INTELLIGENT SUPPORT SYSTEM FOR A PRESSURE FILTER

Jämsä-Jounela S-L. [1], Kämpe J. [1], Vermasvuori M. [1], Koskela K.[2]

1) Helsinki University of Technology
Department of Chemical Technology
Laboratory of Process Control and Automation
Kemistintie 1. FIN-02150 Espoo
FINLAND
E-mail:Sirkka-l@hut.fi
2) Larox Corporation, P.O. Box 29, 53101 Lappeenranta, FINLAND

Abstract: This paper presents the intelligent operating system for the Larox variable volume pressure filter and the online test results obtained with an industrial Larox filter at a Finnish process site. Preliminary analysis of the results indicates that the system works well. During testing, suitable operating parameters for faster filtration cycle were discovered and the production rate was increased. *Copyright © 2003 IFAC*

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1. INTRODUCTION

Artificial intelligence methods have become more common in a wide range of scientific and engineering fields. The number of applications is increasing rapidly and successful results have been reported. Artificial intelligence methods such as expert systems, fuzzy systems, neural networks and combinations of these, have proved to be excellent tools for the control of mineral processes (Jämsä-Jounela et. al., 1996)

During the last 25 years many advanced, model-based fault diagnostic systems have been developed (Isermann, 1997, Himmelblau, 1978). Estimation methods for evaluating changes in parameters and states have been presented in Isermann (1993). There have also been reviews on different fault diagnosis methods and their current status and the future trends (Isermann and Ballé, 1997, and Jämsä-Jounela, S-L.,2001).

This paper presents an intelligent control system for a Larox pressure filter. The support system is programmed using Java, a platform-independent object-oriented programming language. The structure of the system is modular, which makes it updateable and expandable. The system consists of classification, modelling, optimisation, economical, fault diagnostic and remote support modules. The aim of the system is to maximise the capacity of the filter and to find optimal operation parameters so as to ensure that the end product meets the quality criteria. Economical efficiency is improved not only by increasing capacity, but also by lowering the amount of energy consumed and by using fault diagnostic and remote support modules to decrease process downtime.

2. THE STRUCTURE OF THE SUPPORT SYSTEM

2.1 Classification module

The aim of the classification module is to determine what kind of slurry is being filtered. The optimal operation parameters depend on the type of feed, and
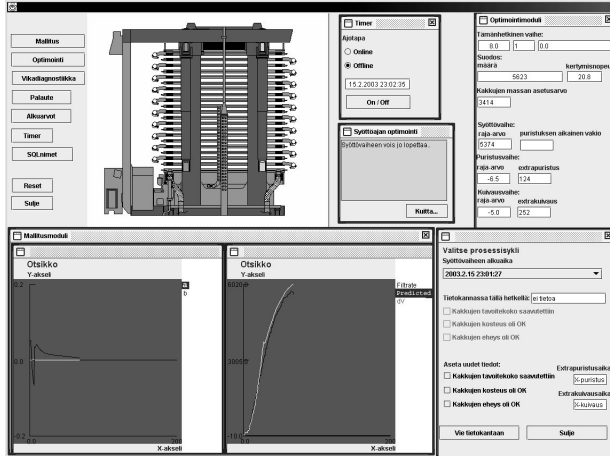
Figure 1. Screen capture of the support system software.

parameters are optimised separately for every type of feed. The classification of the feed type is performed on the basis of measurements that describe the physical properties of the slurry, and it is implemented by means of an artificial neural network, the Kohonen Self-organizing map (SOMs) (Jämsä-Jounela, 1998).

2.2 Modelling module

The modelling module is used to monitor the progress of the feeding stage of the filtration cycle. A model has been derived for a single chamber, constant-pressure filter. The starting point for the model is Darcy's equation (1).

$$Q = k \frac{A \cdot \Delta p}{\mu \cdot l} \qquad (1)$$

where
Q = the accumulation rate of filtrate [m^3/s],
k = a constant, permeability of the cake [m^2],
A = the area of filtration [m^2],
Δp = total filtration pressure difference [Pa],
μ = viscosity of the filtrate, and
l = thickness of the cake

Equation (1) can be formulated to use the overall filtering resistance, R [1/m]:

$$Q = \frac{A \cdot \Delta p}{\mu \cdot R} \qquad (2)$$

The overall resistance can then be divided into two resistances, one caused by the cake and the other caused by the filtering cloth.

$$Q = \frac{A \cdot \Delta p}{\mu \cdot (R_c + R_m)} \qquad (3)$$

where
R$_c$ = the resistance of the cake, and
R$_m$ = the resistance of the cloth.

