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Development and calibration of a dynamic flotation circuit model

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A B S T R A C T

Monitoring of mineral beneficiation processes is difficult due to lack of reliable measurements and hazardous environment. Therefore robust models describing steady-state and dynamic behaviour of the processes are needed when aiming for improved monitoring and control. Specific characteristics of models used in mineral processes are that they require spatial mineralogical information of raw material. In this study, a dynamic simulator combining ore characteristic physical data, process operating parameters and mineralogical properties is developed for the Oulu Mining School (OMS) mini-pilot scale mineral beneficiation plant. The mini-pilot process, theoretical part of the model and the model development are described. Open and closed flotation circuit experiments were carried out in mini-pilot research environment for model identification. Experimental and simulated results of ore type variation and pH change are presented. Based on the results the effects of the aforementioned factors on flotation performance are predicted.

1. Introduction

Due to increasing need of metals and depleting mineral resources, efficient use of existing mineral resources is desired. Life cycle of metals starts from mines and proceeds through mineral processing and metallurgical processes to products. Resource efficient production is achieved through monitoring and control which enable optimal operation of process chain. These require measurements which, however, are only few in numbers for mineral processing unit processes (Bergh and Yianatos, 2011). Thus soft sensors are often used to indirectly obtain information from key variables describing process conditions (Hodouin, 2011; Bergh and Yianatos, 2014). Indirect measurements need models that map the interactions between the observed and desired variables. Specific characteristics of models used for mineral processes are that they require accurate spatial mineralogical information of raw material.

The basis of simulators is models that describe the interactions between process variables. Model types and structures vary depending on their use. Static models study the steady-state behaviour of processes and are useful for example in process design and optimisation. Dynamic models on the other hand describe the time-dependent response of the process and can be used for example in controller design. Models are also required for soft sensors that can be used to indirectly make observations from the process. Models can be based on basic principles of nature (for example conservation of momentum, mass and energy) or they can base on empirical observations. So called hybrid or semi empirical models utilise both of these approaches. A typical mechanistic process model is a set of mass balances derived for the components present in the process. Balances usually are time-dependent but may also map the spatial dependency of the process. Even though real processes depend on time and space, spatial dependency is often omitted because its accurate and reliable modelling is challenging. Also the resulting partial differential equations may be difficult to solve. Mechanistic mass balances are often complemented with empirical kinetic equations.

Accurate models describing steady-state and dynamic behaviour of the processes are needed when aiming for improved resource efficiency. These models often form the basis for control and optimisation strategies (Hodouin et al., 2001). Several software tools are available for building simulators for mineral processing circuits. These are for example JKSimFloat (Schwarz and Alexander, 2006), USIMPAC (Vorster et al., 2001), SUPASIM

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(Hay and Rule, 2003; Hay, 2005; Hay and Schroeder, 2005), Microsim (Klymowsky and Rijkers, 1996), MODSIM™ (King, 2012) and HSC Chemistry® Sim (Coleman and Lamberg, 2010). A drawback of these tools is that they are mostly applicable for steady-state simulation. Additionally, some dynamic simulators have been presented in the literature for mineral processing units and circuits. For example, Asbjörnsson et al. (2013) developed a dynamic simulator for crushing circuit and Irannajad et al. (2006) used population balance models for modelling ball mills. A dynamic model for the whole grinding circuit was developed and verified in Le Roux et al. (2013) and Le Roux et al. (2014). Models are developed also for flotation units and circuits. It is typical that the flotation bank is modelled as a set of tanks in series (Bergh and Yianatos, 2013). In this scheme, the behaviour of each flotation cell is identical. More detailed models can also be developed where the flotation cell is divided into collection and froth zones. The behaviour of these zones is then modelled based on phenomenological and empirical relationships. Reviews of flotation cell and circuit models can be found for example in Finch and Dobby (1990) and Bergh and Yianatos (2013).

This paper describes the process trials carried out in the Oulu Mining School (OMS) mini-pilot beneficiation plant together with subsequent development and verification of the dynamic simulator. The dynamic simulator is built with the *HSC Chemistry®* software's *Sim* process simulation tool. Material flows are described by ordinary differential equations solved numerically while kinetics in the flotation cells are described by semi empirical equations tuned with experimental data. The simulator builds upon the work described in Roine et al. (2011) and Seppälä et al. (2014) showing the details of the model identification and demonstrating the use of a simulator as a decision support system. The effect of pH and ore type is included in the flotation circuit model. As proposed in Roine et al. (2011) the simulator can be, for example, run in parallel with the process and used to determine the effects of control actions.

