AERODYNAMICS OF AN EDDY DRYER FOR LIQUID MATERIALS

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UDC 631.362.7

The article examines the special features of the flow of a high-speed curved air jet in the confuser chamber of an eddy dryer. The effect of the inlet parameter on the aerodynamic characteristics of the chamber is shown.

The application of the eddy process is one of the simplest and very efficient methods of increasing the intensity of operation of various heat- and mass-exchange apparatuses. The peculiarities of the aerodynamics of eddy and cyclone chambers for effecting a number of high-temperature technological processes have by now been studied in detail. These investigations indicate that there is a close correlation between the characteristics of a rotating stream and the geometry of the chamber shape, the method of supplying and removing the air, and the ratios of its decisive dimensions [1-3]. The present article submits the results of the investigation of the aerodynamics of a high-speed isothermal flow in the chamber of a newly designed eddy dryer which is effectively used for obtaining a number of deposited catalysts [4, 5].

The design of the drying chamber incorporated a confuser and a diffuser-cylindrical part with tangential supply of the heat carrier. The liquid was supplied to the dryer chamber through a pneumatic injector. We studied two variants of the design of the drying chamber, differing by the method of gas intake: by concentrated tangential-axial inlet through branch pipes on the chamber lid (Fig. 1) and by distributed gas inlet through adjustable tangential slots on the surface of the chamber while the form of axial supply is maintained [4]. The design features of the drying chamber produce in it an aerodynamic situation that differs greatly from existing apparatuses of eddy and cyclone type, and it is therefore practically impossible directly to use information from the literature for designing these new dryers.

The investigation of the internal structure of the flow was carried out on a dryer with concentrated inlet by blowing cold air through, with the ratio of the tangential and axial flows at the inlet of 2:1. The ratio of the entering flows, chosen on the basis of preliminary experiments, ensured thorough drying of the material without precipitation of the product on the walls, and therefore all the investigations were carried out with the above flow ratio. The air flow rate during the investigations changed between 450 and 1000 m^3/h, and the Reynolds number in the tangential inlet branch pipe was within the limits $Re = 9 \cdot 10^3$ and $200 \cdot 10^3$.

The velocity fields were measured with a cylindrical probe whose head had a diameter of 4.0 mm, by the method of [6] in the cross sections of the apparatus with diameters 320 mm (I), 200 mm (II), 80 mm (III). The vector of full velocity, measured at each point of the cross section, was resolved into two components: the circular (tangential) and

TABLE 1. Mean Integral Velocities in Two Cross Sections of the Drying Chamber

$L, m^3/h$	I			III		
	v, m/sec	v_T, m/sec	v_X, m/sec	v, m/sec	v_T, m/sec	v_X, m/sec
450	4,43	3,62	1,19	37,44	25,27	25,4
600	5,93	5,15	2,94	50,8	31,34	36,4
800	8,08	6,85	3,15	63,3	38,37	45,74
1000	9,73	8,27	3,68	89,2	58,2	56,58

Petrochemical Research Institute, Ufa. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 40, No. 1, pp. 95-100, January, 1981. Original article submitted October 23, 1979.

0022-0841/81/4001-0068$07.50

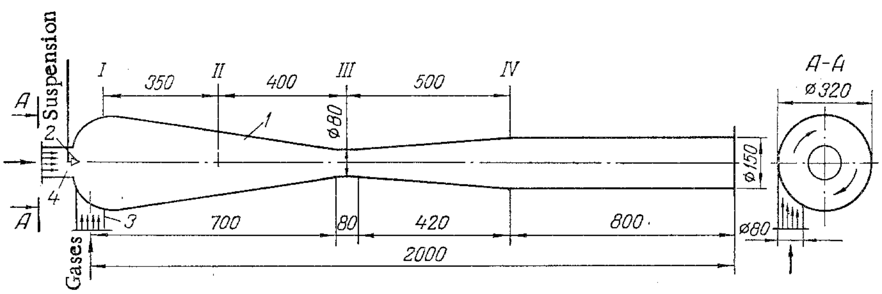

Fig. 1. Schematic diagram of a variant of the eddy drying chamber: 1) drying chamber; 2) sprayer; 3, 4) branch pipes.

longitudinal (axial) components. The direction of the velocity vector at the measured point was determined by the protractor of the cylindrical probe, and the absolute values of the full velocity were calculated by the formula [6]

$$v = \sqrt{\frac{2\eta}{\rho}(2P_2 - P_1 - P_3)}, \tag{1}$$

where P_1, P_2, P_3 are the pressures taken up by the holes of the cylindrical receiver, mm water column; η is an experimentally determined graduation coefficient.

