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VELOCITY AND TEMPERATURE FLUCTUATIONS IN A TURBULENT SUSPENSION

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The effect of the particles of a suspension on the spectrum of velocity and temperature fluctuations is studied on the basis of the equations for the second two-point moments.

The effect of the particles on the spectrum of velocity and temperature fluctuations of a gas with particles arises in connection with the propagation of acoustic, optical, and radio waves in a dusty medium. The distortion of the spectrum of fluctuations of the gas component due to the particles has not been studied sufficiently either theoretically or experimentally. There is no data in the literature on the spectrum of temperature fluctuations of a gas with particles and there is no common view on the nature and degree of the distortion of the distribution of fluctuation energy of the gas among vortices of different sizes in a suspension. For example, it is assumed in [1] that the addition of particles into a turbulent fluid does not change the intensity of velocity fluctuations of power-consuming vortices but leads to a suppression of small-scale vortices whose characteristic sizes are smaller than the diameter of the particles suspended in the fluid. The model of [1] was applied in [2, 3] to the hydrodynamics and heat transfer of the flow of a suspension in a pipe. In [4] the spectrum of velocity fluctuations of the gas component of a suspension was studied theoretically and it was found that the intensity of turbulent velocity fluctuations increases in the inertial part of the spectrum and decreases in the region of viscous dissipation. But the theoretical picture of the distortion of the spectrum of velocity fluctuations of the gas in the presence of particles does not agree with the experimental data of [5, 6]. In these papers it was established that small particles lead to a significant decrease in the intensity of turbulent velocity fluctuations of the gas in energy-containing vortices and in the inertial region of the spectrum, while in the viscous dissipation region fluctuations increase.

In the present paper we consider a fluid with a small volume concentration of impurity particles. On the basis of the equations for the second two-point correlations of the velocity and temperature fluctuations in the discrete and fluid phases we obtain expressions for the spectral functions describing the intensity distribution of velocity and temperature fluctuations of the gas phase as functions of the wave number in the inertial and convective regions of the spectrum. We study the effect of the ratio of the heat capacities of the particles and the gas and also the molecular Prandtl number of the gas on the spectrum of temperature fluctuations of a gas with particles.

The system of equations for the second two-point correlations of the velocity fluctuations for the fluid and discrete phases has the following form, assuming homogeneous isotropic turbulence [4]

$$\frac{\partial E_u(k,t)}{\partial t} - F_u(k,t) = -2\nu k^2 E_u(k,t) - 2\frac{\Phi}{\tau_u}[E_u(k,t) - E_{uv}(k,t)], \tag{1}$$

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$$\frac{\partial E_v(k,t)}{\partial t}-F_v(k,t)=\frac{2}{\tau_u}[E_{uv}(k,t)-E_v(k,t)], \tag{2}$$

$$\frac{\partial E_{uv}(k,t)}{\partial t}-F_{uv}(k,t)=-\nu k^2E_{uv}(k,t)-\frac{\Phi}{\tau_u}[E_{uv}(k,t)-E_v(k,t)]+\frac{1}{\tau_u}[E_u(k,t)-E_{uv}(k,t)]. \tag{3}$$

The system of equations for the second two-point correlations of temperature fluctuations of the fluid and discrete phases, in the case of homogeneous isotropic turbulence, can be written in the form:

$$\frac{\partial E_{\theta 1}(k,t)}{\partial t}-F_{\theta 1}(k,t)=-2\chi k^2E_{\theta 1}(k,t)-2\frac{c_2}{c_1}\frac{\Phi}{\tau_\theta}[E_{\theta 1}(k,t)-E_{\theta 12}(k,t)], \tag{4}$$

$$\frac{\partial E_{\theta 2}(k,t)}{\partial t}-F_{\theta 2}(k,t)=\frac{2}{\tau_\theta}[E_{\theta 12}(k,t)-E_{\theta 2}(k,t)], \tag{5}$$

$$\frac{\partial E_{\theta 12}(k,t)}{\partial t}-F_{\theta 12}(k,t)=-\chi k^2E_{\theta 12}(k,t)-\frac{c_2}{c_1}\frac{\Phi}{\tau_\theta}[E_{\theta 12}(k,t)-E_{\theta 2}(k,t)]+\frac{1}{\tau_\theta}[E_{\theta 1}(k,t)-E_{\theta 12}(k,t)]. \tag{6}$$

