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EVALUATION OF EFFICIENCY AND MONITORING OF THE HYDRAULIC TRANSPORT COMPLEX OPERATION MODES USING A MATHEMATICAL MODEL OF THE PULP FORMATION UNIT

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Abstract. For the pulverisation systems of hydraulic transport complexes used to transport placers from the mining sites to the processing site and using hydraulic monitors to form a hydraulic mixture by washing the placer massif, a methodological support for calculating the parameters and operating modes based on the data of diagrams of relative parameters of the pulverisation process was developed. For the first time, it is proposed to determine the volumes of water and placer supplied to the concentrating production (concentrator), the parameters of the efficiency of the hydraulic transport complex, as well as the characteristics of the pulverisation unit, such as the volume flow rate of water, volume flow rate of placer, volume flow rate, density and concentration of the hydraulic mixture, and the number of hydraulic monitors that provide placer wash-out, by the relative values of the density and flow rate of the hydraulic mixture evaluated by the operational control system. For the first time, formulas for calculating the relative parameters characterising the operation mode of the hydraulic transport complex and the slurry formation unit within the cycle of the process of placer wash-out at the main slurry pumping station are proposed. The existence of the mode of equal distribution of water consumption for slurry formation units that use hydraulic monitors for placer wash-out, in which the total relative water consumption through the nozzles of hydraulic monitors and through the pipelines supplying water to the zumpf is equal, was established. This mode makes it possible to determine the actual values of the specific productivity of hydraulic monitors in terms of solid and specific water consumption based on the diagrams of relative parameters of the slurry formation process. It is shown that the value of the slurry flow homogeneity parameter, which reflects the difference between the actual and the flow rate concentrations of the slurry, is possible to determine by using diagrams of relative parameters of the slurry formation process. For the first time, the dependence of the specific water consumption on the volumetric concentration of the slurry mixture was established, and an approximation of this dependence by an exponential function was recommended. On the example of diagrams of relative parameters of the slurry formation process obtained experimentally in industrial conditions, the adequacy of the proposed calculation dependencies and the possibility of their use for engineering calculations are proved.

Keywords: hydraulic transport, placers, pulp formation, hydraulic monitor, zumpf, determination of parameters.

1. Introduction

Pressure hydraulic transport of bulk materials is very common at mining and processing plants and mining and metallurgical plants in Ukraine [1–8]. One of the advantages of this type of transport is the continuity of the technological process from the place of mineral extraction to the place of its concentration and storage of processing waste. Another advantage of pressure hydraulic transport is the ease of use of operational parameter control systems and the ability to monitor its parameters and operating modes [8–11]. Traditionally, in the second half of the twentieth century, technical means and methods of registration were used for this purpose, which were developed for the conditions of pressure flow of a homogeneous liquid, for example, a Venturi flow meter [6, 7, 12]. Usually, such devices were supplemented with devices that prevented the solid phase of the hydraulic mixture from entering the measuring devices, the so-called separating vessels [6]. Some researchers have designed new devices and recording methods that are more adapted to the conditions of the hydraulic mixture, such as the Anti-Venturi pipe flow meter [8], or an artificial hydraulic resistance in the form of a vertical trapezoid, which allows determining the density of the hydraulic mixture. Since the beginning of the twenty-first century, ultrasonic and induction flow and density meters, as well as radiation devices requiring a permit to handle radiation sources, have been actively used to solve these problems [9–12].

However, despite the design features and the basic operation of control and recording devices, they were usually used either to record the volume of the hydraulic mixture, liquid and solid material delivered to the concentration plant or to control the pulverisation process.

In the first case, the devices were installed at the end of the hydraulic transport complex's main line at the entrance to the concentrator, in fact, to monitor and control the operation of the concentrator. In this case, integral or total indicators were usually recorded for a certain operating time: per hour, per shift, per day. This approach did not provide for the possibility of operational control and management of the hydraulic transport complex's operating parameters, but it allowed adjusting the technological task for the following periods and predicting the possibility of achieving the planned indicators.

