AN ELECTRICAL PROBE WITH ELECTRON EMISSION IN THE REGIME OF A CONTINUOUS MEDIUM

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The influence of electron emission on the current—voltage characteristics of a cylindrical probe placed in a weakly ionized, dense plasma with constant properties and frozen-in chemical reactions is considered.

The theory of an electrical probe in the regime of a continuous medium without allowance for electron emission was developed in [1-3]. In practice, however, the surface temperature of the probe can reach values at which the current density of thermionic emission becomes comparable with the density of the probe current, leading to a significant change in the probe's characteristics. Electron emission from the surface of a probe can be due not only to its heating but also to bombardment by fluxes of high-energy particles and photons [4].

The physical statement and mathematical model of the problem under consideration correspond to those of [1]. A difference consists in the fact that the boundary condition at the probe surface is changed. Instead of the condition that the electron density at the boundary equal zero, which corresponds to the assumption that the probe surface is perfectly catalytic, we assign an electron flux with a density j_{em} which depends on the electron work function, the surface temperature, and the parameters of the surrounding plasma. As was shown in [5], the effective electron work function of a metal at a point of contact with a plasma is $\phi_{ef} = \phi_{met} - \phi_{p\ell}$.

The problem of a probe with emission was solved by the method of successive iterations in time, using the method of large particles at each time step [1]. The time step was chosen from the Courant—Friedrichs—Lewy condition of stability of the solution [6]. The equations were reduced to dimensionless form, the normalization being done by analogy with [1]. The main dimensionless parameters on which the solution of the problem depends are r_0, ϕ_0, D, and j_{em}. The solution was obtained in the following intervals of variation of these parameters: $1 \leqslant r_0 \leqslant 10^3$; $-25 \leqslant \varphi_0 \leqslant 10$; $0 \leqslant j_{em} \leqslant 10^2$. The parameter D = 32 was calculated from the model of rigid spheres [3] and corresponded to the case of a hydrogen plasma. As was shown in [1], it only influences the electron branch of the probe characteristic.

In Fig. 1 we give characteristic curves of the radial distribution of the potential for $r_0 = 5$ and different values of ϕ_0 and j_{em}. From Fig. 1 it follows that the distribution $\phi(r)$ depends on the dimensionless parameters of the problem. In particular, with an increase in j_{em} potential wells are formed in the curves of the function $\phi(r)$, influencing the probe characteristic. The time of their appearance depends on ϕ_0 and r_0. The higher the probe potential ϕ_0, the higher the electric field strength in the wall region which prevents the appearance of a potential well. Therefore, ever higher emission currents are required for their appearance. The potential well grows with a decrease in the probe radius, other conditions being equal, since the negative space charge connected with electron emission is concentrated near the probe axis.

A change in the character of the potential distribution leads to a change in the profile of the electric field strength. For a positive probe potential the field strength near the probe surface also grows with an increase in j_{em}, leading to an increase in the electron flux from the plasma to the probe. This fact ultimately leads to the effect of blocking of electron emission. For a negative probe potential the development of a potential well leads to a change in the sign of the electric field-strength vector: instead of negative, it becomes positive. Because of this, the ion flux from the plasma to the body decreases.

A numerical experiment allows us to separate the probe current into the component connected with emission (j_{em}) and the component connected with the flux of charged particles

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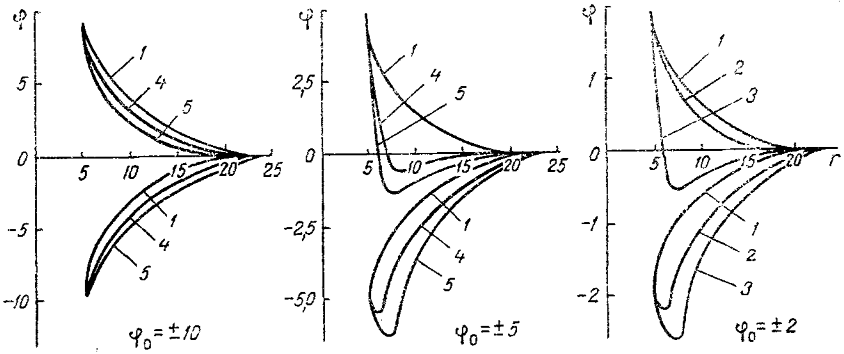

Fig. 1. Function $\phi(r)$: 1) j_{em} = 0; 2) 1; 3) 5; 4) 10; 5) 100.

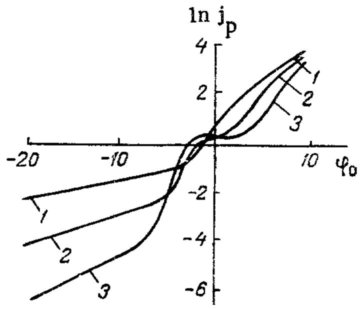

Fig. 2. Current–voltage characteristics of a cylindrical probe with emission: 1) j_{em} = 0; 2) 10; 3) 100.

from the plasma to the body ($j_{i,e}$), which is determined by the gradients of potential ($\nabla\phi$) and of charged-particle concentrations ($\Delta n_{i,e}$). The gradient $\Delta\phi$ varies more significantly than $\Delta n_{i,e}$ under the influence of j_{em}, so that the potential profile $\phi(r)$ has the main influence on the probe current (Fig. 1). Only the resultant current j_p in the probe circuit can be measured in a physical experiment. In the case of a positive potential ϕ_0 the probe current is $j_p = j_e - j_{em}$, while in the case of a negative potential $j_p = j_i + j_{em}$.

