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## A MONITORING SYSTEM FOR THE COPPER SOLVENT EXTRACTION – ELECTROWINNING PROCESS

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**Abstract:** In this paper the current status of the modeling, simulation and control of the copper-leaching, solvent-extraction and electrowinning process (LX/SX/EW) is investigated. No implementations of advanced process control in the copper LX/SX/EW process have so far been reported. However, model-based control has been successfully applied to solvent extraction processes in the chemical industry, as well as to some other electrowinning processes. A prototype of a process monitoring application based on copper SX/EW steady-state mass balances was designed and implemented. In this paper the structure of the system is described and the test results presented and discussed.  
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**Keywords:** Hydrometallurgy, Process control, Material balance, Performance monitoring, Data processing

### 1. INTRODUCTION

During the last two decades the copper-leaching, solvent-extraction and electrowinning (LX/SX/EW) process has become an important process option in the production of copper from low-grade oxidized ore. LX/SX/EW copper production has grown rapidly during the last decade and further growth can be expected. (Jenkins, *et al.*, 1999; Kennedy *et al.*, 1997; Kordosky, 2002)

As the copper LX/SX/EW process is relatively young and intrinsically rather stable, development has so far mainly focused on the process equipment. This has led to a low level of automation compared to other mineral processing operations. Usually only a low-level regulatory control, in which the controller set points are set manually, is implemented. Improvements in plant control would make it possible to keep process variables near their optimal values, thus increasing the amount of copper produced, reducing the amount of chemicals and energy consumed, and improving cathode copper quality. These improvements would lead to

considerable economic benefits. (Bergh *et al.*, 2001a; Flintoff, 1993)

A phenomenological mathematical simulation model for a copper SX/EW pilot plant has been developed by Aminian *et al.* (1998, 1999, 2000). Separate models for the solvent extraction and electrowinning processes have been developed. The models have been linked together in an SX/EW simulator. The SX model describes the steady-state operation of the mixer-settler unit. Ion transfer between the aqueous and organic phases in the mixer unit has been mathematically modeled. Ion transfer between aqueous and organic phases in the settler was found to be negligible and the settler unit has therefore not been modeled. In the EW model, macroscopic operation of the process has been described by means of material balance equations. Mechanisms occurring at the electrodes have also been modeled. In the testing of the SX/EW model the simulated results were found to agree well with the data measured at the pilot plant.

The extraction chemicals producer, Avecia, has developed a MINCHEM® software for the modeling and simulation of solvent extraction operations. The

software is based on mass balance models and experimentally determined solvent extraction isotherms. Dudley *et al.* (2002) published Nifty Copper Operation's solvent extraction circuit configuration simulations with MINCHEM® software.

A dynamic model for modeling heap leach operations has been developed with the METSIM® simulator by Munoz *et al.* (2000). The roles and limitations of heap leach modeling and of various models have been reviewed by Jansen and Taylor (2002).

Specific problems in the control of the copper LX/SX/EW process are long delays and disturbances that either cannot be measured or are difficult to measure. The effects of control actions can be observed in the process only after a considerable time lag because of the long delays. (Bergh and Yianatos, 2001b)

On-line analyzer systems are available for process monitoring and control purposes. So far, information from the analyzers has only been used for monitoring purposes. Proper operation of on-line analyzer systems needs continuous supervision and maintenance. Careful sample piping design plays an important role in on-line analyzer systems. The copper and sulphuric acid concentrations of process streams, as well as of the main impurities, are

analyzed. The metal ion concentrations are analyzed by x-ray fluorescence, and the sulphuric acid and chloride concentrations with an automated titrator. (Hughes and Saloheimo, 2000; Hughes *et al.*, 2002)

The state of the art of the control of hydrometallurgical copper processes has been reviewed by Bergh *et al.* (2001a). The current status and limitations of copper SX/EW plant control has been reviewed by Bergh and Yianatos (2001b). According to these reviews, studies or application of multivariable regulatory control, adaptive, non-linear and robust control theory to the copper LX/SX/EW processes have not been reported in the literature. Application of advanced process control to the copper LX/SX/EW process has not been reported since these reviews.