In the second case, the devices were installed at the beginning of the hydraulic transport complex pipeline directly outside the slurry formation unit in order to monitor and control the operation of the hydraulic transport complex. In this case, the measurement results are displayed promptly, i.e., with instant visualization in the operator's cab by the hydraulic monitor in the form of diagrams of relative or actual parameters of the pulverisation process (Fig. 1) [6, 8]. This approach made it possible to quickly regulate the modes and parameters of the hydraulic transport complex, but does not allow to assess the efficiency of its operation.

Both approaches did not solve the problem of accounting for the volumes of water and placer fed to the concentration plant in the event of changes in the parameters of the primary placer. Typically, the primary placer consists of three or four components, each with its own density and particle size distribution. The content of primary placer components entering the pulverisation process depends on many factors: the content of components in the layer to be mined, the number of vehicles delivering the placer, and the volume of the excavator bucket. When entering the slurry formation, primary placers from different mining sites are mixed and washed away by the hydraulic monitor jet, so the concentration, density and average diameter of the particles of the solid phase of the hydraulic mixture entering the pump is unknown and is probabilistic.

It is almost impossible to track such changes by the readings of the first group of devices installed at the concentration plant. Some information about changes in the concentration, density and average diameter of the particles of the solid phase of the hydraulic mixture can be detected by these devices in a day or several days. Indicators of devices of the second group are more informative for solving this problem, but they lack a methodology for calculating and determining the volume of water and placer supplied to the concentrating production, parameters of the efficiency of the hydraulic transport complex, as well as methods for determining the characteristics of the pulverisation unit, such as the volume flow rate of water, the volume flow rate of placer, the volume flow rate, density and concentration of the hydraulic mixture, and the number of hydraulic monitors that provide placer wash-out.

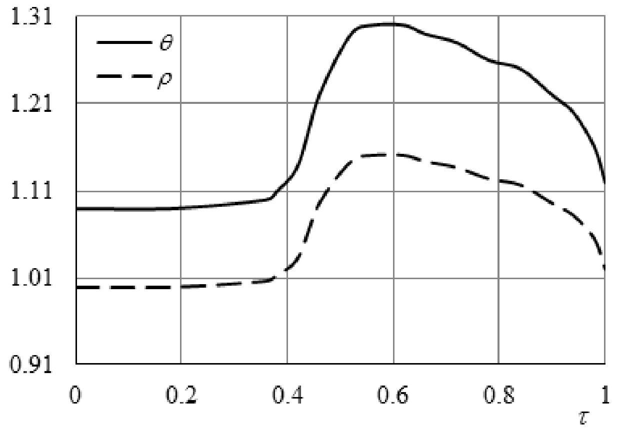

Figure 1 – Diagram of relative parameters of the slurry formation process, dependence of the relative flow rate (θ) and density (ρ) of the hydraulic mixture at the inlet to the pipeline of the hydraulic transport unit on the dimensionless time (τ) [6, 8]

The experience of using hydraulic monitors in open-pit mining operations for washing primary placers during pulverisation indicates the widespread use of diagrams of relative parameters of the pulverisation process to control and monitor operating modes (Fig. 1) [6, 8]. Such diagrams provide a clear operational picture and allow the operator of hydraulic monitors to respond in a timely manner and direct the required number of hydraulic monitors either to wash the placer or to the zumpf. It is logical to try to use these diagrams to solve the problems of accounting for the volume of water and placer supplied to the concentrator plant, as well as to assess the efficiency and monitor the operation of the hydraulic transport complex. This approach complements the data from other measurement and control systems for hydraulic transport parameters installed on the pipeline and expands the capabilities of the operational monitoring and control system [14–16].

Thus, the purpose of the research is to develop methodological support for calculations based on the data of diagrams of relative parameters of the pulverisation process (Fig. 1) of the volumes of water and placer fed to the concentrating production, parameters of the efficiency of the hydraulic transport complex, as well as methods for determining the characteristics of the pulverisation unit, such as the volume flow rate of water, the volume flow rate of placer, the volume flow rate, density and concentration of the hydraulic mixture, and the number of hydraulic monitors that provide placer wash-out.

