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PIPELINES HYDRAULIC DESIGN FOR PNEUMATIC CONVEYING SYSTEMS

The set closed system of hydraulic equations, describing gas suspensions steady flow through pipelines being the basis of the pipelines aerodynamic design for industrial pneumatic conveying systems is given.

Dispersed solids pumping through pipelines by means of gas (air) flow is widely used in different industries. According to the experience, pneumatic conveying of solids can be carried out in the continuous, ridge or plug flow mode. The present work deals with the continuous one.

While the continuous gas suspension motion through a horizontal pipeline, gravity effect plays an essential role in the solid particles uneven spread throughout the pipe cross section, thus most of the particles are located at the pipe bottom. As the unevenness degree of solids spread about the specified cross section depends upon the flow mean velocity, there is the so called critical velocity or the falling velocity at which solids start precipitating and form a siltation layer at the pipe bottom. In addition, axial asymmetry of the velocity field is observed in the flows. The point of it is that the longitudinal mean velocity profile and pipe axis are uneven and the maximum mean velocity location is above the axis. Concerning the pressure drops while pneumatic conveying, at the same mean velocity of the flow they exceed the pressure drops in the corresponding gas flow due to the additional gas energy consumption for solids conveying. The pneumatic conveying hydraulic design is more complicated than the design of an ordinary gas pipeline.

Different pneumatic conveying design methods are mentioned in the scientific literature. However they are foremost of the empiric nature, therefore their scope is limited by the experimental conditions. Furthermore various designed dependences for the determination of pressure drops are characterized by the low accuracy degree. The common disadvantage of the existing design methods is that they do not take into account the connections of the pressure losses determined by the hydraulic resistance with the kinematic structure of the flow. Thus the limitation and in some cases unacceptably low accuracy degree of the recommended design methods with a great variety of the pneumatic conveying conditions in practice do not always assure reliability and efficiency of the engineered pneumatic conveying systems.

Thus the engineering and creation practice of industrial pneumatic conveying systems sets the task of general scientifically proven engineering design method development suitable for practical application in the wide range of pneumatic conveying conditions modification. Several considerations concerning the development of the method are given below. They are based on the current scientific achievements in the field of hydraulic pipeline transport researches.

Gas suspension flows at pneumatic conveying, analogous to flows of solids and liquid mixes at hydraulic conveying are settled. The main difference between them is that gas suspensions flows in the pipes of constant cross section are uneven due to constant gas density change along the pipe, whereas the hydraulic liquid mixtures are even. Therefore from the methodological point of view, the development of the pneumatic conveying hydraulic design method based on the current method of pulp pipes hydraulic design developed in [1], considering the carrier (gas) compressibility, is of interest.

At pneumatic conveying and gas pipelines hydraulic design, two occasions are considered: low pressure motion at minor relative pressure drops between the initial and finite pipeline cross sections; high pressure motion at high drops. However, independent of the case under consideration, the original equations for the task solution of the gas suspension motion in the pipeline should be continuous, energy balance and hydraulic resistance equations. While equating let us suppose that the gas expansion process is adiabatic that is there is no heat exchange between the gas suspension and the environment. Furthermore the flow is considered even. This means that the velocity, pressure, density, temperature and concentration are constant in the pipe cross section and change when passing from one section to another one. In this case the hydraulic equations of gas suspension motion set up for the pipe part between two random cross sections 1 and 2 are as follows:

$$\rho_1(1-c_1)V_1=\rho_2(1-c_2)V_2; \tag{1}$$

$$\rho_S c_1 V_1=\rho_S c_2 V_2; \tag{2}$$

$$\frac{1}{2}\rho_1{}^*V_1^2+P_1+\rho_1{}^\circ gZ_1+\rho_1{}^\circ m\frac{RT_1}{k-1}=$$
$$=\frac{1}{2}\rho_2{}^*V_2^2+P_2+\rho_2{}^\circ gZ_2+\rho_2{}^\circ m\frac{RT_2}{k-1}+\Delta P \tag{3}$$

where the subindexes 1 and 2 specify the values applicable to the first and the second cross sections respectively. In the equations (1) – (3) the following nomenclature is agreed: V – mean velocity of gas suspensions motion through the pipe cross section; ρ and ρ_S – gas and solids density; c – flow rate volume concentration equal to the ratio between the solids volume flow rate and the gas suspension volume flow rate; P – pressure in the gas; g – gravity acceleration; Z – center of gas suspension mass physical height; m – flow rate mass concentration equal to the ratio between the gas mass flow rate and the gas suspension flow rate; R – gas constant; k – adiabatic value equal to the ratio between gas heat capacities at constant pressure and volume (for the air under normal conditions k = 1,405); T – absolute temperature; ΔP – pressure losses, determined by the friction between the gas suspension and pipe walls and local hydraulic resistances; value ρ^0 – is the gas suspension flow rate density and the value ρ^* – the effective density. The densities ρ° and ρ^* included into (3) are evaluated by the formulas

$$\rho^\circ=\rho(1-c)+\rho_S c; \tag{4}$$

$$\rho^*=\rho\frac{(1-c)^3}{(1-s)^2}+\rho_S\frac{c^3}{s^2}, \tag{5}$$

where s – solids volume concentration.

The equations (1) and (2) reflect the continuity of solids and gas mass flow rates along the flow, whereas the equation (3) is Bernoulli equation for the real gas suspension flow. The first three members in the both parts of the equation have the same physical meaning with the corresponding members of an ordinary Bernoulli equation for the incompressible homogeneous liquid flow. The fourth member is related to the gas temperature difference

$$m\frac{RT}{g(k-1)}.$$

For horizontal pipes the potential energies contrast (per unit volume) $\rho_1{}^\circ gZ_1-\rho_2{}^\circ gZ_2$ can be neglected. Supposing furthermore that the flow is isothermal, the equation (3) is simplified and becomes

$$\frac{1}{2}\rho_1{}^*V_1^2+P_1=\frac{1}{2}\rho_2{}^*V_2^2+P_2+\Delta P \tag{6}$$

The system of four equations (1), (2), (5) and (6) is not closed as contains seven undetermined values ρ, ρ*, c, s, V, P and Δ P. The ideal gas law

$$P = \rho RT(T = const), \tag{7}$$

and the equation of C and S concentrations connection, obtained in [1] are used for its closing

$$c = s\left[1 - f(\xi)(1-s)^{2,16}\left(\frac{V_{cr}}{V}\right)^{1,66}\right]; \tag{8}$$

$$f(\xi) = 0,45\left[1 + sign\xi \cdot th(0,967)|\xi|^{0,6}\right]; \tag{9}$$

$$\xi = \lg \mathrm{Re}_S - 0,88, \tag{10}$$

where V_{cr} – the critical velocity of pneumatic conveying;

$\mathrm{Re}_S = Wd_S/\nu$ – the Reynolds number expressed via the solid particles terminal velocity W, their mean diameter d_S and the kinematic viscosity of the carrier ν.

Concerning the value ΔP it is the one estimated by the procedure analogous to the one developed in the [1] hydraulic conveying design method and taking into account the features of the two phase flow kinematic structure. As stated in [2], per its accuracy, the method is applicable to pneumatic conveying as well.

Therefore, the obtained closed system of hydraulic equations, describing the isothermal flow of gas suspensions in the pipes is the basis of the general pneumatic conveying method. The preliminary testing of this method in the conditions of specific experimental data showed that the designed values of the pneumatic conveying parameters satisfactory correspond with the practical ones.

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