Study of the hydraulic parameters of the flow of solid particles in the process of hydrotransport

Askar Babaev*, *Elmira* Teshabaeva, *Axror* Obidjonov, and *Umar* Chorshanbiev

Tashkent State Transport University, Uzbekistan

Abstract. The article presents the characteristics of transferring solids together with water in the process of hydrotransport at pumping stations, that is, the influence on the distribution of kinematic and dynamic parameters of the flow of hydraulic transport, the description of the pressure dispersed flows in the process of hydrotransport with high volume concentrations and a wide range of particle sizes and densities of solid particles that form mixtures.

1 Introduction

Hydrotransport refers to the joint movement of liquid and solid particles forming two or multiphase flows with different physical and mechanical properties. Pipeline capacity research is one of the main tasks of water transportation. When expressing the nature of two-phase flow, it is important to take into account the distribution of the turbidity concentration, which is formed over the section of the pipe under the influence of gravitational forces. The considered flows have a more complex structure than the turbulent flows of homogeneous fluids in pipes. Therefore, the methods of calculating these flows are more complicated than the usual methods of hydraulic pressure flow of homogeneous fluids. The volume concentration of solid particles in dispersed systems, as well as the extreme diversity of their size and density, is one of the distinctive features of dispersed systems in high-pressure hydrotransport systems. The considered flows are more complex in their structure compared to single-phase turbulent flows of liquids in pipes [1, 2].

2 Objects and methods of research

As an object of research, hydraulic processes of dispersistems in mining and processing enterprises were obtained. The characteristics of flow hydraulic mixtures are determined, first of all, by the granulometric composition of solid particles and their hajmium concentration. The interaction of liquid and solid particles during their joint movement determines the specific head loss and flow transportability [3]. The granulometric composition of solid particles, as well as their concentration in the flow of a pressure dispersed system, affects the average flow rate and, as a result, the change in the pressure flow in the pressure system. Turbidity in the flow structure is one of the components of the cocurrent classification, which affects its kinematic properties. In many studies, the concept

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*Corresponding author: askar.babayev@mail.ru of relative turbidity was used, but when determining the hydraulic parameters of dispersed hydrotransport, the features of the flow were not taken into account [4, 5].

3 Results and discussion

Due to the extreme complexity of the processes taking place in the hydrotransport of solid materials in horizontal discharge pipes, the number of theoretical developments on the issues of distribution of the concentration of suspended solid particles by the diameter of the pipe is very small. The need to take into account the distribution of particles by depth of flow according to their large and small size when determining the calculated bonds, etc., is noted in the work, which greatly complicates the research of hydrotransport work of solid materials. The question of the distribution of the average longitudinal organizer in the transverse cross-section of flows of multi-phase media moving along the horizontal cylindrical pipe is complex and is one of the issues that have not yet been resolved. Together with the average longitudinal speed profiles and there are a number of other theoretical developments in which other parameters of hydrotransport are determined.

The non-uniform distribution of the concentration of dispersed systems complicates the solution of the differential equations of motion compared to the solution of the same problem of symmetric flows to the pipe axis. Therefore, most researchers usually limit themselves to plotting average velocities.

Table 1. Parameters of the dispersed system in the research object

Dispersion system	**Maximum**	**Minimum**	**Units of measure**
Production flow consumption	Q=90	Q=75	$\frac{m^3}{hour}$
Concentration of solid particles	Cw=70	Cw=30	%
Specific weight of mud	γ m=1.8	γ m=1.25	$\frac{T}{m^3}$
Temperature	60	5	C
Alkalinity	11	7	pH

Average diameter of particles: $d_{50\_} = 0.071\ mm$.

The existing calculation formulas obtained for different conditions of hydraulic transport in hydraulic mixtures of various solid materials are mainly empirical and semi-empirical. Different research methods and conditions of their implementation lead to conflicting results in a number of specific cases. Some of the researchers determine the value of the critical speed visually, while others determine it using the graphic-analytical method from the value of the minimum pressure loss. Different approaches in experimental determination of critical speed ultimately lead to different results, which make it difficult to apply it in theory and practice.

