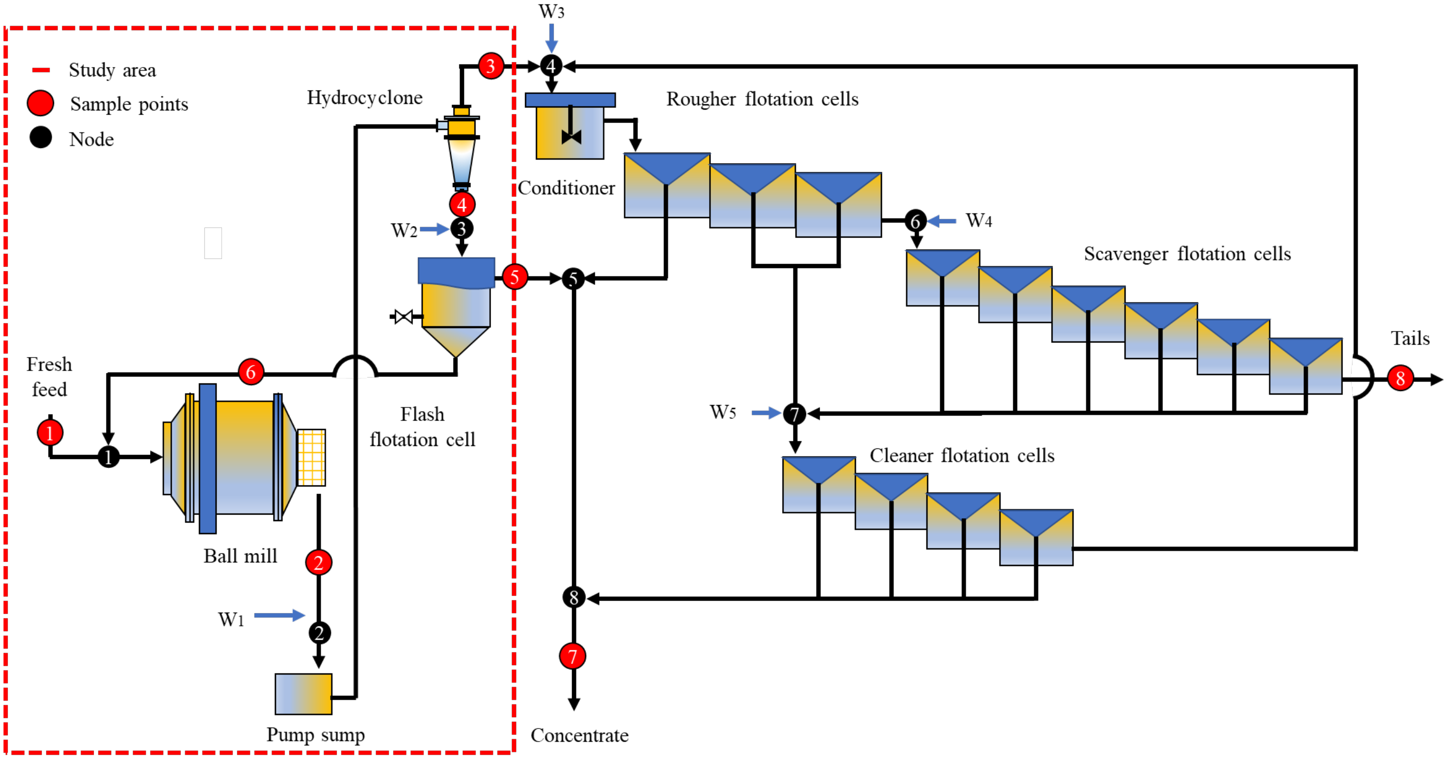

Fig. 3. Sample points

2.2. Algorithm development

For the computation of the adjustment parameters of all the models involved (mill, hydrocyclone and flash cell), the non-linear regression technique was used through the least-square method. As the mass flow Bi remains unbalanced, it was necessary to program in C# language an iteration algorithm to achieve a logical condition of solids and water balance $(Z[3][k] < conv\&\&Zw[5][k] < conv\&\&k < itera)$. This condition indicates that the solids and water balance error must converge when the variable conv reaches a value close to zero (conv= 0.001) to finish the simulation, recalculating in each cycle (k) the total mass flows, by fractions and water flows, before a given number of iterations ($itera$); this to accurately estimate the flows involved in the process, including Bi. Fig. 4 presents the simplified simulation algorithm for the original circuit.