We consider the universal equilibrium region in wave number space ($k \gg k_e$, where k_e is the wave number corresponding to energy-containing vortices). The nature of the turbulence in this region is determined mainly by a flux of energy from larger vortices to smaller ones and by the rate of turbulent dissipation. In this region the terms involving time derivatives in (1) through (6) will be small in comparison with the remaining terms [7]. Neglecting in (2), (3), (5), and (6) derivatives with respect to time and third-order correlations in comparison with pair correlations [8], we obtain expressions for the spectral functions describing the intensity of velocity and temperature fluctuations in the discrete and fluid phases:

$$E_v(k,t)=E_{uv}(k,t)=\frac{E_u(k,t)}{1+\tau_u\nu k^2}, \tag{7}$$

$$E_{\theta 2}(k,t)=E_{\theta 12}(k,t)=\frac{E_{\theta 1}(k,t)}{1+\tau_\theta\chi k^2}. \tag{8}$$

From (7) and (8) it is evident that the degree to which the particles are drawn into the fluctuating motion of the gas is determined by the dynamical $\Omega_u(k) = \tau_u\nu k^2$ and thermal $\Omega_\theta(k) = \tau_\theta\chi k^2$ inertias of the particles. For small-scale turbulence ($\Omega_u(k) \gg 1$, $\Omega_\theta(k) \gg 1$) $E_v(k,t) = E_{uv}(k,t) \to 0$, $E_{\theta 2}(k,t) = E_{\theta 12}(k,t) \to 0$, while for large-scale vortices ($\Omega_u(k) \ll 1$, $\Omega_\theta(k) \ll 1$) $E_v(k,t) = E_{uv}(k,t) \to E_u(k,t)$, $E_{\theta 2}(k,t) = E_{\theta 12}(k,t) \to E_{\theta 1}(k,t)$. Substituting (7) and (8) into (1) and (4), we obtain the following equations for the spectral functions of the velocity and temperature fluctuations of the gas in the presence of particles:

$$\frac{\partial E_u(k,t)}{\partial t}-F_u(k,t)=-2\nu k^2E_u(k,t)\left[1+\frac{\Phi}{1+\tau_u\nu k^2}\right], \tag{9}$$

$$\frac{\partial E_{\theta 1}(k,t)}{\partial t}-F_{\theta 1}(k,t)=-2\chi k^2E_{\theta 1}(k,t)\left[1+\frac{c_2}{c_1}\frac{\Phi}{1+\tau_\theta\chi k^2}\right]. \tag{10}$$

The decrease of the fluctuation kinetic energy and the intensity of the temperature fluctuations of the gas with time is due to turbulent dissipation of velocity Σ_u and temperature Σ_θ fluctuations in the fluid phase:

$$\Sigma_u(t)=-\frac{\partial}{\partial t}\int_0^\infty E_u(k,t)\,dk=2\nu\int_0^\infty dk k^2E_u(k,t)\left[1+\frac{\Phi}{1+\tau_u\nu k^2}\right], \tag{11}$$

$$\Sigma_\theta(t)=-\frac{\partial}{\partial t}\int_0^\infty E_{\theta 1}(k,t)\,dk=2\chi\int_0^\infty dk k^2E_{\theta 1}(k,t)\left[1+\frac{c_2}{c_1}\frac{\Phi}{1+\tau_\theta\chi k^2}\right]. \tag{12}$$

