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DETERMINATION OF THE CHARACTERISTICS OF ELECTRIC-ARC HYDROGEN PLASMA

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A numerical experiment on determination of the characteristics of electric-arc plasma in transpiration cooling by high-melting, low-boiling metals with account of reabsorption and scattering of radiation showed the high heatproof properties of the gas-dust curtain that developed.

Thermal protection of the plasmatron-channel walls in transpiration introduction of high-melting, low-boiling compounds was studied experimentally in [1, 2]. In [1] it is suggested to use low-boiling compounds of high-melting metals, which at a temperature of 15–350°C pass from the solid to the gaseous state, in power plants with a hydrogen working body. Passing through a hot porous wall, these compounds cool the wall and at the outlet they recover at a temperature of 1200–1700°C. A gas-dust curtain consisting of metal particles is formed in the near-wall layer. It absorbs and scatters thermal radiation within a wide range of wavelengths. In [2], it is found that while moving along the plasmatron channel this medium enlarges intensively. Absorbing and scattering properties change constantly. Within the range of wavelengths of thermal radiation $0.005 < \lambda < 1$ μm, particles with radii $0.03 \le r_p \le 0.1$ μm provide the highest value of the mass attenuation factor. As the particle size decreases, the maximum attenuation of radiation shifts to the UV region, for which the highest screening is given by a gas-dust medium with a particle size $0.005 \le r_p \le 0.03$ μm. At a temperature in the volume of the setup within the range of $10^4 \le T \le 10^5$ K, the maximum radiated power falls on the range of wavelengths $0.005 < \lambda < 0.04$ μm. This is the range of x-ray radiation and vacuum ultraviolet. According to [2], to thermally protect walls in this temperature range one must produce a gas-dust curtain with a size of particles of an order of several tens of angströms. The method suggested for obtaining ultradisperse powders is of much current interest. On the other hand, it is known that metal particles of such dimensions almost do not absorb radiation but only scatter it [3]. In all the works mentioned, the effect of the gas-dust curtain on the gasdynamic characteristics of plasma of the setup active volume is not considered. The noted enlargement of particles, i.e., variation of a particle size depending on the time of its residence in plasma, leads to thermal protection that is nonuniform over the wall length.

Object of Investigation. To elucidate the above-given problems it is expedient to conduct a numerical experiment on determination of the characteristics of plasma of the active volume of a high-power setup with account for transpiration cooling and interaction of radiation with metal particles.

Problem Formulation and Solution. As a high-power setup we consider a linear plasmatron with porous walls. Numerical calculations of the characteristics of electric-arc hydrogen plasma are conducted according to the technique described in [4, 5]. To take into account radiation transfer we use the method of partial characteristics [6]. Formation of a gas-dust curtain takes place in injection of WCl_6 (or WF_6) and $SiCl_4$ compounds through the channel porous walls and their recovery in interaction with hydrogen plasma. Account for the kinetics of tungsten (or silicon) formation under these conditions is very difficult; therefore, the problem posed is solved in three stages. At the first stage, thermal and gas-dynamic characteristics of electric-arc hydrogen plasma are determined. At the second stage, the effect of the gas-dust curtain on the characteristics of electric-arc plasma are studied without consideration of the mechanism of formation of this plasma. Here, the presence of tungsten particles is modeled by a special distribution of density and thermophysical properties along the channel radius. At the third stage, characteristics of the electric arc are calculated with account for the kinetics of formation of ultradisperse tungsten powder in the reducing reaction of WCl_6 in hydrogen plasma. In the gas-dust layer, the radiation flow from hydrogen plasma is reflected and partially ab-

