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THEORETICAL ANALYSIS OF HYDROMIXTURE TRANSPORT

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Abstract: This paper presents theoretical considerations and working parameters analyzes of hydrotransport during unstable flow. The variable flow of hydraulic mixture in installations causes unsteady operation and pipes spraying, pump damage, obturation in various sections of the pipeline, reduced capacity as well as higher operating costs. Using mathematical equations presented in this paper, such parameters of the hydraulic mixture, hydrotransport installation and control devices can be determined which protect system from possible clogging. Considering the fact that critical speed of hydraulic mixture depends on transported material grain size, mixture volume mass, diameter of pipeline and specific gravity of solid phase, it is possible to accurately analyze obturation in hydrotransport installations depending on those parameters. In order to prevent hydraulic impacts in hydrotransport installation pipelines, which value can be determined mathematically, it is necessary to adjust installation to hydromixture parameters and pump, or vice versa.

Keywords: hydrotransport, pump, congestion, hydraulic impact, inertia pressure

1 INTRODUCTION

The hydrotransport process in mining is widely applied, both in underground and surface exploitation, for the transfer of grinded ore and concentrates, flotation tailings, sand, coal

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and other materials (Khan et al., 1987; Knezevic et al., 1996; Ristic, 1992; Heywood and Alderman, 2003).

The reasons for such widespread use lie in the fact that it is a very favorable type of transport from the aspect of environmental protection moreover there is a possibility of automation, which today can be achieved with the advancement of technology and, ultimately, high safety during operation. However, when organizing this type of material transport, the most common problem is how to eliminate changes in mix density and flow velocity (Avksentiev and Makharatkin, 2017; Adiansyah et al., 2015; Kumar et al., 2015).

Namely, the density of the mixture and the flow velocity directly influence the occurrence of pipe blockage and hydraulic impacts in the installation. These phenomena occur precisely at the beginning and end of the process, as well as at the time of seemingly steady flow of the mixture (Messa et al., 2014; Ravelet et al., 2013; Zouaoui et al., 2016).

The main reasons for unstable mixture transportation occurrence and blockage in the installation are:

- inappropriate density of hydromixture in relation to the installation parameters,

-transportation through the pipes of materials whose grains have a diameter greater than allowed, that is, greater than 1 / 3D (D-diameter of the pipe through which transport is made),

- sudden interruption of electricity, damage to the pump plant dispenser or pump failure, i.e. dispenser failure.

Minimal speed and pressure fluctuations in the installation during hydrotransport and the installation of safety devices and devices that eliminate blockage would result in an increase in hydrotransport capacity and decrease of costs. Also, occurrences such as pipe spraying, damage to couplings, pumps, etc. would be eliminated. Therefore, the aim of this paper is to analyze the operating parameters of a hydrotransport installation during a variable flow of a hydromixture in a pipeline, to mathematically process the dependence of such a flow, and to make recommendations for the design of safer and more stable hydrotransport (Zandi, 1971; Turian and Yuan, 1977; Doron et al., 1987; Matousek, 2009).

2 HYDROTRANSPORT INSTALLATION OPERATING CHARACTERISTICS

The magnitude of the hydraulic resistances in the pipeline and the parameters of the pump operation are influenced by the density of the hydromixture and the granulometric composition of the material being transported (Kuzeljevic, 1985; Fernandez et al., 2004).

Installation scheme of hydrotransport is shown on Fig. 1.

