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Extension of Method of Computation of Polydisperse Materials Hydraulic Transportation Parameters

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Abstract

The universal method of computation of specific hydraulic slope and critical rate during hydraulic transportation of polydisperse solid materials is suggested. This method enables to raise accuracy in calculations due to consideration of dependence of additional specific hydraulic slope caused by the presence of fine particles in hydraulic mixture and critical rate of pulp flow upon factor of hydraulic resistance.

Keywords: *hydraulic transport, critical rate, specific hydraulic slope, polydisperse material, factor of hydraulic resistance*

Introduction

Pipeline transportation is widely spread in mining, metallurgical, building, chemical and other industries. It is widely used in agriculture as well due to its high efficiency, continuity of shifting of cargo and many other advantages. Furthermore, pipeline transportation is an integral part of most technological processes. Meeting the modern requirements upon ecological safety during hydraulic transportation of mineral raw materials at mining plants means the smallest volume of water consumption, while the economic factors force to search the ways to lower energy intensity during hydrotransportation. Energy intensity of operating modes chosen in hydraulic transport plants depends directly upon accuracy in computations of hydrotransportation parameters. There is a plenty of methods of such computations [1-6]. However, the application of most of them is limited by conditions of experiments on the basis of which they were developed. A.E. Smoldyrev's method is one of the most widely-used methods in CIS countries. It is easy in application and allows considering polydispersity of transport material. However, the key drawback of this method is a substantial interval in change of empirical constants, for the values of which there are no specific recommendations. This inaccuracy can lead to relative error up to 50 % when calculating the pressure loss determined by the presence of particles of 0.16 mm up to 2 mm size. Besides, this method does not permit considering the change in hydraulic resistance of main pipe and critical rate as in case of application of polyethylene and polyvinylchloride pipes [7] and when using hydraulically-active substances [8].

The purpose of work presented is to improve A.E.Smoldyrev's method in the area of computation of specific hydraulic slope and critical rate of hydrotransportation.

While choosing operation modes of hydrotransport plants for solid materials transport, the specific hydraulic slope (specific loss of pressure) and critical rate of hydrotransportation are important calculated parameters that enable to estimate the energy intensity of hydrotransportation. For computation of these parameters during hydrotransportation of polydisperse materials of similar density which is not more than 2650 kg/m^3, A.E. Smoldyrev [2, 3] recommends the following equations:

$$i = \frac{\lambda V^2}{2gD} + \alpha \left(R_1 \frac{\lambda V^2}{2gD} + c_0 R_2 \frac{w}{V} \sqrt{\frac{D}{d_{av}}} + fR_3 \right) S ; \quad \text{(Eq. 1)}$$

$$V_{av} = c_1 \sqrt{gD} \quad \sqrt[3]{\alpha S \frac{wR_2}{\sqrt{d_{av}}}} + c_2 \sqrt{fgDR_3 \alpha S} ; \quad \text{(Eq.2)}$$

$$\alpha = \frac{Ar(1 - S_1)}{1 + ArS_1}; \qquad Ar = \frac{\rho_s - \rho_0}{\rho_0};$$

$$w = w_0 (1 - S_1)^n ; \qquad w_0 = Ar \left(\frac{d_{av}}{1,47} + \frac{t}{52} - 0,5 \right);$$

$$n = 5 - \lg \left(\frac{d_{av} w_0}{v_0} \right); \qquad d_{av} = \sum d_i q_i ,$$

where

i – the specific hydraulic slope during hydromixture flow, m w.g./m ;

c_0 – the dimensionless empirical constant changing from 0.3 up to 0.45;

c_1 – the dimensionless empirical constant changing from 1.8 up to 2.1;

c_2 –the dimensionless empirical constant changing from 6.0 up to 7.0;

V – the average calculated rate of pulp flow, m/second;

V_{cr} – the critical rate of hydrotransportation, m/second;

D – the pipeline diameter, m;

d_{av}– the average weighted diameter of fine fraction particles, m;

g – the gravitational acceleration , m/second^2;

w – the speed of hindered sedimentation of fine fraction particles, m/second;

w_0 - the speed of free sedimentation of fine fraction particles, m/second;

t – the temperature of pulp, °C;

d_i - the average size of *i*-fraction in the structure of fine particles, m;

q_i - the mass fraction of *i*-fraction in the structure of fine particles, fr.unit;

R_1, R_2, R_3 - the mass fractions of thin (not less than 0.16 mm), fine (0.16 up to 2 mm) and lumpy fractions (0.16 up to 2 mm) in transport material, respectively;

S – the volume concentration of pulp;

f – the generalized factor of friction of particles on the bottom pipe wall;

Ar – Archimedes's parameter of transportable material;

ρ_s – the density of transportable material, kg/m^3;

ρ_o– the density of water, kg/m^3;

v_0 – the kinematic factor of water viscosity, m^2/second.

