sure, Pa; ΔT, overheating of the wall, °K; τ_{cr}, time interval from the moment that the thermal load is applied to the onset of film boiling, sec; ΔT_0, overheating of the working section in the presence of nonstationary bubble boiling, °K.

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INFLUENCE OF PARTICLES ON THE TURBULENT HEAT-TRANSFER INTENSITY

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UDC 532.529

The influence of particles on the intensity of turbulent heat transfer by a gas-suspension is investigated on the basis of a system of equations of the second single-point moments of the carrier phase velocity and temperature fluctuations.

A study of the regularities of particle influence on the turbulent transfer of momentum and heat of dusty flows is of great interest for analyzing the operation of installations in which the flows of gas suspensions are used as heat carrier [1]. The majority of experimental and theoretical researches on the heat elimination of dusty flows is devoted to a study of the influence of the particle size and concentration on the heat transfer [1-3]. At the same time experimental investigations of the relative heat elimination of dusty gases show that the magnitude of the solid phase contribution to the heat transfer depends substantially on the ratio between the specific heats of the particle and gas materials and not only on the particle size [1, 2]. Equations are obtained in this paper that describe the turbulent heat diffusion and the intensity of the temperature fluctuations of a carrier gas with particles and a qualitative analysis is performed of the influence of the particle concentration, size and specific heat on the turbulent heat flux, the temperature fluctuation intensity, and the turbulent Prandtl number.

1. The heat-transfer equations for a gas with particles and solid phase have the form

$$\frac{\partial \Theta_1}{\partial t} + U_k \frac{\partial \Theta_1}{\partial x_k} = \chi_1 \frac{\partial^2 \Theta_1}{\partial x_k \partial x_k} - \frac{c_2}{c_1} \Phi \frac{1}{\tau_\theta} (\Theta_1 - \Theta_2), \tag{1}$$

$$\frac{\partial \Theta_2}{\partial t} + V_k \frac{\partial \Theta_2}{\partial x_k} = \frac{1}{\tau_\theta} (\Theta_1 - \Theta_2), \tag{2}$$

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where $\tau_\theta = \rho_2 c_2 a/(3\rho_1 c_1 \chi_1)$ is the thermal relaxation time for particles of infinite heat conduction in the approximation of small Peclet numbers.

Averaging all the flow characteristics in the realization of a turbulent flow, we obtain the solid-phase heat-transfer equation

$$\frac{\partial \langle \Theta_2 \rangle}{\partial t} + \langle V_k \rangle \frac{\partial \langle \Theta_2 \rangle}{\partial x_k} + \frac{\partial \langle \theta_2 v_k \rangle}{\partial x_k} = \frac{1}{\tau_\theta} (\langle \Theta_1 \rangle - \langle \Theta_2 \rangle). \tag{3}$$

The last term in the left side of (3) takes account of the heat-transfer process due to turbulent particle migration.

Averaging (1) and adding to (3), we obtain the heat-transfer equation for the dusty flow as a whole

$$\frac{\partial \langle \Theta_1 \rangle}{\partial t} + \langle U_k \rangle \frac{\partial \langle \Theta_1 \rangle}{\partial x_k} + \frac{c_2}{c_1} \langle \Phi \rangle \left(\frac{\partial \langle \Theta_2 \rangle}{\partial t} + \langle V_k \rangle \frac{\partial \langle \Theta_2 \rangle}{\partial x_k} \right)$$
$$= \frac{\partial}{\partial x_k} \left[\chi_1 \frac{\partial \langle \Theta_1 \rangle}{\partial x_k} - \langle u_k \theta_1 \rangle - \frac{c_2}{c_1} \langle \Phi \rangle \langle \theta_2 v_k \rangle \right]. \tag{4}$$

It follows from (4) that particles entrained in the fluctuating motion of the carrying phase will increase the coefficient of turbulent heat transfer.

