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Static Model for the Drain Rate of Clay Extraction and Power Consumption for Sand Washing

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The issues of modeling the formation of a two-phase liquid-solid particle system in devices operating on the principle of mixing and dispersion. For this purpose, static formulas have been compiled for such parameters as the rate of discharge of clay extraction and the power consumption for washing sand, the speed of rotation of the liquid with untreated sand, the influence of the ratio of geometric dimensions on the above parameters has been considered. A static model has been compiled that allows us to identify patterns of changes in these parameters. Based on the obtained waveforms from the simulation of the model, conclusions were made according to which, when constructing an automatic control system for sand washing, it is necessary to ensure stabilization by such basic indicators as the required sand-clay ratio, the humidity of the cleaned sand, power consumption.

Keywords: Two-phase liquid – solid particles system; mixing and dispersing principle; clay extraction discharge rate; purified sand humidity; power consumption.

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1. INTRODUCTION

Mixing and dispersing are one of the most energy-intensive and expensive operations used in bulk material classifiers, machines designed for washing sand and separating clay and other equipment in the relevant field. Therefore, the rational hardware design of these processes has a significant impact on the economy not only of such auxiliary processes as preparation for the use of construction sand, but also on the overall product cost. Additionally, mixing and dispersion often lead to mechanical activation, which allows to obtain products with specified physical, physico-chemical properties, for example, washing sand with the purpose of separation from a mixture of clay, etc.

With the development and improvement of the technology of preparation of construction sand due to the increasing demands on productivity and processing quality, there is a noticeable trend towards increasing the degree of their dispersion. In this context, modeling the process of mechanical dispersion in newly developed apparatuses and machines, which also includes the development described in [1], is highly relevant and significant. Such a model could facilitate the investigation of process stability, calculation of geometric dimensions of the apparatus or machine, and prediction of undesirable phenomena.

1.1 Problem Statement

Fig. 1 shows classification examples of typical rotary apparatuses. When choosing mixers and dispersers, in addition to their productivity, versatility when changing the type of the same type of product, the degree of automation and the cost of a unit of production, there are basic parameters. The main factors are: type of hull and its location; the shape of its cross section; stirrer type; type of agitator guiding device; the presence and type of jacket for the coolant.

Dispersant mixers with vertically mounted housings (Fig. 1a) are used mainly in stationary shop conditions, for example, in the medical industry and the production of complex granular mineral fertilizers. Dispersant mixers with a horizontal body (Fig. 1b) are used for the preparation of working fluids in agriculture for the draining and hydrophobization of crops [2-4]. In the work [5] it is stated that in apparatuses in whose housings, in addition to agitators, additional guiding devices are installed in the form of ribs, scrapers, or in which the housings are made either in the form of polyhedral or oval, the efficiency of mixing and dispersing heterogeneous systems significantly increases. In the same place, it is said that liquid circulation occurs in rotary-type apparatuses, which should be understood as fluid movement along a closed path in accordance with current lines [6]. The nature of the liquid circulation in the rotary apparatus depends mainly on the type of agitator and whether there are guiding devices in the apparatus.

Circumferential (primary) circulation is associated with the rotation of the entire mass of liquid around the axis of symmetry of the agitator. Radial-axial (secondary) circulation is associated with the pumping action of the agitator. Secondary circulation is essential for the mixing process, as it convection is represents:

$$V_p = Cnd_m^3, \qquad (1)$$

where Vp is the volume flow of liquid through the agitator, m^3/s; C is a constant depending on the type of agitator; n is the speed of rotation of the agitator, rpm; dm is the diameter of the agitator, m.

The numerical values of the constant C, for open turbine agitators are within the following limits C= 0.25-1.2 (most often 0.5-0.8), for propeller agitators with 0.3-1 (most often 0.4-0.8) [7,8].

