HYDROTRANSPORT AND HYDRAULIC CONSTRUCTION AND A UNIVERSAL METHOD OF CALCULATING HEAD LOSS

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The construction of water-development projects is traditionally associated with use of hydraulicking for both the raising of fundamental structures, and in organizing work production. The following apply to the set of operations performed by means of hydraulicking: the filling of dams and dikes, channelization, the filling of lands for industrial bases, the preparation of inert materials for concreting, etc. The excavation of quarries, when they are located at a significant distance from the point where the product is to be used with special requirements for preservation of the environment, as well as the conditioning of inert fillers to the optimum purity and gradation, is introduced as a special problem. Rigid requirements for the effectiveness of hydrotransport are set forth for the solution of these problems under the new economic conditions. Here, special attention is focused on motion regimes in terms of consistency and average velocity, and a new approach to estimation of the wear rate of the walls of the pipeline is required. The applicability of hydrotransport for hydraulic construction (in contrast to other branches: the mining of mineral resources, the removal of wastes from concentrating mills, ash handling, etc.) is, at the present time, associated with its rational literate use, which assumes the existence of modern technology and a good supply of quality equipment.

Codifying domestic and foreign experience with the use of hydrotransport in hydraulic construction, which was expressed in the “Technical Specifications for the Design of Pressurized Hydraulic Transport of Soil” – Institutional Construction Regulation 02-66/Moscow Electrical Engineering Institute of Communication (Энергия, Ленинград (1967)), we stated the following goal: to develop a universal method of determining head loss.

Using the results of analysis of the kinematic structure of the flow and its integral dynamic characteristics for this purpose, i.e., for a generalized approach to the motion of dual-phase systems, it was necessary to find and determine the key link in the relations between these parameters. This link was found to be the relation between the viscosity and the pattern of the velocity distribution over the free cross-sectional area of the flow. As a physical property of a continuously deformable medium, viscosity can understand to be the resistance of the layers to relative shear, and in that case, to develop internal tangential stresses.

The customary approach to determination of viscosity always presumes the use of some hypotheses, as a result of which the number of unknowns exceeds the number of knowns. An accumulation of assumptions and quantities that differ in terms of quality therefore occurs.

The approach using partial solution of a Nova-Stokes form of differential equation of motion in terms of variable kinematic viscosity is presented to us as productive and free of the indicated drawbacks. This solution is derived on the assumption that the velocity derivatives at fixed points of the free cross-sectional area are constant and known quantities.

We reduced the equations of motion to dimensionless form by introducing the following relative quantities:

\[ \rho_0 = \frac{\rho}{\rho_m}, \quad U_0 = \frac{U}{U_m}, \quad v_0 = \frac{v}{v_m}, \]

where \( \rho_m \) is the radius of the pipe, and \( U_m \) is the maximum velocity on the dynamic axis of the flow. The generalized equation for the pressurized flow assumes the form

\[
-\frac{1}{\frac{1}{\text{Re}_m}} \frac{d}{d\rho_0} \left( \frac{U_0^2}{2} \right) \text{Re}_m + \frac{\partial v_0}{\partial \rho_0} \left( \frac{dU_0}{d\rho_0} \right) + v_0 \frac{d^2U_0}{d\rho_0},
\]

where $Re_m = \frac{U_m \rho_m}{\nu_m}$, $Fr_m = \frac{U_m^2 \rho_m g}{\nu_m}$, and $i$ is the hydraulic gradient.

The relation between viscosity $\nu_0$ and the velocity derivatives $U'_0$ and $U''_0$ is obvious in Eq. (1). The second term of the right side of (1) is usually set equal to zero for water, but it may assume major significance for a slurry. Knowing the velocity distribution over the free cross-sectional area of the flow, consequently, it is possible to obtain information on the pattern of the viscosity distribution. This approach was selected, proceeding on the assumption that the viscosity for water and a slurry differ significantly, especially for the lower portion of the pipe, where the solid particles are concentrated (travel). The solution is obtained in the following form:

$$
\nu_0 = \frac{iRe_m}{Fr_m} \frac{1}{U'_0} + \frac{Re_m (U'_0/2)}{U''_0} - \exp \left( \frac{\rho_0 U''_0}{U'_0} \right).
$$

(2)

Using the structure of expression (2) for viscosity, this approach made it possible to organize and conduct special experiments, and also, proceeding in accordance with traditional means, to obtain expressions for the field of tangential stresses and the velocity field, and to perform all conventional operations with these expressions.

The structure of relationship (2), however, makes it possible to determine experimentally only the variation in viscosity over the cross section, comparing the individual points, and also to compare the characteristics of similar points for the water and slurry. This is associated with the fact that it is currently impossible to organize directly an experiment for viscosity determination without some kind of hypothesis, not to mention for such a complex mechanical system, which is a dual-phase flow of slurry. A means of determining the pattern of viscosity variation without determining its magnitude is therefore used. The variation in viscosity was determined by superposing frequency-energy spectra of pressure pulsations for a series of points of realization located over the entire free cross-sectional area of the flow.

The experiments were conducted on a conventional pressure installation using apparatus manufactured by the “Bryul and Kerr,” “Diza,” and “KhBM” companies for water and slurries of different consistencies and with different transported solid particles: coal $\gamma_s = 1.37$ tons/m$^3$, sand of a different gradation $\gamma_s = 2.65$ tons/m$^3$, and iron-ore concentrate $\gamma_s = 4.80$ tons/m$^3$. There were a total of 336 tests and 1680 realizations. Values of the dynamic viscosity coefficient were used in the processing so as to account for the density distribution and eliminate the mass component of viscosity for the slurry. The increase in viscosity was determined from the relationship

$$
\mu' = \frac{\mu_{n+1} - \mu_n}{\mu_n} = 1 - \frac{E_{n+1}}{E_n} = 1 - \frac{1}{\exp(0,1 \cdot \delta dB)},
$$

(3)

where $\delta dB$ is the result of superposition of one frequency-energy spectrum on the other. This superposition makes it possible to exclude the instrument base energy; $\mu_n$ and $\mu_{n+1}$ are the viscosities at two points, and $E_n$ and $E_{n+1}$ are the pulsation energies at the corresponding points.

The experiments (Fig. 1) exposed rather similar relationships for the viscosity derivatives for water. For the slurry, the character of the relationship is in agreement only for the upper portion of the flow, and the relationship assumes a completely different character for the lower portion, where primarily solid particles travel.

The results obtained made it possible to draw the following conclusions:

1) in a dual-phase flow, there is a special zone in the lower fourth of the pipe where the viscosity differs markedly from that at other points. In many respects, this zone can most likely answer questions concerning the suspension and transport of heavy solid particles in slurries with their high saturation. Work is continuing in this direction; and,

2) information on the kinematic structure of a suspension-bearing flow and, particularly, in contrast to a flow of homogeneous liquid, is concentrated in the lower portion of the flow, i.e., below the dynamic axis. This situation was assumed in the development of a universal method of calculating head loss.

Since there is an obvious interrelation between viscosity and the velocity field, this analogy was applied in processing the velocity-distribution curve: the upper part of the flow exhibits similar characteristics for water and slurry, and the lower part markedly different characteristics. All velocity curves for different slurries, which were available to us in cylindrical coordinates normalized with respect to the position of the maximum velocity, were processed in conformity with these positions. This major study was undertaken by Candidate of Technical Sciences L. N. Gusak [1, 2].