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HEAP LEACHING SIMULATION

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Abstract: Ore leaching techniques combined with solution treatment procedures offer exceptional conditions to produce high purity metal from very low-grade ore sources. Essential percentage of the world copper production is based on the heap and dump leaching techniques. The use of computer simulation, is now a basic tool for process design and optimisation, as evidenced by its increasing use of practising engineers through commercially available simulation software products. This paper discusses the modelling and simulation of the hydrometallurgical processes. The simulation example of a copper heap leaching process is presented and evaluated.

Keywords: Heap leaching, leaching model, dynamic simulation, copper extraction.

1. INTRODUCTION

Engineers, in charge of designing equipment for the mineral processing plants have to be able to select the most suitable equipment for each application and to predict the performances under different process conditions. With the increasing capacity of microcomputers, the software companies would like to provide computer tools for plant operators to obtain the best results from the equipment and process. In order to allow the mineral processing engineers to concentrate on their task, the simulation software should offer a user-friendly interface combined with quick and accurate calculations. Hydrometallurgical processes are becoming more and more important in the mineral processing industry, especially in treatment of low grade ores, due to their low capital investment for a given metal extraction rate and low operating costs as well. Simulation offers the advantage of predicting the behaviour of the processes without making excessive tests at the real process. Simulations are quicker, more safe and economic than the process experiments.

Several commercial software-products do not provide all the necessary facilities in the field of hydrometallurgy and mineral processing. The new simulation software, called ConSim, has been developed.

Mathematical models for several operation units were developed and incorporated into the software. In case of the leaching processes, the most essential part of the research work is connected to the process dynamics. The simulation software tool was modified in order to include dynamic calculations. Off-line simulations were carried out and the calculated values are compared with the real plant data.

This simulator is designed to include hydrometallurgical and mineral processing units. Process control and automation elements will be implemented as well. Earlier versions of the simulator gave good results in the field of mineral processing (Jämsä-Jounela, *et al.*, 1996). In the first stage, several simulations were carried out using a commercial simulation-software tool, called METSIM. In the second stage, the development of unit models required for heap leaching process simulation was started. These models are still under development however, the simulation example is presented.

2. HEAP LEACHING

Leaching is a process conducted with a solution in which there is a solubility of the dissolving minerals or compounds in the material being leached sufficient to obtain an acceptable concentration of valuable metals in solution. The principle of heap leaching is presented in figure 1. In case of heap leaching, the crushed and prepared ore is placed in a form of heaps on gently sloping flat ground covered with an impervious pad. The heap is sprinkled with an aqueous acidic solution. The contact of the leaching lixiviant with the surface of solid ore particles leads to selective metal dissolution. Naturally the dissolution process is very slow or it does not happened (Peters, 1991a). Therefore, bacterial populations are used to catalyse the reactions. In this way, the leaching time is reduced to some month up to two years, depending on the ore composition. Air is necessary for biological activity, in this sense the heaps should be enough porous to provide bacteria with oxygen. Under the water table level metal dissolution is not possible. The essential point of the modelling is to establish the kinetic parameters of the metal dissolution. Due to the bacterial activity, this task becomes very complex. In the first stage of the research, an approximation algorithm was used to estimate the kinetic parameters from the leaching test extraction curve. Recently a fuzzy rule base is under development for this task.

The liquid solution is collected by the pipe network and channels, and it is drained into the storage pond. From the gathered solution, called PLS (Pregnant Leach Solution), the copper bearing component is extracted by the solvent extraction unit. At this step the acid from the PLS is recovered and recycled to the raffinate pond, as presented in figure 2. From the metal bearing component, the desired metal is extracted through electrolysis. At the Electro-winning the final product is achieved, in form of high purity (97-99%) copper cathodes and considerable amount of acid is regenerated and recycled to the raffinate pond. The leaching time usually is three to six months for oxide ores, and ten to twenty months for sulphides. The *water table level* usually is not high and it can even be missing.

