DETERMINATION OF ROUGHER FROTH VELOCITY PROFILES AS A FUNCTION OF METALLURGICAL AND OPERATIONAL VARIABLES AND THEIR IMPLEMENTATION THROUGH EXPERT SYSTEMS

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ABSTRACT

To maintain optimum recovery and a proper grade in a rougher flotation circuit, operators adjust the cells' concentrate production along each row in proportion to tonnage and feed grade changes. Many concentrators now deploy image analysis systems to measure the froth velocity in some or all flotation cells in a circuit. On the basis that the superficial froth velocity measurement, with a stable froth and stable conditions, approximates concentrate mass pull, there have been a number of advanced control systems developed to supervise froth production by manipulating the air and bank level setpoints. Success of these advanced control systems hinges on their ability to deal with different operational scenarios generated by process conditions. This paper presents a methodology of how were defined and implemented a set of froth velocity profiles for maximizing the recovery of copper rougher circuit of 80 OK cells of 100 m^3 set in 8 set in 2x2x3x3 parallel lines. It then describes how multiple profiles have been implemented in an expert control strategy. The rougher expert system continuously evaluates the process conditions and automatically selects the most adequate profile defined in the aforementioned study. The results validate that an expert control system with multiple froth velocity profiles is robust and flexible and improves copper recovery in circuits with well maintained instrumentation and regulatory control.

INTRODUCTION

To maintain optimum recovery and a proper grade in a rougher flotation circuit operators adjust the cells' concentrate production along each row in proportion to tonnage and feed grade changes. Many concentrators deploy image analysis systems to measure the superficial froth velocity in some or all flotation cells in a circuit. On the basis that the froth velocity measurement, with a stable froth and stable conditions, approximates concentrate mass pull, there have been a number of advanced control systems developed to supervise froth production by manipulating the air and bank level set points. Success of these advanced control systems hinges on their ability to deal with different operational scenarios generated by process conditions. This paper presents a methodology for how were defined and implemented a set of froth velocity profiles for maximizing the recovery of copper rougher circuit of 80 OK-100-TC cells of 100 m^3, with injected air, set in 8 set in 2x2x3x3 parallel lines in a concentrator plant (Los Colorados, Minera Escondida Limitada, Chile).

In this plant the pulp from the grinding area is sent to a distribution tank and it shares the pulp to every rougher line. The distribution is not similar for every line. The fluxes to the central lines are larger than to the external lines because of the design of the tank. The Figure 1 shows a schematic of the flotation cell lines and the distribution.

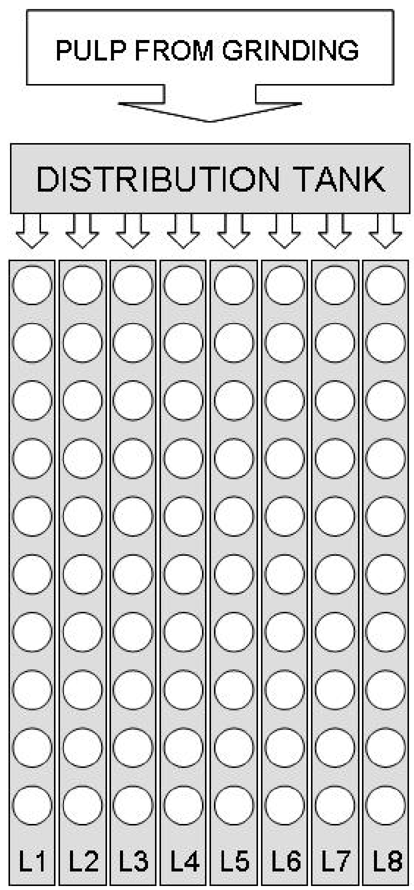

Figure 1: Froth velocity profile in a flotation line.

The rougher flotation has image processing software that allowed the use of a rule-based expert system that controls the superficial foam speed of each cell by adjusting the air flow and the froth depth of the flotation bank. A rule-based expert system is a series of rules, based on the same logic that an operator would use to perform a task. It requires field information from instrumentation to determine the state of the process in relation to predetermined set points.

