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TURBULENT FLOW OF A CHEMICALLY REACTIVE GAS SUSPENSION IN A CHANNEL WITH A BLOW

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The influence of the chemical reactions occurring in the gas phase of a gas suspension flowing in a channel with penetrable walls and the combustion of the condensed-impurity particles in this flow on its gasdynamic structure has been investigated. It is shown that the order of the system of equations defining a flow of a chemically reactive gas suspension with a homogeneous exothermic reaction proceeding at a definite rate and a heterogeneous combustion of the condensed-phase particles can be decreased if certain assumptions are mode. The distributions of the parameters of the gas and dispersed phases were calculated as functions of the rate of blow and the sizes of the particles.

Introduction. In solid-propellant rocket engines (SPRE) there can arise internal flows at large Reynolds numbers corresponding to the turbulent regime of flow in which the viscosity of the fluid depends on the local characteristics of the flow. In the burning of heterogeneous compounds, the turbulence, by the image-bearing expression of A. F. Belyaev, is "pressed" in the initial fuel [1]. The disturbances of the gasdynamic parameters of an inhomogeneous fuel, arising in the process of its combustion in an engine, develop to the level of internal flows. The turbulence influences the characteristics of these flows and intensifies the heat transfer on the surfaces of the prenozzle and nozzle units.

As a model of a flow of the decomposition products of a solid fuel in the combustion chamber of an SPRE, a flow in a channel with a distributed blow [1] is used. This makes it possible to investigate the most important characteristic of the process being considered — the mass transfer on the combustion surface of an SPRE charge. The combustion of the inner surface of the channel (strong blow) or its thermal destruction (weak blow) are simulated.

Complex models defining turbulent flows of a gas suspension with account for the chemical reactions occurring in the gas phase of this suspension and the combustion of the condensed-phase particles in it have been developed fairly well [2, 3]. However, there is a need for the development of simpler models that would allow one to reproduce concrete regimes of flows, to make direct numerical estimates of the characteristics of a flow, to define three-dimensional flows, and to determine the features of the flows formed. Many works are devoted to simulation of flows in channels with penetrable walls [1, 4–12].

Different physico-mathematical models are used for calculating the parameters of combustion-product flows in the channels of SPRE charges. They are realized with the use of finite-difference and finite-volume methods [4–9]. Consideration of the physical characteristics of a flow makes it possible to substantially simplify the solution of this problem [6, 9, 10]. The construction of simplified mathematical models, in which a computational efficiency is attained due to the neglect of some factors of the process, is substantiated by corresponding estimates [9]. The Euler and Lagrange approaches are used for simulation of the motion of condensed-phase particles in channels with a blow with account for the interaction of particles with the vortex structure of the flow [6, 10–12].

In the present work, we investigated the influence of the chemical reactions occurring in the gas phase of a gas suspension flowing in a channel with penetrable walls and the combustion of the condensed-impurity particles in this flow on its gasdynamic structure. For this purpose, a model problem was solved with account for the above-listed factors as applied to the conditions characteristic of an SPRE. It has been possible, with certain assumptions, to construct a self-similar solution for a two-phase flow in a channel with a homogeneous exothermic reaction proceeding with a definite rate and a heterogeneous combustion of the condensed-phase particles.

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Main Assumptions and Computational Relations. We consider a quasi-steady flow of a gas suspension in a long cylindrical channel of radius r_w, into which a gas is blown with a rate v_w on the lateral-surface side. It is assumed that the rate of blow is one and the same at all the points of the penetrable surface of the channel and the vector of this rate is normal to this surface. The liquid spreading on the indicated surface is assumed to be symmetric relative to the line $y = 0$. The processes of mass, momentum, and energy transfer between the carrying and dispersed phases are described with the use of the main postulates of the mechanics of multiphase media with chemical transformations [2, 3]. The works of the friction and pressure forces and the change in the internal energy of the carrying phase, as compared to the energy released as a result of the chemical reaction, are disregarded. Only the change in the density of the gas phase along the transverse coordinate is taken into account. The Lewis number is assumed to be equal to unity. The condensed phase is simulated by a continuous medium free of intrinsic stresses. The particles represent nondeformed spheres of equal diameters, the collisions of which are disregarded. The sizes of the particles are changed only in the process of their combustion. The volume occupied by the particles is not taken into account. The pressure is produced only by the gas.