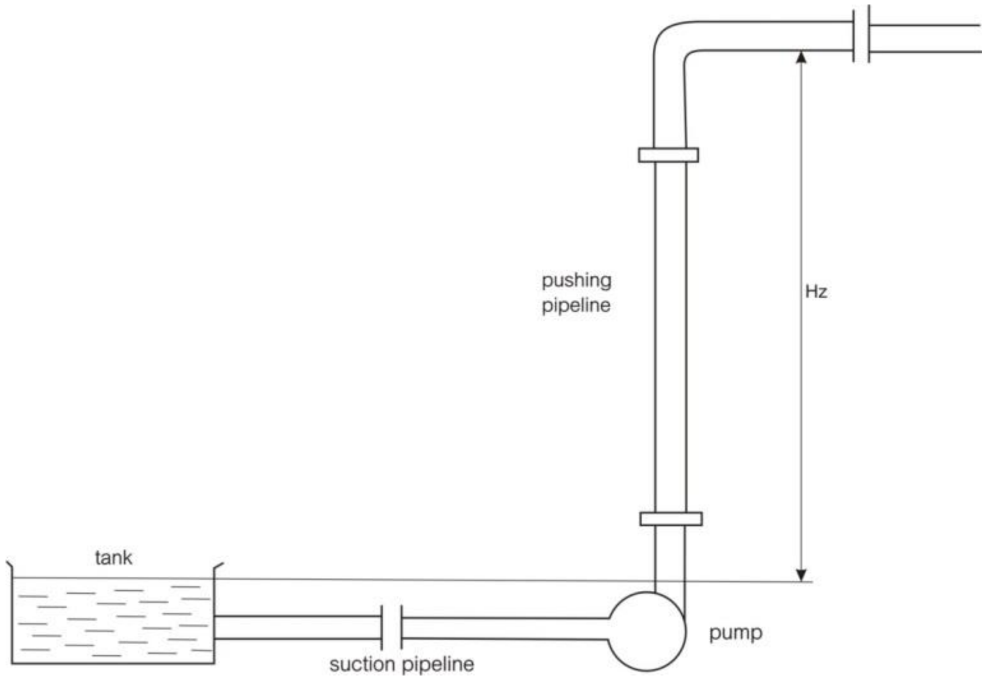

Figure 1 Installation scheme of hydrotransport

Fig. 2 presents the characteristics of a pipeline and pump for a mixture of different densities in the installation shown in Fig. 1.

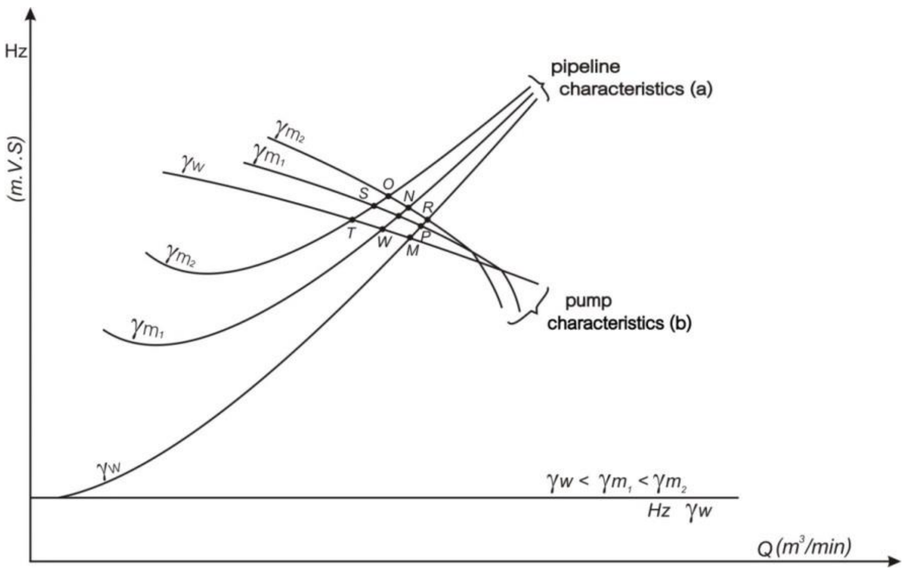

Figure 2 Operating characteristics of a) pipeline and b) pump

Analyzing the operating characteristics of the pipeline and pump, Fig. 2, which most commonly correspond to the installation of the hydrotransport shown in Fig. 1, the following is noticed:

The pipeline and pump performance are intersected for the corresponding density at points M, N, and O. From the diagram it follows that with the increase of the solid phase in the mixture, the volume flow intensity of the mixture decreases. In the case of poor selection of the operating point of the installation, the velocity achieved by the mixture may be lower than the critical velocity. That means that the mixture flow will stop in the installation and system blockage will occur.

During the commissioning phase of the hydrotransport installation, a mixture of solid material and water flows through the pump, while there is only water in the discharge pipeline. The pump will then push the mixture under greater pressure and the flow resistance in the pipeline will be the same as for water. Depending on the density of the mixture, the operating characteristic is moved from point M to point P or R. In the initial phase, the flow velocity increment is achieved and the pump increases its capacity. In the case where a larger amount of solid phase is dosed into the pipeline, the operating characteristic is shifted in the direction of lower capacity. In the diagram, that point ranges from N to O.

