Effect of froth transport on the metallurgical performance in a large industrial flotation cell

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ABSTRACT

One of the main challenges in modern flotation cells are related to the increase in cell size and the consequent increase in the froth transport distances, which has an important effect on the froth recovery and concentrate grade.

This paper presents an evaluation of the metallurgical performance in an industrial flotation cell of 300 m^3 before and after changing the launders design. This change corresponds to a reduction in the froth cross-sectional area by installing a new design and arrangement of concentrate launders. The conditions before and after the new launders installation were predicted by a simulator that was built and calibrated using a wide industrial database, obtained from previous sampling campaigns in a large number of concentrators in Chile. The reduction in the froth area has a direct effect on froth recovery, which is characterized as a function of launder design, froth mineralization and operating condition, in the simulator.

Additionally, the metallurgical performance, before and after the new launders installation, and the effect of reducing the froth area were evaluated by sampling the industrial cell. Then, these results were compared with those predicted by simulation, showing a good agreement between data and simulation, with an error less than 3% (absolute). Thus, the suitable prediction of the results and the response sensitivity under changes in cell design characteristics, such as froth area and operating conditions, allowed the validation of the simulator for predicting different industrial operations. The simulator also allows for the estimation of the effect of launders design on key variables such as froth recovery, froth carrying rate, lip loading rate and others, that are not commonly obtained from plant surveys.

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INTRODUCTION

Flotation cells in industrial circuits have shown a significant increase in size over time. Large mechanical flotation cells of 300 m^3 are being widely used in plants (Yianatos et al., 2008a; Govender et al., 2014) and even cells up to 600 m^3 have been tested and used in industrial operations (Mattsson et al., 2017; Grau et al., 2018; Neethling et al., 2019).

The increase in cell size has brought several benefits for mineral processing such as lower specific energy consumption, more efficient control systems, simpler layouts and others, but some new challenges have come out related to cell design, operational conditions and control strategies. One of the most relevant aspects in cell design is the increase in froth transport distances when cell size increases, which impacts on the metallurgical performance, mainly decreasing the froth recovery. In this context, some research has been carried out on cell design characteristics. The effect of launder configuration on the froth transport have been studied by Coleman (2009) and Brito-Parada and Cilliers (2012). Additionally, Grau et al. (2019) studied the effect of launders configuration on the metallurgical performance at industrial scale, where an improvement in recovery was observed when the froth transport distances were shortened by modifying launders design.

This paper presents a study of the effect that launders design has on the metallurgical performance in an industrial cell of 300 m^3. For this purpose, an industrial simulator was used to predict the changes in metallurgical performance when a launder upgrade was carried out. These results were compared to those obtained from sampling surveys performed in plant. Additionally, the estimation of internal transport variables such as froth recovery, froth carrying rate, lip loading rate and gangue entrainment were analysed by means of the industrial simulator, comparing the original launder design and the launder upgrade.

METHODOLOGY

An industrial simulator was used to predict the metallurgical performance before and after the installation of the new launders in an industrial cell of 300 m^3, which belongs to the rougher circuit of Atalaya Mining Proyecto Riotinto. The simulator was built and calibrated using a wide industrial database, obtained from sampling campaigns performed in different concentrators in Chile.

Then, sampling campaigns were carried out in the industrial circuit of Riotinto and these results were compared with those predicted by the industrial simulator.

Industrial bank simulator

The flotation simulator considers the sequential calculation of each single cell in series, assuming a two-zone system: collection and froth (Finch and Dobby, 1990; Yianatos et al., 2008b).

The feed minerals are characterised in terms of size-by-liberation classes. Additionally, a perfect mixing plus by-pass flow model and a kinetic model, with a single rate constant (k) and a maximum recovery (R_{max}) per each size-by-liberation class, were used to characterise the collection zone.

On the other hand, the froth zone recovery was described as a function of the solid flowrate entering the froth by true flotation (as a proxy to account for the froth stability), launder design (represented by the froth transport distance) and froth residence time.