The study of the heaps can be divided in two main parts. First is the definition of the pre-processing steps, in order to prepare the ore for the heap leaching. The pre-processing step usually includes comminution, acid treatment, agglomeration and addition of biological nutrients. The second part is to determine the configuration of the run time leaching including the parameters as heap dimension, geometry and aeration (Kelly, 1995). The amount and concentration of the percolation acid should be also defined. In practice, during the feasibility studies of a copper production plant, hundred of tests are carried out with different ore pre-processing and acid percolation. These tests are performed in a small scale related to the desired heap size, usually in boxes

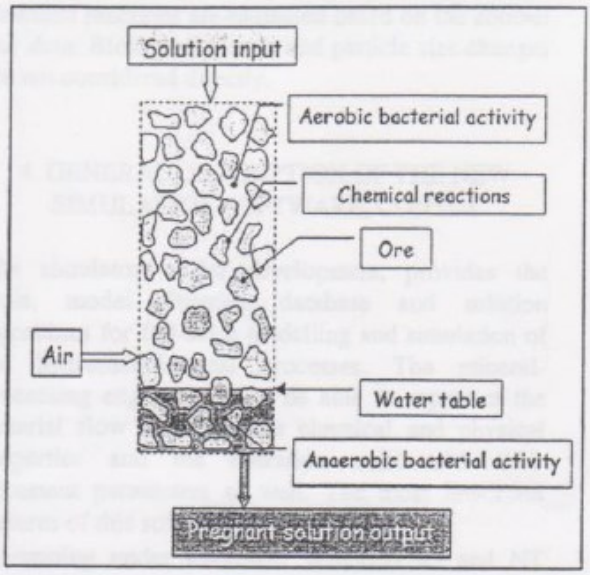

Fig. 1. Vertical section through a heap.

and columns. The experts should define the right pre-processing parameters and then predict the behaviour of the full-size commercial heaps based on the test results. The most important is to predict the expected metal extraction versus time. Due to this reason, the dynamic calculations are also needed. For the metal extraction from the pregnant leach solution (PLS), the simple and reliable models are available.

3. MODELLING OF HEAP LEACHING PROCESSES

Mathematical models are used as the basis for the understanding of mineral and metallurgical processes. Dynamic models are used for production planning and control system design. Efficient control of hydrometallurgical plants often requires the development of relative simple mathematical models for various unit operations involved. These models should be incorporated in on-line supervisory system, which has to perform quick calculations using them. This research is focused on the modelling and simulation of the copper heap leaching process. The percolation liquid is assigned as an input, and the PLS is considered the output of this model. The PLS is a solution with the metal content, usually 5-10 gram/litre.

The heap leaching process involves heterogeneous chemical reactions on the mineral surface catalysed with bacterial activity. There are several main bioprocess-engineering factors that affect the kinetics of bacterial leaching of sulphide copper ores, namely bacterial population, mineral and particle size, nutrients and inhibitors, temperature, pH, oxygen and carbon dioxide supply, leaching kinetics and operational mode (McCready, 1991; Canello, 1995). Under water level, conditions are not oxidising unless ferric ions are present.

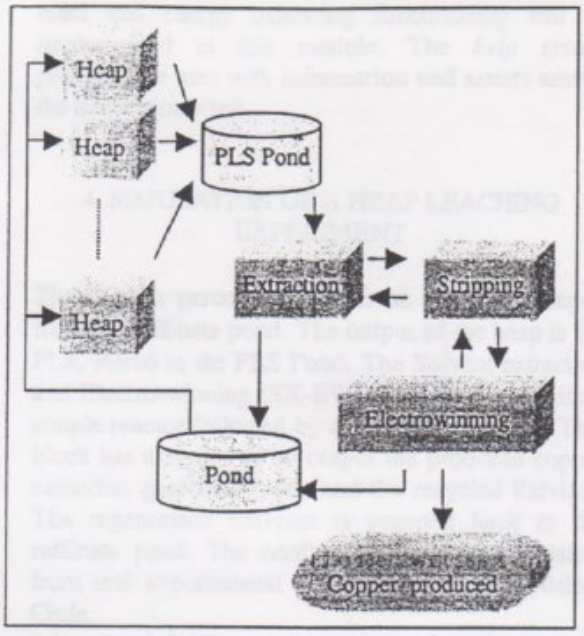

Fig. 2. Typical flowchart of copper production based on heap leaching

Sulphide minerals are usually not leached or are leached very inefficiently in absence of oxygen. Channelling, compaction and blinding-off the heaps can occur as a result of moderate changes in pH, temperature or solution composition, reducing the recovery rate of the copper. Mineralogy of the ore determines leachability and the nature of unwanted side reactions and precipitation. The mathematical model has the pre-processing values (e.g. particle size distribution, temperature, pulp density, chemical and biological properties) assigned as model parameters. The run-time configuration values are also considered model parameters.