At the stage of completion of the hydrotransport installation a mixture having a decreasing density begins to flow through the pump. The moment when there is water in the pump and more mixtures in the pipeline is the most dangerous. The reason lies in the fact that the pump pressure is then the lowest and the flow resistance is greater than the flow resistance of the clean water. Then the installation operates with parameters corresponding to points S, T or W depending on the mixture density in the pipeline. After extrusion of the solid phase from the pipeline, the operating characteristic settles at point M.

In the case of a hydrotransport installation, with the mixture dosing to the pipeline by means of the dispenser, water always flows through the pump and through the pipeline, depending on the situation, the mixture or water. Then the pump characteristic does not change, and higher values for higher densities are obtained in the pipeline, depending on the amount of solid phase, Fig. 3.

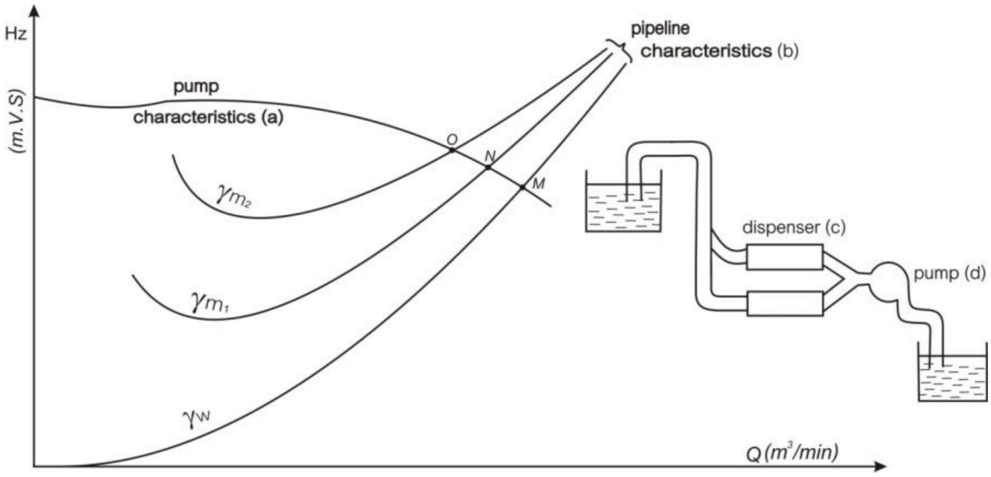

Figure 3 Operating characteristics of pump and pipeline in installation with dispensers: a) pump characteristics; b) pipeline characteristics; c) dispensers and d) pump

The change in flow resistance caused by changes in density affects the capacity reduction during the entire pumping period. The point of operation on the diagram is moved according to the characteristic of the pump to the left or right, depending on whether we increase or decrease the density (points M, N and O).

It follows from these considerations that in the initial and final stages of the installation operation, the flow is variable and that the velocity change (capacity) depends on the value of the change in the density of the mixture.

3 THE CHANGE OF THE HYDROMIXTURE FLOW AT THE PUMP SUDDEN STOP

Sudden pump stop will cause the flow rate of the mixture to drop and may block the installation. The motion of a homogeneous fluid in such a case, with the characteristic of changing its velocity, has been particularly analyzed in the basics of hydraulics. Some authors have adopted common principles of procedures for describing the flow description of the hydromixture velocity change after the pump stop (Gorkin et al., 2010; Coiado et al., 2001; Mihajlovic et al., 2018). In these considerations, a decrease in the velocity of the stream from the value arising from the constant motion of Vm to the value of 0 was analyzed, and then again an increase in the velocity in the direction opposite to the direction of movement and the occurrence of the hydroimpacts occur. Such analysis can be performed for multiple types of hydraulic mix or for hydraulic height transport. This avoids consideration of the problem of deposition of the solid fraction to the bottom of the pipeline and the possible occurrence of blockage or re-carrying of the solid material from the bottom in the event of a velocity increase.

