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SUBSTANTIATION OF THE POSSIBILITY OF DETERMINING THE PARAMETERS OF THE HYDROTRANSPORTED MATERIAL BASED ON OPERATIONAL MEASUREMENTS

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Abstract. The purpose of the publication is to create methodological foundations for determining the critical hydraulic transport speed by the values of hydraulic slope, flow rate and density of the hydraulic compoud and to assess, on the basis of these data, the current characteristics of the hydraulic compoud solid phase particles. To achieve this goal, the following research methods were used: generalisation of the known methods for calculating hydraulic transport parameters and mathematical processing of data obtained from the data of the services of mechanics, power engineering, control of measuring equipment as well as real-time monitoring. A historical review of the introduction of systems for operational monitoring of flow parameters at domestic hydraulic transport complexes of mining enterprises was carried out. The technical means of controlling and recording the flow rate and pressure of the hydraulic compoud, methods for determining its density and cargo flow were analysed. This made it possible to substantiate the parameters that can be used to achieve the research goal of determining the parameters of the transported material based on operational measurements. The results of the study are the establishment of the dependence of generalised values of the parameters of solid particles of the transported material on the hydraulic characteristics of the hydraulic compoud flow, taking into account the characteristics of the pipeline and the characteristics of the transported material. The obtained formulas make it possible to determine the current generalised values of the parameters of solid particles of the transported material based on the data of monitoring and operational control systems of hydraulic transport parameters, taking into account the characteristics of the pipeline and the characteristics of the transported material. These dependencies can be solved in relation to the density of the transported material particles or their diameter, depending on the mining-geological or mining-technological conditions of open-pit mining, which allows to increase the reliability and efficiency of the hydraulic transport complex by timely changing the parameters and operating modes. The scientific novelty of the research results is to determine the dependence of the product of the diameter and Archimedes' parameter of the particles of the solid phase of the hydraulic compoud on the concentration of the hydraulic compoud and its average speed, hydraulic slope of the hydraulic compoud and liquid.
Keywords: critical hydraulic transport speed, parameters of the transported material, hydraulic slope of the hydraulic compound, concentration of the hydraulic compound.

1. Introduction

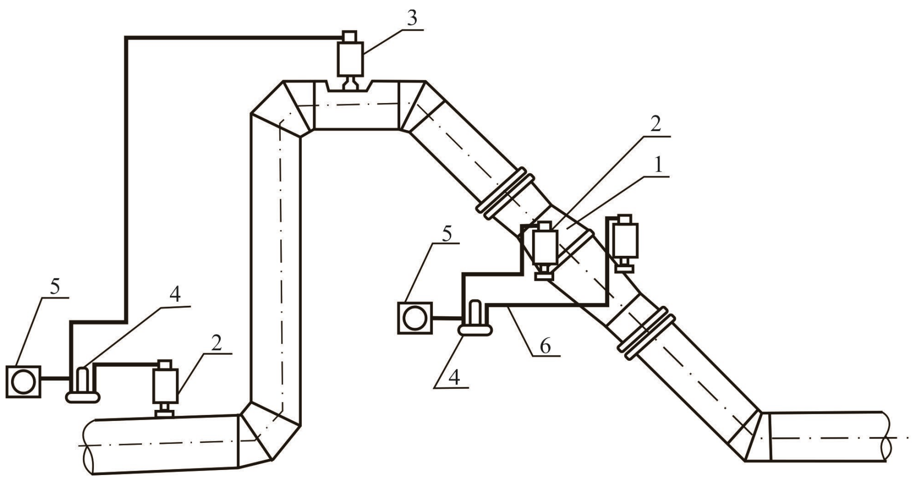
Pressure hydraulic transport is quite widespread at mining enterprises in Ukraine [1–4]. At domestic mining and processing plants, this type of transport is used both to supply primary deposits from mining sites to processing sites and to remove beneficiation waste and store it in storage facilities. Beneficiation waste from coal preparation plants located near mines and coke plants is stored exclusively by hydraulic pressure transport. According to experts, this type of transport will remain relevant and necessary even after the closure of most mining enterprises, as it is the most efficient for use in the development of man-made mineral deposits formed in the storage facilities for beneficiation waste [5–7].

The experience of using pressure hydraulic transport at domestic mining enterprises goes back more than seven decades [8], which made it possible to develop methods for calculating its parameters, recommendations for the selection and justification of equipment, approaches to optimising modes, and to determine the methods and means of operational control and accounting systems [9–11]. Since hydraulic transport complexes of mining enterprises combine the main technological links, their operational control and accounting systems have always received increased attention. If the complex supplied primary placers, its performance determined the workload of the beneficiation production, the ability to meet the plan, and the reliability of all subsequent links. If the complex provided for the discharge of production waste, its operation mode should have ensured the discharge of a certain volume of the hydraulic compound, subject to compliance with the requirements for its safe storage in a storage facility.