The system of equations defining a flow of a reactive gas suspension in the channel being considered has the form

$$\nabla (\rho \mathbf{v}) = -J ,$$

$$\rho \mathbf{v} \cdot \nabla Y_i = \nabla (\rho D \nabla Y_i) + w_i ,$$

$$(\rho \mathbf{v} \cdot \nabla) \mathbf{v} = -\nabla p + J (\mathbf{v} - \mathbf{v}_p) - \mathbf{R} + \nabla T ,$$

$$\rho \mathbf{v} \cdot \nabla h = \nabla \left(\frac{\lambda}{c} \nabla h \right) + \mathbf{R} \cdot (\mathbf{v} - \mathbf{v}_p) - JQ ,$$

$$\nabla (\rho_p \mathbf{v}_p) = J , \ (\rho_p \mathbf{v}_p \cdot \nabla) \mathbf{v}_p = \mathbf{R} , \ \rho_p \mathbf{v}_p \cdot \nabla h_p = Q , \ \mathbf{v}_p \cdot \nabla r_p = -w .$$

The equations presented are supplemented with the equation of state

$$p = \rho \frac{R}{M} \theta .$$

The thermophysical characteristics and the enthalpy of the mixture are determined from the following relations:

$$Y_i = \frac{\rho_i}{\rho} , \quad M = \sum_{i=1}^{4} Y_i M_i , \quad c = \sum_{i=1}^{4} Y_i c_i , \quad h = \sum_{i=1}^{4} \left(c_i \theta - h_i^0 \right).$$

The temperature dependence of the molecular viscosity is determined using the power law

$$\frac{\mu}{\mu_w} = \left(\frac{\theta}{\theta_w} \right)^n .$$

It is assumed that the viscosity of the mixture is independent of the concentration of the reacting materials.

The carrying phase represents a homogeneous mixture of reacting gases. It is assumed that the mechanism of the combustion reaction is as follows:

$$\nu_{O_1} O + \nu_F F \rightarrow \nu_{P_1} P_1 ,$$

$$\nu_{O_2} O + \nu_W W \rightarrow \nu_{P_2} P_2 + \nu_{P_3} P_3 .$$

The main equations are closed on condition that

$$\sum_{i=1}^{4} Y_i = 1,$$

where i = O, F, P_1. The component F is a combustible, O is an oxidizer, P_1 and P_3 are gaseous reaction products, P_2 is a condensed reaction product, and W is a condensed-phase metal.

To close the above-described model, it is necessary to have additional information on the mechanism of the heterogeneous-oxidation and the combustion kinetics. In the model of interaction of a particle with a carrying flow, only the drag force is taken into account. The drag coefficient is determined from the Stokes law $C_d = 24/\mathrm{Re}_p$, where $\mathrm{Re}_p = 2r_p|\mathbf{v} - \mathbf{v}_p|\rho/\mu$ is the Reynolds number in the relative motion of phases. According to the Reynolds approach, the parameters of the flow are represented as the sum of the averaged and pulsatory components. The equations averaged by the Reynolds procedure are closed with the use of the eddy-viscosity hypothesis (the Boussinesq hypothesis) and the equations of the two-parameter k–ε model of turbulence. The correlation moments of the discrete-component concentration pulsations and the pulsations of the gas and dispersed-phase velocities are disregarded.