The minimum pressure loss in the critical velocity regime is observed in the hydrotransport of solid particles of uniform and small grain size at a concentration of less than 10-15%. With an increase in concentration, minimum losses under certain conditions indicate an increase in the values of the critical speed, and the concept of a critical speed practically loses its meaning in hydrotransport of fine-grained solid particles with a high concentration [6-9].

The critical speed is a function of a number of parameters to one degree or another and characterizes a dispersed system:

$$\vartheta_{kg} = f(d_0, \rho_s, \rho_h, D, C, V_m) \qquad (1)$$

The study of the dependence of the critical speed on the average diameter of the particles shows that the granularity of the hard particles affects the value of the speed at a certain limiting value of the particle size.

In the formed movement of the flow carrying suspended particles, we direct the z axis to the side of the observed flow:

$$\left(\frac{dp}{dz}\right)_{\kappa r} = \frac{2\tau_0}{R} \tag{2}$$

This equation physically represents the balance of forces imposed on a dispersed system element.

Denoting the average movement speed of the dispersed system by ϑ, for ϑ and based on other works, we calculate the following:

$$\tau = \rho_0 \frac{\lambda_d \vartheta_2^{\ 2}}{8} \tag{3}$$

At certain flow velocities, solid particles of a certain size can be completely suspended in a certain size called the optimal diameter, the following relationship is proposed to determine the optimal diameter according to the flow rate:

$$d_0 = \sqrt{\frac{18\mu\vartheta \frac{1}{\rho g} \frac{dp}{dz}}{g(\rho_t - \rho)}}. \tag{4}$$

From the analysis of the performed works, we know about the average velocity of the flow, at which the particles of this hydraulic size begin to be transported with the velocity of the carrier fluid.

Thus, the finite pressure gradient, $\left(\frac{dp}{dz}\right)_{\kappa r}$ should be determined from the condition of stable (without being filled with turbidity) mode of movement of dispersed systems in the pipe.

Then [7] and b. is determined as follows:

$$\frac{dp}{dz} = \frac{d_0^2 g(\rho_t - \rho) g V}{18\nu} \tag{5}$$

The study of the dependence of the critical speed on the average diameter of the particles in the conducted research shows that the granularity of solid particles affects the value of the speed up to a certain threshold value of the particle size. It is noted that the granulometric composition of solid particles should be taken into account when evaluating the amount of critical speed. Based on the above, the following calculation formulas for the critical speed based on the balance of friction and pressure forces for the considered flow are proposed:

critical velocity for a solid particle turbulent flow of uniform diameter:

$$\vartheta_{\kappa r} = \sqrt[3]{\frac{D}{\mu_d \lambda_d}} \sqrt[3]{d_i^2} \qquad (6)$$

We propose to find the critical velocity for a solid particle dispersion system with different diameters as follows:

$$\vartheta_{\kappa r} = \beta \cdot \sqrt[3]{\frac{D}{\mu_d \lambda_d}} \sqrt[3]{d_i^2} \qquad (7)$$

Here λ_d - coefficient of hydraulic friction of the dispersion system; β - coefficient that takes into account the different sizes of solid particles; d_i - solid particle diameter; D - the diameter of the pipe; $\mu_d -$ the dynamic coefficient of the dispersed system.

The coefficient, which takes into account the different sizes of solid particles, is defined as follows:

$$\beta = f(\frac{d_{10}}{d_{90}}) \qquad (8)$$

Here: d_{10} and d_{90} - and the percentage of solid particles, respectively, d_{10} and d_{90} - is determined based on the granulometric composition of solid particles [11-12].