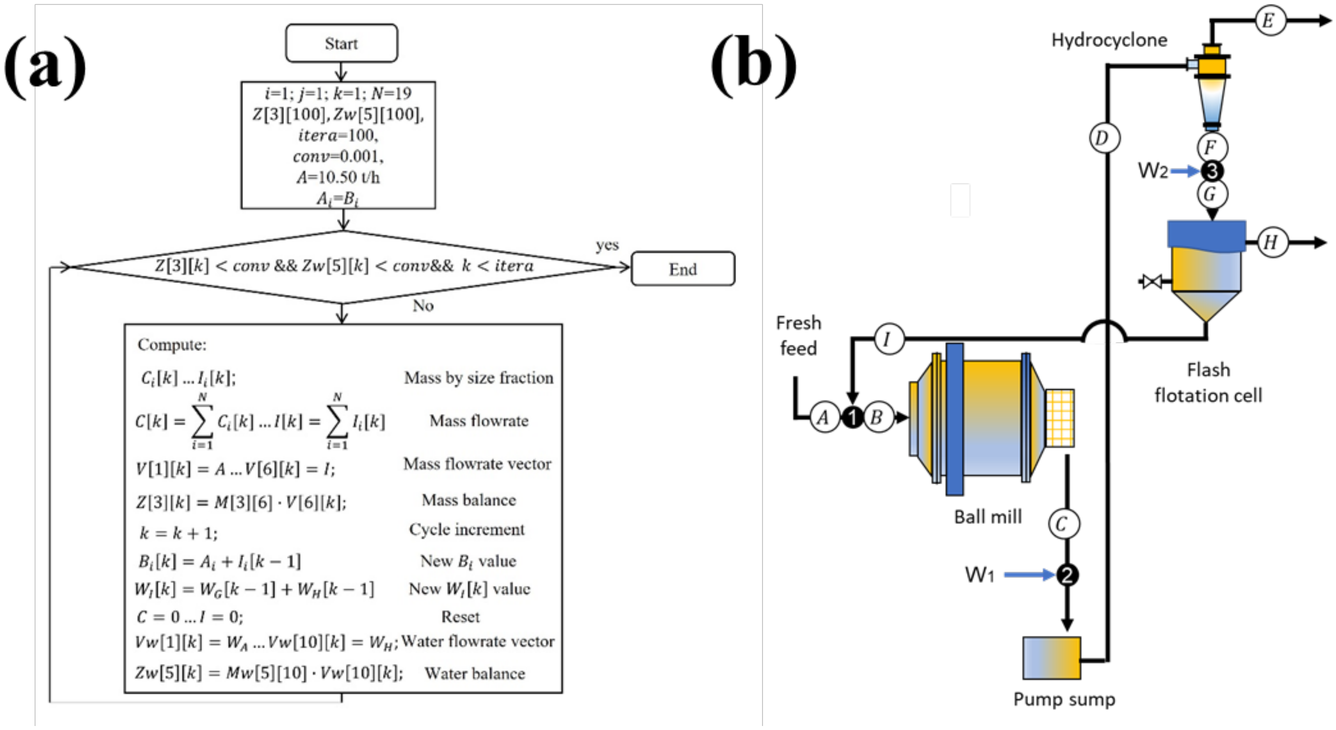

Fig. 4. Repetition algorithm (a), and study area (b)

2.3. Simulations

The simulations consisted of evaluating the installation of a closed-circuit regrinding mill. With this adaptation, it is expected to feed the flash cell a greater quantity of released particles that can be recovered in the concentrate.