In Fig. 2 we give j_p as a function of the potential ϕ_0. With an increase in ϕ_0 the electron branches of the characteristics with different j_{em} come together and coincide with the curve for the case of the absence of emission. This is explained by the fact that a probe with a high positive potential attracts back the electrons emitted from its surface. Therefore, it is convenient to use the saturated electron current in practical probe measurements. But if the ion branch of the characteristic is used, it is desirable to choose characteristic probe parameters such that the potential curve $\phi(r)$ varies insignificantly under the action of j_{em}. For this it is necessary to increase r_0 and $|\phi_0|$ to the maximum. Then, as was shown above, the electric field of the probe depends little on j_{em} and the probe current is $j_p = j_{em} + j_i|_{j_{em}=0}$. If the emission current can be estimated from additional considerations (e.g., from the known surface temperature of the probe), then the plasma component of the ion current j_i proves to be known. Under these conditions, the method of treatment of the probe characteristic coincides with the case of the absence of emission [1-3].

The characteristics obtained in the established regime are qualitatively consistent with the results of the research of Binkowski and Kalnavarns (see [3], Sec. 4.1.2), who made calculations for the steady-state equations of a probe in a dense plasma.

NOTATION

ϕ_{met}, work function from metal to vacuum; ϕ_{pl}, "work function of the plasma," dependent on the ion density n_i; r_0, dimensionless radius of the probe, equal to the ratio of the dimensionless radius to the Debye radius; ϕ_0, dimensionless probe potential, equal to the ratio of the potential energy of the electric field to the ion thermal energy; D, ratio of the diffusion coefficients of electrons and ions; j_{em}, dimensionless emission density, equal to the ratio of the dimensional current density to the scale coefficient [1].

LITERATURE CITED

1. B. V. Alekseev and V. A. Kotel'nikov, Teplofiz. Vys. Temp., 19, No. 6, 1271-1275 (1981).
2. V. A. Kotel'nikov, Inzh.-Fiz. Zh., 46, No. 2, 322-323 (1984).
3. P. M. Chung, L. Talbot, and K. J. Touryan, Electric Probes in Stationary and Moving Plasmas, Springer-Verlag, New York (1975).
4. A. M. Brodskii and Yu. Ya. Gurevich, Theory of Electron Emission from Metals [in Russian], Moscow (1973).
5. A. A. Porotnikov and B. B. Rodnevich, Abstracts of Fifth All-Union Conference on Plasma Accelerators and Ion Injectors [in Russian], Moscow (1982), pp. 96-98.
6. D. E. Potter, Computational Physics, Wiley (1973).

RADIATIVE–CONDUCTIVE HEAT TRANSFER IN LIQUID ORGANIC COMPOUNDS AT 373-473°K

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Experimental and numerical-solution results are presented for radiative–conductive heat transfer (RCHT) in planar layers of organic liquids at elevated temperatures.

Radiative–conductive heat transfer is of interest in relation to working media with weak absorption in the near infrared (IR), particularly in improving methods of calculating equipment for wide temperature and pressure ranges. If one neglects radiation, large errors occur, particularly at elevated temperatures, since the main transport parameter is the effective thermal conductivity λ_{ef}, which has a conductive component λ_c and a radiative one λ_r.

The problem can be considered in the gray approximation if the effect of radiation is small (up to 10%), or it can be treated numerically from a selective model if there is a considerable radiation effect. Experiment is required to evaluate the assumptions made in the model.

Most experiments deal with RCHT for solids and molten materials [1]; effective thermal conductivities have been determined for organic liquids only at atmospheric pressure and temperatures up to 373°K [2-7].

An apparatus has been devised [8] for recording the temperature and heat-flux distributions by interferometry on planar layers of organic compounds at 293-473°K and pressures up to 1 MPa. The method is fast and sensitive and allows one to visualize the processes. One can judge the radiative component from the nonlinearity in the temperature distribution and can derive it from the λ_{ef}/λ_c ratios deduced by two methods: from the relative plane-layer method [2] and from the method due to Girgull and Schodel [4] as modified for high temperatures. The heaters and the opaque boundaries are provided by silica plates with films of invar and platinum evaporated onto the surfaces. The integral degree of blackness normal to the surface has been measured at 293°K with a TRM I thermoradiometer, whose spectral sensitivity covers the range 4-40 μm, the values for the upper and lower plates being $\varepsilon_s = 0.15$ and $\varepsilon_s = 0.16$ correspondingly. High-temperature experiments required a three-stage system, which included air and liquid thermostats, as well as an electronic system for regulating the temperature difference across the layer of liquid ($\Delta T = 0.5–2$ K). The maximal relative errors in the measured λ_{ef}/λ_c have been calculated by means of error theory in accordance with the standardization documents [9-12] and did not exceed $\pm 2\%$.

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