Estimation of pipelines overhaul life duration of installations for pneumatic transport of ash and coal dust of TPPs and recommendations on its increase

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ABSTRACT

Dependences for calculating pipelines operation overhaul life of installations for pneumatic transport of ash, coal dust and other fine bulk materials for rectilinear horizontal, inclined and vertical, and also curvilinear sections of pipelines are presented. Calculation dependences are developed by employees of Boiler Plants and Ecology of Power Engineering Department of the Moscow Power Engineering Institute (Technical University). Operation, technological and complex provisions on raise of service life of pneumotransport pipelines are resulted.

Overhaul life and reliability of pneumotransport pipelines operation strongly depend on erosion wear being one of the main problems of installations for pneumotransport of ash, coal dust, cement, coke, sand and other fine bulk erosive materials. Due to erosion wear of pipelines the economic efficiency of pneumotransporting solid materials is worsened. This results in equipment downtime caused by holes in pipelines, application of pipelines with the overestimated walls thickness and deterioration of transporting parameters owing to increase of the inner pipeline diameter.

Erosion wear of pipelines is observed owing to interaction of particles of the transported material with a pipe wall as a result of which microscopic metal chips of the pipeline are cut off. This interacting is carried out by the turbulent two-phase flow with great *Re* number, and, hence, transported particles attack a pipeline wall at angles which cannot be defined theoretically and described mathematically.

In comparison with other elements of pneumotransport installation the increased erosion wear is observed in curvilinear sections of pipelines, namely in those places where the axis of a dust flow is directed angularly to a surface of pipelines. These elements are: locking and regulating armature, bends of pipelines, T-joints, transitions, flow switches. Rectilinear sections of pipelines are subject to erosion wear essentially less than curvilinear ones. Estimation of erosion wear for curvilinear pipelines sections of pneumotransport installations is much more complex, than for rectilinear pipelines. The reason of it is that until recently there were no standard generalized techniques for its calculation. There were separate recommendations based on operating experience or results of experimental researches of effect of separate significant factors on erosion wear of pipelines bends, T-joints and other curvilinear elements of pneumotransport installation pipelines. It should be underlined, that a scope of these recommendations is restricted by service conditions of operating pneumotransport installations or experimental researches for which they have been developed. Therefore, in the frames of the research work carried on in 2005-2006 by employees of Boiler Plants and Ecology of Power Engineering Department of the Moscow Power Engineering Institute (Technical University) in accordance with the grant of the President of the RF, a mechanism of erosion wear for curvilinear sections of pneumotransport pipelines has been investigated. As a result of carrying on the research works a dependence for calculating erosion wear for curvilinear sections of pipelines at pneumotransport of ash, coal dust and other fine bulk erosive materials defining operation overhaul life for pipelines of pneumotransport installations has been developed.

RECTILINEAR SECTION OF PNEUMOTRANSPORT PIPELINES

According to[1] a dependence for calculating specific linear erosion wear for horizontal and inclined sections of pipelines of pneumotransport installations δ_h is the following:

$$\delta_h = 55,5 \cdot 10^{-6} \frac{U_M^2 \cdot K_P \cdot k_{SiO_2}}{D^2 \cdot m^{0,4} \cdot k_{izn}}, \text{ mm/t} \qquad (1)$$

where U_M — average on section velocity of flow of the material particles, m/s; K_P — Putilov's criteria on calculation of the aerodynamic lightness of particles at pneumotransport of fine bulk materials[2], kg/m^2; k_{SiO2} — factor of the relative SiO_2 content in the transported material; D — inner pipeline diameter, m; m — mass concentration of the material and air mixture flow, kg of material/kg of air; k_{izn} — factor of relative wear resistance of the pipeline material.

According to[2] criteria of the aerodynamic lightness of particles K_P is one of the key characteristics of the pneumatically transported fine bulk materials, equal to the ratio of the particle mass to its surface area. It can be determined as follows:

$$K_P = \frac{d_0 \rho_M}{6}$$

where ρ_M — density of the transported material, kg/m^3; d_0 — average equivalent diameter of particles of the material, m.

A factor of the relative SiO_2 content in the transported material k_{SiO2} is determined as follows:

$$k_{SiO_2} = \frac{\%\ SiO_2 \text{ content in the transported material}}{\%\ SiO_2 \text{ content in the silica sand}},$$

where mass content of SiO_2 in the silica sand makes 94 % in accordance with GOST 6139-91. «Standard sand for cement tests (standard)».

k_{izn} is determined as follows:

$$k_{izn} = 6,42\times10^{-5}\times HV^2 - 0,0157\times HV + 1,97 \quad (2)$$

where HV – Vickers hardness of the pipeline wall material.

