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Predictive Expert Control System of a Hybrid Pilot Rougher Flotation Circuit

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Abstract: In the last decades heuristic approaches based on logic rules have been one favored tool to control flotation units and plants on top of distributed control systems. The lack of fundamental knowledge on flotation processes, expressed in reliable models, and programs to assure the quality of the information, contained in available measurements, have limited the developing of robust predictive control strategies. In this paper we explore the idea of using simplified models jointly with measured disturbances to modify the set points of froth depth and air flow rate controllers. Since these target predictions are only approximate, a conventional feedback expert system, based on logic rules, continues the task of calculating new set points of the distributed controllers, in order to decrease the gap between actual and desirable metallurgical targets. This combined actions permitted a fast response of the process to change the operation of the circuit when a measured disturbance change is detected. This control system was implemented and experimentally evaluated in a pilot rougher flotation circuit, with three pneumatic cells, with froth depth and air flow rate controllers in each cell. Since the circuit is operated for the air-water system, a phenomenological model, with parameters estimated from industrial data, is fed on-line with real operating variables and virtual values, characterizing the feed (grades, solids%, particle size distribution), in order to predict the metallurgical targets (recovery and concentrate grade). Several cases are discussed showing the benefits of this control system and the possible improvements to work on. *Copyright © 2016 IFAC.*

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1. INTRODUCTION

Today, large size mechanical flotation cells of 100 to 300 m^3 are used in rougher operation in different flotation industrial plants, in Chile and worldwide. However, in spite of the advances in fundamental research and the notable growing in equipment size, with more complete instrumentation systems, there are still a lack of reliable data for industrial flotation modeling and simulation to advance in better control systems design.

A typical flotation plant, shown in Figure 1, is composed at least of the following circuits: Rougher, Regrinding, Cleaner and Scavenger. The output of the grinding plant is fed to the Rougher circuit. Usually pulp level control is available for each bank of the circuit. Air flow rates may be controlled or have no regulation, depending on cell design. The collected Rougher concentrates are sent to a regrinding stage and after classifying the undersize stream is fed to the Cleaning circuit. This circuit is generally composed by flotation columns operating in parallel. Froth depth, wash water and air flow rates usually are under control. The collective column concentrates form part of the final concentrate. The column tailings are fed to a Scavenger circuit. Again, usually pulp level control for each bank is available and air flow rate control depends on cell design. This concentrate is returned to the regrinding stage, while the tailings join the collective Rougher tailings to form the final tailings.

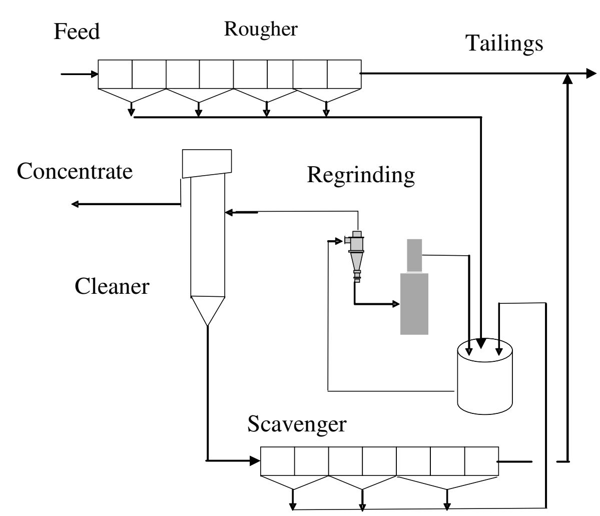

Fig.1. Layout of a typical flotation plant.

The overall control strategy of a flotation plant relies first on good control of local objectives (pulp levels, flow rates), usually as controllers implemented on a distributed control system (DCS). When these local objectives are satisfactorily achieved, then the next level is to be able to modify the operation of each circuit (Rougher, Cleaners, and Scavenger) in order to obtain specific concentrate and tailing grades. This demands the capability of changing the set points of the local controllers in such a manner that the operation of the circuit

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is corrected every time. Then the specific knowledge on how the target variables are related to the local inputs is needed. If this second level of control is possible, then to satisfy the overall target of the plant (final concentrate grade in a specific band and plant recovery over a minimum value) one needs to know what to ask of each circuit. Which is the best combination of circuit targets to maximize the benefits? How will it depend on the feed characteristics and plant constrains? Bergh and Yianatos (2011) discussed different aspects of the regulatory control, the role of disturbances, instrumentation, process interaction, control algorithms, maintenance, supervisory control, target values estimation, and process and instrumentation constraints for flotation plants.

