TIMES OF CAPTURE OF MODERATELY LARGE NONVOLATILE AEROSOL PARTICLES BY GROWING OR EVAPORATING DROPS

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The time of the total clearing of particles from a given volume around growing or evaporating drops is calculated on the basis of the theory of motion of moderately large nonvolatile aerosol particles in binary gas mixtures which are nonuniform in temperature and concentration.

If in a volume containing a binary gas mixture with suspended nonvolatile aerosol particles one places growing or evaporating drops capable of changing into one of the components of the gas mixture through a phase transformation, then under certain conditions one can clear the volume of aerosol particles. The particles can move onto the drops and be adsorbed on them.

Vapors of the drop material form one of the components of the binary gas mixture (the first, to be specific). The number of vapor molecules per unit volume can be either comparable with the number of molecules of the main gas or small in comparison with the latter.

The analysis is performed with the condition that the time of total clearing of a given volume around a drop is considerably less than the time of a significant change in its size. The latter condition occurs in an overwhelming number of the aerosol systems actually observed.

In order to determine the time required for the total clearing of nonvolatile aerosol particles from a given volume around a drop, it is enough to calculate the total velocity of the moderately large nonvolatile aerosol particles relative to the center of the drop. The total velocity of an aerosol particle can be represented in the form

$$\mathbf{u} = \mathbf{u}^{(D)} + \mathbf{u}^{(T)} + \mathbf{u}^{(c.i)}, \tag{1}$$

where $u^{(D)}$ is the velocity of diffusiophoresis, $u^{(T)}$ is the velocity of thermophoresis, and $u^{(c.i)}$ is the velocity of the center of inertia of the binary mixture relative to the center of the drop.

The strictest theory of the thermophoresis of moderately large nonvolatile particles in one-component gases was constructed in [1]. This theory is not suitable for a binary gas mixture, however. An overall equation for the thermo- and diffusiophoresis of moderately large nonvolatile aerosol particles in binary gas mixtures was obtained later in [2]:

$$\mathbf{u}^{(T.D)} = \mathbf{u}^{(T)} + \mathbf{u}^{(D)} = -\frac{2\left(K_{TSl}\eta_0 + K_{TD}^{(Sl)} T_0\rho_0\right)\left(\varkappa_e + \varkappa_i \dfrac{C_T\lambda}{R_0}\right)}{\rho_0 T_0\left(1+2C_m\dfrac{\lambda}{R_0}\right)\left[\varkappa_i\left(1+2C_T\dfrac{\lambda}{R_0}\right)+2\varkappa_e\right]}(\nabla T)_\infty - K_{Sl}\frac{D_{12}(\nabla C_1)_\infty}{\left(1+2C_m\dfrac{\lambda}{R_0}\right)}. \tag{2}$$

The following notation is introduced in Eq. (2): η_0, ρ_0, and T_0 are the viscosity, average density, and average temperature of the gas mixture, respectively, $\varkappa_e$ is the specific thermal conductivity of the mixture, $\varkappa_i$ is the specific thermal conductivity of the particle, λ is the mean free path of the gas molecules, R_0 is the radius of the particle, K_{TSl} and $K_{TD}^{(Sl)}$ are the coefficients of thermal slippage and thermodiffusional slippage, respectively, C_T is the coefficient of the temperature jump, C_m is the slippage coefficient, C_1

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is the relative concentration of the first component of the mixture, and D_{12} is the mutual diffusion coefficient. If the origin of the spherical coordinate system is taken at the center of the drop and it is assumed that the distribution of the concentration C_1 of the component which condenses (or evaporates) at the surface of the particle has spherical symmetry just like the distribution of the temperature T, then these distributions can be found by solving the steady-state equations of diffusion

$$\frac{1}{r^2}\cdot\frac{\partial}{\partial r}\left(r^2\frac{\partial C_1}{\partial r}\right)=0 \tag{3}$$

and heat conduction

$$\frac{1}{r^2}\cdot\frac{\partial}{\partial r}\left(r^2\frac{\partial T}{\partial r}\right)=0. \tag{4}$$

In (3) and in (4) the value r is the distance from the center of the drop to the point ($r > R$) where the concentration C_1 or the temperature T is sought for. We assume that at a large distance from the drop (as $r\to\infty$) the concentration of the first component is equal to $C_{1\infty}$ and the temperature is T_∞. At the surface of the drop (at $r = R$) these values equal C_{10} and T_0, respectively.

