THE SUPERVISOR OF SIMULATION: A STEP FURTHER TO MEET THE PROCESS ENGINEER NEEDS

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ABSTRACT

Simulation of Mineral Processes is now commonly used by the Engineers in charge of plant design or optimization but a good knowledge of the simulation tool is still needed to conduct a project. A new level of algorithm has been defined above the simulator to answer directly to the user's questions.

This level has been called the supervisor of simulation, which is using the automation concepts of sensors and actuators. At any place of the flowsheet (i.e., a stream or an equipment), the user may indicate which value could change by graphically implementing an actuator. Then, he can evaluate the effect of the variation of this value at any other place of the flowsheet by inserting a sensor. Thus, by example, it becomes possible to look at the evolution of the recoveries and/or the circulating loads when scanning an interval of the possible feed flowrates.
This approach conducts to an increased facility in using a simulator and in analyzing the predictions. It is also a very valuable tool for permitting to characterize the sensibility of the simulation results to the variation of some settings (e.g., load of grinding media, rotation speed, water addition, etc.) or feed characteristics (e.g., flowrate, sizes, grades, grindability, etc.). Thus, the most important variables can be identified for design and pre-control optimization of plants

This new level of simulation will be implemented in a further version of the USIM PAC simulator and selected examples are presented.

INTRODUCTION

For the design or the optimization of a mineral processing plant, the use of a steady-state simulation approach is now recognized to be a real help for the process Engineer. Several hundreds of copies of simulation packages are in use in the industry in mining groups, in manufacturers or engineering companies, in research centers or universities.

The capabilities of these software are different in terms of quantity and quality of mathematical models imbedded, in terms of spread of the field of applications or in terms of easiness of the interface but most of them are improving continuously to offer the biggest help for the user. These improvements may cover all the steps of the simulation based approach such as sampling, data reconciliation, modelling, simulation algorithms or cost calculations.

The focus of this paper is to highlight one of the step of this approach which is the closest to the user objectives i.e. the use of the simulation tools for decision making purpose and to evaluate the confidence level of the predictions. A new level of algorithms has been defined, above the simulation per se, to control the effect of some variables on the performances of processing circuit.

Three examples are presented to demonstrate this algorithm. The first one shows in an existing copper grinding flotation circuit the way to automatically control the effect of a variation in the feed rate to the mill on the recovery and grade of the flotation concentrate. The second illustrates the analysis of the sensitivity of a grinding circuit on the possible variation of the grindability of the ore at the design stage.
The third presents the application of this algorithm for the sensitivity analysis of the models used for optimization. This application illustrates the advanced use of the supervisor to improve the calibration of a mathematical model and thus improve the further predictions of the simulator.

THE SIMULATION-BASED APPROACH

This approach is using the mathematical description of the unit operation performances to predict either the design of a new plant or the performances of an existing one under changing conditions (see Figure 1).

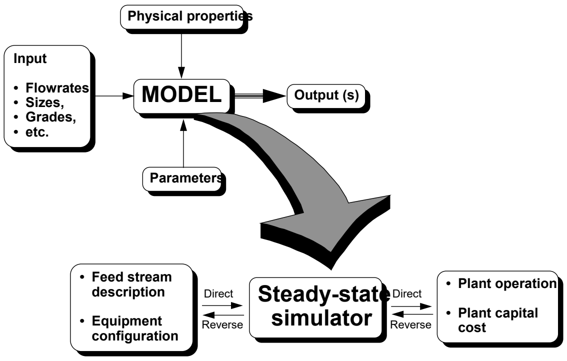

Figure 1 Functions of the models and of the steady-state simulation

The simulation based approach may be used for three main purposes. The first one is for the preliminary design of a new plant, at this stage a balance of the circuit is needed with information on all the streams (i.e., flowrates, grades, size distributions) and then the design of the main equipment of the future plant is obtained even with an estimation of the investment costs. The second one concerns the advanced design of an installation. With more information coming from lab tests or pilot plant runs the prediction of the plant operation is more precise and can be used to study several alternatives of flowsheet or settings, to help at the plant commissioning stage or be a tool for the plant operators training. The third classical application is the plant optimization (or audit, retrofit and adaptation). In that case the available data from the plant is used to build a simulator of the plant which can be used, after validation, to test all the changes which are needed to improve the plant operation.