These dependencies are the basis for distinguishing the flow of a homogeneous fluid from the flow of a hydromixture. If we consider the force acting on the hydromixture located in the space between sections I and II (Fig. 4) in the first part of the inclined pipeline, we will see that it consists of:

- Force of inertia:

$$F = \rho_m \cdot A \cdot L \cdot \frac{dv}{dt} \quad (1)$$

- Net weight of the mixture:

$$G = \rho_m \cdot g \cdot A \cdot L \quad (2)$$

- Pressure on the left side of section I:

$$P_1 = P_1 \cdot A \quad (3)$$

- Pressure on the right side of section II:

$$P_2 = P_2 \cdot A \quad (4)$$

- Friction resistance force (the loss of energy during streaming):

$$T = \tau \cdot \overline{\vartheta} \cdot D \cdot L + T_2 \quad (5)$$

wherein:

τ - tangential stress on the pipe walls,
T_2- additional flow resistances caused by the presence of solid particles in the flow,
A - cross-sectional area of the pipeline,
ρ_m- the density of hydromixture - volume mass,
t - time.

Other markings are explained in Fig. 4.

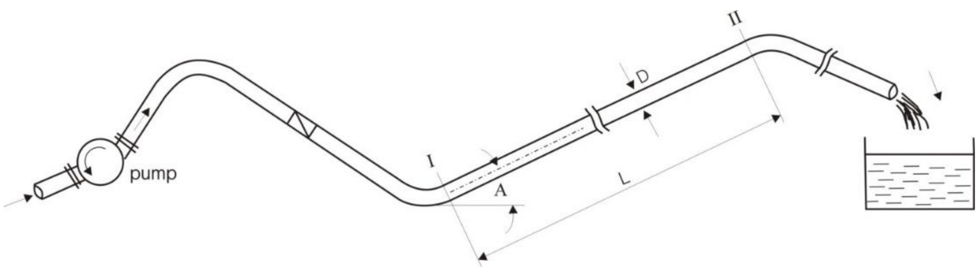

Figure 4 Pipeline position scheme

Using the D'Alembert principle and projecting the force in the direction of the axis of the pipeline we obtain the equation:

$$\rho_m L \frac{dv}{dt} = (P_1 - P_2) - g \cdot \rho_m \cdot L \cdot sin\alpha - \tau \cdot \frac{\overline{u}DL}{A} + \frac{T_2}{A} \tag{6}$$

The expression $\tau \cdot \frac{\overline{u}DL}{A} + \frac{T_2}{A}$ represents the pressure loss caused by the resistance of the hydromixture movement, which is expressed in the form of the following function:

$$\Delta J_{m=} \left(C_1 V^2 + \frac{C_2}{V} \right) L \tag{7}$$

Where C_1 and C_2 are constants dependent on the density of the mixture (own volume mass γ_m) of the pipe diameter, the weight of the solid material fraction, and the roughness of the pipe walls.

When expression (7) is included in expression (6) the following form is obtained:

$$\rho_m L \frac{dv}{dt} = (P_1 - P_2) - g \cdot \rho_m \cdot L \cdot sin\alpha - \left(C_1 V^2 + \frac{C_2}{V} \right) L \tag{8}$$

Equation 8 is the basis for analyzing the duration of loss of velocity V_m or the velocity at which the mixture moves at established motion to the grain deposition velocity, that is, the critical velocity V_{cr}. Knowing the length of time during which the decrease of flow velocity occurs is essential for designing devices that provide installation from pipeline clogging.

4 CONCLUSIONS

The variable flow of the hydromixture in hydrotransport installations causes unsteady operation and spraying of pipes, damage to the pump, blockages in various sections of the pipeline, reduced capacity, and higher exploitation costs. The paper presents the theoretical considerations and analyses of the parameters of hydrotransport operation in unstable flow, on the basis of which the following conclusions are drawn:

1. In the initial and final stages of the installation operation, the flow is variable and that the velocity change (capacity) depends on the value of the change in the density of the mixture. Also, there are high risks of pipeline blockage and fluctuations in the flow velocity. This can be prevented by automatic dosing the grain material into the pumping plant.

2. Failures that cause the flow of the mixture in the pipeline to break also cause plugs in other sections of the installation and hydraulic impacts. Using the dependences of the mathematical quantities, such parameters of the hydromixture, hydrotransport installation and control devices can be determined which protect the hydrotransport from possible blockage. Namely, knowledge of the transport duration in which the flow rate

decreases is necessary for the design of devices that provide installation from the occurrence of pipeline blockage.

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