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Optimization of dewatering systems for mineral processing

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A B S T R A C T

Water is widely used as a solvent in the mining industry and is employed in hydrometallurgical processes and for mineral concentration. Because of the global increase in metal production, the demand for water, including fresh water, is expected to increase continually. In arid and semi-arid regions such as northern Chile, the scarcity of fresh water has led to increased dependence on other sources such as sea water and triggered efforts towards optimization of the use of fresh water.

In copper concentration plants, approximately 40–60% of the total amount of water lost is retained in slurries in the tailings. In this paper, we present a method for optimizing the design of dewatering systems that employ hydrocyclones and thickeners. Mathematical models were generated to determine the maximum water recovery rate and the corresponding system structure for given equipment sizes, and to determine the minimum cost of the equipment and the corresponding system structure for given water recovery rates. The models were based on mixed integer nonlinear programming. Several case studies were performed. The model predictions were consistent with the results of an experimental study of an actual dewatering system in a copper concentrator plant.

1. Introduction

Water is commonly employed in most material processing industries and is one of the most important resources in metallurgical processes. However, industrial processes that involve the use of water are being subjected to increasingly stringent environmental regulations with respect to effluent discharge. There is a growing demand for fresh water because water is scarce in several countries and is a critical commodity in some parts of the world. These issues have increased the need for improved water management and wastewater minimization (Klemes, 2012).

In the mining industry, water is used in hydrometallurgical and mineral concentration processes. For example, in the concentration by flotation process, ore particles are reduced in size to a specific range in order to separate the species of value. At this stage, the mineral is mixed with water and wet milled to an optimal granulometry to achieve flotation. The flotation process yields two products, a concentrate and tail streams, that are sent to dewatering systems for water recovery. These systems usually include thickeners, hydrocyclones, and filters.

Water scarcity in arid and semi-arid mining areas has become one of the most important issues for these regions, as water is essential for the development of all economic activities, environmental care, and the quality of community life. The mining industry assigns vital importance to the rational and efficient use of water in its operations and has taken actions to optimize its consumption through best water management practices and the introduction of improved technologies (Usher and Scales, 2005). For example, in the Antofagasta region of Chile, the water consumption of the mining industry corresponds to 60% of the total consumption, and is projected to increase to 70% by 2020. Further, in Chile, the water consumption of the copper mining industry in 2016 will be 576.2 Mm^3; this represents an increase of 47% over the consumption level in 2012. As a result, several mining companies have started to use seawater in their operations and have also improved their water recycling systems (Johnson, 2003).

The primary technique involved in these dewatering processes is sedimentation, which is the settling of a suspension of particles in a fluid under the effect of an external force, which may be gravity, centrifugal force, or any other body force (Concha, 2001). The purpose of the dewatering system is to increase the concentration of the solid discharge removed from the pulp in order to increase the amount of water recovered.

Owing to several factors, efforts are being made to increase the efficiency of the recycling of 'used' water (Rao and Finch, 1989): (1)

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mineral processing plants can consume a large proportion of the local water resources, and this can reduce the amount of water available for other uses; (2) the collection and transportation of fresh water is usually expensive and affects the operating costs of the mining industry; and (3) the effluents from mineral processing operations are potentially detrimental to the environment because these streams contain both suspended solids as well as a number of dissolved polluting toxic chemicals, in addition to flotation agents and their degradation products.

The objective of this study was to develop a method for designing dewatering systems that allow for the maximum water recovery given a set of equipment or allow for the minimum equipment cost given the water recovery rates. This method creates a set of alternative based on hierarchical superstructures from which the structure most suited for the process in question can be selected. The problem is represented mathematically using models for these superstructures; these models are based on the principle of material balance, and equations representing the behaviors of the hydrocyclones and thickeners are employed. Finally, two objective functions are defined, namely, to optimize water recovery and to reduce the system costs.

2. Problem statement

In this section, we describe a mixed integer nonlinear programming (MINLP) model to optimize water recovery from slurry. The model/problem is labelled as P1 and is solved to determine the maximum amount of water that can be recovered from a tailings separation circuit for a specified set of equipment. This can be considered to be a retrofit problem. A second MINLP model/problem, which is referred to as P2, is used to determine the minimum cost of a dewatering system given a desired rate of water recovery. This can be considered a design problem. The dewatering system configuration and stream flow rates are calculated for both problems (i.e., for P1 and P2). For P2, the equipment design is also determined. These models/problems are independent of one another and can be used as per the objectives of the designer.