That is why, first of all, industrialists were interested in the flow rate and density of the hydraulic compound transported by the pipeline. Several technical means were developed to determine these parameters.

The first operational control systems were located at the main pulp pumping stations, which was due to the need to control the pulp formation process [2, 3]. One of these systems was used in the hydraulic transport complex of the Vilnohirsk Mining and Metallurgical Plant (VMMP), developed by specialists from the Institute of Hydromechanics of the National Academy of Sciences of Ukraine (IHM NAS of Ukraine) [8], and consisted of differential pressure gauges that convert the pressure difference into a corresponding proportional unified electrical signal, and secondary automatic devices that record and visualise the signal.

Devices that create a pressure difference to measure the flow rate and density of the pulp pump are mounted in the building of the pulp pumping station in a trapezoidal pipeline link with a height of 3.4 m (Fig. 1) [9–11]. The upper and lower horizontal parts of this pipeline are used to measure the density of the pulp. At the same time the link that is inclined at 40 degrees to the horizon is used to measure the flow rate of the pulp. Differential pressure gauges, as primary sensors, are located near the measuring link, and secondary devices are located on the dispatcher's console with the help of a cable [9–11]. The flow rate of the hydraulic compound of the hydraulic transport unit was measured hydrodynamically by a flow meter with an increasing cross-sectional area (Fig. 1), on which two samplers with separate tanks are located.



1 – flow meter pipe AntiVenturi; 2 – separate container with elastic diaphragm; 3 – ball pressure tester; 4 – diffuser; 5 – secondary automatic device; 6 – impulse tube

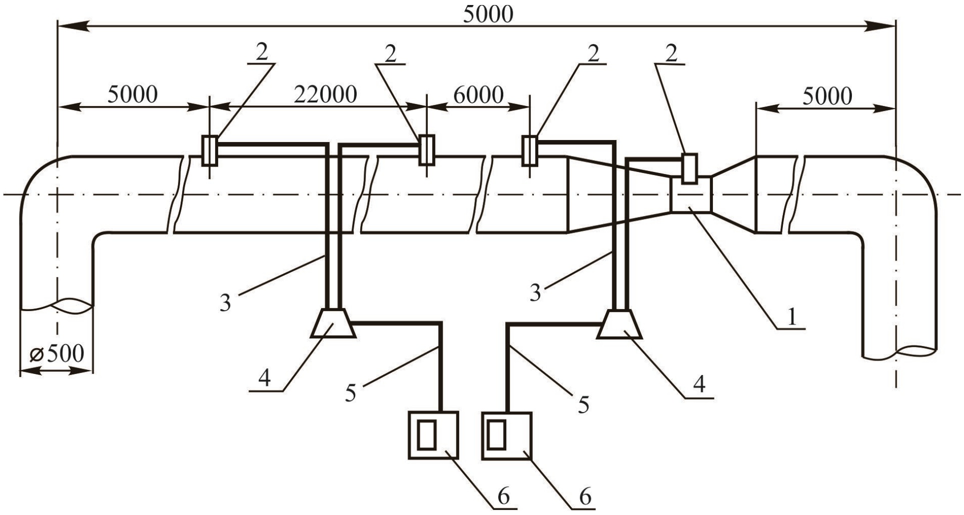
Figure 1 – Measurement link of the operational control system at the pulp pumping station [9–11]

Separate tanks with elastic diaphragms are connected to a primary sensor of the DM-3583M type by means of pulse tubes, which transmits information to an automatic secondary differential transformer device of the KSD-2 type. The flow meter is a so-called Anti-Venturi pipe [9–11]. Separating tanks with an elastic diaphragm, designed by the Institute of Hydrometeorology of the National Academy of Sciences of Ukraine [9–11], are intended to separate the hydraulic compound and the liquid that fills the internal space of elastic diaphragms, pulse tubes, and diffuser chambers, which prevents particles of the solid phase from entering the measuring devices hydraulic system and clogging the pulse networks. In the warm season, the entire hydraulic system of the measuring instruments is filled with water, and in the cold season with a mixture of 60% ethylene glycol and 40% alcohol, which does not freeze at temperatures down to -30°C.

