P a r t 3

ASH AND SLAG HANDLING

3.2. Ash and slag handling systems at TPPs

3.2.2. Ash removal

3.2.2.8. Estimation of erosion in pipelines at pneumatic conveying of fine bulk materials

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ABSTRACT

The basic data on erosion in pipelines at pneumatic conveying of ash, coal dust, cement, coke, sand and other fine bulk erosive materials are presented. Major factors are revealed and estimation of their influence on erosion in pneumotransport pipelines is executed. Dependences for calculating erosion in rectilinear (horizontal, inclined and vertical) and curvilinear sections of pipelines are resulted. Error estimation at calculating erosion in pipelines at pneumatic conveying of fine bulk erosive materials is given. The developed dependences are results of experimental and analytical researches carried out by employees of Informational and Analytical Center "Ecology in Power Engineering" and Boiler Plants and Ecology of Power Engineering Department of Moscow Power Engineering Institute (Technical University).

KEYWORDS

Pneumotransport, fine bulk materials, erosion

1. BASIC DATA ON EROSION IN PIPELINES

Erosion in pneumatic equipment conveying fine bulk materials is one of the major problems of operation of installations for pneumatic transportation of ash, coal dust, cement, coke, sand and other fine bulk erosive multi-grade materials. Due to erosion in pipelines the economic efficiency of pneumatic conveying of 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 negatively influences reliability and profitability of pneumotransport installation operation, and also technological complex, being a part of it. Besides, even at insignificant density disturbances of pneumotransport equipment, leading to shock emissions or a constant dusting of the transported material, ecological conditions in a zone of pneumotransport installation effect considerably worsen.

Erosion in 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 between the pipeline walls by the turbulent two-phase flow with great Re number, and, hence, transported particles attack the pipeline walls at different angles which cannot be defined practically or theoretically and described mathematically. In this case interaction of multi-grade flows of fine erosive particles with the pipeline walls, in which the axis coincides or not with the axes of the pneumotransport pipelines, is observed.

Almost all equipment of pneumotransport installations is subject to erosion, but in comparison with other elements of pneumotransport installation the increased erosion is observed in curvilinear sections of pipelines, namely in those places where the axis of a dust-air 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 essentially less than curvilinear ones. Estimation of erosion in curvilinear pipelines sections of pneumotransport installations is much more complex, than in rectilinear pipelines. The reason of it is that until recently in scientific and engineering publications there was no information on 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 in pipeline 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 №МК-3945.2005.8, a mechanism of erosion in curvilinear sections of pneumotransport pipelines has been investigated. As a result of carrying on the research works the dependence for calculating erosion in curvilinear sections of pipelines at pneumotransport of ash, coal dust and other fine bulk erosive materials estimating operation overhaul life for pipelines of pneumotransport installations has been developed.

Erosion, in general, depends on physical and mechanical properties of the transported material, pipeline material and conditions of transportation [1]. The most important factors are:

- conveying velocity;
- angle of attack (angle between direction of particle flow motion and pipeline wall);
- solids-loading ration;
- diameter and form of particles;
- polydispersity degree of the transported material;
- chemical composition of the transported material;
- structural performance of the pipeline material;
- pipeline bore.

In table 1 the major factors influencing erosion in pipelines at pneumatic conveying of fine loose materials and ranges of change of their quantity indicators are resulted.

Table 1. The main factors influencing erosion and range of their quantity indicators

№	Factor name	Factor symbol	Investigated range of a factor change	Kind of dependence of erosion from a factor	Quality indices of dependence of erosion from a factor
1.	Velocity of the transported material particles	$U_м$	28…120 m/s	$U_м^n$	n = 1,4…6
2.	Mass consumed concentration	m	0,02…20 kg/kg	m^n	n = -0,6…1,0
3.	Coefficient of material abrasivity	f_a	no numeric data	f_a	n=1,0
4.	Diameter of particles of the material	d	23…1000 microns	d^n	n = 1,0…3,0
5.	Inner diameter of the pipeline	D	13…500 mm	D^n	n = -2,0
6.	Attack angle of particles	α	0…90°	α, $sin\alpha$, $cos\alpha$	α_{max} =10...45° α_0 < 15°
7.	Coefficient of particles form	k_f	no numeric data	k_f	n=1,0
8.	Coefficient of particles polydispersity	k_d	0,8…1,4	k_d	n=-1,0
9.	Vickers hardness of the pipe material	HV	30…500	HV^n	n= - 0,4
10.	Coefficient of relative wear resistance of the pipeline material	$k_{изн}$	3,1	$k_{изн}$	n= - 1,0
11.	Temperature	T	For pneumatic conveying of coal dust and ash in TPP conditions it has no influence on abrasivity variation, as a temperature of the transported material and equipment varies insignificantly, and influence of temperature on abrasive material properties are considered in a coefficient of abrasivity		

