JOURNAL OF ENGINEERING PHYSICS

EFFECT OF THE INITIAL VELOCITY OF AN AEROSOL ON ITS TRAJECTORY IN A CURVING GAS STREAM

V. E. Maslov, V. D. Lebedev, and S. G. Ushakov

Inzhenerno-Fizicheskii Zhurnal, Vol. 15, No. 3, pp. 450–454, 1968

UDC 532.529.5

On the basis of an experimental and theoretical investigation, the authors analyze the effect of the initial velocity of an aerosol on its subsequent motion.

In most two-phase media, the initial velocity of the aerosol, w_{φ_0}, differs from the velocity of the carrier flow, v. Accordingly, it is very important to know the effect of w_{φ_0} on the trajectories of the dust particles, which, in the last analysis, determine the precipitation efficiency of various types of inertial equipment. We are unaware of any experimental studies of this problem. Theoretical investigation [1] was made for the large v (120 m/sec) typical of cyclone furnaces burning pulverized fuel.

We have attempted to make an experimental and theoretical investigation of the effect of w_{φ_0} on the trajectory of an aerosol at v = 5–20 m/sec over a broad range of variation of the particle size ($\delta = 16.5–427\ \mu$). As the object of investigation we selected an annular channel with air at T = 293–303° K as the carrier medium.

As the aerosol we used narrow fractions of potassium dichromate dust $K_2Cr_2O_{77}$($\rho_2 = 272$ kg · sec^2/m^4), sifted in air classifiers and, hence, hydrodynamically identical with spherical particles [2].

As the diameter of the nominal spherical particle $\bar{\delta}$ we took the arithmetic mean of the hydraulic diameter of the dust fraction (table). A thin jet of dust 7 mm in diameter was introduced into the entrance region of the channel at various $w_{\varphi 0}$ by means of special feeders.

Sizes of Dust Fractions

δ, μ	13–20	20–30	30–45	45–67	67–101	101–152	152–227	227–341	341–513
$\bar{\delta}$, μ	16.5	25	37.5	56	84	126.5	189.5	284	427

Along the radius of the channel every 12° we introduced rods of length $D_1 - D_2$ consisting of 25 small vaseline coated cylinders 6 mm in outside diameter. The amount of dust precipitated on the individual cylinders was determined by iodometry [3]. Steps were taken to ensure that there was no ricocheting of dust from particles previously precipitated on the sticky surface of the rod [4]. From the maximum of the dust distribution curve along the length of the rod, taking into account its degree of precipitation on the surface of the cylinder [5], we determined one point on the aerosol trajectory.

We first recorded the velocity fields with a five-channel spherical probe at the points where the rods were to be installed. The axial components of the velocities were practically equal to zero, the radial components were 10–20% of the total velocity; therefore in the first approximation the motion of the carrier flow may be assumed tangential.

The very low concentration of the dust (not more than 60 mg/m^3) makes it possible to compare the experimental trajectories with the results of a calculation of the motion of an individual particle in accordance with the following dimensionless differential equations (in polar coordinates):

$$\begin{aligned} d\rho/d\varphi &= \rho W_r/W_\varphi; \\ dW_r/d\varphi &= W_\varphi - \psi'\rho W_r/\mathrm{St}\, W_\varphi - \rho\cos\varphi/W_\varphi \mathrm{Fr}; \\ dW_\varphi/d\varphi &= -W_r + \psi'\rho(1 - W_\varphi)/\mathrm{St}\, W_\varphi + \rho\sin\varphi/W_\varphi \mathrm{Fr}, \end{aligned} \tag{1}$$

where $\psi' = \psi \mathrm{Re} = f(\mathrm{Re})$ is the reduced particle drag coefficient; $\mathrm{Re} = R(W_r^2 + (1 - W_\varphi)^2)^{1/2}$ is the Reynolds number for the particle; $W_r = w_r/v$, $W_\varphi = w_\varphi/v$ are the dimensionless particle velocities; $\rho = r/r_0$ and φ are the polar coordinates of the particle; and St, R, Fr are characteristic parameters.

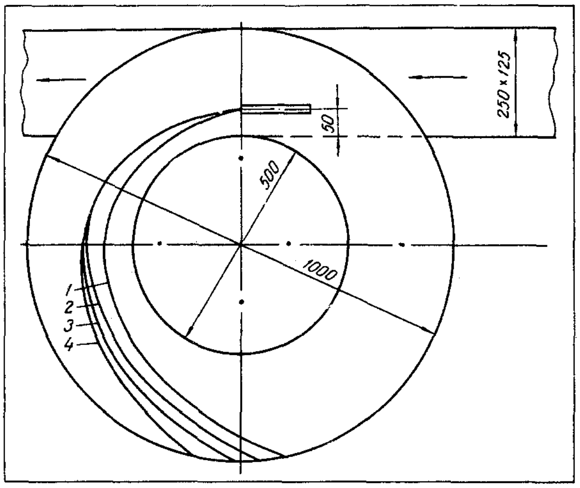

Fig. 1. Experimental trajectories of particles for $\delta = 16.5\,\mu$ and $v = 5$ m/sec ($D_1 = 1000$; $D_2 = 500$): 1) $w_{\varphi 0} = 0$; 2) 0.6; 3) 1.0; 4) 2.0.