2. Methods

To achieve the goal of the research, we will use a mathematical model of the pulverisation process developed by the specialists of the M.S. Poliakov Institute of Geotechnical Mechanics, taking into account the experience of the Vilnohirsk Mining and Metallurgical Plant in the development of the Eastern section of the Malyshevske deposit [6, 8]:

$$Q_S = j_g A_g Q_g \,;\; Q_w = n_z Q_z + k_g Q_g \,;\; Q = n_z Q_z + \left(k_g + j_g A_g\right) Q_g \,;\; C = \frac{Y}{1+E+Y}\,; \quad (1)$$

$$\rho = 1 + \frac{ArY}{1+E+Y}\,;\; \psi_z = \frac{Y}{1+E}\,;\; E = \frac{n_z}{k_g} q_z \,;\; Y = \frac{j_g}{k_g} A_g \,;\; q_z = \frac{Q_z}{Q_g}\,;\; Ar = \frac{\rho_S - \rho_W}{\rho_W}\,; \quad (2)$$

where Q_S – is the total volume flow rate of solid particles fed into the zumpf; Q_g – water flow through the nozzle of the hydraulic monitor; Q_w – total volume flow rate of water supplied to the zumpf; Q_z – water flow through the pipeline supplying water to the zumpf; k_g – number of hydraulic monitors ensuring the pulping process; j_g – number of hydraulic monitors that simultaneously wash-out the face; n_z – number of pipelines supplying water to the zumpf; A_g – specific productivity of the hydraulic monitor for solid; Q – volume flow rate of the hydraulic mixture entering the zumpf; C – volume concentration of pulp in the zumpf; E – effective pulping parameter; Y – specific water consumption; Ar – Archimedes parameter of transported particles; ρ – relative density of the pulp; ρ_s – density of solid particles; ρ_w – water density; q_z – pulping parameter; ψ_z – ratio of pulp phase flow rates in the zumpf.

To solve these issues, it is necessary to study the features of mathematical models of the pulping unit operation within the pulping cycle and to substantiate their equations for each section of the cycle. Having established the difference in the equation of the mathematical model of the slurry formation process for each of the sections, and considering that during the slurry formation cycle the basic volumetric water flow rate, which is the flow rate of the liquid phase of the hydraulic mixture, remains unchanged, it is necessary to write down a system of equations, that will allow determining the volume flow rate of water, volume flow rate of placer, volume flow rate, density and concentration of the hydraulic mixture, as well as the number of hydraulic monitors that provide placer wash-out and specific productivity on solid, the parameter of pulverisation.

3. Theoretical or experimental part

According to the diagrams of the relative parameters of the pulping process (Fig. 1), we divide the pulping cycle into three sections (Tables 1, 2), for each of which the equations of the mathematical model of the pulping process, formulas (1) and (2), will have a certain difference.

For the first section, the equations of the mathematical model of the pulping process, formulas (1) and (2), will be as following:

$$j_g = 0\,; \qquad Q_S = 0\,; \qquad C = 0\,; \qquad \rho = 1\,; \qquad \psi_z = 0\,; \qquad Y = 0\,;$$

$$Q_w = n_z Q_z + k_g Q_g \text{ ; } Q = n_z Q_z + k_g Q_g \text{ ; } Ar = \frac{\rho_s - \rho_w}{\rho_w} \text{ ; } q_z = \frac{Q_z}{Q_g} \text{ ; } E = \frac{n_z}{k_g} q_z \text{ .}$$

Table 1 – Characteristics of the pulping cycle

No	Pulp formation occurs	Distribution of hydraulic monitors between the placer and the zumpf
First	not available	All hydraulic monitors are directed into the zumpf
Second	in an alluvial deposit	All hydraulic monitors are directed at the placer
Third	at the site at the zumpf	Some of the hydraulic monitors are directed at the placer, and some - into the zumpf and the area around it

Table 2 – Relative duration of the pulping cycle stages

No	Pulp formation occurs	The limits of the section
First	not available	from 0.00 to 0.38
Second	in an alluvial deposit	from 0.38 to 0.62
Third	at the site near the zumpf	from 0.62 to 1.00

