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METHOD OF IMPROVING ENERGY EFFICIENCY OF VERTICAL PNEUMATIC TRANSPORT BY A RETARDED COMPACT LAYER

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The energy characteristic of pneumatic transport by a retarded compact layer is considered and recommendations are given on means of reducing its energy consumption.

A significant disadvantage of all kinds of pneumatic transport is high power consumption. There are little data in the literature on a comparison between the energy efficiency of different kinds of pneumatic transport, and the opinions of different authors on this question often diverge. Zabrodskii [1] considers that the pneumatic transport material is not efficient at low concentrations; transport in an ascending fluidized bed is much more advantageous. Reznikovich and Todes [2] carried out a theoretical investigation of the energy characteristics of vertical pneumatic transport and arrived at the deduction that the greatest energy efficiency can be achieved for either a low volume concentration of a two-phase stream ($\varepsilon \to 1$) or volume concentrations close to the concentration of the immobile layer ($\varepsilon \to 0.4$). Vel'shof [3] as well as Sandy, Daubert, and Jones [4] assert that the energy expenditure in pneumatic transport in a compact layer is much higher than in pneumatic transport with low concentration. Taking such a discrepancy in the estimation of the power consumption of different kinds of pneumatic transport into account, as well as the explicit inadequacy of the appropriate data on pneumatic transport by a retarded compact layer (RCL), an investigation of the energy characteristics of this kind of pneumatic transport is an important problem.

The efficiency

$$\eta = \frac{gG_t H}{LQ_0}. \tag{1}$$

is usually considered the principal energy characteristic of vertical pneumatic transport.

The efficiency of the compressor is not introduced into the equation since it is more convenient to take into account just the efficiency of the pneumatic lifter itself and not the efficiency of the pneumatic transport unit as a whole when comparing the energy expenditures of different kinds of pneumatic transport.

Let us clarify the dependence of the RCL pneumatic lifter on the parameters of the transportation process. The specific work of gas compression for an isothermal process is defined by

$$L = p_0 \ln \frac{p_f}{p_0}. \tag{2}$$

Consumption of the material is found from the formulas

$$G_t = us(1-\varepsilon)\rho_t. \tag{3}$$

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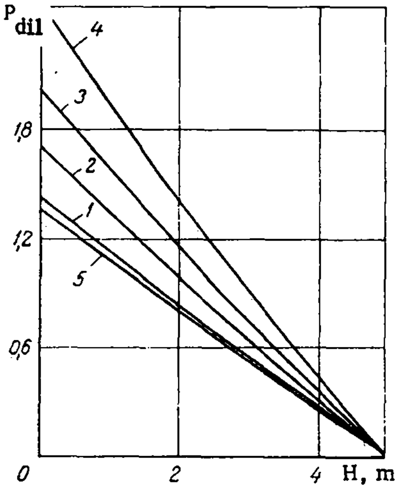

Fig. 2. Pressure change over the height of a RCL variable section pneumatic lifter [transport of polymer material: 1) v_0 = 0.80 m/sec, D_0/D_h = 0.39; 2) 0.90 and 0.39; 3) 1.05 and 0.35; 4) 1.20 and 0.35; 5) 0.80 and 0.41]. P_{dil}, bar; H, m.

reliable transporting velocity in vertical RCL pneumatic lifters can be determined from the condition [5]

$$u_{r.t} = (1.8 - 2.0) v_{fl} . \tag{6}$$

The reliable transporting velocity should also be recommended as optimal for selection of the gas velocity in RCL pneumatic transport.

The efficiency values obtained in our experiments (for almost optimal apparatus operating modes) were 12-15% on the average, and reached 20-22% in a number of cases. The most extensive investigations of the energy indices of pneumatic transport apparatus with low concentrations were performed in [7]. The data presented indicated that the efficiency of such units fluctuates between 3-14% limits, being 8-10% on the average. The lower energy consumption in the RCL pneumatic transport is due to the lower gas consumption since such pneumatic transport is realized at gas velocities many times less than in pneumatic transport with low concentration. For example, the gas velocity recommended in the usual pneumatic transport of semolina is 15 m/sec, while a 0.2-m/sec velocity is sufficient for RLC transport. Therefore, the energy efficiency of RCL pneumatic transport is greater than low-concentration pneumatic transport.

One of the features of RCL pneumatic transport is the greater specific pressure losses and its associated significant gas expansion (magnification of its velocity) along the height of the transport pipeline. The recommendations we presented for the selection of the optimal value of the gas velocity refer to the velocity in the lower part of the RCL pneumatic lifter (in direct proximity to the feeder). The gas velocity will grow during upward motion of the two-phase stream and the danger of an "obstruction" is eliminated. However, a growth in the specific pressure losses hence occurs and a consequent reduction in the energy indices of the pneumatic lifter.

Variable section transport pipelines, whose diameter increases with height, can be used to reduce the pressure losses. Application of such pipelines had earlier been recommended in [8] to assure a constant solid phase concentration to transport a continuous stream. We set assurance of constancy of the transporting gas velocity over the transportation height as the basis of designing the variable section pipeline profile.

