

ОБОГАЩЕНИЕ ПОЛЕЗНЫХ ИСКОПАЕМЫХ

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Thickener as an automatic control object

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Abstract

Introduction. Grain motion in the process of pulp sedimentation in a radial thickener was studied to use the typical links of the automatic control system.

Research objective is to explore the possibility of describing the sedimentation process by means of typical links of the automatic control theory based on the physics of grain motion in a radial thickener and the equation of grain motion under laminar and turbulent flow conditions.

Methods of research. Stokes' law that determines the drag force resisting a solid sphere when it slowly moves forward in an unbounded viscous fluid (laminar motion) and the Newton–Rittinger law for the turbulent motion of grain formed the basis of the mathematical model, making it possible to develop a program that chooses a particular equation to calculate the grain sedimentation time in accordance with the grain size. The equations helped to obtain the sedimentation time and hence the time taken to reach the thickener's bottom, which, in their turn, together with the fractional composition, determine the performance of the thickener. Transition curves were thereby obtained for various granulometric composition, percentage of ore in the pulp, thickener height, ore and pulp density. In the future, this made it possible to approximate the process of sediment accumulation by the equations of one or two lag blocks of the automatic control system.

Research results. A computer program has been used that describes the process of sediment accumulation in a thickener, considering the granulometric composition as well as pulp and ore grain density. The program showed that the process of sediment accumulation in a thickener can be described with fair accuracy by a first-order lag block for laminar or turbulent grain motion. For a mixture of coarse and fine fractions, ore sedimentation can be approximated by two parallel lag blocks.

Conclusions. Sedimentation process approximation by lag blocks, obtained with fair accuracy, can be used when analyzing, designing and adjusting sedimentation automatic control systems.

Keywords: control object; sedimentation; thickening; grain; ore; factions; pulp.

Introduction. It is crucial to carry out a preliminary study of the designed system in the course of automatic control systems (ACS) development. A mathematical model is often used in this regard, which makes it possible to select the controller parameters that will provide the required margin of stability, accuracy, and system characteristics in transient and steady-state conditions.

Thus, the model of the control object (CO) is absolutely crucial. When designing an ACS, the CO model [1] is often represented by transfer functions.

The object under study is a thickener, one of the main facilities of a processing plant (PP).

Based on the solid grain motion laws, the research will proceed to substantiate the form of the transfer function for a radial thickener.

It should be noted that transfer function knowledge is required when carrying out an integrated design of ACS by several interrelated concentration flow processes [2] with

a thickener as a component. The thickened suspension can be removed in two ways: by intermittent or continuous activation of radial thickener rakes. Underflow discharge depends on whether it is directed to filtration or tailings storage facility. Each case has different requirements for the underflow moisture content.

Approximation by a lag block of the automatic control system is an appropriate solution if the transfer function is complex. Based on the physical description of the thickening process, the type and choice of the thickener transfer function parameters are then considered. The main process within a thickener is ore grains sedimentation in the liquid (pulp).

The process of thickening is rather complicated. It depends on a large number of parameters and occurs in space-limited conditions of ore motion. It also depends on pulp density and viscosity, underflow compaction, grain size, etc.

At the same time, it should be noted that in all works devoted to this issue [3–8], the motion of a single spherical ore grain in unrestricted conditions is taken as a basis. The influence of other quantities is corrected by coefficients [9], which often have an empirical character.

Methods of research. The physics of grain motion in a radial thickener is illustrated in Figure 1.

Ore grain weight

$$P_T = \rho_{\text{ore}} V_{\text{ore}} g, \quad (1)$$

where ρ_{ore} is ore density; V_{ore} is ore grain volume; g is the free fall acceleration.

Buoyancy force

$$P_a = \rho_j V_{\text{ore}} g, \quad (2)$$

where ρ_j is pulp density.

Under the action of the resultant of forces, grain moves downward during sedimentation, acquiring acceleration a based on Newton's second law.

The equation of motion is written as:

$$m_{\text{ore}} a = P_T - P_a - R, \quad (3)$$

where m_{ore} is the ore grain mass.

The main difficulties arise when determining the resistance force R . When using the Stokes' law [10], the grain motion is laminar:

$$R = 6\pi\mu r v, \quad (4)$$

where μ is pulp viscosity; r is the ore grain radius; v is the pulp speed.