In the second place, industrial operators began to focus on the electrical energy consumption required for hydraulic transport, as well as the issue of diagnosing pumps with worn impellers. To address these issues, pumping units were equipped with voltmeters and ammeters, and switchgear with pressure gauges was installed on the pump nozzles. The readings from these instruments, together with the data recorded by the monitoring instruments at the pulp pump station, enabled calculations of pump flow rate and pressure, their effective and consumed power, and assessment of deviations from the pump's rated flow-pressure characteristics.

However, these data did not answer all operational questions related to hydraulic transport complexes at mining enterprises, especially when they transported primary placer deposits from extraction sites to processing facilities. In such cases, the granulometric and component composition of the placer depends on many random factors and can change arbitrarily in certain intervals. This affects the hydraulic slope and the critical hydraulic transport speed. For example, a decrease in the fraction of solid particles with a diameter of less than 0.1 mm and a relative density of about 2.8 below the design value very quickly leads to the fall of other particles to the bottom of the pipeline, its plugging and the shutdown of the entire hydraulic transport complex, and subsequently, the beneficiation production. Such changes, given the concentration of the pulp, may not be detectable by devices that measure the density of the pulp, and the increase in pump head can be caused by various reasons and does not necessarily indicate this factor. The critical hydraulic transport speed is the average flow rate at which solid phase particles begin to settle on the bottom of the pipeline, forming a layer of high concentration [2, 3, 12], so the determination of the critical hydraulic transport speed involves the implementation of stratified flow in the pipeline with the formation of a highly concentrated layer of solid phase particles at the bottom of the pipeline, which means the cessation of operation. It is for these reasons that some hydraulic transport complexes have decided to measure the hydraulic slope by installing a special measuring link outside the pulp pumping station (Fig. 2) [13].

Such a measuring unit was located on the horizontal part of the pipeline and was equipped with two pressure samplers, the distance between which was at least 30 metres [13]. The pressure samplers were connected by means of pulse tubes to a differential pressure gauge, the readings of which were recorded by a secondary



device "KSU-2" in conjunction with the device "Sapphire".

1 – Venturi tube flow meter; 2 – separation capacity; 3 – impulse tube;4 – diffuser; 5 – cable; 6 – secondary automatic device

Figure 2 – Measuring link of the operational control system, located on the main pipeline [13]

If there was no horizontal section of the required length on the main line, the measuring link was made in the form of a separate pipeline, which was located horizontally and parallel to the operating pipeline. In this case, the measuring section was separated from the operating pipeline by gate valves or gate inserts. Immediately prior to the start of operation of the hydraulic transport complex, when the pipeline was free of water and hydraulic compound, the measuring link was disconnected from the main line, and part of the operating pipeline was blocked with gate valves. After that, the hydraulic transport system pipeline was filled with liquid and the process of hydraulic transport began. The measuring link of this type usually consisted of the following equipment: a venturi pipe flow meter [13], a straight pipeline for measuring the hydraulic slope.

The flow rate of the hydraulic compound and the pressure loss are determined by the corresponding pressure differences in the venturi pipe and in the straight line. The value of each of the differences was measured by a differential pressure gauge "DM-3583M", which was connected to the pipeline of the hydraulic transport system using pulse tubes and separation tanks. A separation vessel [13] provides separation of the liquid and solid phases by clarifying the mixture that enters its volume. Since there is no flow in this vessel, the solid particles that enter it settle to the bottom, and the pressure is taken from the top of the vessel. To remove the formed sediment, an opening is provided in the lower part of the vessel, which is closed during the operation of the measuring unit. The separation vessel is separated from the pipeline by a ball valve, which allows it to be flushed and filled with liquid without interrupting the operation of the measuring unit.

Subsequently, in the first decade of the 21st century, new means of measuring the density and flow rate of the hydraulic compound and new devices for measuring the differential pressure and liquid pressure appeared at mining enterprises. For example, VMMP's hydraulic transport complex used a computer system based on the Nudam I 7071 ADC 2xCPU 600 MHz 20 MB SCI, which was equipped with measuring and recording devices and the corresponding computer software. Pressure is measured using SHETRAI-43 pressure gauges equipped with UKPK-8 indicating devices. The density of the hydraulic compound is measured by a Bertkold LB 367 device. The flow rate of the hydraulic compound is measured by the flow meter UDR - 010, and the flow rate of the return fluid is measured by the flow meter UVR - 010. These devices are equipped with means of accumulating, storing and processing information and provide for the transfer of measurement results via the Internet and mobile communications. However, all this did not significantly change the measurement scheme and still does not allow to determine the critical hydraulic transport speed in industrial conditions.

The critical rate of hydraulic transport is an integral characteristic of the transported material, which takes into account the influence of both the particle size distribution and the component composition of the placer [2, 3, 12]. That is, operational control of this parameter can indicate changes in mining technology and make appropriate decisions on the management of the hydraulic transport complex. This is an urgent practical task, the solution of which, based on existing control and metering devices, can significantly improve the reliability and efficiency of mining enterprises.