The description of the heap leaching process may need two kinds of models, a *micromodel* that deals with the size changes of the solid particle during the leaching and a *macromodel* that deals with the system changes (Peters, 1991b). Changes taking place in the size, size distribution and shape of the ore particles as a result of the leaching process are computed by the mean of a micromodel. In its simplest form, a micromodel follows the size distribution of particles that are shrinking as the leaching process removes material from the surface. The micromodel contains a rate equation that defines the size changes of a typical particle as a function of extraction. The equation is a simple differential equation, which is integrated through the residence time.

The leaching process is also accompanied by chemical composition changes, temperature and volume changes. These are macroproperties, so the mathematical model that connects them to extraction may be referred to as a macromodel. The computed particle size distribution serves as input parameter for the chemical reaction model, thus connecting the micromodel with the macromodel (Box, *et al.*, 1986). The kinetic rate parameters of the undergoing chemical reactions are estimated based on the *column test data*. Biological factors and particle size changes are not considered directly.

4. GENERAL DESCRIPTION OF THE NEW SIMULATION SOFTWARE, CONSIM

The simulator, under development, provides the tools, model libraries, database and solution algorithms for full-scale modelling and simulation of the hydrometallurgical processes. The mineral-processing engineer has to be able to represent the material flow including the chemical and physical properties and the operation units with their important parameters as well. The most important features of this software are:

- running under Microsoft Windows 95 and NT operating systems
- having a user-friendly graphical interface
- being suitable for hydrometallurgical applications
- dynamic calculation possibility
- independent chemical database implemented as a relational database
- model development possibilities

The software was written with Microsoft Visual C++ compiler, using the object-oriented methodology proposed by Grady Booch. The software can be divided in 5 distinct modules: user interface, unit library, database connection, simulation and expert help modules. The *user interface* module provides all the graphical functionality. Generic classes are created for the operational units, for streams, which connect these units, and for text labels. All the objects from the flowsheet are managed by this module. The representation of the circulating mass is implemented using streams. The *unit library* collects all the particular unit classes. Every unit class is derived from the generic unit class, thus inheriting all the graphical functionality. Physically every unit class is placed in a separate and independent module. The unit classes have their own data structure together with the necessary dialog boxes. Unit classes have contains the simulation algorithms formed by a dynamic model, mass and energy balance checking routines. These virtual member-functions are called by the user interface and simulation modules. The *database connection* module is offering services for any unit class. The database is implemented in MS Access, a relational database management system having a 32-bit ODBC driver suitable for the connection with the simulator. At the execution time, the chemical properties required for the unit models are reached through this module. The *simulation module* is responsible for all the dynamic calculations.

The sequential simulation module calls the simulation routines for all the active unit objects within the flowsheet. At the end of each time-step, the stream data is updated with the calculated new values. The

mass and energy balancing functionality will be implemented in this module. The *help system* provides the user with information and assists among the simulation work.

4. SIMULATION OF A HEAP LEACHING EXPERIMENT

The heap is percolated with fresh lixiviant pumped from the raffinate pond. The output of the heap is the PLS, stored in the PLS Pond. The Solvent-extraction and Electro-winning (SX-EW) are substituted with a simple reactor followed by a phase-splitter unit. This block has assigned as an output the produced copper cathodes, gaseous oxygen and the recycled lixiviant. The regenerated lixiviant is pumped back to the raffinate pond. The configuration values are taken from real experimental data coming from Codelco, Chile.

After the definition of the pre-processing steps, the column test is carried out. From the obtained experimental data, the kinetic parameters of the undergoing chemical reactions are computed, using an approximation method. The column test configuration parameters for this simulation example are listed in the table 2. The ore is considered to be of two kinds, one fast and one slow reacting component. In the first step, the simulator calculates the amounts of fast and slow reacting copper with their reaction rates based on the column-test extraction curve. The kinetics of the undergoing main chemical reactions are described by reaction rate laws in the following form:

$$d[A]/dt = k\,[A]^a\,[B]^b\,[C]^c \ldots$$

where:

- **A** is the reactant or product being considered and the square brackets indicate concentration in mol/L
- **B, C** are reactants or products of the reaction
- **k** is the reaction rate constant
- **a,b,c** are the reaction orders relative to the components A, B respectively C

The approximation algorithm is based on simple first-order rate low. The estimated values are suggested for the user and not automatically used for further calculations. The user, based on his own experience can set different reaction kinetic parameters than the estimated values. The estimated kinetic parameters are presented in table 1. In the present example, these values are used further to compute the dynamics of the chemical reactions. The flowsheet and dialog window for heap leaching unit is presented in figure 3. The simulated and experimental curves are presented in figure 4. The computed copper extraction data is very close to the experimental values and the similar results were obtained in simulation tests of other heap leaching experiments. The operational units are represented on the

