MOTION OF SMALL AEROSOL PARTICLES, CONTAINING HEAT
SOURCES UNEVENLY DISTRIBUTED OVER VOLUME,
IN POLYATOMIC GASES

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An expression is obtained for the velocity of steady motion of a particle, containing internal heat sources unevenly distributed over volume, in polyatomic gases.

In those cases when heat sources act within an aerosol particle a nonuniform temperature distribution is established over the particle's surface. In this case molecules flying off from the more strongly heated part of the surface impart additional momentum to the particle, which leads to orderly motion of the particle. If the heating of the surface is caused by electromagnetic radiation, such motion is called photophoretic [1-3].

In describing particle motion taking place under the action of heat sources we will neglect the influence of the particle on the velocity distribution and internal energies of the molecules incident on its surface, which we describe through the function

$$f_i = n \left(\frac{m}{2\pi kT} \right)^{\frac{3}{2}} \exp\left[-\left(\frac{m\mathbf{v}^2}{2kT} + \frac{E_i}{kT} \right) \right] \left[\sum_i \exp\left(-\frac{E_i}{kT} \right) \right]^{-1} [1 - 2\mathbf{cU}], \tag{1}$$

where

$$\mathbf{c} = \left(\frac{m}{2kT} \right)^{\frac{1}{2}} \mathbf{v}, \qquad \mathbf{U} = \left(\frac{m}{2kT} \right)^{\frac{1}{2}} \mathbf{U}_p,$$

and U_p is the velocity of the given point of the particle's surface.

The distribution function f_i^+ of molecules flying off from the particle's surface will be sought in the form

$$f_i^+ = (1 - \delta) f_i^- [\mathbf{v} - 2\mathbf{n}_\xi (\mathbf{vn}_\xi)] + \delta n_w \left(\frac{m}{2\pi kT_w} \right)^{\frac{3}{2}} \exp\left[-\left(\frac{m\mathbf{v}^2}{2kT_w} + \frac{E_i}{kT_w} \right) \right] \left[\sum_i \exp\left(-\frac{E_i}{kT_w} \right) \right]^{-1}. \tag{2}$$

Here n_w and T_w are the concentration and temperature of the reflected molecules, determined from the boundary conditions; n_ξ is the unit vector normal to the surface at the given point of the particle.

To find n_w and T_w we use the boundary conditions

$$(\mathbf{N} \cdot \mathbf{n}_\xi) = 0, \tag{3}$$

$$(\mathbf{E} \cdot \mathbf{n}_\xi) = -\varkappa (\nabla T_{in} \cdot \mathbf{n}_\xi), \tag{4}$$

$$(\mathbf{E}^- + E_w^+) \cdot \mathbf{n}_\xi = [\gamma_1 (\mathbf{E}_1^- + \mathbf{E}_{s1}^+) + \gamma_2 (\mathbf{E}_2^- + \mathbf{E}_{s2}^+) \cdot \mathbf{n}_\xi, \tag{5}$$

where $\mathbf{N} = \mathbf{N}^- + \mathbf{N}^+$; $\mathbf{E} = \mathbf{E}^- + \mathbf{E}^+$; $\mathbf{N}^-$ and $\mathbf{N}^+$, flux densities of incident (−) and reflected (+) molecules, respectively; $E^{\mp}$, flux densities of thermal energy carried by the molecules incident on (−) and flying from the surface; γ_1 and γ_2, energy accommodation coefficients [4]; the indices 1 and 2 correspond to the translational and internal energy of a molecule; E_s, energy flux density of reflected molecules at the temperature equal to the surface temperature T_s.

We find the force F with which gas molecules act on the particle and the moment L of this force from the equations

$$\mathbf{F} = -\sum_{\mp} \oint ds\, m \sum_i \int d\mathbf{v}\,(\mathbf{vn}_\xi)\, \mathbf{v} f_i^{\mp}, \tag{6}$$

$$\mathbf{L} = -\sum_{\mp} \oint ds\, m \sum_i \int d\mathbf{v}\,(\mathbf{vn}_\xi)\,[\mathbf{rv}]\, f_i^{\mp}, \tag{7}$$

where ds is a differential element of particle surface.

The expressions for the force components F_j and the force-moment components L_j are

$$F_j = -\frac{2kT}{\sqrt{\pi}} \oint ds\, \psi_j, \tag{8}$$

$$L_x = -\frac{2kT}{\sqrt{\pi}} \oint ds\,(y_s\psi_z - z_s\psi_y), \tag{9}$$

$$L_y = -\frac{2kT}{\sqrt{\pi}} \oint ds\,(z_s\psi_x - x_s\psi_z), \tag{10}$$

$$L_z = -\frac{2kT}{\sqrt{\pi}} \oint ds\,(x_s\psi_y - y_s\psi_x), \tag{11}$$

$$\psi_j = n\sum_l U_l \left\{ \left[A_{\xi j}A_{\xi l} + \frac{1}{2}(A_{\eta j}A_{\eta l} + A_{\varphi j}A_{\varphi l}) \right](2-\delta) + \frac{\pi\delta}{4}\sqrt{\frac{T_{w0}}{T}}\left[1 + \frac{1}{8}(1-\gamma_1)\frac{k}{\Phi}\frac{T}{T_{w0}} \right] A_{\xi j}A_{\xi l} \right\}$$
$$+ n\sum_l \delta\sqrt{\frac{\pi}{8}}\sqrt{\frac{1}{TT_{w0}}} A_{\xi j}\Delta T_s \left[\frac{\gamma_1 k + \frac{1}{2}\gamma_2 c_v}{\Phi} \right]. \tag{12}$$