For the second section, the equations of the mathematical model of the pulping process, formulas (1) and (2), will be as follows:

$$j_g = k_g \text{ ; } \quad Q_S = k_g A_g Q_g \text{ ; } \quad Q_w = n_z Q_z + k_g Q_g \text{ ; } \quad Q = n_z Q_z + k_g \left(1 + A_g\right) Q_g \text{ ;}$$
$$C = \frac{A_g}{1 + E + A_g} \text{ ; } \quad \rho = 1 + \frac{Ar A_g}{1 + E + A_g} \text{ ; } \quad \psi_z = \frac{A_g}{1 + E} \text{ ; } E = \frac{n_z}{k_g} q_z \text{ ; } Y = A_g \text{ .}$$

For the third section, the equations of the mathematical model of the pulping process, formulas (1) and (2), will be as follows:

$$0 < j_g < k_g \text{ ; } Q_S = j_g A_g Q_g \text{ ; } Q_w = n_z Q_z + k_g Q_g \text{ ; } Q = n_z Q_z + \left(k_g + j_g A_g\right) Q_g \text{ ;}$$
$$C = \frac{Y}{1 + E + Y} \text{ ; } \quad \rho = 1 + \frac{Ar Y}{1 + E + Y} \text{ ; } \psi_z = \frac{Y}{1 + E} \text{ ; } E = \frac{n_z}{k_g} q_z \text{ ; } Y = \frac{j_g}{k_g} A_g \text{ .}$$

To solve the problem of accounting for the volumes of water and placer fed to the concentration plant, we will determine the difference in the equation of the mathematical model of the pulverisation process for each of these sections (Tables 1, 2).

Within the first stage, the basic volume water flow rate is determined, which will ensure slurry formation and pressure hydraulic transport. The methodology assumes that this value remains unchanged during the slurry formation cycle:

$$Q_0 = n_z Q_z + k_g Q_g \text{ ,}$$

where Q_0 – basic volumetric water flow rate; Q_g – water flow through the nozzle of the hydraulic monitor; Q_z - water flow through the pipeline supplying water to the zumpf; k_g – number of hydraulic monitors ensuring the pulping process; n_z – number of pipelines supplying water to the zumpf.

The second section determines the maximum possible concentration, flow rate of the hydraulic mixture and the largest flow rate, i.e. the volume flow rate of the bulk:

$$\overline{Q} = n_z Q_z + k_g \left(1 + A_g\right) Q_g \; ; \; Q_S = \overline{Q} - Q_0 \; ; \; \overline{C} = \frac{\overline{\rho} - 1}{Ar} ; \; \rho_m = \overline{\rho} \rho_w \; ; \; Ar = \frac{\rho_s - \rho_w}{\rho_w} , \quad (3)$$

where $\overline{Q}$ – maximum possible volume flow rate of the hydraulic mixture; Q_S – total volume flow rate of solid particles fed into the zumpf; A_g – specific productivity of the hydraulic monitor for solid; $\overline{C}$ – maximum volume concentration of the hydraulic mixture in the zumpf; $\overline{\rho}$ – relative maximum density of the hydraulic mixture; ρ_s – density of solid particles; ρ_w – water density; Ar – Archimedes parameter of transported particles.

The data obtained at the first two stages are used to determine the parameters of the pulping process at the third stage, since they allow us to write a system of two equations

$$\overline{\theta} = n_z \theta_z + k_g \left(1 + A_g\right) \theta_g \; ; \; 1 = n_z \theta_z + k_g \theta_g \; ; \; \overline{\theta} = \frac{\overline{Q}}{Q_0} ; \; \theta_z = \frac{Q_z}{Q_0} ; \; \theta_g = \frac{Q_g}{Q_0} ;$$

and determine the relative values of water flow rates through the pipeline to the zumpf and to the hydraulic monitor within the current slurry formation cycle:

$$\theta_S = \overline{\theta} - 1 ; \qquad k_g \theta_g = \frac{\theta_S}{A_g} ; \qquad n_z \theta_z = 1 - \frac{\theta_S}{A_g} , \quad (4)$$

where θ_S – relative total volume flow rate of solid particles fed into the zumpf; $\overline{\theta}$ – relative maximum possible volume flow rate of the hydraulic mixture; θ_g – relative water flow through the nozzle of the hydraulic monitor; θ_z – relative water flow through the pipeline supplying water to the zumpf.

