DETERMINING THE PARAMETERS OF THE HYDRAULIC TRANSPORT OF TAILINGS FOR PROCESSING IRON ORE

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Abstract. The system for hydrotransport of tailings for iron ore processing at JSC EVRAZ Kachkanarsky GOK (Kachkanarsky Ore Mining and Processing Plant) acts as an object of research. The aim of the work was to determine the parameters of the hydraulic transport of tailings for processing iron ore at mass concentrations of the solid phase from 30% to 70% and to develop recommendations for the industrial operation of the hydrotransport systems of highly concentrated pulp from the Kachkanarsky GOK. Methods of carrying out the work include laboratory studies of hydrotransport parameters of thickened tail pulps with the development of a calculation technique; pilot-industrial tests of the hydrotransport system in the conditions of the Kachkanarsky GOK. As for the main structural, technological, technical and operational characteristics, it is established that when using polyurethane coatings on the inner surface of the pipes, the specific loss of pressure of thickened mixtures on hydrotransport is significantly reduced (1.75). This makes it possible to significantly increase the transportation range for laying the tailings for processing to the far parts of the tailing dump. Completed technical and economic calculations confirm the economic efficiency of using steel pipelines with an internal polyurethane coating. The degree of implementation of the research results is in the project for the reconstruction and development of tailing dump of the Kachkanarskiy GOK for the period of 2018-2020. As a recommendation for implementation of the research results, it is proposed to use the results of work in the project of reconstruction of the hydrotransport system at the Kachkanarsky GOK (ore processing plant) by switching to hydrotransport of slurries thickened to mass concentrations of 35-40% in pipes with an internal polyurethane coating, which will provide energy saving in the technological process of hydrotransport.

1. Introduction

The analysis of the hydrotransport systems working at mining enterprises shows that the efficiency of this transport does not correspond to its technical capabilities, requires the high complexity of the operation, is accompanied by the high hydroabrasive wear of pipelines, high metal consumption and energy intensity of the hydrotransport systems.

The energy intensity of the hydraulic transport depends on the specific pressure loss and the concentration of the solid phase of the slurry, according to the formula [1, 2]:

\[ E = \frac{N}{\eta_{sol}L} = \frac{\rho_{sl}g\eta_{sl}}{3.6\rho_{sol}C_{sol}}, \]
where $E$ is the specific energy intensity, kWh/(tonne-kilometre); $N$ - the capacity of pump’s, kW; $q_{sol}$ - the system capacity in solid material, t/h; $L$ - the length of the pipeline (the transportation distance), km; $\rho_{sl}$ - the slurry density, t/cbm; $\rho_{sol}$ - solid tailing density, t/m$^3$; $g$ - acceleration of gravity, m/s$^2$; $I_{sl}$ - the specific pressure loss, mm WG; $c_{sol}$ - volume concentration of solids in the slurry.

The formula shows that the energy intensity of the process mainly depends on the specific pressure loss and the concentration of the solid phase of the slurry being transported. A reduction of pressure loss and an increase of concentration lead to the decrease of the specific energy for pumping a given volume of solid material – tailings.

2. Laboratory tests

Laboratory tests over the hydrotransport of the tail pulp were carried out in the laboratory at the Department of mining transport machines of the St. Petersburg Mining University. The scheme of the experimental hydrotransport system is shown in Fig. 1, and the general view - in Fig. 2.

The granulometric composition of solid particles within the tailings arranged by size grades is given in Table 1.

| Size grade, mm | Content, % |
|---------------|------------|
| + 1.6         | 3.6        |
| - 1.60 + 0.56 | 25.3       |
| - 0.56 + 0.28 | 23.0       |
| - 0.28 + 0.14 | 20.7       |
| - 0.14 + 0.071| 14.8       |
| -0.071        | 12.6       |

The solid material is represented, basically, by size grades equal to -0.14 mm (27.4 %) and -0.071 (12.6%). The average particle diameter is equal to
The bar chart of the distribution of solid particles within tailings is shown in Fig. 2.

\[ d_{cp} = \frac{\sum_{i=1}^{n=5} Pd_i}{100} = 0.491 \text{ mm}. \]

The bar chart of the distribution of solid particles within tailings is shown in Fig. 2.