2. Methods

Thus, the purpose of the article is to develop a methodological framework for determining the critical hydraulic transport rate by the values of hydraulic slope, flow rate and density of the hydraulic compound and to assess, on the basis of these data, the current characteristics of the particles of the solid phase of the hydraulic compound.

3. Results and discussion

To solve this problem, we analysed about twenty methods for calculating hydraulic transport parameters that were known and widespread in the former USSR [2, 3, 12–16]. In these methods, the hydraulic transport parameters mean the dependence of the hydraulic slope on the flow rate and the critical hydraulic transport speed on the concentration of the hydraulic compound and the parameters of the solid phase particles and the pipeline [2, 3]. The analysis of the hydraulic slope dependencies on the speed and concentration of the hydraulic compound, as well as the dependencies of the critical speed on the concentration of the hydraulic compound and the properties of the transported material, indicate that there is a dependence of the hydraulic slope on the critical speed of hydraulic transport, which for most of the studied methods has the following form (Tables 1–3) [16]:

$$i = b_0\left(1+\frac{b_1}{k_V^m}\right)i_0\ ;\ i_0 = \frac{\lambda}{2}Fr^2\ ;\ k_V = \frac{Fr}{Fr_{kp}}\ ;\ Fr = \frac{V}{\sqrt{gD}}\ ;\ Fr_{kp} = \frac{V_{kp}}{\sqrt{gD}}, \qquad (1)$$

where k_V – hydraulic transport parameter [2, 3]; b_0, b_1 – coefficients (Tables 1–3); m – degree indicator (Tables 1–3); λ – hydraulic friction resistance coefficient; Fr – the actual value of Froude's criterion; Fr_{kp} – critical value of Froude's criterion (Tables 1–3); V – actual average flow rate of the hydraulic compound; V_{kp} – critical speed of hydraulic transportation; g – acceleration of free fall; D – internal diameter of the pipeline; i_0 – hydraulic slope of the carrier fluid.

Depending on the formula for calculating the coefficients b_0, b_1 and Fr_{kp} the parameter of the methodology for calculating the parameters of hydraulic transport, it is proposed to divide the existing ones into three groups, characterised by:

– independence of parameters b_0 and b_1 from the concentration, density and diameter of solid phase particles, for the methods of the first group (Table 1);

Table 1 – Characteristics of dependencies of hydraulic transport parameters on the hydraulic transport coefficient for the methods of the first group

Authorship techniques	Significance m	Formulas for calculation		
		b_0	b_1	Fr_{kp}
Karasyk	1	$\frac{2\sqrt{S}-1}{\sqrt{S}}$	$\frac{0.7}{2\sqrt{S}-1}$	$64.1\sqrt[3]{d}\sqrt[6]{\frac{g}{D}SAr^5}$
Dmitriiev (lumpy particles)	2	1	$\frac{2}{\lambda c^2}$	$c\sqrt{fArS}$
Smoldyrov (lumpy particles)	2	1	$\frac{2}{\lambda c^2}$	$c\sqrt{fArS}$
VNIDI of reinforced concrete and Hydromechanization Project	2.8	1	0.003	$\sqrt[3]{a\sqrt{d}-\frac{b}{\sqrt{d}}}\frac{\sqrt[3]{ArS}^{0.36}}{0.02}$
Zhyvotovsky - Halsenberg	2.8	1	1	$\sqrt{a\sqrt{d}-\frac{b}{\sqrt{d}}}\frac{\sqrt[4]{ArS}^{0.36}}{0.173}$
Duran	3	1	1	$7.43\sqrt[4]{\frac{d}{D}Ar\sqrt[3]{S}}$
Dmitriiev (small particles)	3	1	$\frac{2c_1}{\lambda c^3}$	$c\sqrt[3]{a\sqrt{d}-\frac{b}{\sqrt{d}}}\sqrt[3]{SAr^2}\sqrt[6]{\frac{d}{D}}$
Smoldyrov (small particles)	3	1	$\frac{2c_1 g}{\lambda c^3}$	$\frac{c_1}{\sqrt[3]{g}}\sqrt[3]{a\sqrt{d}-\frac{b}{\sqrt{d}}}\sqrt[3]{SAr^2}$
Aksenov - Podkorytova	3	1	$0.12\left(\frac{d}{D}\right)^{0.83}$	$0.781\frac{\sqrt[6]{ArS}}{\sqrt[3]{\lambda}\sqrt[6]{dD}}$

Notes. The following notations are used in the table: $Ar = \rho - 1$ – Archimedes parameter of solid particles; ρ – relative density of solid particles; n, k – empirical coefficients; c_1 – empirical coefficient for fine coal particles; c – empirical coefficient for lumpy coal particles; c_0 – empirical coefficient for small ore particles; f – generalised coefficient of friction of lumpy particles on the pipe surface; d – generalised diameter of solid particles; S – concentration of the hydraulic compound.