The cloth resistance is usually assumed to be constant, and the cake resistance to be a function of the thickness of the cake. Solving (3) for Δp and assuming that the overall pressure difference consists of the pressure difference over the cake and over the filtering medium, Δp can be expressed as (4).

$$\Delta p = \frac{\mu \cdot Q}{A}(R_c + R_m) = \Delta p_c + \Delta p_m \qquad (4)$$

An acceptable calculation precision is usually achieved by assuming that the pressure difference over the cake is equal to the overall difference.

For non-compressible cakes, the resistance can be expressed with the cake resistance coefficient and its magnitude.

$$R_c = \alpha \cdot w \qquad (5)$$

where
α = the cake resistance coefficient [m^3], and
w = the weight of the cake per area [kg/m^2]

From equations (4) and (5) the accumulation rate of the filtrate, Q, can be written

$$Q = \frac{A \cdot \Delta p}{\mu \cdot \alpha \cdot w + \mu \cdot R_m} \qquad (6)$$

The amount of dry cake can be calculated if the amount of filtered slurry and its concentration of solids are known.

$$w \cdot A = c \cdot V \qquad (7)$$

where
V = the cumulative amount of filtrate, and
c = the concentration of solids in the slurry.

By combining (6) and (7), an equation for the accumulation rate of filtrate, Q, can be written as

$$Q = \frac{A \cdot \Delta p}{\mu \cdot \alpha \cdot c \cdot \dfrac{V}{A} + \mu \cdot R_m} \qquad (8)$$

The accumulation of filtrate at a certain point in time is known to be

$$Q = \frac{dV}{dT} \qquad (9)$$

(8) can then be reformulated as

$$\frac{dV}{dt} = \frac{A \cdot \Delta p}{\mu \cdot \alpha \cdot c \cdot \dfrac{V}{A} + \mu \cdot R_m} \Rightarrow$$

(10)

$$\frac{dt}{dV} = \mu \cdot \alpha \cdot c \frac{V}{A^2 \cdot \Delta p} + \frac{\mu \cdot R_m}{A \cdot \Delta p}$$

If the filtration pressure is constant, (10) can be integrated as

$$\int_0^t dt = \frac{\alpha \cdot \mu \cdot c}{A^2 \cdot \Delta p} \int_0^V V dV + \frac{\mu \cdot R_m}{A \cdot \Delta p} \int_0^V dV \quad (11)$$

$$t = \frac{\alpha \cdot \mu \cdot c \cdot V^2}{A^2 \cdot \Delta p \cdot 2} + \frac{\mu \cdot R_m}{A \cdot \Delta p} V \quad (12)$$

All the terms in (12), except time and the cumulative amount of filtrate, are constants. For the sake of convenience, (12) can be written as

$$t = aV^2 + bV \quad (13)$$

where dummy variables a and b are:

$$a = \frac{\mu \cdot \alpha \cdot c}{A^2 \cdot \Delta p} \qquad b = \frac{\mu \cdot R_m}{A \cdot \Delta p} \quad (14)$$

The duration of the feeding stage is then a function of the filtrate volume and, when we know the desired volume, the time taken to reach this volume can be determined if the parameters a and b are known. The parameters a and b are identified using the recursive least squares method proposed in Åström et al., 1984.

2.3 Optimisation module

The optimisation module optimises the feeding, pressing and drying stages of the filtration cycle. The individual stages are optimised independently.

The feeding stage. In the feeding stage the goal is to continue feeding long enough for the chambers of the filter to become filled with slurry. The stage should not last longer than this because overfilling of the chambers causes problems during the next operation cycle. The optimal increase in the mass of the filter during the feeding stage is determined on the basis of information about successful operation cycles in the past. The time when the mass of the filter reaches this optimal value and the feeding can be stopped is predicted using the recursive model described earlier.

