AERODYNAMIC ANALYSIS OF A VORTICAL-SPRAY DESICCATOR

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Described are the characteristics of air flow in a spray chamber with two opposing vortices. The results of velocity distribution measurements are shown, followed by a comparative analysis of air flow in a vortical mode with that in a purely rectilinear mode.

Spray desiccators are generally characterized by a low moisture field intensity. With larger size, moreover, this trend toward a lower moisture field intensity – the basic performance parameter – becomes more pronounced.

As is well known, the moisture field intensity in a spray desiccator depends on the spray dispersivity, on the transport potential, and on the relative velocity of both mixture components (drying agent and sprayed liquid).

The first two factors cannot have any great effect on raising the moisture field intensity, inasmuch as they in turn depend on the properties of the dried material (thermal lability, viscosity, etc.) and on the sprayer design. An increase in the relative velocity of the mixture components will have a dominant effect on the rates of heat and mass transfer in the stream. It will eventually lead to a separation of the vapor film from a droplet surface, owing to the turbulized flow of the suspension and to an increased supply of heat.

One effective method of increasing this relative velocity is by inducing vortices, a basic feasibility study of this method having been made in connection with mass-transfer processes based on a two-phase stream [1, 2] and with the aerodynamics of cyclone devices [3-9].

The principle of the proposed vortical spray chamber (Fig. 1) is as follows. Two counterflowing vortices are generated with opposite senses of rotation. In order to explain the mechanism by which the transfer processes are enhanced and the moisture field intensity is raised here, it is necessary to analyze the aerodynamics of a gas stream in this chamber.

The explanation of complex aerodynamics in cyclone and vortex devices is usually based on treating the stream as a turbulent jet tube [9] and characterizing the latter qualitatively in terms of the tangential velocity.

We will present here the results of an experimental study revealing how the distribution of tangential velocity and of turbulence intensity in an isothermal vortex depends on the geometry of the chamber and on the operating conditions in it.

The vortex-type spray chamber in Fig. 1 comprises a horizontal tube with tangential inlet orifices for the heat carrier to be injected in two opposing directions. The air exits through an outlet at the center of the tube. The chamber can be tentatively divided into three regions. In region 1 air is injected tangentially from both ends and opposing vortices are generated. Region 2 is confined between the boundary of region 1 on one side and region 3 on the other side; in the latter region both streams collide.

The basic difference between this chamber and a cyclone chamber is that, for all practical purposes, no backward vortex flow occurs here [4]. The vortex collision zone (region 3) constitutes this important departure from earlier described vortex chambers [4].

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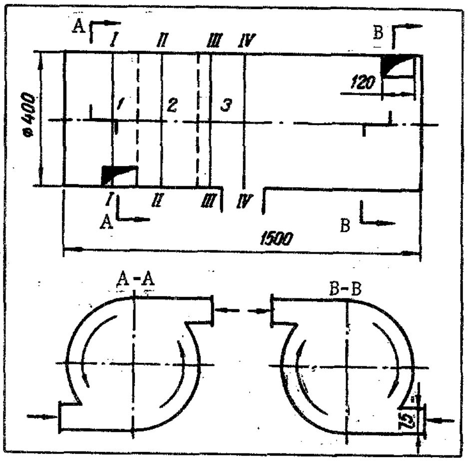

Fig. 1. Basic schematic diagram of a vortex-type desiccator chamber.

TABLE 1. Variation in the Tangential Velocity (m/sec) of the Stream, at L = 500 m^3/h

r, m	Sections			
	I	II	III	IV
0,04	3	2,6	5	4,6
0,06	3,2	3,0	5,8	4,65
0,08	3,8	3,4	6,8	4,6
0,1	4,8	4	8,4	4,6
0,12	6	5	9,8	4,7
0,14	9,5	7,4	11,1	5,1
0,16	14,5	13,4	12,5	5,5
0,18	17,8	16,8	13,5	5,6

The chamber in Fig. 1 is symmetrical. Measurements were made on the left-hand side only, with the right-hand side representing a mirror image. The velocity field was measured at four sections along the tube generatrix, with 200 mm between sections I-III and 150 mm between sections III-IV (L/D = 0.5, 1.0, 1.5, and 1.9).

For an aerodynamic analysis of this vortical-spray desiccator, the latter was operated without liquid spray. The total air flow rate was varied from 200 to 500 m^3/h in 100 m^3/h steps and was measured with a Pitot tube installed in the inlet duct. The amount of air supply was regulated by means of gate valves.

The tangential air velocities were measured with a thermoanemometer (Disa Elektronik Co., Denmark) and a film-type probe serving as the transducer. This probe was operated on the principle of cooling its hot platinum film by the air stream. The test data were then evaluated in terms of dimensionless quantities:

$$\frac{v}{v_{\text{in}}} = f\left(\frac{r}{R}\right). \tag{1}$$

Dimensionless transverse and longitudinal velocity profiles of the chamber are shown graphically in Fig. 2.

