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DISTRIBUTION OF DISPERSE-PHASE VAPORS IN A HIGH-TEMPERATURE GAS FLOW

D. I. Lamden and O. G. Stonik

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The distribution of disperse-phase vapors is obtained in the case where this phase is introduced unevenly into the flow.

The design and analysis of a whole range of production processes requires knowledge of the distribution of disperse-phase vapors in a gas flow when the disperse phase is introduced unevenly into the flow in space. Such introduction naturally leads to a significantly nonuniform distribution of the disperse fraction along and across the flow [1].

It was shown in [2] that the evaporation of drops (particles) occurs much more slowly than their deceleration within a broad range of flow parameters. Thus, the problem of determining the distribution of a disperse phase and its vapors in a gas flow can be broken down into two steps. First we find the mass distribution function of the polydisperse condensed phase in the flow without allowance for the change in the diameters of its constituent particles. We then solve the problem of determining the distribution of the vapor in the gas flow with sources prescribed by the particle distribution function with allowance for polydispersity and differences in the dynamics of evaporation of different-size particles. The study [1] obtained a mass distribution function $g_m(\mathbf{r}, \delta)$ for a disperse phase in a gas flow (the mass of drops with diameters from δ to $\delta + d\delta$ in a volume element dV containing a point with the coordinate $\mathbf{r}$ is given as $dm = g_m(\mathbf{r}, \delta) \cdot d\delta dV$).

In selecting a model for the diffusion process, we note that the rate of molecular diffusion is too low and that during the time the vapor has been carried several meters by the flow it has diffused by fractions of a millimeter across the flow. As regards turbulent diffusion, it is intense in the core of the flow but approaches zero going toward the wall. Thus, in this region diffusive transport across the flow becomes less than convective transport along the flow. This fact allows us to ignore the effect of the walls and to thereby reduce the diffusion boundary-value problem to a Cauchy problem. It should also be noted that the turbulent diffusion in a developed flow is almost constant up to distances on the order of 20% of the tube radius going from the tube wall [3]. Moreover, agitating grids are often used, which leads to equalization of the turbulent diffusion coefficients across the flow. Thus, in solving the diffusion problem, we will assume it to be constant.

We choose the coordinate system as follows: the X axis is directed along the gas flow, the Y axis is directed over the diameter of the gas flow from the wall to the core, and the Z axis is directed perpendicular to the XY plane. Then, with allowance for the above assumptions, the steady-state problem of determining the distribution of disperse-phase vapors ρ_v in the gas flow takes the form

$$\frac{\partial \rho_v}{\partial x} = a^2 \Delta \rho_v + \Phi. \tag{1}$$

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Here, $a^2 = D_t/v_g$, $\Phi = I/v_g$, where D_t is the turbulent diffusion coefficient; v_g is the velocity of the gas flow; I is the mass intensity of the vapor sources. We take the Laplacian in the right side of (1) in the YZ plane. We place the coordinate origin in a flow section where disperse-phase vapors are absent. Such a section would obviously exist, for example, in the event of the use of a direct-jet nozzle and would coincide with the plane containing the nozzle axis. Then the initial condition for Eq. (1) takes the form: $\rho_v|_{x=0} = 0$. The solution of the stated Cauchy problem is given by the following expression:

$$\rho_v(x, y, z) = \frac{1}{4\pi a^2} \int_0^x \int_{y', z'} \frac{\Phi(x', y', z')}{x - x'} \exp\left\{-\frac{(y-y')^2 + (z-z')^2}{4a^2(x-x')}\right\} dx'dy'dz'. \quad (2)$$

The integrals of y' and z' are taken over the regions where the function $\Phi(x, y, z)$ is nontrivial.

To obtain the final solution of the problem, it is necessary to find an explicit expression for the mass intensity of the vapor sources. A study of the dynamics of evaporation of individual drops [4] showed that the following approximate relation between the running drop diameter δ and the distance from the point of introduction is satisfied:

$$x = l_f(d_m)\left(\frac{\delta_0}{d_m}\right)^2\left[\frac{l_{in}(d_m)}{l_f(d_m)} + \left(1 - \frac{l_{in}(d_m)}{l_f(d_m)}\right)\left(1 - \left(\frac{\delta}{\delta_0}\right)^2\right)\right]. \quad (3)$$

Here, $l_{in}(d_m)$, $l_f(d_m)$ are the distances at which a drop of diameter d_m begins to evaporate and at which it has completely evaporated, respectively; δ_0 is the initial diameter of the drop. Differentiating (3) with respect to time and changing over from the drop diameter to the drop mass, we obtain the following expression for the rate of drop evaporation:

$$\frac{dm}{d\tau} = -\frac{\pi\rho_k\delta\delta_0^2 v_x}{4l_f(d_m)(\delta_0/d_m)^2(1 - l_{in}(d_m)/l_f(d_m))}, \quad (4)$$

where ρ_k is the density of the drop; v_x is the component of its running velocity along the X axis. The number of drops located in the volume dV and having initial diameters within the range from δ_0 to $\delta_0 + d\delta_0$ is obtained from determining $g_m(r, \delta)$:

$$dn = \frac{6g_m(r, \delta_0)}{\pi\rho_k\delta_0^3} d\delta_0 dV. \quad (5)$$

If a drop with the initial diameter δ_0 is not completely evaporated up to the given point r, then the number of such drops coincides with (5). Having multiplied the right side of (4) by (5), we obtain the mass intensity of the vapor sources:

$$I(r) = \frac{3}{2l_f(d_m)(1 - l_{in}(d_m)/l_f(d_m))} \int \frac{g_m(r, \delta_0)}{(\delta_0/d_m)^2} \frac{\delta}{\delta_0} d\delta_0. \quad (6)$$

