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THE PIPE DIAMETER AND FINE SOLIDS MASS FLOW RATE INFLUENCE ON THE AIR CRITICAL VELOCITY AND SPECIFIC PRESSURE DROP WHILE PNEUMATIC CONVEYING

Influence of diameter of a pipe and the mass expense fine-dispersed firm materials for critical velocity of movement of air and specific pressure difference corresponding it is investigated at pneumotransport of such materials on horizontal direct pipes.

Key words: pneumotransport; critical velocity; specific pressure difference; the expense fine-dispersed firm material.

The paper is dedicated to the pneumatic conveying of fine disperse solids with the size of no more than 100 micron. It deals with the critical mode of pneumatic conveying through horizontal pipes which is the most power efficient one. The paper objective is in studying the influence of the pipe diameter and fine disperse solids mass flow rate on the pneumatic conveying basic parameters – the air flow critical velocity v_{cr} and the specific (across the pipe length unit) pressure loss $\frac{\Delta p}{L}$ corresponding with it. The current design technique of the above given parameters is used for the objective achievement. The technique is developed by the Institute of Hydromechanics of the National Academy of Sciences of Ukraine together with the Automobile Transport and Highway Engineering Institute of Donetsk National Technical University.

Depending on the air flow mean velocity there can be three modes of bulk materials pneumatic conveying through horizontal pipes: solids stable motion without lower wall saltation mode, solids unstable motion with partial or full saltation mode and the critical mode isolating the pneumatic conveying stable and unstable modes from each other.

Solids stable motion is observed at sufficiently high mean velocities of the air flow and is characterized by the solids conveying in the suspended state and their almost even distribution throughout the pipe cross section. In this case the solids suspending process, determined by the flow velocities vertical turbulent fluctuations, prevails over gravity. At lower velocities gravity prevails and therefore solids redistribution throughout the pipe cross section is observed: the greater concentration appears near the pipe lower section and the smaller – near the upper one. With the further air velocity decrease the solids major part gathers near the pipe bottom causing the conveying process stability interrupt. And finally at the much lover velocities the settled layer forms on the pipe lower wall.

The air flow velocity, corresponding with the beginning of solids conveying process stability interrupt, i. e. the lower wall saltation beginning, is called the pneumatic conveying critical velocity. It should be noted that at the critical velocity the pressure specific loss is the smallest in comparison with specific pressure losses at greater velocities or the velocities that are smaller the critical one, thus the pneumatic conveying critical mode is considered the most economic efficient.

The algebraic equation, describing the fine disperse solids pneumatic conveying critical mode, has the following form [1]:

$$\bar{\lambda}\left[1+\left(\frac{\rho_S}{\rho}-1\right)\frac{\alpha}{1+\alpha}\right]\lambda\frac{v_{cr}^2}{2gD}=\left(\frac{\rho_S}{\rho}-1\right)K; \quad (1)$$

$$\bar{\lambda} = \left[1 - \;\; 1 - \varphi \;\; th \;\; 47{,}16\sqrt{\alpha} \;\; \right]; \tag{2}$$

$$\varphi = 0{,}127 + \;\; 1 + 1{,}016\,\mathrm{Re}_S \;\; 0{,}022\,\mathrm{Re}_S; \tag{3}$$

$$\alpha = \frac{G_S}{\rho_S F v_{cr}}; \tag{4}$$

$$K = \begin{cases} \beta_1 \alpha & \text{at } \alpha \le 0{,}04; \quad (5) \\ 0{,}04\beta_1 + \;\; \alpha - 0{,}04 \;\; \beta_2 & \text{at } \alpha > 0{,}04. \quad (6) \end{cases}$$

The following notations are accepted in (1)–(6): ρ_S, ρ – solids and the air density; G_S – solids mass flow rate; v_{cr} – air flow critical velocity; λ – hydraulic resistance coefficient; g – gravitational acceleration; D – pipe inner diameter; Re_S – Reynolds number for solids:

$$\mathrm{Re}_S = \frac{dw}{v}, \tag{7}$$

where d and w – solids diameter and the free fall velocity (settling velocity);

v – air kinematic viscosity. The coefficients β_1 and β_2 in (5) and (6) depend on the diameter ratio $\frac{d}{D}$.

The equation (1) obtained on the assumption that the air is an incompressible medium. As in the operating facilities the ratio between the pressure losses at the pipe ends Δp and the pressure in the pipe original section p_1 does not exceed 0.05 as a rule, thus in this case according to [2] the air compressibility can be neglected.