An expert control system for the hydrometallurgical zinc process has been published by Wu *et al.* (1998, 1999, 2001). The group has continued their research, and a fault diagnosis system for the zinc leaching process has also been published. (Wu *et al.*, 2002) Application of model predictive control to uranium solvent extraction has been reported by Harper (1995), and to aluminium electrowinning by Meghlaoui *et al.* (1998). Increased production levels, improved product quality and a reduction in the production costs as a result of advanced process control were reported in every case.

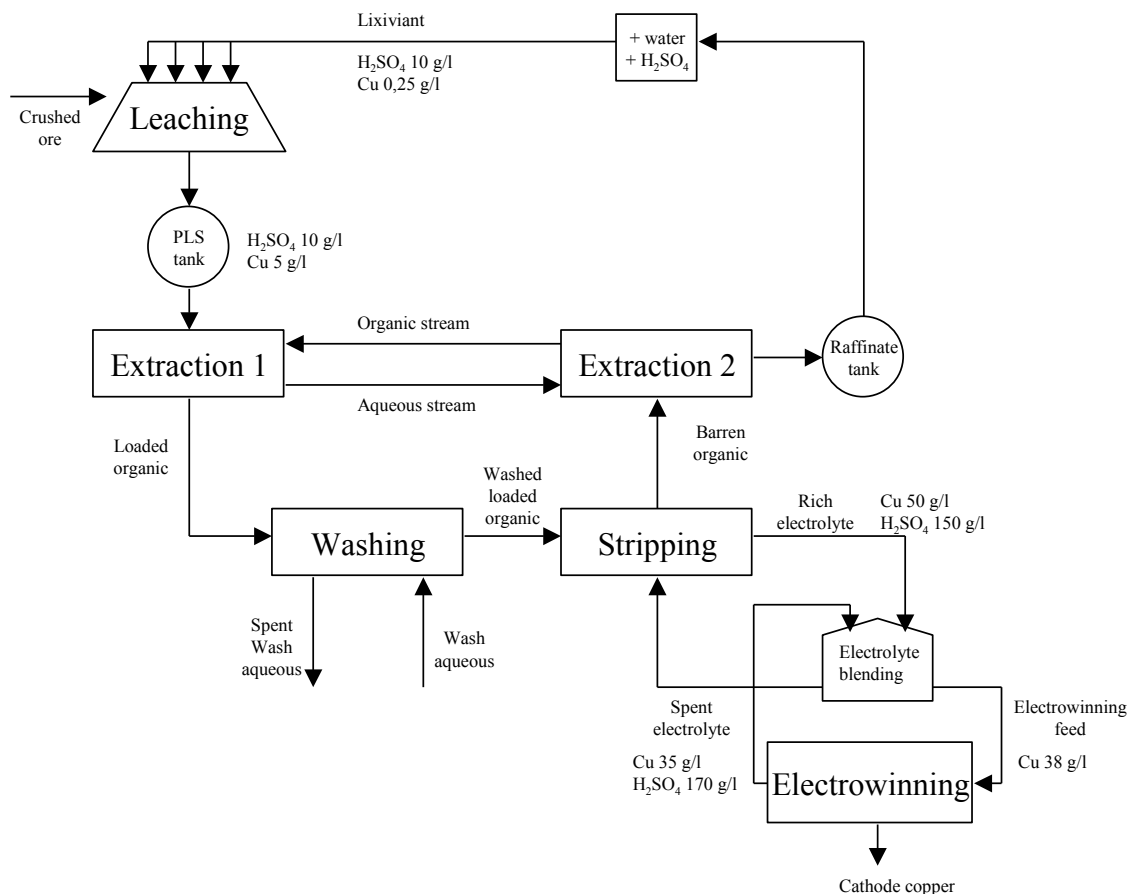


Fig. 1. A simplified flow diagram of a copper LX/SX/EW process.