**Figure 2.** The bar chart of the distribution of solid particles arranged by size grades

The measured average values of pressure loss obtained during the experimental study of slurries of iron ore tailings of 4 concentrations, flowing through the pipeline, are given in Table 2. The dependence of pressure losses on the average slurry flow rate is shown in Fig. 3.

**Table 2.** Experimental data concerning the flow of tailing slurries for processing iron ore in the pipeline \( D = 50 \text{ mm} \)

| \( D_{wp}, \text{ m} \) | Average speed, mps | Pressure losses (m)/Re at the mass concentration (%) |
|------------------------|---------------------|----------------------------------------------------------|
| 30                     | 40                  | 50            | 60            | Water                  |
| 0.05                   | 0.352               | 0.026/1075    | 0.057/790     | 0.134/590   | 0.323/440     | 0.003 |
| 0.704                  | 0.033/2150          | 0.069/1590    | 0.148/1190    | 0.342/890   | 0.012 |
| 1.06                   | 0.041/3200          | 0.078/2390    | 0.162/1780    | 0.360/1340  | 0.024 |
| 1.41                   | 0.048/4300          | 0.088/3180    | 0.175/2360    | 0.380/1780  | 0.039 |
| 1.76                   | 0.056/5370          | 0.098/3970    | 0.189/2950    | 0.41/2230   | 0.058 |
Pressure losses increase when solid material concentration increases, which is clearly seen in the diagrams from Fig. 3. The inclination of the linear sections increases when the volume concentration increases. The dotted lines are drawn to continue the line sections of the curves from the point with the minimum average slurry flow, the axis of pressure losses eliminates the ordinates corresponding to the initial inclination \( i_0 \). The values of the initial inclination increase with the concentration growth, see Fig. 4.

The initial hydraulic inclination indicates the non-Newtonian nature of the slurry flow. Concentrated slurries of iron ore tailings, the solid phase of which contains predominantly particles of relatively small classes (\( d_o = 0.491 \) mm with a predominant class of -0.044 amounts to 80 %), are charac-
terized by the formation of the internal structure due to adhesion and coagulation of individual particles distributed in a continuous liquid medium.

The initial pressure losses (the initial inclination) is the result of summing the resistance values of adhesion and friction between particles, i.e.: 

\[ i_0 = i_p + i_f, \]

Where \( i_0 \) is the initial inclination, \( i_p \) - a part of the initial inclination due to adhesion between particles; \( i_f \) - a part of the initial inclination due to friction between particles.

The curve in Fig. 4 is described by the formula

\[ i_0 = \frac{0.496 \times 10^{4.525 x_{cp}}}{\rho_{sl} D}, \text{ mm WG} \]

The initial inclination, as follows from the above formula, depends on the concentration of solid tailing particles and pipeline diameter.

Table 3 shows the calculated values of the initial inclination for different concentrations and pipeline diameters [3].

| Mass concentration, \( c_{cp} \) | The initial inclination, mm WG for the pipeline diameter, m |
|---------------------------------|----------------------------------------------------------|
| 0.05 | 0.1 | 0.2 | 0.4 | 0.5 | 1.0 |
| 0.3 | 0.0182 | 0.009 | 0.004 | 0.002 | 0.0018 | 0.001 |
| 0.4 | 0.048 | 0.024 | 0.012 | 0.006 | 0.005 | 0.002 |
| 0.5 | 0.121 | 0.06 | 0.03 | 0.015 | 0.012 | 0.006 |
| 0.6 | 0.305 | 0.153 | 0.076 | 0.038 | 0.03 | 0.015 |
| 0.7 | 0.761 | 0.381 | 0.19 | 0.095 | 0.076 | 0.038 |

Table 3 demonstrates that the increase of the solids concentration leads to the increase of the initial inclination but the latter decreases with the growth of the pipeline diameter. When starting the pumping unit, the hydrotransport system needs the pressure to be higher than the initial inclination.