At the wall of the channel (at $y = r_w$), the boundary conditions of normal blow are set for the velocity components of the carrying flow and the boundary conditions of initial nonequilibrium velocity flow are set for the dispersed phase. The temperature of the channel wall is considered as the boundary heat condition. The turbulence is characterized by the absence of velocity pulsations at the penetrable surface of the channel. As a result, we obtain the following boundary conditions at the wall of the channel:

$$u = 0\,, \quad v = -v_w\,, \quad h = h_w\,, \quad Y_1 = 0\,, \quad Y_3 = 0\,, \quad k = 0\,, \quad \varepsilon = 0\,,$$

$$\rho u Y_O + \rho D \frac{\partial Y_O}{\partial y} = \rho_w Y_O^0 v_w\,, \quad \rho u Y_F + \rho D \frac{\partial Y_F}{\partial y} = \rho_w Y_F^0 v_w\,,$$

$$\rho_p = -\beta_1 \rho_p^0\,, \quad u_p = 0\,, \quad v_p = -\beta_2 v_w\,, \quad h_p = h_w\,, \quad r = r_{p,w}\,.$$

For the flow at the axis of the channel (at $y = 0$), the following symmetry boundary conditions are set:

$$\frac{\partial u}{\partial y} = v = \frac{\partial Y_i}{\partial y} = \frac{\partial h}{\partial y} = \frac{\partial k}{\partial y} = \frac{\partial \varepsilon}{\partial y} = 0\,.$$

In the flows formed by the blow, the transverse velocity component is much smaller than the longitudinal one and does not make a significant contribution to the pressure distribution. The indicated circumstances allow us to formulate the problem being considered in the parabolic form without regard for the boundary conditions downstream of a site.

Back Action of the Dispersed Phase. The back action of the dispersed phase, caused by the interphase speed sliding and the thermal creep, is defined by the relations

$$S_{vi} = \frac{\rho_p}{\rho} \frac{v_i - v_{pi}}{\tau_v}\,, \quad S_\theta = \frac{\rho_p}{\rho} \frac{c_p}{c} \frac{\theta - \theta_p}{\tau_\theta}\,.$$

In the equations used in the model of turbulence, the back action of particles is accounted for by the terms

$$S_k = \frac{\rho_p}{\rho \tau_v} \left(\langle v_i' v_i' \rangle - \langle v_{pi}' v_{pi}' \rangle \right), \quad S_\varepsilon = 2 \frac{\mu}{\rho} \frac{\rho_p}{\rho \tau_v} \left\langle \frac{\partial (v_i' - v_{pi}')}{\partial x_j} \frac{\partial v_i'}{\partial x_j} \right\rangle\,.$$

The summation is performed by the recurring indices.

To simulate the motion of gasdynamically small particles, we will restrict ourselves to the construction of a local-homogeneous approximation to the method of space-time averaging [2]. When the convective and diffusion terms

in the equations of transfer of the second one-point moments of the condensed-phase velocity pulsations are disregarded, the following relations are obtained for calculating the correlation moments of the gas and dispersed phases [3]

$$\langle v'_{pi} v'_{pj} \rangle = \alpha_{vv} \langle v'_i v'_j \rangle, \langle v'_{pi} \theta'_p \rangle = \alpha_{v\theta} \langle v'_i \theta' \rangle .$$

The accuracy of the indicated relations increases with decrease in the characteristic times of relaxation of particles (in practice, $\tau_v \sim \tau_\theta$). As a result, the additional terms in the model equations of turbulence take the form

$$S_k = 2 \frac{\rho_p}{\rho \tau_v} k (1 - \alpha_{vv}) , \quad S_\varepsilon = 2 \frac{\rho_p}{\rho \tau_v} \varepsilon (1 - \alpha_\varepsilon) .$$

The coefficients of involvement of a particle in the pulsatory motion of the carrying turbulent flow α_{vv} and $\alpha_{v\theta}$ are calculated by the formulas presented in [3]. In this case, the exponential approximation of the two time correlation functions of the pulsations of the carrying-flow velocity and temperature along the trajectory of the particle motion is used. The properties of the correlation functions of the velocity and temperature are assumed to be identical. The difference between the scales of the turbulent velocity pulsations in different coordinate directions is estimated with the use of the theory of local-homogeneous and local-isotropic turbulence [1].

