Study of the motion of modified solid particles in hydratransport systems

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Abstract. The article examines the movement of solid particles, the hydraulic calculations of pipes in the process of movement, the classification of reducing the impact of solid particles on hydrotransport systems. The effect of solid particle magnification on flow rate, pressure loss, speed reduction as a result of the effect of internal friction forces of solid particles, friction in the flow of solid particle hydroarations, pressure loss as a result of the impact of Resistance Forces, internal corrosion process observed in the pipe, increased energy consumption were analyzed using the example of hydrotransport systems Recommendations have been made to solve the problems of speed reduction and pressure loss due to the movement of solid particles in the hydroaration flow through the modification method. The prior and subsequent movement of solid particles in a pipe modification is shown through comparison graphs. Information about the gossipol Tar selected as a modifier is provided.

1 Introduction

In mining and construction processes, there are various ways of continuous supply of solid raw materials, the most convenient method is hydrotransport, in the process of hydrotransport, solid raw materials are transferred to a state of hydroaeration, studying the effect of solid particles in the transferred hydroaeration on the flow is the main goal of the work.

The result of the research carried out showed that increasing the economic efficiency of hydrotransport is achieved by reducing the specific consumption of water contained in hydroaration and increasing the concentration of solid particles [1]. In the hydrotransport of hydroarations, under the influence of the movement of solid particles, there is an increase in friction and rapid failure of technological systems and machines, in addition, an increase in the amount of solid particles in the hydroaration flow leads to an increase in hydraulic resistance. As a result, energy consumption and pressure loss increase in the hydrotransport process. Through the modification of solid particles, hydrotransport systems are the task of the work to reduce the ductility of technological systems and machines, hydraulic resistances, energy consumption and pressure loss.

The existing calculated dependencies of the main parameters of hydrotransport are based on the law of turbulent transfer of the solid phase with the flow of liquid, and the

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effectiveness of the process has been considered by many scientists in connection with the effect on the turbulent properties of solid particles [2-11].

For small sized particles (d_0<1 mm) and large particles, the quantitative values of hydraulic resistance increase vary [3]. Pressure loss increases due to large particles (d_0>1,5 mm) [20]. When solid particles of different sizes (heterogeneous) move in the flow, additional vortices appear around it due to various physical characteristics of the hydroaration flow, therefore, at the expense of which turbulent changes are observed and energy consumption increases.

Through the modification of solid particles, the effect it gives to flow, hydrotransport systems during its movement is studied, changes in friction, edirability, pressure loss, energy consumption and flow rate are compared. The effect of the action of modified solid particles in the hydroaration current on the flow regime is calculated.

Taking into account the above, this article provides information on the influence of the method of modification of the waste of the metallurgical industry on hydrotransport [4, 5].

2 Object and method of research

The object of research is the waste of a metallurgical plant, and as a modifier we used gossypol tar, a residue from the production of an oil plant.

When studying the movement of modified solid particles in the research work, the parameter indicators specified in “State Standard 32388-2013 Pipeline technology, Standards and methods for calculating durability, vibration and seismic effects” are taken into account. The Nave Stokes method is used to calculate the effect of modified solid particle movement on hydraulic resistance, pressure loss, and energy consumption. The Nave-Stokes method has been widely used to determine the movement of solid particles, viscosity, and flow rate in hydromixed flow. The grapho-analytical method was used to determine the deformation caused by the movement of solid particles to hydrotransport systems, whether particles obey Archimedes' law in a suspended state and are in a state of tension [4, 5, 11, 12].

3 Results and discussion

During modified solid particle motion, the phase velocity is practically balanced at high flow rates $v_m>1.5v_{kr}$ in hydraulic transport systems used in ore mining and processing plants. As a result of the analysis of the forces acting on the solid particles in the fluid flow, the relative velocity formula was determined as follows [6].

$$v = v_m - v_s = \sqrt{\frac{\pi*d*g}{6*\psi_r*\rho_l} * \left(\frac{\rho_s-\rho_l}{\rho_l}\right) - (k' - v_m)^2} \qquad (1)$$

Here v_m – the average flow rate of the hydraulic mixture, m/s; v_s – solid particle speed, m/s; ψ_r – coefficient of resistance of hydraulic mixture flow; d – diameter of solid particles, m; ρ_s, ρ_h - density of solid particles and hydraulic mixture in flow, kg/m^3, respectively; (where the density of hydromixture is not equal to the density of water ρ_w, because the density of hydromixtures with water differs due to the composition of solid particles); $k'=\frac{U_m}{v_m}$=0.05-0.08 – coefficient of proportionality; U_m – The component of the average vertical velocity of the hydraulic mixture flow. It was observed that the density of solid particles, their distribution along the pipe, their relative velocities, and their resistance affect the dynamics of the flow.