The equations for the second single-point moments of the velocity and temperature fluctuations that describe the turbulent diffusion of heat and the intensity of the carrying phase temperature fluctuations in the presence of particles agree with the appropriate equations for a pure gas, with the exception of terms taking into account the interphasal interaction. The correlations occurring here between the solid and carrying phase velocity and temperature fluctuations in an inhomogeneous flow are expressed in closed form in terms of the carrying gas velocity and temperature fluctuation correlations (analogously to [4]). For example, the following expressions:

$$\langle \theta_2 v_i \rangle = g_{\theta u1} \langle \theta_1 u_i \rangle - 2 \frac{\tau_u \tau_\theta}{\tau_u + \tau_\theta} g_{\theta u2} \left\{ \langle V_k \rangle \frac{\partial \langle \theta_1 u_i \rangle}{\partial x_k} + \right.$$
$$\left. + \langle \theta_1 u_k \rangle \frac{\partial \langle V_i \rangle}{\partial x_k} + \langle u_i u_k \rangle \frac{\partial \langle \Theta_2 \rangle}{\partial x_k} + g_{\theta u1} \frac{\partial \langle \theta_1 u_i u_k \rangle}{\partial x_k} \right\}, \tag{5}$$

$$\langle \theta_2^2 \rangle = f_{\theta 1} \langle \theta_1^2 \rangle - \tau_\theta \left\{ f_{\theta 2} \langle V_k \rangle \frac{\partial \langle \theta_1^2 \rangle}{\partial x_k} + 2 g_{\theta u2} \langle \theta_1 u_k \rangle \frac{\partial \langle \Theta_2 \rangle}{\partial x_k} + g_{\theta 1} \frac{\partial \langle \theta_1^2 u_k \rangle}{\partial x_k} \right\} \tag{6}$$

are obtained for the heat flux and the square of the solid phase temperature fluctuations.

The system of equations for the turbulent heat flux and the square of the carrying phase temperature fluctuations has the form

$$\langle U_k \rangle \frac{\partial \langle \theta_1 u_k \rangle}{\partial x_k} + \langle \Phi \rangle \langle V_k \rangle \left(g_{u2} \left\langle \theta_1 \frac{\partial u_i}{\partial x_k} \right\rangle + \right.$$
$$\left. + \frac{c_2}{c_1} g_{\theta 2} \left\langle \frac{\partial \theta_1}{\partial x_k} u_i \right\rangle \right) + \langle u_i u_k \rangle \left(\frac{\partial \langle \Theta_1 \rangle}{\partial x_k} + q_{\theta 2} \frac{c_2}{c_1} \langle \Phi \rangle \frac{\partial \langle \Theta_2 \rangle}{\partial x_k} \right) +$$
$$+ \langle u_k \theta_1 \rangle \left(\frac{\partial \langle U_i \rangle}{\partial x_k} + g_{\theta 2} \langle \Phi \rangle \frac{\partial \langle V_i \rangle}{\partial x_k} \right) + \frac{\partial \langle \theta_1 u_i u_k \rangle}{\partial x_k} + \tag{7}$$
$$+ \langle \Phi \rangle \left(g_{u1} g_{u2} \left\langle \theta_1 \frac{\partial u_i u_k}{\partial x_k} \right\rangle + \frac{c_2}{c_1} g_{\theta 1} g_{\theta 2} \left\langle \frac{\partial \theta_1 u_i}{\partial x_k} u_k \right\rangle \right) =$$
$$= - \frac{1}{\rho_1} \left\langle \theta_1 \frac{\partial p}{\partial x_i} \right\rangle + \chi_1 \left\langle \frac{\partial^2 \theta_1}{\partial x_k \partial x_k} u_i \right\rangle + \nu_1 \left\langle \theta_1 \frac{\partial^2 u_i}{\partial x_k \partial x_k} \right\rangle - \frac{\langle \Phi \rangle}{T} \left(g_{u3} + \frac{c_2}{c_1} g_{\theta 3} \right) \langle \theta_1 u_i \rangle,$$

$$\left(\langle U_k \rangle + \langle \Phi \rangle \frac{c_2}{c_1} f_{\theta 2} \langle V_k \rangle \right) \frac{\partial \langle \theta_1^2 \rangle}{\partial x_k} + \langle \theta_1 u_k \rangle \left(\frac{\partial \langle \Theta_1 \rangle}{\partial x_k} + \right.$$
$$\left. + g_{\theta u2} \frac{c_2}{c_1} \langle \Phi \rangle \frac{\partial \langle \Theta_2 \rangle}{\partial x_k} \right) + \left(1 + f_{\theta 1} f_{\theta 2} \frac{c_2}{c_1} \langle \Phi \rangle \right) \frac{\partial \langle \theta_1^2 u_k \rangle}{\partial x_k} =$$
$$= \chi_1 \frac{\partial^2 \langle \theta_1^2 \rangle}{\partial x_k \partial x_k} - \chi_1 \left\langle \left(\frac{\partial \theta_1}{\partial x_k} \right)^2 \right\rangle - 2 \frac{c_2}{c_1} \langle \Phi \rangle \frac{f_{\theta 3}}{T} \langle \theta_1^2 \rangle. \tag{8}$$