3. Results

3.1. Mineralogy

Quartz, feldspar, clay, and silicates are the most common ores in fresh feed (Fig. 5(a and b)). Pyrite is the most abundant sulphide ore. In fresh feed, gold and silver represent much less than 1%, so their concentration is preferably reported in g/t. Both visible gold and silver in fresh feed are distributed in highly varied particle sizes (Fig. 5(c)). For example, the highest silver grade occurs in fractions from 75 to 38 μm, reaching an average of 520 g/t close to 50 μm, while the presence of gold occurs in a wide range of particle size, quantifiable from 1180 μm up to a maximum of 25 g/t at 19 μm. Therefore, an average fresh feed assay of 5.0 g/t gold and 58 g/t silver is obtained (with a variation close to 25% in each size fraction for both gold and silver).

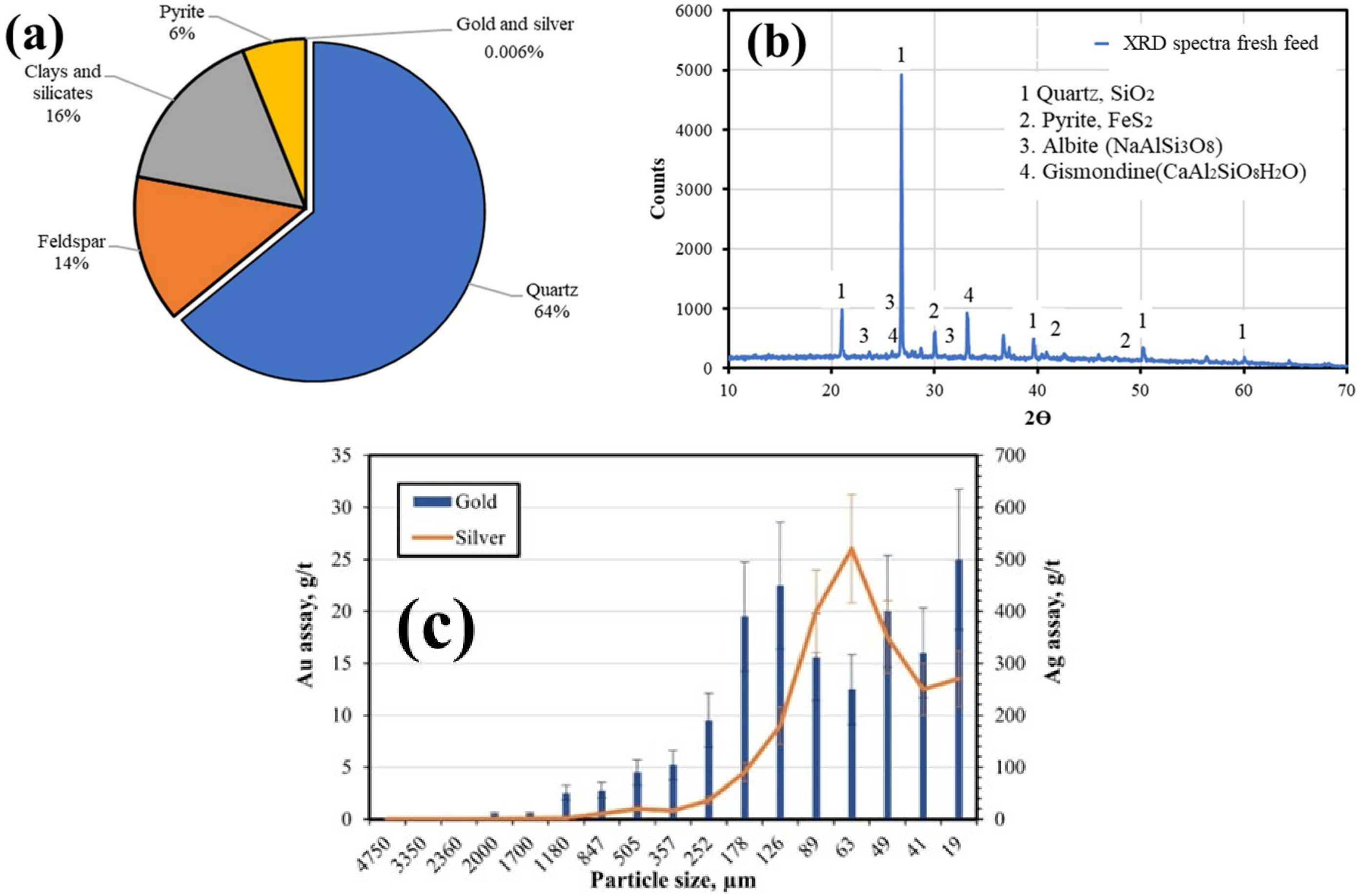

Fig. 5. Fresh feed mineralogy: (a) composition, and (b) Fresh feed minerals identification by x-ray diffraction.

