A STUDY OF A LINEAR EDDY-CURRENT TYPE ELECTRIC-ARC GAS HEATER WITH AN INTERELECTRODE INSERT

V. P. Terent'ev, V. L. Sergeev, and G. M. Bezladnov

UDC 537.523.5

Results are shown of an experimental study concerning an electric-arc gas heater with an interelectrode insert. The performance characteristics here are compared with those according to other authors.

Of considerable interest today is the linear electric-arc gas heater operating with an interelectrode insert. The first studies of this device [1-3] have demonstrated the feasibility of its practical application. An interelectrode insert has made it possible to heat air to 5500-5900°K [1, 2] and to 6200°K [3]. Without the insert, only 5000-5400° and 5000°K respectively could be attained.

With an interelectrode insert present, the volt-ampere characteristic of an electric-arc gas heater includes in certain cases an ascending branch, which is very important for operating the heater with the rheostat cut out.

With a solid insert [1] it was possible to maintain a fixed arc length while raising the voltage and the power. In [2], furthermore, ascending volt-ampere characteristics were obtained with a segmented insert and a distributed gas supply.

A solid insert was used in high-power industrial electric-arc gas heaters [4, 5], with the narrow segment of a stepped anode structure serving as the insert electrically connected to that anode. The range of gas temperatures attained with these electric-arc heaters was 3000-4100°K. The volt-ampere of such heaters with gaseous arc stabilization included ascending branches within a limited operating range.

An analysis of these volt-ampere characteristics [2] has shown that the ascending branch results from an elongation of the arc by the insert, while the volt-ampere characteristics of an arc in the Mecker channel as the prototype interelectrode insert ascend because of the arc constriction by the channel walls

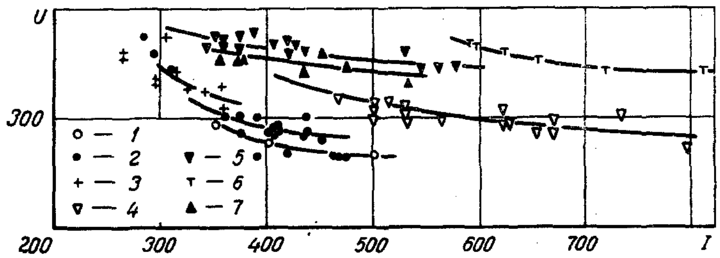

Fig. 1. Volt-ampere characteristics of an electric-arc gas heater with an interelectrode insert: G = 5 g/sec (1, 2,3), 7 g/sec (4), 8 g/sec (5), 10 g/sec (6), 6 g/sec (7); L_i = 4.6 cm (2,4) 7 cm (3,5,6), 9.4 cm (7), no insert (1). Voltage U (V), current I (A).

Institute of Heat and Mass Transfer, Academy of Sciences of the Belorussian SSR, Minsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 24, No. 2, pp. 271-275, February, 1973. Original article submitted June 21, 1972.

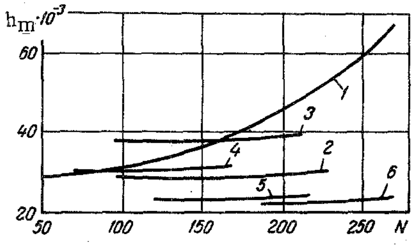

Fig. 2. Enthalpy of the main-stream h_m (J/g) as a function of the arc power N (kW): G = 6 g/sec (1, 2, 3), 5 g/sec (4), 8 g/sec (5), 10 g/sec (6); heater without insert (1), insert length l_i = 9.4 cm (3), 7 cm (2, 4, 5, 6).

and its filling the entire channel section. The first method of producing an ascending branch is more expedient from the standpoint of increasing the performance margin of an insert, the second method is more effective in raising the stream temperature but also results in a fast breakdown of the channel walls. Both effects are apparent, generally, when an insert is used.

