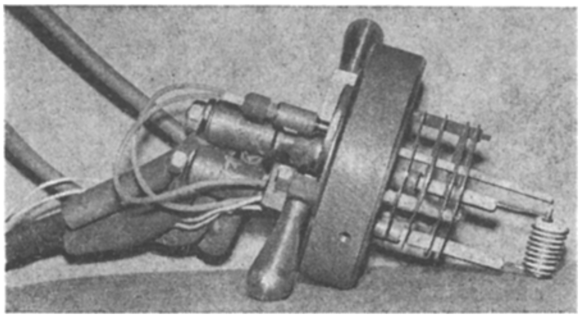

Fig. 3. Mechanism for ejecting the melt.

in the usual handbooks [7, 8] were not more than 2% for iron or 1.6% for silicon, while for nickel the measurements were essentially in agreement with the published values, which is definitely related not only to the errors of the equipments, but also to the purity of the specimens.

The enthalpies of these materials ($H_T - H_{298}$) up to 2100°K were as follows (in J/g): iron 0.686 T + 75 (±10); nickel 0.665 T − 43 (±7); and silicon 0.933 T + 1444 (±13).

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A METHOD OF MEASURING THE THERMAL CONDUCTIVITY OF POOR HEAT CONDUCTORS UNDER MONOTONIC CONDITIONS

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UDC 536.2.08

A method of measuring the thermal conductivity of poor heat conductors under monotonic conditions is described which enables one to make measurements on large specimens at different rates of heating and over a wide temperature range.

Existing calorimeters for measuring the thermal conductivity of laminar specimens under monotonic conditions are based on the use of a heat sink to collect the heat passing through the specimen. Blocks of metal with a thermal capacity C_A somewhat exceeding the thermal capacity of the specimen C_0 ($C_0/2\ C_A \leqslant 0.1$) are usually employed as heat sinks [1, 2].

To investigate specimens of low thermal conductivity ($\lambda = 0.1$–0.5 W/m·°K) such a ratio of the thermal capacities does not enable one to obtain convenient values of the measured quantities occurring in the theoretical equation. For example, for a rate of heating of about 5°K/min, the drop in temperature of specimens of thickness 5 mm reaches 100°K. A reduction

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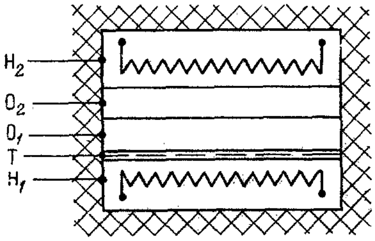

Fig. 1. Basic arrangement of the method.

in the rate of heating and in the thickness of the specimens leads to additional errors and to difficulties in carrying out the experiment.

To investigate the temperature dependence of the thermal conductivity of polymer materials we designed a calorimeter without a heat sink. The method is based on symmetrical heating of the composite plate. The basic arrangement on which the method is based is shown in Fig. 1.

The composite plate consists of two similar specimens O_1 and O_2 and is heated symmetrically from both sides with heaters H_1 and H_2. The thermal flux passing through the specimen from the heater H_1 is measured with the heat standard T. Symmetry of the heating is achieved by keeping the temperatures of the surfaces of the heat standard and the heater H_2 next to the plate equal.

The theoretical equation for the method can be obtained from an analysis of the temperature field in a two-plate system: the heat standard—specimen (Fig. 2).

A constant heat flux q_T flows into the flat heat standard. One part of this flux goes to heat the heat standard and the other (q_0) passes into the specimen. The heat flux emerging from the specimen is zero, since the specimen is in thermal contact with a similar symmetrically heated specimen.

The temperature field of the system can be found by solving the thermal-conductivity equation under quasistationary conditions:

$$a\,\frac{\partial^2 t(x,\,\tau)}{\partial x^2} = b. \tag{1}$$

The solution of this equation for the heat standard and the specimen has the form

$$\begin{aligned} t_T(x,\,\tau) &= \frac{b}{2a_T}\,x^2 + C_{1T}x + C_{2T}, \\ \frac{\partial t_T(x,\,\tau)}{\partial x} &= \frac{b}{a_T}\,x + C_{1T}, \\ t_0(x,\,\tau) &= \frac{b}{2a_0}\,x^2 + C_{10}x + C_{20}, \\ \frac{\partial t_0(x,\,\tau)}{\partial x} &= \frac{b}{a_0}\,x + C_{10}. \end{aligned} \tag{2}$$

The constants of Eqs. (2) can be found from the boundary conditions

$$q_T = -\lambda_T\,\frac{\partial t_T(0,\,\tau)}{\partial x},\quad t_T(R_T,\,\tau) = t_0(R_T,\,\tau), \tag{3}$$

$$q_0 = -\lambda_0\,\frac{\partial t_0(R_T,\,\tau)}{\partial x} = -\lambda_T\,\frac{\partial t_T(R_T,\,\tau)}{\partial x},\quad \frac{\partial t_0(R_T + R_0,\,\tau)}{\partial x} = 0. \tag{4}$$

From Eqs. (2), taking the boundary conditions into account, we find the drops in temperature across the heat standard and the specimen:

$$\theta_T = \frac{b}{2a_T}\,R_T^2 + \frac{q_0}{\lambda_T}\,R_T, \tag{5}$$

$$\theta_0 = \frac{q_0}{2\lambda_0}\,R_0 = \frac{bR_0^2}{2a_0}. \tag{6}$$

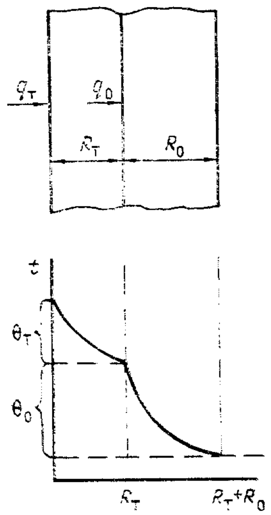

Fig. 2. Temperature distribution in the heat standard—specimen system.