2. Materials & methods

2.1. Mini-pilot process description

The Oulu Mining School (OMS) mini-pilot mineral beneficiation plant was developed based on the beneficiation plant of FQM Pyhäsalmi mine. The scaling ratio of the unit sizes was 1:5000. The current configuration can be used to process different kinds of sulphide ores, because the structure of the plant is flexible and can be adjusted for other processing alternatives as well.

OMS mini-pilot plant consists of the comminution section followed by two flotation sections (in this case: Cu and Zn) and a dewatering unit. The comminution circuit includes a rod mill, a screw classifier and a ball mill. The flotation section contains two conditioners and eight flotation banks with four cells in each unit. If necessary, a possibility to use another ball mill to clean up mineral surfaces before Zn scavenger cleaner is available. Also a tails thickener can be utilised. Comminution and the copper flotation circuits are described in details in the following subsections. These subsections also provide a short introduction for these processing units. This study focuses on the comminution circuit and copper flotation section, their flow sheet is given in Fig. 1.

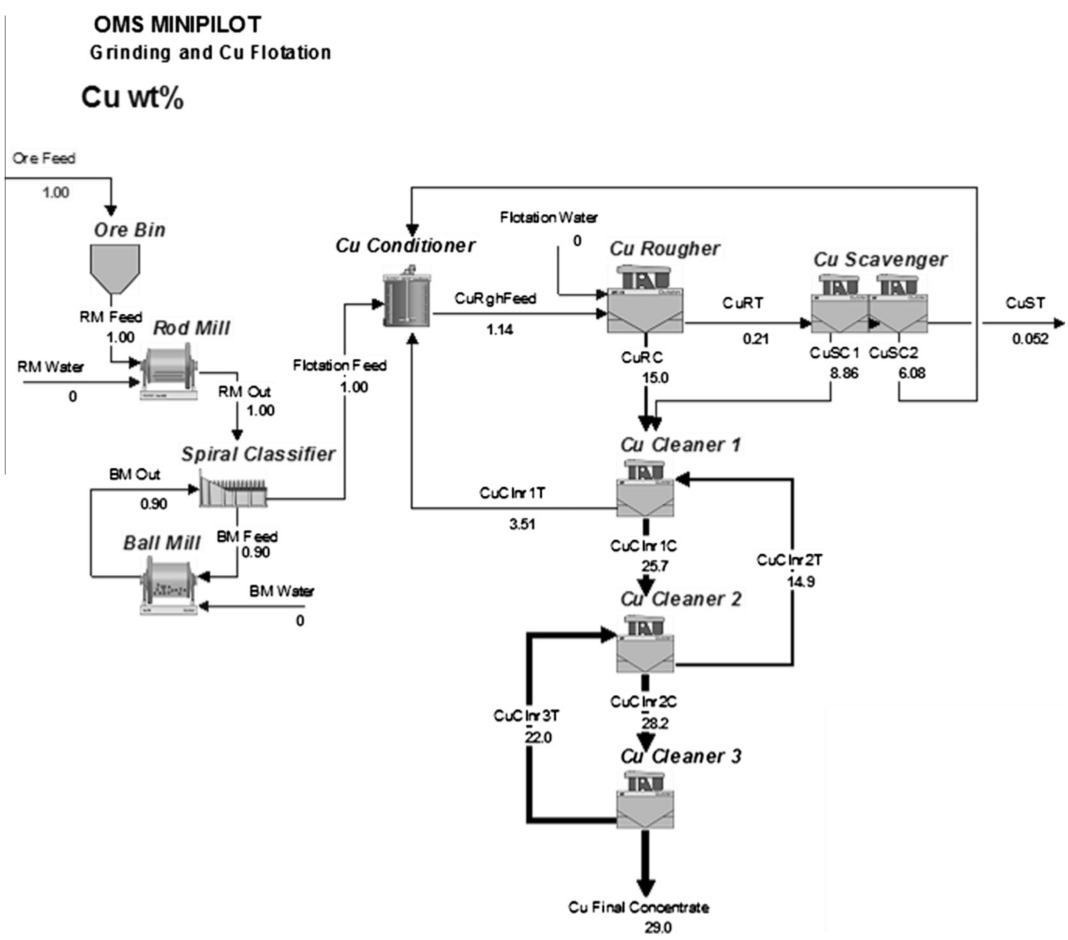

Fig. 1. The flow sheet of the OMS mini-pilot plant's copper circuit.