Rearrangement of Equations. To decrease the order of the initial system of equations, we will assume that the distributions of the characteristics of the flow at different cross sections of the channel differ only by the length and velocity scales

$$\rho = \delta (\eta) \rho_w , \quad \rho u y = \rho_w v_w \xi f (\eta) r_w , \quad \rho v y = - \rho_w v_w g (\eta) r_w ,$$

$$Y_i = \Phi (\eta) Y_w , \quad h = H (\eta) h_w , \quad k = K (\eta) v_w^2 , \quad \varepsilon = E (\eta) v_w^3 / r_w ,$$

$$\rho_p = \delta_p (\eta) \rho_w , \quad \rho_p u_p y = \rho_w v_w \xi f_p (\eta) r_w , \quad \rho_p v_p y = - \rho_w v_w g_p (\eta) r_w ,$$

$$h_p = H_p (\eta) h_w , \quad r_p = A (\eta) r_{p,w} .$$

Here $\xi = x/r_w$ and $\eta = y/r_w$.

On substitution, we obtain the following system of ordinary differential equations:

$$f - g' = - \eta J ,$$

$$\frac{8}{3} \left\{ Z \left[\frac{f}{\eta \delta} + \left(\frac{f}{\eta \delta} \right)' \right] \right\}' + \frac{1}{\mathrm{Re}} \left[2 (\zeta + \zeta_t) \left(\frac{f}{\eta \delta} \right)' + (\zeta + \zeta_t)' \frac{f}{\eta \delta} \right]' + \left(\frac{g}{\eta} \frac{f}{\eta \delta} \right)'' +$$

$$+ \frac{4}{\eta} \left(\frac{f}{\eta \delta} \right)' + \left(\frac{g}{\eta} \frac{f}{\eta \delta} \right)' - 2 \left(\frac{f}{\eta} \frac{f}{\eta \delta} \right)' - B \left[\delta_p \left(\frac{f}{\eta \delta} - \frac{f_p}{\eta \delta_p} \right) \right]' + \left[J \left(\frac{f}{\eta \delta} - \frac{f_p}{\eta \delta_p} \right) \right]' ,$$

$$\left[\frac{\eta}{\mathrm{Re}} \left(\frac{\zeta}{\mathrm{Sc}} + \frac{\zeta_t}{\mathrm{Sc}_t} \right) \Phi_i' \right]' + (g \Phi_i)' + \eta w_i = 0 ,$$

$$\left[\frac{\eta}{\mathrm{Re}} \left(\frac{\zeta}{\mathrm{Pr}} + \frac{\zeta_t}{\mathrm{Pr}_t} \right) H' \right]' + (gH)' - \eta J Q = 0 ;$$

$$f_p - g_p' = \eta J ,$$

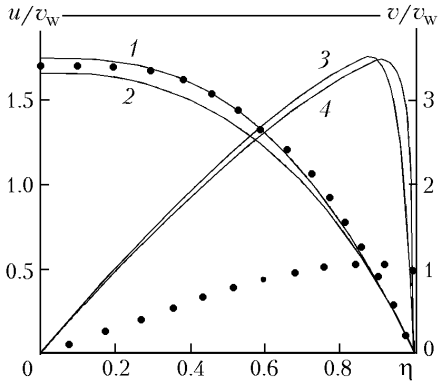


Fig. 1. Profiles of the axial (1, 2) and radial (3, 4) velocity components of the gas (1, 3) and dispersed (2, 4) phases.

$$\frac{f_p}{\delta_p}\frac{f_p}{\eta\delta_p} - \frac{g_p}{\delta_p}\left(\frac{f_p}{\eta\delta_p}\right)' = B\left(\frac{f}{\delta} - \frac{f_p}{\delta_p}\right) + \left[\eta\alpha_{vv}Z\left(\frac{f}{\eta\delta}\right)'\right]',$$

$$\frac{g_p}{\delta_p}\left(\frac{g_p}{\eta\delta_p}\right)' = -B\left(\frac{g}{\delta} - \frac{g_p}{\delta_p}\right) + 2\alpha_{vv}Z\left(\frac{f}{\eta\delta}\right)' - \left\{\eta\alpha_{vv}Z\left[2\left(\frac{g}{\eta\delta}\right)' + \frac{2}{3}\frac{f}{\eta\delta} - \frac{2}{3\eta}\left(\frac{g}{\delta}\right)'\right]\right\}',$$