– dependence of parameters b_0 and b_1 from Fr_{kp} for the methods of the second group (Table 2);

Table 2 – Characteristics of dependencies of hydraulic transport parameters on the hydraulic transport coefficient for the methods of the second group

Authors techniques	Value m	Formulas for calculation		
		b_0	b_1	Fr_{kp}
Nurok – Hryshko	$2+n$	$1+ArSR_c$	$\frac{2Fr_{kp}^{1-n}}{S^{0.25(n+1)}}$	$\sqrt{k\frac{Ar(1-SR_c)}{1+ArSR_c}S^{0.5}}$
Trainis	3	$1+ArS$	$\frac{1.99}{Fr_{kp}}$	$\frac{0.325}{\sqrt[6]{Ar}}\sqrt{\frac{c}{\lambda}\frac{S}{1+ArS}}$
Smoldyrov small ore particles	4	$1+\frac{(1-SR_c)Fr_{kp}^4}{c_0^4\left(a\sqrt{d}-\frac{b}{\sqrt{d}}\right)^2 Ar^2}$	$\frac{2c_0}{\lambda c^4}$	$c_0\sqrt{a\sqrt{d}-\frac{b}{\sqrt{d}}}\sqrt[4]{\frac{Ar^3S}{1+ArS}}$

Notes. The following notations are used in the table: R_c – weight fraction of particles with a diameter of less than 100 μm.

– dependence of parameters b_0 and b_1 on the concentration, density and diameter of particles of the solid phase, for the methods of the third group (Table 3).

Table 3 – Characteristics of the dependence of hydraulic transport parameters on the hydraulic transport coefficient for the methods of the third group

The formulas for calculation	Authorship of the methodology	
	Yufin	Kobernik -Voitenko
b_0	$1+ArS$	$1+R_cArS^2$
b_1	$\frac{7+4D+\sqrt{d}}{2}(ArS)^{0.8}$	$1.2\left(\frac{1+150\frac{d}{D}}{1+SArSR_c}(1+ArS)^{1.5}-1\right)$
Fr_{kp}	$\sqrt[4]{Ar}\frac{ArS+0.6}{0.014}\frac{\sqrt[4]{g}\sqrt{d}}{\sqrt[12]{D^5}}$	$\frac{ArS+0.6}{0.009}\frac{\sqrt[4]{g}\sqrt{d}}{\sqrt[12]{D^5}}\sqrt[4]{Ar}$
The value m	2.35	3

The results of the preliminary analysis of the methods of the second and third groups indicate that for these methods, since the dependence of the parameters b_0 and b_1 from Fr_{kp} on the concentration, density and diameter of solid phase particles, it is either impossible to obtain the dependence of the hydraulic transport coefficient on the ratio of hydraulic slopes of the hydraulic compound and liquid in an analytical form, or it is necessary to solve the algebraic equation of the third or fourth degree, which significantly complicates the use of the formulas obtained. Therefore, in the article we will consider the solution of the problem formulated in the objective for the methods of the first group (Table 1), for which, based on formulas (1), the following expression can be written [16]:

$$\frac{1}{k_V} = \frac{1}{\sqrt[m]{b_1}} \sqrt[m]{\frac{i}{i_0 b_0} - 1}, \quad \frac{1}{k_V} = \frac{Fr_{kp}}{Fr}, \tag{2}$$

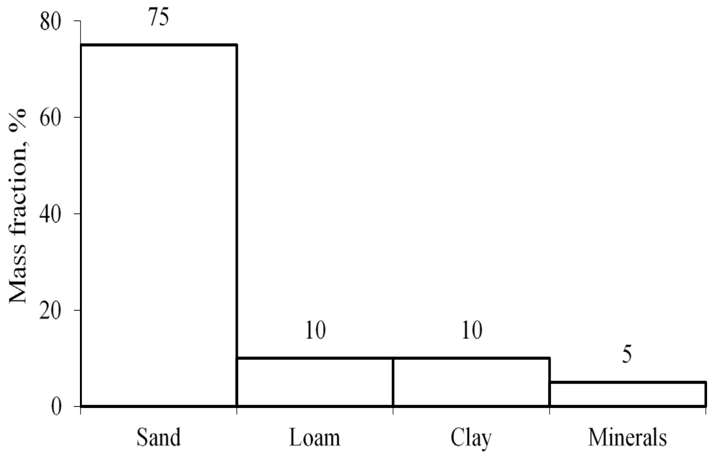
the joint consideration of which allows us to obtain a formula for calculating the critical speed of hydraulic transportation