THE SUPERVISOR

This algorithm is standing above the simulation per se. The figure 2 shows the architecture of the supervisor with the choice of the actuators (e.g., flowrates, grades, sizes, parameters of the models, etc.) and of the sensors which can be local (e.g., flowrates, grades, sizes) or a comparison of two streams such as a circulating load or a recovery.

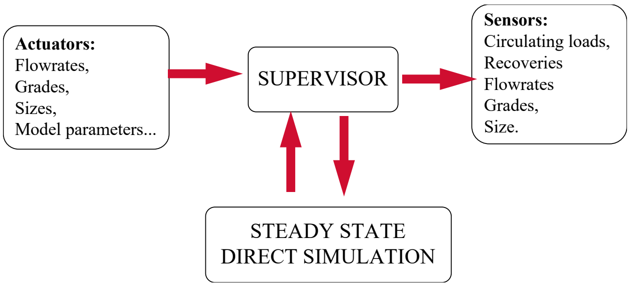

Figure 2 Functions of the supervisor

FIRST EXAMPLE: LOOKING AT THE GRADE/RECOVERY CURVES WHILE INCREASING THE FEEDRATE

In the case of an existing copper concentrator, after building a simulator of the plant (which requires the different steps of the simulation-based approach: sampling campaign, data reconciliation, parameters estimation and simulator validation), the process Engineer may want to test several changes in the plant and, in the case of this example, quantify the change of the fresh feedrate on the grade and recovery of the copper concentrate (see Figure 3).

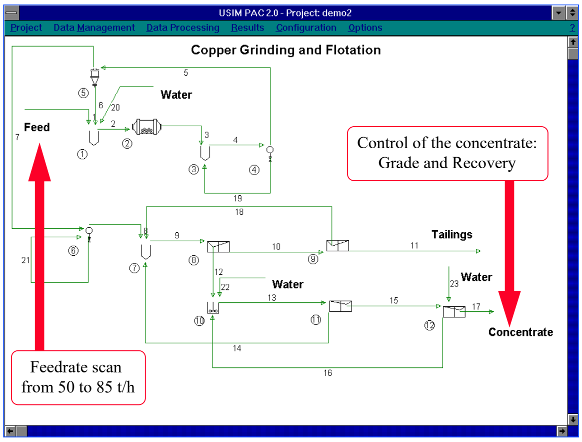

Figure 3 Flowsheet of the copper circuit

At this point several possibilities are open, the user may change the feedrate of solid (as the water balance is automatically adjusted by the simulation) step by step, control the grade and calculate the recovery of the concentrate after the simulation and finally, restart the process with a new feedrate. On the other hand, the user may use the supervisor to directly select the "actuator", and graphically follow the results on the screen (see Figure 4).
Once again this may be obtain by another way but, it has been seen that the important increase of easiness given by the supervisor conduct to a much more efficient valorization of the simulation use.

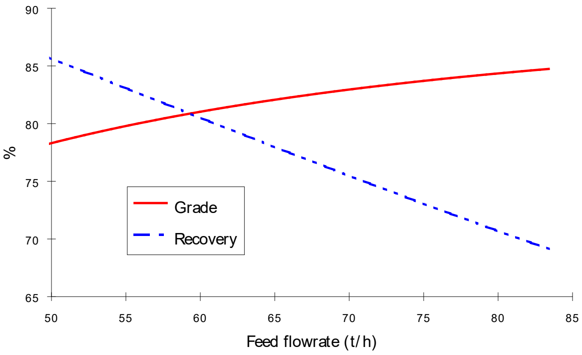

Figure 4 Variations of the Grade and Recovery of the concentrate versus the feedrate of the grinding circuit

The "what happens if ..." procedure used to analyse a process (e.g., what happens if I change the quantity of balls from 35 % to 40 % in my mill on the d80 of the flotation feed?) is then extended to the study of the tendencies in the effect of one parameter (e.g., what is the evolution of the d80 of the flotation feed if I gradually increase my ball load from 25 % to 50 % in the mill?).
This approach is really useful for a better understanding of the effect of one change or, more generally, for a better understanding of a process avoiding the general problem of the use of the simulation which is to discriminate the most important results within a huge amount of information provided by the simulation software.
In this example, it can be seen that for a feedrate ranging from 50 to 85 t/h, the Recovery dropped from 85 down to 70 % while the Grade increase from 78 to 85 %. If an increase of capacity is planned and regarding the operating costs and the price of the products, these curves are very helpful to take a decision.
One of the points which has to be kept in mind is the quality (i.e., the level of accuracy) of the models used (Villeneuve et al., 1994).