For the equation (1) accuracy degree determination, the critical velocity v_{cr} designed values, obtained from the solution of the equation for the pneumatic conveying specified conditions, are compared with the experimental values. The experimental data of v_{cr} while cement, ash, coal dust [3] and iron ore concentrate [4] measuring is used for this purpose. As a result it is found out that the standard relative deviation of v_{cr} designed values from the experimental ones does not exceed 3 %.

For the determination of the pipe diameter and solids mass flow rate influence on the abovementioned parameters, pneumatic conveying of milled iron ore concentrate with the mean size $d = 80$ micron and the density $\rho_S = 4500\,\text{kg/m}^3$ is considered. The critical velocity of the material conveying air through the horizontal pipe is determined by the equation (1) solution. At that the pipe diameter varied from 50 to 100 mm and the solids mass flow rate was from 500 to 1500 kg/hour. The air density was taken equal to 1.2 kg/m^3 and its kinematic viscosity $v = 0{,}15 \cdot 10^{-4}\ \text{m}^2/\text{sec}$.

The equation (1) was solved by the graphical method. For the pneumatic conveying specified conditions. For the specified pneumatic conveying conditions F_1 and F_2 versus the arbitrarily assigned values of the v_{cr} curves, being the equation (1) left and the right parts, correspondingly, were plotted.

The equation (1) left and right parts physically being the pressure specific loss (at the pipe length division unit), related to the air unit weight and corresponding with the pneumatic conveying critical mode. Having taken the equation (1) right part as the pressure losses expression, it can be written:

$$\frac{1}{\rho g} \frac{\Delta p}{L} = \left(\frac{\rho_S}{\rho} - 1 \right) K, \tag{8}$$

where Δp pressure losses throughout the pipe designed segment length L.

From (8) we obtain

$$\frac{\Delta p}{L} = \rho g \left(\frac{\rho_S}{\rho} - 1 \right) K. \qquad (9)$$

Specific pressure losses designed values were determined for the pneumatic conveying conditions analogous with the critical velocity. The parametric, by solids G_S flow rate, v_{cr} and $\frac{\Delta p}{L}$ values versus the pipe diameter D curves are shown in figure 1 and 2, respectively.

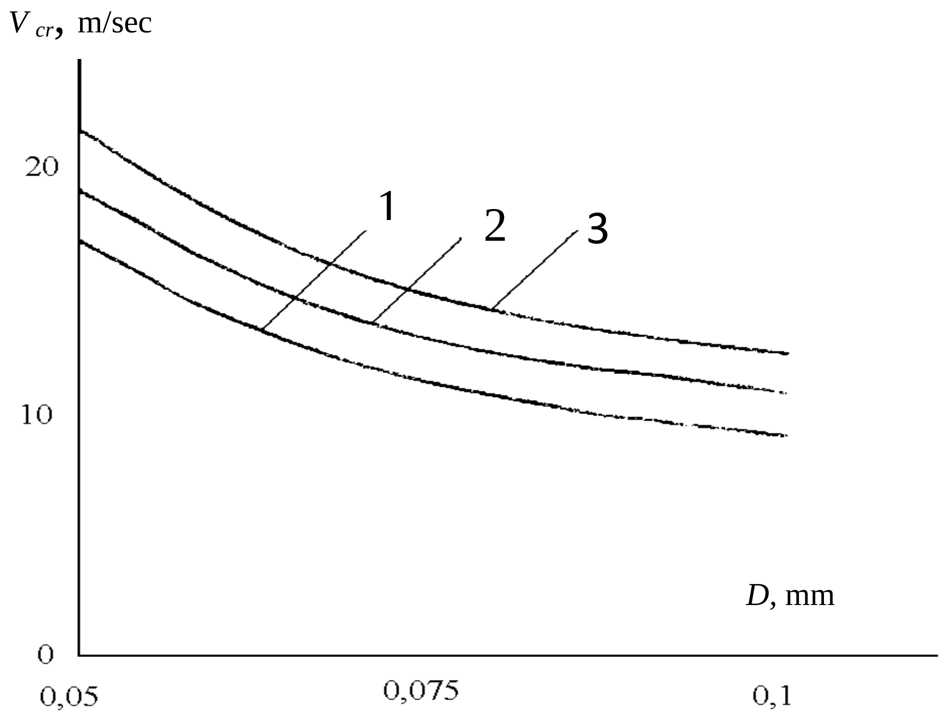

Figure 1 – The dependence of v_{cr} from D and G_S; G_S kg/hour: 1 – 500; 2 – 1000; 3 – 1500