2. DEPENDENCES FOR CALCULATING EROSION WEAR OF PNEUMOTRANSPORT PIPELINES

2.1. Rectilinear sections

According to [2] the dependence for calculating specific linear erosion in horizontal and inclined sections of pipelines of pneumotransport installations δ_h is the following:

$$\delta_h = 55{,}5 \cdot 10^{-6} \frac{U_M^2 \cdot K_P \cdot k_{SiO2}}{D^2 \cdot m^{0,4} \cdot k_{izn}} \text{, mm/t} \quad (1),$$

where $U_м$ — 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 materials², kg/m²; 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 [3] 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:

$$K_P = \frac{d_0 \rho_M}{6} \quad (2),$$

where $\rho_м$ — density of the transported material, kg/m³; 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:

$$k_{SiO_2} = \frac{\%\ SiO_2\ content\ in\ the\ transported\ material}{\%\ SiO_2\ content\ in\ the\ silica\ sand} \quad (3),$$

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:

$$k_{izn} = 6{,}42 \times 10^{-5} \times HV^2 - 0{,}0157 \times HV + 1{,}97 \quad (4),$$

where HV – Vickers' hardness of the pipeline wall material.

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

$$\delta_h = 13{,}9 \cdot 10^{-6} \frac{U_M^2 \cdot K_P \cdot k_{SiO2}}{D^2 \cdot m^{0,4} \cdot k_{izn}} \text{, mm/t} \quad (5),$$

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

2.2. Curvilinear sections

Developing the dependence for calculating erosion in curvilinear sections of pipelines at pneumatic conveying of fine bulk materials the dependence for calculating rectilinear sections of pneumotransport pipelines has been taken as a base and it has been completed considering estimation of attack angle of dust-air flows k_α and the factor of ratio of the pipeline turning radius to its inner diameter $k_{R/D}$. At that impact estimation of attack angle and ratio of the pipeline turning radius to its inner diameter has been made. During dependence development the convergence of calculating results using the developed dependences with the actual data on erosion in curvilinear sections of pipelines at pneumotransport of fine bulk materials has been estimated.

Finally, the dependence for calculating specific linear erosion in curvilinear sections of pipelines considering k_α and $k_{R/D}$ has been developed:

$$\delta_h = 5{,}55 \cdot 10^{-7} \frac{U_M^2 \cdot K_P \cdot k_{SiO2} \cdot k_\alpha \cdot k_{R/D}}{D^2 \cdot m^{0,4} \cdot k_{izn}} \quad (6)$$

The factor k_α is defined as follows:

$$k_\alpha = 0{,}0065\alpha^2 - 0{,}0385\alpha + 1{,}033$$

at 0<α≤28,3° (7)

$$k_\alpha = 5e^{4,57} \cdot \alpha^{-1,39}$$

at 28,3<α≤90° (8)

Attack angle of dust-air flows being more that 90° hasn't been considered as it's not characteristic for the real pneumotransport installations of ash and coal dust of thermal power plants.

The factor kR/D is determined as follows:

kR/D = -0,1113·R/D2 + 0,6336·R/D + 0,1143

at 0<R/D≤3,3 (9)

kR/D = 1,448·R/D-0,3843

at R/D>3,3 (10)

Overhaul life duration of pipelines of pneumotransport installations on erosion 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* (11)

Service life of the pipeline is determined as follows:

$T_{izn} = (\delta_{st} - \delta_{ost})/(3{,}6\times\delta_h\times G_M)$, h (12)

In table 2 data on parameter errors influencing erosion in pipelines of installation for pneumotransport of fine bulk polydisperse materials are presented.