Equation (1) hypothesizes validity of superposition of specific hydraulic slopes determined by the presence of particles of various sizes in the pulp that does not contradict the principles of hydraulics and hydromechanics of heterogeneous environments. However, in the computation of critical rate, the use of superposition principle causes well-grounded objections.

The critical rate in Equation (2) is expressed by sum of two summands. The first sumand represents the critical rate in transportation of fine-sized particles, the second one – the critical rate in transportation of lump-sized particles. However, strict mathematical calculations lead to the formula for computation of critical rate of polydisperse materials hydrotransportation. These calculations differ from Equation (2).

As a part of A.E.Smoldyrev's method [2, 3], M.A.Velikanov's principle forms the basis of critical rate determination that can be expressed as follows [1-3]:

$$\frac{i_{cr} - i_{cr}^0}{i_{cr}} = K , \qquad \text{(Eq. 3)}$$

where

i_{cr} – the specific hydraulic slope during pulp flow with critical rate, m w.g./m ;

i_{cr}^0 – the specific hydraulic slope during water flow with critical rate, m w.g./m ;

K – M.A.Velikanov's constant [1].

It is easy to verify that, having substituted Equation (1) in Equation (3), we obtain nonlinear equation as regard to critical rate. This equation cannot be solved analytically irrespective of chosen dependence type of hydraulic resistance factor upon Reynolds's criterion. Equation (2) cannot be obtained from equation considered even upon condition that hydraulic resistance factor does not depend upon Reynolds's criterion, since the sum of relevant summands will be in cubic root. Thus A.E. Smoldyrev changed the type of functional dependence, neglected Reynolds's criterion effect upon factor of hydraulic resistance and tried to consider the effect of all these factors by means of set of three experimental coefficients with a wide range of possible values. Obviously, it was done to simplify the computations by his method because at the time of this method creating the technological level of computer engineering facilities left much to be desired.

To develop A.E. Smoldyrev's method, the authors of this paper have analyzed experimental data on hydrotransportation of various materials published in scientific literature [1-4]. Analysis of A.E. Smoldyrev's experimental data and of recommendations concerning the choice of value C_0 [2, 4] shows that his method does not provide explanation of dependence of empirical factor C_0 upon the pulp rate and pipeline diameter, i.e. upon Reynolds's criterion. Besides, the results of research presented in papers [1, 6] mean that in the transportation of particles of 0.2 up to 2 mm size, the value of additional specific hydraulic slope is determined by the ratio of hydraulic size of particles to amplitude of vertical turbulent pulsations, which is proportional to hydraulic resistance factor [5, 6]. Specification of factor C_0 value according to experimental data by A.E. Smoldyrev [2, 4] enabled to determine the dependence of value C_0 upon hydraulic resistance factor and to suggest a new formula to calculate a specific hydraulic slope during flow of pulps containing polydisperse materials [8],

$$i = \frac{\lambda V^2}{2gD} + \alpha\left(R_1 \frac{\lambda V^2}{2gD} + \frac{0.71}{\sqrt{\lambda}} R_2 \frac{w}{V}\sqrt{\frac{D}{d_{av}}} + fR_3\right)S, \qquad \text{(Eq. 4)}$$

In Equation (4), the value of empirical factor practically does not depend upon granulometric structure of material and pulp rate. Due to this, the difference between maximum and minimum absolute values of empirical constant decreased by 14 times, and, if to consider above-mentioned values in view of average values, the difference decreased by 1,75 times.

With regard to dependence of additional specific hydraulic slope determined by the presence of fine particles in hydromixture upon hydraulic resistance factor, the formula for calculation of critical rate of hydrotransportation has been changed. Having substituted suggested expressions for specific hydraulic slope (4) in Equation (3) and collected similar terms, we obtain a cubic equation in dimensionless number, which is physically the square root of specific hydraulic slope. Solution of this equation by Kordan's method [9] results in two formulas applied to calculate physically real roots. With the application of these solutions and power law dependence of hydraulic resistance factor upon Reynolds's criterion it is easy to obtain analytical dependence for calculation of critical rate of hydrotransportation of polydisperse materials.

Under the absence of thin-class particles

$$V_{cr} = \begin{cases} \sqrt[2-n]{\left(\dfrac{0{,}71\beta w}{\sqrt{gd_{av}}}\right)^{2/3} \dfrac{gD^{1+n}}{m\nu^n}} \left(\sqrt[3]{1+\sqrt{1-q}} + \sqrt[3]{1-\sqrt{1-q}}\right)^{\frac{2}{2-n}}, & q \le 1 \\ \sqrt[2-n]{2{,}67 f\beta \dfrac{gD^{1+n}}{m\nu^n}} \cos^{\frac{2}{2-n}}\left(\dfrac{1}{3}\arccos\left(\dfrac{1}{\sqrt{q}}\right)\right), & 1 \le q \end{cases}; \qquad \text{(Eq. 5)}$$

$$\beta = \frac{\alpha(1 - SR_1)}{\chi - \alpha SR_1};\; q = \frac{(\chi - \alpha SR_1) g d_{av} f^3 R_3^3}{1{,}704\alpha SR_1 w^2 R_1 R_2^2}; \qquad \chi = \frac{K}{1-K}; \qquad \lambda = \frac{m\nu^n}{D^n V^n},$$

where n, m - the empirical factors of power law dependence of hydraulic resistance factor λ upon Reynolds's criterion; ν – the kinematic factor of water viscosity.