The third section is characterized by unstable values of flow rate, density and concentration of the hydraulic mixture

$$C = \frac{\rho' - 1}{Ar} ; \qquad S = \frac{\theta' - 1}{\theta'} ; \qquad \theta' = \frac{Q'}{Q_0} ; \qquad Q' = n_z Q_z + \left(k_g + j_g' A_g\right) Q_g , \quad (5)$$

where C – volumetric concentration of the hydraulic mixture in the zumpf at the third section of the cycle; S – volumetric flow rate concentration of the hydraulic mixture in the zumpf at the third section of the cycle; θ' – relative volume flow rate of the hydraulic mixture at the third section of the cycle; Q' – volumetric flow rate of the hydraulic mixture at the third section of the cycle; j_g' – number of hydraulic monitors that simultaneously wash out the face.

The data of the second and third sections, formulas (3) and (4), allow us to determine the number of hydraulic monitors that simultaneously wash out the face in two ways:

$$\frac{j_g'}{k_g} = \frac{\theta' - 1}{\bar{\theta} - 1}; \qquad \frac{j_g'}{k_g} = \frac{\dfrac{\rho' - 1}{Ar}}{1 - \dfrac{\rho' - 1}{Ar}} \frac{1 + \dfrac{n_z}{k_g} q_z}{A_g}, \tag{6}$$

where ρ' – relative density of the hydraulic mixture during the third stage of the cycle.

Using the data of the second and third section indicators, formulas (3) and (4), we can determine that

$$\frac{n_z}{k_g} q_z = \frac{A_g}{\bar{\theta} - 1} - 1, \tag{7}$$

and obtain the following formula for determining the Archimedean parameter of transported particles

$$\wp Ar = \frac{\theta' \left(\rho' - 1\right)}{\theta' - 1}; \tag{8}$$

$$\wp = \frac{C}{S},$$

where $\wp$ – parameter of homogeneity of the hydraulic mixture flow [6–9].

The analysis of the relations (4) indicates the existence of a point of equal distribution of water flow, in which the total relative water flow through the nozzles of hydraulic monitors and through the pipelines supplying water to the zumpf will be equal:

$$k_g \theta_g = n_z \theta_z ; \qquad \bar{\theta}_0 = 1 + 2A_g ,$$

that allows to calculate the specific productivity of the hydraulic monitor for solid

$$A_g = \frac{\overline{\theta}_0 - 1}{2}, \tag{9}$$

where $\overline{\theta}_0$ – relative volumetric flow rate of the hydraulic mixture at the point of equal distribution of water flow.

In most cases, the efficiency of the hydraulic transport complex is assessed by the specific water consumption, which is calculated using the following formula

$$A = \frac{Q_w}{Q_S}.$$

Diagrams of the relative parameters of the slurry formation process (Fig. 1) can also be used to quickly assess the efficiency of the hydraulic transport complex. Recording the equations of the mathematical model of the slurry formation process using hydraulic monitors within each section allows to obtain the following system of equations:

$$\overline{\theta} = n_z\theta_z + k_g(1 + A_g)\theta_g \text{ ; } \theta_g = \frac{1}{n_z q_z + k_g} \text{ ; } \theta' = n_z\theta_z + (k_g + j'_g A_g)\theta_g \text{ .}$$

The solution of this system of equations allows us to obtain the following formulas for calculating the specific productivity of the pulverisation unit for solid:

$$\overline{A} = \frac{1}{\overline{\theta} - 1}; \qquad A' = \frac{1}{\theta' - 1}; \tag{10}$$

where $\overline{A}$ – minimum possible specific water consumption; A' – specific water consumption at the third stage of the cycle.

