# HEAT TRANSFER WHEN AN ELECTRIC ARC INTERACTS WITH A LONGITUDINAL FLOW OF GAS

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The heat transfer in a longitudinal flow of gas in a cylindrical channel with an arc is investigated. Empirical expressions are obtained for calculating heat transfer in the range of Reynolds numbers 9000 > Re > 50, determined from the mean-mass temperature.

The problem of the heat transfer of a low-temperature plasma from the walls of the channel is an extremely urgent one at the present time because of the technical application of high-temperature gas as a working substance. Only a small number of papers have been published on heat transfer in a flow of low-temperature plasma in channels with cooled walls. In [1] the heat transfer is investigated in the section of an arc channel after the anode attachment. In [2] the heat transfer of helium, nitrogen, and argon was investigated for flow in water-cooled channels, when the temperature of the gas at the input did not exceed 7000°K. Empirical expressions for calculating the heat transfer in a laminar flow of air, argon, and nitrogen in an arc channel were obtained in [3, 4]. However, existing experimental data still do not enable one to draw any final conclusions regarding the effect on the heat transfer of such factors as the temperature head, changes in the hydrodynamic flow conditions, etc.

In the present paper we describe an experimental investigation of local heat transfer for gas flow in a cylindrical channel with an electric arc electrically isolated from the electrodes. The experiments were made with flows of argon and helium in the range of Reynolds numbers 9000 > Re > 50, determined from the mean-mass temperature. The experimental arrange-

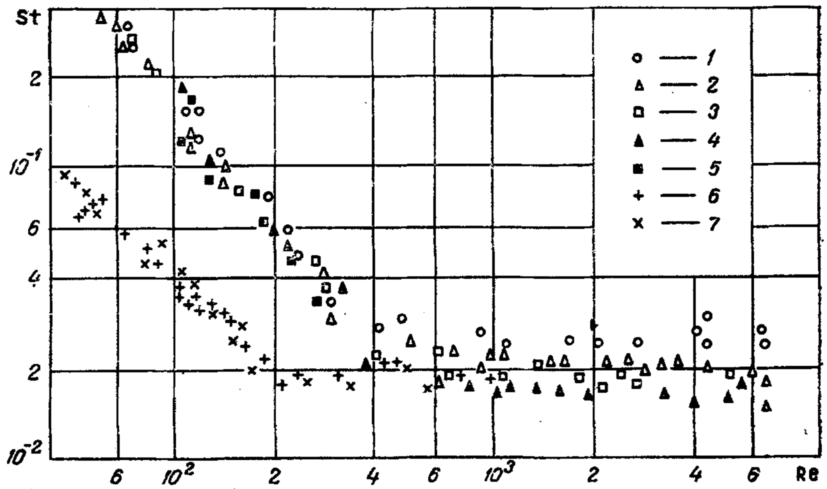


Fig. 1. Stanton criterion as a function of the Reynolds number: 1) l/d = 1.66; 2) 3.3; 3) 5; 4) 10; 5) 15; 6) 3.3; 7) 5. 1-5 are for argon and 6-7 are for helium.

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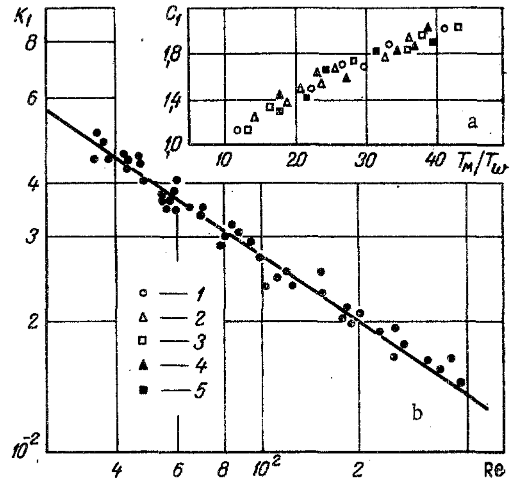


Fig. 2. The parameter $C_1$ as a function of the temperature factor (a), and the results of a generalization of the heat transfer for argon in the range 300 > Re > 50 (b): 1) $l/d$ = 1.66; 2) 3.3; 3) 5; 4) 10; 5) 15

ment was a DC electric-arc generator with a sectioned channel and a central rod electrode [5]. The diameter of the inner channel was 6 and 10 mm for a section width of 7 mm. The overall length of the channel could be varied from 70 mm to 150 mm. The gas flow rate when using helium was 0.05 g/sec to 0.5 g/sec, and for argon it was 0.1-3.0 g/sec for a current of 30-200 A. The ohmic heat dissipation in the arc was found by measuring the total current and potential across the section. The overall heat flow into the wall of the channel was measured by calorimetric measurements in each section. The heat of the emerging jet of gas was measured with a cylindrical calorimeter, which was an extension of the arc channel. The thermal radiation was measured with a radiation heat element with a quartz window. The mean-mass temperature distribution of the gas along the channel was found by the heat-balance method. In the section of channel coinciding with the middle of the section the mean-mass temperature was calculated as the average of the values at the input and output of the section from the values of the mean-mass enthalpy. We carried out the investigations over the mean-mass temperature range from 4000°K to 13000°K. All the data were processed in dimensionless form, in which we used the Reynolds, Stanton, and Prandtl criteria. When determining the Stanton criterion we used the integral heat flow which consists of the set of thermal condition, convective heat transfer, and thermal radiation.