## 2. DESCRIPTION OF THE LX/SX/EW PROCESS

In the copper LX/SX/EW process, crushed oxidized copper ore is piled into a heap that is irrigated with a

sulphuric acid solution. Copper is leached from its minerals with lixiviant in order to produce pregnant leach solution (PLS). The solution is drawn off from the base of the heap through piping.

The PLS contains impurities which have to be removed. The solution is purified and concentrated in the solvent extraction process. In the extraction stage, copper ions are selectively moved from the aqueous phase to the organic phase by means of an organic extraction chemical in an organic solvent. The copper-containing loaded organic solution is washed with water to remove impurities. In the stripping stage, copper ions are moved from the loaded organic phase back to the aqueous phase to form the rich electrolyte. The barren organic solution is recycled back to extraction. The sulphuric acid concentration of the aqueous solution leaving the extraction stage (raffinate) is adjusted to the appropriate level by adding water or sulphuric acid.

The mixture of raffinate, water and sulphuric acid has formed lixiviant, and it is recycled back to leaching. Rich electrolyte leaving the stripping is mixed with spent electrolyte in electrolyte blending in order to achieve the proper copper concentration in the electrowinning feed. High purity copper cathodes are produced in the electrowinning. Spent electrolyte is recycled back to stripping. (Biswas and Davenport, 1994) A flow diagram of the process is shown in figure 1.

### 3. THE COPPER SX/EW PROCESS MONITORING APPLICATION

A prototype of a process monitoring application for the copper SX/EW process was designed and implemented. The application is based on steady-state mass balances of the process. Flow measurements and on-line analyzer copper assays are used to calculate the amount of copper transferred in different stages of the process. These values are compared to theoretical values calculated on the basis of solvent extraction isotherm data in order to monitor the performance of the process. The purpose of the application is to assist process operators in process control, and to function as a basis for a control application to be developed in the future.

#### 3.1 Data reconciliation

Process measurements always contain random errors and a mass balance reconciliation algorithm is therefore used in the monitoring application in order to make the measurement data conform to mass conservation laws.

The linear data reconciliation problem for steady-state mass balances can be formulated as

$$\text{Min}_x (y - x)^T \Psi^{-1} (y - x) \text{ s.t. } Ax = 0 \quad (1)$$

where  $y$  is a vector of the measurements,  $x$  is a vector of the true values of the variables,  $\Psi$  is a matrix that

contains error variances of the measurements on the main diagonal, and  $A$  is the mass balance of the process in a matrix form.

The measurement vector can be written as

$$y = x + \varepsilon \quad (2)$$

where  $\varepsilon$  is a vector of the measurement errors.

Problem 1 can then be written as

$$\text{Min}_\varepsilon \varepsilon^T \Psi^{-1} \varepsilon \text{ s.t. } A(y - \varepsilon) = 0 \quad (3)$$

The solution for problem 3 is obtained with the Lagrange multipliers method. The Lagrangian for this problem is

$$L = \varepsilon^T \Psi^{-1} \varepsilon - 2\lambda^T (Ay - A\varepsilon) \quad (4)$$

Since  $\Psi$  is positively definite, and the constraints are linear, the necessary and sufficient conditions for minimization are

$$\frac{\partial L}{\partial \varepsilon} = 2\Psi^{-1} \varepsilon + 2A^T \lambda = 0 \quad (5)$$

$$\frac{\partial L}{\partial \lambda} = A(y - \varepsilon) = 0 \quad (6)$$

which yield

$$\varepsilon = -\Psi A^T \lambda \quad (7)$$

$$\lambda = -(A\Psi A^T)^{-1} Ay \quad (8)$$

Finally, the estimate of the true values of the process variables can be obtained as

$$\hat{x} = y - \Psi A^T (A\Psi A^T)^{-1} Ay \quad (9)$$

(Romagnoli and Sánchez, 2000)

