EFFECT OF GRAVITATIONAL FORCE ON AEROSOL MOTION IN CURVILINEAR GAS FLOW

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Based on experimental studies, the effect of gravitational force on aerosol trajectories is analyzed for various values of the Froude number of the carrier flow.

In planning, designing, and simulating various devices and apparatus in which motion and inertial deposition of solid or liquid aerosols occurs at low volume concentrations (for example, dust cyclones, centrifugal ash collectors with a water film, cyclone furnaces, etc.), it is necessary to know the effect of gravitational force on the process.

For this purpose an experimental study was made of the trajectories of aerosols having an average size from 16.5 to 427 μ in curvilinear turbulent air flow at $T = 303°K$ for various orientations of the latter with respect to the direction of gravity.

The studies were carried out on a test stand (Fig. 1), the experimental portion of which was an annular channel ($D = 1.0$ m and $d = 0.5$ m) connected to an exhaust fan. Two sets of experiments were performed to determine the effect of gravitational force: a) the annular channel was positioned in its normal (original) position (Fig. 1a); b) the annular channel was in an inverted position (Fig. 1b).

The aerosol used was a limited fraction of potassium dichromate dust separated in an air sorter, and consequently consisted of identical spherical particles with respect to hydrodynamics [1].

The arithmetic-mean diameter of the dust fraction (Table 1) was taken as the diameter $\bar{\delta}$ of the spherical particles. The dust was introduced into the entrance portion of the channel by a special feeder, either with zero initial aerosol velocity ($W_{\varphi 0} = 0$) or with velocity approximately equal to the velocity of the carrier flow ($W_{\varphi 0} \approx 1$).

Every 12°, rods of length $D-d$ and made up of 25 cylinders were installed along the radius of the channel; the cylinders had an external diameter of 6 mm and were covered with Vaseline. The amount of dust deposited on the individual cylinders was determined by iodometry.

Furthermore, the absence of dust ricochet from particles previously deposited on the sticky surface of a rod was ensured [2]. A single point in the aerosol trajectory was determined from the maximum of the dust distribution curve along the length of a rod, taking into account the degree of deposition on the surface of a cylinder [3].

In this way trajectories were determined for dust particles of various dimensions and for carrier-flow velocities $V = 4.6$, 7.5, 17.5, and 23 m/sec.

TABLE 1. Fractional Dust Composition

Dust fraction, δ in μ	13—20	20—30	30—45	45—67	67—101	101—152	152—227	227—341	341—513
Average dimension $\bar{\delta}$ of dust fraction in μ	16,5	25	37,5	56	84	126,5	198,5	284	427

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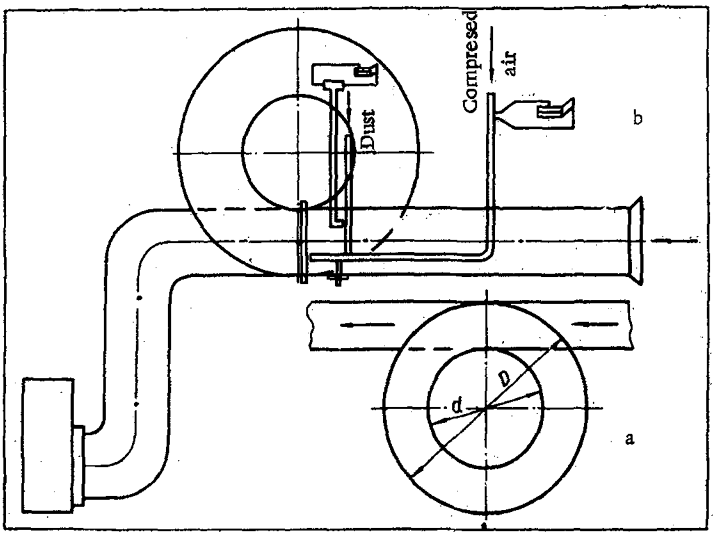

Fig. 1. Experimental arrangement: a) annular channel in normal position; b) annular channel in inverted position.

All experiments were carried out at very low volume concentrations of dust (no more than 60 mg/m^3), which made it possible to neglect interaction forces between particles.