The initial conditions are $\varphi_0 = 0$; $\rho_0 = 1$; $W_{r0} = 0$; $W_{\psi 0}$. System (1) was integrated on a Ural-2 computer, the computation algorithm being a four-point Runge-Kutta scheme, and the relative error of the computations $\varepsilon \le 0.001$.

The experiments and calculations showed that variation of $W_{\psi 0}$ in the range 0–2.0 affects the dust trajectory at all the $\bar{\delta}$ investigated. However, the degree of this effect, in turn, depends on the magnitude of δ and v. It is clear from Fig. 1 that at $\delta = 16.5\,\mu$ the trajectories with $W_{\psi 0} = 0.6$ and $W_{\varphi 0} = 2.0$ begin to diverge only after the aerosol has traversed a path equal to $\pi/2$. A sharper elongation of the trajectories is observed on transition to $W_{\varphi 0} = 0$. The trajectories of the aerosol with $\delta = 126.5\,\mu$ at different $W_{\varphi 0}$ begin to diverge even in the entrance region of the curved channel (see Figs. 2 and 3). A comparison of Fig. 2 and Fig. 3 also shows that at $\bar{\delta} = \mathrm{const}$ the effect of $w_{\varphi 0}$ is manifested the more strongly, the smaller v. However, the degree of divergence of the trajectories due to the variation of $W_{\varphi 0}$ at various absolute values of v depends, in turn, on $\bar{\delta}$ and is manifested the more strongly, the coarser the aerosol. In particular, at $\bar{\delta} = 16.5\,\mu$ the divergence of trajectories with different $W_{\varphi 0}$ at $v = 5$ and 19 m/sec is practically the same.

To demonstrate the effect of $W_{\varphi 0}$ in "purer" form, we have presented in Fig. 4 the experimental and theoretical $\varphi_c/\varphi_{c0} = f(\bar{\delta})$ curves characterizing the degree of deviation of the end point of the trajectory at various values of $W_{\varphi 0}$ ($v = 5$ m/sec) from the case $W_{\varphi 0} = 1.0$. At $\bar{\delta} = \mathrm{const}$ the degree of deviation is the stronger, the more $W_{\varphi 0}$ differs from the case $W_{\varphi 0} = 1$. The end point of the trajectory of fine dust ($\delta < 16.5\,\mu$) is almost independent of $W_{\varphi 0}$.

At $\bar{\delta} \ge 16.5\,\mu$, it is possible to distinguish three characteristic cases of the curve $\varphi_c/\varphi_{c0} = f(\delta)$. At $W_{\varphi 0} = 0$, φ_c/φ_{c0} increases continuously with increase in $\bar{\delta}$. At $\delta = 427\,\mu$, dust begins to settle out of the stream onto the inner surface of the channel owing to the influence of gravity (Fig. 2, dashed line) and, hence, $\varphi_c/\varphi_{c0} \to \infty$. At $1 > W_{\varphi 0} > 0$, the effect of $\bar{\delta}$ on φ_c/φ_{c0} is felt only up to a certain limit, beyond which a further increase in $\bar{\delta}$ has almost no effect on the behavior of the curve $\varphi_c/\varphi_{c0} = f(\bar{\delta})$.

At $W_{\varphi 0} > 1$ and $\varphi_c/\varphi_{c0} = f(\bar{\delta})$ curve has a clearly expressed maximum at a certain value of $\bar{\delta}$, beyond which it begins to tend toward a constant value. The presence of a point of inflection on the curve at $W_{\varphi 0} > t$ is attributable to the fact that the trajectories for different δ are compared on the basis of different path lengths.

At $v = 19$ m/sec the qualitative nature of the curves with $W_{\varphi 0} = 0$ is analogous to the corresponding curves at $v = 5$ m/sec. At $W_{\varphi 0} = 0$ and $v = 19$ m/sec the coarse dust does not fall out of the stream (Fig. 3, dashed curve), and the nature of the curve recalls the curve at $1 > W_{\varphi 0} > 0$ for the case $v = 5$ m/sec.

