RADIATIVE-CONVECTIVE HEAT TRANSFER FOR HIGH-TEMPERATURE TWO-PHASE FLOW AROUND BODIES

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Some methods for determining the basic parameters of high-temperature two-phase flows and the results of investigation of radiative–convective heat transfer with a flowing body in a flow are presented.

Creating a physical model of the interaction of a high-temperature two-phase flow with a solid surface over a wide range of parameter variation is a complex problem, since it requires a reliable knowledge of the regularities of the basic processes of the phenomenon under study. Among these processes is, in particular, radiative-convective heat transfer of bodies in a high-temperature two-phase jet.

The present work introduces some methods for determining the basic parameters of high-temperature two-phase flows (velocity and temperature of gas and particles, composition and concentration of gaseous and condensed components) and the results of investigation of radiative-convective heat transfer with a body in a flow. To perform these investigations, an experimental complex is developed, which includes a system of gasdynamic tests on the basis of an arc plasmatron and a measuring-computing unit [1].

The system of gasdynamic tests includes a unit for generating a high-temperature flow, a unit for the introduction of a dispersed phase, and a unit for the formation of a high-temperature two-phase flow. The measuring-computing unit incorporates a system of thermal diagnostics based on nonstationary software sensors of temperature and heat fluxes, a gas analyzing system based on the chromato-mass-spectrometric complex, and a system of optical diagnostics based on a spectral-computing complex, optical pyrometry, laser diagnostics, and video equipment.

The experimental complex makes it possible to determine the velocity and temperature fields of the gas and condensed phases, the distribution of gaseous and condensed components, and to investigate thermophysical processes in the interaction of high-temperature two-phase flows with solids.

The methods for measuring the velocity and temperature of a solid phase are adequately described in [2]. Thus, measuring the solid phase velocity is based on a comparison of the velocities of motion of the investigated and reference objects by time-scanning the image of the object perpendicularly to the direction of its motion with a mirror, rotating at a known rate. The temperature of a particle is measured by its radiation with a considerable excess of the intensity of the particle radiation as compared to the natural radiation intensity.

Particles of graphite, aluminum, steel, chromium, and iron-based metallic composite material served as the dispersed phase of the two-phase flow [2]. As the density of the material of particles increases, their velocity decreases (Fig. 1).

The distribution of the gas and particle temperature along the jet axis is obtained; in this case it is noted that there is a substantial disagreement of the temperatures of the gas and condensed phases, which decreases along the jet length. The presence of the relaxation region and that of "almost" equilibrium flow, where the values of phase temperatures are fairly close, is observed. In the relaxation zone the particles cool down the carrier phase, their temperature monotonically increasing as the coordinate increases and the carrier phase temperature decreasing. When moving along the jet axis the particles have time to warm up, and on their surface heterogeneous oxidation reactions are initiated. For graphite, these

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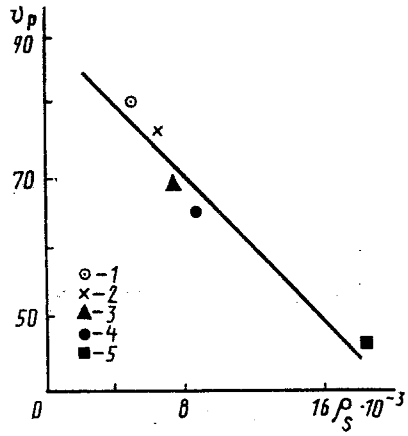

Fig. 1. Dependence of the particle velocity v_p (m/sec) on the material density of material $\rho_s \cdot 10^{-3}$ (kg/m^3) at x = 10: 1) aluminum; 2) iron-based composite material, 3) chromium; 4) steel; 5) tungsten.

reactions are accompanied by a considerable exothermal effect; as a result the particle temperature exceeds the gas temperature.

To investigate the influence of physicochemical transformations on heat transfer on the surface of bodies in a high-temperature two-phase flow, use was made of a model which is a frustum of a cone or a cylinder with a spherical or flat blunting, in the vicinity of the critical point of which a heat flux sensor is set [3, 4]. The calculation of the heat fluxes and measurement errors is performed by the developed procedure [4] on the automated complex [1].