The functions f_i, g_i, q_i ($i = 1, 2, 3$) that describe the degree of particle influence on the carrying phase heat-transfer intensity and temperature fluctuations are expressed in terms of two-time correlations of the gas velocity and temperature fluctuations and depend on the time of the particle thermal and dynamical relaxations:

$$f_{u1} = \frac{1}{\tau_u}\int\limits_0^\infty \exp\left(\frac{-s}{\tau_u}\right) F_u(s)\,ds, \quad f_{\theta 1} = \frac{1}{\tau_\theta}\int\limits_0^\infty \exp\left(\frac{-s}{\tau_\theta}\right) F_\theta(s)\,ds,$$

$$g_{\theta u1} = \frac{1}{\tau_u + \tau_\theta}\int\limits_0^\infty \left[\exp\left(\frac{-s}{\tau_u}\right) + \exp\left(\frac{-s}{\tau_\theta}\right)\right] F_{\theta u}(s)\,ds,$$

$$f_{u2} = \frac{1}{\tau_u^2}\int\limits_0^\infty s\exp\left(\frac{-s}{\tau_u}\right) F_u(s)\,ds, \quad f_{\theta 2} = \frac{1}{\tau_\theta^2}\int\limits_0^\infty s\exp\left(\frac{-s}{\tau_\theta}\right) F_\theta(s)\,ds,$$

$$g_{\theta u2} = \frac{1}{\tau_u - \tau_\theta}\int\limits_0^\infty \left[\exp\left(\frac{-s}{\tau_u}\right) - \exp\left(\frac{-s}{\tau_\theta}\right)\right] F_{\theta u}(s)\,ds,$$

$$g_{u1} = \frac{1}{\tau_u}\int\limits_0^\infty \exp\left(\frac{-s}{\tau_u}\right) F_{\theta u}(s)\,ds, \quad g_{\theta 1} = \frac{1}{\tau_\theta}\int\limits_0^\infty \exp\left(\frac{-s}{\tau_\theta}\right) F_{\theta u}(s)\,ds, \tag{9}$$

$$q_{u2} = \frac{1}{\tau_u - \tau_\theta}\int\limits_0^\infty \left[\exp\left(\frac{-s}{\tau_u}\right) - \exp\left(\frac{-s}{\tau_\theta}\right)\right] F_u(s)\,ds,$$

$$q_{\theta 2} = \frac{1}{\tau_u - \tau_\theta}\int\limits_0^\infty \left[\exp\left(\frac{-s}{\tau_u}\right) - \exp\left(\frac{-s}{\tau_\theta}\right)\right] F_\theta(s)\,ds,$$

$$f_{u3} = \frac{T}{\tau_u}(1 - f_{u1}), \quad f_{\theta 3} = \frac{T}{\tau_\theta}(1 - f_{\theta 1}),$$

$$g_{u3} = \frac{T}{\tau_\theta}(1 - g_{\theta 1}), \quad g_{\theta 3} = \frac{T}{\tau_\theta}(1 - g_{\theta 1}),$$

where the functions $F_u(s)$, $F_\theta(s)$, and $F_{\theta u}(s)$ determine the two-time correlations according to the relationships

$$\langle u_i(x, t)\, u_j(x, s)\rangle = F_u(|t-s|)\langle u_i(x, t)\, u_j(x, t)\rangle, \quad \langle \theta_1(x, t)\,\theta_1(x, s)\rangle = \\ = F_\theta(|t-s|)\langle \theta_1^2(x, t)\rangle, \quad \langle \theta_1(x, t)\, u_i(x, s)\rangle = F_{\theta u}(|t-s|)\langle \theta_1(x, t)\, u_i(x, t)\rangle. \tag{10}$$