SECOND EXAMPLE: LOOKING AT THE EFFECT OF A GRINDABILITY CHANGE AT THE DESIGN STAGE

The figure 5 shows the flowsheet of the circuit to be design. In that simple case, there is a Ball Mill in closed circuit with a Hydrocyclone. The two other units on the flowsheet are used for the automatic water balancing (i.e., two density regulation units).

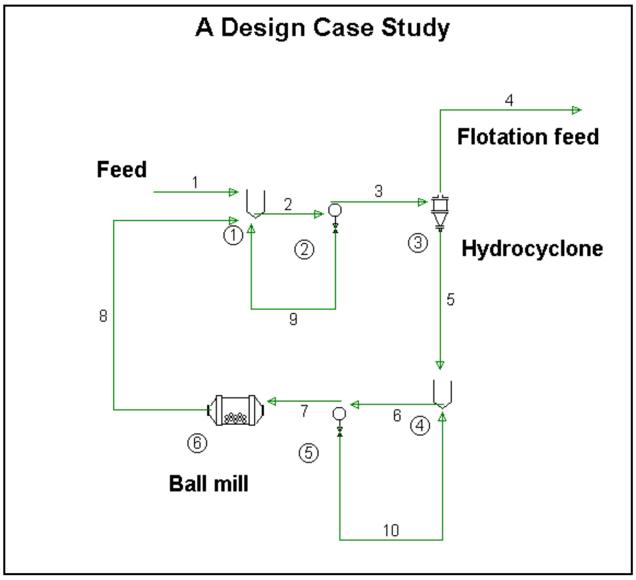

Figure 5 Flowsheet of the grinding circuit

The actuator is one of the parameters of the selected model for the ball mill (i.e., the "level 1" ball mill model of USIM PAC): the Work Index (i.e., the grindability of the ore expressed in kWh/st). At a preliminary design stage, this value is usually not precisely known and the flexibility of the evaluated circuit must be investigated.

In our case, the value used for the design is 12.7 kWh/st but the evolution of the d80 of the Hydrocyclone overflow (i.e., the Flotation feed) has to be checked for a wider range as from 11 to 14 kWh/st.

The figure 6 shows that within the range of Work Index values, the d80 of the flotation feed is increasing from 56 to 63 µm, which is, in most cases, acceptable for the industrial operation.

Figure 6 Evolution of the d80 of the Flotation feed versus the value of the Work Index

THIRD EXAMPLE: CALIBRATION OF THE SELECTION FUNCTION OF A BALL MILL MODEL

This example shows the interest of the supervisor approach for the analysis of the response of a mathematical model during calibration. The figure 7 is presenting the simulation-based optimization approach in which the calibration is a key step. The case presented here regards the "level 2" ball mill model which is one of the ball mill models used in USIM PAC.

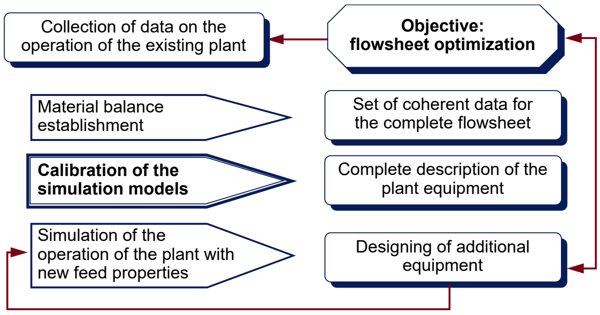

Figure 7 Simulation-based optimization approach

This model is based on the work of Austin (1984) and of Herbst & Bascur (1979). It combines a simplified kinetic approach with an energetic approach. The energy consumed by the mill is first computed as a function of its characteristics, this being the empirical formula used in the Allis Chalmers methods for dimensioning mills:

$$W = 4.879 D^{0.3}(3.2 - 3Tc)Vr\left[1 - \left(\frac{0.1}{2^{(9-10Vr)}}\right)\right]$$

where:
W: power (kW) consumed per ton of grinding media
D: mill diameter (m)
Tc: fraction of mill volume occupied by the balls
Vr: fraction of critical speed.