In the Los Colorados concentrator plant, since 1998 there is a rougher flotation expert system developed by SGS Mineral Services, whose strategy originally was based on the level control of the concentrate launders. This system has been a useful tool in monitoring the operation of this area [2]. However, in 2008 was developed a project that sought to optimize the performance of the expert system. The control strategy was modified to control based on the froth speed profile. This new control philosophy defines a foam velocity set point in each cell along each line. The whole is called speed profile set point of the line. The new strategy continuously evaluates metallurgical parameters of the process and operational constraints by changing the profile of the line. That is, if the rougher flotation recovery is low, the expert increases the speed set point of the line, emphasizing the first banks. The opposite example would be given if the system is restricted downstream (eg, a high level in the global launder), the expert system reduces the foam speed set point in the line, with emphasis on lastest banks so not impair the throughput of the first banks in the line. The Figure 2 shows a diagram about the optimization in a flotation line.

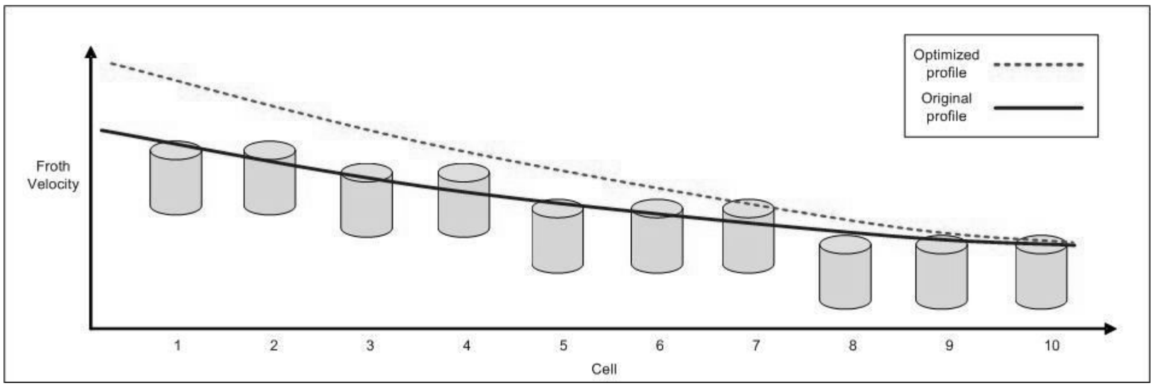

Figure 2: Froth velocity profile in a flotation line.

This philosophy is a reflex of the operational practices that privileges the production of the first banks because of the main recovery is generated in this point of the lines. Then the production of the last banks is “sacrificed” when is necessary to solve constrain downstream (e.g. high level in a concentrate launder).

The new strategy (using a common profile for every operational scenario) has generated a +0.4% improvement in the global recovery of cooper and has generated an improvement of the rougher weight recovery of +2.0 points [1]. However, analysis performed by the plant indicates that the results differ depending on the law of the ore fed to the flotation and the tonnage rate supplied. The Figure 3 shows the main interface of the expert system redesigned.