As a result of the modification, the interfacial friction coefficient of the solid particles decreases as the velocity of the solid particles approaches the velocity of the fluid. This process was determined by the following formula:

$$\frac{\rho_s-\rho_w}{\rho_w} > \frac{\rho_s-\rho_h}{\rho_h} \quad (2)$$

Here: ρ_w – Water density, kg/m^3.

An important parameter that affects the value of the interphase speed is the solid particle shape coefficient - b, which determines the resistance coefficient of the hydromix to the value of ψ_r.

$$b = \frac{w_p}{f_{min}-l_{min}} \quad (3)$$

here w_p – solid particle size, m^3; f_{min} – minimum surface area of a solid particle, m^2; l_{min} - the minimum length of a solid particle, m.

As a result of the modification of the solid particles, the hydrodynamic effect on the inner surface of the pipe decreased, but the overall mechanical friction between the solid particles increased. Taking this into account, the following formula was used for the relative velocity of the solid phase:

$$v = \sqrt{\frac{\pi * d * g}{6 * \psi_r * \rho_l} * \frac{\rho_s}{\rho_l} * \left(\frac{\rho_s-\rho_l}{\rho_l}\right) + (1 - f * k) - (k' * v_m)^2} \quad (4)$$

Here f=0.1 – 0.6 coefficient of interlayer friction, k - coefficient taking into account the probability of collision of solid particles [8, 13].

The relative speed of solid particles determines the nature of their movement in the flow, therefore its value affects the value of hydraulic resistance and is determined by the average speed values.

$$v = \overline{v} + v' \quad (5)$$

Here v- relative speed, $\overline{v} \geq 0$ – average value of relative velocity, $v' \neq 0$ – pulsation component of relative velocity.

Accordingly, the force of interaction between particles and the fluid flowing around them was expressed as a sum of forces:

$$p = \overline{p} + p' \quad (6)$$

The movement of solid particles can be determined from formulas (4) and (5), the speed of the movement of solid particles decreases as the friction increases. Compared with the movement of modified solid particles, experimental results on the increase in speed of modified solid particles under the influence of friction force were obtained (Fig. 1).

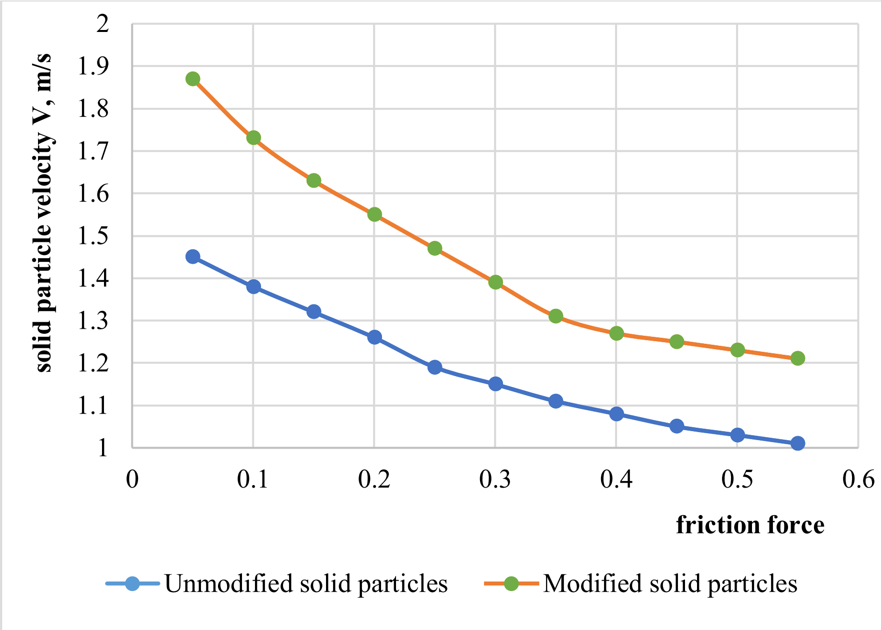


Fig 1. Reduction of the speed of solid particles under the influence of frictional forces