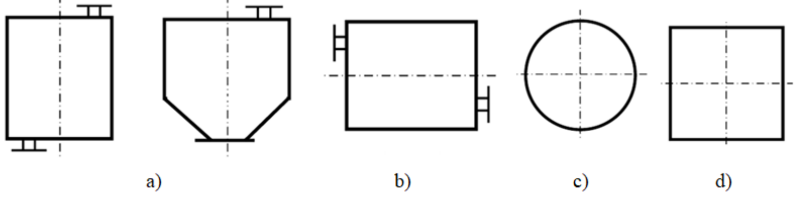

Fig. 1. Typical rotary apparatuses. a) with a vertical body: b) with a horizontal body; with a transverse; cross-sections of mixers-dispersants in the form of c) circles; d) in the form of a square

Assuming that the volume of liquid in the apparatus is equal to:

$$V = \frac{\pi D^2}{4} h \tag{2}$$

Where:

$$V = V_p t_C \tag{3}$$

Then we get:

$$\pi D^2 h = 4 t_C Cnd_m^3 \tag{4}$$

or:

$$t = \frac{\pi h D^2}{4 Cnd_m^3} \tag{5}$$

On the basis of equation (5), it is possible to investigate the rotation frequency of a liquid mixture with clay and sand with the condition of reaching their inner wall capacity ($d_m = D$):

$$\frac{\pi}{4 \tau_C Cn} = \frac{d_m}{D} \tag{6}$$

$$\tau_C = \frac{\pi}{4Cn} \tag{7}$$

The significance of this formula lies in the fact that, it allows you to study the performance of the rotary apparatus and the process of dispersing solid particles in a liquid. In essence, we are talking about the time of obtaining a two–phase liquid-solid system in a rotary apparatus.

Thus, the main purpose of this study is to model the properties of a two–phase liquid-solid system produced in a tube apparatus and calculate the power consumed during the formation of such a system.

1.2 Solving the Problem

Considering liquid–solid particle systems as a dispersed system, it can be convincingly arguedthat, like the conclusions of [9,10], the main technological characteristics of processing devices will be determined by the rheological properties of such two-phase dispersed systems.

The Khodakov rheological model uses additional parameters to describe the viscosity of dispersed systems: $k(\varphi_0)$ - tortuosity of the layers of the dispersed medium; $V(\varphi_0)$ - the relative volume of the dispersed medium determined with the solid particles enclosed here. In this case, the formula for calculating the dynamic viscosity of this medium has the form:

$$\mu = \frac{\mu_0 k(\varphi_0)}{1 - \left[1.5(1-\varphi_0)^{1.5} + 1 + V(\varphi_0)\right]\varphi_0} \tag{8}$$

Where μ_0 - dynamic viscosity of the dispersion medium, *Pasek*; $k(\varphi_0)$ - the coefficient of tortuosity of the layers of the dispersed medium, which takes the following values.

For low-viscosity liquids, the mPa-s value (millipascal-second) is used. Although, theoretically, the dynamic viscosity of water at 20 ° C is equal to 1,002 mPa-s, but in practical calculations, its value can be taken as one, as it was done in the work [11,12],

φ_0 - the relative volume of the dispersed medium, determined by the following formula:

$$\varphi_0 = \varphi_M \left(\frac{1}{\rho_T} + \frac{S_M \delta}{\rho_J}\right) \frac{1}{\varphi_M \left(\frac{1}{\rho_T} + \frac{S_M \delta}{\rho_J}\right) - \frac{1-\varphi_M}{\rho_J}} \tag{9}$$

or:

$$\varphi_0 = \frac{\rho_J + \rho_T S_M \delta}{\rho_J + \rho_T (S_M \delta + \varphi_M - 1)} \tag{10}$$

Where φ_M - mass fraction of the solid phase; ρ_J; ρ_T - true density of liquid and solid phase, *kg/m^3* S_M - specific surface area of the solid phase, m^2; δ - thickness of the dispersion medium layer occluded by a solid phase particle, m .

The following conditions and equalities are also valid:

$$\begin{cases} 1 \le k(\varphi_0) \le 5 \\ \varphi_0 \le 0{,}15;\ k(\varphi_0) = 1 \\ \varphi_0 \ge 0{,}5;\ k(\varphi_0) = 5 \end{cases}$$

The above parameters determine the quality of construction sand processing. But, any technological machine also has such a significant indicator as power. Since the power consumption on the one hand determines the performance of the machine, on the other – the efficiency of use.