Usually rougher circuits are operated in order to maximize the recovery of valuable minerals subjected to produce a concentrate that can be adequately processed by the following circuits, that is, regrinding, cleaner and scavenger circuits. The goal is to produce a final concentrate with a grade inside a narrow band determined by its commercial value, without sacrificing the global recovery of valuable minerals by saturating the capacity of grinding and scavenger circuits, for example, by increasing the material circulating rate. Therefore the specification of the desired quality of the rougher concentrate is changing over time, depending mainly on how the characteristic of the rougher feed is changed by the previous mining and grinding processes and by the operation of the rougher circuit. Then the problem on how to set the metallurgical targets for each circuit is not straightforward. If reliable process models were available then the optimization problem can be solved as in many other chemical processes. In the absence of reliable models, feedback control can be used when the metallurgical targets can be measured. Usually, the behaviour of the process under different operating conditions is partially known by combining experience and fundamental knowledge, which can be expressed in a heuristic form as rules of behaviour, which are the bases for building expert decision systems. To increase the effectiveness of the operating decisions, fuzzy logic is widely used to process these logic rules, incorporating nonlinear effects. However, these expert-fuzzy systems work as feedback control, and since the feed characteristics are usually changing over time the metallurgical results are always deviating from their targets. In other words, the feed disturbances in the rougher circuit are partially propagated to the following circuits, creating different scenarios which in fact may change back the temporal desired targets for the rougher circuit. To decrease the variability of the global results, the use of some simpler models relating the feed measured characteristics with the metallurgical targets of the rougher circuit can be used in a feed-forward or predictive form to aid the feedback expert fuzzy control system. This idea is developed in this work and implemented, tested and evaluated in a pilot rougher flotation circuit at our Process Control Laboratory.

In this work we present a brief summary of modeling flotation cells and circuits, then a description of the hybrid pilot plant, the instrumentation and the distributed control system. Then we discuss feedback expert systems including the use of a predictive model. We discuss some experimental results and we draw main conclusions and further work.

2. MODELING FLOTATION CELLS AND PLANTS

At present, important efforts have been addressed for characterizing flotation circuits as distributed systems. Tsatouhas et al. (2005) reported a decreasing of the froth recovery along a rougher bank in two industrial rougher circuits. Dobby and Savassi (2005) reported the change of flotation rate in the collection zone, along a bank of cells, based on the results of batch tests.

The distributed character of a flotation rougher bank requires mass balances around each cell for solid and liquid phases in order to describe the operating conditions downward the bank, i.e. mean residence time per cell, froth depth, entrainment, and solid liberation, among others. In addition, the performance of each flotation cell in terms of mineral recovery and concentrate grade depends on the flotation rates in the collection zone and the cleaning effect controlled by the froth depth. Reviews on the collection and froth zone modeling have been reported in literature by Finch and Dobby (1990), Mathe et al. (1998) and Yianatos (2007), where detailed hydrodynamic characterization of the collection zone and summaries of the froth transport modeling are presented.

Several approaches for flotation process simulation have been proposed in literature which typically simplify or remove the froth phase. For example, Sosa-Blanco et al. (1999), developed a simulator to integrate the grinding and flotation process, where the flotation cells were modeled as a perfect mixer with entrainment in the froth phase; Ferreira and Loveday (2000) described the collection zone as a perfect mixer and the froth phase in terms of the froth recovery for a flotation circuit with 3 nodes; Casali et al. (2002) proposed a dynamic rougher simulator without considering the froth zone due to the close to plug flow behaviour. Bergh and Yianatos (2013) presented a static model for a flotation circuit and perform some simulations to find out some control strategies depending on when recovery of valuable minerals needs to be increased with minimum degradation of concentrate grade and when concentrate grade need to be increased with minimum degradation of recovery. This model parameters were estimated from data collected in industry and the input and output variables are displayed in Figure 2.

3. HYBRID PILOT ROUGHER PLANT

The pilot plant instrumentation and control is shown in Figure 3. The rougher circuit is composed by three pneumatic cells with a volume of 36 L each one. The feed flow rate is controlled by a peristaltic variable speed pump. The three froth depth are measured by ultrasonic sensors and controlled by regulating the opening of pneumatic control valves acting on the tailings of each cell. Each air mass flow rate is measured and controlled. Since the circuit is operated by the air-water (and frother) system, the feed characteristics, such