PERFORMANCE CHARACTERISTICS OF AN ELECTRIC-ARC GAS HEATER WITH SEGMENTAL ELECTRODES

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UDC 537.523.5

Relations are established for the arc length as a function of the electric field intensity in an arc column and for the heat loss in the base spot as a function of the electric current and of the gas flow rate.

Those portions of the electrodes in an electric-arc gas heater which are located behind the arc remain useless in terms of energy conversion. In order to determine the optimum length of heater electrodes with a self-sustained arc length, it is necessary to know how the arc location and length depend on the heater parameters. The optimum thermal operating mode with a hot gas jet of given characteristics depends on the ratio of the energy which is transmitted to an electrode by convection and radiation to the energy which is dissipated in the base spot.

In this study the authors have tried to establish these heater performance characteristics. For the study we used the linear vortex-flow electric-arc heater some characteristics of which had been determined earlier [1]. This heater had also been used, specifically, in a study concerning the heat transfer at the stagnation point on a blunt body [1, 2]. The performance analysis of an arc column in various models of electric-arc gas heaters [3] does not make it easy to apply the results to realistic designs. The electrodes of our heater were built in the form of thick-walled copper tubes consisting of 20 mm long segments. The innermost cathode and anode segments at the interelectrode gap were 30 mm long. The cathode channel made of three segments was 80 mm deep. The anode consisted of ten segments with a total length of 230 mm, including Paranite spacers 2 mm wide each. The inside diameter of the electrode channels was 20 mm. Each segment was separately water cooled.

The heater was operated on power levels of 40-280 kW and gas flow rates of 1.7-9.5 g/sec, with the interelectrode gaps 2-4 mm wide. These and other characteristics of the segmental heater matched the operating conditions of the electric-arc gas heater with solid electrodes [1].

Each segment was connected to the voltage supply through a shunt. Signals picked off these shunts were recorded on a loop oscillograph. After preliminary measurements, segments beyond the base spot of the arc were disconnected from their shunts and used for measuring the voltage profile along the arc column.

For the same purpose, in many tests we placed 1 mm thick copper washers between the segments and the Paranite insulating spacers. The potentials of isolated segments relative to the cathode, and relative to the anode (as a check), were measured with a model S-95 voltmeter of an electrostatic system. For comparison, we also measured these potentials with a model M 106 voltmeter of an electromagnetic system according to the procedure in [4, 5]. The results of both measurements were in close agreement. When referred to the center of a segment, according to estimates, the values of these potentials were sufficiently close to their values measured at the copper washers between segments.

In addition to the electrical quantities, we also measured the flow rate and the temperature rise of the cooling water in each segment. The temperature was read by triple differential Chromel–Copel

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Institute of Heat and Mass Transfer, Academy of Sciences of the Belorussian SSR, Minsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 25, No. 1, pp. 73-76, July, 1973. Original article submitted November 9, 1972.

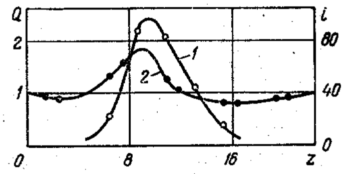

Fig. 1

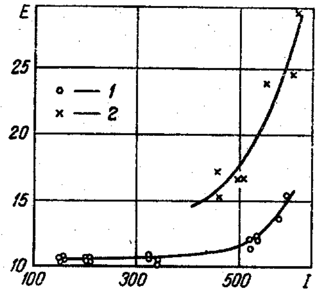

Fig. 2

Fig. 1. Profile of (1) electric current i (A) and (2) heat loss Q (kW/cm) along the anode, with G = 2 g/sec and N = 59 kW; z (cm).

Fig. 2. Mean electric field intensity E (V/cm) in an arc column, as a function of the electric current I (A): 1) G = 2-3 g/sec; 2) G = 6.5 g/sec.

thermocouples in conjuction with a model M001.1A vibrator of a loop oscillograph. Also the total heat loss in the anode and the cathode was determined here and found equal, within 1-8%, to the sum of the losses in all individual segments.

The measurements have yielded lengthwise profiles of the electric current and the thermal flux (Fig. 1), both indicating sharp peaks. These peaks occur in close vicinity of one another. The results confirm the hypothesis that the peak along the thermal flux profile is a consequence of energy losses in the base spot of the arc. The results of arc length measurements, in millimeters, by the said two methods with a 10-20% error can be generalized by the following relation:

$$l_{A(\text{arc})} = -0.435I + 24G + 230, \tag{1}$$

where I denotes the electric current (A) and G denotes the gas flow rate (g/sec).