This integral is taken over all δ_0 at the given point. It should be noted that δ is expressed through δ_0 from (3). Thus, (2), (3), and (6) completely solve the problem of determining the density of the vapor in the gas flow.

For a direct-jet nozzle, when the mass intensity of the vapor sources is concentrated in a layer of thickness D (where D is the diameter of the nozzle) about the plane Z = 0 (see [1]), Eq. (2) can be simplified:

$$\rho_v = \frac{D}{4\pi a^2} \int_0^x \frac{\exp\left\{-\frac{z^2}{4a^2(x-x')}\right\}}{x - x'} \int_{y'} \Phi(x', y') \exp\left\{-\frac{(y-y')^2}{4a^2(x-x')}\right\} dx'dy'.$$

As an example of the use of the above-derived relations, below we present curves of the distribution of particles of K_2CO_3 and their vapors in a gas flow with the pressure P_g = 0.5 MPa, temperature T_g = 2800°K, and velocity v_g = 100 m/sec. The disperse phase was introduced with a direct-jet nozzle perpendicular to the flow and characterized by the Rosen–Rammler par-

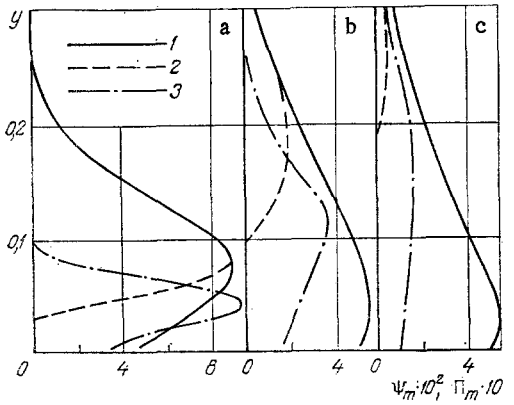

Fig. 1

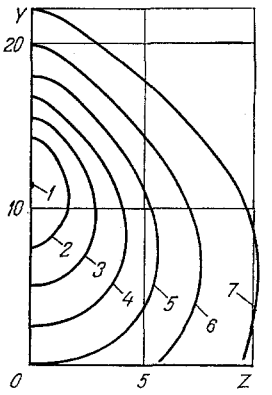

Fig. 2

Fig. 1. Distribution of a disperse phase and its vapor in the axial section of a flow at different distances from the site of introduction: 1) disperse phase without allowance for evaporation; 2) residue of disperse phase with allowance for evaporation; 3) vapor distribution (1, 2 — Ψ_m, sec/m^2; 3 — Π_m, sec/m^3); a) X = 0.5 m; b) 2; c) 4 m. y, m.

Fig. 2. Pattern of vapor distribution in the flow cross section 2 m from the site of introduction (direct-jet nozzle directed along the Y axis; Y and Z, cm): 1) Π_m = 0.37 sec/m^3; 2) 0.3; 3) 0.25; 4) 0.2; 5) 0.15; 6) 0.1; 7) 0.05 sec/m^3.

ticle-size distribution function. The median diameter of the particles d_m = 100 μm, the distribution index n = 2, and the rate of introduction V_0 = 15 m/sec. The channel diameter was taken equal to one meter. The turbulent diffusion coefficient was calculated from formulas [3] for a developed flow.

Figure 1 shows the pattern of transverse distributions of particles and their vapors in the axial section of the flow at different distances X from the site of introduction. Here, $g_m = M\Psi_m/D$, where M is the discharge velocity of the nozzle. The dashed line corresponds to that particle fraction which did not evaporate before reaching the given section. It is apparent from the figure that practically all of the particles have evaporated by the time a distance of 4 m has been reached. The dot-dash line corresponds to the vapor distribution. It should be noted that here and subsequently, $\rho_v = M\Pi_m$, so that the numbers of the curves of particle and vapor mass distribution differ by a multiplier equal to the diameter of the nozzle. Thus, the vapor distribution density in the chosen section is an order of magnitude less than disperse-phase distribution density, which corresponds to its diffusive resorption in the perpendicular direction. This is illustrated by Fig. 2, which shows the vapor distribution pattern under these conditions in a section located 2 m from the site of introduction. The nozzle was directed along the Y axis, and the lines of constant concentration are symmetrical relative to it. It can be seen that there is a substantial decrease in concentration at distances on the order of 100 mm.

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