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HYDRODYNAMICS OF TWO-CHAMBER VORTEX DRYERS WITH COUNTER-COLLIDING TWISTED FLOWS OF A GASEOUS SUSPENSION

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Results of experimental studies of the hydrodynamics of two-chamber vortex dryers are presented. Empirical relations are obtained for determining the critical velocity of gas outflow and the retentivity of an apparatus as a function of the operating and design parameters and the properties of the disperse material. It is found that the hydraulic resistance of the developed dryers does not depend on the properties of the treated material and is proportional to the square of the gas flow rate. Relations for calculation of the coefficients of hydraulic resistance for apparatuses not loaded and loaded with material are obtained.

Flat (disk) vortex dryers are widely used in various branches of industry [1-5], for example, for drying fiber composites, styrene copolymer, lactose, and other disperse and fiber materials. In these materials the rate of heat and mass transfer processes increases substantially due to growth of the relative velocities of motion of the interacting phases, the concentration of the material in the apparatus, and the time of residence of the material in the zone of drying. Thus, the moisture capacity of the working volume of flat vortex dryers can attain 600–1580 $kg/(m^3 \cdot h)$ [2, 4], thus stipulating their low metal content and small size.

A new class of flat vortex dryers with counter-colliding twisted flows of a gaseous suspension (CCTFGS) has been developed [6-8]. Compared to disk vortex dryers, they are two-chamber and possess a common highly active zone where multiple collisions, retardation, and overflow of material particles from one twisted flow to the other and constant recirculation of them in flat vortex flows of gaseous suspension take place. This leads to the creation of a highly active hydrodynamic mode of interaction between the heat carrier and the particles of moist material in which maximum interphase velocity is attained and the largest surface of contact of the phases is provided.

Figure 1 presents one of the designs of the developed dryers with CCTFGS, namely, a two-chamber vortex dryer with cylindrical chambers [7, 8]. It is comprised of two cylindrical vortex chambers 1 coupled to each other by side surfaces with formation of crest 2 and overflow window 3, slot nozzle 4 positioned at the site of the upper coupling of chambers 1, connecting pipe 5 for heat-carrier supply, connecting pipe 6 for supply of moist material that is placed above slot nozzle 4, bypass gas channels 7, and exhaust air duct 8.

The heat carrier is fed to connecting pipe 5 and is divided into two flows: one is directed to slot nozzle 4 through bypass gas channels 7 and the other is directed to vortex chambers 1 through tangential intakes. Moist material arrives at connecting pipe 6 and is injected by plane jets of heat carrier through slot nozzle 4 to chambers 1.

The process of material drying occurs in a mode of multiple cyclic collisions between counter-twisted flows of gaseous suspension in the zone of overflow window 3 with subsequent recirculation of them in the form of counter-rotating annular layers of gaseous suspension around the perimeters of vortex chambers 1. In this case, in the zone of window 3 multiple collisions, retardation, and overflow of particles of the material from one chamber to the other take place. After this treatment the dried particles are carried away by the flow of waste heat carrier to exhaust air duct 8.

In this paper, the hydrodynamics of two-chamber vortex dryers with CCTFGS is studied.

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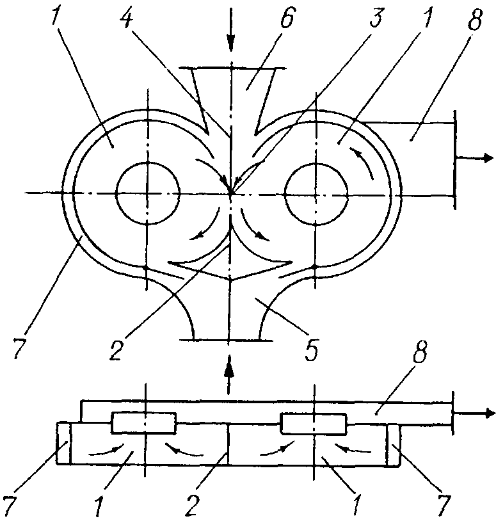

Fig. 1. Two-chamber vortex dryer with cylindrical chambers.