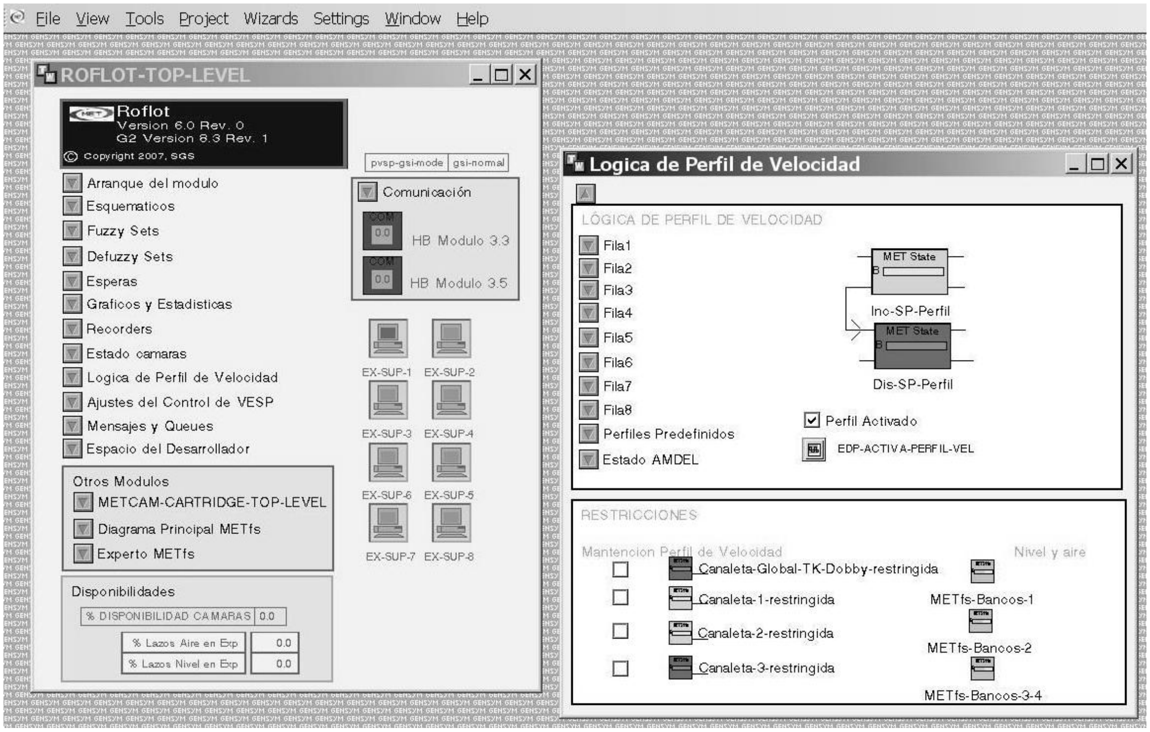

Figure 3: Interface of the rougher flotation expert system redesigned

From the above situation is the need to determine the most appropriate froth speed profiles for each main operating condition to optimize the recovery of copper in the rougher flotation.

METHODOLOGY

Was gathered information by a system of historical data administration, generated by the foam speed analysis system for a period of 8 months of operation of the rougher flotation. Additionally, was gathered metallurgical data about the plant operation, so as to evaluate the performance of advanced control system for recovery of the rougher flotation. Additionally, was examined the stages high-tonnage, medium-tonnage and low-tonnage. Statistical analysis of 700 MB of data was done using My-SQL.

For this analysis just was used data in the range from 0 cm/sec to 30 cm/sec to eliminate errors in the measurement of the froth velocity. The data of the cell 2-9, 3-7, 3-9, 3-10, 4-8, 4-9, 4-10, 5-10, 6-8, 6-9, 6-10, 7-8, 7-9, 8-4, 8-6, 8-9 and 8-10 was not used to calculate the average of each velocity range because its had more than 20% of measurements out of range. Almost all of these cells are in the end of the line and the measurement problems are caused by the small size of the bubbles and the low level of pulp in the cells.

The first step of the analysis was identifying the values for the limits of the ranges of velocity for every cell in the rougher system. Data was divided in thirds with the same number of samples. These values lets define 3 profile levels: high-velocity, medium-velocity and low-velocity. The analysis considers the determination of 3 scenarios for the feed grade called high-grade, normal-grade and low-grade. The criteria for the definition of the ranges of superficial froth velocity has a temporal philosophy because of the total period are divided in similar period of time. Every couple of grade level and tonnage level define an operational scenario.

Then, for every profile level was analyzed the copper recovery versus every stage of feed grade and tonnage. Finally, from the above analysis was able define the optimal froth velocity profile for every operational scenario by comparison of the historical results of every profile.

Both tonnage data and feed grade were filtrated for the definition of the operational scenarios. For the copper feed grade, just were used the data in the range 0.5 to 2.0%. For the tonnage, just were used the data in the range 4.000 to 7.000 tph.