Graphite C, aluminum Al, aluminum oxide Al_2O_3, and quartz sand SiO_2 served as dispersed materials. The choice of these materials is made by the following reasoning. Graphite – a chemically active material – models the condensed combustion products. It should be pointed out that the processes of heat transfer by the action of a plasma jet on graphite specimens are adequately investigated in [5, 6]. Aluminum particles model the components of powdered materials in plasma application of heatproof and wear-resistant coatings. Aluminum oxide and quartz sand have been used to model the erosional action of natural and artificial atmospheric formations in dense layers of the atmosphere and the abrasive action in technological operations when preparing the surface for gas-thermal application of coatings.

Figure 2 shows the dependence of the ratio of local heat fluxes ($q = q_q/q_0$) in the vicinity of the critical point of the surface in a flow in the presence q_p and in the absence q_0 of particles in the gas flow on the mass concentration of the dispersed phase μ_p. It characterizes the influence of the solid phase concentration on the heat transfer of flat and semi-spherical models in a two-phase flow. The flow rate mass concentration μ_p is defined as $\mu_p = G_p/(G_p + G_g)$.

For all investigated materials, the intensification of heat transfer on the surface of the body in a flow as compared with a single-phase flow is noteworthy. In addition, a nonmonotonic character of the dependence of the ratio q_p/q_0 on the mass concentration of particles is observed.

An increase of the heat flux on the surface in a high-temperature two-phase flow can be due to impairment of the flow field by particles of the incoming flow and those recoiling from the surface, the roughness, caused by surface erosion, the transition of a portion of the kinetic energy into thermal energy when the particles impact against the surface, the physicochemical processes on the boundary between the media, as well as to radiation from the heated particles [7-10].

To obtain a more complete picture of the flow and heat transfer, visualization of the process of interaction of the two-phase flow with the surface in a flow was performed [2]. As the particle concentration increases in the flow near the surface, a luminous zone begins to form, which apparently consists of the incoming flow particles and those reflected from the surface of the body in the flow. The presence of the reflected particles tends to additionally inhibit the gas and incident particles and to highly increase the concentration of the dispersed phase in the wall zone. As the mass concentration of particles in the flow increases, the velocity of the incident particles flying to the surface decreases due to the intense inhibition by the reflected particles. Thus, the character of the dependence of q on μ_p can be explained by the presence of the mentioned zone.

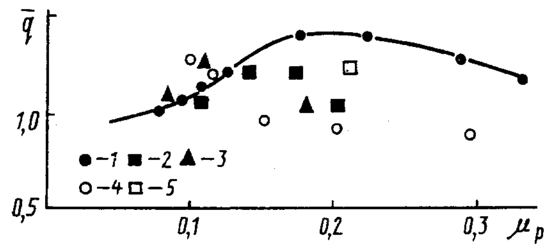

Fig. 2. Ratio of local heat fluxes with particles and in the absence of them vs the dispersed phase concentration: 1) aluminum; 2) graphite; 3) silicon dioxide; 4) phosphorite [7]; 5) aluminum oxide [8].

As has been shown above, one of the factors determining the intensification of the heat transfer of bodies in the two-phase flow is radiation. The growth of the heat flux radiant component is due to the complex of physical and chemical phenomena in the wall layer. In the first place, there are exothermal reactions of oxidation on the particle surface, which causes an increase in the temperature of the surface of particles, in particular, graphite, up to 2200 K [5]. As a result, there occurs radiation from the surface of particles heated by the exothermal reaction to a temperature equal to or exceeding the temperature of the carrier gas. Similar results are obtained with aluminum particles in the flow.

As for the particles of aluminum oxide (Al_2O_3), when the melting point is passed in the visible and near infrared spectral regions the emissive power of particles sharply increases [11].

The mentioned processes together with increasing concentration of particles near the surface lead to an increase in the heat flux radiant component on the surface. This is an additional factor affecting the increase in the heat fluxes on the surface of bodies in a high-temperature two-phase flow, which should be taken into account when developing a physical model of the interaction of high-temperature heterogeneous flows with a solid.

NOTATION

$x = x/d$, x, distance from the plasmatron nozzle exit section; d, diameter of the plasmatron nozzle; $q = q_p/q_0$, q_p, heat flux in the vicinity of the critical point of the surface in a flow given the particles in the gas flow; q_0, heat flux in the absence of particles in the flow; μ_p, mass concentration of particles in the flow; G_p, mass flow rate of the condensed phase; G_g, mass flow rate of the gas phase.

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