The gangue recovery by entrainment was estimated in terms of water recovery and the entrainment factor described by Yianatos and Contreras (2010). The water recovery was represented as a function of the solid froth recovery, froth depth and air flowrate.

The models used to build this simulator were reported by Yianatos et al. (2020) and the calibration and testing of the simulator was reported by Vallejos et al. (2020).

Industrial tests

Atalaya Mining Proyecto Riotinto:

A rougher flotation circuit of Proyecto Riotinto copper concentrator was studied. The rougher circuit consists of one cell of 300 m^3 and three cells of 100 m^3, as shown in Figure 1. Thus, the whole rougher bank is composed of four flotation cells with a total nominal volume of 600 m^3 in a configuration of 1+1+1+1 (Grau et al., 2019).

The sampling campaign consisted of sampling the feed, concentrate and tail streams from the first cell (300 m^3), as well as the final tail and concentrate streams of the rougher circuit. Thus, the metallurgical performance in the first cell and in the whole circuit was obtained. The sampling campaign was performed before and after the installation of the new launders in the cell of 300 m^3.

The feed flowrate during the sampling campaigns was 1196 t/h, with a Cu grade of 0.42-0.49%, solid content of 40-41% and a particle size (P_{80}) of 180-198 μm (Grau et al., 2019).

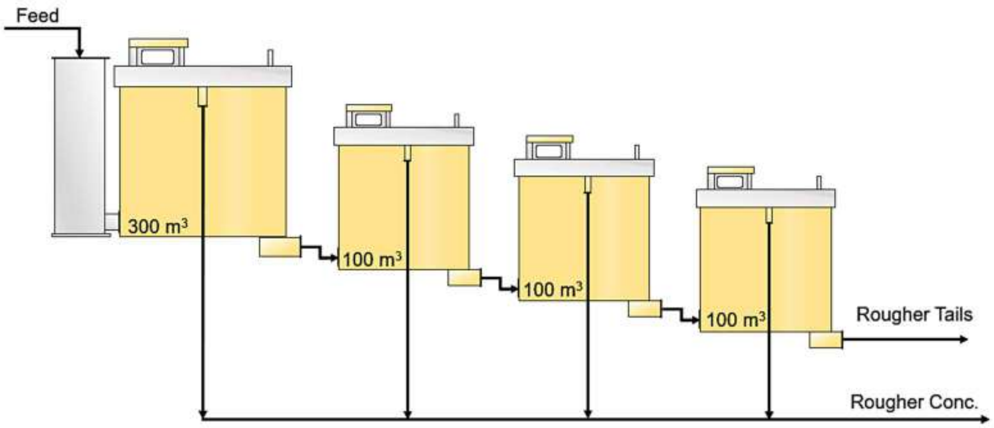

Figure 1. Rougher circuit at Atalaya Mining Proyecto Riotinto.

Concentrate launder design:

New concentrate launders were installed as an upgrade of the original launders (internal peripherical launders) in the first cell of the rougher flotation bank previously described (Figure 1). This installation considers a new adjustable crowder and center launders, whose objective was to improve the recovery of the cell and therefore the recovery of the rougher bank. The launder designs before and after the upgrade are shown in Figure 2. The new adjustable froth crowder and the additional center launders are highlighted in grey in Figure 2b. The center launders are indicated between the original froth crowder and the new adjustable crowder.

The new launders design drastically reduces the froth surface area to 36% of the original area and increases the overflow perimeter to 204% of the original perimeter, without significantly modifying the effective volume of the cell. This increases the froth recovery because of the decrease in the froth transport distances.