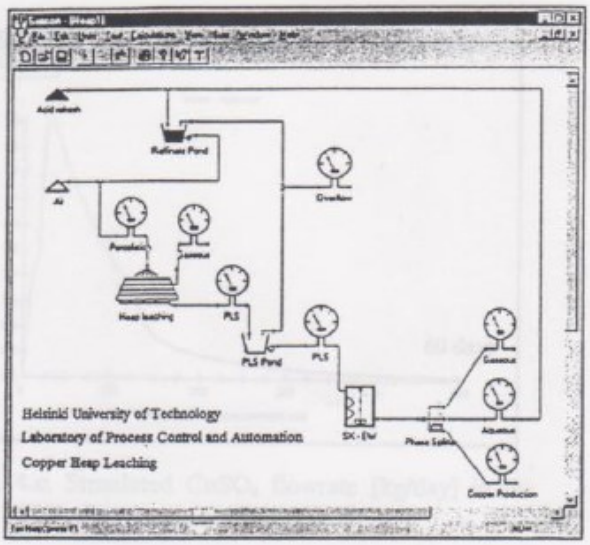

Fig. 3.a. Flowsheet representation with ConSim

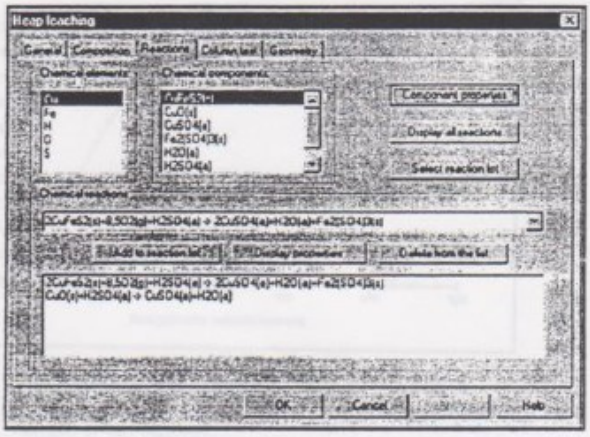

Fig. 3.b. Dialog window of the heap leaching unit

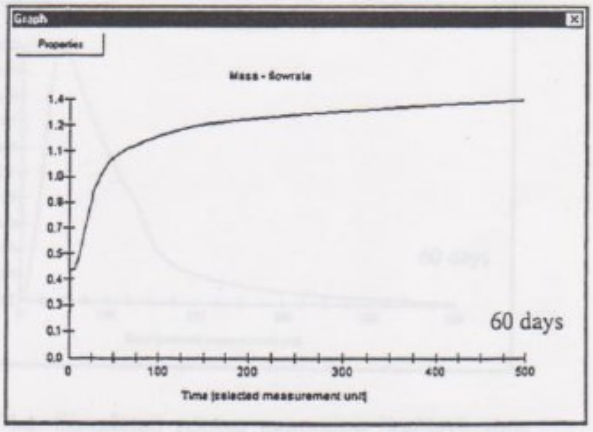

Fig. 4.a. Acid irrigation rate [kg/day].

Table 1.Coefficients calculated from the experimental column test data

Coefficient	Estimated value
Fast reacting copper	69.46 [mass/mass]
Slowly reacting copper	30.53 [mass/mass]
Fast copper reaction rate	0.1581 [sec^{-1}]
Slow copper reaction rate	0.03406 [sec^{-1}]

Table 2.Configuration parameters of the heap-leaching unit

Parameter	Configuration value
Area	0.27 [m^2]
Height	5.28 [m]
Total mineral	950 [kg]
Copper content	1.02 [mass/mass]
Acid cure	13 [kg/ton]
Leaching time	60 [days]
Temperature	18 [Celsius]
Channelling	1 [vol./vol.]
Moisture content	4 [mass/mass]