RESULTS AND DISCUSSION

The Table 1 shows the averages of froth speed for the 3 ranges (valid data are in the range 0 to 30 cm/sec) for the period analyzed:

		Cell									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Low-velocity	Line 1	3,5	3,5	5,3	2,5	0,7	0,6	0,3	0,3	0,5	0,1
	Line 2	6,5	5,9	3,6	3,8	1,2	0,8	0,3	0,5	*0,4*	0,2
	Line 3	7,0	5,6	7,2	4,6	0,8	0,6	*0,4*	0,4	*0,2*	*0,2*
	Line 4	4,8	4,1	2,6	3,4	1,3	1,7	0,7	*0,7*	*0,5*	*0,2*
	Line 5	7,8	7,6	3,9	5,6	1,3	1,0	0,7	0,6	0,5	*0,2*
	Line 6	5,8	3,4	3,8	2,7	0,8	1,0	0,4	*0,2*	*0,3*	*0,1*
	Line 7	5,2	3,6	1,1	1,8	0,6	0,4	0,3	*0,2*	*0,1*	0,2
	Line 8	2,5	2,0	3,7	*7,9*	0,3	*0,2*	0,2	0,2	*0,1*	*0,1*
	Average	**5,4**	**4,5**	**3,9**	**3,5**	**0,9**	**0,9**	**0,4**	**0,4**	**0,5**	**0,2**
Medium-velocity	Line 1	6,4	6,3	10,0	6,9	3,3	3,1	1,9	1,6	2,1	0,6
	Line 2	11,3	10,9	7,6	8,2	4,3	3,3	2,2	2,1	*1,8*	1,2
	Line 3	11,2	9,8	12,3	8,4	3,8	3,2	*2,0*	2,9	*1,1*	*0,9*
	Line 4	9,1	8,5	7,4	6,9	4,7	5,1	3,7	*2,5*	*2,4*	*1,7*
	Line 5	12,8	12,8	7,6	11,7	5,3	4,5	3,3	2,8	2,3	*1,3*
	Line 6	10,5	7,7	9,5	6,9	4,1	3,5	2,7	*1,7*	*1,9*	*2,0*
	Line 7	10,7	7,9	5,4	6,5	3,1	2,7	1,6	*1,3*	*0,8*	0,8
	Line 8	7,0	5,3	8,1	*15,9*	2,0	*1,3*	1,2	1,5	*0,7*	*0,5*
	Average	**9,9**	**8,7**	**8,5**	**7,9**	**3,8**	**3,6**	**2,4**	**2,2**	**2,2**	**0,9**
High-velocity	Line 1	10,6	10,5	14,1	11,5	7,5	8,1	6,4	5,3	5,4	2,1
	Line 2	16,0	14,8	12,1	11,6	8,4	8,0	7,2	5,2	*5,6*	5,5
	Line 3	16,0	13,7	17,5	11,3	8,2	7,7	*5,3*	10,1	*4,2*	*4,2*
	Line 4	14,2	12,1	11,8	10,2	8,7	8,6	6,9	*5,4*	*5,9*	*4,8*
	Line 5	18,1	18,4	11,7	17,4	10,9	9,5	7,4	6,5	6,1	*4,4*
	Line 6	15,1	11,7	14,7	10,9	8,6	7,3	8,0	*5,9*	*7,0*	*5,4*
	Line 7	16,4	12,7	12,1	11,6	9,5	9,5	6,0	*4,8*	*4,6*	4,2
	Line 8	12,7	8,9	11,9	*16,6*	6,8	*3,9*	4,6	6,4	*3,9*	*2,7*
	Average	**14,9**	**12,9**	**13,2**	**12,1**	**8,6**	**8,4**	**6,6**	**6,7**	**5,8**	**3,9**

Table 1: Average froth velocity per range. The values of the cells with more than 20% data out of range (in cursive) were not used to calculate the averages

For every lines was calculated the average superficial froth velocity per cell in every range. Data shows the higher velocities are in the first bank and the lower velocities are in the end of every line. In the condition when the system is operated at low velocities (low-velocities stage) the production of the last bank is very low. This condition is registered with a velocity close to zero.