The relationship between the power spent on dispersion and the dispersion conditions is represented in the form:

$$N_{disp} = 3.7 \cdot 10^{-5} 3\pi^3 k_N \rho_{dm} \omega^3 d_M^3$$

ρ - reduced density of heterogeneous medium, *kg/m* ω - angular velocity of the dispersed medium, rad/sec.; d_M diameter of the rotating volume -m; k_N – a certain coefficient depending on the type of agitator and its geometric parameters.

$$N_{disp} = \frac{30}{\pi} M_{bf}\, n$$

$$M = 3.7 \cdot 10^{-5} 3\pi^3 k_N \rho_{dm} \omega^2 d_M^5 \quad (11)$$

In [13], washing machines were studied and an analysis of modern hydraulic methods for processing and enriching metal-bearing sands was carried out, according to fr. The significance of this information for these studies lies in the fact that definitions are given for such basic indicators as clay plasticity, wash ability coefficient and productivity (mass / time) of the washing process.

The plasticity index is a positive number (plasticity number) determined by the difference in the moisture content of clay, which correspond to the upper and lower (upper lower) limits of plasticity:

$$P = W_u - W_l, \quad (12)$$

Where P – plasticity number; W_u – the upper limit of plasticity, (characterized by the transition of clay from a plastic to a liquid state), causing the spreading of wet clay along the plane, (%) ; W_l, – the lower limit of plasticity, (characterized by loss of plasticity), causing the scattering of already non-plastic clay under pressure, (%)

Clay with a relatively small number of plasticity (up to 7) easily integrates with sand and vice versa - the higher the plasticity (7-17-medium plasticity; 17- high plasticity), the more difficult the integration process. Similarly, but in the opposite direction, it is necessary to reason when the disintegration of clay with sand is considered.

To assess the flushing characteristics, the flushing coefficient (flushing coefficient) is proposed:

$$k_{fc} = 0.5 t_0 I_0 + (t_0 I_0)^2 \quad (13)$$

Where i_0 – the maximum value of the rate of draining the extraction of impurities contained in the clay, which is achieved at the time t_0 (characteric flushing time).

To calculate the productivity (tons / hour) of the washing machine according to the consumption of electricity required for washing 1 ton of material, the formula is used

$$Q = \frac{N\eta}{q} \quad (14)$$

N – power consumption of the drive motors, kW; η –power utilization factor (= 0.7-0.8); q – specific power consumption for washing the material (is a tabular value, is taken per unit volume *kWh / m*^{3}.

An important factor is the ability to link the specific power consumption with the flushing coefficient. In the literature [14,15], this relationship is presented in numerical terms as follows: the flushing of the material is estimated by the specific consumption of electricity for disintegration, which is: for easily flushing materials less than 0.25 kWh/t; for medium-washed materials - 0.25 - 0.5 kWh / t. In the literature [12,14] there is a table showing numerical data for different degrees of wash ability. It should be noted that data on specific electricity consumption have also been added to the Table 1.

Thus, on the basis of these tabular data, the following ratios can be written for construction sands with a ratio of the number of clays 1:50:

$$k_{fc} = 0.5(0.83\, x_t) I_0 + ((0.83\, x_t) I_0)^2 = 1 \quad (15)$$

$$Q = \frac{N\eta}{q} = \frac{N\eta}{0{,}25} \quad (16)$$

Similarly, you can write formulas for building sands with the ratio of the number of clays 1:40; 1=20, 1:10; 1-8. Now, having such a table at our disposal, on the basis of equation (13), we can investigate the maximum value of the discharge rate of extraction of impurities contained in clay-I0. For this purpose, first you need to write the formula (15) in the form:

$$k_{fc} = 0.5 T_{fc} x_T I_0 + (T_{fc} x_T I_0)^2 \quad (17)$$

Where T_{fc} - duration of sand washing, hour; x_T - the relative value of the time at which the maximum value of the discharge rate of the extraction of impurities contained in clay is reached (characteristic washing time)

The solution of equation (17) with respect to the discharge rate of extraction of impurities contained in clay- I0 will be:

$$I_0 = \frac{1}{Tx_t} 0.5 + \sqrt{0.25 + 4k_{fc}} .$$

For easy-to-clean flushing - $k_{fc} = 1;\ T = 50 \text{ min}$.

$$I_0 = \frac{0.5 + \sqrt{4.25}}{0{,}83\ x_t} \quad (18)$$

For medium wash ($k_{fc} = 1{,}5;\ T = 80 \text{ min}$):

$$I_0 = \frac{0.5 + \sqrt{6.25}}{1{,}33\ x_t} \quad (19)$$

and for hard-to-wash flushing

($k_{fc} = 2;\ T = 120 \text{ min}$.)