It follows from (11) and (12) that the participation of the particles in the fluctuating motion increases the turbulent dissipation of the velocity and temperature fluctuations of the gas component of the suspension in comparison with a single-phase fluid because of an increase in the flux of energy from the larger vortices to the smaller ones. The contribution of the discrete phase to the rate of momentum and heat transport over the spectrum is determined by the dynamical and thermal inertias of the particles. We consider (11) and (12) in more detail. The integrands on the far right hand sides of these expressions reach a maximum near $k \sim k_\eta$ and $k \sim k_{\eta\theta}$, respectively, and $\nu k_\eta^2 = \tau_\eta^{-1}$ and $\chi k_{\eta\theta}^2 \sim \tau_{\eta\theta}^{-1}$ [7] (τ_η, k_η^{-1} are the Kolmogorov characteristic time and length of the velocity fluctuations; $\tau_{\eta\theta}$, $k_{\eta\theta}^{-1}$ are the analogs of these quantities for temperature fluctuations). The first terms in the far right hand sides of (11) and (12) represent, respectively, turbulent dissipation of velocity and temperature in the gas due to small-scale turbulent shear stresses and temperature gradients in the gas:

$$\Sigma_{u1}(t) = 2\nu \int_0^\infty dk k^2 E_u(k, t), \tag{13}$$

$$\Sigma_{\theta 1}(t) = 2\chi \int_0^\infty dk k^2 F_{\theta 1}(k, t). \tag{14}$$

With the help of (13) and (14) one can estimate the magnitudes of turbulent dissipation of of velocity and temperature fluctuations in the suspension:

$$\Sigma_u(t) \approx \Sigma_{u1}(t)\left[1 + \frac{\Phi}{1 + \tau_u/\tau_\eta}\right], \tag{15}$$

$$\Sigma_\theta(t) \approx \Sigma_{\theta 1}(t)\left[1 + \frac{c_2/c_1\Phi}{1 + \tau_\theta/\tau_{\eta\theta}}\right]. \tag{16}$$

It is evident from (15) and (16) that the contribution of the discrete phase to the turbulent dissipation becomes significant when the dynamical and thermal relaxation times of the particles are smaller than the Kolmogorov time scales of the turbulence τ_η and $\tau_{\eta\theta}$. We note that the turbulent dissipation of heat in a suspension depends on the ratio of the thermal parameters of the particles and the gas phase.

We consider in more detail the inertial and convective regions of the spectrum, assuming statistically stationary, homogeneous, isotropic turbulence. In these regions energy and heat is transferred from large vortices to smaller ones by cascade transport over the spectrum. In analogy with models of cascade transport of energy and heat in single-phase turbulence [9-11], we obtain from (9) and (11) an expression for the total energy flux $S_u(k)$ into a vortex with wave number k from larger vortices with wave numbers ranging from zero to k:

$$S_u(k) = -\int_0^k F_u(k)\, dk = -\frac{kE_u(k)\left[1 + \frac{\Phi}{1 + \tau_u \nu k^2}\right]}{T(k)}, \tag{17}$$

where T(k) is the time of energy transport into a vortex with characteristic size k^{-1}. Because for a suspension with a small volume concentration of particles, the time of energy, transport over the spectrum depends on the turbulent shear stresses in the fluid phase only, we assume that the characteristic time T(k) in a dusty medium is the same as that for a single-phase fluid and has the form [9, 10].

$$T(k) = \alpha_u [\Sigma_{u1}^{-1/3} k^{-2/3} + Q_u \tau_\eta].$$

In the same way we find the following expression for the cascade transport of heat in the wave number region from zero to k in a gas with particles:

$$S_{\theta 1}(k) = -\int_0^k F_{\theta 1}(k)\, dk = -\frac{kE_{\theta 1}(k)\left[1 + \frac{c_2}{c_1}\frac{\Phi}{1 + \tau_\theta \chi k^2}\right]}{\alpha_\theta [\Sigma_{u1}^{-1/3} k^{-2/3} + Q_\theta \tau_\eta]}. \tag{18}$$

