β_u^- values in Fig. 2 for drying of steatite ceramic determined from the drying intensity according to Eq. (1) and according to our method respectively indicate a close agreement.

The question as to which equation has to be used for determining the Biot number in a given range of moisture content variation can be answered uniquely in each specific case. When Eq. (10) yields a Biot number $N_{Bi,m} = 0.1$, for instance, then Eq. (12) must be used for calculations, and so on in the case of other bodies. In the case of drying in a fluidized disperse coolant, the Biot number will exceed 0.1 very soon after the beginning of the process [4]. The mass transfer coefficients must then be calculated according to Eqs. (12), (14), and (15).

NOTATION

β_u^-, external mass transfer coefficient referred to the motive force in the solid phase; u_s, u_e, respectively, the surface moisture content and the equilibrium moisture content in the porous body; $N_{Bi,m} = \beta_u^- R/a_m$, Biot mass-transfer number; $N_{Fo} = a_m\tau/R^2$, Fourier number; a_m, molecular diffusivity; τ, time; R, characteristic dimension of the body; μ_n, roots of the characteristic equations; and u, mean-volume moisture content.

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HEATING OF CERAMIC AND SILICATE MATERIAL SURFACES BY AN ARC PLASMA FILAMENT

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The heating of ceramic and silicate material surfaces by a heavy current arc plasma filament is investigated in an air atmosphere. The possibility of using optical pyrometry methods for highly heated surfaces is studied for T > 2000°K.

A rise in the efficiency of many high-temperature technological processes requires a detailed study of the interaction between high-enthalpy plasma fluxes and the surface of a solid. Despite the considerable amount of investigations, there are many unsolved questions in this area [1]. Especially few are the confident results in studying plasma interaction with a surface with ablation taken into account. Theoretical methods do not permit the confident solution of this problem at this time because of the complexity of taking account of the whole set of elementary processes occurring here, as well as the lack of information about the properties of a plasma that are realized in the boundary zone during interaction. Difficulties in the experimental investigations are due primarily to the lack of reliable methods and apparatus for body temperature and plasma parameter diagnostics during its action on the body surface.

The behavior of ceramic and silicate materials subjected to plasma fluxes is investigated in this paper, and the possibility of using optical pyrometry methods for a heated surface is examined. The schematic diagram is presented in Fig. 1a, and is described partially in [2]. In order to assure high density of the energy delivered stationarily to the item surface and to obtain reproducible results, a current-carrying plasma filament placed between two specimens being investigated which were mounted in parallel at a 6-mm spacing and

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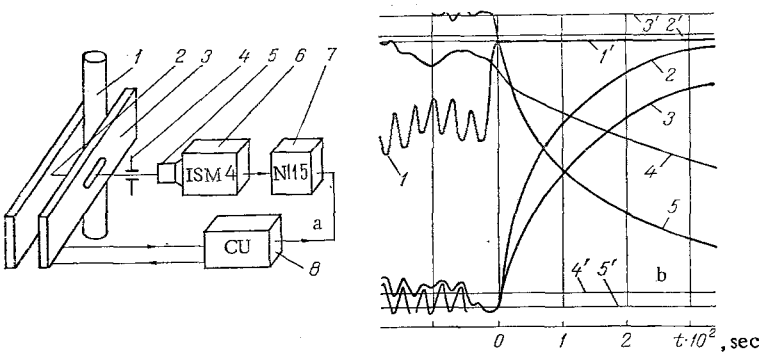

Fig. 1. Schematic diagram of specimen heating by a plasma filament and recording of the radiation of their surfaces (a) and typical current and radiation oscillograms (b): a) 1 is the plasma filament; 2, 3, specimens being investigated; 4, diaphragm; 5, shutter; 6, spectrometer; 7, oscilloscope; 8, control unit; b) 1, arc current prior to disconnection; 1', t = 0; 2, radiation $E_2\lambda_2$ = 1.15 μm, 2', E_2 = 0; 3, radiation $E_3\lambda_3$ = 1.53 μm, 3', E_3 = 0; 4, $E_4\lambda_4$ = 2.3 μm, 4', E_4 = 0; 5, radiation $E_1\lambda_1$ = 0.96 μm, 5', E_1 = 0. $t \cdot 10^2$ sec.

could be displaced translationally, was the heating source.* The surface being heated was observed through a rectangular (2 × 6 mm) window in the specimen lying opposite. The low window height permitted the assumption of constancy of the plasma parameter along the length of the electrical arc, and a corresponding surface temperature T_{SO} along the heating zone. Working regimes with specimen ablation were examined in the experiment, which were achieved for a discharge current of i = 220-660 A and a rate of specimen displacement of 0.11 m/sec and higher. After the action of the plasma filament on the specimen surface, a glasslike porous layer of 0.1-0.2-mm thickness remained. In its composition the glass being formed for both the silicate and ceramic material is similar to the type of glass called window glass in the literature [3].