The equations of the mathematical model of the slurry formation unit allow theoretical calculation of the minimum possible specific water consumption and specific water consumption at the third section of the cycle by the following formulas:

$$\overline{A} = \frac{1}{A_g k_g \theta_g}; \qquad A' = \frac{1}{j'_g A_g \theta_g},$$

which, after appropriate transformations, take the following final form:

$$\overline{A} = \frac{1 + \frac{n_z}{k_g} q_z}{A_g}; \qquad A' = \frac{1 + \frac{n_z}{k_g} q_z}{\frac{j_g'}{k_g} A_g}.$$

The calculated dependencies obtained by formulas (3)–(10) for the first time allow, based on the data of diagrams of relative parameters of the pulverisation process (Fig. 1), to calculate the volumes of water and placer supplied to the concentration production, the parameters of the efficiency of the hydraulic transport complex, as well as the characteristics of the pulverisation unit, such as the volume flow rate of water, the volume flow rate of placer, the volume flow rate, density and concentration of the hydraulic mixture, and the number of hydraulic monitors that ensure the wash-out of the placer.

4. Results and discussion

To test and verify the methodological support of the developed calculations, the data of diagrams of the relative parameters of the pulp formation process (Fig. 1) were digitized and tabulated (Table 3) [6, 8]. The results of the analysis of Tab. 3 indicate the correspondence of changes in the relative total volume flow rate of solid particles supplied to the zumpf (column 4), the relative total water flow rates through the nozzles of hydraulic monitors (column 6) and through pipelines, water supply to the zumpf (column 7), volume and volume flow rate concentration of the hydraulic mixture in the zumpf (columns 5 and 11), as well as the relative number of hydraulic monitors that simultaneously wash out the face (column 8), dynamics of the pulp formation process.

All of these values, except for the relative total water flow rate through the pipelines supplying water to the zumpf, increase in the second stage of the slurry cycle and decrease in the third stage. At the same time, the relative total water flow rate through the pipelines supplying water to the zumpf , on the contrary, decreases in the second stage of the pulping cycle and increases in the third stage. This is consistent with the physics of the slurry formation process and indicates the adequacy of the models used.

According to Table 3, the point of equal distribution of water flow, at which the total relative water flow through the nozzles of the hydraulic monitors and through the pipelines supplying water to the zumpf, will be equal, is:

$$\overline{\theta}_0 = 1.255,$$

and the specific productivity of the hydromonitor for solid and specific water consumption will be:

$$A_g = 0.1275; \qquad j_g' \theta_g A' = 7.843.$$

The latter value correlates quite well with the data of column 12 of Table 3, and the difference between these values is explained by the different number of hydraulic monitors that simultaneously wash out the face (column 8) at the second and third stages of the pulverisation cycle.

Table 3 – Results of calculations by formulas (3)–(10)

τ	θ	ρ	θ_S	C	$k_g\theta_g$	$n_z\theta_z$	$\frac{j_g'}{k_g}$	$\wp Ar$	$\frac{n_z}{k_g}q_z$	S	A'
0.00	1.09	1,000	0.09	0.00	0.18	0.82	0.30	0.000	4.56	0.00	11.11
0.18	1.09	1.000	0.09	0.00	0.18	0.82	0.30	0.000	4.56	0.00	11.11
0.36	1.10	1.007	0.1	0.42	0.2	0.8	0.33	0.077	4.00	0.83	10.00
0.38	1.11	1.014	0.11	0.85	0.22	0.78	0.37	0.141	3.55	1.65	9.09
0.42	1.14	1.034	0.14	2.06	0.28	0.72	0.47	0.277	2.57	4.02	7.14
0.46	1.22	1.096	0.22	5.82	0.44	0.56	0.73	0.532	1.27	9.78	4.55
0.52	1.29	1.144	0.29	8.73	0.58	0.42	0.97	0.641	0.72	14.22	3.45
0.56	1.30	1.151	0.3	9.15	0.6	0.4	1.00	0.654	0.67	14.82	3.33
0.62	1.30	1.151	0.3	9.15	0.6	0.4	1.00	0.654	0.67	14.82	3.33
0.66	1.29	1.144	0.29	8.73	0.58	0.42	0.97	0.641	0.72	14.22	3.45
0.72	1.28	1.137	0.28	8.30	0.56	0.44	0.93	0.626	0.79	13.62	3.57
0.78	1.26	1.124	0.26	7.52	0.52	0.48	0.87	0.601	0.92	12.38	3.85
0.84	1.25	1.117	0.25	7.09	0.5	0.5	0.83	0.585	1.00	11.74	4.00
0.90	1.22	1.096	0.22	5.82	0.44	0.56	0.73	0.532	1.27	9.78	4.55
0.94	1.20	1.082	0.2	4.97	0.4	0.6	0.67	0.492	1.50	8.41	5.00
0.98	1.16	1.055	0.16	3.33	0.32	0.68	0.53	0.399	2.13	5.54	6.25
1.00	1.12	1.021	0.12	1.27	0.24	0.76	0.40	0.000	3.17	2.46	8.33

