Red mud flocculation process in alumina production

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Abstract. The process of thickening and washing red mud is a gooseneck of alumina production. The existing automated systems of the thickening process control involve stabilizing the parameters of the primary technological circuits of the thickener. The actual direction of scientific research is the creation and improvement of models and systems of the thickening process control by model. But the known models do not fully consider the presence of perturbing effects, in particular the particle size distribution in the feed process, distribution of floccules by size after the aggregation process in the feed barrel. The article is devoted to the basic concepts and terms used in writing the population balance algorithm. The population balance model is implemented in the MatLab environment. The result of the simulation is the particle size distribution after the flocculation process. This model allows one to foreseen the distribution range of floccules after the process of aggregation of red mud in the feed barrel. The mud of Jamaican bauxite was acting as an industrial sample of red mud; Cytec Industries of HX-3000 series with a concentration of 0.5% was acting as a flocculant. When simulating, model constants obtained in a tubular tank in the laboratories of CSIRO (Australia) were used.

1. Introduction
At factories operating according to the Bayer and Bayer-sintering schemes, the thickening and washing stage is necessary to separate the red mud from the liquid phase of the diluted pulp before control filtration, to reduce the loss of alkali and to finally desilicate the aluminate solution [1, 2]. With the liquid phase of the red mud on the mud field, 10-20% of the caustic alkali introduced into the process is irretrievably lost. For example, in the conditions of the Ewarton plant, the reduction of the alkali loss by 1% gives an annual economic effect of USD 300 thousand. The introduction of an automated control system at the stage of thickening and washing of red mud allows one to reduce the liquid-to-solid ratio sands by 0.1 units, which will provide an equivalent reduction of alkali loss by 0.25%, a reduction of the load on the filters by reducing the concentration of solids in the drain of the thickener, stabilization of the zones in the thickener, improvement of the performance of the site.

The functions of the existing automated process control systems for thickening are to stabilize the parameters of the primary technological circuits of the thickener as a separate control object. The process of thickening is a typical example of a system with a multitude of nonlinearly interrelated input and output parameters, with various restrictions to control actions [3]. The main parameters for stabilizing the work of the thickener are: the bed level, which is affected by the degree of flocculation, and the weight of the bed, which influences the density of the thickened product [4] and the composition of the solid phase in the upper drain of the thickener. The control system for the thickening process with different variants of the control circuits has its pluses and minuses. The
cascade control system, for example, reduces the control time, reduces the oscillation of transient processes, but the multicoupling of parameters of the control object creates additional difficulties for its control. In the conditions of existing production due to the changing total flow of pulp, the composition of the leached bauxite, the disruption in the leaching process and manual control, the thickening process is unstable.

The future of the thickening process is in the development of a high-level control and management system. The optimal solution in this situation is the control based on the predictive model. The model, tracking the perturbation value, predicts the behavior of the objective function and, knowing the coefficient of amplification and response period, adjusts the control parameter in such a way as to compensate the perturbing and prevent the target value from running beyond the required limits. Naturally, the main element for this type of control is the model, if it is adequate, accurately describes the process, then it is possible to ensure the proper quality of the target parameter. A lot of works [5 – 8] of domestic and foreign authors, such as A.I. Liner, A.L. Rutkovskii, V.A. Rastiapin, F. Concha, J. Farrow, P. Scales, S. Usher, R Burger are devoted to this question.

Existing models do not fully consider the presence of perturbing effects, in particular the particle size distribution in the feed, the size of flocculated particles, the shape of the formed flocules, the settling of the thickener.

This work is devoted to the process of flocculation of the solid phase of the feeding suspension in a feed barrel.

2. Population balance model

A generalized thickening model of the red mud includes a submodel of the flocculation zone. The flocculation process takes place in the feed barrel, the size and shape of the formed floccule play a key role in the free-settling process (the Stokes law) and the cramped settling (Richardson and Zaki law) of the mud.

