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Simulation of iron concentrate suspension filtration process

Iron-bearing ore concentration process is one of the principal stages in making steel of different grades. The main purpose of concentration is to produce dry powder, concentrate with heavy percentage of iron. Using well-ground, dry and iron-ore impurity-free concentrates results in a considerable reduction of expenses relevant to further pyrometallurgical processing.

As a rule, iron concentrate (Fe_3O_4) contains much moisture after grinding operation and should be dehydrated. Since convection drying is a highly energy-consuming process there is a tendency at the concentration plants to replace it with filtration that is a more economic way of separation. It is the installed filters efficiency that affects both the quality and quantity of filtrate and also the costs of material afterbaking if it is necessary. Therefore intensification of different filters operation is of primary importance at present.

Up-to-date, high-efficiency filter represents a most complex unit with a set of functions and working regimes. The tuning of such a filter and control of all its subsystems operation is not an easy task. Undoubtedly, its solution should not be maintenance personnel's responsibility, but a function of automatic control system (ACS), the latter being a part of a filter.

Automatic vertical press filters are currently one of the most successful examples of realization of filtration process and automatic control system combination among all varieties of filter equipment.

The filters are characterized by the following advantages:

1) high capacity;

2) developed filtration surface with small floor space occupied by a filter;

3) capabilities to control filter cake thickness and moisture content as filter basic output characteristics;

4) insignificant time consumption needed for secondary operations such as filter medium washing and cake discharge;

5) cloth renovation with non-stop filter operation;

6) complete automation of filtration process.

The filters made by the Finnish company Larox Oy are among the examples of most fruitful implementation of automatic vertical press filters. The company produces Larox PF filters with filtration area from 1.5 up to 144 m^2, their capacity being from 0.1 to 150 tonnes per hour in dry product. They enable to reduce considerably the costs of suspension separation (in some cases more than by 70 %).

Development of suspension filtration simulation model

Technological fine pulp filtration is a very complex process from the point of view of exact mathematical formulation. It is connected with the following, viz. fluid motion through a layer of porous material depends on many factors specific for the properties of the substances involved in the process. However, the mathematical relations based on Kozeni-Karman equation [1] describe the process with the accuracy appropriate for commercial capacity calculations of filters.

In the given paper the authors would like to draw attention to the suspension filtration model under constant pressure difference with cake formation. Practically this is the most common filtration process.

The main equation of filtration is based on Darcy law [2] and demonstrates the way filtrate rate changes depending on the pressure difference before and after the filter medium, as well as on this medium resistance and the formed cake layer.

$$\frac{dV}{dt} = \frac{\Delta pA}{\mu\alpha_{uar}\left[\frac{C_W\rho V}{(1-C_W m)}\right]\frac{V}{A} + \mu R_n}, \qquad (1)$$

where V is filtrate volume [m^3], t is time [c], Δp is pressure difference before and after filter medium [Pa], A is filter medium area [m^2], μ is dynamic viscosity of suspension fluid phase [Pa·s], α_{uar} is cake unit-area resistance [$m\cdot kg^{-1}$], C_W is solid fraction of total mass in suspension [-], ρ is density of suspension fluid phase [$kg\cdot m^{-3}$], m is cake moisture content after filtration [-], R_n is filter medium resistance [m^{-1}].

After integrating the equation (1) under constant pressure difference (i. e. under Δp = const) the basic equation of filtration will be the following, viz.

$$\frac{t}{V} = \frac{\mu\alpha_{uar}}{2A^2\Delta p}\left[\frac{C_W\rho}{(1-C_W m)}\right]V + \frac{\mu R_n}{A\Delta p} = aV + b, \qquad (2)$$

where a and b are constants, if the same filter with constant pressure difference is used when filtrating suspension with constant weight composition.

For the sequential simulation to determine filtrate quantity depending on time it will be more convenient to apply the following equation:

$$V = \frac{-b + \sqrt{b^2 + 4at}}{2a}. \qquad (3)$$

The height of the cake formed on the surface of the filter medium is directly proportional to the filtrate passed through the medium [3]. Therefore to determine cake height depending on time it is convenient to apply the following formula:

$$L = \frac{VC_W\left[\rho_s(m-1) + \rho\right]}{A\rho_s(1 - mC_W)}, \qquad (4)$$

where ρ_s is density of suspension solid phase [$kg\cdot m^{-3}$].

Cake moisture content after filtration can be calculated if its average porosity is known, and also the density of suspension fluid and solid phases, viz.

$$m = 1 + \frac{\rho\varepsilon}{\rho_s(1-\varepsilon)}. \qquad (5)$$

where ε is cake average porosity [-].

The pressure difference during filtration has an inevitable effect on the properties of the formed cake changing its average resistance and porosity. If the effect is sufficient, then the cake is called compressible and if the effect can be neglected, then the cake is incompressible. To evaluate the pressure effect on cake properties is possible by application of the following functional connections, viz.

$$\alpha_{uar} = \alpha_0(\Delta p)^n, \qquad (6)$$

$$\varepsilon = \varepsilon_0(\Delta p)^{-\lambda}, \qquad (7)$$

where α_0, n, ε_0 and λ are constants for the given suspension which are determined during the experiment.