At vertical sections of pipelines erosion wear occurs uniformly on the whole surface. Thus, the dependence (1) can be applied for calculating specific erosion wear for horizontal and inclined pipelines, but for vertical pipelines the following dependence should be used:

$$\delta_h = 13,9\cdot10^{-6}\frac{U_M^2\cdot K_P\cdot k_{SiO_2}}{D^2\cdot m^{0,4}\cdot k_{izn}}, \text{ mm/t}, \quad (3),$$

that differs from (1) only for the numerical constant 4 times reduced.

CURVILINEAR SECTIONS OF THE PNEUMOTRANSPORT PIPELINES

Developing a dependence for calculating erosion wear for curvilinear sections of pipelines of pneumatic transportation of fine bulk materials the dependence for calculating rectilinear sections of pneumotransport pipelines has been taken as a base and it has been completed. At that impact estimation of attack angle and ratio of the pipeline turning radius to its inner diameter has been made.

The dependence for calculating specific linear erosion wear for curvilinear sections of pipelines is the following:

$$\delta_h = 5,55\cdot10^{-7}\frac{U_M^2\cdot K_P\cdot k_{SiO_2}\cdot k_\alpha\cdot k_{R/D}}{D^2\cdot m^{0,4}\cdot k_{izn}} \quad (4)$$

An impact of the attack angle α on erosion wear of curvilinear sections of pneumotransport pipelines is considered by the factor k_α:

$$k_\alpha = 0,0065\alpha^2 - 0,0385\alpha + 1,033 \quad \text{at } 0<\alpha\le28,3^\circ \quad (5)$$

$$k_\alpha = 5e^{4,57}\cdot\alpha^{-1,39} \quad \text{at } \alpha>28,3^\circ \quad (6)$$

The factor of ratio of the pipeline turning radius to its inner diameter is determined as follows:

$$k_{R/D} = -0,1113\cdot R/D^2 + 0,6336\cdot R/D + 0,1143 \text{ at } 0<R/D\le3,3 \quad (7)$$

$$k_{R/D} = 1,448\cdot R/D^{-0,3843} \text{ at } R/D>3,3 \quad (8)$$

Overhaul life duration of pipelines of pneumotransport installations on erosion wear conditions T_{izn} is defined by the period, during which a pipeline wall thickness δ_{st} is reduced to the normative value δ_{ost}, determined due to adequate mechanical strength of the pipeline. In practice the residual pipeline thickness δ_{ost} is commonly 4 mm. So, a depth of the operational wear of the pipeline δ_{izn} is defined as follows:

$$\delta_{izn} = \delta_{st} - \delta_{ost},\ mm \quad (9)$$

Service life of the pipeline is determined as follows:

$$T_{izn} = (\delta_{st} - \delta_{ost})/(3,6\times\delta_h\times G_M),\ \text{h} \quad (10)$$

PROVISIONS ON RAISE OF SERVICE LIFE OF PNEUMOTRANSPORT PIPELINES

Provisions on reducing erosion wear of pipelines of pneumotransport installations can be divided into 2 groups: operation and constructive.

The main operation provisions are:
1. turning rectilinear horizontal and inclined sections of pipelines about the axis through the angle 70…80º;
2. transporting dust-air flow with optimal parameters in accordance with[4, 5];

The following provisions are in the second group:
1. optimization of the form of curvilinear sections of pipelines[6];
2. implementation of aerodynamic stabilization sections of dust-air flows at the inlet in the curvilinear sections of pipelines and at the outlet taking into account maximum erosion zone;
3. application of antierosive inserts in the pipeline bends;
4. using cast stone material for pipeline bends;
5. application of pipes with alumothermal covering of with the reduced erosion wear;
6. covering inner surfaces of the manufactured curvilinear sections of pipelines with antierosive materials.

Turning rectilinear horizontal and inclined sections of pipelines about the axis. Rectilinear horizontal and inclined sections of pipelines subjected to intensive erosion wear are commonly turned about the axis 3 times. This helps to prolong their service life 4 times in comparison with the calculated one. At vertical sections of pipelines erosion wear occurs uniformly on the whole surface. Therefore, by turning horizontal and inclined sections of pipelines about their axis at operation, volume of the transported material can be increased more than 4 times before their replacement. It's very important that the service life of rectilinear horizontal and vertical sections of pipelines is about the same.