Finally in the Table 1, for every stage of velocity, was calculated an average velocity like a reference. Data shows the effect of the bad distribution on the lines. The average froth velocity in the lines 1 and 8 are 30% less than the average of the full lines. This data is interesting when the profiles are defined individually for every line. The expert system updated has the features to define froth velocity profiles individually for every line. It features let the operator a more flexible strategy that adapted to the geometry of the equipments.

The Table 2 shows both the copper feed grade range and the tonnage range used in the study. Every range has the same number of samples. This analysis follows the same temporal criteria used for the froth velocity.

	Feed grade, %			**Tonnage, tph**		
	Low	Medium	High	Low	Medium	High
Low limit	0,50	0,88	1,09	4000	5494	5971
Average	0,78	0,98	1,31	4979	5784	6135
High limit	0,88	1,09	2,00	5494	5971	7000

Table 2: Ranges used to define the operational scenarios in the velocity profile study

Copper recovery was compared in each stage for different velocity profiles. For example, for the stage high-tonnage and medium-feed-grade were compares the recovery when the froth profile used was high-velocity, medium-velocity and low-velocity. The Table 3 shows that the best recovery is obtained when the froth profile is high-velocity. The recovery values from statistical shows difference up 4% in any operational scenarios according to the profile used. The analysis compares only similar grades and tonnages but does not consider the effect of mineralogy.

The Table 3 shows the optimal froth velocity profiles for different ranges of feed grade and tonnage.

		Feed grade		
		Low	Medium	High
Tonnage	Low	low-vel	med-vel	med-vel
	Medium	med-vel	med-vel	med-vel
	High	med-vel	high-vel	high-vel

Table 3: Optimal froth velocity profiles for different operational scenarios

These profiles were validated with the operation area and metallurgical area previous to uses it in the real process. For example, in the scenario with low-tonnage and low-feed the optimal profile is the “low-vel”. In this scenario, the conclusion has sense because the standard operational practice is to make more selective the cells to obtain a best performance of the flotation. In this plant the most common profile is the “med-vel”. However this analysis should be repeated annually because the ore features could be different to previous periods and could be necessary to define new ranges for the feed grade and for the tonnage level.

From the results of the scenarios identified above was programmed in the expert system specialized froth velocity profiles for each scenario. The rougher expert system continuously evaluates the process conditions and automatically selects the most adequate profile defined in the aforementioned study to optimize the cooper recovery in the rougher flotation.

With this new feature operators have reported a more effective control system expert who has given the operating flexibility to address changing process conditions. This has been reflected in higher levels of recovery, especially in the most extreme scenarios. Additionally, the new profiles have enabled the process control logic is adapted much faster to changing process conditions to have profiles that are already predefined and have the approval of both the process control area and the metallurgy area. Since the new system was introduced has been measured an increase of up to 0.5% in the copper recovery (the information about the recovery value is confidential because of politics of Minera Escondida Limitada).

CONCLUSIONS

The results of the control logic upgrade project validates that an expert control system with multiple froth velocity profiles is a system more robust and flexible and improves copper recovery in circuits with well maintained instrumentation and regulatory control.

The analysis shows that different ranges of froth velocity profiles applied in every operational stage reach a difference for the copper recovery up +4% in any operational scenarios according to the profile used. The analysis compares only similar grades and tonnages but does not consider the effect of mineralogy.

When the optimal profiles were implemented in the plant and it were used according the different operational scenarios, the operational performance showed an increasing of the copper recovery up +0.5%.

The methodology described in this paper is useful in any plant that deploys image analysis systems to measure the superficial froth velocity by the implementation of a multiple froth velocity profiles in a flotation advanced control system. The impact in the performance of the study plant shows the potential of this techniques where the statistical analysis and the operational experience works together for to optimize the performance of a concentrator plant.

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