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# A NOTE ON THE MECHANISM OF HEAT TRANSFER IN AN ARC IN A CROSS FLOW

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It is shown that turbulent heat transfer prevails in an electric arc in a cross flow.

An electric arc in a cross flow, moving under the action of a magnetic field, was investigated by Kukekov in[1]. His experimental relation for the intensity of the electric field in the arc column as a function of current strength and arc velocity agrees well with theory, if the theoretical analysis is based on the principle of minimum intensity and the model of a blown arc. For this case three equations may be written:

Ohm's law

$$I = \pi R^2 E F_1(T); \tag{1}$$

the law of conservation of energy

$$IE = 2KRvF_2(T); \tag{2}$$

the minimum principle

$$(\partial E/\partial R)_T = 0; \quad (\partial E/\partial T)_R = 0. \tag{3}$$

Hence, for given I and v, Kukekov obtained

$$E = A\sqrt[3]{v^2/I}, \tag{4}$$

where

$$A = \sqrt[3]{4K^2 F_2^2(T)/F_1(T)}.$$

The blowing rate is considered equal to the transverse velocity. As may be seen from (1), the function $F_1(T) = \sigma$ is the mean electrical conductivity of the plasma in the arc column, while the function $kF_2(T) = \rho h$ is the volume energy density. The coefficient A, determined by experiment, is equal to 1900.

The fact that Eq. (4) is a good generalization of the experimental data is evidence that among the complex of processes occurring in an electric arc in a cross flow there is some dominant process that determines the conditions of approximate similarity. It follows from Eq. (2) that this process is the removal of energy from the arc by convection. The generalized dimensionless argument of this process may be obtained from the energy equation, which in this case takes the form

$$\rho \mathbf{v}\, \mathrm{grad}\, h = \mathbf{jE}. \tag{5}$$

Rephrasing (5) in dimensionless form, we obtain the criterion

$$j_o E_o R_o/\rho_o v_o h_o \sim I^2/\rho_o \sigma_o h_o R_o^3 v_o. \tag{6}$$

The generalized current-voltage characteristic of the blown arc may be written as the criterial equation [2]

$$EI/\rho_o h_o R_o v = f(I^2/\rho_o \sigma_o h_o R_o^3 v). \tag{7}$$

Since the characteristic quantities $\rho_0$, $h_0$, $\sigma_0$, $R_0$ do not depend on I or v, they may be considered constant, and in dimensional form we have, instead of (7),

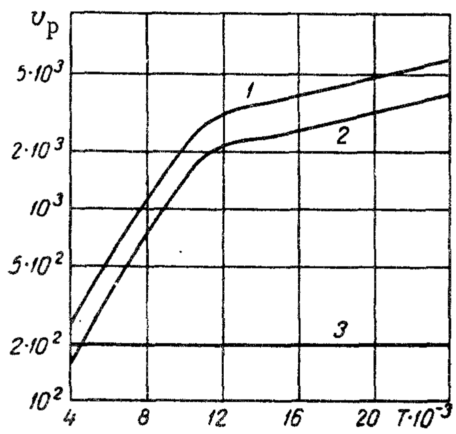
$$EI/v = f_1(I^2/v). \tag{8}$$

Putting (4) in the form of (8), we obtain

$$EI/v = 1900(I^2/v)^{1/3}. \tag{8'}$$

The result obtained is evidence that in the electric arc in a cross flow approximate similarity does, in fact, hold. The similarity criteria have been determined for the model of a blown arc. However, the initial system of characteristic quantities (I, v, $R_0$, $\rho_0$, $\sigma_0$, $h_0$) does not correspond to the given model along. In the case of developed turbulent heat transfer, it is also possible to disregard the molecular transfer coefficients. Therefore, the turbulent heat transfer model leads to the same result as the blown-arc model. It is also possible that energy is removed from the arc column by the charged particle flux, and from the outer part of the column by convection.

The amount of energy removed from the arc column may be estimated from Eq. (4). using data on the electrical conductivity of air [3], together with enthalpy and density data [4]. The results of such calculations are shown in the figure.




Gas velocity as a function of temperature of arc column: 1) Blowing rate required to remove all power released in arc column at I = 600 *a*, $v_b$ = = 200 m/sec; 2) at I = 100 a, $v_b$ = 200 m/sec; 3) velocity of cross flow ($v_b$ = 200 m/sec).

It may be seen from the figure that at the temperatures which may be established in the core of an arc in a cross flow the required blowing rates are considerably greater than the cross flow velocity. Consequently, energy can be removed by the gas flow only from the outer sheath of the arc, and only some of the released power is removed from the core by convection.

Transfer of energy within the arc column is accomplished by turbulence or some other means whose mechanism may be described by the above-mentioned system of characteristic quantities. Energy transfer by molecular heat conduction and other processes depending on the molecular constants and temperature gradient must be excluded, since the molecular transfer coefficients do not appear in the system of characteristic quantities. The power removed from the arc by the charged particle flux may be determined from the expression [5]

$$N = 2R\frac{kT}{2m_o}\left(5 + \frac{2E_I}{kT} - \frac{\rho}{\rho_o + \rho_e}\right)\frac{1}{a}\,\frac{\rho_o\rho_L}{\rho}\,[\mathbf{jB}], \quad (9)$$

where

$$a \approx n_L n_o \frac{8}{3}\sqrt{\frac{2}{\pi} kT \frac{m_i m_o}{m_i + m_o}}\, Q_{io}.$$

In this case the induction of the magnetic field may be determined from the empirical formula [6]

$$v = 0.595\sqrt{B/\text{M}}\sqrt[3]{I/\rho^2}. \quad (10)$$

Taking handbook values for the constants and values of the concentration for an air plasma from [4], we can find the power N removed from the arc column by the charged particle flux. It turns out that this power is 4-5 orders lower than the power released in the arc.

Thus, taken together, experimental and theoretical data indicate the presence of turbulence in an arc in a cross flow.

NOTATION

I – current; j – current density; E – electric field intensity; B – magnetic induction; v – gas velocity; R – radius of arc; T – temperature; $\rho$ – density; h – enthalpy; $\sigma$ – electrical conductivity; k – Boltzmann constant; K – proportionality factor; m – particle mass; $E_I$ – effective ionization potential; Q – particle cross section; $\mu$ – magnetic permeability; n – particle concentration. Subscripts: 0 – characteristic quantity, neutral particle; L – charged particle; e – electron: i – ion; b – gas flowing over arc; p – gas blown through arc.

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