From (9), (10), (17), and (18) we obtain the following equations for the spectral functions for the velocity and temperature fluctuations in a dusty gas:

$$-\alpha_u^{-1}\frac{d}{dk}\left[\frac{kE_u(k)\left(1+\dfrac{\Phi}{1+\tau_u\nu k^2}\right)}{\Sigma_{u1}^{-1/3}k^{-2/3}+Q_u(\nu/\Sigma_{u1})^{1/2}}\right]=2\nu k^2\left[1+\frac{\Phi}{1+\tau_u\nu k^2}\right]E_u(k), \tag{19}$$

$$\alpha_\theta^{-1}\frac{d}{dk}\left[\frac{kE_{\theta1}(k)\left(1+\dfrac{c_2}{c_1}\dfrac{\Phi}{1+\tau_\theta\chi k^2}\right)}{\Sigma_{u1}^{-1/3}k^{-2/3}+Q_\theta(\nu/\Sigma_{u1})^{1/2}}\right]=2\chi k^2\left[1+\frac{c_2}{c_1}\frac{\Phi}{1+\tau_\theta\chi k^2}\right]E_{\theta1}(k). \tag{20}$$

It is evident from (15), (16), (19), (20) that particles with small dynamical and thermal inertias ($\tau_u \ll \tau_\eta$ and $\tau_\theta \ll \tau_{\eta\theta}$), and also particles whose dynamical and thermal relaxation times are much larger than the Kolmogorov characteristic times, do not distort the spectrum of velocity and temperature fluctuations of the gas from the case of single-phase turbulence. The intensity of the velocity and temperature fluctuations of a single-phase fluid in the inertial and convective regions of the spectrum is determined by turbulent dissipation of kinetic energy and heat (Σ_{u1} and $\Sigma_{\theta1}$). Choosing the same parameters Σ_{u1} and $\Sigma_{\theta1}$ as the determining parameters for the intensity of velocity and temperature fluctuations in a suspension, we obtain, after integrating (19) and (20), expressions for the three-dimensional normalized spectra of the velocity and temperature fluctuations in a gas with particles:

$$e_u(y)=\frac{\alpha_u y^{-5/3}(1+Q_u y^{2/3})\exp[-\alpha_u(Q_u y^2+1{,}5y^{4/3})]}{\left[1-\dfrac{\alpha_u\Phi}{T_d}\exp\left(\dfrac{\alpha_u}{T_d}(1+\Phi)\right)E_1\left(\dfrac{\alpha_u}{T_d}(1+\Phi)\right)\right]\left[1+\dfrac{\Phi}{1+T_d y^2}\right]}, \tag{21}$$

$$e_{\theta1}(y)=\frac{\alpha_\theta y^{-5/3}(1+Q_\theta y^{2/3})\exp[-\alpha_\theta(Q_\theta y^2+1{,}5y^{4/3})/\mathrm{Pr}]}{1+\dfrac{c_2/c_1\Phi}{1+(3c_2)/(2c_1)T_d y^2}}\times$$
$$+\left[1-\frac{2}{3}\frac{\alpha_\theta}{\mathrm{Pr}}\frac{\Phi}{T_d}\exp\left(\frac{2}{3}\frac{\alpha_\theta}{\mathrm{Pr}}\frac{1+c_2/c_1\Phi}{c_2/c_1T_d}\right)E_1\left(\frac{2}{3}\frac{\alpha_\theta}{\mathrm{Pr}}\frac{1+c_2/c_1\Phi}{c_2/c_1T_d}\right)\right]^{-1}. \tag{22}$$

The normalized three-dimensional spectra (21) and (22) obey the following relations, analogous to the case of a single-phase fluid:

$$2\int_0^\infty y^2e_u(y)\,dy=\frac{2}{\mathrm{Pr}}\,y^2e_{\theta1}(y)\,dy=1.$$

The three-dimensional spectra (21) and (22) can be transformed to one-dimensional normalized spectra using the equations of [10, 11].

