ENVIRONMENTAL-PROTECTION AND ENERGY-SAVING DIRECTION
OF DEVELOPMENT OF HYDRAULIC TRANSPORT SYSTEMS

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This direction of pipeline hydraulic transport systems (HTSs) is examined in the given case for the example of one of the most extensive areas of use of HTSs: storing of ash, tailings of mining and concentration plants, and other industrial wastes in hydraulic-fill storages. The amount of such storing is measured in hundreds of millions of tons per year. Hydraulic filling with low consistencies of the pulp is characteristic for most such waste storages. For instance, 2.5 million kWh of energy, or 9.8 million tons of standard fuel, was expended on hydraulic transport of ash in 1980, and only 1% of this energy pertains to expenditures "on a useful load," i.e., on transporting the ash being stored, and 99% on pumping the water of the pulp [1]. Approximately the same situation exists today. An analogous picture is seen in ferrous metallurgy when storing tailings; however, in nonferrous metallurgy the consistency of the tailings pulp most often is several times greater under analogous working conditions.

The excess amount of water in the pulp in many cases could be reduced by 30-40 times. In addition of saving energy, this also has environmental significance, since it substantially reduces the amount of consumption and pollution of large masses of water participating in hydraulic transport and filling.

An increase of the consistency of the pulp when constructing industrial waste storages can be related to a number of measures. In some cases pulp thickeners are needed if the yield of low-consistency pulp is due to the technology of the main production not amenable to change. In other cases the need to increase the reliability of the HTS in the event of increased pulp consistencies is possible. Other conditions being the same, the reliability of the HTS decreases with increase of pulp consistency, since the probability of plugging of the pulp pipeline and of the occurrence of other emergency situations increases. In many cases the operation of a HTS with low consistencies is explained precisely by reliability, which is the simplest of all to provide by such a method at the expense of overconsumption of energy and excessive water consumption.

With consideration of the ever-increasing importance of environmental protection and saving energy, it is necessary to evaluate an HTS on the basis of efficiency (\(\eta\)), which in the given case is simultaneously both an energy and environmental index of the HTS with respect to perfection of its design and operating technology. The difficulties of determining the efficiency of an HTS consist in that the useful expenditures of energy in the HTS must be evaluated for an optimal consistency of the pulp. The question of optimum pulp has been arising periodically in the press for tens of years now and has still not been solved in a general form.

The optimal consistency most often is very great, and for now it is difficult to operate an HTS with such a consistency. As is shown below, for calculating the efficiency of an HTS we can take in the first approximation the energy expenditures proportional to the mass flow rate of the solid in the pump as the useful work. The energy expenditures corresponding to the mass flow rate of solid particles can be expressed in the form:

\[
E_{so} = E \frac{Q_{so}}{Q_w + Q_{so}},
\]

where \(E\) is the total energy expenditures; \(Q_w\) and \(Q_{so}\) are the mass flow rates of water and solid. When expressing the pulp consistency by \(S/L\), where \(S\) and \(L\) are the masses of the solid and liquid (water), the efficiency of the HTS in the variant under consideration can be expressed as

\[
\eta_{so} = S/(S + L).
\]


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For instance, for \( S/L = 1:10 \) the efficiency will be about 0.09, or 9%.

Head losses increase with increase of pulp consistency. Therefore, the hydropower characteristics of the HTS are subjected to the effect of two opposite factors with increase of consistency: an increase of heat losses increases energy consumption, but a simultaneous decrease of flow rate reduces energy consumption (with the same output with respect to the solid).

Let us examine variants of the conventional parameters of a HTS with various pulp consistencies and the same output with respect to the solid (Table 1). The solid output here can be, for example, 100 or 1000 tons/h and is taken as unity. The head losses \( H = 1 \) for \( S/L = 1:20 \) can be any, for instance, 100 m, and are also taken as unity. The two lower rows containing the efficiency of the given system are the purpose of examining the data in Table 1. In the penultimate row the efficiency was determined by the formula

\[
\eta_{hs} = \frac{Q_{so} H_{opt}}{(Q_{so} + Q_w) H}
\]

where \( H_{opt} \) is the head at \( S/L = 1:2 \) corresponding to the minimum useful energy expenditures \( Q_{so} H \).

The series of values of head losses \( H \) here is taken from the results of calculating one of the real systems and is only a particular case of solving the problem of optimization on the basis of the criterion of minimum energy expenditures and water consumption. In the general case of optimization on the basis of the criterion of minimum reduced expenditures, the hydraulic transport system of the industrial waste storage should be considered open and regarded as a subsystem in the overall system of the industrial waste storage. However, under current conditions with the ever-increasing significance of environmental protection it is necessary reexamine the optimization criterion. In this case the reduced expenditures can be considered less significant compared with environmental protection factors, in the given case a reduction of water consumption and energy expenditures.

Many dependencies have been proposed for calculating head losses in an HTS. The graph (Fig. 1) presents the result of calculating an HTS with the use of two dependencies having an opposite character of increase of head losses with increase of consistency. As a result three efficiency curves are obtained: 6 — according to dependence of type 2; 6' — according to dependence of type 3; and 6" — according to a simplified formula \( \eta = S/(S + L) \). Curve 6 did not reach the extreme in the investigated range of \( S/L \), curve 6' has an extreme at \( \eta = 0.5 \), and curve 6" does not have an extreme and in the zone up to \( S/L = 1 \) lies between curves 6' and 6". This shows that for a comparative evaluation of an HTS we can use the simplified formula \( \eta = S/(S + L) \), especially in the zone of low and medium consistencies.

The concepts of low and high consistencies are vague and depend on the area of use of HTSs. For example, in the area of hydraulic transport of ash, 1:30–1:50 are common \( S/L \). Therefore, \( S/L = 1:10 \) here is considered a high consistency. During operation of suction dredges in hydrotechnical construction the consistency is estimated in % as the ratio of the volume of porous mud to the volume of the mud-and-water mixture. Consistencies of 7–12% are common here, which corresponds to \( S/L \) of about 1:8–1:4.5. Therefore consistencies of about 20% are considered high here, which correspond to \( S/L \) of about 1:2.5, and can be called superhigh in ash removal.

For uniformity of estimating the consistency regardless of the type of material being transported and method of calculating consistency, it is advisable to consider low consistencies for which the efficiency of the system is less than 0.1, medium for an efficiency from 0.1 to 0.3, high for an efficiency of 0.3–0.5, and superhigh for an efficiency of more than 0.5.

### Table 1

<table>
<thead>
<tr>
<th>( S/L )</th>
<th>1:20</th>
<th>1:10</th>
<th>1:5</th>
<th>1:2</th>
<th>1:1</th>
<th>1:0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Q_{so} )</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>( Q_{so} + Q_w )</td>
<td>21</td>
<td>11</td>
<td>6</td>
<td>3</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>( H )</td>
<td>1</td>
<td>1.05</td>
<td>1.1</td>
<td>1.3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>( (Q_{so} + Q_w)H )</td>
<td>21</td>
<td>11.6</td>
<td>6.6</td>
<td>3.9</td>
<td>4</td>
<td>4.5</td>
</tr>
<tr>
<td>( \eta_{hs} )</td>
<td>0.062</td>
<td>0.111</td>
<td>0.2</td>
<td>0.33</td>
<td>0.325</td>
<td>0.29</td>
</tr>
</tbody>
</table>

\( \eta_{hs} = S/(S + L) \)

| \( \eta_{hs} \) | 0.0475 | 0.091 | 0.167 | 0.33 | 0.5 | 0.67 |