ELECTRIC ARC IN HYDROGEN FLOW AT HIGH PRESSURE

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The interaction of an electric arc with laminar hydrogen flow at a pressure of 100 atm is examined with account for the transverse flows. Results of calculations are presented for a current strength of 30 A and tube radius 0.3 cm. It is shown that for these parameters radiation plays the defining role in the heat transfer process.

The electric arc in a gas stream without account for radiation has been studied previously in [1–4] and with account for radiation in [5]. However, in these studies only the longitudinal velocity component was taken into account in the energy equation.

1. Laminar gas flow in a tube with energy addition is described by equations of the boundary layer type [6], which are valid for high Reynolds numbers and for a small value of the ratio of the transverse and longitudinal velocity components. Assuming in addition that the Mach number is much less than unity, we write [7]

$$\frac{\partial \rho U r}{\partial x}+\frac{\partial \rho V r}{\partial r}=0,$$
$$\rho U\frac{\partial U}{\partial x}+\rho V\frac{\partial U}{\partial r}=-\frac{dp}{dx}+\frac{1}{r}\frac{\partial}{\partial r}\left(r\mu\frac{\partial U}{\partial r}\right),$$
$$\rho U C_p\frac{\partial T}{\partial x}+\rho V C_p\frac{\partial T}{\partial r}=\frac{1}{r}\frac{\partial}{\partial r}\left(r\varkappa\frac{\partial T}{\partial r}\right)-\varphi+\sigma E^2. \tag{1.1}$$

Here φ is the divergence of the radiant energy flux density, which was computed as indicated in [7, 8]; E is the electric field intensity, constant along the radius; σ is the electrical conductivity, and the other notations are conventional.

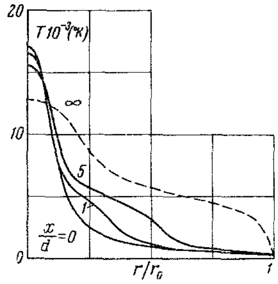

Fig. 1

The current strength I is related with the electric field intensity and the electrical conductivity by Ohm's Law

$$I=E2\pi\int_0^{r_0}\sigma r dr. \tag{1.2}$$

The system of equations (1.1), (1.2) was solved for the same initial and boundary conditions as used in [7]. Since the pressure changes only slighly, the density, electrical conductivity, specific heat capacity, viscosity, and thermal conductivity, and also the optical properties were considered known functions of the temperature [7].

Under these assumptions the system of equations (1.1) with the boundary conditions permits the expansion

$$x_1=\alpha x,\quad r_1=r,\quad U_1=\alpha U,\quad V_1=V,\quad T_1=T,\quad \left(\frac{dp}{dx}\right)_1=\alpha\left(\frac{dp}{dx}\right),\quad Q_1=\alpha Q.$$

This makes it possible to convert the resulting solution to any value of the flow rate Q for flow with similar initial velocity profile and for the same pressure.

The problem was solved by the finite-difference method with the use of iterations with respect to the nonlinearity [7]. The actual temperature dependences of the optical and transport properties for hydrogen at a pressure of 100 atm were taken from [8].

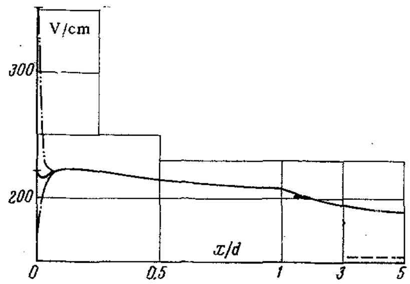

Fig. 2

In addition to the radiant energy flux q_1 to the wall, the conductive heat flux density q_2, and the mass-average enthalpy $H^{(1)}$, calculated in [7], at each section of the arc, we calculated the power input W per unit arc length, and the power Π transferred to the wall,

$$W = IE, \ \Pi = 2\pi r_0 (q_1 + q_2).$$

In this case, the energy balance equation is written as

$$Q\,[H^{(1)}(x) - H^{(1)}(0)] = \int_0^x (W - \Pi)\,dx. \tag{1.3}$$

This relation (1.3) was used to check the accuracy of the computation.