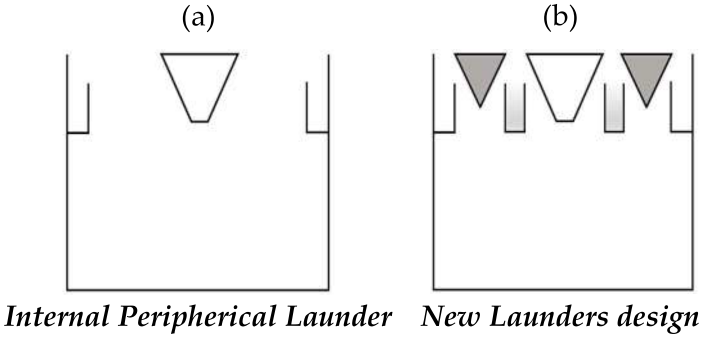

Figure 2. Launders design in the 300 m^3 cell: (a) original design and (b) new launder design.

Table 1 shows the operating conditions, gas flowrate and froth depth, in the 300 m^3 cell during the sampling campaigns before and after the installation of the new launders. It should be noticed that the air flowrate was drastically reduced after the installation of the new launders, because of the reduction of the froth surface area. Even so, the gas mean residence time in the froth decreases by 25%.

On the other hand, it has been observed that decreasing the gas rate may increase the froth stability, by increasing the bubble loading. This has been evaluated indirectly by measuring the increase of air recovery, as reported by Mesa (2020).

Table 1. Operating conditions in the 300 m^3 cell before and after the installation of the new launders.

	Gas flowrate (m^3/min)	Froth depth (cm)
Original Launders (before)	37.0	13.0
New launders design (after)	22.6	16.5

RESULTS

Comparison of measured and predicted data

Table 2 shows the predicted and measured recovery and concentrate grade for the operation with the original launders and with the new launders design after upgrade. These data are presented comparatively in Figure 3.

Table 2. Predicted and measured data for the original launders and the new design.

	Recovery		Concentrate grade	
	Predicted	*Data*	*Predicted*	*Data*
Original Launders (before)	59.9	59.0	16.4	19.4
New launders design (after)	67.3	68.7	14.1	11.8

The results showed a good prediction of the recovery for the condition before and after the new launder installation, with an absolute error less than 1.5%. On the other hand, the prediction of the concentrate grade presented greater error, but it was still less than 3% (absolute). The differences between measured and predicted data can be partially attributed to the measurement error, because the analyzed circuit corresponds to an industrial operation and it is difficult to keep the feed characteristics and operating conditions constant during sampling surveys. Additionally, the input information to the simulator includes data from chemical and mineralogical analysis as well as granulometric analysis, which can introduce some error for prediction.

The simulator allowed for representing the changes in recovery and concentrate grade by modifying the launders design, specifically by reducing the froth transport distance. Thus, the simulator was validated as a useful and practice tool to characterize industrial circuits, using data measured in plant.

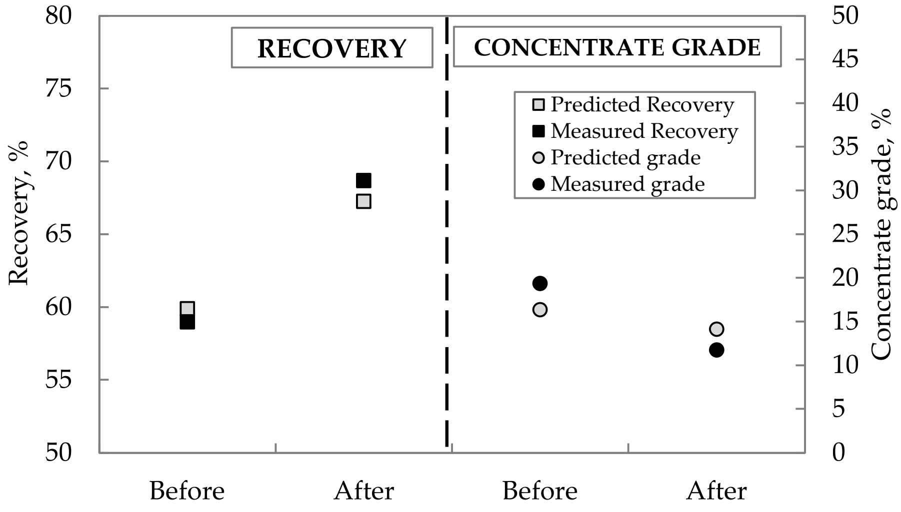

Figure 3. Comparison between predicted and measured data before and after launders upgrade.