#### 3.2 Operational principle of the copper SX/EW process monitoring application

In the application, the copper SX/EW process is monitored on the basis of the flow rate measurements and on-line analyzer copper assays in order to calculate the copper mass balance for the process. Flow rate measurements and copper assays of the process streams (i.e. PLS, raffinate, loaded organic, barren organic, rich electrolyte, spent electrolyte) are used to calculate the copper mass flow rate for each stream. The theoretical copper concentrations in an ideal situation can be calculated by using solvent extraction isotherms. Solvent extraction isotherms are determined experimentally and are dependent on the copper concentration of PLS, the extractant concentration and the sulphuric acid concentration of the aqueous phase. The process can be monitored by comparing actual copper mass flow rates to theoretical copper mass flow rates. Extraction efficiency can be monitored by calculating the amount of copper actually moved from the aqueous phase (PLS) to the organic phase (loaded organic), and then comparing this value to the theoretical values of the ideal situation. Stripping can be monitored by calculating the amount of copper moved from the organic phase (loaded organic) to the rich electrolyte, and then comparing this value to the theoretical values of the ideal situation.

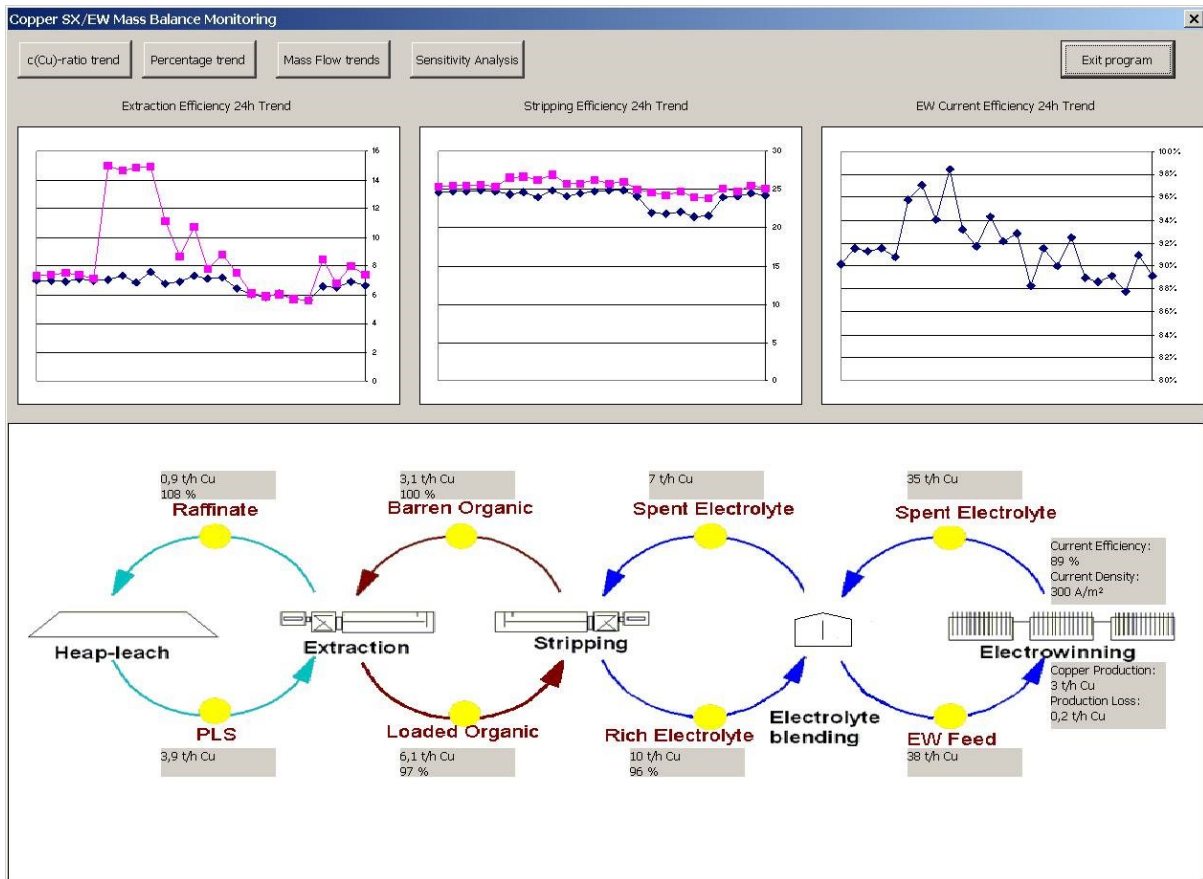


Fig. 2. The main monitoring view of the copper SX/EW process monitoring application.