The analysis of the experimental dependences of specific pressure losses on the average slurry flow [4] shows that the slurries at mass concentrations in the range from 30% to 60% are non-Newtonian fluids, the flow of which is described by the Bingham-Shvedov equation [3, 4]. Due to the high concentrations, the flow pattern in the pipeline \( D = 50 \text{ mm} \) is laminar and transitional to the turbulent pattern at almost all concentrations. The general equation for pressure losses can be written as follows [5, 6]:

\[ \frac{f_m}{m} = \frac{4(\tau_0 + \eta e^{(\nu/V)} \rho_{sl} D)}{\rho_{sl} D^2}, \]

where \( \tau_0 \) is the initial shear stress, Pa; \( \eta e^{(\nu/V)} \) - a dynamic factor of effective viscosity, Pa\( \cdot \)s; \( V \) - the average slurry flow rate, mps; \( D \) - the pipeline diameter, m; \( \rho_{sl} \) - the slurry density, kg/m\(^3\); \( g \) - gravity acceleration, m/s\(^2\).

The results of the laboratory tests allow pre-evaluating the magnitude of pressure losses in the pipelines of a different diameter, for example in the industrial pipeline of a \( DN 1000 \) diameter through the method of hydrodynamic processes similarity [7, 8].

Table 2 finds that the actual (measured) pressure loss amounts to 0.046 mm WG. The calculated and experimental data error is [9, 10]:

\[ \varepsilon = \frac{\Delta p_{act} - \Delta p_{calc}}{\Delta p_{calc}} = \frac{0.05 - 0.046}{0.046} = 100\% = 4.8 \%. \]

Therefore, the developed method of pressure losses recalculation can be used for preliminary estimation of pressure losses associated with the change of pipeline diameter.
3. THE RESULTS OF PILOT-INDUSTRIAL TESTS

A pilot production unit for testing hydrotransport was mounted by workers of BPS-I TFW (boosting pumping station-I at the tailings facility workshop) in accordance with the developed scheme, fig. 5 [11].

![Figure 5](image)

**Figure 5.** The scheme and the picture of the individual items of pilot-industrial tail pulp hydrotransport unit

The slurry with a predetermined concentration of solid tailings was pumped with a slurry pump 8Gr-8 with a capacity of \( Q = 400 \text{ m}^3/\text{h} \). The transport line is made in the form of a loop consisting of two pipelines – a steel one \( DN 200 \), and the one \( DN 190 \) with an internal polyurethane coating. This part of the pipeline loop \( DN 190 \) is located 3 m below the steel pipeline.

Each pipeline has a test section of \( L = 15 \text{ m} \) length. The test sections are equipped with spring-pressure gauges with phase separators for measuring the differential pressure.

The \( W = 1.7 \text{ m}^3 \) volume flow tank includes a pipe \( 1000 \text{ mm} \) in diameter and \( 2.5 \text{ m} \) in height. The tank bottom bevelled towards the induction pipe. The slurry flow was absorbed with a slurry pump, transported through a pipeline loop and poured into the feed tank. A fixed mass of solid tailings was poured into the feed tank by means of a travelling crane. The level and volume of slurry remained constant in the feed tank. Mass concentration of slurry was calculated by the formula

\[
\begin{align*}
C_p &= \frac{M_{sol}}{M_{sl}} = \frac{M_{sol}}{M_w + M_{sol}},
\end{align*}
\]

\( C_p \) - the mass concentration of slurry, unit fraction; \( M_{sol} \) - the weight of solid tailings loaded into the feed tank, kg; \( M_w \) - the mass of water, numerically equal to the volume of water, kg.

The measured parameters of tailings hydrotransport, obtained during the pilot-industrial tests, are given in Table 4 and in the diagrams, Fig. 6.

The results of the tests show that the specific pressure losses are \( DN 190 \) 1.4 times less in the experimental coated pipeline than in the steel one \( DN 200 \). It is necessary to take into account that the coated pipeline was of smaller diameter that led to a higher flow rate of the slurry, which in turn influenced the kinetic energy of the flow and, consequently, friction losses. At equal pipeline diameters, the pressure losses ratio would make not less than 1.75 times in steel and coated pipelines.