Here x_s, y_s, and z_s are the coordinates of points of the particle's surface in the coordinate system rigidly connected with the particle; the coefficients A_{tl} (where t takes the values ξ, η, and φ while $l = $ x, y, and z) are elements of the conversion matrix $A_{tl}\{(n_tn_l)\}$; n_ξ, n_η, $n\varphi$ is the right-handed triple of a system of three mutually perpendicular vectors, the vector n_ξ being perpendicular to the plane tangent to the particle's surface at the given point while the other two vectors lie in this plane;

$$\Phi = k + \frac{1}{2}c_v, \quad c_v = \frac{\partial}{\partial T}(\langle E \rangle),$$

$$\langle E \rangle = \sum_i E_i \exp\left(-\frac{E_i}{kT}\right)\left[\sum_i \exp\left(-\frac{E_i}{kT}\right)\right]^{-1}. \tag{13}$$

The quantity ΔT_s equals $T_s - T_{s0}$ (T_{s0} is the average temperature of the particle's surface) and the temperature T_{w0} is determined from the equation

$$kT_{w0} + \frac{1}{2}\langle E_{w0} \rangle = \gamma_1 kT_{s0} + \frac{1}{2}\gamma_2\langle E_{s0} \rangle + (1-\gamma_1)kT + \frac{1}{2}(1-\gamma_2)\langle E \rangle. \tag{14}$$

The distribution of temperature T_{in} inside the particle is found through the solution of the Poisson equation together with the boundary condition (4),

$$\Delta T_{in} = -\frac{q(\mathbf{r})}{\varkappa}, \tag{15}$$

where $q(\mathbf{r})$ is the density of heat sources at the point of the particle.

Equation (15) is solved most simply in a spherical coordinate system. We give the final expression at once for the velocity of the steady motion of a spherical particle under the action of internal heat sources:

$$\mathbf{U}_p = -\frac{3}{64}\sqrt{\frac{2k}{\pi}}\frac{\delta\int dV\, \mathbf{r}q(\mathbf{r})}{\sqrt{m}\sqrt{T_{w0}}(1+\theta)R^2\varkappa}\frac{\gamma_1 k + \gamma_2\frac{c_v}{2}}{\Phi}, \tag{16}$$

$$\theta = \left(\frac{\delta}{8}\pi\sqrt{\frac{T_{w0}}{T}} + \frac{\delta}{64}\frac{k(1-\gamma_1)\pi}{\Phi}\sqrt{\frac{T}{T_{w0}}}\right). \tag{17}$$

It follows from (16) that in the case when the values of the accommodation coefficients γ_1 and γ_2 are close ($\gamma_1 \simeq \gamma_2$) the equation obtained in [5] for the velocity U_p in a monatomic gas can be used to estimate the velocity of particle motion in a polyatomic gas. The error committed in doing this does not exceed 5%, as the above calculations showed.

NOTATION

n, number of gas molecules per unit volume; $\mathbf{v}$, m, velocity and mass of a molecule; T, gas temperature at the position of the particle; E_i, internal energy of a molecule in the i-th quantum state; U_p, velocity of the given point of the particle's surface; $f_i^{\mp}$, distribution functions of incident (−) and reflected molecules; δ, coefficient of accommodation of tangential momentum; γ_1 and γ_2, energy accommodation coefficients for translational and internal energies of a molecule; q(r), density of heat sources; $\varkappa$, coefficient of thermal conductivity of particle material; T_{wo}, average temperature of reflected molecules; k, Boltzmann constant; N, E, flux densities of molecules and energy; $\mathbf{F}$, $\mathbf{L}$, force and force moment acting on a particle.

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EFFECT OF A CORONA DISCHARGE FIELD ON

EVAPORATION OF LIQUIDS FROM CAPILLARIES

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Results of a study of the effect of a corona discharge field on evaporation of water and aqueous KCl solutions from quartz capillaries 2-30 μm in radius are presented.

It has been experimentally shown [1, 2] that the electric field of a corona discharge can have a significant effect on the mass-transfer properties of capillary—porous systems. To clarify the mechanism underlying this effect, it is of interest to study the effect of such a discharge on evaporation and motion of liquids in individual capillaries, which, as is well known, can serve as the simplest model of pores.

Measurements were made of the relative evaporation rate of pure water and aqueous KCl solutions from quartz capillaries 2-30 μm in radius in air at atmospheric pressure in a corona discharge field and with the field absent. Evaporation took place within the volume of a thermally stabilized chamber, in which a constant relative humidity φ was maintained by a saturated salt solution. The evaporation rate was determined from the displacement of the liquid meniscus x, which was determined by a KM-6 cathetometer as a function of time τ. The experimental equipment used, and the conditions under which experiments were performed