Effect of new launders on the metallurgical performance of the flotation process

The industrial simulator allows for estimating flotation process characteristics that are not commonly obtained from plant surveys. Thus, the effect of the launders modification on flotation process variables such as froth recovery, concentrate flowrate, froth carrying rate and others was analyzed. For this study, the metallurgical performance of the 300 m^3 cell was predicted by simulation for the original launders and the new launders. The operating conditions were kept constant in both cases, J_G = 1.7 cm/s and froth depth = 13 cm, which corresponds to the conditions observed in plant during the first sampling survey (original launders, "before"). Thus, the effect of launders design and froth transport distances is evaluated without including confounding effects.

Figure 4 shows the froth, collection and overall recovery in the 300 m^3 cell for the operation with the original launders and the new launders design. As expected, the froth recovery increased, from 58.3% to 89.6%, by reducing the froth surface area and increasing the overflow perimeter. Similarly, the overall recovery also increased, from 59.9% to 66.6%. On the other hand, it should be noticed that the collection recovery slightly decreases after modifying the launders design, from 71.9% to 69.0%. This effect occurs because the increase in froth recovery decreases the valuable mineral drop-back to the collection zone and changes the feed grade to this zone. Thus, the mineral (fresh feed + drop-back) entering the collection zone has different characteristics. However, the drop-back flowrate is significantly lower than the feed flowrate, so the decrease in the collection recovery is slight.

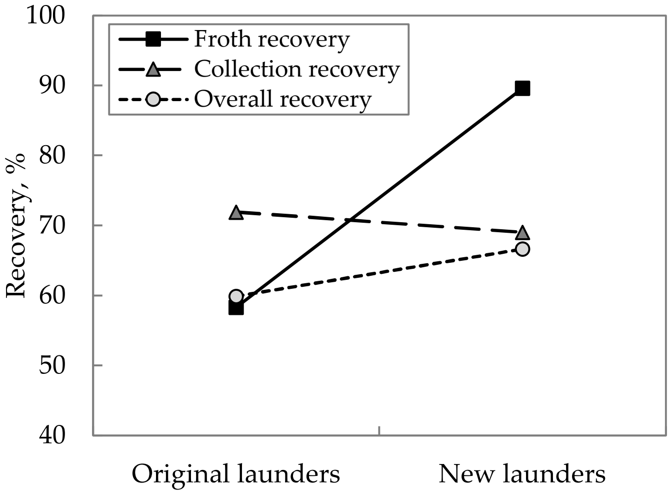

Figure 4. Froth, collection and overall recoveries, using original launders and new launders design.

Figure 5 shows the composition of the concentrate flowrate for the conditions with original launders and new launders design. Figure 5a shows the solids and water flowrates in concentrate, where an increase in both components was observed after reducing the froth transport distance, with smaller froth surface area and larger overflow perimeter.

Figure 5b shows the mineral composition in the concentrate flowrate. The minerals were divided into three groups: valuable minerals that corresponds to Cu sulphides; floatable minerals that includes Cu sulphides, non-valuable floatable minerals (e.g. pyrite) and non-floatable associated minerals; non-floatable (gangue) entrainment. A significant increase in the gangue entrainment flowrate was observed for the new launders design, because of the increase in the overflow perimeter and the decrease in the froth transport distance. Additionally, the results showed an important increase in the floatable mineral flowrate for the new launders design. However, the increase in the valuable mineral flowrate was less significant. This means that the increase in the floatable mineral flowrate is due to the recovery of less liberated valuable minerals (higher content of associated minerals) and non-valuable floatable minerals (e.g. pyrite). A similar result was found in other copper concentrator, where the comparison between two parallel circuits, one using internal launders and the other without launders, showed a significant increase in the recovery of molybdenite in coarser particles by using internal launders (Yianatos et al., 2008a). Thus, the launders upgrade by shortening the froth transport distance favours the recovery of minerals with lower kinetic such as less liberated or coarse particles as well as non-valuable floatable minerals. This can be observed in Figure 6, where the floatable mineral flowrate (valuable mineral + associated minerals) per three liberation classes is presented for the conditions using original launders and new launders design.