Let us show it through certain recalculation, see the data in Table 4.
Table 4. The values of the pressure losses according to the experimental data

| Concentration | Density | Speed in pipelines, m/s | Pressure losses in pipelines, mm WG, mm WG | Resistance coefficient λ |
|---------------|---------|-------------------------|-------------------------------------------|--------------------------|
|               |         | Steel coated            |                                           |                          |
| 7             | 1051    | 3.82                    | 4.23                                      |                          |
| 13            | 1100    | 3.88                    | 4.3                                       |                          |
| 19            | 1152    | 3.85                    | 4.27                                      |                          |
| 24            | 1200    | 3.73                    | 4.14                                      |                          |
| 29            | 1253    | 3.66                    | 4.06                                      |                          |
| 34            | 1310    | 3.54                    | 3.92                                      |                          |
| 38            | 1361    | 3.49                    | 3.86                                      |                          |
| 42            | 1414    | 3.41                    | 3.78                                      |                          |
| 45            | 1458    | 3.29                    | 3.64                                      |                          |
| 49            | 1517    | 3.15                    | 3.49                                      |                          |
| 52            | 1568    | 2.98                    | 3.3                                       |                          |
| 53            | 1584    | 2.91                    | 3.22                                      |                          |

Figure 6. Pressure losses in pipelines when calculating the slurry concentration

1. The calculation is based on the formula:
   \[ i = \lambda \frac{v^2}{2gD} \cdot \frac{\rho_c}{\rho_o} \]
2. Let us take the average speed in the coated pipeline as equal to the speed in the steel pipeline.
   \[ v_{st} = v_{co} \]
3. Let us set the pulp concentration
   \[ c_p = 49 \% \]
4. Calculate the hydraulic resistance coefficient according to the formula obtained for the coated pipeline
   \[ \lambda = 0.05 c_p 0.0045 = 0.05 \times 0.49 + 0.0045 = 0.029. \]

Explanatory note: This formula is obtained when processing the experimental data.
5. For the mass concentration of 49%, the pulp density is equal to 1517 kg/m³ and the pulp rate is equal to 3.15 mps.
6. The pressure losses in a coated pipeline with a diameter of 200 mm will be equal to: 
The relative decrease of pressure losses in a coated pipeline:

\[ \varepsilon = \frac{i_{st}}{i_{co}} = \frac{0.199}{0.111} = 1.79; \quad \varepsilon = \frac{i_{st}-i_{co}}{i_{co}} \times 100\% = \frac{0.199 - 0.111}{0.111} \times 100\% = 79\%. \]

We have recalculated the pressure loss values at other concentrations for the coated pipeline, see Table 4. The results are shown in the graph, fig. 7.

![Graph showing pressure loss reduction coefficient depending on pulp concentration](image)

Figure 7. The pressure loss reduction coefficient depending on the pulp concentration in the coated pipeline compared to steel pipeline

The diagram in Fig. 5 shows that pressure losses at all concentrations of the slurry of tailings for iron ore processing are \( DN\ 200 \) at least 1.75 times less in a polyurethane coated pipeline than in a steel pipeline \( DN\ 200 \) without any coating.

The results of the laboratory and pilot-industrial tests are accepted for the project of reconstructing the system for hydrotransport of thickened tailings for iron ore processing at Kachkanarsky GOK in accordance with the plan "Development of tailings facility TFW at EVRAZ Kachkanarsky GOK".

4. CONCLUSIONS

1. The use of pulp lines with an inner polyurethane coating enables the flow of thickened pulp for storage in the far sections of the tailing dump.

4. According to the technical and economic calculations on the ten-year scale of operating the technological section of thickened tailing hydrotransport, the economic effect from applying the pulp lines with internal polyurethane coating will be about 2658.16 million rubles to compare with traditional steel pulp lines.

5. The application of steel pipes with an inner polyurethane coating enables to reduce power consumption for the thickened tailings hydrotransport on average by 22-24 % in comparison with a steel pipe.

6. Life-cycle costs for 10 years of operating pipes with polyurethane coating are two times cheaper than operating steel pipes without coating at the technological section of thickened tailing hydrotransport.

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