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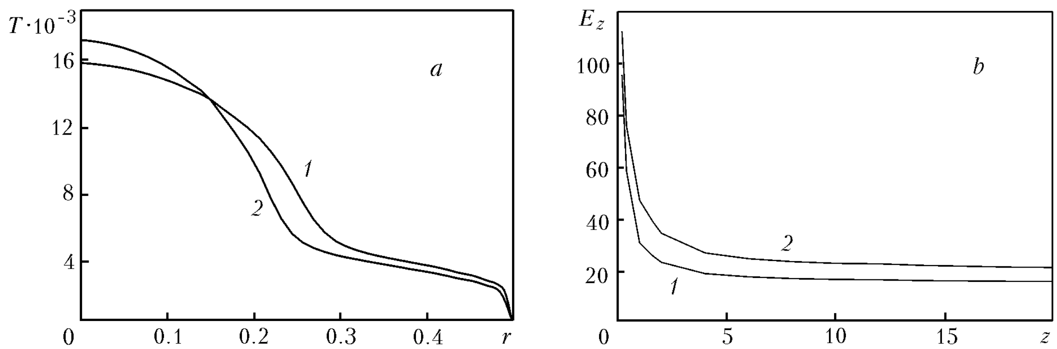

Fig. 1. Temperature distribution in the steady-state section (a) and variation of the electric field intensity along the channel length (b): 1) without the curtain; 2) with a gas-dust curtain of tungsten particles with a size of 1 μm. I = 200 A, G = 0.1 g/sec; R = 0.5 cm, L = 20 cm. T, K; r, cm; E_z, V/cm; z, cm.

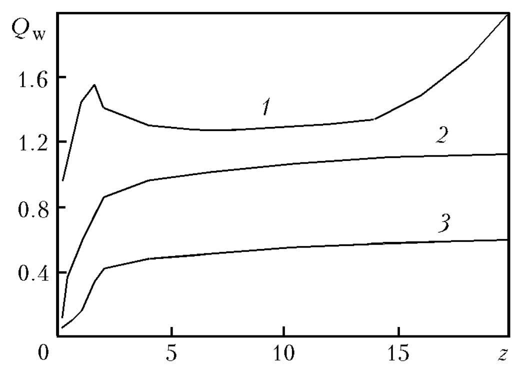

Fig. 2. Heat flux into the plasmatron-channel wall: 1) without the curtain; 2) with a curtain of tungsten particles with a size of 1 μm; 3) with a curtain of particles with a radius 0.1 μm. I = 200 A, G = 0.1 g/sec; R = 0.5 cm. Q_w, kW/cm^2; z, cm.

sorbed by tungsten particles. The ratio between reflected and absorbed flows depends on the size of the particles. Calculations are made at atmospheric pressure for channels having radii of 0.5 and 1 cm. The range of current variation was from 100 to 300 A. We considered hydrogen flow rates of 0.1 and 1 g/sec. Allowing for the fact that in the reducing reaction 94 wt.% of WCl_6 is tungsten [7], in the simplest version (second stage) the flow rate of W was taken to be 2.35 g/sec. The boundary condition for the equation of enthalpy transfer was selected from considerations of the constancy of the channel-wall temperature.

Investigation Results. Electric-arc plasma was modeled based on the transport equations in the boundary-layer approximation, which were solved by the method of flow sweep [4, 5]. At present, the problem posed has been solved at both the first and second stages. To allow for scattering of heat flux by tungsten particles, at the third stage it is proposed to use the tables and technique of [3].

In all versions of calculation, the maximum temperatures on the channel axis for hydrogen plasma were much higher than for the arc in argon or air [5]. Figure 1 presents temperature distributions on the steady-state part of the arc (a) and intensities of the electric field along the channel length (b) for hydrogen electric-arc plasma. It is of interest to note that the presence of the gas-dust curtain increases the axial temperature and intensity in the plasmatron channel. Figure 2 shows a decrease in the total heat flux to the plasmatron-channel wall in the presence of a gas-dust curtain with tungsten particles with a size of 1 and 0.1 μm. The total heat flux includes radiative and conductive heat fluxes with account for scattering by tungsten particles.

A simplified version of the problem solution (without consideration of the kinetics of formation of tungsten particles) showed the efficiency of gas-dust protection of the walls. The presence of metal particles decreases heat fluxes to the channel wall by 2–3 times.

NOTATION

E, electric-field intensity; G, gas flow rate; I, current; Q, heat flux; r_p, particle radius; R and L, radius and length of the channel; T, temperature; z and r, cylindrical coordinates; λ, wavelength. Subscripts: p, particle; w, wall.

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