LITERATURE CITED

1. A. P. Chernogortsev, Small Fish Processing Based on Fermentation of the Stock [in Russian], Pishchevaya promyshlennost', Moscow (1973).
2. A. A. Buinov and A. P. Chernogortsev, "Problem of drying fish protein hydrolyzates," Tr./KTIRPKh (1978), No. 76; Technological Processes and Equipment for Fish Processing Enterprises in the Western Basin, pp. 3-7.
3. A. A. Buinov, A. S. Ginzburg, and V. I. Syroedov, "Hygroscopic properties of fish protein hydrolyzates dried in a foamed state," Izv. Vyssh. Uchebn. Zaved., Pishchevaya Tekhnol., No. 3, 110-113 (1977).
4. A. A. Buinov, "Thermodynamic analysis of the mechanism of interaction of food fish hydrolyzates with water," Tr./MTIPP (1977), Progress in the Technology of Drying Different Products and Materials, pp. 86-89.
5. A. V. Lykov, Theory of Drying [in Russian], Énergiya, Moscow (1968).
6. A. A. Buinov, A. S. Ginzburg, and V. I. Syroedov, "Effect of depth of fermentation on the properties of fish food hydrolyzate foams," Izv. Vyssh. Uchebn. Zaved., Pishchevaya Tekhnol., No. 1, 132-134 (1978).

TEMPERATURE FIELD OF GRAPHITE ELECTRODE IN PLASMATRON

N. V. Pashatskii, E. A. Molchanov, and
S. A. Chugin

UDC 533.924

Results of an experimental study are presented pertaining to the temperature field of a graphite electrode in an ac power plasmatron.

Graphite electrodes have found broad applications, in electrometallurgy and electric welding, in light sources, in plasmatrons, and in many other devices. The electrodes in such devices operate at high current densities and under heavy heat loads, at temperatures near their melting point. A study of the temperature field of such an electrode is of both scientific and practical interest, inasmuch as indeed the temperature determines many processes occurring in the electrode body and at the electrode surface (electron emission, heat conduction, radiation, erosion of material, etc.).

Most attention in the technical literature on this subject has been paid to the thermal state of carbon and tungsten electrodes with a small diameter [1-3]. The surface temperature is measured most effectively by methods of optical pyrometry [2, 3]. In this way have been determined temperature distributions over the radius of the end face and over the length of the lateral surface of an electrode, also the dependence of the electrode bulk temperature on the current and on the length of the electrode rod. In another study [4] the temperature field of a thick (diameter d $\sim$0.5 m) graphite electrode was measured by the thermoelectric method.

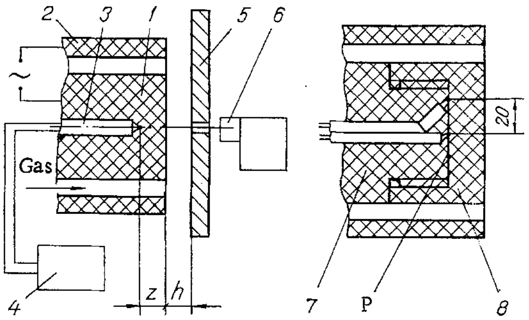

Fig. 1. Schematic diagram of experimental apparatus: 1) rod-type electrode, 2) graphite sleeve, 3) thermocouple, 4) model KSP4 potentiometer, 5) fusible wall, 6) model OPPIR-017É pyrometer, 7) electrode body, 8) front assembly.

Moscow Institute of Engineering Physics. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 43, No. 1, pp. 100-103, July, 1982. Original article submitted April 29, 1981.

0022-0841/82/4301-0782$07.50

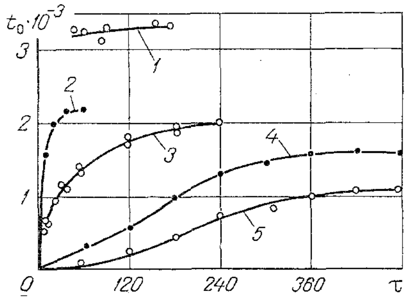

Fig. 2

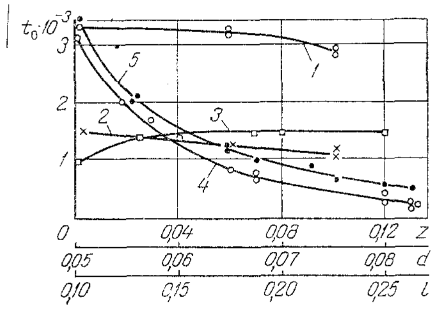

Fig. 3

Fig. 2. Temperature t_0(°C) at electrode axis as function of time τ (sec), at various sections of the electrode rod: 1) $z = 0$; 2) 0.003; 3) 0.024; 4) 0.070; 5) 0.130 m.

Fig. 3. Dependence of electrode temperature on rod diameter d, m (curves 1, 2), rod length l, m (curve 3), and arc current I, A (curves 4, 5): 1) $z = 0$; 2, 3) 0.06 m; 4) $I = 1200$; 5) 1800 A; $\tau = 5$ min.