$$\frac{g_p}{\eta\delta_p}A' = \gamma w .$$

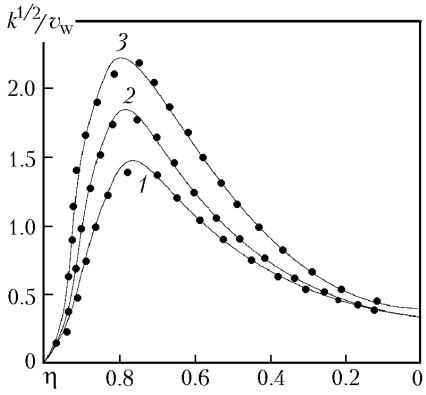
Here, $\zeta = \mu/\mu_w$, $\zeta_t = \mu_t/\mu_w$, $Z = \xi\zeta_t$, $\gamma = r_w/r_{p,w}$, and $B = 1/\mathrm{Stk}$. The Reynolds number is calculated by the parameters of the flow at the wall of the channel ($\mathrm{Re} = \rho_w v_w r_w/\mu_w$). In the case where a quasi-developed flow arising at a fairly large distance from the left boundary of the computational region is considered, the terms of the order of $1/\xi$ are disregarded.

The above system of equations is a generalization of the equations obtained in [6] and [10].

A two-point boundary-value problem is solved at a definite value of ξ on the basis of scalar and vector marchings with the use of the factorization of the matrix of coefficients and the iterated interrelationship of nonlinearities and blocks of equations. The convergence was improved with the use of the lower-relaxation method.

Results of Numerical Simulation. As a result of the numerical calculations, we obtain the distributions of the velocity components in the axial and radial directions, the concentration distribution of the reacting materials, and the temperature and size distributions of the dispersed-phase particles. To determine the influence of the rate constants of the reactions, the initial sizes of the particles, the coefficients determining the interphase interaction, the rate of escape of particles from the penetrable surface of the channel, and the temperature on the distributions of the gasdynamic parameters of the flow, we have performed a series of calculations for different values of the input parameters of the flow. The calculations carried out for an inert gas suspension have shown that, as the intensity of the blow increases, the influence of the viscous effects on the structure of the turbulent flow decreases; this influence manifests itself mainly in the near-axis region and leads to an insignificant scaffolding of the axial-velocity profile. The profiles of the transverse velocity component of the condensed phase differ insignificantly from each other. The initial inhomogeneity of the flow under conditions where the velocity of the particles at the wall differ from the rate of blow (at $\beta_2 \neq 1$) causes a deformation of the profile of the transverse velocity component of the dispersed phase near the penetrable surface of the channel. The results of our numerical simulation are in good agreement with the data obtained with the use of the approximate approach [10] and the results of solution of the completely formulated problem [9].

The numerical calculations have shown that the Reynolds number, the physical properties of the flow, and the heat released as a result of the chemical reaction substantially influence the velocities of the gas and dispersed phases. The characteristic profiles of the velocities of the gas and dispersed phases, constructed with account for the bimolecu-



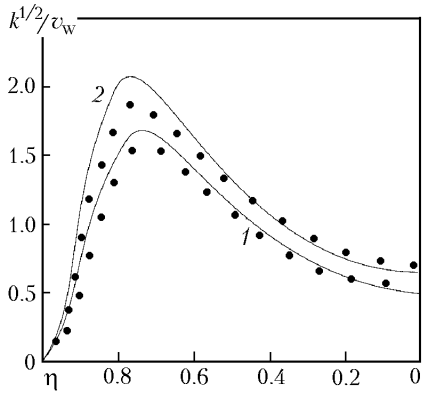


Fig. 2. Distribution of the turbulence intensity over the radial coordinate at r_w = 15 mm, v_w = 1.5 m/sec in the case where the back action of the impurity is absent: ξ = 5 (1), 7.5 (2), and 10 (3).