In Fig. 5, it is observed that the particles with gold and silver of interest are reported in fine sizes under 100 microns, which is why a strategy is sought through process simulation to feed minerals in finer sizes to the flash cell. This is achieved by implementing a closed-circuit regrinding mill with the flash cell.

3.2. Steady state simulations

Table 1 presents the simulation of processes in the conventional circuit shown in Fig. 4. This table shows that in the feed flow *G* to the flash cell the mass flow is 38 t/h. On the other hand, in flow *H* the concentrate flow is only 0.02 t/h. It is also observed that the P80 size in the concentrate is close to 44 microns. The circulating load factor can also be calculated, which in this case is close to 3.6. Therefore, an operational work rate close to 16 kWh/t can be estimated. When the relationship between operational and laboratory work index is evaluated, a relationship no greater than 1.1 is obtained, therefore the consumption of electrical energy in the silver mining unit is adequate according with [19].

Table 1. Simulations of traditional circuit

Fresh feed (*A*)		**Mill feed (*B*)**		**Mill discharge (*C*)**		**Hydrocyclone feed (*D*)**		**Hydrocyclone O/F (*E*)**	
Ore, t/h	10.50	Ore, t/h	48.48	Ore, t/h	48.48	Ore, t/h	48.48	Ore, t/h	10.48
Solids, %	97.58	Solids, %	71.36	Solids, %	71.36	Solids, %	48.94	Solids, %	21.95
Water, m³/h	0.26	Water, m³/h	19.45	Water, m³/h	19.45	Water, m³/h	50.58	Water, m³/h	37.28
P_{80}, µm	3109.64	P_{80}, µm	586.22	P_{80}, µm	327.78	P_{80}, µm	327.78	P_{80}, µm	95.67
Hydrocyclone U/F (*F*)		**Flash cell feed (*G*)**		**Flash cell conc. (*H*)**		**Dilution (*W*1)**		**Dilution (*W*2)**	
Ore, t/h	38.00	Ore, t/h	38.00	Ore, t/h	0.02	Water, m³/h	31.13	Water, m³/h	6.18
Solids, %	74.05	Solids, %	66.09	Solids, %	6.45				
Water, m³/h	13.31	Water, m³/h	19.49	Water, m³/h	0.29				
P_{80}, µm	383.47	P_{80}, µm	383.47	P_{80}, µm	44.56				

Table 2 presents the simulation that was commissioned on an industrial scale. This table shows that the flash cell concentrate could have a P80 close to 40 microns at a feed flow to the flash cell of 51 t/h. With this information, a much greater quantity of gold and silver particles recovered in the flash concentrate is expected. Additionally, the mass flow of feed to the remoulding mill was calculated, calculated at 7.7 t/h.

Table 2. Simulation of circuit with regrinding station

Fresh feed (*A*)		**Mill feed (*B*)**		**Mill discharge (*C*)**		**Hydrocyclone feed (*D*)**		**Hydrocycl. O/F (*E*)**		**Hydrocyclone U/F (*F*)**	
Ore, t/h	10.50	Ore, t/h	54.24	Ore, t/h	54.24	Ore, t/h	54.24	Ore, t/h	10.47	Ore, t/h	43.77
Solids, %	97.58	Solids, %	66.39	Solids, %	66.39	Solids, %	48.07	Solids, %	20.89	Solids, %	69.81
Water, m³/h	0.26	Water, m³/h	27.45	Water, m³/h	27.46	Water, m³/h	58.58	Water, m³/h	39.66	Water, m³/h	18.92
P_{80}, µm	3109.64	P_{80}, µm	511.38	P_{80}, µm	285.44	P_{80}, µm	285.44	P_{80}, µm	82.89	P_{80}, µm	328.02
Flash cell feed (*G*)		**Flash cell conc. (*H*)**		**Flash cell tails (*I*)**		**Regrind. mill feed (*J*)**		**Regri. mill disch. (K)**		**Dilution (*W*1)**	
Ore, t/h	51.48	Ore, t/h	0.03	Ore, t/h	43.74	Ore, t/h	7.71	Ore, t/h	7.71	Water, m³/h	31.13
Solids, %	62.10	Solids, %	6.00	Solids, %	61.66	Solids, %	67.27	Solids, %	55.00		
Water, m³/h	31.41	Water, m³/h	0.47	Water, m³/h	27.19	Water, m³/h	3.75	Water, m³/h	6.31	**Dilution (*W*2)**	
P_{80}, µm	312.46	P_{80}, µm	38.53	P_{80}, µm	312.58	P_{80}, µm	312.58	P_{80}, µm	256.04	Water, m³/h	6.18