The velocity profiles in the investigated cross sections (Fig. 2) indicate that the jets of heat carrier entering the drying chamber induce in it an intense rotary motion of the gas flow whose internal structure is determined by the tangential component of the velocity. In all the three sections the circular velocities over the chamber radius from the center to the periphery at first increase, and then they gradually decrease, i.e., they change from the flow characteristic of quasisolid rotation to rotation characteristic of potential flow. With changing air flow rate we discovered that the velocity profiles in one and the same cross section are identical, but in different cross sections along the chamber there was no similarity of the velocity fields because the maximum circular velocities noticeably increase (by a factor of 6-7 between cross sections I and III) with decreasing diameter of the drying chamber, and they somewhat shift along the radius of the chamber.

The axial velocities increase in all cross sections from the periphery to the center of the chamber, and they always retain their positive values in the entire range of changes of air flow rate, thus confirming that there are no reverse flows. On the other hand, we must point out the more rapid increase of the axial velocities when the flow shifts along the drying chamber (by a factor 12-15 between the cross sections I and III). Whereas in cross section I the circular velocities considerably predominate over the axial ones, the velocities of the longitudinal motion in the neck of the chamber (cross section III), on the other hand, are fully commensurable with the rotary velocity and even exceed it somewhat. This can be seen from the data of Table 1 which presents the mean integral values of the velocities in two cross sections with different air flow rates.

The many times repeated increase of the velocity in the gas stream induces an accelerated rotary motion of the dried particles while they are being intensively blown upon during the drying process, and this increases the liquid pressure intensity and intensifies the heat- and mass-exchange processes in the drying chamber.

In the tail part of the apparatus, behind the neck of the drying chamber, it is difficult to discover the direction of the vector of full velocity (section IV); this is due to the abrupt turbulization of the flow occurring in the narrowest cross section and during the subsequent broadening of the jet in the diffuser.

It follows from an analysis of the circular velocities that the internal structure of the flow for the confuser section, which is the basic one, obeys to some degree of accuracy the laws of a curved flow of an incompressible liquid. The profiles of the axial velocities confirm the displacement of the flow along the drying chamber without reverse flows, and consequently, without longitudinal displacement of gas volumes with the given design of the dryer.

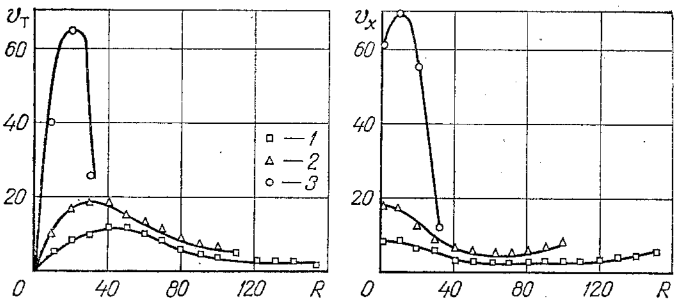

Fig. 2. Profiles of the circular (v_T) and axial (v_x) velocities for three cross sections of the drying chamber for L = 800 m³/h: 1) cross section I, 320-mm diameter; 2) II, 200-mm diameter; 3) III, 80-mm diameter.

The velocity losses caused by the broadening of the air jets upon their supply to the drying chamber were assessed by the coefficient of velocity reduction that was determined by the formula $\varepsilon = v_{max} \cdot R / v_{in} \cdot R_{in}$

Regardless of the Reynolds number, the coefficient ε for each cross section remains constant, and along the chamber it increases slightly (from 0.45 to 0.6), regardless of the decrease of the chamber diameter to one quarter between the extreme cross sections I and III. Such a result is apparently due to the large energy losses in friction and other near-wall effects.