The dynamic balance equation between the external forces related to the volume of the hydraulic mixture and the forces of resistance to movement balancing them in the x,y coordinate system (x - the coordinate corresponding to the direction of movement, y - the vertical coordinate of the flow) has the following form:

$$p = p_w + p_{min} + p_{max} \tag{7}$$

Here: $p = \pi r^2 L \frac{dp}{dx}-$ external acting force; $\frac{dp}{dx}$ - pressure gradient in the direction of movement, $p_w = 2\pi r L \tau_w$- resistance force due to turbulent motion, τ_w - deformation stress on the pipeline wall caused by the turbulent flow of the hydraulic mixture; $p_{min} = 2\pi r L \tau_{min}$ – resistance force due to the presence of small particles in the flow of the hydraulic mixture, p_{max}- resistance force caused by the flow of large particles around the liquid, this value was determined by the following formula:

$$p_{max} = gL \int_0^D c_v\,(\rho_s - \rho_w)\frac{d_0'}{d_s} D\left[1 - \left(1 - \frac{y}{r}\right)^2\right]^{0.5} dy \tag{8}$$

For high concentration hydraulic mixture of different fractions, the resistance forces are greater due to the friction of the supersaturated layer of the hydraulic mixture with respect to the adjacent flow layers, i.e.:

$$p = p_w + p_{min} + p_{max} + p_b \tag{9}$$

Here: $p_b = 0.9 g f c_b(\rho_s - \rho_w)\left(\frac{S_b}{S}\right) L\pi r^2$ - resistance of the sedimentary layer to the movement of modified solid particles, S_b – cross sectional surface of the sedimentary layer, S- cross sectional surface of hydraulic mixture flow, c_b - volume concentration of solid particles in the settling layer of the flow, f - coefficient of friction of solid particles on the walls of the pipe [5, 6].

From the dynamic balance equation, the pressure loss of the hydraulic mixture flow was determined as follows:

$$i_h = \frac{1}{\pi r^2 \rho h g}\frac{dp}{dx} = \frac{p}{\pi r^2 L g \rho h} \qquad (10)$$

The dependence formulas of the resistance forces generated during the movement of solid particles and the pressure loss under the influence of these forces were considered above, from the experimental solutions of these formulas it was found that the density of the hydraulic mixture along the length of the pipe, the pressure loss increases as the resistance force increases due to the existing pressure of the pipe surface and flow (Fig. 2).