Figure 1 shows the spectra of velocity fluctuations of the gas in the presence of particles with different inertias. We see that the particles cause a decrease in the intensity of turbulent fluctuations in the inertial region of the spectrum and an expansion of the region of small-scale turbulence into the viscous dissipation region. Figure 1 also shows the one-dimensional spectrum $e_v^{(1)}(y)$ of fluctuations in the discrete phase; an increase in the dynamical inertia of the particles leads to a sharp decrease in the intensity of turbulent fluctuations of the discrete phase in the region of small-scale turbulence. Figure 2 illustrates the behavior of the dissipation functions describing the total turbulent dissipation in the suspension and the part of the turbulent dissipation due to turbulent stresses in the gas:

$$\sigma_u(y)=y^2e_{u1}(y)\left[1+\frac{\Phi}{1+T_d y^2}\right],\quad \sigma_{u1}(y)=y^2e_{u1}(y).$$

Particles with a large dynamical relaxation time shift the maximum of the dissipative function $\sigma_{u1}(y)$ toward larger wave numbers. The addition of the particles leads to an increase in the turbulent dissipation of the suspension over that occurring in a pure gas. The easier the particles are drawn into the fluctuating motion, the larger the turbulent dissipation in the suspension.

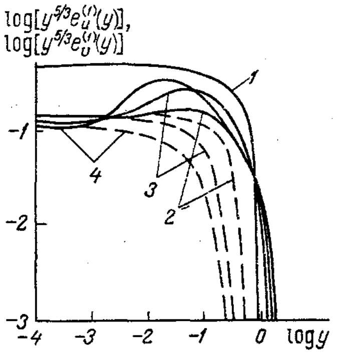

Fig. 1

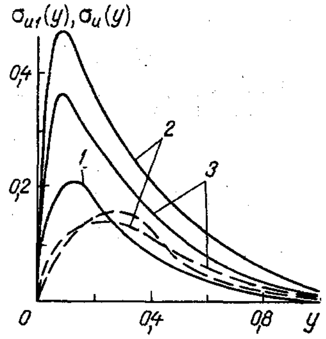

Fig. 2

Fig. 1. One-dimensional spectra of velocity fluctuations of the gas (solid curves) and the discrete phase (dashed curves) in a suspension: 1) $\Phi = 0$; 2-4) $\Phi = 8$; 2) $T_d = 25$; 3) 50; 4) 100.

Fig. 2. Spectral dissipation functions (solid curves — total dissipation; dashed curves — the part of the dissipation due to shear stresses in the gas): 1) $\Phi = 0$; 2, 3) $\Phi = 8$; 2) $T_d = 25$; 3) 50.

Figure 3 shows the effect of the discrete phase on the one-dimensional spectrum of temperature fluctuations of the gas for different thermal and physical properties of the particles and the gas. For a pure fluid the results obtained from (18)-(21) reduce to the results of [12, 13]: A small Prandtl number of the gas phase shifts the diffusion region of the spectrum toward smaller wave numbers and a large Prandtl number expands the convective region of the spectrum in comparison with the one-dimensional spectrum of velocity fluctuations of the gas. It is clear from this figure that in the presence of the particles the intensity of the temperature fluctuations of the gas decreases in the convective region and the diffusion region of the spectrum expands. With increasing ratio of the heat capacities of the particles and gas there is a strong suppression of turbulent temperature fluctuations of the gas in the convective region and a sharp reduction of the level of turbulent temperature fluctuations in the discrete phase; the latter occurs because an increase in the ratio of the heat capacities of the particles and gas leads to an increase in the thermal inertia of the impurity particles.

The three-dimensional spectrum of velocity fluctuations in a single-phase fluid can often be approximated by the Carman formula [7, 10] over the entire range of wave number. For a suspension the Carman dependence modified to take into account the distortion of the spectrum in the presence of the impurity particles can be written in the form

$$\frac{E_u(k)}{u^2} = \frac{A}{k_e}\,\frac{x^4(1+x^2)^{-17/6}}{1+(\Phi/(1+T_e x^2))}. \tag{22}$$

The constant A is found from the normalization condition $\frac{3}{2}u^2 = \int\limits_0^\infty E_u(k)\,dk$:

$$A = \frac{3}{2}\left[\int\limits_0^\infty \frac{x^4(1+x^2)^{-17/6}dx}{1+(\Phi/(1+T_e x^2))}\right]^{-1}.$$