The investigations of the aerodynamics of the drying chamber confirmed the similarity of the flow due to the discharge of the air inside the chamber within the studied range of Reynolds numbers. A change in the air flow rate has practically no effect on the distribution of the relative circular velocities (v_T/v_{in}) over the radius in the cross sections I—III of the chamber. This result is in agreement with the known data of [2, 7].

By generalizing the experimental results, we obtained the empirical equations for calculating the circular velocities along the radius:

$$\frac{v_T}{v_{in}} = 9.6\left(\frac{r}{R}\right)^{1.45} \exp\left(-5.11\frac{r}{R}\right), \text{ section } I, \tag{2}$$

$$\frac{v_T}{v_{in}} = 8.0\left(\frac{r}{R}\right)^{1.22} \exp\left(-3.5\frac{r}{R}\right), \text{ section } II, \tag{3}$$

$$\frac{v_T}{v_{in}} = 4.7\left(\frac{r}{R}\right)^{0.47} \exp\left(-1.39\frac{r}{R}\right), \text{section } III. \tag{4}$$

The maximum discrepancy between the experimental and calculated values of the circular velocities, calculated by Eqs. (2) and (3), does not exceed 15.0%, for Eq. (4) it is 25% with $r/R \leqslant 1.0$.

In the study of designs of drying chambers, feed devices for material and drying agent it was established that an apparatus with one concentrated inlet of drying agent is simpler, but it is sometimes advisable to distribute the gas supply to the chamber over several tangential channels. In that case the gas is distributed uniformly over the chamber perimeter, thus excluding the possibility of the material sticking to the walls of the drying chamber.

The internal structure of the flow in this case does not undergo any substantial changes. The nature of the rotation of the flow with distributed gas inlet is analogous to the nature of the rotation with concentrated inlet. The distribution of both the circular and axial velocities is the same as the distribution of the velocities presented in Fig. 2. A notable feature is the increase in the symmetry of the velocity profiles relative to the chamber axis, and also the slow velocity increase along the chamber; this indicates that the velocities are distributed more evenly along the chamber.

It is interesting to analyze such aerodynamic characteristics of the eddy drying chamber ber as the coefficients of hydraulic resistance (ξ) and of velocity reduction (ε_T) in

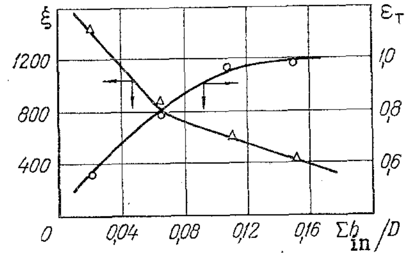

Fig. 3. Dependence of the aerodynamic characteristics ξ and ε_T on the design parameters of the inlet.

dependence on the design parameter of the inlet $\Sigma h_{in}/D$. These coefficients, which are of great practical importance in calculating energy losses and selecting the aerodynamic regime, which is indispensable from the technological point of view, may be used as principal criteria of evaluating the aerodynamics of the apparatus and the efficiency of its design [2].

The effect of the inlet parameter on ξ and ε_T was studied in a chamber with distributed gas supply through adjustable tangential slots with fixed air flow rate and changing relative size of the tangential inlet channels within the limits $\Sigma h_{in}/D = 0.022$-0.155. The results of these experiments are presented in Fig. 3.

The values of the coefficients ξ and ε_T were determined by the formulas:

$$\xi = \frac{2\Delta P g}{\rho v_{\mathrm{redc}}^2}, \tag{5}$$

$$\varepsilon_T = \frac{v_{T\max}}{v_{\mathrm{in}}}. \tag{6}$$

It can be seen from Fig. 3 that when $\Sigma h_{in}/D$ changes within the given limits, ξ has two regions of change. Up to the value $\Sigma h_{in}/D = 0.06$ the hydraulic resistance decreases more rapidly, after that it decreases more slowly. At the same time, ε_T, characterizing the level of the tangential velocities in the range of values of $\Sigma h_{in}/D$, increases 2-2.5 times, and the circular velocities decrease correspondingly. With $\Sigma h_{in}/D = 0.06$, the coefficient ε_T is small, and the circular velocities consequently still retain their relatively high value. It is therefore inexpedient to increase the inlet parameter to more than $\Sigma h_{in}/D = 0.06$ (in other words, $\Sigma h_{in}/D \leqslant 0.06$). This permits the conclusion that the optimum heights of the tangential inlet slots Σh_{in}, to which the maximum level of circular velocities with minimum hydraulic resistance in the dryer of the given design corresponds, lies in the region (0.04-0.08)D.