If the grain motion is turbulent, then Newton's law is used to determine R :

$$R = \frac{\pi}{2} \rho_j r^2 v^2. \quad (5)$$

An experimental verification of Newton's formula disagreed with the experimental

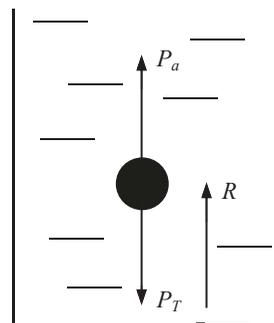


Figure 1. The scheme of ore grain sedimentation
Рисунок 1. Схема осаждения зерна руды

data (a grain does not look like a sphere, the motion is constrained, etc.), and therefore coefficient Q was introduced:

$$R = Q \frac{\pi}{2} \rho_j r^2 v^2. \quad (6)$$

Resistance alternation in accordance with (6) is called the Newton–Rittinger formula.

Based on numerous experimental data, it can be claimed that for small grains (50–100 microns, up to 200 microns in some sources), expression (4) can be used to determine R . For larger grains, (6) should be used. Integrating (3), it is possible to obtain the dependence between the travel time t and the relative velocity γ :

$$\gamma = \frac{v}{V_m}, \quad (7)$$

where V_m is the maximum attainable sedimentation rate.

With laminar motion:

$$t = \rho_{\text{ore}} \frac{V_m}{(\rho_{\text{ore}} - \rho_j)g} \ln \left(\frac{1}{1 - \gamma} \right); \quad (8)$$

$$V_m = \frac{2}{9\mu} (\rho_{\text{ore}} - \rho_j) r^2 g. \quad (9)$$

The sedimentation conditions have been considered for the turbulent mode, and the following relations have been found:

$$t = \frac{\rho_{\text{ore}} V_m}{2(\rho_{\text{ore}} - \rho_j)g} \ln \left(\frac{1 + \gamma}{1 - \gamma} \right). \quad (10)$$

Here

$$V_m = \sqrt{\frac{8}{3Q} g \frac{\rho_{\text{ore}} - \rho_j}{\rho_j} r}. \quad (11)$$

For both laminar and turbulent motion of an ore grain, the value of V_m can be found by setting the right-hand side of equation (3) to zero, which corresponds to steady-state motion with a maximum speed balanced by the resistance to motion.

Given that ore particle speed is a derivative of the path, and the acceleration is the second derivative of the path, it is possible to find the dependence between the path and ore grain motion time. For the laminar motion it is written as follows:

given

$$C = \frac{R_{\text{ore}} - R_j}{R_{\text{ore}}} g; \quad (12)$$

$$B = \frac{9}{2} \cdot \frac{\mu}{R_{\text{ore}} r^2}, \quad (13)$$

we get

$$S = \frac{C}{B} - \frac{C}{B^2} + \frac{C}{B^2} e^{-Bt} \quad (14)$$

where R_{ore} , R_j are the ore grain weight and the displaced pulp weight, respectively.

Table 1. Possible proportions between small and big fractions in the pulp
Таблица 1. Варианты соотношения мелких и крупных фракций в пульпе

Experiment	Proportion by weight, small : big fractions	Properties of the approximating lag blocks			
		T_1, s	τ_1, s	T_2, s	τ_2, s
1	100	–	–	333.3	20
2	0 : 100	3.7	3.00	–	–
3	66 : 34	3.7	3.63	33.3	40
4*	81 : 19	4.7	5.00	333.3	20

T_1, τ_1 – constant of time and time of sump tank delay as an object of automation for big fractions, respectively; T_2, τ_2 – for small fractions; * – typical experiment.

For the turbulent motion we get:

$$S = AV_m \ln \left(\frac{2 + e^{t/A} + e^{-t/A}}{4} \right), \quad (15)$$

where

$$A = \frac{\rho_{\text{ore}} \cdot V_m}{2(\rho_{\text{ore}} - \rho_j)g}. \quad (16)$$

By equating S to the thickener height, it is possible to determine the sedimentation time for various parameter values and find the performance of the thickener.

However, it is necessary to solve a nonlinear power equation in order to determine the sedimentation time from (14) and (15), which is hardly possible analytically.

The authors have coded a program in MATLAB that has ore grain fraction distribution in the pulp, thickener height, and ore and pulp density set as parameters.

The program calculates the grain motion in the course of sedimentation. The modeling process ends when each fraction reaches the bottom of the thickener.

It is easy to move towards the thickener performance, considering that the share of each fraction in one cubic meter of pulp is proportional to the percentage of the fraction in question and the share of ore λ in one cubic meter of pulp.

Here

$$\lambda = \frac{\rho_j \rho_{\text{water}}}{\rho_{\text{ore}} - \rho_{\text{water}}}, \quad (17)$$

where ρ_{water} is the density of water.

