18th International Conference on
TRANSPORT AND SEDIMENTATION OF SOLID PARTICLES
11-15 September 2017, Prague, Czech Republic
ISSN 0867-7964 ISBN 978-83-7717-269-8

PRESSURE HYDROTRANSPORT SYSTEM MAIN PIPELINE STRENGTH CALCULATION

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Pipeline hydrotransport is very widely used all over the world today. Analogous systems are successfully used in almost all areas of industry, agriculture and household conditions. For their reliable and effective operation, critical importance is attached to calculation of main pipeline strength, i.e. correct determination of the minimum allowable value of its wall thickness. In case of its wrong determination, various damages may occur; this may result in economic loss, environmental contamination. Therefore, it is not surprising that particular importance is attached to this issue in many leading countries, many methods and methodologies of pipeline strength calculation are developed, many state manuals and normative documents are created. As a result of the study and analysis it was established that the issue of hydrotransport pipeline strength calculation considering all significant factors common for design and operation of analogous systems is not reviewed in any of them. Unlike pipeline systems of another designation, two factors of particularly common for the reviewed systems: hydroabrasive wear of pipeline walls and frequent formation of impulse flow, which must not be disregarded. The report is dedicated to consideration of these two factors in pipeline strength calculation methodology and their inclusion in the normative document based on the results of wide-scale fundamental and experimental researches carried out at G. Tsulukidze Mining Institute.

KEY WORDS: Pipeline hydrotransport, thickness of wall, hydroabrasive wear, impulse flow, normative document, manuals document.

1. INTRODUCTION

Pressure pipeline hydrotransport systems intended for transportation of various solid loose materials by pipelines at any distance in the form of their mixture with water or other carrier liquid masses (hydraulic fluids) are widely used throughout the world currently. Such systems are successfully used in almost all areas of industry, agriculture and household conditions. Despite simplicity of construction of this type of transport, its operation is difficult which is crucially influenced by strength of the main pipeline. In case of its incorrect calculation, various damages involving high economic loss, as well as environmental contamination may occur.

Due to the above, decisive significance is attached to calculation of the pipeline strength, i.e. calculation of the minimum allowed pipeline wall thickness, considering the impact of all processes during the operation. Thus, this issue is highlighted in many leading countries of the world, many methods are processed, and many state guidance and statutory documents are created. As a result of their study and analysis it was established that none of them reviews the issues of calculation of hydrotransport system pipeline strength, while there are the most important creation of pulsating flow by overpressure during transportation of the liquid mass (hydraulic fluids) transported by the pipeline and more importantly, unequal intensive hydroabrasive wear of pipeline walls according to the pipeline perimeter are particularly common for analogous systems.

As a result of review and analysis of the reference sources and statutory documents it was established that the most significant researches in these regards were performed at Grigol Tsulukidze Mining Institute in consideration of which the pressure main hydrotransport system pipeline strength calculation methodology should be processed and a unified mathematical relationship should be adopted for statutory and the guidance documents [1-7, 13-15].

Due to the above, two main factors must be considered for processing the pressure main hydrotransport system pipeline strength calculation methodology when hydraulic fluids are transported in them with loose, solid abrasive impurities.

The first and the most important factor is hydroabrasive wear of pipeline walls which depends on the regime of the liquid mass moving in them and especially, on the concentration of loose, solid, abrasive impurities in the flow, abrasive properties and granulometric composition. They must be taken into consideration, because these parameters predetermine the nature (regularity) of hydroabrasive wear of pipeline walls depending on its perimeter. The large-scale fundamental researches conducted under lab and industrial conditions at the above Institution allow for adequate inclusion of results of these researches in the methodology to be processed.

The second but not less important factor is the sudden pressure fluctuation in pressure hydrotransport systems during the dynamic processes, even during the processes envisaged by their operation technology - operation and stoppage of series-connected pumps to the main pipeline when pressure increase significantly exceeds the value allowed for such pipelines based on which its wall thickness is calculated. The large-scale researches conducted in this regard on semi-industrial lab and large industrial facilities at Grigol Tsulukidze Mining Institute, in case of large-scale variability of all parameters, allow for adequate inclusion of results of these researches in the methodology to be processed and accordingly, in the statutory and guidance documents.