An analysis of the curves indicates that the trend of relation (1) is identical at sections I-III. An exception here is the zone within section I around the air injection orifice (curve 3 in Fig. 2). Such an anomaly is characteristic of whirled streams and can be explained by a stronger wall effect during tangential air injection. The coefficient of entrance losses $\xi = v_{\varphi}/v_{\text{in}}$ increases with the ratio r/R [3]. The local eddies in region 1 near the inlet nozzles – caused by inadequate streamlining and some variance in the performance characteristics of the latter – may also explain this anomaly.

At section IV (curve 2) the velocity profile is characteristically different than at sections I-III. This can be explained by the interaction of the two colliding high-velocity streams which rotate in opposite senses, resulting in a sharp drop and a complete attenuation of circular velocities at the center of the chamber. This is accompanied by an intensive vortex formation. In such a case, which is analogous to that of unwhirled colliding streams [10], one may expect multiply induced oscillations and rotations of particles (during spray desiccation) within the mixing zone and this in turn will raise the moisture field intensity and thus the process rate.

According to Fig. 2, a change in the air flow rate has almost no effect on the velocity profiles. Consequently, a vortex-type spray chamber is characterized by self-adjointness of the flow over the test range of flow rates.

An evaluation of the test data yields a simple empirical relation for the 0-600 mm segment, i.e., for 80% of the chamber length:

$$\frac{v}{v_{\text{in}}} = \left(\frac{r}{R}\right)^3 + 0.1. \tag{2}$$

This relation is valid for $r/R < 1$.

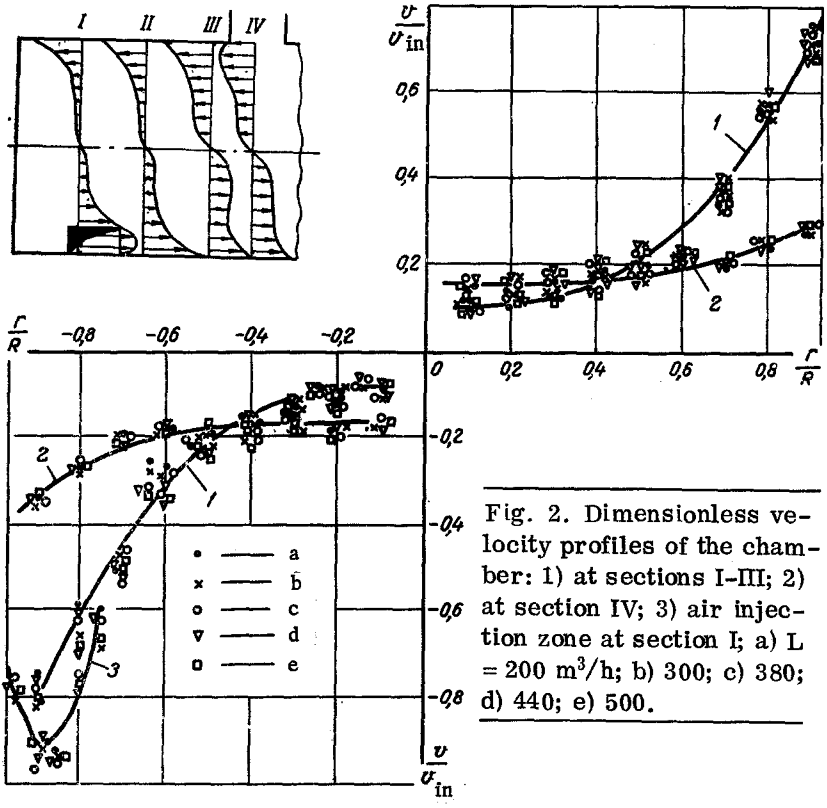

Fig. 2. Dimensionless velocity profiles of the chamber: 1) at sections I-III; 2) at section IV; 3) air injection zone at section I; a) L = 200 m³/h; b) 300; c) 380; d) 440; e) 500.

TABLE 2. Values of ζ for Sections of the Vortex Chamber

L, m³/h	Sections	
	I–III	IV
200	6,8	5,05
300	6,18	4,7
380	5,95	4,55
440	5,66	4,62
500	5.55	4,27
	$\zeta_{mean} = 6{,}03$	$\zeta_{mean} = 4{,}62$

For section IV we have obtained the following relation:

$$\frac{v}{v_{in}} = 0.3\left(\frac{r}{R}\right)^{4,4} + 0.2. \qquad (3)$$

The error of this test data evaluation did not exceed ±15%.

An analysis of the graphs in Fig. 2 indicates that at section IV the relative velocity v/v_{in} in the mainstream ($r/R \leq 0.5$) is higher than in the vortex region and is much lower at the stream periphery ($r/R \geq 0.5$). This has to do with a flattening of the transverse velocity profile within the stream collision zone (region 3) inside the chamber.

Our study has established that the stream structure in a vortex chamber (Fig. 1) follows the laws governing a whirled flow of incompressible fluid.