3.3. Commissioning

In fig. 6 (a-d) presents variables of interest during the commissioning of the modifications derived from the simulation, this during a commissioning period of 41 days. In Fig. 6 (a and b), it is observed that both the global recovery of gold and silver tends to increase to the value calculated by the simulation.

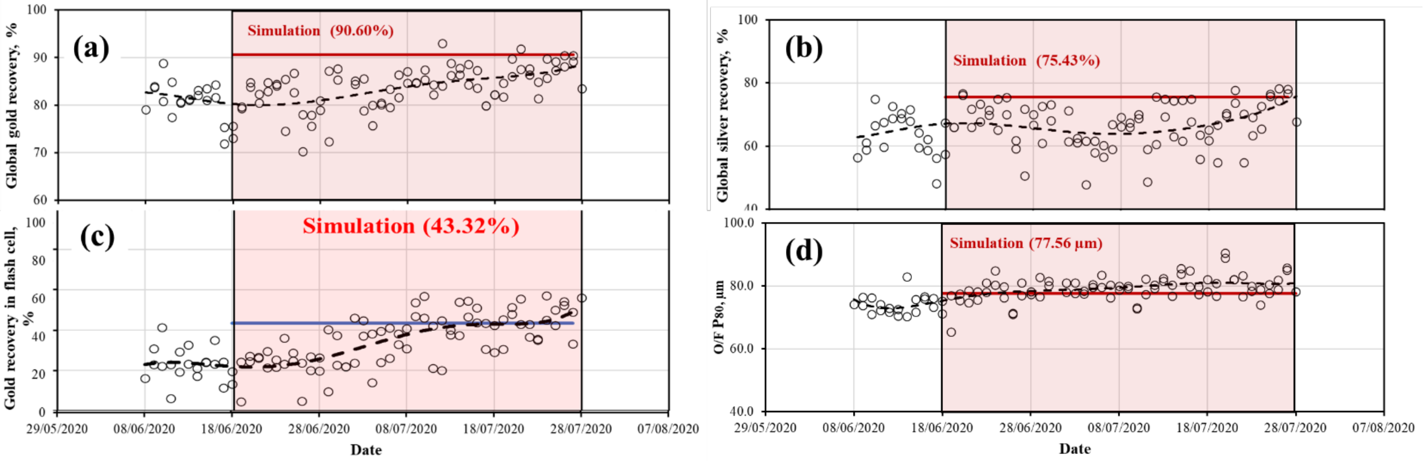

Fig. 6. Commissioning

In the figure. 6(c) a significant increase in gold recovery in the flash cell is observed, close to 50%, in a single cell. Therefore, alternatives can be proposed to reduce the number of flotation cells in the conventional flotation circuit. On the other hand, in Fig. 6(d) it is observed that the P80 size of the hydrocyclone o/f is not significantly modified, so this reason does not significantly change the behaviour of the flotation after the flash cell.

4. Conclusion

In the present work, the solution of a low gold recovery problem was obtained by making interesting changes to the re-grinding ball mill circuit that includes a flash flotation cell. This was done by taking advantage of the information generated through the process diagnosis, the mineralogical characterization, the processes of steady-state simulation, and the industrial commissioning. It can be concluded that the process modifications allowed important improvements in gold and silver recovery in the flash cell and in global gold and silver recovery.

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