In this study the experiment was performed with an electric-arc gas heater of the linear eddy-current type at near atmospheric pressures. The voltage of the supply source was 500 V, the electrode channels were 20 mm in diameter, the anode was 100 mm long, and the cathode was 80 mm deep. The water-cooled insert had segments 22 mm long and 15 mm in diameter, the intersegment gaps were 2 mm wide. Gas (nitrogen) was fed into all gaps with a whirl. The gas flow rate into the insert was separately from the gas flow rate between the insert and the electrodes. The gas flow rate along the insert was 0.30–0.35 g/sec·cm (0.275–0.368 g/sec·cm in [2] and 0.14–0.47 g/sec·cm in [3]).

The heat losses in the electrodes and in each insert segment were measured separately. The values of enthalpy $\bar{h}$ and h_m at a distance 10 mm from the nozzle throat were found on the basis of the energy balance in the heater, from the measured thermal fluxes and pressure at the stagnation point and with the aid of the relation in [6].

The potential profile of the arc in the insert was determined according to the procedure in [7-9].

In the experiment we measured fluctuations of the stream temperature. They were determined on the basis of temperature recordings over some time period, made by means of the photoelectronic attachment shown in [10], and the relative brightness of two lines in the copper spectrum (wavelengths λ_1 = 5153 Å and λ_2 = 5105 Å) at a distance 10 mm from the nozzle throat.

The results indicate temperature fluctuations 1.5–2.0 times smaller than in a heater without an insert, when the insert is 70–94 mm long, i.e., longer than the shortest fluctuating free glow arc in a conventional heater.

Electrical measurements have confirmed the feasibility of producing an ascending volt-ampere characteristic by means of an insert in the electric-arc gas heater. Ascending volt-ampere characteristics have been obtained for the insert region, but the volt-ampere characteristics of the complete heater becomes merely horizontal (Fig. 1), because an insert segment is relatively short in comparison with the total channel length.

The formation of an ascending branch begins at certain minimum values of the electric field intensity E. In [11] under a pressure p = 10^5 N/m^2 these values of E were equal to 19-25 V/cm along the horizontal ranges of a volt-ampere characteristic which had also a slightly ascending branch, but in [2], according to our estimate, the mean electric field intensity of the heater was 26.8-27.2 V/cm along the ascending branch at a 150 A current. In our tests the E—I characteristics ascended at an electric field intensity of about 20 V/cm. In these experiments the authors have not observed any variation in the electric field intensity along the insert, which confirms the data in [3]. This is exceptional, however.

An analysis of the volt-ampere characteristics of heaters with inserts indicates a rise in the arc voltage with an increase in the insert length. With I = 400 A and G = 5 g/sec, for example, the arc voltage was 20% higher with a 94 mm long insert than with a 46 mm long insert. The volt-ampere characteristic here was descending, but became flatter and then horizontal with a higher current and a larger number of insert segments. As in [1, 2], at lower current levels the volt-ampere characteristics of the heater with an insert approached that of the heater without one, indicating that in a weak-current operating mode an interelectrode insert has no effect on the heater performance. The effect on an insert becomes more pronounced at strong currents, which is directly related to the tendency of an arc to become shorter at higher currents.

The earlier formula derived by the authors for heat losses in the anode of a plain electric-arc gas heater $Q_a/N = f(I^2/Gd,\ G/d,\ l/d)$ [12] is accurate within 8% for calculating the anode losses Q_a = f(N) for a heater with an insert within the test range of parameter values.