Having fractions distribution at the start time in each cubic meter, it is possible to find the underflow's change over time, that is, the transfer function of the thickener, where the thickener performance is the output value [11], and any parameter used to create the ACS is the input value. In the authors' calculations, this was the distribution of pulp granulometric composition.

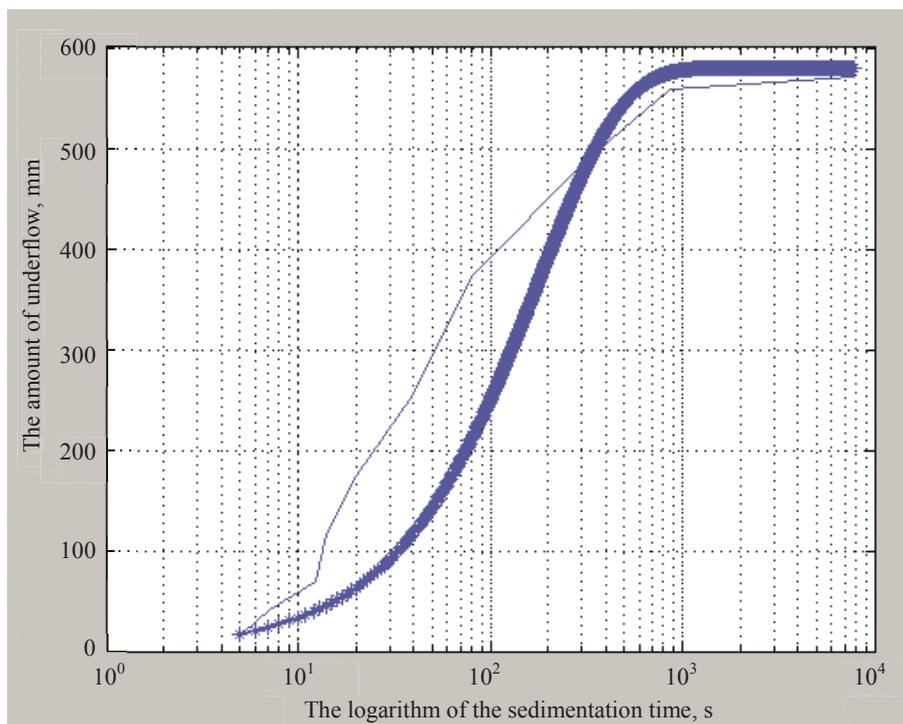


Figure 2. Change of the amount of underflow over time
Рисунок 2. Изменение величины осадка во времени

Ore and pulp density, ore grain fraction distribution in the pulp, and sump tank height were previously mentioned as initial data in the MATLAB model. These parameters can be changed during calculations. To determine the output value, the thickener performance, the results for individual fractions are summarized. Thus, the performance per square meter of the thickener is obtained.

Results. In the course of the research, various ratios of small and large fractions in the pulp were considered (Table 1).

The results of a typical experiment no. 4* are shown in Figures 2 and 3.

The figures show the thickener performance change as a function of time under the following simulation conditions: $\rho_{\text{ore}} = 3,200 \text{ kg/m}^3$; $\rho_{\text{water}} = 1,000 \text{ kg/m}^3$; pulp density $\rho_j = 1,400 \text{ kg/m}^3$; thickener height $H = 4.2 \text{ m}$.

In Figure 2, the base logarithm of time is plotted on the Ox axis.

The granulometric composition [12–14] for individual fractions is as follows: over 3% for a particle size of 5 microns and up to 20% for a particle size of 0.25–0.15 microns. The minimum percentage corresponded to the class of large fractions.

Figure 2 shows that the material accumulation transient curve [15–16] can indeed be approximated by the first-order lag block with a delay:

$$W(p) = 562.5e^{-(x-5)/178}, \quad (18)$$

which makes up no more than 15–20%, with sufficient accuracy for practical calculations of ACS.