2. REVIEW AND ANALYSIS OF REFERENCE SOURCES DEDICATED TO THE REVIEWED ISSUE, STATUTORY AND GUIDANCE DOCUMENTS

As we have mentioned above, fundamental researches of many well-known scientists of the world were dedicated to the issue of pressure pipeline strength calculation and related issues. Results and analysis of these researches are reflected in many monographs and scientific papers. Specific conditions for their design, construction and operation, considering construction of the main pipeline and its structural composition, are presented in all of them. Mathematical relationships (mathematical formulas) for pipeline strength calculation are provided, we do not find it reasonable to perform their detailed analysis, because none of them considers or even mentions pipelines used for transportation of multi-phase hydraulic liquids, i.e. pipelines for hydrotransport systems.

Due to the above, the existing strength calculation methodologies of the currently existing pressure pipelines intended to be used for transportation of hydraulic liquids are unacceptable, because the wall thickness calculated depending on them cannot ensure the required durability and effectiveness. This is confirmed by results of the research performed on lab benches and hydrotransport systems of large industrial facilities at Grigol Tsulukidze Mining Institute.

In view of the fact that results of the research conducted by specialists and scientists are presented in the guidance and statutory documents approved by relevant state authorities in a more generalized form, we found it reasonable to analyse them too.

As the search of the currently existing guidance and statutory documents has shown there are many varieties of such documents and their number is more than 100 and are processed in almost all developed and developing countries of the world, but as mentioned above, the pipelines used for transportation of multi-phase hydraulic liquids, i.e. pipelines for hydrotransport systems are not reviewed or mentioned in any of them. Thus, we do not find it reasonable to analyse all of them because they do not significantly differ from each other.

Search and analysis of the above documents have shown that priority should be given to the statutory documents processed in the Soviet Union [8-10] and the USA [12] because the mathematical relationships of pipeline strength calculation provided in them are the most complete, as the contain the parameters which are necessary to consider, however they do not consider the two main factors which must not be disregarded in case of pipelines used for transportation of hydraulic fluids.

In the first case [8-10] the effective main pipeline wall thickness during the maximum design value of pressure and the minimum value of tensile strength of the material it is made of, shall be calculated according to the formula:

$$\delta_{min.} = \frac{n\,P_{max.allow.}\,D_o}{2\left(R_1 + n\,P_{max.allow.}\right)}, \tag{1}$$

where D_0 - pipeline outer diameter, cm; $P_{max.\,allow.}$ - maximum allowed pressure in the main pipeline, kPa/cm^2; n = 1,20 - main pipeline reliability factor depending on the pressure developed in it when the pipeline is located underground; R_1 - pipeline design tearing resistance, MPa;

$$R_1 = \frac{R^{H}_{1(min.)} \cdot m}{K_1 \cdot K_s}, \tag{2}$$

$m = 0{,}75$ – factor envisaging the main pipeline operation conditions; $K_1 = 1{,}40$ - pipeline safety factor depending on the material of its manufacture; envisages physical-mechanic properties of the material; design pressure value; operation conditions under conditions of snow, wind, frost, using cleaning agents, testing (strength and tightness test); $K_s = 1{,}05$ - reliability factor depending on the pipeline designation, diameter and pressures developed in it; $R^{H}_{1(min.)} = 483$ MPa – minimum design value of the main pipeline tearing resistance.

According to the statutory document developed by the American Society of Mechanical Engineers [12], the formula for calculation the same parameter (1) shall be as follows:

$$\delta_{min.} = \frac{P_{max.allow.} D_{o.}}{2SFET} , \tag{3}$$

where D_0 - pipeline outer diameter, cm; $P_{max.allow}$ - maximum allowed pressure in the main pipeline, kPa/cm^2; *S* – minimum design value of the main pipeline tearing resistance (paragraph 817,13 (C) and Annex D, kPa/cm^2; F = 0,72 - factor envisaging design factors (Annex 841.114 A); *E* =1,0 - factor envisaging the influence of connection (welding) of pipes along the main pipeline and other local resistances (Table 841.115 A, section 817.13 (d); T - factor envisaging influence of the temperature factor (Table 841.116 A).