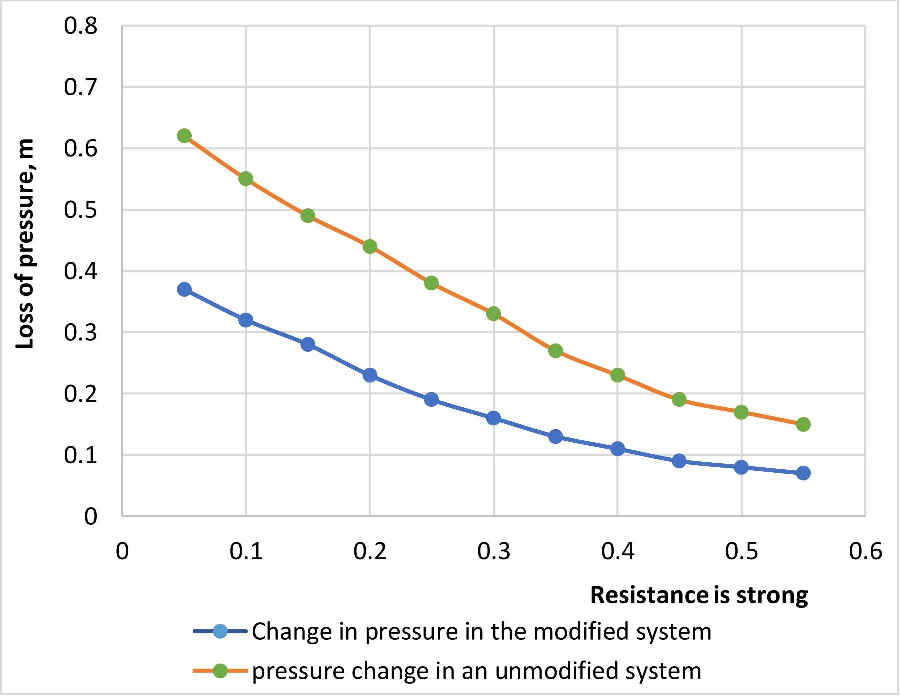
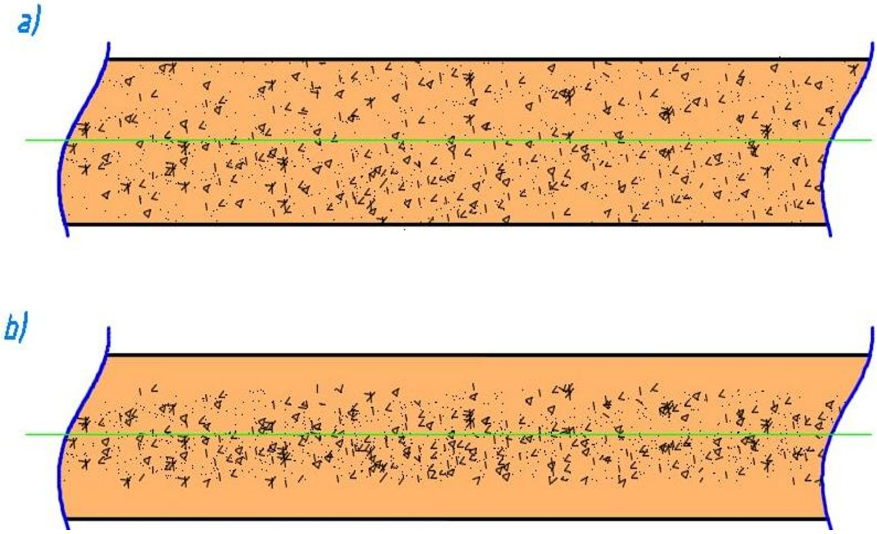


Fig. 2. Pressure loss due to resistance

It was found that during the movement of solid particles, they have a negative effect on the flow speed, pressure, energy consumption and the internal walls of the pipe. As a result of the modification, the flow rate (Fig. 1) increased by reducing the effect of internal friction forces, and the pressure loss due to resistance forces (Fig. 2) decreased.

It was observed that the solid particles move in a dispersed state in the pipe during the flow, which causes a dynamic stress on the inner surface of the pipe, which causes a decrease in the service life of the pipe [14-15].

By modifying solid particles, the phenomenon of cohesion - (lat. cohaesus — stuck, joined) occurs in the pipe. Due to the increase in the mutual viscosity of the modified solid particles, they move away from the pipe wall and the flow rate increases, it was observed that the effect of friction and resistance forces decreases. The picture below shows the state of solid particles before and after modification (Fig. 3).



a) movement of unmodified solid particles in the pipe,
b) movement of modified solid particles in the pipe

Fig 3. Movement of solid particles in a pipe

After modification of solid particles, it was found that the energy consumption decreased due to the increase in speed in the hydromix flow, the decrease in pressure loss, and the increase in the service life due to the decrease in friction in hydrotransport systems [16-24].

4 Conclusions

Problems such as friction of solid particles on internal surfaces in hydrotransport systems, reduction of flow speed as a result of irregular movement in turbulent regime, pressure loss due to resistance forces, increase of energy consumption due to sedimentation of solid particles, as a result, increase of flow speed in hydrotransport systems, reduction of pressure and energy loss, work productivity and the main tasks were to increase the efficiency and extend the period of use. The formula (2) for determining the speed of the modified solid particles in the hydromix flow approaches the liquid speed during the modification process, the formula for determining the pressure loss of the hydromix flow from the dynamic balance equation (10) and the speed and pressure after modification graphs of changes were created. As a result, it was shown that modification of the movement of solid particles in hydrotransport systems plays a key role in improving the efficiency of the hydrotransport process and solving process problems.

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