$$I_0 = \frac{0.5 + \sqrt{8.25}}{2 x_t} \quad (20)$$

Based on equation (5), in which if we take the duration of washing as the time of filling the internal volume of the washing machine: $T = t$:

$$n = \frac{\pi h D^2}{4 C T d_m^3} \quad (21)$$

Let's move on to the relative values of geometric dimensions. For convenience, we assume that when filling the working volume with liquid, the diameter formed by the rotational movement of the liquid flow is equal to the diameter of the working volume of the washing machine: $D = d_m$; for the height of the working volume, we take a parameter that is a multiple of the diameter. Then:

$$n = \frac{\pi a}{4CT} \quad (22)$$

Now that the results on the rotation speed have already been obtained, investigating the power spent on the sand washing process:

$$N_{disp} = k_N \rho_{dm} n^3 d_M^3 \quad (23)$$

According to the accepted conditions regarding the ratios of geometric dimensions:

$D = d_m$; $h = aD$, then: $d_M^3 = (h / a)^3$

$$N_{disp} = k_N \rho_{dm} \left(\frac{\pi h}{4CT} \right)^3 \quad (24)$$

Table 1. Assessment of the wash ability of sands

Degree of flushing	Specific power consump-tion kWh/t	Duration of washing, *min*.	Screening efficiency according to class 4 mm, %	Relation of the number of clays to sands	Molecular humidity, %	Washout time in the trough sink, min.	Efficiency coefficient
Easily washable	0,25	50	80	1 : 50	7	-	1
Medium - washe	0,25-0,5	70-80	70-75	1 : 20-40	7-15	1-1,5	1-1,5
Hard - to - wash	0,5-0,75	120	50-60	1 : 8-10	15-20	4,0	2

Fig. 2 show static models of the process of formation of a two-phase liquid-solid medium and oscillograms showing changes in parameters such as the speed of rotation of a two-phase water-sand system with clay, the rate of discharge of clay extraction and the power of sand washing. Chilen data for parameters included in formulas (5), (7)-(9), (17), (19) and (24) are as follows: C=0,25-1,2.