Then, this energy is used in a formula which results from a simplification of the kinetic approach:

- the transport of the ore is characterised by a number of perfect mixers in series.
- the grinding and selection functions are represented together in application of the hypothesis of compensation using the relationship:

$$BijSj = S_{i-1} = S_1.\exp\left(\alpha_1 \ln\frac{d_i}{d_1} + \alpha_2\left(\ln\frac{d_i}{d_1}\right)^2\right)$$

where:
di: mean particle size in particle size class i
S_1: rate of breakage (1/h)
α_1: parameter
α_2: parameter

Furthermore, it is considered that S_1 depends on the energy consumed during grinding according to the relationship given by Herbst:

$$S_1 = S_1^E \frac{P}{H}$$

where:
P: energy available for grinding
H: total hold up of material in the mill.

The particle size distribution of the mill discharge is then computed:

$$RP_i = RF_i . \left(1 + \frac{S_{i-1}P}{N \times Q}\right)^{-N}$$

where:

RP_i: proportion (in mass) of particles coarser than particle size class i in the mill product

RF_i: proportion (in mass) of particles coarser than particle size class i in the mill feed

S_i: value computed using the above equations, and using S_1^E, α_1 and α_2, for particle size class i

P: power consumed by the mill (kW)

Q: solids flowrate

N: number of perfect mixers in series.

The numerical values of α_1, α_2 and S_1^E for each mineral are obtained by calibration employing experimental data on at least one point of operation of a continuously running mill, called the calibration point.

The calibration of these parameters is done by minimising the sum of squares of the relative or absolute differences between the experimental data and the model's predictions.
Calibration is sometimes made difficult by the shape of the mathematical problem of minimisation. According to the data on which the model has to be fitted, there may be local minima and/or an undetermined solution.
Two main possibilities remain to overcome these difficulties: take another set of experimental data or try to visualise what happens during calibration.

The supervisor allows to record the value of the error function while scanning a range of parameters values. Figure 8 shows the results of such a scan on parameters S_1^E and α_1. In that case, it is clear that an absolute minimum exists over a large domain. Calibration of the ball mill model will be successful.
A more detailed analysis should also be possible to calculate the precision needed on parameters estimation to achieve a given error on calibration.
The sensitivity analysis made on several models of a flowsheet is of importance to determine which parameter of which model has the greater influence on the precision of simulation results.

One of the main interest is to identify which stream of the actual plant has to be known with the best accuracy.

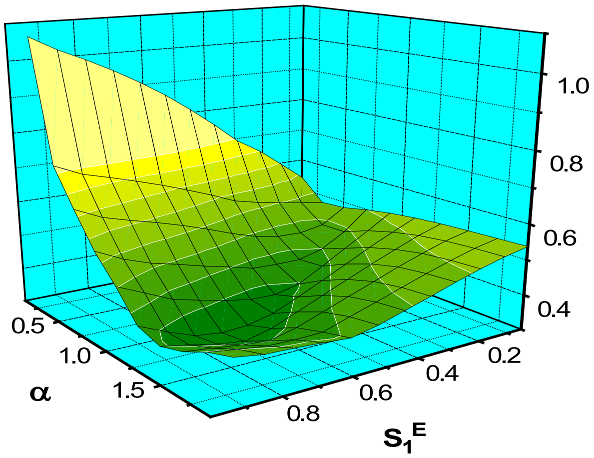

Figure 8 Sensitivity analysis: surface response during calibration of the selection function

CONCLUSIONS

The three examples presented have been chosen to highlight the interest of the supervisor algorithm even for simple and rather different tasks. For preliminary design, plant optimization or advanced analysis of the sensitivity of a mathematical model, this approach has shown its efficiency and offers a new level of control of the simulation tool to the end user.

A new step of development has been conducted to define new "actuators" (e.g., changes in grades or operating conditions of a unit) and new "sensors" (e.g., power consumption of a mill or Gold lock-up in a CIP unit).

These developments combined with an easy use of the software under Windows and an increasing number of validated models within the simulator are contributing to a new step of the simulation-based approach to meet the Process Engineer needs.

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