As seen from (7) and (8), the terms describing the convective transfer, the turbulent diffusion, and the generation of turbulent fluctuations change during solid phase fluctuating motion; moreover, new terms appear that are due to the additional dissipation of gas fluctuations because of the fluctuating slip of the phase velocities and temperatures. For inertialess particles τ_u, $\tau_\theta \to 0$ the functions f_i, g_i, q_i ($i = 1, 2$), associated with the degree of particle involvement by carrying phase fluctuations, tend to one while the functions f_3 and g_3 describing the additional dissipation in the particles tend to zero, and (7) and (8) go over into a system of equations for the second single-point moments of single-phase fluctuations of a fluid with the specific heat c_1 ($1 < \Phi > c_2/c_1$).

3. To illustrate the particle influence on the turbulent heat-transfer intensity, the correlation functions $F_u(s)$, $F_\theta(s)$, $F_{\theta u}(s)$ in (10) are given in the form

$$F_u(s) = F_\theta(s) = F_{\theta u}(s) = \begin{cases} 1 & \text{for } 0 \leqslant s \leqslant T, \\ 0 & \text{for } s > T. \end{cases} \tag{11}$$

Taking (11) into account, the functions describing the degree of particle involvement in the fluctuating solid phase motion (9) take the form

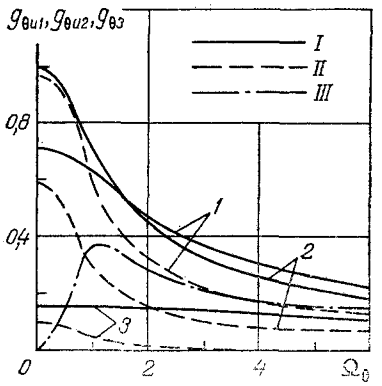

Fig. 1

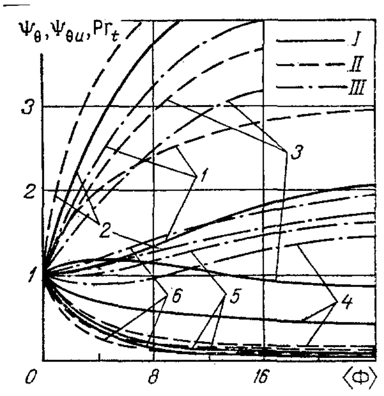

Fig. 2

Fig. 1. Functions describing the degree of particle involvement in temperature fluctuations of the gas: 1) $\Omega_u = 0.2$; 2) 1; 3) 10; I) $g_{\theta u1}$; II) $g_{\theta u2}$; III) $g_{\theta 3}$.

Fig. 2. Intensity of turbulent transfer of a dusty gas ($Pr_1 = 0.7$); 1) $\Omega_u = 0.2$, $c_2/c_1 = 0.1$; 2) 0.2 and 1; 3) 0.2 and 10; 4) 10 and 0.1; 5) 10 and 1; 6) 10 and 10; I) Ψ_θ; II) $\Psi_{\theta u}$; III) Pr_t.

$$f_{u1} = g_{u1} = 1 - \exp(-1/\Omega_u), \quad f_{\theta 1} = g_{\theta 1} = 1 - \exp(-1/\Omega_\theta),$$
$$g_{\theta u1} = 1 - [\exp(-1/\Omega_u) + (\Omega_\theta/\Omega_u)\exp(-1/\Omega_\theta)]/(1 + \Omega_\theta/\Omega_u),$$
$$f_{u2} = g_{u2} = 1 - (1 + 1/\Omega_u)\exp(-1/\Omega_u),$$
$$f_{\theta 2} = g_{\theta 2} = 1 - (1 + 1/\Omega_\theta)\exp(-1/\Omega_\theta),$$
$$g_{\theta u2} = q_{u2} = q_{\theta 2} = 1 - [\exp(-1/\Omega_u - (\Omega_\theta/\Omega_u)\exp(-1/\Omega_\theta)]/(1 - \Omega_\theta/\Omega_u), \tag{12}$$
$$f_{u3} = g_{u3} = \exp(-1/\Omega_u)/\Omega_u, \quad f_{\theta 3} = g_{\theta 3} = \exp(-1/\Omega_\theta)/\Omega_\theta,$$

where $\Omega_\theta = \tau_\theta/T$ and $\Omega_u = \tau_u/T$ are the parameters of the thermal and dynamical inertia of the particles, respectively.