The arc length decreased with increasing electric current and with decreasing gas flow rate. At 550 A and 2 g/sec the arc moved between the electrodes and the latter burned down. A rise in the gas flow rate to 6 g/sec shifted the short-circuit current to 800-850 A. Our tests were performed over the 100-800 A range.

According to our measurements, the voltage profile along the discharge chamber depends largely on the operating conditions of the heater.

At a relatively low gas flow rate and a low electric current, the electric field intensity remained uniform over a large part of the arc. An exception were the arc areas in the vicinity of the base spot, where the electric field intensity was higher. As both the input power and the gas flow rate were increased, the linear range of the lengthwise potential profile became shorter. The field intensity profile along the arc became U-shaped, as had been found earlier in [6]. The mean-over-the-length field intensity is shown in Fig. 2 as a function of the electric current and the gas flow rate. The sharp rise of the field intensity at currents above 500 A could probably be explained by the rising influence, in short arcs, of the near-electrode arc segments across the gas stream.

From the thermal flux profile along the anode (see Fig. 1) one can determine the amount of heat transmitted to the wall at the base spot of an arc (Fig. 3). The heat loss in the base spot is determined by the electric current and does not depend on the gas flow rate. It was as high as 20-30% of the total heat loss in the anode for the given heater design. The relative fraction of heat loss in the base spot was almost independent of the current within the 200-800 A range.

With the aid of the relation represented in Fig. 3, one can not only estimate the effective voltage drop at the anode (including the voltage drop proper) but also the work function and the thermal energy of electrons as well as the voltage drop across the arc segments across the gas stream:

$$\Delta U^{\text{eff}}_{\text{anode}} = 0.0171I + 17.3. \tag{2}$$

The range of parameter values within which relation (2) applies has been given earlier.

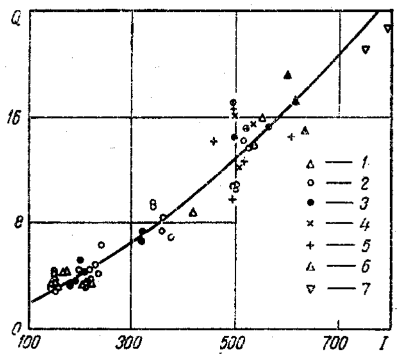

Fig. 3

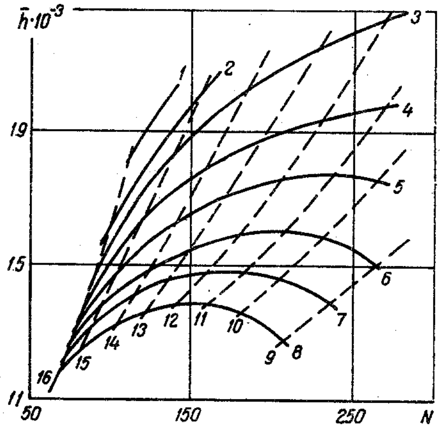

Fig. 4

Fig. 3. Transfer of energy Q (kW) through the base spot of an arc at the anode: 1) G = 1.7 g/sec; 2) G = 2.0 g/sec; 3) G = 3.0 g/sec; 4) G = 5 g/sec; 5) G = 6 g/sec; 6) G = 7 g/sec; 7) G = 9.5 g/ sec; current I (A).

Fig. 4. Characteristics for estimating the optimum anode length of a heater: solid lines are the constant-length lines 1) l = 90 mm; 2) l = 100 mm; 3) l = 110 mm; 4) l = 120 mm; 5) l = 130 mm; 6) l = 140 mm; 7) l = 150 mm; 8) l = 160 mm; dashed lines are the constant-rate (gas flow) lines 9) G = 9.5 g/sec; 10) G = 8 g/sec; 11) G = 7 g/sec; 12) G = 6 g/sec; 13) G = 5 g/sec; 14) G = 4 g/sec; 15) G = 3 g/sec; 16) G = 2 g/sec; anode diameter d_{anode} = 20 mm, N (kW).

With the obtained data one can estimate the minimum anode length sufficient for spreading the arc over a column length corresponding to a given heater power and gas flow rate (Fig. 4), i.e., to the required enthalpy level. For instance, at a 200 kW power input and a gas flow rate of 8 g/sec in the given heater system, the minimum anode length should be approximately 150 mm and the mean-over-the-mass enthalpy of the hot gas should be 14,500 kJ/kg (Fig. 4).

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