Fig. 3. Distribution of the turbulence intensity over the radial coordinate at r_w = 30 mm, v_w = 1.5 m/sec, $r_{p,w}$ = 5 μm, and $\varphi = 5.0 \cdot 10^{-6}$ in the case where the impurity exerts a back action: ξ = 5 (1) and 8 (2).

lar reaction proceeding in the carrying phase and the combustion of metal (aluminum) particles, are shown in Fig. 1 (the points correspond to the calculation data obtained for the medium with constant physical properties). Curves 1 and 2 reflect the distributions of the axial velocity components of the carrying and dispersed phases. It is seen that the chemical reaction insignificantly influences the axial-velocity distribution and substantially influences the profiles of the radial velocity component. In the narrow region where chemical reactions proceed, the radial velocities of the carrying (curve 3) and dispersed (curve 4) phases sharply increase.

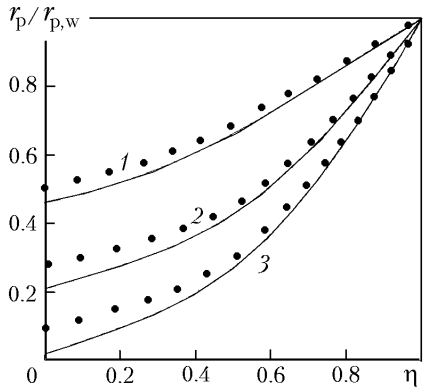
A peculiarity of a flow in a channel with a distributed blow is that in this flow there arises a negative pressure gradient as a result of the blow, which substantially influences the mechanism and intensity of the turbulent transfer. As the coordinate x increases, the maximum of the kinetic turbulence energy shifts from the wall to the flow. The level of turbulent velocity pulsations sharply increases in the region of large shift at a certain distance from the wall of the channel, where the liquid particles moving in the direction normal to the surface are forced to turn in the narrow near-surface zone.

A comparison of the calculation data (points) with the data of simulation of the completely formulated problem on the basis of the model of [9] (curves) is presented in Fig. 2. A certain disagreement of the data in the region of maximum kinetic turbulence energy is explained by the inaccuracy of the mathematical model constructed, which does not take into account the derivatives of quantities with respect to the longitudinal coordinate and a number of terms proportional to $1/\xi$.

The discrete component of the flow exerts a laminarization action on it. The back action of the impurity on the turbulence field is determined by the ratios between the temporal micro- and macroscales of turbulence in different regions of the flow and the relaxation time of the particles. The existence of the two scales in the equations of the k–ε model results in the action of the discrete component depending on the inertia of the impurity. The turbulization action of the small particles ($r_{p,w} \sim 2$ μm) moving in equilibrium with the gas is a result of the decrease in the viscous dissipation in the kinetic-energy equation. This is explained by the fact that the small particles, which do not interact with high-energy pulsations of the gas, suppress the high-frequency pulsations responsible for the turbulent-energy dissipation. The decrease in the kinetic-turbulence energy in the case of introduction of particles with $r_{p,w} > 8$ μm into the flow is explained by the fact that an additional dissipation arises as a result of the interphase slip.

The results of calculations of the characteristics of turbulence in a two-phase flow are presented in Fig. 3 (the curves correspond to the pure gas and the points represent the data obtained with account for the back action of the condensed phase).

The size distributions of metal particles with different initial sizes at the cross section of the channel are shown in Fig. 4 (the points correspond to the laminar regime of flow [6]). The turbulence influences the rate of com-



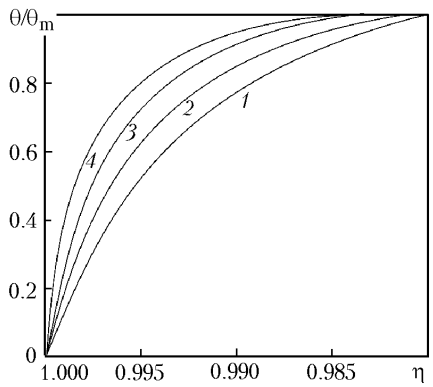


Fig. 4. Size distribution of particles at the cross section of the channel: $r_{p,w}$ = 20 (1), 10 (2), and 5 μm (3).