Dependences of the expressions $g_{\theta u1}$, $g_{\theta u2}$, and $g_{\theta 3}$ that are, respectively, the contribution of the solid phase to turbulent heat transfer, to generation, and to additional dissipation of the carrying phase temperature fluctuations on the parameter Ω_θ are shown in Fig. 1. It is seen from Fig. 1 that the degree of particle influence on the fluctuating gas motion grows as the particle thermal and dynamic inertia diminishes. The maximum additional dissipation in the temperature fluctuations is achieved at $\Omega_\theta = 1$.

3. Analysis of the particle influence on the turbulent heat-transfer intensity is performed for high turbulence Reynolds numbers $Re_E \to \infty$. To describe the dissipative and exchange terms in (7) and (8), we use the Monin–Kolovandin approximate relationships [5, 6]

$$\chi_1 \left\langle \left(\frac{\partial \theta_1}{\partial x_k} \right)^2 \right\rangle = b_\theta \frac{E^{1/2}}{L_\theta} \langle \theta_1^2 \rangle, \quad -\left\langle \frac{p}{\rho_1} \frac{\partial \theta_1}{\partial x_k} \right\rangle = k_\theta \frac{E^{1/2}}{L_\theta} \langle \theta_1 u_k \rangle.$$

Neglecting the convective and diffusion components in (7) and (8), we obtain a system of equations for the second nonzero moments of the carrying phase velocity and temperature fluctuations

$$\langle u_x u_y \rangle \left(1 + q_{\theta 2} \frac{c_2}{c_1} \langle \Phi \rangle \right) \frac{\partial \langle \Theta_1 \rangle}{\partial y} + \langle \theta_1 u_y \rangle \times$$
$$\times (1 + g_{\theta 2} \langle \Phi \rangle) \frac{\partial \langle U \rangle}{\partial y} + k_\theta \frac{E^{1/2}}{L_\theta} \langle \theta_1 u_x \rangle + \frac{\langle \Phi \rangle}{T} \left(g_{u3} + \frac{c_2}{c_1} g_{\theta 3} \right) \langle \theta_1 u_x \rangle = 0, \tag{13}$$
$$\langle u_y^2 \rangle \left(1 + q_{\theta 2} \frac{c_2}{c_1} \langle \Phi \rangle \right) \frac{\partial \langle \Theta_1 \rangle}{\partial y} + k_\theta \frac{E^{1/2}}{L_\theta} \langle \theta_1 u_y \rangle + \frac{\langle \Phi \rangle}{T} \left(g_{u3} + \frac{c_2}{c_1} g_{\theta 3} \right) \langle \theta_1 u_y \rangle = 0,$$

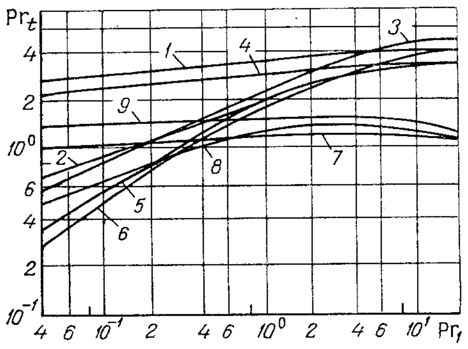

Fig. 3

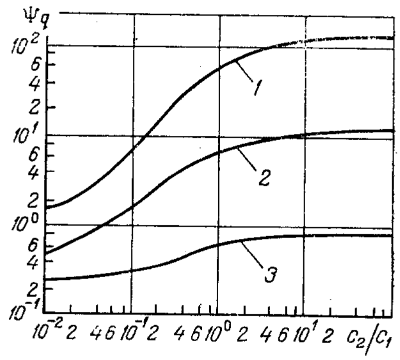

Fig. 4

Fig. 3. Dependence of the turbulent Prandtl number of a gas with particles on the molecular Prandtl number of the gas ($\langle\Phi\rangle = 8.0$): 1) $\Omega_u = 0.2$, $c_2/c_1 = 0.1$; 2) 0.2 and 1; 3) 0.2 and 10; 4) 1 and 0.1; 5) 1 and 1; 6) 1 and 10; 7) 10 and 0.1; 8) 10 and 1; 9) 10 and 10.

