PLANE HEATERS WITH LOW SPECIFIC HEAT FOR THERMOPHYSICAL STUDIES

V. V. Vlasov and I. A. Cherepennikov

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Plane heaters having low specific heat are described; this is important for determining the thermophysical characteristics in the quasi-steady mode. The experimental data necessary for using these heaters are obtained.

The complex automatic determination of the thermophysical coefficients of nonmetallic materials in the quasi-steady mode [1] imposes special requirements on the plane electric heaters used.

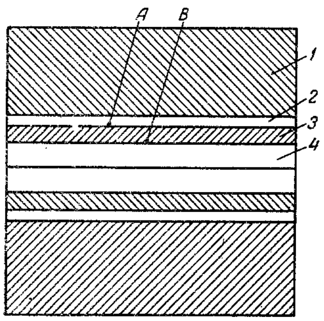

Fig. 1. Placement of materials under study and plane heaters; 1) ceramic base of heater; 2) nickel heating element; 3) mica, $\delta = 0.1$ mm; 4) nickel plate under study, $\delta = 2.0$ mm.

The intrinsic specific heat of the heater must be considerably lower than the specific heats of the standard and specimen under study. The heater should be representable as an infinite plate. For ease of performing experiments, it is convenient to have a resistance of 5–30 ohms.

To a certain degree, the plane heaters to be described satisfy these requirements.

Two methods for depositing a thin layer of nickel on nonmetallic plates were used in working out the technology for obtaining the heaters: a) electrodeposition on a previously silvered surface; b) electrodeposition on a surface previously coated with tin by precipitating the metal from the gas state of one of its compounds. Stannous chloride is an example of the latter.

To obtain the silver sublayer, silver nitrate was allowed to react with potassium sodium tartrate in the presence of an aqueous solution of ammonia. Before reaction, the backing was degreased in a solution of stannous chloride. The duration of the process depended on the desired thickness of the coating. Since the conductivity of the silver backing must be a minimum, the reaction time was limited to 3.5–4 min; this resulted in a thickness of about 0.1 μ.

To deposit a tin sublayer, specimens with low masses (glass plates $100 \times 2 \times 100$ mm) were placed in a muffle furnace at room temperature. The furnace temperature was then increased to 883–893° K. At this temperature, the stannous chloride was then loaded into the furnace and the furnace was cooled. Specimens with a large mass (ceramic tile $100 \times 100 \times 8$ mm) were heated to 620° K. Three to five grams of stannous chloride was placed on the working surface and heating was continued to 880° K. The specimen was then gradually cooled. It is necessary to note that the second method of obtaining a thin conducting backing is characterized by the instability of the tin deposition.

A nickel layer was then plated onto the electrically conducting sublayer of silver or tin. A solution of nickel sulfate, with other reagents added to improve coating quality, served as the electrolyte.

Anodes made of brand N-1 nickel (GOST-2132-43) were used in the electroplating. The nickel-coated surface served as the cathode. Coating uniformity was ensured by making the anode and cathode areas equal. As the current source, a VSA-5 selenium rectifier was used.

The current density was held at 60–80 A/m^2 at a voltage of 8–12 V. The plating duration was 40–45 min; this resulted in a nickel layer thickness of about 5 μ. The nickel was deposited on specimens of ceramic, marble, porcelain, and textolite.

Thus, the plane heater consists of a thin plate of nickel ($\delta = 5\ \mu$) deposited on a backing of nonconducting material with a silver sublayer ($\delta = 0.1\ \mu$). Various dielectrics can be used as backings. The choice of backing is determined by the experimenter.

The authors tested a ceramic-based plane heater (Fig. 1). This heater consists of two treated and cemented ceramic tiles $100 \times 100 \times 10$ mm. Naturally, the same heater cannot be used in all cases. However, the high thermal stability of the ceramic makes it a very suitable backing.

To increase the resistance, the nickel plate was divided into twenty equal parts by short straight cuts. The average width of a cut was 0.35 mm. The ratio of the heater thickness to its length was 1/20 000.

The heater resistance to a dc current at 293° K is 18 Ohms. The maximum temperature to which the studied material could be heated using a plane heater was 598° K. The maximum permissible current density was about 48 A per mm^2 of cross section of one section of the heater (including the silver sublayer).

The maximum voltage on the heater terminals was 50–60 V. This corresponded to a voltage difference of 2.5–3 V between neighboring sections. For terminal voltages greater than 60 V, the metal coating of the heater broke down in certain areas. The intrinsic specific heat of the heater was low. For example, a polystyrene specimen 100 × 100 × 4 mm had a specific heat 280 times greater than the specific heat of the heater.