The results of the statistical processing of the data from Table 3 are shown in Table 4 and Table 5. These tables show that the initial data of the diagrams of the relative parameters of the pulping process (column 2 and 3) are characterised by satisfactory coefficients of variation, while other values, when generalized for the entire pulping period, are characterized by a significantly essential deviation from the mean value.

Table 4 – Results of statistical processing of calculations according to formulas (3)–(10) for the entire period of the pulping cycle

Parameter	θ	ρ	θ_S	C	$k_g\theta_g$	$n_z\theta_z$	$\frac{j_g'}{k_g}$	$\wp Ar$	$\frac{n_z}{k_g}q_z$	S	A'
$\overline{x}$	1.20	1.08	0.20	4.90	0.40	0.60	0.67	0.40	2.00	8.14	6.01
Δx	0.08	0.06	0.08	3.52	0.16	0.16	0.27	0.26	1.44	5.67	2.87
k_v,%	6.7	5.4	40.0	72.0	40.0	26.9	40.0	64.5	71.7	69.7	47.7

Table 5 – Results of statistical processing of calculations according to formulas (3)–(10) for the period of the pulp formation cycle from 0.46 to 0.94

Parameter	θ	ρ	θ_S	C	$k_g\theta_g$	$n_z\theta_z$	$\frac{j_g'}{k_g}$	$\wp Ar$	$\frac{n_z}{k_g}q_z$	S	A'
$\overline{x}$	1.26	1.12	0.26	7.53	0.52	0.48	0.87	0.60	0.95	12.38	3.91
Δx	0.04	0.03	0.04	1.54	0.07	0.07	0.12	0.06	0.30	2.35	0.60
$k_v,\%$	2.9	2.3	14.2	20.4	14.2	15.5	14.2	9.8	31.3	19.0	15.3

Comparing Tables 4 and 5, it can be seen that when generalizing the values exclusively within the second and third sections, the consistency of the calculated values is significantly improved. The low coefficient of variation for column 9 is noteworthy, which indicates the invariance of the value of the parameter of homogeneity of the hydraulic mixture flow, provided that the density of the placer material remains unchanged. The value of the coefficient of variation for the specific water flow rate does not allow using its generalized value in the calculations, but numerical processing allowed us to recommend an approximation of the dependence of this value on the volume flow rate of the hydraulic mixture (Fig. 2) by an exponential function ($R^2 = 0.9904$):

$$A = \frac{10.283}{e^{0.0793S}}.$$

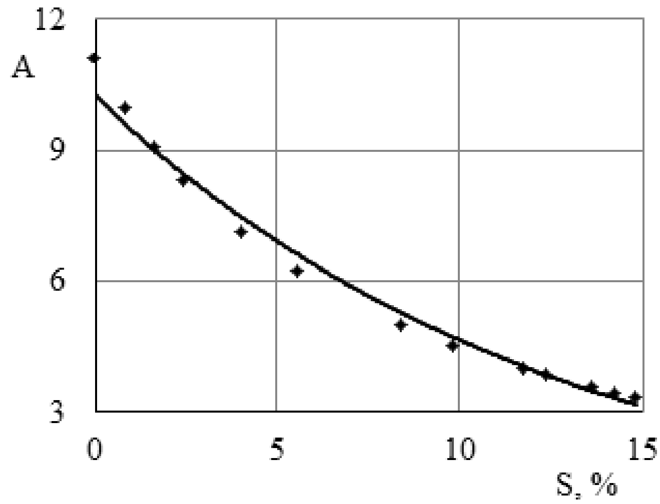

Figure 2 – Dependence of specific water consumption on the volumetric flow rate of the hydraulic mixture