The heat losses in the cathode are described by a single Q_c = f(N) curve, as in the case of a heater

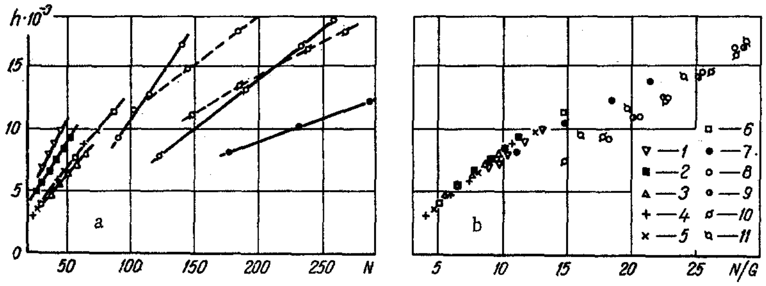

Fig. 3. Mean-over-the-mass enthalpy of the gas stream $\bar{h}$ (J/g) as a function (*a*) of the arc power N (kW) and (b) of the parameter N/G (kW · sec/g). Solid insert [1] l_i = 6.5 cm and $d_i = d_a = d_c$ = 1 cm: G = 3.3-3.5 g/sec (1), 4.7-4.8 g/sec (2), 6.6-6.9 g/sec (3). Segmented insert [2] $d_i = d_a = d_c$ = 1 cm and G = 6 g/sec: l = 12.6 cm (4), 14.7 cm (5), 16.9 cm (6). Segmented insert [3] d_i = 1 cm, d_a = 1.2 cm, d_c = 1.4 cm, l_i = 33 cm, and G = 16 g/sec (7). This study d_i = 1.5 cm, $d_a = d_c$ = 2 cm, l_i = 7 cm: G = 5 g/sec (8), 7 g/sec (9), 8 g/sec (10), 10 g/sec (11).

without an insert. The cathode losses in a heater with an insert are lower than in a plain heater without one.

The heat losses in an insert segment do not vary along it. This can be explained, evidently, by the lengthwise distributed gas injection, which produces a cold layer along the walls of the insert channel and approximately equal conditions of heat transfer between stream and wall within each segment. Such a method of gas supply into an insert increases the efficiency of the device.

An examination of the mainstream (Fig. 2) has shown that its enthalpy h_m increases with decreasing gas rate and with increasing insert length. Furthermore, the presence of an insert in this type of heater tends to make the temperature profile of the gas stream flatter than in such a heater without an insert, as a comparison between the respective $h_m/\bar{h} = f(N)$ curves clearly shows. For heaters without an insert $h_m/\bar{h}$ = 3–4, while the heaters with an insert $h_m/\bar{h}$ = 1.5-3.0 within the same ranges of power (90-270 kW) and gas rate (5-10 g/sec). This is explained by the longer arc in a heater with an insert and by the distributed gas supply, which both yield a uniform heating over the section. A distributed gas supply makes for a more thorough mixing of cold and hot gas, while its effect on constricting the arc column is smaller than in a plain heater.

An analysis of the relation $\bar{h}$(N, G) over the range G = 5-10 g/sec (Fig. 3) shows that the $\bar{h}$(N) curve rises more steeply for a heater with a segmented insert (solid lines 8, 10) than for a heater without an insert (dashed lines 8, 10). A heater with an insert operates more efficiently above, and a heater without an insert operates more efficiently below the intersection points between solid and dashed lines (equal-efficiency points) for each gas rate. Thus, the region has been found where a heater with an insert is more efficient and the stream enthalpy $\bar{h}$ is higher than in the case of a plain heater operating at the same level of arc power N.

For comparison, in Fig. 3 have also been plotted test data for two typical gas rates (curves 8, 10) and calculations based on the results in [1-3] (curves 1-7).

The $\bar{h}$(N) relation for inserts of various lengths but the same diameter is described by a single curve (points 4-6). The enthalpy decreases with increasing channel diameter and increasing gas rate. All points for the same pressure and insert diameter fit on the same $\bar{h}$(N/G) curve in Fig. 3b, regardless of the gas rate, the insert length, and the number of insert segments. The deviation of some points according to [3] is due to the higher pressure in that heater. A further evaluation of these curves in $\bar{h}[(N/G)\eta + (N/G)(1-\eta)(d_1/d_2)^n]$ coordinates yields a single universal equation for the enthalpy of the various linear electric-arc gas heaters with interelectrode inserts used in [1-3] and in our study. In this equation d_1 denotes a selected constant channel diameter, $d_2 = (d_i l_i + d_a l_a + d_c l_c)/l$ denotes the average channel diameter, and n = 1.3 is a constant.