Thus, using the known possibilities of the theory of turbid media movement in pressure pipes, computational dependences of the hydraulic parameters of the hydraulic transport of solid particles through the proposed critical speed are proposed. The coefficient of hydraulic friction in determining the critical speed of the dispersed system was determined based on experiments. For this, the consumption coefficient is determined from the formula for determining the hydraulic calculation of pipes based on experiments as follows:

$$\mu = \sqrt{\frac{1}{\frac{\lambda l}{D}}}. \qquad (9)$$

Based on the above, the determination of the coefficient of hydraulic friction in the pressure pipe is performed based on the following formula:

$$\lambda \frac{l}{D} = \frac{1}{\mu^2} \qquad (10)$$

Then we have the following relation to determine the coefficient of hydraulic friction:

$$\lambda = \frac{D}{l}\left(\frac{1}{\mu^2}\right) \tag{11}$$

Thus, a new relationship was proposed to experimentally determine the coefficient of hydraulic friction of a dispersed system (11). The analysis of this formula was carried out on the basis of specially performed experiments. The experiments were carried out in a specially designed laboratory device. Thus, a new relation (7) was proposed to determine the critical flow rate. This connection takes into account a number of parameters of hydro transport, so the method of calculating the critical speed is sufficiently accurate within wide limits of changes in hydrotransport conditions, so it can be recommended to use it in practice [5, 13].

Currently, the found mathematical relationships are used in practice to determine the main parameters of hydrotransport, in particular, they form the basis of recommendations for calculating the hydrotransport of turbid media.

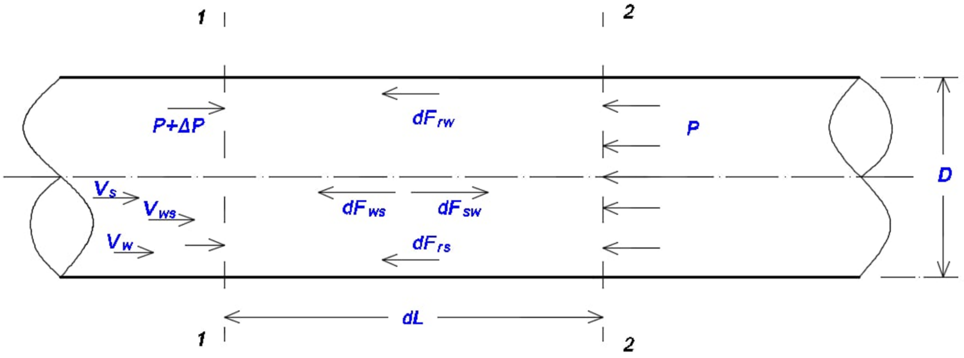

Fig. 2. Scheme of forces acting on flow elements in a dispersed system
1 - 2 – selected sections; dL – the distance between selected sections; p- pressure; Δp –dL length pressure change; v_w - the flow rate of the liquid; V- the absolute value of slip.

Let's look at the following mathematical model to evaluate the hydraulic processes occurring in the dispersed system as well as the interaction of liquid and turbid particles in the dispersed system. Considering that in a cylindrical pipe the diameter is D and the flow consumption is Q, we express the change in the flow energy depending on the difference in speeds. We select 1-1 and 2-2 cuts in the cylindrical pipe. The distance between the cuts dL - an infinitely small distance between the selected section.

We determine the forces affecting the volume of the Dispersed system between the sections under consideration. Since the pipe is in a horizontal position, we take into account the pressure force and the friction force from the forces acting on the dispersion system. We use the momentum theorem to derive the equation of motion of a dispersed system in a one-dimensional flow. We write the change in momentum of a dispersed system separately for liquid and solid particles.

We write the change in momentum for the liquid as follows:

$$m_1 d\vartheta_1 = (dP_{x1} + dT_{01})dt \tag{9}$$

We write the change of momentum for the flow of solid particles as follows:

$$m_2 d\vartheta_2 = (dP_{x2} + dT_{02})dt \tag{10}$$

dT_{01}, dT_{02} - friction forces affecting the flow of liquid and solid particles, respectively; dP_{x1}, dP_{x2} - pressure forces acting on the flow of liquid and solid particles, respectively.

For the scheme under consideration, the friction forces acting on the flow of liquid and solid particles are expressed as follows:

$$dT_{01} = dF_{rw} + dF_{ws}; \qquad dT_{02} = dF_{rs} + dF_{sw} \tag{11}$$

dF$_{rw}$ - friction on the upper wall of the pipe (from the flow of Clean Liquid), dF$_{rs}$ - this is the friction on the bottom wall of the pipe.