In this study will be described a method and the results of complex (thermoelectric and pyrometric) temperature measurement at various points of rod-type graphite electrodes in an ac plasmatron.

Experiments were performed with the apparatus shown schematically in Fig. 1. A rod-type graphite electrode 1 was placed inside a graphite sleeve 2 and screwed into a water-cooled steel fixture. The temperature t_0 along the electrode axis was measured with a tungsten-rhenium thermocouple 3 inside a protective sheath of aluminum oxide and a potentiometer 4. This thermocouple was inserted from the side of the water-cooled fixture into a hole which had been drilled in the electrode to the required depth. The radiant flux emitted from the electrode face passed through a hole in a fusible wall 5 and impinged on the pyrometer objective 6. The electrical supply system for the plasmatron was the same as in our earlier study [5].

The temperature of electrode rods made of grade GÉ graphite, 0.05 m in diameter and 0.18 m long, was measured with the plasmatron operating at $I = 1600$ A, $U = 100$ V, and flow rate of the plasma generating gas (air) 5 m^3/h. The plasmatron current was maintained constant by regulation of the distance h from nozzle throat to fusible wall ($h = 0.01$-0.03 m under the given conditions). The arc in the plasmatron was ignited by touching the outer electrode (sleeve) with the inner one.

Measurements at points on the electrode axis at distances z shorter than 0.03 m from the hot end, i.e., at points with temperatures expected to be close to 2000°C, were made by insertion of the thermocouple for a short time only (∿10 sec) so as to avoid its destruction. In all other cases the thermocouple was installed permanently. The shortest distance from the hot end at which temperature measurement with a thermocouple was still possible was 0.003 m. At distances z shorter than that the thermocouples became inoperative, as a result of their interaction with hot graphite.

The mean temperature of the hot face of an electrode was determined visually with a model OPPIR-017É pyrometer, through a light filter for the effective wavelength $\lambda = 0.65 \cdot 10^{-6}$ m. In a determination of the brightness temperature with the aid of such a filter one can disregard the radiation coming from the plasma, inasmuch as this radiation at wavelengths $\lambda \geq 0.6 \cdot 10^{-6}$ m is negligible [2]. For conversion from brightness temperature to real temperature we used $\varepsilon_\lambda = 0.85$ as the spectral emissivity of graphite [6].

The data shown in Fig. 2 indicate that at small distances from the hot end ($z < 0.01$ m) the temperature becomes steady very soon.

As the electrode is made shorter and its diameter is made larger, the thermal resistance between a given rod section and the hot end decreases and this is manifested in a lower electrode temperature (Fig. 3).

The current dependence of the electrode temperature has been determined in other studies [2, 3] for the hot end only. The data of this study (Fig. 3) indicate that, as the current

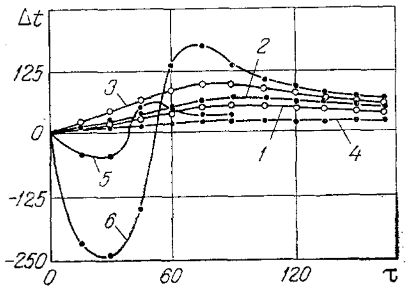

Fig. 4. Radial temperature drop in electrode as function of time: 1) $V = 3.5$; 2) 4.5; 3-6) 6.0 m^3/hr; 5) $l = 0.12$ m; 1-3) $z = 0.06$; 4) 0.09; 5, 6) 0.03 m.

increases, the temperature increases over the entire length of the electrode. This temperature rise is a result of increased Joule-effect heat generation.

The radial temperature distribution in a rod depends on many factors such as distance from the hot end, location of electric arcs at the electrode end, heat radiation from the arcs and from the outer electrode, intensity of cooling of the lateral surface by the plasma generating gas, design of the electrode holding fixture, etc. In the technical literature [2, 3] there has been given a thorough account of temperature measurement along the radius of the hot face of a thin electrode ($d \leq 1 \cdot 10^{-2}$ m).

Temperature measurement at $r > 0$ and $z > 0$ is a difficult problem. It is most successfully done, in these authors' view, with use of a compound electrode (Fig. 1).

The electrode rod 7 was fastened to the water-cooled fixture, two thermocouples passing through the electrode rod for measurement of temperature t_0 at the rod axis and temperature t_r at a point $r = 0.02$ m from the axis. The junctions were pressed against the electrode body by the front assembly 8. In order to eliminate the effect of nonuniform Joule heat generation on the temperature distribution, special attention was paid to a tight contact between component parts in plane P.

The results of experiments with a compound electrode 0.06 m in diameter and 0.18 m long (Fig. 4) indicate that as the flow rate of the plasma generating gas (air) fed through the annular interelectrode gap increases, so does also the radial temperature drop $\Delta t = t_0 - t_r$ in the electrode — a result of the cooling action of the gas (curves 1, 2, 3).

The cooling action of the gas (air) weakens toward the cold end of the electrode, which causes the temperature drop to decrease (curves 3, 4).