The experimental studies showed that the operating and design parameters substantially affect the retentivity and hydraulic resistance of two-chamber vortex dryers. Here the design of the dryer that provides maximum retentivity with minimum hydraulic resistance is the most rational. This is stipulated by the fact that the mean time of residence of the material in the apparatus increases with the retentivity, thus providing a more complete process of drying. At the same time, a decrease in the hydraulic resistance leads to a reduction in energy consumption for organization of twisting and pneumotransport of the gaseous suspension in the apparatus.

Theoretical studies of the author showed that the value of the retentivity q_0 is a function of many variables, the main ones of which are the gas flow rate, the diameter and density of the particles of the material, and the geometric dimensions of the apparatus [9].

Figure 2a presents the experimental dependence of the retentivity of two-chamber vortex dryers with CCTFGS on the gas flow rate for various disperse materials. The experiments were conducted on a laboratory setup with the dimensions $D = 0.2$ m, $H = 0.08$ m, $L = 0.22$ m, $d_0 = 0.08$ m, $\Sigma h = 0.05$ m.

An analysis of the results obtained shows that a value of q_0 for various disperse materials first increases in proportion to the gas flow rate to a power of 1.5. According to the data of the experiments the value of the power ranged from 1.46 to 1.53. However, on attaining the gas flow rate $V = V_{cr}$ the retentivity remains constant (Fig. 2). Here its values are different for particles of materials of different dispersivity and density. Moreover, it was found that at gas flow rates $V > (2-2.5)\, V_{cr}$ the retentivity of the dryers begins to decrease slowly. This is explained by an increase in the force of aerodynamic radial gas discharge from the apparatus and a change in the conditions of flow past the particles.

Empirical equations for determination of the critical velocity of gas outflow v_{cr} and the retentivity as a function of the geometric dimensions of the dryer, the operating parameters, and the properties of the disperse material are obtained by computer processing of experimental data recorded in experiments with two-chamber vortex dryers of different dimensions.

The relation

$$\mathrm{Re}_{cr} = 1.443\cdot 10^4 \left(\frac{D}{\Sigma h}\right)^{0.5} \mathrm{Ar}^{0.073} . \tag{1}$$

is obtained for determination of the critical value of the Reynolds number. Equation (1) is valid for

$$\frac{D}{\Sigma h} = 4 - 13.3 ; \quad \mathrm{Ar} = 1.5 - 9\cdot 10^5 .$$

At gas flow rates $V \le V_{cr}$ the equation for determination of the retentivity of two-chamber vortex dryers with CCTFGS has the form

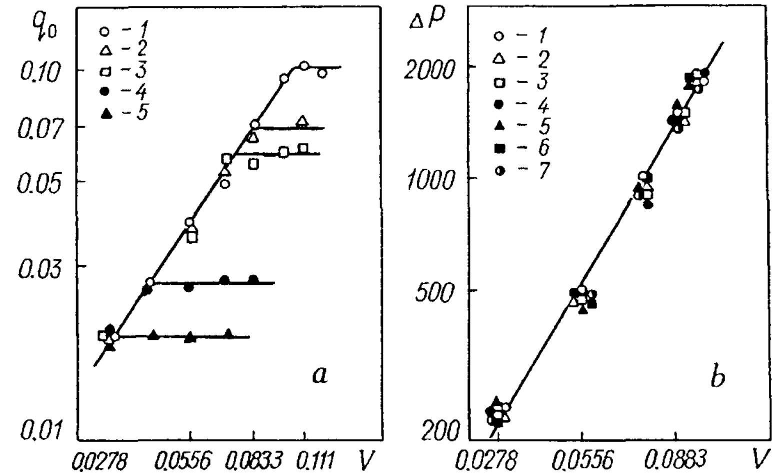

Fig. 2. Retentivity (a) and hydraulic resistance (b) of a two-chamber vortex dryer as a function of the gas flow rate for various disperse materials: a: 1) polyethylene granules; 2) millet grains; 3) lactose; 4) potato starch; 5) malachite; b: 1) malachite; 2) millet grains; 3) lactose; 4) potato starch; 5, 6, 7) polyethylene granules (d_{eq} = $3.5 \cdot 10^{-3}$, $3.25 \cdot 10^{-3}$, and $3.0 \cdot 10^{-3}$ m, respectively).

$$q_0 = A \left(\frac{V}{V_{cr}}\right)^{1.5} \left(\frac{H}{D}\right)^{0.5} \mathrm{Ar}^{0.155} . \tag{2}$$

Here $V/V_{cr} = 0.32-1.0$, $H/D = 0.15-0.8$, $\mathrm{Ar} = 1.5-9 \cdot 10^5$.