Transporting dust-air flows with the optimal parameters. If at implementation of pipeline optimal velocities and mass concentrations of dust-air flows haven't been considered, erosion wear of its separate parts can be much more high in comparison with other sections. To improve the situation optimal parameters of the whole pipeline should be calculated according to[4 и 5] and pipes of the calculated diameter should be installed at the mostly erosive sections.

Optimization of the form of curvilinear sections of pipelines. As the mostly erosive pipeline sections are bends of pipelines, T-joints, transitions, flow switches and other armature, at design of the pipelines their quantity should be minimum and curvilinear sections should have optimal characteristics in relation to erosion wear and aerodynamic resistance. For example, it's known that a form of the diffuser transiting from the smaller diameter of the stepped pipeline to the greater one strongly influences on the pressure drop and erosion wear both in the diffuser transition, and in the sections of the pipeline bordering to it. According to[5] a recommended transition form is presented in fig.1.

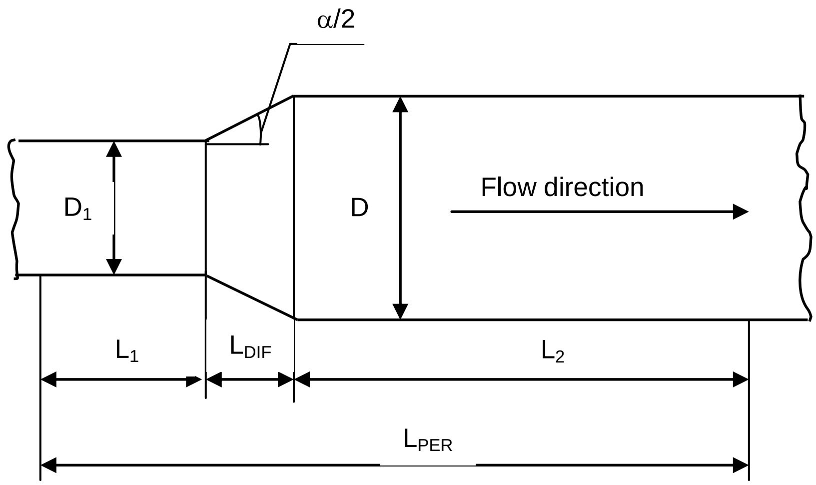

Fig.1. A form of the diffuser transiting from the smaller diameter of the stepped pipeline to the greater one: L_{PER} — total transition length with sections of aerodynamic stabilization of the dust-air flow; L_{DIF} — diffuser transition length; D_1 and D_2 — inner pipeline diameters before and after diffuser transition; L_1 and L_2 — aerodynamic stabilization sections of the dust-air flow before and after diffuser transition; α — diffuser transition angle.

The length of the diffuser transition is the following:

$$L_{DIF} \geq \frac{D_2 - D_1}{2\mathrm{tg}\ \alpha/2} = \frac{D_2 - D_1}{0{,}263}.$$

Lengths of aerodynamic stabilization sections of the dust-air flow are defined from the ratios: $L_1 \geq 20\ D_1$ and $L_2 \geq 30\ D_2$; diffuser angle should be less than 15° to avoid dust-air flow separation from the pipe wall, resulting in pressure loss increase and erosion wear intensification due to formation of the turbulent zones in the wall area of the diffuser transition and pipeline section bordering to it.

Implementation of aerodynamic flow stabilization sections at the inlet in the curvilinear sections of pipelines and at the outlet taking into account maximum erosion zone. The increased erosion wear with other things being equal occurs at the pipelines sections at the inlet and outlet from pipelines bends, diffusers, locking, regulating and switching armature (fig. 1 and fig. 2).

According to[5] the total length of aerodynamic stabilization sections of the dust-air flow for the case from the fig. 2 should meet the following requirement:

$$L_{stab} \geq 50D.$$

However in accordance with[4] an intensive erosion wear occurs not on the whole length of aerodynamic stabilization sections, but in the sections bordering to the disturbing elements of pipelines. That is why to avoid frequent repair or replacement of the mostly erosive pipelines sections, it's necessary to install branches with antierosive covering or with the increased wear resistance with the length more than 5D each at the inlet in the curvilinear sections and at the outlet.