$$Fr_{kp} = \frac{Fr}{\sqrt[m]{b_1}} \sqrt[m]{\frac{i}{i_0 b_0} - 1}. \tag{3}$$

Formula (3) was tested in the conditions of the VMMP open-pit hydraulic transport complex (Table 4, Figs. 3, 4), where the author participated in the development and implementation of the hydraulic transport complex monitoring system in from 2005 to 2009 [3, 12, 15, 16]. The monitoring of the hydraulic transport system includes a set of measures aimed at the collection, registration, processing, analysis, and generalization of information on the parameters and operating modes of the hydraulic transport system to form a database for assessing the efficiency of operation [3, 12, 15, 16].

Table 4 – Parameters of VMMP's open-pit hydraulic transport complex and placers of the Eastern area of the Malyshevske deposit [3, 12, 15, 16]

Parameter	Value
Steel pipe diameter, m	0.6
Diameter of polymer pipes, m	0.57
Generalised density of placer particles, kg/m^3	2802
The generalised diameter of the placer particles, mm	0.19
Hydraulic coarsening of placer particles, m/s	0.0157
Weight fraction of placer particles with a diameter of less than 0.1 mm	0.314
Weight fraction of placer particles with a diameter of more than 0.1 mm	0.686



1.

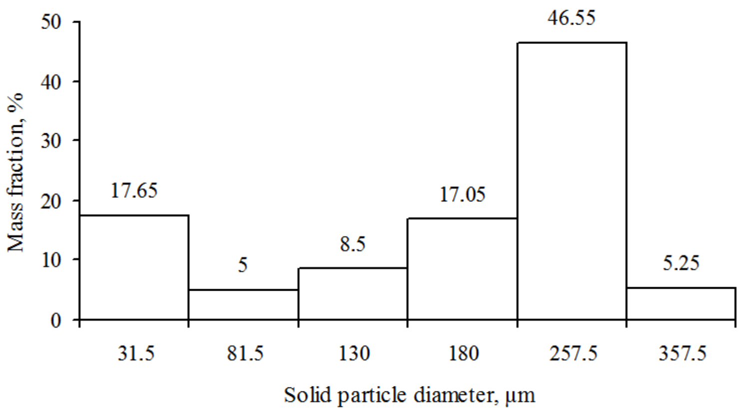
Figure 3 – Fractional composition of the placer at the Eastern area of the Malyshevske deposit (Sand – 2.7 relative density, Loam –2.72 relative density, Clay –2.75 relative density, Minerals – 4.59 relative density) [2, 3, 12, 15, 16]

2.

Taking into account the results obtained earlier, Tables 1–3 and formula (3), for the Yufin and Kobernik-Voitenko methods, formulas were proposed for calculating the experimental values of the critical hydraulic transport speed. The results of experimental studies on the hydraulic transport complex of VMMP in the form of calculation results according to these formulas were compared with the results of calculations using Smoldyrev's formulas for fine particles from Table 1 and the generalised formula of M. S. Poliakov Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine (IGTM NASU) (Fig. 5, Table 5). [6, 7, 15, 16]:

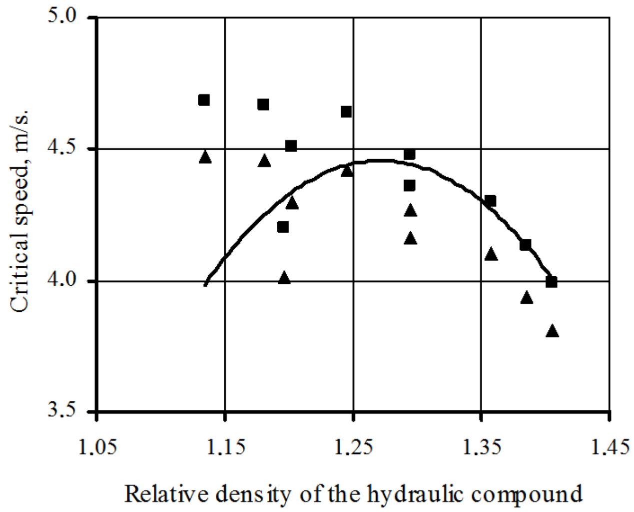
$$V_{\kappa p} = 10.1 \sqrt[3]{g v_0} \sqrt[6]{S} \sqrt[10]{\frac{D}{d}} \sqrt[4]{\frac{\omega}{\sqrt{gd}}} \sqrt[3]{\frac{D}{\Delta}}, \qquad (4)$$

where ω – hydraulic coarsening of solid particles; Δ – the absolute value of the roughness of the inner surface of the pipeline; v_0 – kinematic coefficient of viscosity of water.