Particle size distribution (PSD) is determined by two main processes: flocculation of particles (aggregation) and subsequent possible deflocculation (decay) of flocules. Growth and decay of flocules (populations) are described by a system of differential equations.

The initial data for the population balance model are the initial particle size distribution, the flocculant consumption, and the concentration of the feed slurry. The effect of additional dilution was simulated by a change in the concentration of the feeding suspension. The grain-size composition data obtained in the course of the experimental study was used as the initial distribution. According to the analysis of the grain-size composition, it is revealed that the solid is mainly represented by small classes, of which class is <0.005 mm - 75.19%; the particle size distribution range in the initial pulp is 0.3-100 µm.

Analysis of the grain-size composition of the pulp allows one to determine only the prevailing size of the aggregates as the dispersion of the red mud is affected by a number of factors: the amount of time between sampling for analysis and the analysis process, the conditions of storage and transportation of samples, the chemical-mineralogical composition of the original bauxite, the degree of bauxite grinding at the first stages of the Bayer process, the chemical dispersion of bauxite particles in the process of autoclave leaching [9].

The population balance model has channel sizes intervals (discretization). The coarse intervals are much coarser than those obtained in the course of the study.

The discretization of the population balance model is [10]:

\[
\frac{V_i}{V_{i+1}} = 2
\]  

(1)

where \( V_i \) is the mass-equivalent volume of the agglomerate in section i, that is the volume of the completely formed flocule, which contains \( x_1 = 2^{l-1} \) spherical monodisperse particles of the \( d_p \) diameter:

\[
V_i = \frac{\pi}{6} d_i^3 = x_1 v_p = x_1 \frac{\pi}{6} d_p^3 .
\]  

(2)
A maximum of 40 channels can be used in the population balance model. In the work, the calculation was made using 20 channels.

3. Population dynamics

The stages of growth and decay of populations are presented in Table 1. Growth and decay of flocules can be described as follows [10]:

\[
\frac{dN_i}{dt} = \sum_{j=1}^{i-2} 2^{i+j+1} a_{i,j} N_i N_j + \frac{1}{2} a_{i-1,i} N_i^2 - N_i \sum_{j=1}^{i-1} 2^{i-1} a_{i,j} N_j - N_i \sum_{j=1}^{\infty} a_{i,j} N_j - S_i N_i + \sum_{j=i}^{\infty} \Gamma_{i,j} S_j N_j
\]

where \( N_i \) – number of \( i^{th} \) sized particles; \( t \) – time; \( \beta_{i,j} \) – rate of collision between \( i \) and \( j \) sized particles (aggregation kernel); \( S_{i,j} \) – breakage rate (kernel) of \( i \) and \( j \) sized particles; \( \Gamma_{i,j} \) – breakage distribution function (number of \( k \) size particles produced from the breakage of \( i \) and \( j \) sized particles); \( a \) – capture efficiency (0–1).

| Description | Equation |
|-------------|----------|
| \( i^{th} \) sized particles | \( \frac{dN_i}{dt} = \sum_{j=1}^{i-2} 2^{i+j+1} a_{i,j} N_i N_j + \frac{1}{2} a_{i-1,i} N_i^2 - N_i \sum_{j=1}^{i-1} 2^{i-1} a_{i,j} N_j - N_i \sum_{j=1}^{\infty} a_{i,j} N_j - S_i N_i + \sum_{j=i}^{\infty} \Gamma_{i,j} S_j N_j \) |
| Aggregation of flocules (the birth of \( i^{th} \) sized particle through the coalescence of two smaller flocules) | \( \frac{dN_i}{dt} = \sum_{j=1}^{i-2} 2^{i+j+1} a_{i,j} N_i N_j + \frac{1}{2} a_{i-1,i} N_i^2 - N_i \sum_{j=1}^{i-1} 2^{i-1} a_{i,j} N_j - N_i \sum_{j=1}^{\infty} a_{i,j} N_j - S_i N_i + \sum_{j=i}^{\infty} \Gamma_{i,j} S_j N_j \) |
| Aggregation of flocules (the birth of particle in the collision of \( i^{th} \) sized particle and another particle) | \( N_i \sum_{j=1}^{i-1} 2^j a_{i,j} N_j - N_i \sum_{j=1}^{\infty} a_{i,j} N_j = \sum_{j=i}^{\infty} \Gamma_{i,j} S_j N_j \) |
| Destruction of flocules (the destruction of larger particle in a collision with another particle into a \( i^{th} \) sized particle and another particle) | \( \frac{dN_i}{dt} = \sum_{j=1}^{\infty} \Gamma_{i,j} S_j N_j \) |
| Destruction of flocules (the destruction of \( i^{th} \) sized particle into several particles of small dimensions) | \( S_i N_i \) |

