Red mud thickener statistical model in MATLAB system identification toolbox

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Abstract. The process of red mud thickening and cleaning is a bottleneck of the alumina production. The existing automated systems of thickening process control are intended for the stabilization of parameters of primary process loops of thickeners. The relevant area of scientific research is making up and upgrade of the models and systems for the control of the thickening process under the model. The paper presents a model of a red mud thickener obtained on the basis of archive manufacturing data in the software environment MATLAB with the help of System Identification Toolbox. The measured parameters were the feed pulp consumption rate in the thickener, flocculant flow rate, thickened product consumption from the thickener’s cone and the thickened product density. The model allows predicting the density of a thickened product from the thickener cone. As an industrial prototype of red mud the authors used the mud from Ural Aluminum Plant, as a flocculant – Cytec Industries, series НХ-3000.

1. Introduction
The processing stage of red mud thickening and cleaning is one of the most important stages in alumina production. The relevant areas of scientific research on the mud thickening are considered in numerous papers [1-11]. The red mud processing consists in its thickening, cleaning and further filtration. The task of red mud thickening and cleaning section is the separation of the alkaline aluminate liquor from red mud for its further processing.

The factors influencing the red mud precipitation process are the mud particle coarseness, bauxite mineralogical and granulometric content, viscosity of the aluminate solution (concentration and temperature), the introduction method and the flocculation and coagulation processes, solid fraction concentration in the feed pulp, pulp Ph. The use of flocculants and (or) coagulants increases the production volume of thickeners and, consequently, the production volume of the red mud thickening and cleaning section. Most companies started to use flocculants. For example, UAP (Ural Aluminum Plant, Russia) uses the flocculants produced by Sytec, series HX-3000, in the thickening branch line while the overflow rates increase several times.

A large part of red mud is presented by the fraction particles of no more than 0.5 um. With such small weight and size of mud particles they will precipitate very slowly as they are exposed to the gravitation force only as mud is polydisperse, and its particles precipitate with various rates: the large ones precipitate faster than the small ones and in addition, the large particles collide with the small ones more often. That is why one can draw a conclusion that at the presence of large particles in mud the precipitation occurs better and the mud setting rate is higher.

It should be also mentioned that the red mud components in relation to water are divided into 2 groups: hydrophobic and hydrophylic ones; the hydrophobic group is larger, however, the thickener works better with the hydrophobic ones. At the desalinization stage, when the temperature decreases up to 280-300 ºС, virtually all the mud components become hydrophobic and thus, start precipitating faster, however, the temperature growth decreases the pulp viscosity.

During red mud precipitation several zones form in the thickener:

1. lightened solution zone (overflow) cleaned from red mud particles and continuously removed from the device;
2. free precipitation zone where no interaction between the particles occur and the precipitation rate is described by the Stocks’ law;
3. hindered precipitation zone where the interaction between the particles is described by the empirical equation of Richardson&Zaki;
4. constant and final concentration and precipitation compression&thickening zone where the aluminum solution is displaced from the solid phase under the pressure of upper layers and the raker action;
5. raker action zone, or the solid phase thickening zone.

Thickening is a complex process comprising multiple parameters. This paper focuses on such thickening properties as the suspension permeability, suspension compressibility, and free settling velocity, or Stokes’ velocity.

2. Control purpose and tasks
The control purpose and tasks consist in stabilizing the density of the red mud from the thickener’s cone at the setup level stipulated for in the technical regulations with the provision of information to a process control operator. The key objective of this paper was the synthesis of a statistically valid thickener model on the basis of the archive production data.

3. Data preparation and analysis in MATLAB
The authors analyzed the production data provided by the company as an archive back-up file of the data base SQL and draw the conclusions:

1. By the type of the measured parameters & time interdependence, the authors established that the company provided the data slice containing the information of the object parameters as of the moment of the thickener’s start and for the period of such thickener continuous operation. To generate the thickener’s model on the basis of statistical data and for a further model training and re-training, let us use the slice of data as of the thickener (s) operation in a continuous mode.
2. The following actions are assumed as the control ones: flocculant flow rate in the thickener, red mud consumption rate from the thickener’s cone; the consumption rate of the diluted pulp in the thickener was assumed as a disturbing parameter while the density of the thickened mud from the thickener’s cone was taken as a target/controllable parameter. The suspended load/density of filtrated water (the thickener’s overflow) and the bed level are not measured at the company, so, it seems impossible to consider these parameters as target ones.

Before identifying the object (thickener) it is necessary to complete the table of mutual correlation factors for all measured parameters. To do this, the function corrcoeff of the software package MATLAB is used; this function defines the correlation factor between the data (-1<coef<1) (Table 1).

Table 1. The table of mutual correlation factors for all measured parameters.

|                         | Pulp consumption rate in the thickener | Flocculant flow rate | Mud consumption rate | Mud density |
|-------------------------|----------------------------------------|----------------------|----------------------|-------------|
| Pulp consumption rate in the thickener | 1                                      | 0.299                | 0.4412               | 0.2837      |
| Flocculant flow rate    | 0.299                                  | 1                    | 0.4412               | 0.2837      |
| Mud consumption from the cone | 0.4412                                | -0.1464              | 1                    | -0.7110     |
| Mud density             | 0.2837                                 | 0.3658               | -0.7110              | 1           |

The generation of the thickener’s statistical model in the environment System Identification Toolbox MATLAB [1].
The archive set of production data is imported into System Identification Toolbox, where the input and output parameter and the model discretization time are set. The data, loaded in MATLAB and graphically presented in Figures 1, 2, 3 and 4.

Figure 1. Archive data on mud density from the thickener’s cone.

Figure 2. Archive data on the diluted pulp consumption in the thickener.

Figure 3. Archive data on the flocculant flow rate in the thickener.

Figure 4. Archive data on the thickened mud density consumption from the thickener’s cone.

In addition to operating data (mydatah) (the slice of data used for the model training), the authors loaded validation data (mydata) (test data used for the evaluation of the model validity) (Figure 5).
Figure 5. System Identification Toolbox working window.

The run screen GUI System Identification Toolbox allows selecting the generated model type. The authors used the Hammerstein-Weiner nonlinear model: the object dynamic properties on each channel are described by a linear element while the static properties are described by nonlinear input and output blocks; the paper does not consider the output non-linearity as there is only one target parameter; the input non-linearity is considered as a piecewise linear function (Figure 6) [1, 4].

Figure 6. Screens GUI when building the Hammerstein-Wiener model.

4. Research results
Figure 7 presents the charts of possible models and the quality of the model comparison with reference data (at the right) in percent. One can understand that the best result is demonstrated by the model nlhw5 (76.05 % of correspondence). This model with a non-linearity of the piecewise linear function and the transfer function with 2 poles (nominator polynomial roots) and 2 zeros (numerator polynomial roots).
Figure 7. Chart Model Output.

The chosen model was checked at the test data slice. Further, transfer functions for each of the three channels (feed pulp consumption rate - mud density from the thickener’s cone, flocculant flow rate - mud density from the thickener’s cone, mud density from the thickener’s cone - mud density from the thickener’s cone) were exported to the software environment Workspace, the transfer functions on each channel are presented in Figure 8.

Figure 8. Control object model in Simulink.

5. Conclusion

The paper presents general information on the researched process, control object, generation of a thickener statistical model, implemented control systems for a radial thickener. A synthesized control object model was checked for its validity for the test data slice, this model can be further trained offline for other archive data slices or online. The generated object model is recommended to be applied in the control system according to the model.

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