Let us use the stream continuity equation by writing it for the gas and solid phases:

$$\rho_0 v_0 s_0 = \rho_x v_x s_x, \tag{7}$$

$$u_0 s_0 (1 - \varepsilon_0) = u_x s_x (1 - \varepsilon_x), \tag{8}$$

and also the condition that the process is isothermal:

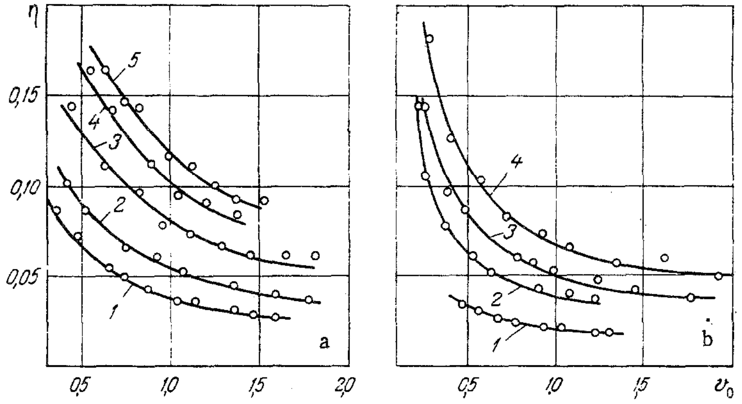

Fig. 1. Dependence of the efficiency of an RCL pneumatic lifter on the transportation process parameters: a) cationite transport in a 40-mm-diameter pipeline [1) $D_0/D = 0.15$; 2) 0.20; 3) 0.25; 4) 0.30; 5) 0.35]; b) semolina transport in a 28-mm-diameter pipeline [1) $D_0/D = 0.18$; 2) 0.26; 3) 0.32; 4) 0.39).

Taking account of (2) and (3), Eq. (1) as well as the expressions to determine the mean velocity of the material [5] become

$$\eta = \frac{2.53\,K_{\mathrm{m}}^{0.5}\left(\frac{D_0}{D}\right)^{0.61}\left(\frac{D_0}{d}\right)^{0.60}\left(\frac{\rho_0}{\rho_{\mathrm{t}}}\right)^{0.46}\rho_{\mathrm{t}}gH(1-\varepsilon)}{p_0\ln\frac{p_{\mathrm{f}}}{p_0}}. \tag{4}$$

For given transporting material and pneumatic transport unit, the pressure losses in the transporter pipeline, and therefore, the quantity p_f also, are determined mainly by the gas velocity and the degree of particle deceleration [6]. Hence, by analyzing (4), the deduction can be made that the efficiency of the pneumatic lifter should also depend on these same parameters. Data obtained during operation of an experimental apparatus [6] were used to refine the nature of this dependence. Values of the material consumption, the pressure in the feeder of the apparatus, as well as the volume gas consumption were measured during the experiments. The results of the experiments were processed by means of Eq. (1). A dependence of the efficiency of the RCL vertical pneumatic lifter on the gas velocity during transport of cationite and semolina in 5-m-long steel pipelines 28 and 40 mm in diameter is represented in Fig. 1a, b. It is seen from the figure that the maximum efficiencies are achieved at low velocities and maximum diameters of the decelerating nozzles (low deceleration intensity). Let us determine the optimal values of the parameters mentioned.

The deceleration intensity of material during RCL pneumatic transport is estimated by the magnitude of the simplex D_0/D. As the value D_0/D increases the deceleration intensity is reduced, and as is seen from the figure, the efficiency is raised. However, as has been shown earlier [5], values 0.38-0.41 of this simplex are critical. A further increase in this parameter results in spoiling the stability of the transportation process, the compact layer of material in the pipeline is broken into individual batches separated by gas gaps, and the RCL pneumatic transport goes over into a "free" unretarded pneumatic transport. Hence, the values 0.30-0.35 of the simplex should be recommended as optimal. Then

$$D_0 = (0.30 - 0.35)\,D. \tag{5}$$

It was noted earlier [5] that the correct selection of the gas velocity is quite important from the viewpoint of assuring stability of the transportation process. Selection of lowered gas velocities results in the formation of "obstructions" in the transport line. On the other hand, as is seen from Fig. 1a, b, exaggeration of the gas velocity reduces the energy efficiency of the RCL pneumatic transport. The minimum gas velocity at which the mode of continuous, stable transportation is realized is called the reliable transporting velocity. It depends on a whole number of factors (the physical properties of the material and the transporting medium, the method of feeding material into the pipeline, the deceleration conditions, the capacity of the material to form particle clusters, etc.). It is shown that the

$$\frac{p_0}{\rho_0} = \frac{p_x}{\rho_x}. \tag{9}$$

The parameters with subscript 0 in (7)-(9) refer to the pipeline section s_0 in the upper part (before the braking cap), and the parameters with subscript x to the pipeline section at the arbitrary height (s_x).