Elimination of the influence of the plasma during observation of the highly-heated surface was achieved, exactly as in [4], by disconnecting the arc. It was established experimentally that the time of switching off the plasma current for this apparatus was ~2 msec. After switchoff of the arc, the measuring unit records only radiation of the heated surface. After 2 msec the T_{SO} should not change substantially and the specimen radiation recorded by the measuring unit right after switchoff of the current will characterize the state of its surface during the plasma lifetime.

A study of the possibility of optical pyrometry of bodies at temperatures above 1000°K is of independent interest. Hence, the emissive characteristics were investigated in this paper during their natural cooling off. To assure observation on the given section of the surface, a unit was used to deflect the translational displacement of the specimens investigated instantaneously.

The pyrometric investigations of the surface were performed by using an ISM-4 spectrometer [5] which was created to study fast-moving high-temperature processes by the methods of multicolor pyrometry [6]. The spectrometer permits the recording of hot object radiation in the near IR range in four spectral bands simultaneously with a time resolution of 10^{-3} sec. Channels with the effective wavelengths 0.95, 1.15, 1.53, and 2.3 μm with a 10^{-2} μm half-width were selected for this experiment. The spectrometer electrical signals were recorded by an N115 light-ray oscilloscope.

The spectrometer 6 recorded the radiation intensity of the specimen surface 2 through the slit 3 in the specimen and the diaphragm 4. To protect the receivers from prolonged and intensive blanking, a shutter 5 was mounted after the diaphragm. Because of the necessity of performing a given sequence of operations in a comparatively short time (~2 sec) during the experiment, the control unit 8 was used in the experiment. After ignition of the arc filament, the mechanism to displace the carrier with the specimens was switched on, the plasma filament entered the gap between the specimens 2 and 3, and heated their surface. At this time the electric motor of the light-ray oscilloscope 7 was switched on, the shutter 5 was opened, the carriage drive was disconnected as was the arc current, and the specimen surface radiation was recorded as it cooled for 0.5

*An electrical discharge apparatus PS-1, developed in the Institute of Physics of the Belorussian Academy of Sciences, was used in performing the experiments.

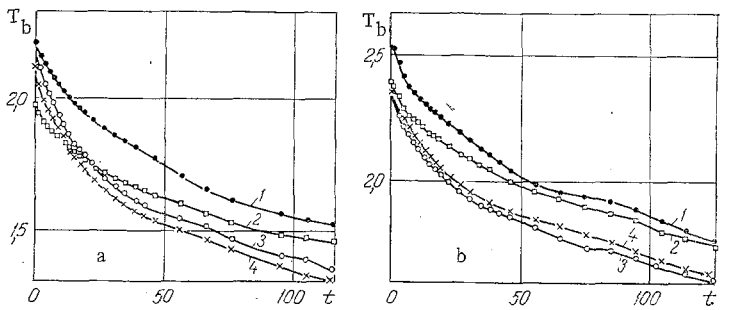

Fig. 2. Change in the brightness temperature of a ceramic specimen during its cooling (a) i = 250 A, u = 1.85 B; (b) i = 500 A, u = 190 B: 1) $\lambda_1 = 0.96\ \mu m$; 2) $\lambda_2 = 1.15\ \mu m$; 3) $\lambda_3 = 1.53\ \mu m$; 4) $\lambda_4 = 2.3\ \mu m$. T_b, 10^3°K; t, msec.

TABLE 1. Efficiency of Specimen Heating in Different Working Regimes of the Apparatus

Parameters	Ceramic brick							Silicate		
Current intensity i, A	250	300	350	400	450	500	540	450	500	540
Temperature T_b, °K	2190	2190	2240	2470	2410	2470	2480	2300	2300	2300

sec. A typical oscillogram of the current and radiation brightness in four near-IR-spectrum bands is presented in Fig. 1.