Values of the tangential velocity are listed in Table 1. An analysis of these data makes the center region in the chamber (r = 0-180 mm) appear as a quasiforced vortex. The velocity here increases with the radius. Such a structure is, however, characteristic of sections I-III in the chamber. Within the stream collision zone (section IV) the velocity becomes uniform. This means that there is no quasiforced vortex here. Thus, the center region of the chamber departs from the law of constant circulation (vr = const), which can be explained by the presence of local eddies. In this case the generation of local eddies also improves the mixing of both components.

The turbulence structure of the stream, which determines the rates of transfer processes in the chamber, is characterized also by the distribution of turbulence intensity.

According to Fig. 3, the turbulence is most intense at sections I and II along the chamber axis within $0 < r/R < 0.6$ (3-4%) and decreases with increasing distance from the center. The trend of the ε_i variation is different at sections III and IV. The profiles of turbulence intensity are qualitatively analogous to the velocity profiles. The profiles of turbulence intensity in Fig. 3 confirm the self-adjointness of air flow in a vortex chamber with the Reynolds number within the 70,000 < Re < 150,000 range. Only at section IV,

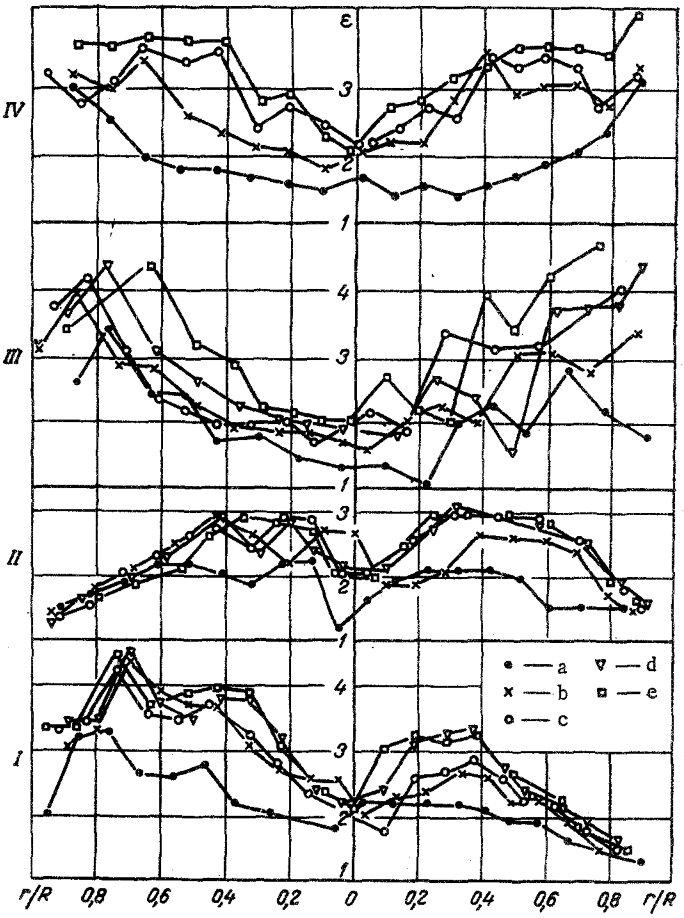

Fig. 3. Profiles of turbulence intensity in the vortex chamber, at sections I-IV: a) L = 200 m^3/h; b) 300; c) 380; d) 440; e) 500.

where the collision of streams results in a different flow mode, does the turbulence intensity increase with a higher Reynolds number.

It would be interesting to compare the magnitudes of the resultant velocity in a whirled and in a straight air stream through this tube. The degree of nonuniformity is estimated on the basis of the appropriate factor. The resultant velocity of a whirled stream v_1 is defined as the mean-integral velocity for each section along the chamber. In the case of a straight stream, the resultant velocity v_2 is defined as the mean-over-the-section velocity in the chamber (section area F).

Values of $\xi = v_1/v_2$ as a function of the air flow rate are listed in Table 2 for the given sections across the chamber. An analysis of these data indicates that the nonuniformity profile, like the velocity profile (Fig. 2), is independent of the air flow rate. The local values depart from the mean value by not more than 6-12% at all four sections.

The high degree of nonuniformity constitutes the main advantage of a whirled stream over a straight stream of air through a chamber. This effect comes into play where increasing the transfer rates in whirled streams is concerned.

The results of this study can be used for estimating the characteristics of an air stream in a chamber with counterflow. The velocity profiles obtained here are entirely suitable as a basis for the design of such desiccators, inasmuch as only 2-3% of the air supply is expended on spraying the liquid and has almost no effect on the aerodynamics inside the chamber.

NOTATION

L is the air flow rate, m^3/h;
r is the radial coordinate in the chamber, mm;

R	is the chamber radius, mm;
F	is the area of a chamber section, m^2;
v	is the velocity at any point, m/sec;
v_{in}	is the air velocity at the orifice, m/sec;
v_1, v_2	are the mean velocity of a whirled and of a straight stream, respectively, m/sec;
ε_i	is the turbulence intensity, %;
ζ	is the nonuniformity factor.

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