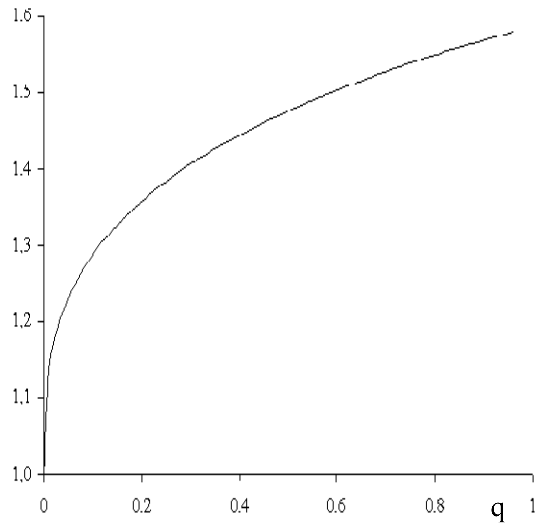

Figure 1. Dependence of multiplier that considers the effect of thin and fine-sized particles upon parameter q at $1 \le q$

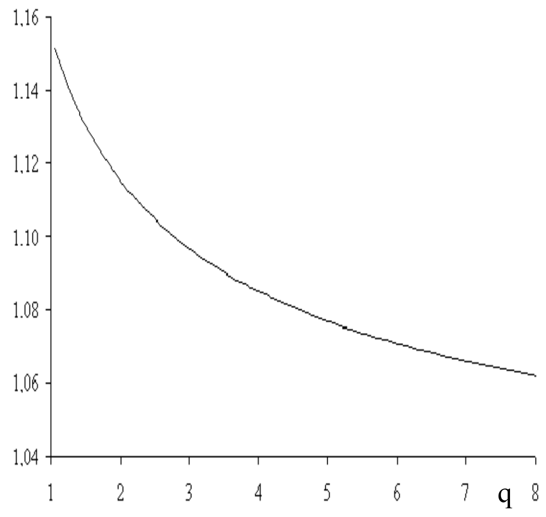

Figure 2. Dependence of multiplier that considers the effect of fine and thin-sized particles upon parameter q at $q \le 1$

(R_1=0) in transportable material, parameter q is calculated as follows:

$$q = \frac{\chi g d_{av} f^3 R_3^3}{1{,}704 A r w^2 R_2^2}, \qquad \text{(Eq. 6)}$$

From Equation (5) it is clear that when calculating the critical rate of hydrotransportation of polydisperse materials, the principle of superposition of critical rates of relevant size classes cannot be applied. In this case, depending on value q, the formula for calculation of critical rate can be changed as that corresponding to the presence of particles of either only lumpy ($1 \le q$) or only fine ($q \le 1$) size classes where the effect of particles of other size classes is considered by last multiplier (Figures 1, 2).

The application of Equations (4) and (5) as well as (1) and (2) enables to perform analytical research of operating modes of hydrotransportation systems and substantiate the effective rate and concentration of pulp. However, unlike Equations (1) and (2), dependence of critical rate of pulp flow upon hydraulic resistance factor is considered in Equations (4) and (5). This enables not only to raise accuracy in computations of hydrotransportation parameters but also to expand the area of application of computation method, in particular, for hydraulically-active substances.

The application of Equations (4) - (6) is complicated by the fact that available data for determination of parameter χ, which describes the ratio of main and additional specific hydraulic slope in a critical mode of flow, are rather contradictory [1, 4, 10]. Solution of this problem requires additional investigation and can be regarded as the area of further scientific search.

Summary

The method in the area of computation of specific hydraulic slope and critical rate in the hydrotransportation of polydisperse solid materials is advanced. This method enables to improve accuracy in computations due to consideration of dependence of additional specific hydraulic slope determined by the presence of fine particles in hydromixture, and of critical rate of pulp flow upon the hydraulic resistance factor.

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Усовершенствование метода расчета параметров гидротранспорта полидисперсных материалов

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Предложен универсальный метод расчета гидравлического уклона и критической скорости при гидротранспорте полидисперсных твердых материалов, позволяющий повысить точность расчетов за счет учета зависимости дополнительного гидравлического уклона, обусловленного присутствием в гидросмеси мелких частиц, и критической скорости течения пульпы от коэффициента гидравлического сопротивления.