In determining the thermophysical coefficients by the method of [1], it is necessary to know the thermal flux density. When the heater is between two solids with the same properties (such as two semibounded rods) the thermal flux density is calculated by the formula

$$q_m = \frac{W}{2F} - c_h \rho_h \frac{dT_h}{d\tau} \delta_h. \quad (1)$$

When the heater is located between two insulated semibounded rods made of differing materials (a standard and an object under study), the density of the thermal flux directed toward the specimen is given by the approximate formula

$$q_m = \frac{W}{F} - \frac{2b_1 \sqrt{\tau}}{\sqrt{\pi a_s}} - c_h \rho_h \frac{dT_h}{d\tau} \delta_h. \quad (2)$$

To solve Eqs. (1) and (2), it is necessary to know the heating rate of the heater. The value of $dT_h/d\tau$ for nickel is given experimentally for several values of q_0 (Fig. 2).

The quantity q_0 is constant for each mode. The thermal flux power was measured by a wattmeter. Experiments were performed using two polished nickel plates 100 × 100 × 2 mm placed between plane heaters.

To prevent the heater elements from short circuiting, a mica sheet of thickness δ = 0.1 mm was placed between the heater and the nickel plate. Contact between plates was ensured by polishing and application of an additional external pressure p = 11 800 N/m^2.

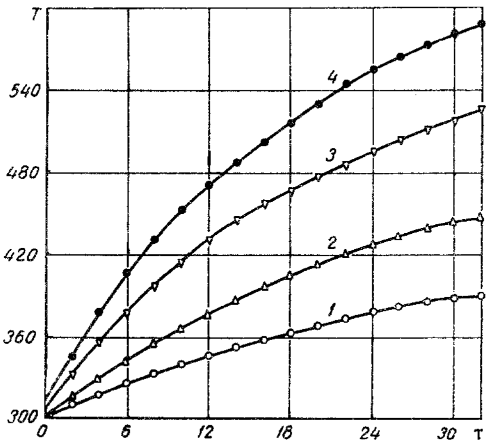

Fig. 2. Experimental graph of T (° K) as a function of τ (min) for nickel: 1) for q_0 = 3000 W/m^2; 2) 5000; 3) 7500; 4) 10 000.

The additional thermal resistance of the mica must be allowed for in formula (2), when determining the density of the thermal flux heating the material under study. As a result, the formula for q_m takes the form

$$q_m = \frac{W}{F} - \frac{2b_1 \sqrt{\tau}\, \lambda_s}{\sqrt{\pi a_s}} - \left(c_h \rho_h \frac{dT_h}{d\tau} \delta_h + c_{mi} \rho_{mi} \frac{dT_{mi}}{d\tau} \right). \quad (3)$$

The quantity $b_1 = dT_2/d\tau$ is given graphically in Fig. 2. Here it is assumed that $T_2 = T_1$, in view of the small heater thickness.

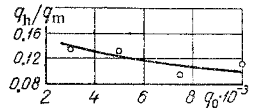

Fig. 3. Graph of q_h/q_m (%) as a function of q_0 (W/m^2) for initial period (τ = 2 min).

Since the same temperature is established at point B for the mica surface and the nickel plate, we can write, approximately,

$$\frac{dT_2}{d\tau} = \frac{dT_{mi}}{d\tau}.$$

The presence of an additional thermal resistance due to the mica causes a temperature drop between points A and B, although its relative magnitude is not too great. The actual temperature at point A can be found approximately, according to [2]:

$$T(x, \tau) - T_0 = \frac{q_m}{\lambda} \left[\frac{a\tau}{R} - \frac{R^2 - 3x^2}{6R} + R \sum_{n=1}^{n=\infty} (-1)^{n+1} \frac{2}{\mu_n^2} \cos \mu_n \frac{x}{R} \times \exp(-\mu_n^2 \mathrm{Fo}) \right]. \quad (4)$$

It was not necessary to use mica when studying nonmetallic materials. The error in determining q_m due to the additional thermal resistance of the mica is not present in this case.

Owing to the small thickness of the plane heater there is an insignificant decrease in the density of the thermal flux q_m due to the heating of the natural heating element. According to the experimental data (Fig. 2) the heating rate for the nickel plate has a maximum in the initial period. Therefore, q_h will be a maximum in this period.

Figure 3 shows q_h/q_m as a function of q_0 (for average $dT_h/d\tau$ in the first two min). The value of q_h is small in comparison with q_m even in the initial period. For subsequent time segments, q_h is even smaller. Therefore, for engineering calculations, it is quite permissible to ignore q_h.

NOTATION

q_m and q_h are, respectively, the thermal flux densities expended on heating the material under study and the heater; W is the thermal flux power of the heater; F is the area of the plane heating surface; $b_1 = dT_2/d\tau$ is the heating rate at point B; T_1 and T_2 are, respectively, the temperatures at points A and B; τ is the instantaneous time; c_h, ρ_h, δ_h, c_{mi}, ρ_{mi} are the specific heat, density, and thickness of, respectively, the heater and mica; q_0 is the over-all thermal flux density of the heater; a_s, λ_s and a_{mi}, λ_{mi} are, respectively, the thermophysical constants of the standard and mica; T_0 is the initial temperature of the heater and mica; and $dT_{mi}/d\tau$ is the mica heating rate at point A.

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