Pilot plant description and experimentation

Suspension used to carry out experiments was a mixture of iron concentrate (Fe_3O_4) and water. The suspension initial characteristics are presented below, viz.

1) solid phase density ρ_s = 3947.25 kg/m^3;
2) fluid phase density ρ = 987.45 kg/m^3;
3) fluid phase viscosity (at 18.2 ^{o}C) μ = 0.0286 Pa·s
4) solid mass fraction in suspension C_W = 0.38.

The laboratory periodic nutsch-filter with filter medium area A=0.0022 m^2, installed in Lappeenranta University of Technology (Lappeenranta, Finland) was used to carry out the experiments. The filter layout and its diagrammatic view are given in Fig. 1.

The experiments were carried out with the use of three different pressure differences Δ*p* (2 bars, 4 bars и 6 bars), and the weight of produced filtrate was fixed on-line. On the basis of the experiments the following characteristics of cake were determined (depending on pressure differences) and filter plate, viz.

$$\alpha_{uar} = 1.791\cdot 10^{10}(\Delta p)^{0.154} \text{ m/kg},$$

$$\varepsilon = 0.628(\Delta p)^{-0.497},$$

$$R_n = 2.5\cdot 10^{11} \text{ 1/m}.$$

Fig. 1. Laboratory filter layout (a) and diagrammatic view (b): 1 — filter; 2 — tank for filtrate collection; 3 — scales; 4 — valve to control pressure feed; 5 – inlet nozzle for suspension; 6 — nitrogen container to produce pressure; 7 — valve for pressure feed; 8 — computer for data concentration.

Development of filtration simulation model in Matlab (Simulink)

Filtration simulation model with the use of constant pressure difference was realized in Simulink program on the basis of equations (3)–(5) and dependence of unit resistance and cake average porosity on pressure difference, considering compressibility of the formed cake. The model is presented in Fig. 2.

Filtrate flow variations depending on time for different pressure differences are shown in Fig. 3. They were obtained experimentally and by means of process simulation.

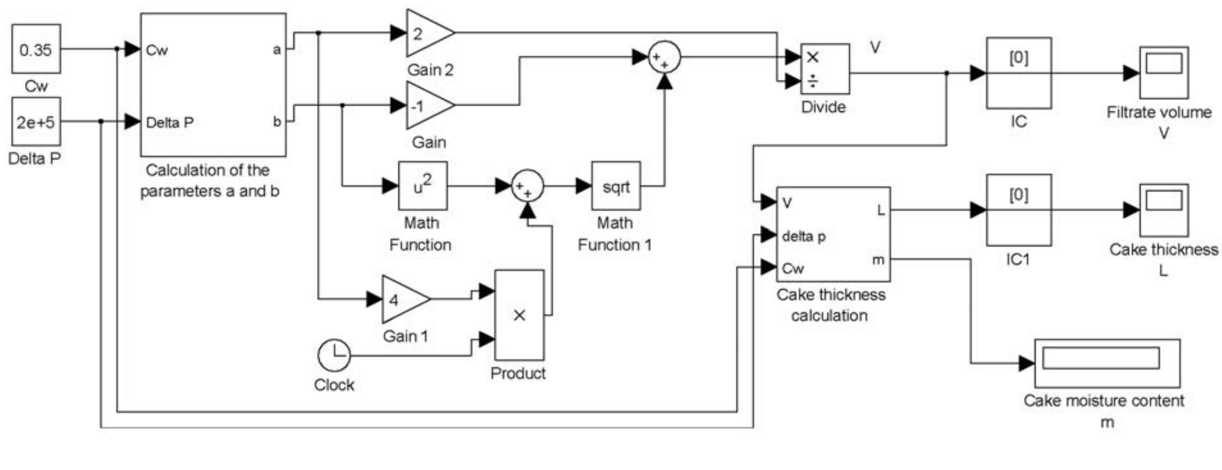

Fig. 2. Filtration process model developed in Simulink (Δ*p*=2 bars)

As it is evident from the curves given in Fig. 3 the model describes filtrate volume variation depending on time rather closely. There are modifications between experimental and simulation data in some filtration moments. It is primarily connected with pressure variability during the filtration process.

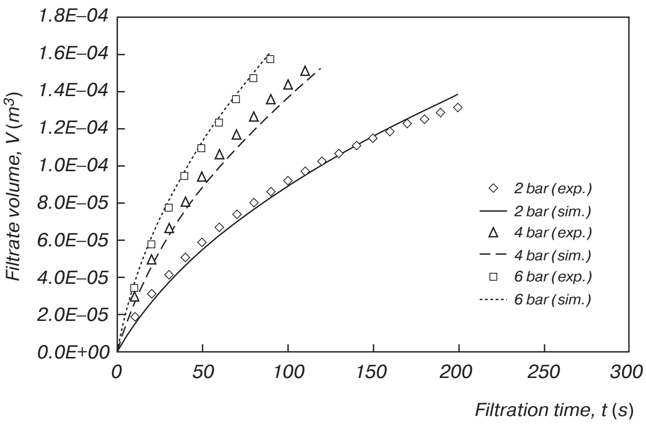

Fig. 3. Experimental data obtained as a result of use of the laboratory filter and data of process simulation in Simulink

Development of filter automatic control system

Generally PCS (process control system) represents a multilevel man-computer control system, the functions of which include monitoring, data collection and control of all systems of some equipment. PCS filter simulated in Matlab program functions for the most part as a filtration pressure stabilizer.