The reviewed calculation formulas and the parameters included in them clearly confirm the above mentioned fact that neither hydrotransport system pipelines nor the two factors which are most significant among the processes developed during transportation of various types of hydraulic fluid in the pipeline are mentioned in them.

3. ANALYSIS, RELIABILITY, SCIENTIFIC AND PRACTICAL VALUE OF RESEARCHES CONDUCTED AT GRIGOL TSULUKIDZE MINING INSTITUTE

Fundamental researches were conducted during more than half a century and are conducted currently at Grigol Tsulukidze Mining Institute**.** The obtained results are recognized by the International Scientific Society, have gained high evaluation. They large part were published in monographs and scientific papers [1-7, 13-15]. Two Soviet statutory documents [4, 5] were developed on the basis of these results, in which the influence of the above two most important factors common for hydrotransport systems on the pipeline strength calculation are not reviewed like in other documents. But unlike the existing sources, all preconditions for it are detailed in the analysis conducted by us [2, 3] in detail and their volume is rather large. Thus, we do not find it reasonable to reiterate all of them.

We will only mention that the minimum allowed thickness of hydrotransport system pipelines should be calculated as follows [2]:

$$\delta' = \delta_{min.} + \delta_{abr.} , \tag{4}$$

where $\delta_{min.}$ should be calculated by formula (1) and $\delta_{abr.}$ - should be calculated by formula [2]

$$\delta_{abr.} = \frac{T_{e.l.}}{T_1 \, n_{m.r.} \Psi \eta_{m.r.}} \quad , \qquad (5)$$

where $T_{e.l.}$ - the estimated life during the entire period of the pipeline operation, year; $n_{m.r.}$ - number of maintenance rotation of the pipeline in the operating mode; Ψ - irregular wear factor on the pipeline diameter circumvention; $\eta_{m.r.}$ - pipeline wall thickness resource usage factor in case of maintenance rotation; T_1 - specific resource of pipeline operation – time to reduction of pipeline wall thickness to 1 mm during the pipeline operation, year/mm.

Specific resource of the main pipelines of the pressure hydrotransport system is calculated by formula:

$$T_1 = \frac{Q_1}{Q_{ann.}} \quad , \qquad (6)$$

where Q_1 – specific throughput of the pipeline – volume (mass) of the solid abrasive material transported by the pipeline during which the pipeline wall was reduced by 1 mm, m^3/mm (ton/mm); $Q_{ann.}$ – amount of solid loose material transported by the main pipeline during 1 year; m^3/year (ton/mm).

Considering the results of the researches conducted by us, the technical resource (operation period) of pressure hydrotransport systems may be calculated by the formula [2]:

$$T = (\delta - \delta_{min.}) T_1 \frac{n_{m.r.} \Psi \eta_{r.}}{K_{oper.}} \quad , \qquad (7)$$

where $K_{oper.}$ – factor envisaging the hydrotransport system operation conditions: $K_{oper.}$ = 1,2 – for pipelines made of corrosion-proof materials (steels) and those operating permanently irrespective of the material the pipeline is made of; $K_{oper.}$ = 1,35 - for pipelines made of low-carbon steels and which are often in reserve without special packaging.

Considering all the above, the factual operation period of pressure hydrotransport system should be calculated by the formula:

$$T_{act.} = T + t_{stop.} \quad , \qquad (8)$$

Where $t_{stop.}$ - total time of all stoppages during the operation period until full exhaustion of operational life T, year.