Fig. 4. Influence of the ratio between the specific heats of the solid and carrying phases on the turbulent heat flux of a gas suspension ($\langle\Phi\rangle = 8.0$; $Pr_1 = 0.7$): 1) $\Omega_u = 0.2$; 2) 1; 3) 10.

$$\langle \theta_1 u_y \rangle \left(1 + g_{\theta u2}\frac{c_2}{c_1}\langle\Phi\rangle\right)\frac{\partial\langle\Theta_1\rangle}{\partial y} + b_\theta \frac{E^{1/2}}{L_\theta}\langle\theta_1^2\rangle + \frac{c_2}{c_1}\frac{\langle\Phi\rangle}{T} f_{\theta 3}\langle\theta_1^2\rangle = 0. \qquad (13)$$

It was assumed in writing (13) that $\partial\langle U\rangle/\partial y \gg \partial\langle U\rangle/\partial x$ and $\partial\langle\Theta_1\rangle/\partial y \gg \partial\langle\Theta_1\rangle/\partial x$.

Considering the distributions of the average gas velocity and temperature known, taking the spatial scales of the fluctuations in the thermal and hydrodynamic quantities equal, and taking account of the expressions for the tangential stresses and the velocity fluctuation energy for a gas with particles [4], we obtain expressions for the turbulent heat flux, the intensity of the temperature fluctuation, and the turbulent Prandtl number of the dusty gas

$$\langle\theta_1 u_y\rangle = -\frac{k}{b^{1/2}}\left[\frac{2}{3k}\left(1-\frac{b}{k}\right)\right]^{3/2}\frac{(1+f_{u2}\langle\Phi\rangle)}{\left(1+\dfrac{2\langle\Phi\rangle f_{u3}L}{bTE^{1/2}}\right)^{1/2}}\times$$

$$\times\frac{\left(1+q_{u2}\dfrac{c_2}{c_1}\langle\Phi\rangle\right)L^2\dfrac{\partial\langle\Theta_1\rangle}{\partial y}\dfrac{\partial\langle U\rangle}{\partial y}}{\left(1+\dfrac{2\langle\Phi\rangle f_{\theta3}L}{k_\theta TE^{1/2}}\right)^2\left[1+\dfrac{\langle\Phi\rangle L}{k_\theta TE^{1/2}}\left(g_{u3}+\dfrac{c_2}{c_1}g_{\theta3}\right)\right]} \qquad (14)$$

$$= -\frac{k}{b^{1/2}}\left[\frac{2}{3k}\left(1-\frac{b}{k}\right)\right]^{3/2}\Psi_{\theta u}L^2\frac{\partial\langle\Theta_1\rangle}{\partial y}\frac{\partial\langle U\rangle}{\partial y},$$

$$\langle\theta_1^2\rangle = \frac{2}{3}\frac{1}{k_\theta b_\theta}\left(1-\frac{b}{k}\right)\frac{\left(1+q_{u2}\dfrac{c_2}{c_1}\langle\Phi\rangle\right)\left(1+g_{\theta u2}\dfrac{c_2}{c_1}\langle\Phi\rangle\right)}{\left(1+\dfrac{2\langle\Phi\rangle f_{u3}L}{kTE^{1/2}}\right)\left(1+\dfrac{c_2}{c_1}\dfrac{\langle\Phi\rangle f_{\theta3}L}{b_\theta TE^{1/2}}\right)}\times$$

$$\times\frac{\left(L\dfrac{\partial\langle\Theta_1\rangle}{\partial y}\right)^2}{\left[1+\dfrac{\langle\Phi\rangle L}{k_\theta TE^{1/2}}\left(g_{u3}+\dfrac{c_2}{c_1}g_{\theta3}\right)\right]}\;\frac{2}{3}\frac{1}{k_\theta b_\theta}\left(1-\frac{b}{k}\right)\Psi_\theta\left(L\frac{\partial\langle\Theta_1\rangle}{\partial y}\right)^2,$$

$$Pr_t = \frac{k_\theta}{k}\frac{\left[1+\dfrac{\langle\Phi\rangle L}{k_\theta TE^{1/2}}\left(g_{u3}+\dfrac{c_2}{c_1}g_{\theta3}\right)\right](1+f_{u2}\langle\Phi\rangle)}{\left(1+q_{u2}\dfrac{c_2}{c_1}\langle\Phi\rangle\right)\left(1+\dfrac{2\langle\Phi\rangle f_{u3}L}{kTE^{1/2}}\right)}.$$