We assume that the wave number region corresponding to power-consuming vortices is sufficiently distant from the wave number region corresponding to inertial transport; in other words, there exists a region of wave numbers such that $k_e \ll k \ll k_d$. Then, comparing (22) in the limit $x \gg 1$ and (18) in the limit $y \ll 1$, we obtain an expression for the wave number of power-consuming vortices

$$k_e = \frac{\alpha_u^{3/2}\Sigma_{u1}}{\left\{\left[1 - \frac{\alpha_u\Phi}{T_d}\exp\left(\frac{\alpha_u}{T_d}(1+\Phi)\right)E_1\left(\frac{\alpha_u}{T_d}(1+\Phi)\right)\right]Au^2\right\}^{3/2}}. \tag{23}$$

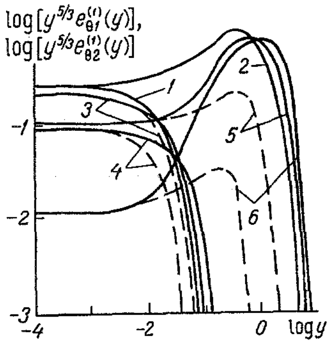

Fig. 3

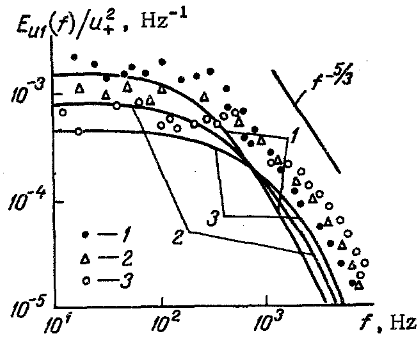

Fig. 4

Fig. 3. Effect of the thermal and physical properties of the particles and the gas on the one-dimensional spectra of temperature fluctuations in the gas (solid curves) and in the discrete phase (dashed curves): 1, 2) $\Phi = 0$; 3-6) $\Phi = 4$; $T_d = 50$; 1, 2) Pr = 0.04; $c_2/c_1 = 1$; 3) 0.04 and 10; 4) 0.7 and 1; 5) 10 and 1; 6) 10 and 10.

Fig. 4. Comparison of the experimental (points) [6] and calculated (curves) spectra of velocity fluctuations in a gas with particles: 1) $\Phi = 0$; 2) 1.3; 3) 2; $R_e = 2.3 \cdot 10^4$; $R/a = 200$.

The three-dimensional spectrum (22) can be transformed to a one-dimensional spectrum using the formula of [10]. In Fig. 4 the one-dimensional spectrum of a suspension calculated according to the modified Carman formula (22) is compared with the experimental data of [6]. The experimental spectra were measured at the center of a pipe, where, with known exceptions, the turbulence can be considered as homogeneous and locally isotropic. The turbulent dissipation in the gas is calculated according to the formula [6]

$$\Sigma_{u1} = bu_+^3/R.$$

The Taylor hypothesis was used in calculating the frequency of turbulent fluctuations. It is evident from Fig. 4 that the modified Carman spectrum (22) reproduces the basic features of the effect of impurity particles on the fluctuation spectrum of the gas phase.