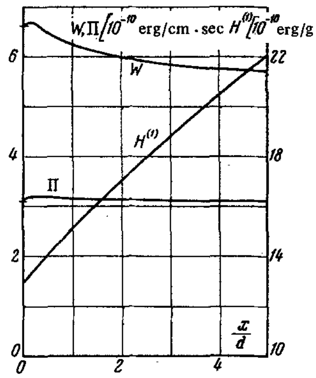

Fig. 3

2. All the calculations were made for an arc in a hydrogen stream at a pressure of 100 atm. We are not aware of any studies which present the velocity and temperature profiles in a plasmatron operating on hydrogen at this pressure. Therefore we took the initial longitudinal velocity component profile to be parabolic and the initial temperature profiles were varied. The temperature profiles were taken to be narrow near the axis and flat near the wall. The calculations showed that the effect of the initial temperature profile on the flow parameters is small. All the calculated quantities in the various versions began to coincide at fractions of a diameter (Q = 1 g/sec).

Figures 1–4 show the computational results for the current I = 30 A, tube radius r_0 = 0.3 cm, and flow rate Q = 1 g/sec. The solid curves in Fig. 1 show the temperature profiles at the various sections. We see from the figure that the temperature on the axis decreases, while the profile segment in the temperature region up to 5000° K broadens. The dashed curve is the asymptotic temperature profile take from [8].

The electric field intensity curve in Fig. 2 decreases monotonically along the axis. The region up to one diameter is expanded in the figure and we see how the intensity curves for different initial profiles merge (the solid curve is for an initial temperature at the axis of 17000° K, the dash-dot curve is for 18 000° K, and the dash-double dot curve is for 15 000° K). The dashed line shows the asymptotic value of the intensity from [8].

Figure 3 shows curves of the power supplied W, removed Π, and enthalpy $H^{(1)}$. More than half of the power supplied is removed to the wall, and the remainder goes to increase the flow enthalpy. The conductive heat flux density to the wall increases by a factor of two over five diameters, but remains two orders of magnitude less than the radiative heat flux density. Thus, for the given plasmatron parameters radiation plays the defining role in the heat transfer process.

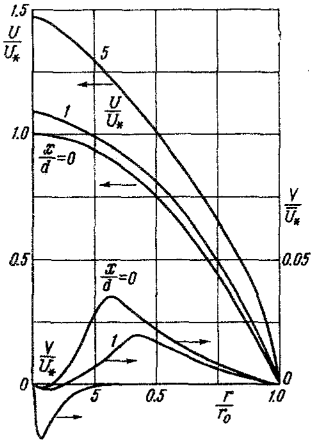

Fig. 4

The existence of a strong influence of radiation on the heat transfer during interaction of an electric arc with a gas stream was noted previously in [5], in which an arc in a turbulent argon stream at atmospheric pressure was studied.

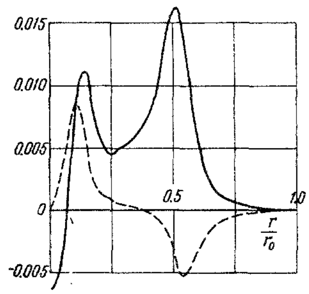

Fig. 5

The longitudinal and transverse velocity component profiles are shown in Fig. 4. The transverse velocity component increases significantly in the current conducting zone at five diameters. The longitudinal velocity component also increases but its profile remains nearly parabolic.

We note that both convective terms in the energy equation (1.1) had the same order of magnitude. In Fig. 5 the solid curve shows the first convective term, the dashed curve shows the second convective term, referred to the same magnitude. These values correspond to a section located four diameters from the entrance.

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