The pressing stage. The aim in the pressing stage is to get the cake dense enough for the drying stage. If the cake is not pressed hard enough, it may break during the drying stage. If the cake cracks, the pressurised air used for drying flows mainly through the cracks and the cake will not dry properly. If this happens then the desired moisture level of the cake

cannot be achieved. The pressing stage can be divided into two separate sub-stages (Kämpe, 1999). At first, the excess liquid on top of the cake is pressed through the cake and filtering medium. The cake is then further pressed in order to achieve the density required in the drying stage. During the second sub-stage the amount of filtrate coming from the filter is much smaller than during the first sub-stage. As a result, the transition from the first sub-stage to the second can be seen from the rate at which filtrate accumulates.

The drying stage. In the drying stage the object is to dry the cake to the desired moisture level as fast as possible. As for the pressing stage, the drying stage can also be divided to two sub-stages: in the first stage the liquid between the particles is blown out, and in the second sub-stage the air flow removes moisture from the surface of the particles. Again, the transition between sub-stages can be seen from the change in the rate of accumulating filtrate.

2.4 Economical module

The main purpose of this module is to support the decision making of the optimisation module and to motivate the operator to run the process in an economical way by monitoring and displaying the operating costs of the filtering process. If the same quality and amount of final product can be achieved with different operating strategies, the one with the lowest costs is chosen. The operating costs are calculated once per cycle using information from all process stages.

2.5 Fault diagnostic module

The fault diagnostic module uses parameter values a and b of the modelling module to monitor the behaviour of the filter. During the normal feeding stage, the parameters level off at certain near-constant values. In the case of a specific problem, the model does not describe the situation, which is indicated by the continuously changing values of the parameters. Normal process measurements are monitored and, if they behave abnormally, symptoms are generated. The symptoms are then compared against known symptom combinations of different malfunctions in order to identify the abnormal operating condition.

2.6 Remote support module

The purpose of the remote support module is to provide a secure and reliable way of transferring data from the filter to experts, who can then analyse the data if a malfunction occurs. The remote support module consists of an SQL database server that is connected to a Larox pressure filter, a Microsoft Internet Information Server (IIS), workstations, and a LAN network. The workstations are connected to each other either over the Internet or via modems.

For security reasons the Internet connection has been secured by means of a Virtual Private Network (VPN) and access to the local network is restricted by a firewall. This structure is presented in figure 2.
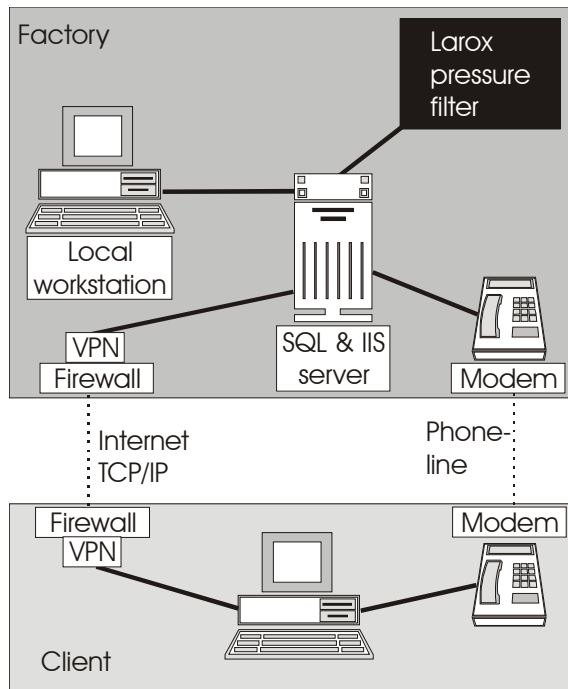

Figure 2. The structure of the remote support module.

3. ON-LINE TESTING OF THE SUPPORT SYSTEM

The support system software has been earlier tested off-line with data collected from a Larox pressure filter with 10 chambers. The test results are presented in (Kämpe, et al. 2003).