The magnitude of the signal is determined at the beginning of the oscillogram by the total radiation of the plasma and the heated surface. Its intensity varies with time in conformity with the current fluctuations due to the inadequate smoothing of the variable component of the electrical supply source. Analysis of the oscillograms obtained permitted estimation of the contribution of plasma radiation in the signal being recorded at different wavelengths. The maximal plasma contribution to the radiation is observed in the 1.15 μm channel and can reach 20% in individual cases. The contribution is less than 10% for the 0.96 and 1.53 μm wavelengths and is generally several percent for 2.4 μm. The results obtained indicate that the estimate of the specimen surface temperature can be performed even without disconnecting the arc.

The time dependences obtained for the specimen surface radiation intensity permitted determination of the change in brightness temperature during specimen cooling in each experiment. Temperature profiles are presented in Fig. 2 for two heating regimes. It is seen that the brightness temperatures in the spectrum ranges under investigation have different values. The temperature for the 0.96 μm channel is always higher than the corresponding values obtained in the other channels, which are in satisfactory agreement to the accuracy of the measurement error ($\sim 5\%$).

Analysis of the curves obtained for the specimen surface cooling shows that the cooling rate is a maximum right after disconnecting the discharge current, and then diminishes substantially. This can be a result of the preeminent role of radiant heat transfer in high temperature domains. For T > 2000°K the cooling of the surface layer is determined by heat conduction, which will be a comparatively slow process for the dielectric materials under investigation. It is characteristic that the rate of change of the cerican and silicate specimen surface temperature is several times higher than that obtained for tungsten at similar temperatures [4].

Obtaining confident time profiles of the true temperature is a complex problem because of the lack of information about the spectral emissivity factors at temperatures above 1200°K for the materials under investigation [3]. Hence, under the conditions of the present experiment, only approximate methods of multicolor pyrometry not requiring knowledge of the absolute values of the emissivities could be used for this purpose. For the case of tricolor pyrometry (the possibilities of the ISP-4 spectrometer), it is assumed that the emissivity in the spectrum range under investigation can be approximated by the expression

$$\ln \varepsilon_\lambda = a_0 + a_1\lambda + a_2\lambda^2, \qquad (1)$$

where a_0, a_1, a_2 are constant coefficients.

Such a dependence assumes a monotonic change in the spectral brightness of the thermal emitter with wavelength. The results obtained indicate that such a dependence is observed only right after disconnecting the

arc (t = 0) and at the end of the time interval under investigation (t = 130 msec). Redistribution of the relative role of the contributions of the different wavelength bands, for instance at t = 10 and 40 msec, is observed in the 0-130-msec range. This is apparently the result of the complex nature of the physicochemical transformations in the fused layer during cooling, which results in the impossibility of approximating the emissivity factor by (1) in the temperature range under investigation. Processing the data of the experiment on an electronic computer by the three-color pyrometry method confirms this assumption. The system of transcendental equations had no solution satisfying the general physical conceptions of body heating by plasma fluxes in the majority of cases.

Comparing specimen heating efficiency in the different working regimes was performed by the change in brightness temperature for the 1.15 μm wavelength. Values at the time of discharge current disconnection are presented in Table 1.

It is seen that the surface temperature of the ceramic specimens is ~2200°K for currents i = 250-350 A, and then reaches 2450°K by a jump as the current grows, and remains constant within the limits of experimental error up to a 540 A current. It is difficult to obtain reproducible results for currents i < 450 A for silicate materials in this geometric configuration of the discharge apparatus, and the surface temperature is constant at 2300°K in the i = 450-540 A current range. The quantities presented in the table are the brightness temperatures. If it is assumed that $\varepsilon_\lambda = 0.5$ for the wavelength 1.15 μm, then the true values of the surface temperatures will be approximately 300°K higher.

A negligible rise in temperature for a substantial increase in the discharge current is a result of the growth in the fraction of specific thermal flux expended in increasing the thickness of the melted layer. This is in agreement with the dependence of the thickness of the fused layer on the discharge current after specimen cooling, and appears as a change in temperature after cooling (Fig. 2); the temperature T = 1500°K for i = 250 A is built up 75 msec after disconnecting the current, and for i = 500 A after 140 msec.

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