The value of the coefficient A in Eq. (2) depends on the properties of the disperse material treated and the forces of cohesive interaction between the particles and the surface of the apparatus. For the materials studied the mean value of the coefficient A varied from 0.02 to 0.0413.

The hydraulic resistance (ΔP) of the developed dryers as a function of the operating and design parameters was studied experimentally. The experiments were conducted for both apparatuses loaded and not loaded with material.

It is found experimentally that the dependence of ΔP on the gas flow rate has a quadratic character. Consequently, ζ_{in} is not related to the velocity of the gas, but is a function of the geometric dimensions of the apparatus. As a result of processing the results of the experiments on a Pentium-233 MMX computer a relation is obtained for determination of the coefficient of hydraulic resistance of two-chamber vortex dryers with built-in narrowings not loaded with material as a function of their geometric parameters:

$$\zeta_{in} = 85.5 \left(\frac{\Sigma h}{D}\right)^{1.95} \left(\frac{d_0}{D}\right)^{-1.2} \left(\frac{H}{D}\right)^{1.15} \tag{3}$$

for $\Sigma h/D = 0.075-0.25$, $d_0/D = 0.25-0.6$, $H/D = 0.2-0.8$.

Self-similarity of the hydraulic resistance to the properties of the disperse material treated is an important feature of two-chamber vortex dryers. Figure 2b presents the dependence of the hydraulic resistance of a dryer on the gas flow rate for various materials in logarithmic coordinates. The results of the experiments show that at any V = const the value of ΔP is the same for all the materials studied, which differ substantially in the density, size, and shape of the particles (Fig. 2b). Here it is found that upon filling the dryer with the material the hydraulic resistance decreases by a factor of 1.5–2 and is proportional to the square of the gas flow rate.

By generalizing the results of the experiments we obtained a relation for calculation of the coefficient of hydraulic resistance of two-chamber vortex dryers of the same retentivity loaded with material:

$$\zeta_{\text{in}(q_0)} = 36 \left(\frac{\Sigma h}{D}\right)^{1.9} \left(\frac{d_0}{D}\right)^{-1.45} \left(\frac{H}{D}\right) . \tag{4}$$

The range of variation of the parameters corresponds to that adopted in Eq. (3).

In operation of the dryers in the continuous mode the coefficient of hydraulic resistance is increased compared to the values determined by Eq. (4). This is caused by growth of pressure losses for displacement of the material, the amount of which in the dryer is increased somewhat compared to its retentivity. In this case the coefficient of hydraulic resistance of two-chamber vortex dryers is found from the relation

$$\zeta_{\text{in}(q)} = (1 + 0.45\,\mu_{\text{p}})\,\zeta_{\text{in}(q_0)} . \tag{5}$$

The flow-rate concentration of the disperse materials varied within the range $\mu_{\text{f.r}} = 0-0.55$.

The error in the values determined by Eqs. (1)-(4) does not exceed ±12%.

The obtained relations (1)-(5) form a basis for the design and calculation of two-chamber vortex dryers. A two-chamber vortex dryer for drying milk sugar has been developed and introduced into production in conformance with the results of the studies conducted.

NOTATION

D, diameter of the vortex chambers, m; H, width of the two-chamber vortex dryer, m; L, interaxial distance between the vortex chambers, m; d_0, diameter of the exhaust holes, m; Σh, total height of the tangential inlet nozzles, m; q_0, retentivity, kg; q, quantity of material in the apparatus in the continuous mode of operation, kg; ΔP, hydraulic resistance, Pa; V, volumetric flow rate of the gas, m^3/sec; v_{cr}, critical velocity of gas outflow to the vortex chambers, m/sec; d_{eq}, equivalent diameter of the particles, m; ζ_{in}, coefficient of hydraulic resistance of the dryer not loaded with material; $\mu_{\text{f.r}}$, flow-rate concentration of the disperse material; Ar, Archimedes number; $\text{Re}_{\text{cr}} = v_{\text{cr}}\Sigma h/\nu$.

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