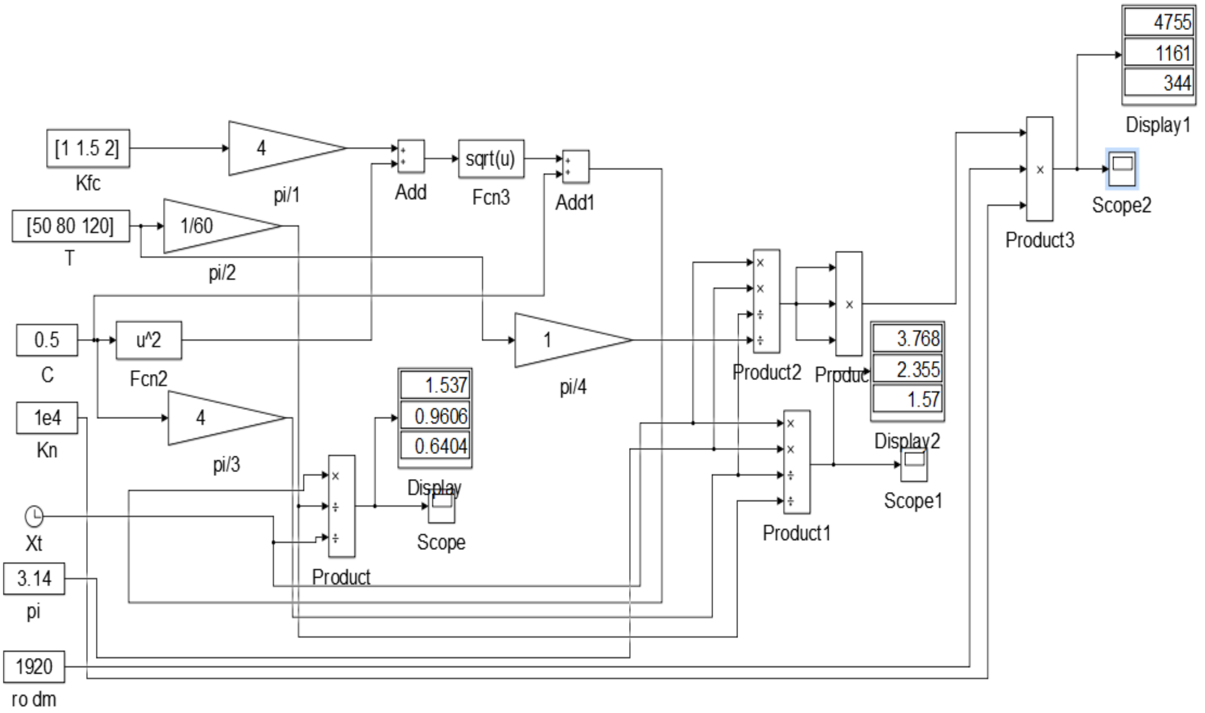

Fig. 2. Static models of the process of formation of a two-phase medium of liquid-solid particles (based on formulas (19)-(24))

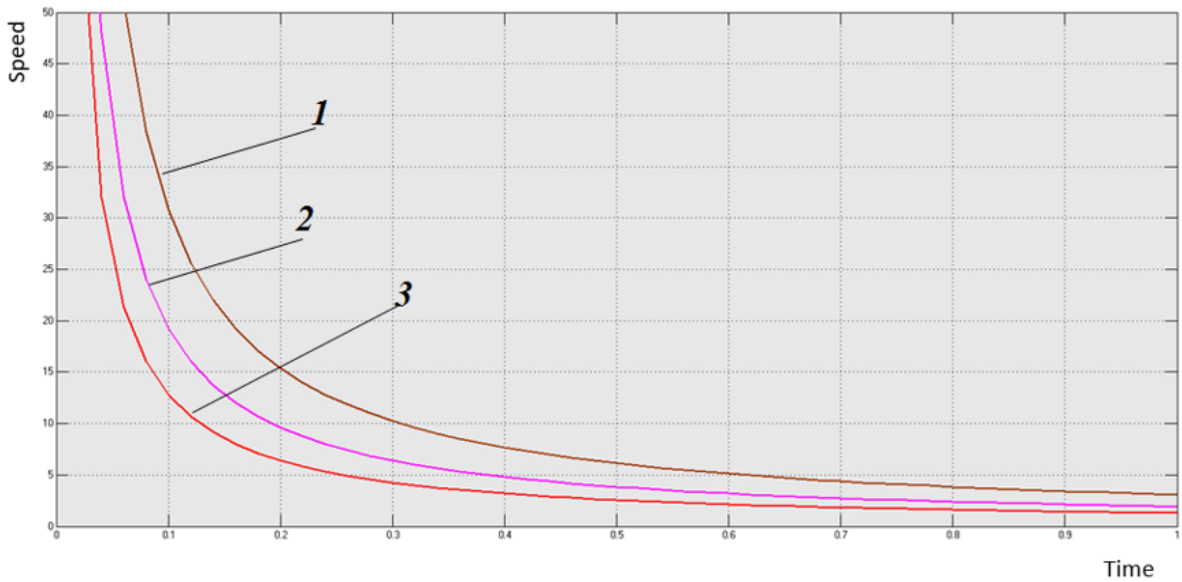

Fig. 3. Oscilloscopes obtained from simulation of the model Graphs of the function I_0=f(xT) equation (19)