A filter with filtration area of 30 m^2 and operating under pressure of 6 bars was chosen as a commercial filter. The resistance of the filter medium is $R_n = 2\cdot10^{10}$. Solid mass fraction (iron concentrate) in suspension that is fed for filtration is 0.65.

The general structure of filtration model with a pressure stabilization circuit is given in Fig.4.

As a result of simulation of the commercial filter operation the graphs of behaviour of filtrate volume and cake growth depending on time have been obtained (Fig. 5 a, b). According to the cake growth graph it is possible to determine time when it is necessary to cease the filtration process and start cake washing. Accordingly it is possible to control filtration rate by varying cake thickness.

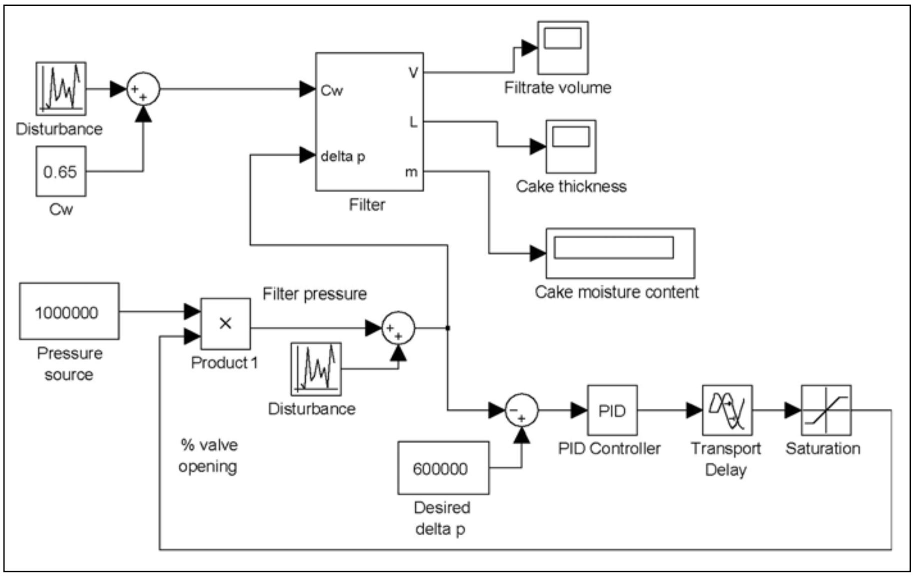

Fig. 4. Filter model with filtration pressure stabilization circuit

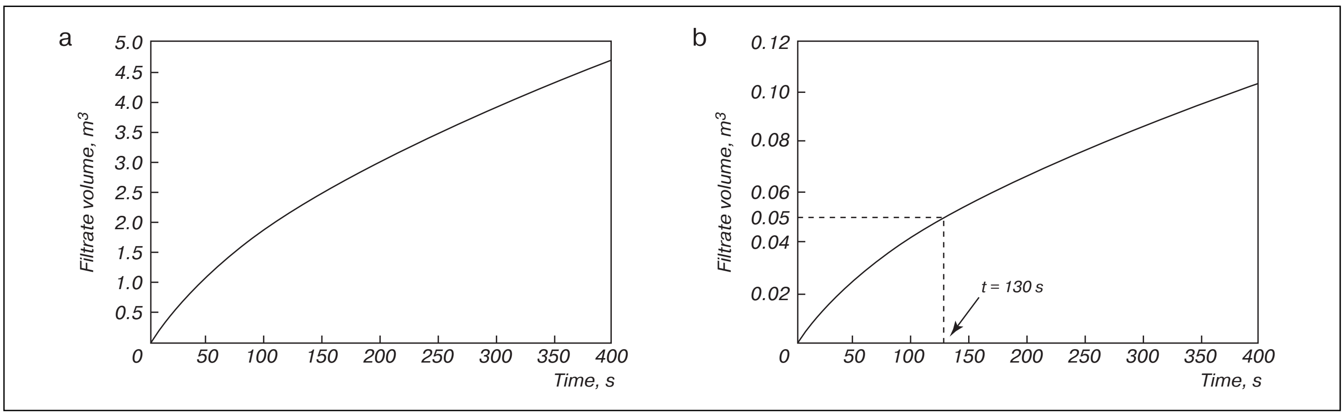

Fig. 5. Curves of filtrate volume (a) and cake thickness (b) variations depending on filtration time

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