In June 2003 a set of on-line tests was carried out at an industrial mineral processing plant. The on-line tests were made using a Larox Powerex PF60 filter with 10 chambers and a total pressing area of 60 m^2. The filtration plant consists of four different Larox filters with a common drying air supply and solid conveyor.

The tests were carried out by performing series of filtration cycles with different stage times. The duration of the feeding, pressing and drying stages were varied and the cake moisture was measured. Other process variables were also monitored in order to investigate the performance of the model parameter estimation.

3.1 Feed stage tests

During all the tests the feed time was kept at a fixed value. The model satisfactorily estimated the progress of the feeding stage. The original model (13) was modified so that it takes into account the measured pressure (15), instead of keeping it at a constant value.

$$t = \frac{a}{\Delta p}V^2 + \frac{b}{\Delta p}V \qquad (15)$$

This depicts the behaviour of the feeding pressure in an industrial size pressure filter in equation (13). The feeding pressure is not constant, but is raised stepwise to its final value. The change in feeding pressure is shown in figure 3.
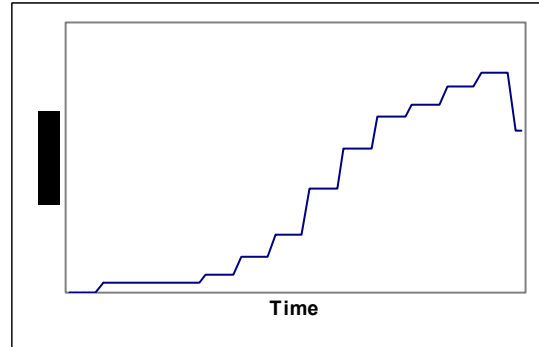

Figure 3.Gradual increase in feeding pressure during the feeding stage.

3.2.Pressing stage test

In accordance with the control strategy the pressing stage was divided into two sub stages. The duration of the first sub stage is defined on the basis of the rate of filtrate accumulation. The duration of the second sub stage has to be optimised.

The model predicted the amount of accumulated filtrate well, and there was only a minimal difference between the measured and the predicted values in the cumulative amount of filtrate. The results are shown in figure 4.
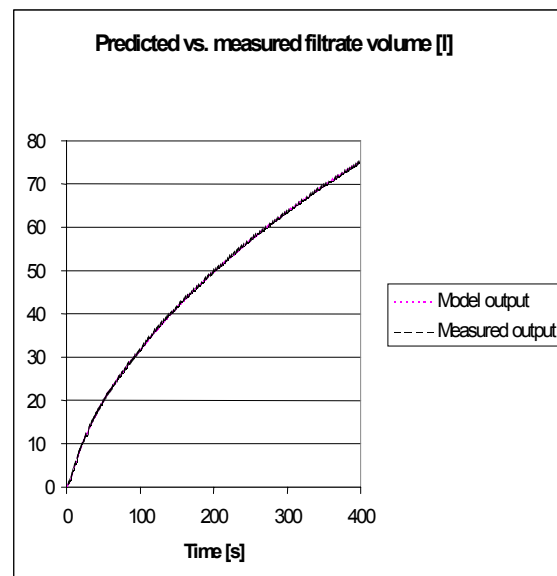

Figure 4. Modelling the change in filtrate volume.

The model proposed an average duration of 50 seconds for the first sub stage. One unusual value was probably due to an error in data transfer. The estimated durations for the first sub stage are shown in figure 5.
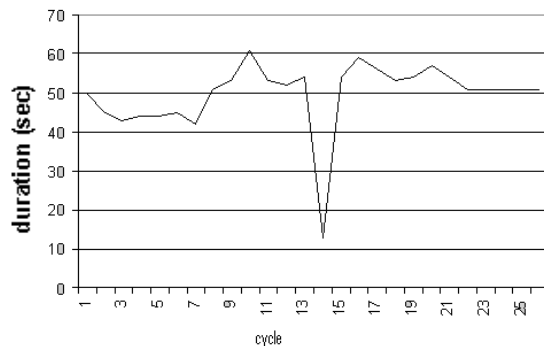

Figure 5. The calculated durations of the first sub stage of the pressing stage, cycle vs. duration in seconds.