Since $v_x = v_0$ (by assumption) and $\varepsilon_x = \varepsilon_0$ (according to experimental results), we can obtain from the equations considered

$$\rho_x = \rho_0 \frac{p_x}{p_0}, \tag{10}$$

$$u_x = u_0 \frac{p_x}{p_0}, \tag{11}$$

$$s_x = s_0 \frac{p_0}{p_x}. \tag{12}$$

Substituting (10) and (11) into the dependence governing the law of pressure variation over the height of the constant section RCL pneumatic lifter [6], we obtain

$$\frac{dp_x}{dH} = \varphi \left[72 \frac{(1-\varepsilon_0)^2 \mu \left(v_0 - \varepsilon_0 u_0 \frac{p_x}{p_0} \right)}{\varepsilon_0^3 d^2} + 0{,}6 \frac{(1-\varepsilon_0) \rho_0 \frac{p_x}{p_0} \left(v_0 - \varepsilon_0 u_0 \frac{p_x}{p_0} \right)^2}{\varepsilon_0^3 d} \right] \div$$

$$+ 0.32 \left(\frac{D_\mathrm{n}}{d} \right)^{1.32} \left(\frac{p_0}{p_x} \right)^{0.27} \left(\frac{u_0^2}{gd} \right)^{-0.62} \left(\frac{v_0}{u_0} \right)^{0.87} \frac{u_0^2 \rho_\mathrm{t} (1-\varepsilon_0)}{2D_\mathrm{n}}. \tag{13}$$

Exact integration of (13) is impossible; however, it can be solved by numerical methods. Having determined the law of pressure variation with respect to the height of a transport pipeline of curvilinear profile, the profile itself can be constructed by using the dependence (12).

Equation (13) has been solved numerically by using an "Odra" electronic computer in application to the transport of a polymer material for different transportation modes. The results of the calculations are represented in Fig. 2. Comparing the computed results of the specific pressure losses with the experimental data for constant section pipes discloses a significant diminution in the pressure losses of variable section pipelines, which permits raising the efficiency of a RCL pneumatic transport unit.

Fabrication of a pipeline of complex curvilinear profile under industrial conditions is fraught with great difficulties, hence replacement of the design curvilinear profile by a step profile with the requisite degree of accuracy must be recommended. Pipeline sections of different diameter must be connected by conical inserts with a cone angle on the order of 10°.

NOTATION

ε, porosity of the moving layer; d, mean equivalent particle diameter of the transporting material; ρ_t, apparent solid-phase density; ρ_0, gas density under normal conditions; Q_0, volume gas consumption (referred to normal conditions); G_t, mass flow rate of the granular material; v, filtration velocity; v_0, gas velocity at the exit from the transport pipeline; u, mean velocity of material motion; v_{fl}, velocity of the beginning of fluidization of the transporting material; H, transportation height; D, diameter of a constant section transport pipeline; D_0, diameter of the braking nozzle; s, constant diameter pipeline section; D_n, variable section pipeline diameter (before the braking nozzle); p_f, pressure in the pneumatic lifter feeder; p_0, pressure at the exit from the transport pipeline; L, specific work (per unit volume) of gas compression; K_m, coefficient of transporting material mobility.

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MASS TRANSFER DURING EXTRACTION OF A SOLID SUBSTANCE FROM A MIXTURE OF POLYDISPERSE POROUS PARTICLES

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Mass transfer during the extraction of a solid soluble phase from a mixture of polydisperse porous particles is considered. Equations are obtained which permit prediction of the kinetics of the extraction.

Few cases of the extraction of a soluble solid phase from porous particles are known in practice (hydrometallurgy, chemical industry, nutrition, etc.). Realization of the processes mentioned under production conditions requires knowledge of the kinetic regularities permitting computation of the extraction apparatus.

Mainly, the kinetics of extraction from monodisperse porous particles under conditions of constancy of the moving force are examined in papers devoted to this problem [1-4]. However, cases of extraction from a polydisperse mixture with a variable moving force almost always occur in practice. The present paper is devoted to a study of this problem.

If it is assumed that the porous particles have a spherical shape and an isotropic structure with respect to diffusion, then the quantity of material being transferred into solution can be determined from the fundamental diffusion equation

$$\frac{d(G_0-G)}{dt}=-D_mF\left(\frac{\partial c_1}{\partial r}\right)_{r=R}. \tag{1}$$

Taking the concentration distribution with the porous particle [5] in the form

$$\frac{c_s-c_1}{c_s-c}=\frac{1-\dfrac{r_0}{r}}{1-\dfrac{r_0}{R}} \tag{2}$$

and the mass of material remaining within the porous particle at the time t equal to

$$G=\frac{4}{3}\pi r_0^3m=\frac{4}{3}\pi\varphi_0^3R^3m, \tag{3}$$

Eq. (1) reduces to the form

$$\frac{d\varphi_0}{dt}=-\frac{D_m}{mR^2}\cdot\frac{(c_s-c)}{\varphi_0(1-\varphi_0)}. \tag{4}$$

In combination with the material-balance equation

$$M_0\left(1-\frac{M}{M_0}\right)=W(c-c_1)$$

we can use (4) to describe the kinetics of extraction from a polydisperse mixture of particles. To do this the polydisperse mixture is considered as a set of separate fractions, each of which introduces its contribution to the total kinetics of extraction.

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