Values of the constants in (14) are selected from a comparison between the characteristics of near-wall turbulence of a single-phase flow and experimental data: $b = 0.14$, $k = 1.12$, $b_\theta = 0.2$, $k_\theta = 1.0$. The turbulence time scale is given in the form $T = \gamma L/E^{1/2}$. The constant γ in the definition of the time scale is estimated from the formula $T = E/\varepsilon$, where $\varepsilon = bE^{3/2}/L$, which yields $\gamma \approx 8$. In the computations it was assumed $\gamma = 10$.

Dependence of the temperature fluctuation level Ψ_θ, the turbulent heat flux $\Psi_{\theta u}$, and the turbulent Prandtl number of the carrying phase on the particle weight concentration are presented in Fig. 2. The intensity of the turbulent gas fluctuations is reduced in the presence of inertial particles ($\Omega_u > 1$) because of the fluctuating slip of the phases, and depends weakly on the ratio between the specific heats of the solid and the carrying phases. The nature of the influence of low-inertial particles ($\Omega_u < 1$) on the heat transfer of a dusty gas is determined by the ratio c_2/c_1. The nonmonotonic nature of the dependences of Ψ_θ, $\Psi_{\theta u}$, and Pr_t on the ratio between the specific heats of the particle material and the gas is explained by the shift in the additional dissipation maximum for the temperature fluctuations along Ω_u, corresponding to $\Omega_\theta = 1$.

The influence of the molecular Prandtl number of the carrying phase on the turbulent Prandtl number of a dusty gas is due to the dependence of the particle thermal relaxation time on Pr_1 and is illustrated in Fig. 3.

The expression for the degree of solid phase influence on the complete turbulent heat flux of a gas suspension is obtained from the heat-transfer equation for the dusty flux as a whole (4) and has the form

$$\Psi_q = \Psi_{\theta u}\left(1 + \frac{c_2}{c_1} g_{\theta u 1} \langle \Phi \rangle\right).$$

Dependences of Ψ_q on the ratio between the specific heats of the solid and carrying phases are shown in Fig. 4. It is seen that for $c_2/c_1 \ll 1$ the turbulent heat flux of the gas suspension depends substantially on the ratio between the specific heats of the solid and carrying phases. In the domain $c_2/c_1 \gg 1$ the influence of the ratio between the specific heats of the particles and gas on the heat transfer of a dusty flux is weak. The nature of the influence of the ratio between the specific heats c_2/c_1 on the heat-transfer intensity by the gas suspension is in qualitative agreement with experimental results [2].

NOTATION

Φ, $\langle\Phi\rangle$, total and average weight concentration of the solid phase; Θ_1, $\langle\Theta_1\rangle$, θ_1, total, average, and fluctuating temperature of the carrying phase; Θ_2, $\langle\Theta_2\rangle$, θ_2, total, average, and fluctuating temperature of the solid phase; ρ_1, c_1, density and specific heat of the carrying phase; ρ_2, c_2, density and specific heat of the particle material; U_i, $\langle U_i\rangle$, u_i, total, average, and fluctuating velocities of the carrying phase; V_i, $\langle V_i\rangle$, v_i, total, average, and fluctuating velocities of the solid phase; a, particle radius; ν_1, χ_1, kinematic viscosity and the thermal diffusivity coefficients of the carrying phase; $\tau_u = 2\rho_2 a^2/(9\rho_1\nu_1)$, particle dynamic relaxation time; T, turbulence time scale; $Pr_1 = \nu_1/\chi_1$, carrying phase molecular Prandtl number; L_θ, L, spatial scales of the thermal and hydrodynamic fluctuations; $E = 0.5(\langle u^2{}_x\rangle + \langle u^2{}_y\rangle + \langle u^2{}_z\rangle)$, fluctuating gas energy; and ε, turbulent dissipation of the carrying phase energy.

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