3.

Figure 4 – Grain size distribution of the placer of the Eastern area Malyshevske deposit[2, 3, 12, 15, 16]



■ – Yufin's formula; ▲ – Kobernik–Voitenko formula;
— – methodology of the IGTM of the NAS of Ukraine formula (4)

Figure 5 – Comparison of the values of the critical rate of hydraulic transport obtained experimentally with theoretical values for primary placers of the Eastern section of the Malyshevske deposit depending on the relative density of the hydraulic compound [15, 16]

From Fig. 5 and Table 5 show that the results of calculations based on the proposed dependencies are in satisfactory agreement with the experimental results. Thus, the relative error of the total values is 3.07 and 1.62 %, respectively, for the Yufin and Kobernik-Voitenko formulas, and the maximum relative deviation does not exceed 4% and 7%.

Table 5 – Comparison of the results of theoretical calculations of the critical rate of hydraulic transport of primary placers of the Eastern section of the Malyshevske deposit with the data of industrial experiments [15, 16].

Relative density hydraulic compounds	The ratio of the value determined by the formula			
	IGTM NASU and for		Smoldyrov and for	
	Yufin	Kobernik-Voitenko	Yufin	Kobernik-Voitenko
1.196	1.199	1.144	0.975	0.930
1.357	1.258	1.201	1.023	0.976
1.385	1.231	1.175	1.001	0.955
1.406	1.205	1.150	0.980	0.936
1.134	1.448	1.382	1.177	1.124
1.181	1.359	1.297	1.105	1.055
1.202	1.276	1.218	1.038	0.991
1.246	1.244	1.188	1.012	0.966
1.295	1.217	1.162	0.990	0.945
1.295	1.252	1.195	1.018	0.972
Total value	1.269	1.211	1.032	0.985
Standard deviation	0.055	0.053	0.045	0.043
Coefficient of variation. %	4.35	4.35	4.35	4.35

The validity of the proposed method for determining the critical rate of hydraulic transport based on operational measurements is substantiated, and having verified the reliability of dependence (3), it is possible to begin to develop a methodology for determining the parameters of solid particles of the transported material. To do this, substituting the corresponding formulas from Table 1 into the left part of expression (3) and performing the necessary transformations, it is easy to obtain dependencies for estimating the diameters and Archimedean parameters of the particles of the solid phase of the hydraulic compound based on the values of the concentration of the hydraulic compound, hydraulic slopes of the hydraulic compound and liquid (Tab. 6).

4. Conclusions

On the right side of the formulas presented in Table 6, there are values that are either recorded by the monitoring and operational control system of hydraulic transport parameters, such as the concentration of the hydraulic mixture and its average speed, hydraulic slope of the hydraulic mixture, and fluid, or known after the start of operation of the hydraulic transport complex, such as the diameter of the pipeline and empirical coefficients used in calculation methodologies.

On the left side of the formulas given in Table 6 is the product of the diameter and the Archimedean parameter of the solid phase particles, which are raised to powers with different indicators, or the product of the Archimedean parameter of the solid phase particles, which is raised to powers, and a nonlinear two-term relative to the square root of the diameter of the solid particles.

Table 6 – Formulas for determining the parameters of solid phase particles from the hydraulic characteristics of the flow for the methods of the first group

Authorship of the methodology	Calculation formula
Karasyk	$\sqrt{Ar^5}d = 1.1\cdot 10^{-5} Fr^3 S\sqrt{\frac{D}{g}\left(\frac{i}{i_0}-\frac{2\sqrt{S}-1}{\sqrt{S}}\right)^3}$
Dmitriiev (lumpy particles)	$fAr = Fr^2\frac{\lambda}{2S}\left(\frac{i}{i_0}-1\right)$
Smoldyrov (lumpy particles)	$fAr = Fr^2\frac{\lambda}{2S}\left(\frac{i}{i_0}-1\right)$
VNIDI of reinforced concrete and Hydromechanization Project	$\left(a\sqrt{d}-\frac{b}{\sqrt{d}}\right)Ar = 0.004\frac{Fr^3}{S^{1.08}}\left(\frac{i}{i_0}-1\right)^{1.07}$
Zhyvotovsky - Halsenberg	$\left(a\sqrt{d}-\frac{b}{\sqrt{d}}\right)\sqrt{Ar} = 0.03\frac{Fr^2}{S^{0.72}}\left(\frac{i}{i_0}-1\right)^{0.71}$
Duran	$dAr = 0.0024D\left(\frac{Fr^3}{S}\left(\frac{i}{i_0}-1\right)\right)^{\frac{4}{3}}$