The prototype of the process monitoring application was developed with Microsoft Excel and Visual Basic for Applications. One-hour average values of the flow rate measurements and on-line analyzer copper assays are read from the plant history database when calculating the copper mass balance for different stages of the process. Process measurements contain random errors and the mass balance reconciliation algorithm is therefore used to adjust measurement data to conform to mass conservation laws. Theoretical values for the copper concentrations are also calculated from the solvent extraction isotherm data in the application.

The main monitoring view of the application shows the copper mass flow rate for each stream. The ratio of the actual copper mass flow rate to the theoretical mass flow rate is also shown. Trend graphs for extraction, stripping and electrowinning efficiencies are plotted. The main monitoring view of the application is shown in figure 2. The amount of copper produced is calculated on the basis of the amount of copper removed from the electrolyte in electrowinning. Copper production loss due to disturbances in the process is also calculated.

It is also possible to plot trends for the copper mass flow rates of each stream. Process variable variation is monitored by calculating the ratio of the daily range of the copper mass flow rate to the daily average of the copper mass flow rate for each process stream. The application also has a feature for sensitivity analysis of the process variables in solvent extraction. With this feature process operator can test

what kind of change a change in the flow rate or copper concentration causes in the other process variables. This calculation is done on the basis of the solvent extraction isotherm data.

#### 4. OFF-LINE TESTING OF THE SX/EW-PROCESS MONITORING APPLICATION

The application was off-line tested with historical data from the copper SX/EW plant. Historical data consisted of one-hour average values of the on-line analyzer copper assays and the volume flow rate measurements of the most important process streams from a time period of two weeks. The historical data consisted of 336 one-hour average measurement values.

Monitoring of the copper mass flow rates in extraction and stripping were tested with the historical data. Solvent extraction isotherm data were not available and therefore the operation of the monitoring procedure was evaluated by examining the solvent extraction performance trends. Some disturbances in the copper mass flow rates of the process could be detected on the basis of the monitoring trends. 35 different disturbances were detected. After examining the historical data, 18 situations were found to be real disturbances and 17 situations to be incorrectly detected disturbances. The detected disturbances that were found to be real were mainly high variations in the copper mass flow rate of raffinate or barren organic. In the detected disturbance situations the copper mass flow rate of

raffinate had temporarily increased by 9-13 %, and the short disturbance then gradually returned to the normal value. In the detected disturbance situations the copper mass flow rate of barren organic had temporarily decreased by 7-20 %, and the short disturbance then gradually returned to the normal value. In most of the situations the duration of the disturbance was only one hour.

The disturbances were detected by examining the variation of the monitoring trends. In the normal situation the trend values change within certain limits. In the disturbance situation the trend value had a high deviation from the values of the normal situation.

An example of a disturbance that was detected in both the extraction and stripping monitoring trends is shown in figures 3 and 4. The duration of the disturbance was one hour. After examining the historical data from the corresponding time period, a 20 % decrease was found in the barren organic copper mass flow rate. The disturbance is detected at the hour average time of 12 in the figures.

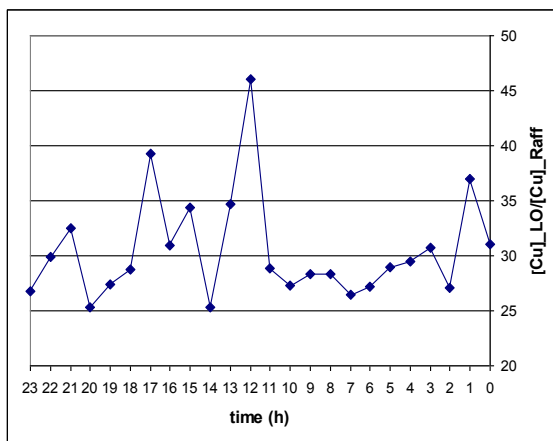


Fig. 3. The monitoring trend for extraction.