Let us write the solutions of the equations of diffusion (3) and heat conduction (4) with the boundary conditions noted above:

$$C_1=C_{1\infty}-(C_{1\infty}-C_{10})\frac{R}{r}, \tag{5}$$

$$T=T_\infty-(T_\infty-T_0)\frac{R}{r}. \tag{6}$$

An additional migration relative to a stationary drop will be observed for nonvolatile aerosol particles if there is a diffusional flux to the drop (or from it) of the first component through the quiescent second component of the binary gas mixture.

This migration is equal to the velocity of the center of gravity of the gas mixture [3]:

$$\mathbf{u}^{\mathrm{c.i}}=-D_{12}\frac{n_0^2 m_1}{n_{02}\rho_0}\nabla C_1, \tag{7}$$

where n_{02} is the number of molecules of the second component of the gas mixture per unit volume. $n_0 = n_{01} + n_{02}$. and m_1 is the mass of a molecule of the first component.

Because of the spherical symmetry of the problem the radial component u_r of the total velocity of a particle relative to the evaporating or growing drop will be different from zero.

Let us substitute the concentration and temperature distributions (5) and (6) into (2) and (7) and consider that it is necessary to retain only the radial component of the gradients. As a result we obtain

$$u_r=-\frac{2\left(K_{TSl}\eta_0+K_{TD}^{(Sl)}T_0\rho_0\right)\left(\varkappa_e+\varkappa_i\dfrac{C_T\lambda}{R_0}\right)R}{\rho_0T_0\left(1+2C_m\dfrac{\lambda}{R_0}\right)\left[\varkappa_i\left(1+2C_T\dfrac{\lambda}{R_0}\right)+2\varkappa_e\right]r^2}(T_\infty-T_0)$$
$$-K_{Sl}\frac{D_{12}R(C_{1\infty}-C_{10})}{\left(1+2C_m\dfrac{\lambda}{R_0}\right)r^2}-D_{12}\frac{n_0^2m_1R}{n_{02}\rho_0r^2}(C_{1\infty}-C_{10}). \tag{8}$$

Equation (8) can be represented in a more compact form:

$$u_r=-(\psi_1+\psi_2)\frac{R}{r^2}, \tag{9}$$

where

$$\psi_1=\frac{2\left(K_{TSl}\eta_0+K_{TD}^{(Sl)}T_0\rho_0\right)\left(\varkappa_e+\varkappa_i\dfrac{C_T\lambda}{R_0}\right)(T_\infty-T_0)}{\rho_0T_0\left(1+2C_m\dfrac{\lambda}{R_0}\right)\left[\varkappa_i\left(1+2C_T\dfrac{\lambda}{R_0}\right)+2\varkappa_e\right]}, \tag{10}$$

$$\psi_2 = D_{12}\left[\frac{K_{Sl}}{\left(1+2C_m\frac{\lambda}{R_0}\right)} + \frac{n_0^2 m_1}{n_{02}\rho_0}\right](C_{1\infty} - C_{10}). \tag{11}$$

If the coefficient $(\psi_1 + \psi_2)$ is positive then the particle will be attracted toward the drop and it will be repelled if it is negative. We assume that $(\psi_1 + \psi_2) > 0$. Then we can calculate the time required for the total clearing of nonvolatile aerosol particles from a given spherical volume of radius $R_V > R$ encompassing the drop. This time follows from the equation

$$t = \int_{R_v}^{R} \frac{dr}{u_r} = \frac{R_v^3 - R^3}{3(\psi_1 + \psi_2) R}. \tag{12}$$

To sum up, an equation is obtained for the time of clearing a given volume (with the selected values of $C_{1\infty}$, C_{10}, T_∞, and T_0) of moderately large nonvolatile aerosol particles.

LITERATURE CITED

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