Collisions occur due to the always present thermal motion, or shear of the layers of liquid. Only for particles smaller than a micron, it is assumed that the thermal motion is negligibly small in comparison to the shear velocity, i.e. a spatial average velocity gradient, which is homogeneous and constant.

4. Adsorption of flocculant on the surface of particles during mixing

Experiments on the adsorption of flocculant on the surface of particles during mixing in a feed barrel (Figure 1), the formation of flocules during the decay of coarse flocules (Figure 2), the formation of coarser flocules from smaller flocules and particles are carried out in a tubular tank (Figure 3), in which the studied pulp is flowing. The flocculant diluted to a certain concentration is fed to the tank with a certain angle and with a certain rate.
The purpose of the experiment is to obtain the model parameters (for the studied Jamaican bauxite, they were determined in a tubular tank in the laboratories of CSIRO (Australia)). The parameters of the model are $k_1=0.075$, $k_2=94.7$, $k_3=0.691$.

\[ a = 1 - e^{-k_1 \sqrt{fL/D}} \]  

where $k_1$ is a parameter of the model (dimensionless), $L$ is a length of the pipe from the point of addition of the flocculant (m), $D$ is a pipe diameter (m), and $f$ is a friction coefficient in the pipe (dimensionless).

5. The formation of floccules in coarse floccules decay

\[ S_i = \frac{k_2 \varepsilon k_3 \mu a_{agg,i}}{\theta_f} \]  

where $\theta_f$ is an effective coverage of the flocculant area (kg/m$^2$), $\mu$ is a viscosity of the suspension (Nsec/m$^2$), $\varepsilon$ is an energy dissipation rate per unit mass (m$^2$/sec$^3$), $k_2$ is a model parameter (dimensionless), $k_3$ is a model parameter (dimensionless).

\[ \theta_f = \frac{m_f}{A_s} M(1-\Theta) \]  

where $m_f$ is a mass of the flocculant (kg), $A_s$ is a surface area of the solid particles (m$^2$), and $\Theta$ is a degree of degradation of the flocculant (0-1).

6. Formation of coarser floccules from smaller floccules and particles
\[ \beta_{ij} = 1.294aG(a_i + a_j)^3 \]  

(7)

where \( G \) is an average velocity of turbulent shear (sec\(^{-1}\)), \( a_i \) is a radius of the \( i \)-th particle (m).

### 7. Conclusion

The population balance model is implemented in the MatLab environment. The simulation result for 20 channels is shown in Figure 4.

Analyzing the obtained data, it can be said that the composition of the flocculated red mud is polydisperse, and therefore contains both structured and unstructured hydraulic fluid with a fairly wide range of particle sizes. The percentage of fine fractions in the feed pulp of the thickener was very high, and the characteristics peculiar for structured hydraulic fluids had a strong effect on the range of the flocculated particles. On the basis of the simulation results, the solid is mostly represented by classes – 45 - 100 \( \mu \)m - 70%.

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