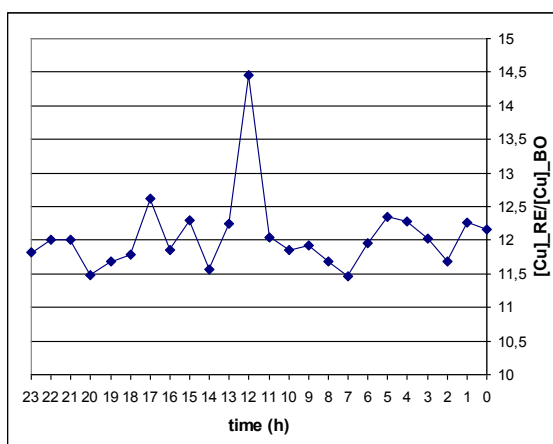


Fig. 4. The monitoring trend for stripping.

The disturbance in the barren organic copper mass flow rate is shown in figure 5.

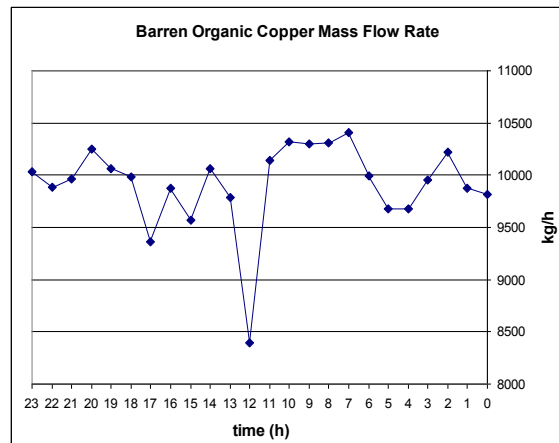


Fig. 5. Barren organic copper mass flow rate trend.

The trend of the barren organic copper concentration shows a high deviation from the average value. The barren organic copper concentration trend is shown in figure 6.

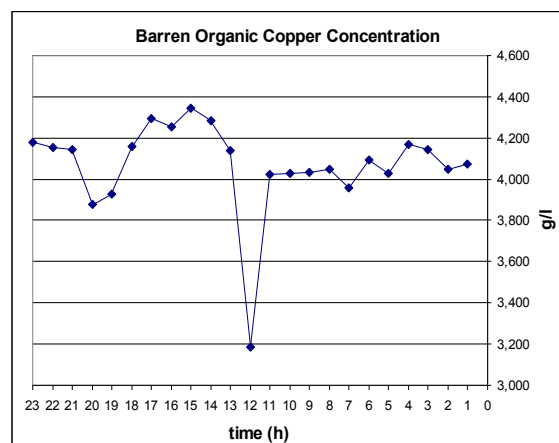


Fig. 6. Barren organic copper concentration trend.

The incorrectly detected disturbances were mainly caused by lasting level changes in the electrolyte flow rate. The monitoring trends incorrectly show these situations as a disturbance.

In the off-line testing it was found that the operational principle of the application is functional and that the application will probably work at the plant with only small plant-specific modifications.

## 5. CONCLUSIONS

The state of the art of the control of the copper LX/SX/EW process was investigated. Implementations of advanced process control in the copper LX/SX/EW process have so far not been reported. However model-based control has been successfully applied to other solvent extraction and electrowinning processes.

A prototype for a copper SX/EW process monitoring application was developed in this project. In the off-line testing of the application the operational principle of the application was found to be functional and the application will probably work at the plant with only small plant-specific

modifications. However, on-line testing of the application should still be carried out.

The successful operation of the monitoring application requires that the solvent extraction isotherm data correspond to the state of the process. Isotherm data have to be updated at sufficiently frequent intervals. The on-line analyzer and flow rate measurements also have to be properly calibrated.

With the help of the application, process operators would be able to control the process such that there is a reduction in process variable variations, resulting in an increase in copper production and copper cathode quality.

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