As a preliminary, the velocity fields were obtained with a five-channel spherical probe along a radius at several channel sections (for various air flow rates), and the self-similarity of phenomena with respect to $\mathrm{Re} = DV\rho/\mu$ determined. The resultant velocity profiles indicated that the aerodynamic flow was close to potential and resembled to a considerable extent the picture occurring in actual cyclone equipment.

The experiments showed that the effect of gravity on aerosol trajectory is closely related to aerosol dimension and initial velocity and to the velocity of the carrier flow.

As an illustration, trajectories are shown in Fig. 2 (for $W_{\varphi 0} = 0$) for an aerosol with $\bar{\delta} = 16.5\ \mu$ and $\bar{\delta} = 284\ \mu$ at carrier flow velocities $V = 4.6$ m/sec and $V = 17.5$ m/sec along with the trajectory of an aerosol with $\bar{\delta} = 427\ \mu$ and $V = 4.6$ m/sec for normal and inverted channel positions.

Figure 2 makes it clear that for fine dust ($\bar{\delta} = 16.5\ \mu$), both at $V = 4.6$ m/sec and $V = 17.5$ m/sec, there is practically no separation of trajectories because of the effect of gravity.

At $\bar{\delta} = 284\ \mu$, the picture changes. Here the aerosol trajectories begin to differ from one another because of the effect of mg even in the initial portion of the channel with the effect being more important at the lower carrier-flow velocities.

As a parameter characterizing the extent of the gravity effect in more explicit form, the quantity $C = (\Delta\varphi/\varphi_{C1}) \cdot 100\%$ was chosen; this is the maximum relative divergence of aerosol trajectories for various positions (with respect to mg) of the experimental section.

To estimate the effect of mg quantitatively at values of $D, \bar{\delta}, \rho_2, \rho_1$, and μ not investigated experimentally, it is useful to analyze the results in criterial form.

It is indicated [4] that for low concentrations of suspended matter, self-similarity of the carrier flow and $W_{\varphi 0}$ constant, the effect of gravity on aerosol motion is determined by the Froude number. In addition, the extent of the mg effect also depends implicity on the criteria St and R. The relationship $C = f(\log \mathrm{Fr})$ is shown in Fig. 3 for various St and R in the cases $W_{\varphi 0} \approx 1$ (curves 2 and 4) and $W_{\varphi 0} = 0$ (curves 1 and 3).

Analysis of the curves mentioned for $W_{\varphi 0}$ constant shows that the parameter C decreases and asymptotically approaches zero as Fr increases despite a simultaneous increase in St and R.

When Fr is constant, and its absolute value is small, the value of the parameter C is higher for larger aerosols, or more correctly, for higher values of the criteria St and R.

For fine fractions of the aerosol ($\bar{\delta} \leq 16.5\ \mu$, $\mathrm{St} = 0.0925$, $R = 5$), the parameter C does not exceed 2.5% even for small values of the Froude number ($\mathrm{Fr} = 4.25$) and is independent of $W_{\varphi 0}$. At $\mathrm{Fr} = 4.25$ and a transition from $\bar{\delta} = 16.5\ \mu$ to $\bar{\delta} = 284\ \mu$, i.e., for an increase in St from 0.0925 to 28.45 and in R from 5 to 86, the parameter C