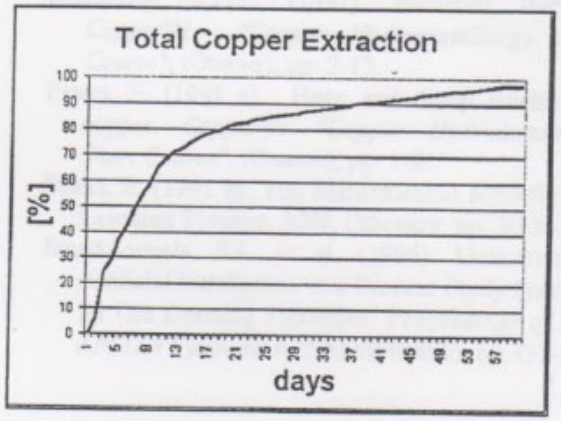

Fig. 4.b. Experimental copper extraction [%]. Total quantity of copper: 9.69 [kg].

flowsheet by bitmap images and the connecting streams with lines. To show the information flowing in streams, there is a dedicated unit, called Graph unit. The mass flow is represented by chemical formulas and molecular flowrate.

CONCLUSIONS

The simulation software have become very important tools for the design and improvement of the mineral processing plant. The value of simulation is judged in the terms of its utility for the practising engineers. However, the quality of the simulation software package can be measured through the incorporated models and the plant data available for the model calibration and parameter estimation. There exists the necessity for the development of fundamental mathematical models that can be customised to the specific applications.

The presented simulation was based on the real plant data. The simulated results are very close to the experimental data, which let us to conclude that simulation can be used as an efficient tool in the field of hydrometallurgy. Earlier software products usually have a very difficult user interface, therefore exists the need for a calculation tool with a user-friendly graphical interface combined with quick and reliable calculations.

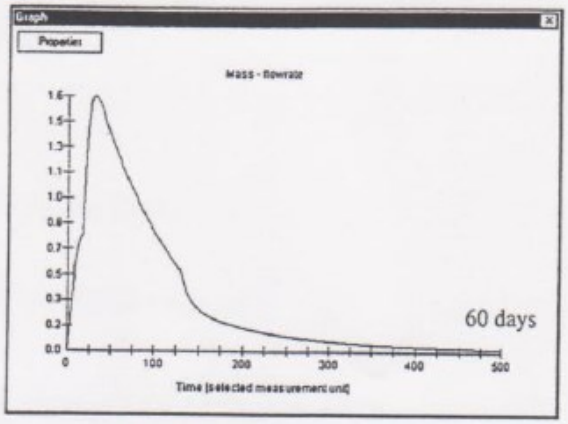

Fig. 4.c. Simulated $CuSO_4$ flowrate [kg/day] in the PLS, time range: 0-60 [days].

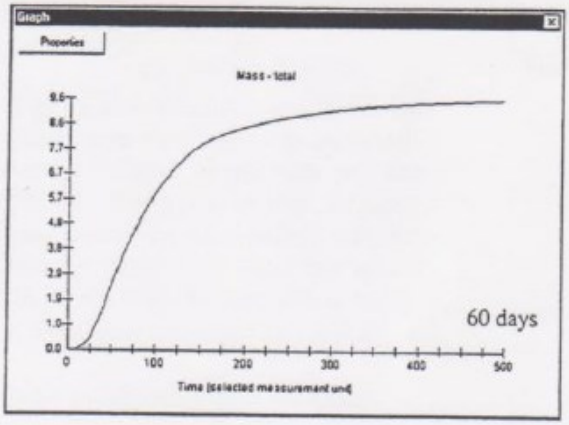

Fig. 4.d. Accumulated copper extraction [kg], time range: 0-60 [days].

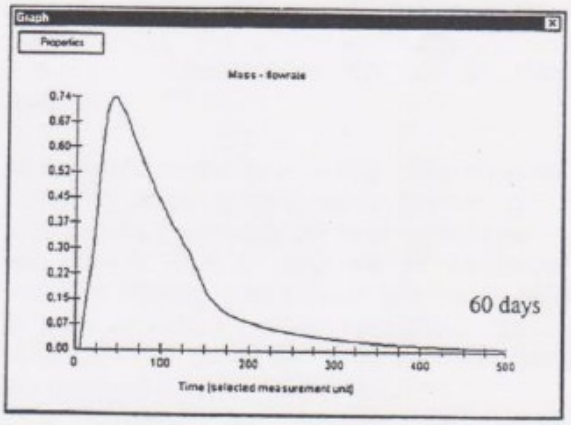

Fig. 4.e. Simulated copper extraction [kg/day], time range: 0-60 [days].

The software can be integrated in the automation system of any hydrometallurgical plant, and with minor modifications, it can be used in real-time control systems. On the other hand, it can be used as a teaching tool.

Although the incorporated models are relatively simple, the software offers a frame for further development. New models can be easily added to the unit library.

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