continuation of Table 6

Authorship of the methodology	Calculation formula
Dmitriiev (small particles)	$\left(a\sqrt{d}-\frac{b}{\sqrt{d}}\right)\sqrt{d}Ar^2=\frac{(\lambda Fr)^2\sqrt{D}}{2c_1S}\left(\frac{i}{i_0}-1\right)$
Smoldyrov (small particles)	$\left(a\sqrt{d}-\frac{b}{\sqrt{d}}\right)Ar^2=\frac{(c\lambda Fr)^3}{2c_1^4S}\left(\frac{i}{i_0}-1\right)$
Aksenov - Podkorytova	$d^{0.7}Ar=\frac{\lambda^2Fr^6}{0.003S}D^{2.7}\left(\frac{i}{i_0}-1\right)^2$

Thus, the formulas presented in Table 6 allow for the determination of the current generalized values of the parameters of the solid particles in the transported material based on data from monitoring systems and operational control of hydraulic transport parameters, taking into account the characteristics of the pipeline and the specifics of the transported material.

The dependencies under consideration can be solved in relation to the density of the transported material particles or their diameter, depending on the mining-geological or mining-technological conditions of open-pit mining, which allows to increase the reliability and efficiency of the hydraulic transport complex, due to timely changes in parameters and operating modes.

Minor changes in the values on the right side of the formulas provided in Table 6 can be compensated by adjusting the concentration of the hydraulic mixture to maintain the reliability of the hydraulic transport process. In contrast, significant changes in these parameters require adjustments to the characteristics of the alluvial material entering the pulp formation.

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ОБГРУНТУВАННЯ МОЖЛИВОСТІ ВИЗНАЧЕННЯ ПАРАМЕТРІВ МАТЕРІАЛУ, ЩО ГІДРОТРАНСПОРТУЄТЬСЯ, ЗА ДАНИМ ОПЕРАТИВНИХ ВИМІРЮВАНЬ

Семененко Є., Медведєва О., Татарко Л., Гальченко З., Сімес В., Мирзахметов С.

Анотація. Метою публікації є створення методичних основ визначення критичної швидкості гідротранспортування за величинами гідравлічного ухилу, витрати та густини гідросуміші та оцінки на основі цих даних поточних характеристик частинок твердої фази гідросуміші. Для досягнення мети використані наступні методи дослідження: узагальнення відомих методів розрахунку параметрів гідротранспорту та математична обробка даних, що отримані з даних служб механіка, енергетика, контролю вимірювального обладнання та оперативного моніторингу. Виконано історичний огляд впровадження систем оперативного контролю параметрів течії на вітчизняних гідротранспортних комплексах гірничих підприємствах. Проаналізовано технічні засоби контролю та реєстрація витрати та тиску гідросуміші, методи визначення її густини та вантажопотоку. Це дозволило обґрунтувати параметри, які можуть бути використані для досягнення мети дослідження – визначення параметрів матеріалу, що транспортується, за даним оперативних вимірювань. Результатами дослідження є встановлення залежність узагальнених значень параметрів твердих частинок матеріалу, який транспортується, від гідравлічних характеристик потоку гідросуміші, що враховує характеристики магістралі та особливості матеріалу, який транспортується. Формули, що отримані, дозволяють визначити поточні узагальнені значення параметрів твердих частинок матеріалу, що транспортується, на основі даних систем моніторингу та оперативного контролю параметрів гідротранспорту, враховуючи характеристики магістралі та особливості матеріалу, що транспортується. Ці залежності можуть бути розв'язані відносно густини частинок матеріалу, що транспортується, або їх діаметру в залежності від гірничо-геологічних або гірничо-технологічних умов ведення відкритих гірничих робіт, що дозволяє підвищити надійність та ефективність роботи гідротранспортного комплексу, за рахунок своєчасної зміни параметрів і режимів роботи. Наукова новизна результатів дослідження полягає у визначенні залежності добуток діаметру та параметру Архімеду частинок твердої фази гідросуміші від концентрації гідросуміші та її середньої швидкості, гідравлічного ухилу гідросуміші та рідини.

Ключові слова: критична швидкість гідротранспортування, параметри матеріалу, що транспортується, гідравлічний ухил гідросуміші, концентрація гідросуміші.