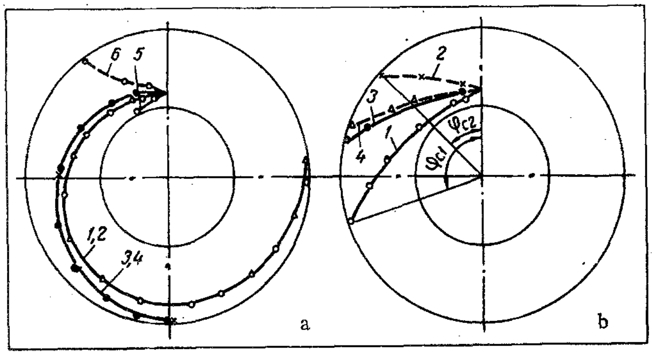

Fig. 2

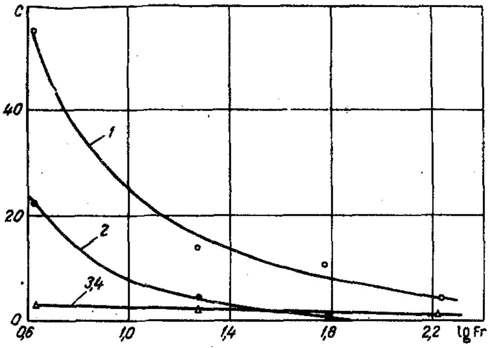

Fig. 3

Fig. 2. Aerosol trajectories: a) 1, 2) $\bar{\delta} = 16.5\ \mu$, $V = 4.6$ m/sec; 3, 4) $\bar{\delta} = 16.5\ \mu$, $V = 17.5$ m/sec; 5, 6) $\bar{\delta} = 427\ \mu$, $V = 4.6$ m/sec; b) for $\bar{\delta} = 284\ \mu$, 1, 2) $V = 4.6$ m/sec; 3, 4) $V = 17.5$ m/sec (odd numbers – model in normal position, even numbers – model in inverted position).

Fig. 3. Dependence of $C = (\Delta\varphi/\varphi_{c1}) \cdot 100\%$ on log Fr: 1) $\bar{\delta} = 427\ \mu$ and $W_{\varphi 0} = 0$; 2) $\bar{\delta} = 417\ \mu$ and $W_{\varphi 0} = 1$; 3, 4) $\bar{\delta} = 16.5\ \mu$ and $W_{\varphi 0} = 0$ and 1.

increases sharply with the increase being more abrupt at lower $W_{\varphi 0}$ (to 17.5% for $W_{\varphi 0} = 1$ and to 55% for $W_{\varphi 0} = 0$).

With an increase in Fr, however, the effect of the criteria St and R (for Fr constant) weakens continuously and for a certain value of the Froude number the curves C = f(log Fr) with different values of St and R merge into one. For $W_{\varphi 0} \approx 1$, in particular, this phenomenon sets in at Fr ≈ 45.

This last situation offers an opportunity to confirm that at sufficiently large values of the Froude number it is a unique criterion which determines the extent of the effect of gravity on aerosol behavior in curvilinear flows where the operating process ceases after contact of the aerosol with the collecting surface.

On the basis of the material presented, for example, one is justified in asserting the effect of gravity on the motion and deposition of fuel and ash can practically be neglected ($C \leq 3\%$) in power cyclone furnaces which burn both dust and crushed fuel but which operate at high gas velocities ($Fr \geq 50$, $St \leq 70$, $R \leq 100$). As far as equipment with a cleaning efficiency which is mainly determined by the finest ash fractions (0-10 μ) is concerned, centrifugal scrubbers with a water film for example, the effects of gravity can also be neglected for the very large dimensions of commercial installations. Actually, the parameter C does not exceed 2.5% (see Fig. 3, curve 4) even for $Fr = 2.5$ ($r = 2$ m, $V = 10$ m/sec, $St \leq 0.025$, and $R \leq 6.5$).

A more cautious approach must be taken in estimating the effect of gravity on the motion and separation of coarse air-suspended matter in technical cyclone furnaces ($W_{\varphi 0} = 0$) and also in dust cyclones and dust concentrators with dry walls where the total effect is determined not only by dust motion in the gas flow, but also by secondary phenomena occurring after aerosol contact with the collecting surface [5].

NOTATION

V	is the carrier-flow velocity at the point of aerosol introduction;
$W_{\varphi 0}$	is the dimensionless initial aerosol velocity;
φ_{c1}, φ_{c2}	are the aerosol separation angles for the inverted and normal model;
$\Delta\varphi = \varphi_{c1} - \varphi_{c2}$	is the absolute value of the maximum divergence of the trajectories;
g	is the gravitational acceleration;
r, $\bar{\delta}$, ρ_2	are the radius of introduction, average size, and density of the aerosol;
μ, ρ_1	are the dynamic viscosity and density of the gas flow;
$Fr = V^2/rg$;	
$St = \bar{\delta}^2 V \rho_2/\mu r$;	
$R = \bar{\delta} V \rho_1/\mu$	is a criterion appearing when the resistance to the motion of a solid particle in the flow ceases to obey Stokes' Law.

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