5. Conclusion

Thus, the methodological support for calculations based on the data of diagrams of relative parameters of the pulverisation process of the volumes of water and placer fed to the concentrating production, parameters of the efficiency of the hydraulic transport complex, as well as a methodology for determining the characteristics of the pulverisation unit, such as the volume flow rate of water, the volume flow rate of bulk, the volume flow rate, density and concentration of the hydraulic mixture, and the number of hydraulic monitors that provide placer washing, was developed. For the first time, formulas for calculating the relative parameters characterizing the operation mode of the hydraulic transport complex and the slurry formation unit within the cycle of the process of placer washing at the main slurry pumping station are proposed. It was established that for the slurry formation with the use of hydraulic monitors for washing the placer, there is a mode of equal distribution of water flow, at which the total relative water consumption through the nozzles of the hydraulic monitors and through the pipelines supplying water to the zumpf will be equal. This mode makes it possible to determine the actual values of the specific productivity of hydraulic monitors in terms of solid and specific water consumption based on the diagrams of relative parameters of the slurry formation process. The possibility of determining the value of the slurry flow homogeneity parameter, which reflects the difference between the actual and the flow rate concentrations of the slurry, is shown using the data of diagrams of relative parameters of the slurry formation process. For the first time, the dependence of the specific water consumption on the volumetric concentration of the hydraulic mixture was established, and the approximation of this dependence by the exponential function was recommended. On the example of diagrams of relative parameters of the pulping process obtained experimentally in industrial conditions, the adequacy of the proposed calculation dependencies and the possibility of their use for engineering calculations are proved.

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ОЦІНКА ЕФЕКТИВНОСТІ ТА МОНІТОРИНГ РЕЖИМІВ РОБОТИ ГІДРОТРАНСПОРТНОГО КОМПЛЕКСУ З ВИКОРИСТАННЯМ МАТЕМАТИЧНОЇ МОДЕЛІ РОБОТИ ВУЗЛА ПУЛЬПОУТВОРЕННЯ

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Анотація. Для систем пульпоутворення гідротранспортних комплексів, що використовуються для транспортування розсипів від місць видобутку до місця переробки, й використовують гідромонітори для утворення гідросуміші шляхом розмиву масиву розсипів, розроблено методичне забезпечення розрахунків параметрів та режимів роботи за даними діаграм відносних параметрів процесу пульпоутворення. Вперше запропоновано визначати обсяги води та розсипу, що подані на збагачувальне виробництво, параметри ефективності роботи гідротранспортного комплексу, а також характеристики роботи вузла пульпоутворення, таких як об'ємна витрата води, об'ємна витрата розсипу, об'ємна витрата, густина та концентрація гідросуміші, й кількість гідромоніторів, що забезпечують розмив розсипу, за відносними значеннями густини та витрати гідросуміші, що вимірюються системою оперативного контролю. Вперше запропоновані формули розрахунку відносних параметрів, що характеризують режим роботи гідротранспортного комплексу та вузла пульпоутворення в межах циклу процесу розмиву розсипу на головній пульпонасосній станції. Встановлено існування для вузлів пульпоутворення, що використовують гідромонітори для розмиву розсипу, режиму рівного розподілення витрати води, в якому сумарні відносні витрати води через насадки гідромоніторів та через трубопроводи, що подають воду в зумпф, будуть рівні. Цей режим дозволяє за даними діаграм відносних параметрів процесу пульпоутворення визначити фактичні значення питомої продуктивності гідромоніторів по твердому та питому витрату води. Показана можливість визначення за даними діаграм відносних параметрів процесу пульпоутворення величини параметру гомогенності потоку гідросуміші, який відображає різницю між фактичною та витратною концентраціями гідросуміші. Вперше встановлена залежність питомої витрати води від об'ємної витратної концентрації гідросуміші, та рекомендована апроксимацію цієї залежності експоненційною функцією. На прикладі діаграм відносних параметрів процесу пульпоутворення, що отримані експериментальним шляхом в промислових умовах, доведена адекватність розрахункових залежностей, що запропоновані, та можливість їх використання для інженерних розрахунків.

Ключові слова: гідротранспорт, розсипи, пульпоутворення, гідромонітор, зумпф, визначення параметрів.