It also follows from Fig. 4, that, qualitatively, the theoretical curves are in quite good agreement with

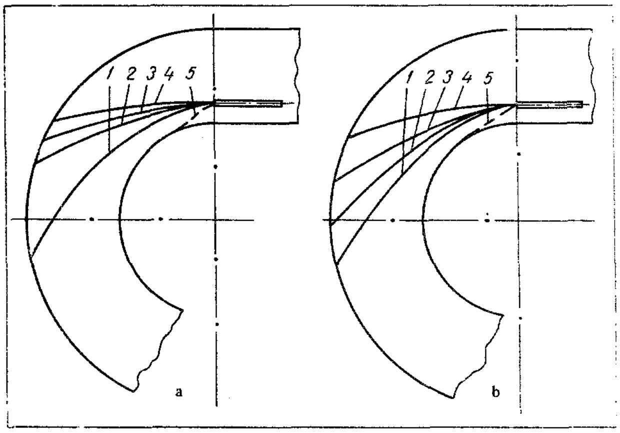

Fig. 2. Experimental (a) and theoretical (b) aerosol trajectories ($\delta = 126.5\,\mu$ and v = 5 m/sec): 1) $W_{\varphi_0} = 0$; 2) 0.6; 3) 1.0; 4) 2.0; 5) 0 at $\delta = 427\,\mu$, v = 5 m/sec.

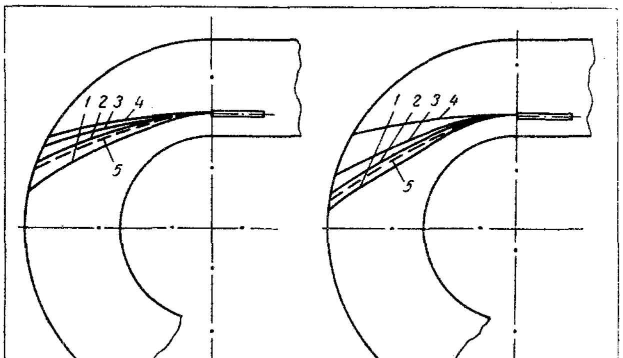

Fig. 3. Experimental (a) and theoretical (b) aerosol trajectories ($\delta = 126.5\,\mu$ and v = 19 m/sec): 1) $w_{\varphi_0} = 0$; 2) 0.6; 3) 1.0; 4) 2.0; 5) 0 at $\delta = 427\,\mu$, v = 19 m/sec.

experiment. This, in turn, provides some justification for using calculations, rather than experiment, to determine the influence of $W_{\varphi 0}$.

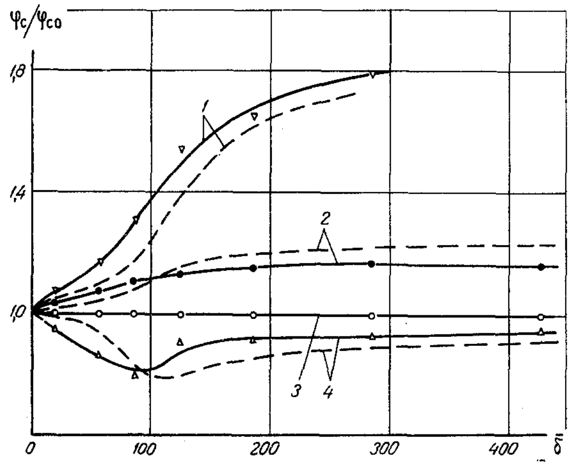

Fig. 4. Relation $\varphi_c/\varphi_{c0} = f(\delta)$: 1) $W_{\varphi 0} = 0$; 2) 0.6; 3) 1.0; 4) 2.0 (solid curve—experimental, dashed curve—theoretical).

The quantitative discrepancy between the theoretical and experimental curves can be attributed, on the one hand, to experimental inaccuracies and, on the other, to certain simplifications introduced into the calculations, for example, the fact that the radial component of the carrier flow velocity is not introduced into the equations of particle motion, although in reality it should be.

NOTATION

v is the velocity of the carrier flow; w_r and w_φ are the radial and tangential components of the particle velocity; φ_c—separation angle; φ_{c0} is the same at $W_{\varphi 0} = 1$; r_0—radius of aerosol admission point; r, φ are the polar coordinates of particle; δ, $\bar{\delta}$, and ρ_2 are the size, mean size, and density of the particle; η and ρ_1 are the viscosity and density of the gas; g is the acceleration of gravity; $St = 4\,\delta^2\rho_2 v/3\eta r_0$; $R = v\,\delta\rho_1/\eta$; $Fr = v^2/r_0 g$.

REFERENCES

1. I. P. Basina and A. V. Tonkonogii, Izv. AN KazSSR, no. 1, 21, 1962.
2. V. I. Ignat'ev and N. I. Zverev, Teploénergetika, no. 2, 1960.
3. V. E. Maslov and Yu. L. Marshak, Teploénergetika, no. 6, 1958.
4. V. E. Maslov and Yu. L. Marshak, Zav. lab., no. 10, 1959.
5. V. I. Mansurov and V. E. Maslov, Telploénergetika, no. 3, 1964.

11 December 1967

Eastern Branch,
Dzerzhinskii All-Union Heat Engineering Institute,
Chelyabinsk