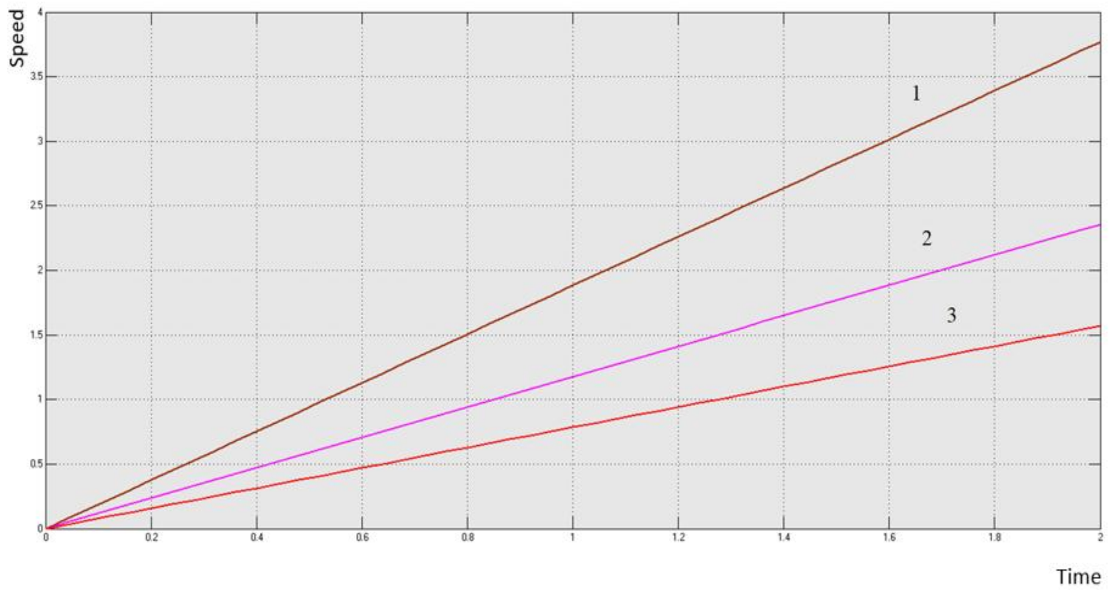

Fig. 4. Oscilloscopes obtained from simulation of the model Graphs of the function n=f(a) equation (22)

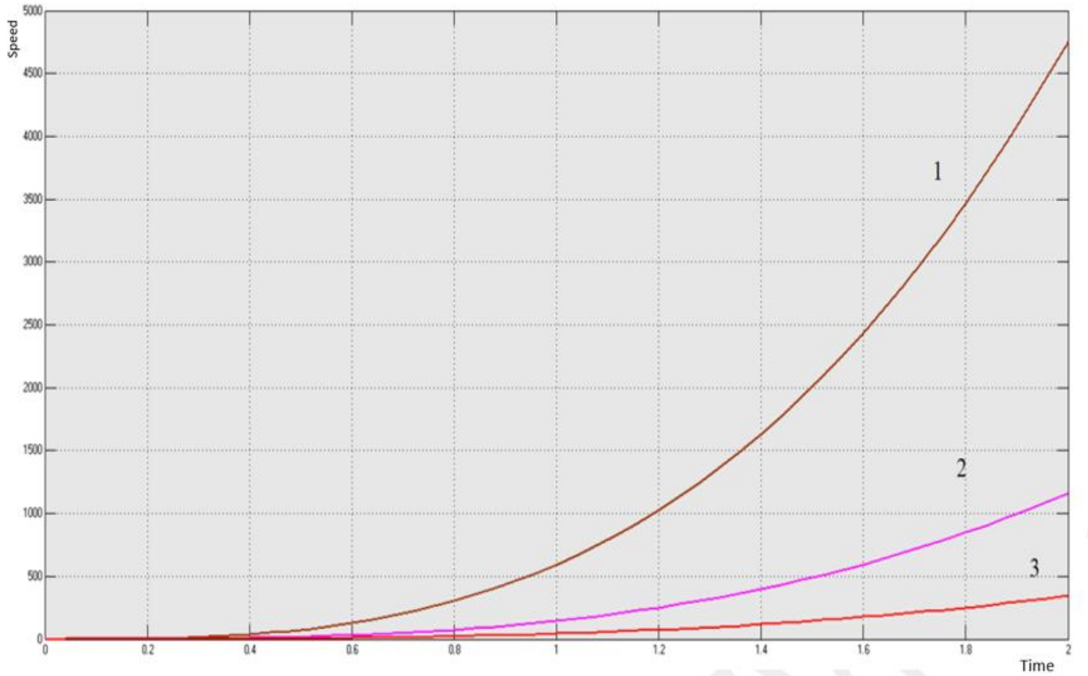

Fig. 5. Oscilloscopes obtained from simulation of the model Graphs of the function N=f(h) equation (24)

2. CONCLUSIONS

The main conclusions of the theoretical studies carried out are as follows:

1. The parameters of the rate of discharge of clay extraction and the power consumed for washing sand do not change linearly depending on the geometric parameters of the working volume, and the parameter of the speed of rotation of the liquid with untreated sand has a linear character of change.
2. The linear change in the rotation speed of the liquid with uncleaned sand is provided that when filling the working volume with

liquid, the diameter formed by the rotational movement of the liquid flow is equal to the diameter of the working volume of the washing machine.
3. When constructing an automatic control system for sand washing, it is necessary to ensure stabilization by such basic indicators as the required sand-clay ratio, the humidity of the cleaned sand, power consumption, etc.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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