Thus the results of the investigation make it possible correctly to evaluate the real aerodynamic situation in the eddy dryer, to carry out kinetic calculations of the processes of heat and mass transfer, and to select the optimum design parameters in designing dryers of similar type. The aerodynamic features of the drying chamber create conditions in the dryer for intense contact of the material streams and for heat and mass exchange between them. At the same time this increases the retentivity of the chamber for the disperse phase and the liquid pressure intensity throughout its volume, and the temperature and concentration fields at the outlet become quickly stabilized. For instance, in drying catalytic suspensions in the eddy dryer [5], the liquid pressure intensity per unit volume of the drying chamber attained 3.0-5.0 tons/m³·h.

NOTATION

L, air flow rate, m^3/h; r, R, current radius and chamber radius, respectively, in the investigated cross section, m; D, maximum diameter of the drying chamber, m; Σh_{in}, total height of the tangential inlet slots, m; v, v_T, v_x, total, circumferential, and axial velocities, respectively, m/sec; v_{in}, v_{redc}, velocity at the inlet of the drying chamber and velocity for its full cross section, respectively, m/sec; $v_{T\max}$, maximum circumferential velocity in the design cross section, m/sec; ΔP, drop of total pressure in the eddy drying chamber, mm w.c.; g, acceleration of gravity, m/sec^2; ρ, density of air, kg/m^3; ξ, coefficient of hydraulic resistance; ε_T, coefficient of velocity decrease.

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PIEZOELECTRIC MEASUREMENT OF THE LOCAL CHARACTERISTICS OF THE MOTION OF SOLID PARTICLES IN A TWO-PHASE FLOW

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UDC 53.082.73:532.529.5

We develop the design of a piezosensor and a method for measuring the hydrodynamic characteristics of the motion of solid particles in a two-phase flow.

The mechanism and intensity of various transfer processes in the flow of a gas suspension are determined to a large extent by the structure of the suspension, in particular by the transverse distribution of concentrations, velocities, and flow rates of the solid material. These characteristics, in spite of the considerable number of studies [1-8] on the hydrodynamics of two-phase flows, have not been adequately investigated; this fact is due to the multiplicity of forms and the complexity of the systems themselves, as well as to inadequate development of the methods of measurement. The instrumentation used today is, as a rule, limited either to flows with a low flow-rate concentration ($\mu_f < 2$ kg/h/kg/h) of the solid phase (high-speed cinematography [3, 4] and other optical methods [5, 6]) or to small ($d < 200$ μm) particles (isokinetic sampling [7, 8], laser diagnostics [9]) or else by the information on the values averaged over the cross section (the cutoff method [10, 11], photoelectric methods [12, 13]).

According to available estimates [14], the experimental conditions impose no practical limitation on a method using the piezoelectric effect for measuring the local characteristics of the motion of solid particles. The present paper is devoted to a discussion of the possibilities of piezosensors. The special features of two-phase flow as an object of investigation place a number of specific requirements on the design of the sensor. Above all, it is necessary to maintain high sensitivity when the solid particles exert a destructive effect (impact and abrasion).

The sensor was designed in accordance with current recommendations [15]. The total thickness of the impact-absorbing sensitive zone, made of steel, and the piezoplate did not exceed 1 mm. As the inertial mass, we used a zinc rod whose significant dimensions ensured three-dimensional scattering of acoustic deformation waves.

An analysis of the oscillograms of the first series of experiments (Fig. 1a) enabled us to establish the duration of the contact between small glass spheres ($d \sim 1$ mm) moving at a velocity of 1-15 m/sec with the steel end-face zone of the sensor, $\tau = (3.0\text{-}3.2)\cdot 10^{-6}$ sec; this corresponds to a response of $n \sim 3\cdot 10^{5}$ impacts/sec. Obviously the response of the sensor must exceed the possible frequency of particle collisions with its sensitive zone:

Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 40, No. 1, pp. 101-108, January, 1981. Original article submitted November 20, 1979.

0022-0841/81/4001-0072$07.50