Table 2. Errors of the main factors influencing erosion in pneumatic conveying pipelines

№	Parameter name	Errors (accuracy class) δ, %	Measuring device (method of measurement)
1.	Transporting material consumption G_m, kg/s	1,5	Dynamometer DOSM-3-5
2.	Volumetric air consumption Q_v, m^3/s	1,5	Differential pressure gauge DSP-786N
3.	Pipeline diameter *D*, m	2,11[1]	–
4.	Vickers' hardness of the pipe metal *HV*, MPa	3,0	Hardness gauge
5.	Average diameter of particles of the material d_0, microns	5,0	Sieving, pneumatic classification
6.	Silica content, SiO_2, %	1,0	Chemical analyses
7.	Absolute pressure in the pipeline *P*, MPa	0,5	Pressure sensor MED 2306
8.	Air temperature t_v, °C	0,5	Laboratory thermometer
9.	Sample weight M_p, kg	1,0	Analytical scales
10.	Sample volume V_p, m^3	1,0	Measuring vessel
11.	Attack angle α, degrees	0,56	Angle meter
12.	Turning radius of the pipe *R*	0,05	Mathematical calculation

[1] According to [4] estimation of the pipeline diameter error is made considering ovality and variation in wall thickness of the pile. The relative error connected with the pipe ovality is 1,25 % at *D*>219 mm, variation in wall thickness – 0,86 % at *D*≥219 mm and wall thickness of the pile 15 mm.

Let's consider $\delta_h = f(U_m^2, K_P, k_{SiO2}, m^{-0,4}, D^{-2}, k_{izn}^{-1})$.

The carrying air velocity is as follows:

$$U = \frac{Q_v}{\pi D^2/4} \quad (13)$$

The relative error of U_v definition makes:

$$\delta U = \delta U_м = \sqrt{\delta Q_в^2 + (2\delta D)^2} = 4{,}479\,\% \quad (14)$$

The error of ρ_m definition:

$$\delta\rho_m = \sqrt{\delta M_p^{\ 2} + \delta V_p^{\ 2}} = 1{,}414\ \% \quad (15)$$

The error of K_P definition:

$$\delta K_P = \sqrt{\delta\rho_m^{\ 2} + \delta d_0^2} = 5{,}196\ \% \quad (16)$$

The error of ρ_v definition:

$$\delta\rho_v = \sqrt{\delta P^2 + \delta t_v^{\ 2}} = 0{,}707\ \% \quad (17)$$

The error of G_v definition:

$$\delta G_v = \sqrt{\delta\rho_v^2 + \delta Q_v^2} = 1{,}658\ \% \quad (18)$$

The error of *m* definition:

$$\delta m = \sqrt{\delta G_m^2 + \delta G_v^2} = 2{,}236\ \% \quad (19)$$

The error of k_{izn} definition:

$$\delta k_{izn} = \sqrt{(2\delta HV)^2 + \delta HV^2} = 6{,}708\ \% \quad (20)$$

Using the relative errors, calculated according to the above dependences, we get the final relative error of the dependence for estimating erosion in rectilinear sections of pipelines δ_h:

$$\delta(\delta_h) = \sqrt{(2\cdot\delta U_m)^2 + \delta K_P^2 + \delta k_{SiO2}^2 + (0{,}4\cdot\delta m)^2 + (2\cdot\delta D)^2 + \delta k_{izn}^{\ 2}} \quad (21)$$

$$\delta(\delta_h) = \sqrt{(2\cdot 4{,}479)^2 + 5{,}196^2 + 1{,}0^2 + (0{,}4\cdot 2{,}236)^2 + (2\cdot 2{,}11)^2 + 6{,}708^2} = 13{,}1\,\% \quad (22)$$

The relative error of the dependence for estimating erosion in curvilinear sections of pipelines δ_h is calculated as follows:

$$\delta(\delta_h) = \sqrt{(2\cdot\delta U_m)^2 + \delta K_P^2 + \delta k_{SiO2}^2 + (0{,}4\cdot\delta m)^2 + (2\cdot\delta D)^2 + \delta k_{izn}^{\ 2} + \delta k_\alpha^{\ 2} + \delta k_R^{\ 2}} \quad (23)$$

$$\delta(\delta_h) = \sqrt{(2\cdot 4{,}479)^2 + 5{,}196^2 + 1{,}0^2 + (0{,}4\cdot 2{,}236)^2 + (2\cdot 2{,}11)^2 + 6{,}708^2 + 0{,}56^2 + 0{,}05^2} = 13{,}12\% \quad (24)$$

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