The duration of the second sub stage is optimised on the basis of the cake moisture requirements. According to the test results, the pressing time does not affect the cake moisture substantially (see figure 6). As a conclusion, the pressing time could be shortened considerably after further test runs.
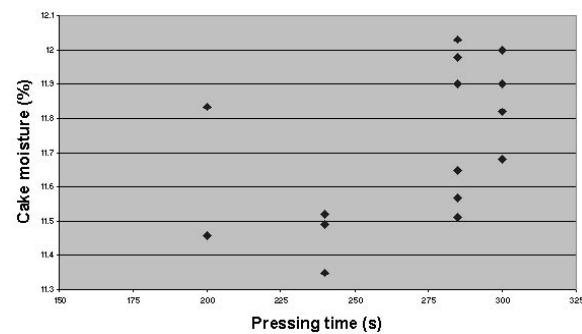

Figure 6. The effect of pressing time on cake moisture.

3.2.Drying stage test

The drying stage can be divided into two sub stages in the same way as for the pressing stage. The duration of the first sub stage is estimated. The control strategy calculation proposed an average duration of 14 seconds for the first sub stage. The second stage duration was optimised to achieve the desired cake moisture. The defined duration – moisture –relationship is shown in figure 7.

During the drying stage the total mass of the pressure filter was measured and monitored on-line. Measurement of the mass during this sub stage is presented in figure 8.
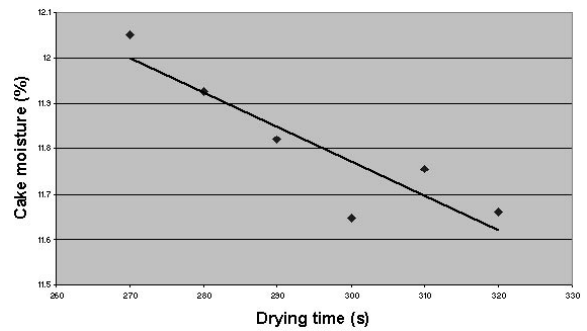

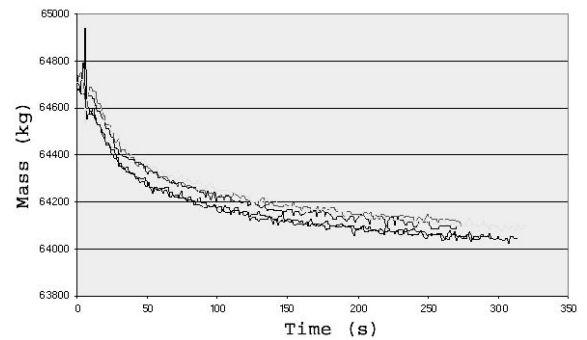Figure 7. Affect of the drying time to the cake moisture.

Figure 8. Mass of the filter during the drying stage.

The filter mass was also used to predict the moisture of the cake during the drying stage. The calculated moisture of the cake and its linear approximation is shown in figure 9.
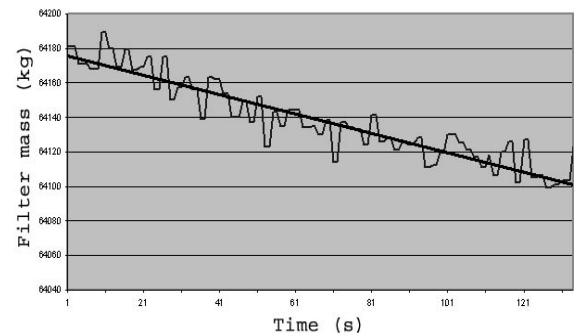

Figure 9. Calculated cake moisture as a function of the drying time.

4. CONCLUSION

The on-line support system software worked well in an industrial environment. Before the test runs the support system was tested off-line and satisfactory results were obtained. The system suggested new operation parameters, which considerably shorten the filtering cycle. During the test, the cycle time was shortened to 100 seconds even. As a result, the economic efficiency of the process was significantly improved. The research will be continued by running industrial on-line tests with different minerals.

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