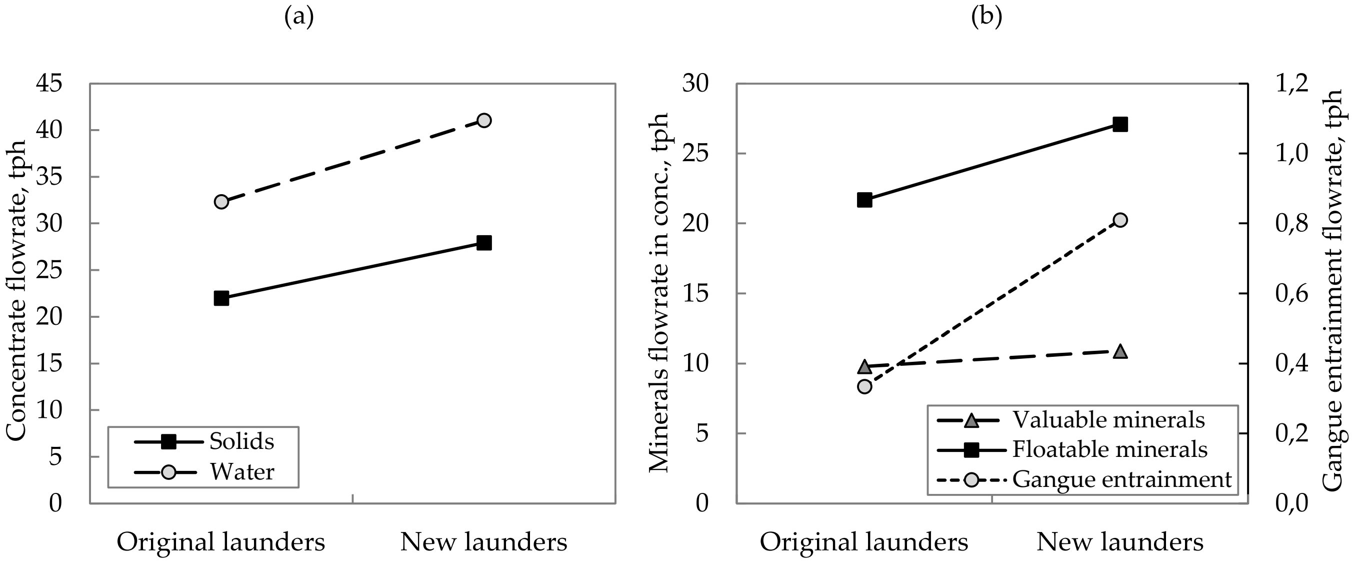

Figure 5. Concentrate flowrate using original launders and new launders design: (a) Solids and water flowrates and (b) Valuable, floatable and non-valuable minerals flowrates.

From Figure 6, an increase in the floatable mineral flowrate was observed for the three liberation classes (<20%, 20-80% and >80% liberation) for the new launders design. The mineral flowrate in >80% liberation class increased by 10%, while the mineral flowrate in 20-80% and <20% liberation classes increased by 35% and 50%, respectively. This reduces the floatable mineral grade in concentrate, because the floatable mineral in <20% liberation class has a significant lower grade than in >80% class, which allows for recovering a greater amount of associated non-valuable minerals, mainly coarse particles. The floatable mineral grade in concentrate (by true flotation) decreases from 45.2% to 40.2% between the conditions using original launders and new launders design.