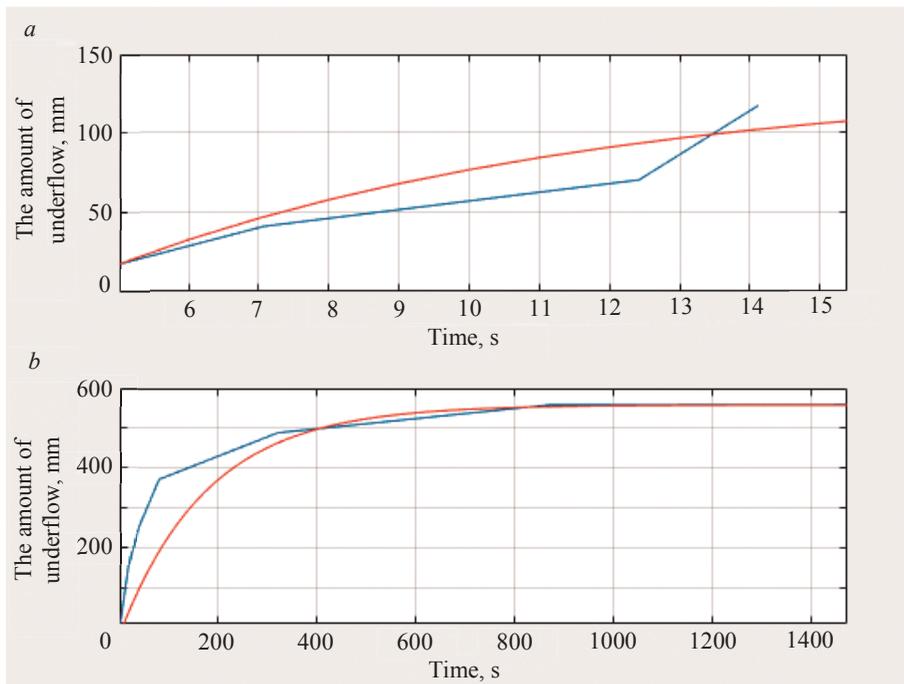


Figure 3. Change of the amount of underflow over time:

a – for big fraction; *b* – for small fraction

Рисунок 3. Изменение величины осадка во времени:

a – для крупной фракции; *b* – для мелкой фракции

Conclusions. The results indicate that the transfer function of the thickener greatly depends on pulp fractional composition. The transient process curve with a homogeneous fractional composition (the motion of all fractions is laminar or turbulent) corresponds to a lag block with a delay.

If the fractional composition changes at a greater range, the sump tank can be represented by the sum of two lag blocks with a delay for small and large fractions, for the purposes of automation. Such representation corresponds to large ore size classes sedimentation by a lag block with a small time constant and small grains with a large time constant and delay.

The thickener operation model obtained based on the accepted assumptions is quite approximate and does not consider many specific conditions. It is unclear how to calculate the sedimentation of intermediate-sized grains which have no sufficient theoretical justification for the resistance to motion. This problem warrants further study.

Meanwhile, it seems that obtaining even approximate values of the thickener transfer functions for different pulp fractional composition is of theoretical and practical importance when designing ACS by flow processes at processing plants since it explains the physics of the values of time constants and delay times and makes it possible to

select control modes and controller's parameters correctly. The developed computer program can be used in a wide range of pulp fractional composition at processing plants.

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Сгуститель как объект автоматического регулирования

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Реферат

Введение. Исследовано движение зерна в процессе осаждения пульпы в радиальном сгустителе с целью замены типовыми звеньями системы автоматического регулирования. **Цель работы.** На основе использования физической картины движения зерна в радиальном сгустителе и уравнения движения зерна при ламинарном и турбулентном режиме выяснить

возможность описания процесса осаждения типовыми звеньями теории автоматического управления.

Методология исследований. В основу разработки математической модели положены закон Стокса, определяющий силу сопротивления, испытываемую твердым шаром при его медленном поступательном движении в неограниченной вязкой жидкости (ламинарное движение), и закон Ньютона–Риттингера для турбулентного движения зерна. Такой подход позволил создать программу, которая рассчитывает время осаждения зерна в зависимости от его крупности, выбирая для расчета то или иное уравнение. С помощью них удалось получить время осаждения, а следовательно и время достижения дна сгустителя. С учетом фракционного состава это, в свою очередь, определяет производительность сгустителя. Таким образом были получены переходные кривые при различных гранулометрическом составе, процентном содержании руды в пульпе, высоте сгустителя, плотности руды и пульпы. В дальнейшем это позволило аппроксимировать процесс накопления осадка уравнениями инерционных звеньев (одного или двух) автоматического управления.

Результаты работы. На основании компьютерной программы, которая описывает процесс накопления осадка в сгустителе с учетом гранулометрического состава, плотности пульпы и зерен руды, показано, что процесс накопления осадка в сгустителе с достаточной точностью может быть описан инерционным звеном первого порядка в случае ламинарного или турбулентного движения зерна. При смеси крупных и мелких фракций осаждение руды можно аппроксимировать двумя инерционными звеньями, включенными параллельно.

Выводы. Аппроксимация инерционными звеньями процесса осаждения, полученная с достаточной точностью, может быть использована при анализе, проектировании и настройке систем автоматического регулирования процесса осаждения.

Ключевые слова: объект управления; осаждение; сгущение; зерно; руда; фракции; пульпа.

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