Figure 1 shows the Stanton criterion as a function of the Reynolds number for argon and helium. It follows from this graph that for Reynolds numbers from 300 to 500 there is a transition from laminar heat transfer to turbulent heat transfer, and for Re > 500 the Stanton criterion depends only slightly on the Reynolds number. The experimental data on heat transfer at low Reynolds numbers 300 > Re > 50 were processed using the well-known expression for laminar flows

$$St = C_1 Re^{-0.5} Pr^{-0.67}.$$

The results are shown in Fig. 2a in the form of a curve of $C_1$ as a function of $T_g/T_w$. It is seen from the graph that the heat transfer depends on the parameter $T_g/T_w$, and the coefficient $C_1$ has the value of 0.6-2.0 for a change in the temperature factor from 10 to 40, whereas subdivision with respect to the parameter $l/d$ is unimportant. For a flow in an arc channel at low values of Reynolds numbers it is characteristic that rearrangement of the temperature profile is completed, the channel section is filled with a high-temperature current conducting zone, and the flow occurs under limiting or quasi-limiting conditions (the heat dissipation and the heat transfer are constant over the length) in two to three calibrations. The sharp change in the temperature profile close to the walls leads to a dependence of the heat transfer on the temperature factor. The Peclet criterion Pe = RePr < 200, which by analogy with heat transfer in liquid metals indicates the predominant effect of molecular heat conduction.

By generalizing the experimental results on complex heat transfer and on convective heat transfer, subtracting the radiation power, it was not possible to obtain a general relationship for argon and helium, which is possible due to the different heat dissipation profile and temperature dependence of the electrical conductivity and heat conductance for these gases. A formal generalization of the experimental data on combined heat transfer gives the following expressions (Fig. 2b):

for argon $St = 0.275 Re^{-0.5} Pr^{-0.67} (T_g/T_w)^{0.5}$;
for helium $St = 0.19 Re^{-0.5} Pr^{-0.67} (T_g/T_w)^{0.5}$.

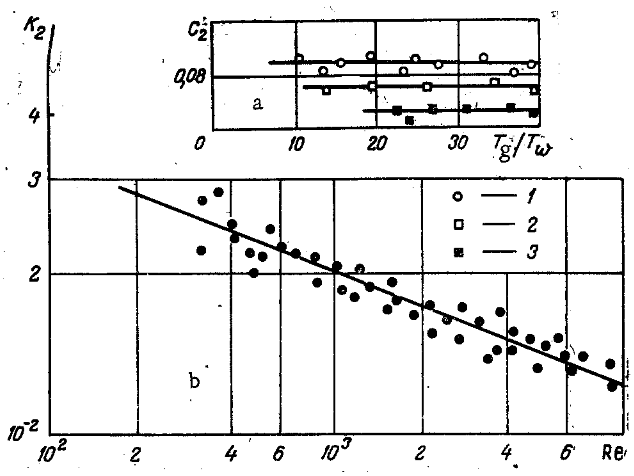

Fig. 3. The parameter $C_2$ as a function of the dimensionless length (a), and the results of a generalization of the heat transfer for argon in the range 9000 > Re > 500 (b): 1) $l/d$ = 1.66; 2) 3.3; 3) 5.

The experimental results for high Reynolds numbers 9000 > Re > 500 were processed using the expression

$$\mathrm{St} = C_2\,\mathrm{Re}^{-0.2}\,\mathrm{Pr}^{-0.6}.$$

It follows from Fig. 3a that the experimental points are clearly subdivided with respect to the parameter $l/d$ and in this case no dependence of the heat transfer on the temperature factor is observed. The flow in this case in an arc channel occurs when there is a change in the temperature profile over the whole length of the channel (input-section mode). Close to the walls of the channel there is a cold boundary layer, in which turbulent heat transfer occurs. A sharp change in temperature occurs outside this layer. The data on heat transfer for argon and helium can be generalized by the single relationship (Fig. 3b)

$$\mathrm{St} = 0.078\,\mathrm{Re}^{-0.2}\,\mathrm{Pr}^{-0.6}\,(l/d)^{-0.17},$$

which is explained by the decisive role played by turbulent heat transfer compared with molecular heat transfer.

The results obtained differ from the data given in [4], where the experimental investigation was made for a channel diameter of 12 and 18 mm, a current of 30 - 80 A, and the experimental data on convective heat transfer over the whole range of Reynolds numbers of 200 to 5000 for argon, nitrogen, and air was generalized with a single relationship. In this case no dependence of the heat transfer on the temperature factor was found. It may be assumed that under the experimental conditions described in [4] for large channel diameters and low discharge current values the high-temperature current conducting zone fills only a small central region of the channel cross section, and the heat flow to the walls is determined by the radiation component from the arc column and by the convective component from the low-temperature boundary layer.

Note that in [6] for the transient mode of operation for gas flow in an arc channel a value of the Reynolds number Re = 110-250 is recommended. In our experiments the laminar nature of the heat transfer was preserved up to Re = 500, which was due to the high level of the mean-mass temperature of the gas and the effect of ionization when, for a conducting gas, the electron heat conductance increases and the molecular heat conductance becomes comparable with the turbulent heat conductance or exceeds it [1].

Hence, the nature of the heat transfer in a stabilized arc channel for Re < (300-500) is determined to a large extent not by the hydrodynamic flow but by the internal heat dissipation and the molecular heat conductance. A generalization of the results of heat transfer in the form St = f(Re, Pr) is not justified in this case. For high flow rate Re > 500 in the boundary layer turbulent heat transfer can occur in the presence of a laminar heat dissipation region and the heat transfer for argon and helium can be generalized by a single relation of the form St = F(Re, Pr, e/d).

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