Fig. 5. Temperature distribution of particles near the wall of the channel.

bustion of particles. The rate of change in the sizes of the particles depends on their initial radius: the sizes of smaller particles change more rapidly.

Figure 5 presents the dependences of the temperature distributions of particles near the wall of the channel on the nonequilibrium criterion of the process (the nonequilibrium parameters are varied by changing the radius of the channel). The data presented were obtained for the case where the carrying phase represents a one-component gas and the combustion of metal particles is realized in the vapor-phase regime. Curves 1 and 2 were obtained for a narrow channel (r_w = 15 mm) and curves 3 and 4 were obtained for the channel of a large-dimension engine (r_w = 30 mm). Curves 2 and 4 correspond to the temperature of the medium, calculated with account for the heat action of the particles on the parameters of the carrying flow, and curves 1 and 3 correspond to the temperature calculated without regard for the heat action of the impurity.

Conclusions. A mathematical model for investigating a flow of a gas suspension in a channel with a blow has been constructed. This model makes it possible to investigate the influence of different factors (the characteristics of combustion of the condensed-impurity particles, the oxidation potential, the geometric characteristics of the channel, the sizes of the particles) on the distributions of the gasdynamic parameters of the gas-suspension flow.

Comparison of the results of our numerical simulation with the calculation data obtained for the completely formulated problem shows that the method developed allows one to adequately define the pattern of a gas-suspension flow in a channel with a blow and determine its main characteristics. This method can be realized fairly simply in the program form in the case of a reasonable compromise between the accuracy of calculations and their duration.

The method proposed for calculating a flow in a channel with penetrable walls allows one to determine the influence of individual factors on the formation of the structure of the flow and develop recommendations, making the solution of the main system of equations defining the indicated flow easier. This method can be used for construction of models of two- and three-dimensional flows in channels with a blow.

NOTATION

A, dimensionless radius of a particle; *c*, specific heat capacity, J/(kg·K); *B*, reciprocal of the Stokes number; *C*, drag coefficient; *D*, diffusion coefficient, m^2/sec; *E*, dimensionless rate of dissipation of the kinetic turbulence energy; *f*, dimensionless longitudinal velocity; *g*, dimensionless transverse velocity; *h*, enthalpy, J; *H*, dimensionless enthalpy; *J*, term accounting for the interphase mass transfer, kg/(m^3·sec); *k*, kinetic turbulence energy, m^2/sec^2; *K*, dimensionless kinetic energy of turbulence; *M*, molecular mass, kg/mole; *n*, exponent depending on the viscosity and temperature; *p*, pressure, Pa; Pr, Prandtl number; *Q*, term accounting for the interphase energy transfer, J/(m^3·sec); *r*, radius, m; *R*, universal gas constant; J/(mole·K); **R**, term accounting for the interphase momentum transfer, kg/(m^2·sec^2); Re, Reynolds number; *S*, source term; Sc, Schmidt number; Stk, Stokes number; T, viscous stress tensor; *u*, *v*, velocity components, m/sec; **v**, velocity vector, m/sec; *w*, rate of change in the concentration of a mixture com-

ponent, kg/(m^3·sec); x, y, coordinates, m; Y, mass concentration of a mixture component; Z, dimensionless complex; α, coefficient of involvement of a particle in the pulsatory gas motion; β, proportionality coefficient; γ, relation between the radius of the channel and the initial radius of a particle; δ, dimensionless density; ε, rate of dissipation of the kinetic turbulence energy, m^2/sec^3; ζ, dimensionless viscosity; η, dimensionless transverse coordinate; θ, temperature, K; λ, heat conduction, W/(m·K); μ, dynamic viscosity, Pa·sec; ν, stoichiometric coefficient; ξ, dimensionless longitudinal coordinate; ρ, density, kg/m^3; τ, relaxation times, sec; φ, volume concentration of the impurity; Φ, mass concentration; $\langle\ \rangle$, averaging. Subscripts: d, drag; i, j, indices of summation; m, maximum; p, condensed phase; t, turbulent; w, wall; 0, initial instant of time; prime, pulsations.

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