The superstructure of the water recovery system comprises a hydrocyclone system and a thickener system that along with two dividers and three mixers constitutes a set of alternatives from which the optimum system structure is selected. This superstructure is known as the overall superstructure (OS). The OS comprises a set of nine dewatering structures (Fig. 1) that correspond to various combinations of the dividers (i.e., three options for the feed slurry stream and three options for the hydrocyclone system overflow stream).

Each system in the OS (Fig. 1) has an internal superstructure. The internal superstructures of the hydrocyclone system and the thickener system are illustrated in Figs. 2 and 3, respectively. The combinatorial nature of the problem results in an exponential increase in the number of alternatives with an increase in the number of hydrocyclones and/or thickeners. Thus, the method requires that the number of hydrocyclone and thickeners employed be predefined.

Equations for the particles, water flow, and slurry were developed, including mass balance expressions and unit operation models. The resulting MINLP model for problem P1 can be formulated as follows:

$$\begin{aligned}&\text{Maximize}\quad c^T x\\&s.t.\quad h(x,y)=0\\&g(x,y)\leqslant 0\\&x\in R^n, y\in\{0,1\}^m.\end{aligned}$$

The MINLP model for problem P2 can be formulated as follows:

$$\begin{aligned}&\text{Minimize}\quad f(x,y,d)\\&s.t.h\quad (x,y,d)=0\\&g(x,y,d)\leqslant 0\\&x\in R^n, d\in R^p, y\in\{0,1\}^m,\end{aligned}$$

where y is a binary vector that denotes the rejection (i.e., $y = 0$) or acceptance (i.e., $y = 1$) of a particular alternative solution; x represents the operating variable (e.g., the mass flow rate); d denotes the vector of design variables that represent the sizes of the process units, (e.g., the diameters of the thickeners); and h and g represent the various equality and inequality constraints, such as the mass balance relations and the equipment design models, respectively. The objective function for P1 is the total amount of water recovered, whereas that for P2 is the minimum equipment cost.

2.1. Overall dewatering superstructure model

The mass balance relation for the overall superstructure can be expressed as

$$\sum_{s\in S^{in}_{e,s}} W_{s,c} - \sum_{s\in S^{out}_{e,s}} W_{s,c} = 0 \qquad \forall c\in C,\quad e\in E \tag{1}$$

Eq. (1) states that the input and output flows of each component in the hydrocyclone system, the thickener system, the mixers, and the splitters must be equal. In the equation, $W_{s,c}$ is the mass flow rate of particles of different sizes and the pulp volumetric flow

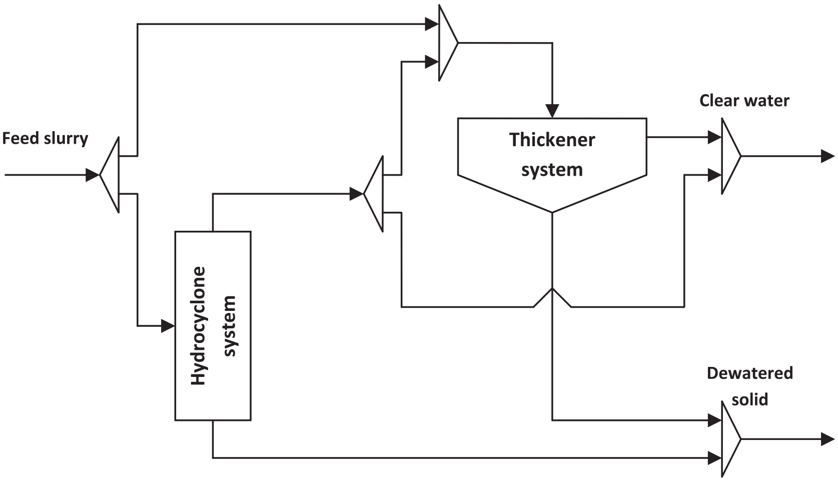

Fig. 1. Dewatering overall superstructure (OS).