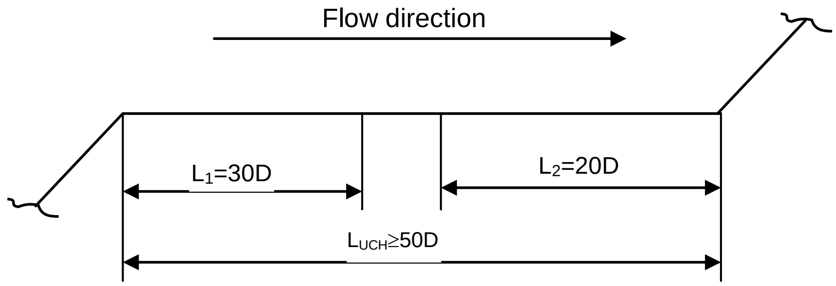

Fig.2. Configuration of the pneumatic ash pipeline section: L_{uch} — length of the rectilinear horizontal (vertical) section at the complex pneumatic ash pipeline route; L_1 — length of the aerodynamic stabilization section of the ash-air flow after the local resistance; L_2 — the same, but before the local resistance.

Application of antierosive inserts in the pipeline bends. Antierosive inserts reduce wear rate. Wear rate reduction depends on the inserts material and in practice makes more than 20 % in comparison with the figures for the same pipelines bends without any inserts.

Using cast stone materials. Using inserts made of basalt castings at the curvilinear sections and branches at the dust-air flow sections of aerodynamic stabilization increases their wear- and acid-resistance.

Analyzing the results of pneumotransport installation operation it has been established, that overhaul life duration for equipment, protected with stone casting is 4…6 times more. Application of the basalt casting at metallurgical works in the amount of 30…36 thousand t contributes in saving more than 100 thousand t of metal per year. For every ton of the cast stone products 2…5 t of metal is saved and pipelines maintenance load is greatly decreased. However, application of pipelines protected with stone casting in the conditions of sharply continental climate at the largest part of Russia has the following main disadvantages:

1) cracking of stone cast inserts owing to changes of geometrical sizes of the curvilinear sections because of high temperature drops while in service and knocking out separate fragments of inserts to the pipeline that frequently leads to a blockage of the pipeline;
2) necessity of installing «dead support» for strong fixing of the curvilinear sections of pipelines in order to prevent negative aftereffects specified in item 1;
3) necessity of installing temperature compensators at rectilinear sections of pipelines for compensating a change of linear dimensions of pipelines because of temperature drops;

4) very tough requirements for transportation and storage of stone cast products, and also for quality of installation works at construction and repair of pneumotransport installations;
5) insufficient type sizes of the inner diameters of bends (D_u =150, 175, 200, 225 and 250 mm), that essentially restricts an opportunity of their application.

Application of pipes with alumothermal covering. Pipes with alumothermal covering are applied in systems of hydraulic ash removal at Pavlodarskaya PP-1 and PP-2 (about 30 years), dust preparation system of Reftinskaya PP (more than 22 years) and pneumatic ash removal of Aksusskaya PP (more than 16 years). Nowadays there are no data on replacement or repair of pipelines sections with alumothermal covering installed before as they are maintained without any notes. Pipelines with alumothermal covering have essentially greater erosive durability in comparison with durability of the pipelines made from other materials. It is necessary to emphasize, that it refers both to rectilinear and curvilinear sections of pipelines. The estimated service life of pipelines with alumothermal covering, in opinion of representatives of manufacturer, is approximately 10 times more in comparison with the service life of pipelines made from steel St.5. On the basis of our researches[4] numerical value of the factor of relative wear resistance of pipelines with alumothermal covering are over the range 300 … 400. Relative wear resistance of pipelines made from various materials is resulted in table.

Table. Relative wear resistance of pipelines made from various materials

Pipeline material	Vickers hardness, *HV*	Factor of relative wear resistance of pipelines made from various materials, k_{izn}
Copper	125	1,00
Steel 5	130	1,01
Steel 25L	130	1,01
Steel 3	135	1,02
Steel 10	137	1,02
Steel 4sp	140	1,03
Steel 5sp	150	1,06
Steel 20	156	1,08
Steel 35L	160	1,10
Steel 35	187	1,28
Steel 25G2	200	1,40
Steel 37 (St37)	210	1,50
Steel 40, 40H (with annealing)	217	1,59
Gray iron	223	1,66
Steel 30HGS, steel 30HGSZ (with annealing)	229	1,74
Steel 55Л (with thermal treatment)	240	1,90
Steel 45	241	1,92
Steel 30H13	270	2,41
Steel 40H13	300	3,04
Steel 55L	340	4,05
Steel H5CrNi189	380	5,27
Pipes with alumothermal covering	2500	364,00

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