Today, in the chemical, petrochemical, and petroleum refining industries, the transport of catalyst and other granular materials and dusts between vessels is most often accomplished in the fluidized state, in which the volume concentration of solid particles in the stream may range from 5% to 40-50%. This form of pneumotransport has a number of important advantages over conventional pneumotransport [1].

The movement of high-concentration two-phase streams has not been studied adequately. The present work was devoted to study of the hydraulic resistance for pneumotransport in the fluidized state in a stabilized section of a mass transport line.

At comparatively low velocities of the transport agent, the pressure drop in vertical airlifts is consumed mainly in lifting the material ($\Delta P_1$) and in friction of the particles with each other and on the pipe walls ($\Delta P_2$). The energy losses in gas friction at the pipe walls are usually very small.

For an elementary section of the pipe, we can write

$$\Delta P = \Delta P_1 + \Delta P_2$$

(1)

The first term $\Delta P_1$ is determined from the well-known expression

$$\Delta P_1 = \rho g \varepsilon (1 - \varepsilon) \Delta H,$$

(2)

where $\rho$ is the density of the granular material; $\varepsilon$ is the void fraction of the two-phase stream; and $\Delta H$ is the length of the section.

The second term $\Delta P_2$ can be found by a phenomenological approach to studying the movement of disperse streams, using a formula analogous to the D'arcy equation for pipe hydraulics:

$$\Delta P_2 = \lambda^* \frac{u^2}{2} \rho_s (1 - \varepsilon) \frac{\Delta H}{D},$$

(3)

where $D$ is the diameter of the transport line; $u$ is the velocity of the solid particles relative to the pipe wall.

In order to calculate the coefficient of friction $\lambda^*$ in pneumotransport over a range of concentrations from 5 to 30%, we have proposed in [2] the empirical equation

$$\lambda^* = 5.5 \left(1 - \frac{d_e}{D}\right)^2 Fr_s^{-0.65},$$

(4)

where $d_e$ is the equivalent diameter of the particles; $Fr_s = u^2/(gd_e)$ is the Froude number.

For values $D/d_e > 25$, Eq. (4) assumes the form (with an error of no more than 8%)

$$\lambda^* = 5.5 Fr_s^{-0.65}.$$

(5)

The complexity of calculating hydraulic resistance in pneumotransport in the fluidized state is due to expansion of the transport agent as it passes up the transport line. The parameters in Eqs. (2)-(4) change with height; hence, there is also a variation in the pressure drop in the different sections of the transport line. In order to obtain a calculation formula for the entire line, Eq. (1) must be integrated.
Let us express the velocity of the particles in terms of the specific weight flow rate

$$u = \frac{q}{g \rho_s (1 - \epsilon)}$$  \hspace{1cm} (6)

Transforming Eqs. (3) and (4), with Eq. (6) taken into account, we obtain

$$dP = g \rho_s (1 - \epsilon) dH + 5.5 \frac{q^{0.7} d^{0.65}}{2g^{0.35} D} (g \rho_s^{0.3}) (1 - \epsilon)^{0.3} \frac{d \rho_s}{dH}.$$  \hspace{1cm} (7)

Within the concentration interval from 5 to 30%, we can write (with an accuracy within 10%)

$$(1 - \epsilon)^{0.3} = 0.4 + (1 - \epsilon).$$  \hspace{1cm} (8)

Then Eq. (7) assumes the form

$$dP = \left[ (g \rho_s + 7.7 \frac{q^{0.7} d^{0.65}}{2g^{0.35} D} \rho_s^{0.3} \rho_x^{0.3}) - (g \rho_s + 5.5 \frac{q^{0.7} d^{0.65}}{2g^{0.35} D} \rho_s^{0.3} \rho_x^{0.3}) \right] \frac{d \rho_s}{dH}.$$  \hspace{1cm} (9)

In order to integrate this equation, we must know how the void fraction varies with the pressure. For this purpose, we have used a modified equation of Todes [3]

$$\epsilon = \left( \frac{18Re^* + 0.36Re^{**}}{18Re^{**}} \right)^{0.21}$$  \hspace{1cm} (10)

where $\phi$ is the hydrodynamic factor for particle shape.

The feasibility of using Eq. (10) in calculating pneumotransport in the fluidized state with concentrations from 5 to 30% has been confirmed by experiment [4]. In a fluidized bed of great height, as a result of gas expansion, the linear velocity of the gas $V_g$ will increase; however, for the isothermal pneumotransport that is normally observed, the mass velocity $V_g \rho$ remains constant. The value of the Archimedes number varies in proportion to gas density:

$$Ar = \frac{g d^3}{\eta^2 \rho_s \rho},$$  \hspace{1cm} (11)

where $\eta$ is the dynamic viscosity of the gas; $\rho$ is the density of the gas.

Considering that, for isothermal expansion of the gas, $\rho = \rho_i P / P_i$, we have

$$Ar = Ar_i \frac{P}{P_i},$$  \hspace{1cm} (12)