This study of electric-arc gas heaters with interelectrode inserts leads to the following conclusion. An insert stabilizes the arc, reducing the temperature fluctuations in the gas stream, and produces a horizontal range on the volt-ampere characteristic. The gas temperature in a heater with an insert is more uniform along the radius than in a plain heater. A comparison between the heater characteristics reveals a boundary between energywise proper performance regions with and without insert, making it possible to determine the operating range where the efficiency η and the enthalpy $\bar{h}$ are higher for a heater with an insert than in a heater without one operating at the same power level.

NOTATION

$\bar{h}$	is the mean-over-the-mass enthalpy of the gas stream;
h_m	is the enthalpy of the mainstream;
E	is the electric field intensity in the arc column;
I	is the arc current;
U	is the arc voltage;
p	is the pressure in the heater chamber;
G	is the gas flow rate;
Q_a	is the heat losses in the anode;
Q_c	is the heat losses in the cathode;
N	is the electric power of the arc;
η	is the efficiency of electric-arc gas heater;
d	is the diameter of heater channel;
l	is the length of heater channel;
d_i, d_a, d_c	is the diameter of interelectrode insert, of anode, and of cathode respectively;
l_i, l_a, l_c	is the length of interelectrode insert, of anode, and of cathode respectively.

LITERATURE CITED

1. G. Yu. Dautov, Yu. S. Dudnikov, and M. I. Sazonov, Izv. Sibirsk. Otdel. Akad. Nauk SSSR, Ser. Tekh. Nauk, Issue 3, No. 10, 56 (1965).
2. G. Yu. Dautov, Yu. S. Dudnikov, M. F. Zhukov, G. M. Mustafin, and M. I. Sazonov, Prikl. Mekhan. i Tekh. Fiz., No. 1, 172 (1967).
3. G. M. Mustafin, Prikl. Mekhan. i Tekh. Fiz., No. 4, 124 (1968).
4. A. S. An'shakov, G. Yu. Dautov, Yu. S. Dudnikov, I. S. Mazuraitis, and M. I. Sazonov, Fiz. i Khim. Obrabotki Mater., No. 1, 27 (1969).
5. A. S. An'shakov, M. F. Zhukov, M. I. Sazonov, and A. N. Timoshevskii, Izv. Sibirsk. Otdel. Akad. Nauk SSSR, Ser. Tekh. Nauk, Issue 2, No. 8, (1970).
6. V. L. Sergeev, G. M. Bezladnov, and V. D. Lyashkevich, Inzh. Fiz. Zh., 20, No. 4, 622 (1971).
7. E. Pfender, E. R. G. Eckert, and G. Raithby, Proc. Seventh Internatl. Confer. on Ionization Phenomena in Gases, Belgrad [Yugoslavia] 1965, 1, 691 (1966).
8. É. I. Asinovskii and A. V. Kirillin, Teplofiz. Vys. Temp., 3, No. 5, 677 (1965).
9. Buchhorn, VRT, No. 6, 9 (1961).
10. V. E. Kukonin, Inzh. Fiz. Zh., 14, No. 5, (1968).
11. G. Yu. Dautov, Yu. S. Dudnikov, M. F. Zhukov, and M. I. Sazonov, Prikl. Mekhan. i Tekh. Fiz., No. 5, 132 (1965).
12. V. L. Sergeev and G. M. Bezladnov, Reports to the Fifth All-Union Confer. on Low-Temperature Plasma Generators, Novosibirsk (1972).