We express the effect of pressure forces as follows:

$$dP_{x1} = (p + dp)\omega_1 + p\omega_1 \ ; \qquad dP_{x2} = (p + dp)\omega_2 + p\omega_2; \tag{12}$$

From the equality of Normal and tangential forces, we get the following expression:

$$\begin{gathered} \rho_1 Q_1 d\vartheta_1 - (P + dP)\omega_1 + P\omega_1 + dF_{rw} + dF_{ws} = 0, \\ \rho_2 Q_2 d\vartheta_2 - (P + dP)\omega_2 + P\omega_2 + dF_{rw} + dF_{ws} = 0. \end{gathered} \tag{13}$$

The Q_1 and Q_2 in the above equation are as follows:

Liquid consumption $Q_1 = \omega_1 \vartheta_1$ solid particle consumption $Q_2 = \omega_2 \vartheta_2$

As the diameter of dispersion systems increases, the curvature of the turbidity concentration distribution increases. As a result of the calculations, it was also observed that the distribution of turbidity concentration at different ratios of *d$_i$/d$_o$* intersects around one point. This condition corresponds to the average amount of turbidity concentration. By determining the concentration distribution of each fraction, the concentration of the total turbidity amount is determined as follows [8-15].

Based on the values obtained from the experiments, the pressure characteristic of the turbidity flow *H=f (Q)* was constructed. We can see how it changes when solid particles are transferred to the pump's operating mode from the graph (Fig. 3).

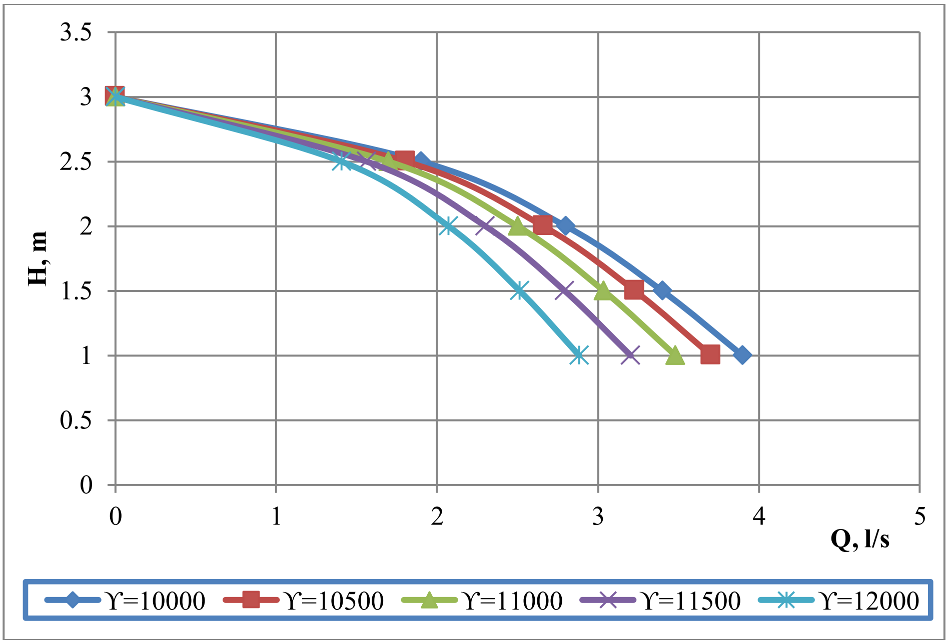

Fig. 3. Relationship between dispersion system consumption and effort

4 Conclusions

As a result of the conducted research, it can be concluded that muddy particles move together with water in the pressure pipes of pumping stations, and they should be taken into account when calculating hydrotransport parameters. Using the proposed method to represent the turbidity distribution over the pipe cross-section, it is possible to calculate the turbidity concentration distribution taking into account the composition of the turbidity particles. For the state of the dispersion system movement in the turbulent regime, using the known possibilities of the theory of solid particle flow in pressure pipes, the dependences for the calculation of the hydraulic parameters of the hydraulic transport of turbidity in the proposed pipe systems were proposed. During the conducted studies, the expression for the critical speed was comparatively evaluated on the basis of experience and on the basis of data obtained by other authors.

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