The peculiar trend of Δt as a function of time at small distances ($z = 0.03$ m) is attributable to the intricate process of heat conduction near the electrode end, this process depending on the location of the arc supporting spots. The arcs shift with time from the edge of the electrode face, where they were supported during the initial period, toward the rod axis [5] with an attendant change of sign of the temperature drop Δt (curves 5, 6).

In the short electrode ($l = 0.12$ m) Δt changes sign at section $z = 0.03$ m much sooner and the absolute magnitude of the temperature drop becomes smaller than in the long electrode ($l = 0.18$ m), because of a shorter time in which the rod heats up and because the given section is closer to the cold end of the electrode.

These data on the temperature field of a rod-type graphite electrode under transient and steady conditions suggest that the ways to decrease erosion of such an electrode [5] are basically also the ways to decrease its temperature.

Temperature measurements along the radius of an electrode at various instants of time yield information about the dynamics of the electric arcs here and data for estimating the magnitude of the thermal flux at the lateral surface of a rod electrode.

NOTATION

d, l, diameter and length of a rod electrode; t_0, t_r, temperatures at the rod axis and at distance r from the rod axis; I, current; U, voltage across the plasmatron electrodes; h, distance between fusible wall and throat of plasmatron nozzle; z, distance along the rod axis from the hot end to the thermocouple location; λ, wavelength; ε_λ, spectral emissivity; Δt, temperature drop; τ, time, and V, flow rate of the plasma generating gas.

LITERATURE CITED

1. W. Finkelnburg and H. Mecker, Electric Arcs and Thermal Plasma [Russian translation], IL, Moscow (1961).
2. A. V. Pustogarov, "Measuring the temperature of plasmatron electrodes," in: Near-Electrode Processes and Erosion of Plasmatron Electrodes [in Russian], Inst. Termofiz., Novosibirsk (1977), pp. 41-60.
3. M. F. Zhukov, A. S. An'shakov, G.-N. B. Dandaron and Zh. Zh. Zambalaev, "Temperature distribution over a thermocathode," in: Proc. Eighth All-Union Conf. on Generation of Low-Temperature Plasma [in Russian], Vol. 2, Inst. Termofiz., Novosibirsk (1980), pp. 12-15.
4. B. M. Kuzin, M. A. Ryss, V. M. Belousova, et al., "Thermal performance of 555 mm (diameter) electrode of model DCP-80A plasmatron smelting stainless steel at the Chelyabinsk Metallurgical Plant," in: Trans. Chelyabinsk Metallurgical Combine [in Russian], Issue 4, Metallurgiya, Moscow (1975), pp. 191-196.
5. N. V. Pashatskii and E. A. Molchanov, "Erosion of graphite electrodes in ac plasmatron," Izv. Sib. Otd. Akad. Nauk SSSR, Ser. Tekh. Nauk, No. 8, Issue 2, 62-65 (1980).
6. A. E. Sheindlin (ed.), Radiative Properties of Solid Materials [in Russian], Énergiya, Moscow (1974).

CURRENT AND HEAT FLOW DENSITY ON THE ANODE OF A PLASMATRON WITH RECIPROCAL POLARITY

S. P. Polyakov

UDC 537.525

Current and heat flow density to the end electrode of a plasmatron were measured with different currents and flow rates of argon.

Physical processes in the regions near the electrodes of the electric arc of plasmatrons determine their thermal efficiency and life. Many works deal with the investigation of the physical properties of the electric arc and the processes occurring near the electrodes; an entensive bibliography of these works is contained in [1, 2]. The authors of [3-5] present the results of measurement of the local parameters of the arc spot with a sectional electrode that scans the arc column perpendicularly to its axis. However, we do not know of any work that contains the results of measurement of the current and heat flow density in the end electrode of a plasmatron.

The present work contains an attempt to devise a direct action plasmatron with sectional end electrode, and to measure the current and heat flow density in the spot of the electric arc. The sensor for measuring the current and heat flow density to the end electrode is a direct action plasmatron with sectional end electrode (Fig. 1). The end electrode is made of two water-cooled copper sections which touch each other but are thermally and electrically insulated; each section has a working surface of 1.5 × 1.5 cm. The heat and electrical insulator is mica, 0.1 mm thick. The two sections of the end electrode are fastened to each other and can be shifted inside the plasmatron perpendicularly to their interface on the flat surface of the insulator of fabric glass laminate which is 2-3 mm thick, has in the center a circular opening of 10-mm diameter, and covers the plasmatron nozzle of 5-mm diameter. On its inner side the flat insulator has grooves milled tangentially to the opening for the supply of stabilizing gas. After the sectional copper electrode is assembled, it is carefully ground. Grinding of the electrode has two objects. Firstly, to prevent its erosion in operation, and secondly, to prevent leakage of the stabilizing gas between the electrode and the insulator. The newly devised direct action plasmatron with sectional end electrode makes it possible to measure the current and heat flow density in the spot of the electric arc with convective flows minimally affecting the arc and the spot. For the sake of brevity we will call the newly devised installation a PSE, plasmatron with sectional electrode.

Dnepropetrovsk Metallurgical Institute. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 43, No. 1, pp. 104-109, July, 1982. Original article submitted November 21, 1980.

0022-0841/82/4301-0785$07.50