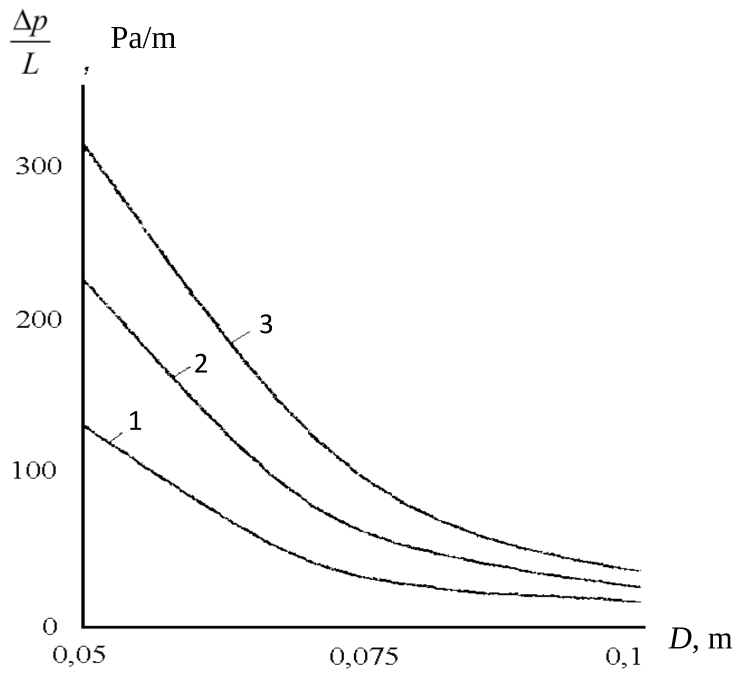

Figure 2 – The dependence of $\frac{\Delta p}{L}$ from D and G_S; G_S kg/hour: 1 – 500; 2 – 1000; 3 – 1500

In figures 1 and 2 it can be seen that the air critical velocity and the specific pressure loss, corresponding with it, decrease with the pipe diameter enlargement at the specified solids mass flow rate and the parameters increase with the solids mass flow rate increase at the specified pipe diameter.

Using the above mentioned methods of the parameters v_{cr} and $\frac{\Delta p}{L}$ design, the curves analogous to the curves in the figures 1 and 2 can be plotted for any fine disperse material. The indicated curves are needed for pneumatic conveying facilities engineering and development.

Bibliography

1. Криль С. И. Гидравлический расчет потоков газовзвесей / С. И. Криль, М. Н. Чальцев // Промислова гідравліка і пневматика. – Вінниця: ВДАУ, 2005. – № 4 (10). – С. 26–29.

Kril S. I. Gidravlicheskiy raschet potokov gazovzvesey (Suspension Flows Hydraulic Design) / S. I. Kril, M. N. Chaltsev // Promyslova hidravlyka i pnevmatyka. – Vinnytsia: VDAU, 2005. – № 4 (10). – S. 26–29.

2. Альтшуль А. Д. Гидравлика и аэродинамика / А. Д. Альтшуль, П. Г. Киселев. – М.: Стройиздат, 1974. – 327 с.

Altshul A. D. Gidravlika i aerodinamika (Hydraulics and Aerodynamics) / A. D. Altshul, P. G. Kiselev. – M.: Stroyizdat, 1974. – 327 s.

3. Исследовать параметры пневмотранспортных потоков повышенной и средней концентрации // Отчет о НИР, Автомобильно-дорожный инст-т ДонНТУ. – Горловка. – 2002. – 128 с.

Issledovat parametry pnevmotransportnykh potokov povyshennoy i sredney kontsetrstsii (Flows of Higher and Mean Concentration Research) // Otchet o NIR, Avtomobilno-dorozhnyi inst-t DonNTU. – Gorlovka. – 2002. – 128 s.

4. Кузнецов Ю. М. Теоретические основы, принципы конструирования и внедрение устройств для интенсификации процессов производства чугуна и стали путем вдувания в металл порошкообразных материалов: дисс. … док. наук / Ю. М. Кузнецов. – Свердловск, 1987. – 321 с.

Kuznetsov Yu. M. Teoreticheskiye osnovy, printsipy konstruirovaniya i vnedreniya ustroystv dlya intensifikatsii protsessov proizvodstva chuguna i stali putem vduvaniya v metal poroshkoobraznykh materialov (Theoretical Basis, Principles of Engineering and Implementation of the Devices for the Intensification of the Process of Cast Iron and Steel Manufacturing by Means of Dusty Materials Blowing in): diss. … dok. nauk / Yu. M. Kuznetsov. – Sverdlovsk, 1987. – 321 s.