As for the second and not less important factor, sudden pressure fluctuation during dynamic processes in the reviewed systems, even during the processes envisaged by their operation technology - operation and stoppage of pumps connected in-series to the main pipeline, the results of the experimental researches performed by us in this area are much more impressive because they were conducted on specifically designed original lab facilities and main pipelines of large industrial hydrotransport system of the Soviet period with diameters of 250-1200 mm [1-3, 6, 13-15].

The obtained results clearly confirm that during operation and stoppage of pumps in the main hydrotransport systems operating continuously with the centrifugal pumps in-series connected to the main pipeline the pressure value in the main pipeline significantly their value during the set mode which certainly negatively influences the system durability and reliability and therefore, this factor must be considered in the pipeline strength calculation methodology, guidance and statutory documents, in particular, the member of formula (2) - K_s, which represents the reliability factor according to the pipeline designation, diameter and pressures developed in it.

Based on the results of the researches performed by us, it must be increased by at least 35% and must become equal to $K_s = 1{,}4$. This will guarantee that reliability of analogous systems will increase on the basis of increase of the minimum allowed value of the main pipeline thickness because pressure fluctuation will be considered during the entire period of operation.

4. MATHEMATICAL RELATIONSHIP OF PRESSURE HYDROTRANSPORT MAIN PIPELINE STRENGTH CALCULATION WHICH MUST BE INCLUDED IN THE GUIDANCE AND STATUTORY DOCUMENTS

On the basis of results of review and analysis of the above reference sources, guidance and statutory documents, as well as the experimental researches conducted on lab facilities and large industrial hydrotransport systems at Grigol Tsulukidze Mining Institute, a mathematical relationship for pressure main hydrotransport system pipeline strength – allowed minimum wall thickness calculation is obtained and its final form is:

$$\delta'_{min.} = \frac{n\,P_{max.allow.} D_{o.}}{2(R_1 + nP_{max.allow.})} + \frac{T_{e.l.}}{T_1\, n_{m.r.} \Psi \eta_{r.}} \quad , \tag{9}$$

where where D_o - pipeline outer diameter, cm; $P_{max.allow.}$- maximum allowed pressure in the main pipeline, kPa /cm^2; n = 1,2 - main pipeline reliability factor depending on the pressure developed in it when the pipeline is located underground, p/cm^2; R_1 - pipeline design tearing resistance, MPa;

$$R_1 = \frac{R^H_{1(min.)}\, m}{K_1\, K_s} \quad , \tag{10}$$

m = 0,75 – factor envisaging the main pipeline operation conditions; K_1 =1,40 - pipeline safety factor depending on the material of its manufacture; envisages physical-mechanic properties of the material; design pressure value; operation conditions under conditions of snow, wind, frost, using cleaning agents, testing (strength and tightness test); K_s =1,4 - reliability factor depending on the pipeline designation, diameter and pressures developed in it; $R^{H}_{1(min.)}$ = 483 MPa – minimum design value of the main pipeline tearing resistance; $T_{e.l.}$ - the estimated life during the entire period of the pipeline operation, year; $n_{m.r.}$ - number of maintenance rotation of the pipeline in the operating mode; Ψ - irregular wear factor on the pipeline diameter circumvention; $\eta_{m.r.}$ - pipeline wall thickness resource usage factor in case of maintenance rotation; T_1 - specific resource of pipeline operation – time to reduction of pipeline wall thickness to 1 mm during the pipeline operation, year/mm.

The pressure hydrotransport system main pipeline strength calculations performed by the formula (9) for absolutely different conditions have shown that in all cases, the pipeline wall thickness exceeds the values obtained without consideration of those two most important conditions which are common for pressure hydrotransport systems, i.e. for the cases when the pipelines are used for transportation of solid loose, abrasive materials using liquid carrier fluids. This means that together with increase of thickness the cost of their manufacture increases as well but this is not a negative factor at all. Increase of the pipeline thickness allows for increasing the main pipeline operational life, i.e. durability which enables transportation of much more solid loose material. This is also predetermined by reliability of the main pipeline operation, i.e. it does not require to carry out measures which are currently necessary. Finally, all the above will have a positive impact on cost effectiveness, i.e. significant cost effectiveness will be achieved.

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