NOTATION

$E_u(k, t)$, $E_v(k, t)$, $E_{uv}(k, t)$, spectral functions describing the second one-point correlations of velocity fluctuations in the fluid, discrete phase, and fluid plus discrete phase, respectively; $F_u(k, t)$, $F_v(k, t)$, $F_{uv}(k, t)$, spectral functions describing the third two-point correlations of the velocity fluctuations in the fluid, discrete phase, and fluid plus discrete phase, respectively and representing inertial transport of energy of turbulent fluctuations over the spectrum; $\tau_u = (2\rho_2 a^2)/(9\rho_1 \nu)$, dynamical relaxation time of the particles; ρ_2, ρ_1, densities of the particles and the gas; a, particle radius; ν, molecular viscosity of the gas; Φ, mass concentration of particles; $E_{\theta 1}(k, t)$, $E_{\theta 2}(k, t)$, $E_{\theta 12}(k, t)$, spectral functions describing the second one-point moments of the temperature fluctuations in the fluid, discrete phase, and fluid plus discrete phase, respectively; $F_{\omega 1}(k, t)$, $F_{\theta 2}(k, t)$, $F_{\theta 12}(k, t)$, spectral functions representing convective transport of temperature fluctuations in the fluid, discrete phase, and fluid plus discrete phase, respectively; $\tau_\theta = (3\rho_2 c_2 \cdot a^2)/(2\rho_1 c_1 \chi)$, thermal relaxation time of the particles; c_2, c_1, heat capacities of the particles and the gas; χ, molecular thermal diffusivity of the gas; α_u, Q_u, α_θ, Q_θ, universal constants whose values are determined for single-phase flow; $Pr = \nu/\chi$; $\tau_\eta = (\nu/\Sigma_{u1})^{1/2}$, Kolmogorov characteristic time; $y = k/k_\eta$; $k_\eta = (\Sigma_{u1}/\nu^3)^{1/4}$, Kolmogorov characteristic wave number; $T_d = (2\rho_2 a^2 k_\eta^2)/(9\rho_1)$, dimensionless dynamical relaxation time of the particles; $e_u(y) = E_u(k)/(\Sigma_{u1}\nu^5)^{1/4}$; $e_{\theta 1}(y) = E_{\theta 1}(k)/(\Sigma_{u1}\nu)^{1/4}/\Sigma_{\theta 1}$; $x = k/k_e$; $k_{\eta\theta} = (\Sigma_{u1}/\chi^3)^{1/4}$, Kolmogorov characteristic wave number for temperature fluctuations; $\tau_{\eta\theta} = (\chi/\Sigma_{u1})^{1/2}$, Kolmogorove characteristic time for temperature fluctuations; $T_e = (2\rho_2 a^2 k_e^2)/(9\rho_1)$; u^2, mean-square velocity of the fluctuations; $E_1(y) = \int_1^\infty \exp(-yt)dt/t$, exponential integral; $e_v(y) = E_v(k)/$

$(\Sigma_{u1}\nu^5)^{1/4}$; $e_{\theta 2}(y) = E_{\theta 2}(k)/(\Sigma_{u1}\nu^{1/4})\Sigma_{\theta 1}$; b = 2.2, constant used in the calculation of turbulent dissipation for the flow of a gas in a pipe; u_+, dynamical velocity; R, radius of the pipe; $e_u^{(1)}(y)$, $e_v^{(1)}(y)$, $e_{\theta 1}^{(1)}(y)$, $e_{\theta 2}^{(1)}(y)$, one-dimensional normalized spectra of velocity and temperature fluctuations of the particles; Re, Reynolds number of the flow.

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GASDYNAMICS AND HEAT TRANSFER DURING AXISYMMETRIC TURBULENT JET INTERACTION WITH A NORMALLY DISPOSED AREA

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UDC 532.525.6

The influence of selecting the kind of turbulence model on the results of a numerical computation of turbulent jet interaction with an obstacle is analyzed.

At this time the investigation of turbulent jet interaction with different obstacles is of considerable practical interest. This paper is devoted to an analysis of certain results of numerical and experimental investigations of the flow and heat transfer during impingement of a submerged isothermal axisymmetric turbulent jet on a normally disposed heated area.

The method elucidated in [1] was used for the numerical solution of the time-averaged Navier–Stokes turbulent viscous fluid flow equations with constant thermophysical properties.

Closure of the system of differential equations in the vortex intensity ω, stream function ψ, and temperature T variables was realized by using the following two turbulence models: $K(L_\nu)$ and $K - \varepsilon$.

The one-parameter turbulence model $K(L_\nu)$ proposed in [2, 3] assumes dependence of the turbulent viscosity ν_T on energy of the turbulent fluctuations K and the turbulence scale L_ν:

$$\nu_T = C_\nu \sqrt{K} L_\nu.$$

The energy of turbulent fluctuations K is determined by solving the differential equation of the fluctuation energy balance. Far from a solid surface the turbulence scales are

*Deceased.

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