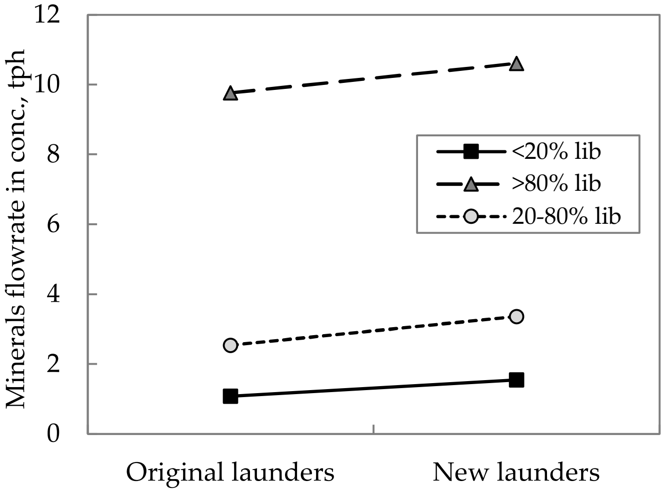

Figure 6. Floatable mineral flowrate in concentrate per liberation class, using original and new launders.

Figure 7 shows the froth carrying rate and the lip loading rate for the conditions with original launders and new launders design. The results showed an increase in the froth carrying rate, from 0.6 tph/m² to 2.2 tph/m², for the new launder design, due to the increase in the concentrate flowrate and the decrease in the froth surface area. On the other hand, the lip loading rate decreases from 1.0 tph/m to 0.6 tph/m when using the new launder design, mainly due to the significant increase in the overflow perimeter.

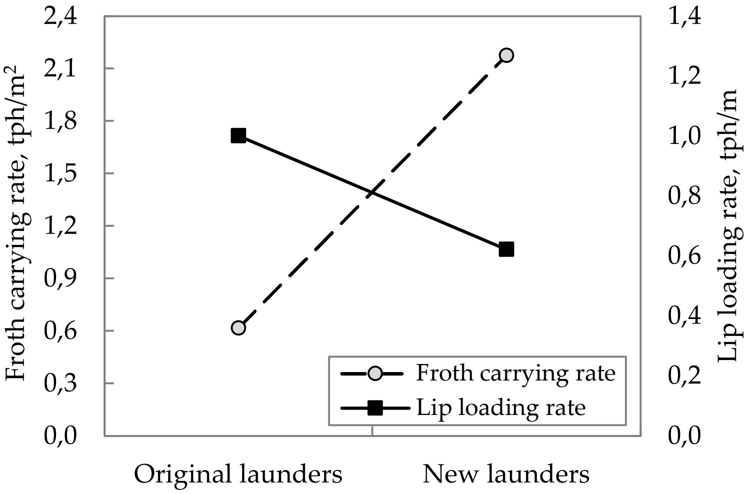

Figure 7. Froth carrying rate and lip loading rate using original launders and new launders design.

CONCLUSIONS

This study addressed a key problem related to the froth transport distances in large flotation cells, which have increased dramatically in the last years, while generating a greater detrimental impact of the froth zone on the overall recovery.

The metallurgical performance of an industrial flotation cell of 300 m^3 was evaluated before and after changing the launders design. Results from both plant surveys and prediction using an industrial flotation simulator were compared with each other. A good agreement was observed between experimental data and predicted ones by simulation. This allowed exploring the advantages and disadvantages of new cells designs for improvement and optimization of the froth transport.

The change in launders design reduced the nominal froth transport distance, by decreasing the cross-sectional area to 36% of the original area and increasing the overflow perimeter to 204% of the original perimeter. Additionally, the gas residence time in the froth decreased by 25% despite a decrease of 39% in the total gas flowrate.

The main results from simulation and plant experience showed an increase in flotation recovery of valuable minerals, mainly due to recovery of less liberated valuable minerals (higher content of associates and coarser particles), non-valuable minerals of low floatability, such as pyrite, and non-valuable gangue minerals recovered by entrainment. The same conditions also promote a decrease in the total concentrate grade. In summary, these findings show a space for improving the froth transport design as well the operating conditions optimization.

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