From the relations obtained, taking into account the fact that $a_T = \lambda_T/c_T\rho_T$, we obtain the following relation for the thermal conductivity:

$$\lambda_0 = \frac{\lambda_T R_0}{2R_T}\cdot\frac{\theta_T}{\theta_0} - \frac{c_T\rho_T R_T}{4}\cdot\frac{bR_0}{\theta_0}. \tag{7}$$

Introducing the constant characteristics of the heat standard $k_T = \lambda_T/R_T$ and $l_T = c_T\rho_T R_T/4$, Eq. (7) can be represented in the form

$$\lambda_0 = k_T\,\frac{R_0\theta_T}{2\theta_0} - l_T\,\frac{bR_0}{\theta_0}. \tag{8}$$

It is seen from (8) that the constants k_T and l_T can be found experimentally with a calibrated calorimeter using two different standard specimens. Thus, when carrying out the calibration and when determining the thermal conductivity, the average temperature of the specimen, the drop in temperature across the specimen θ_0 and across the heat standard θ_T, and the rate of heating b are measured.

The theoretical equation and the method of measurement can be simplified if we introduce certain limitations on the conditions under which the experiment is carried out and on the construction of the calorimeter. This can be shown if Eq. (8) is converted to a more convenient form, taking into account condition (6) and using the total heat capacity of the specimen C_0 and of the heat standard C_T:

$$\lambda_0 = \frac{k_T R_0}{2}\cdot\frac{\theta_T}{\theta_0}\Bigg/\left(1+\frac{C_T}{2C_0}\right). \tag{9}$$

When $C_T \ll C_0$, the theoretical equation simplifies to

$$\lambda_0 = \frac{k_T R_0}{2}\cdot\frac{\theta_T}{\theta_0}. \tag{10}$$

In this case the constant k_T can be found with a single standard specimen and there is no need to measure the rate of heating.

This method can be employed when the heat capacity of the heat standard has a finite value. However, this is only possible if the heat capacity of the specimen being investigated and of the standard specimen are close to one another. In this case the quantity $k_T/(1 + C_T/2C_0)$ in Eq. (9) is approximately the same for the specimens compared and can be taken as the effective constant of the heat standard:

$$k_T' = \frac{k_T}{1 + C_T/2C_0}. \tag{11}$$

For example, when $C_T = C_0/2$ the disagreement between the values of k'_T for specimens whose heat capacities differ by 50% according to (11) is about 8%, and for $C_T = C_0/5$ it is 3.5%, etc.

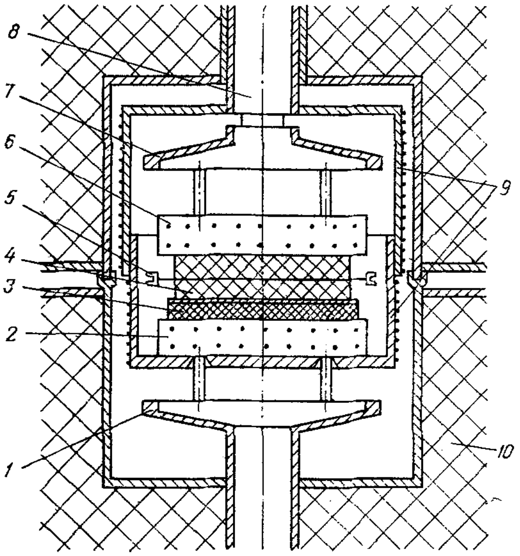

Fig. 3. Scheme of the calorimeter.

The method was investigated on a model whose schematic form is shown in Fig. 3. The main heater unit 2 is attached to the lower support disk 1; the heater consists of an asbestos cement packing, covered with a metal plate. The heater is wound in a helix under the plate. The heat standard 3 is attached to the main heater to measure the heat flux from the main heater to the specimen 4. The heat standard is made of 2-mm-thick mica and covered with a metal plate attached to the main heater unit. The temperature drop across the heat standard is measured with a differential thermoelectric battery.

Two similar specimens 4 are placed on the heat standard. A "heat cross" 5 is placed between them; this consists of two thermocouples connected crosswise. One of them is used to measure the temperature of the specimen and the other, connected differentially with the thermocouple placed under the upper plate of the heat standard, is used to measure the temperature drop in the specimen. Above the upper specimen there is the symmetrical heating unit 6, the temperature of which is maintained equal to the temperature of the heat standard using the differential thermocouple, placed on the heater and heat standard plates next to the specimen. The unit is attached to the upper support disk 7 which is connected to a movable rod 8. By means of a load placed above the rod the specimens are clamped to the heat standard and heater.

The main heater, the heat standard, the specimens, and the upper heater are surrounded by a guard cylinder 9, whose temperature is maintained close to the temperature of the specimens by means of a differential thermocouple placed between the plate of the heat standard and the external surface of the guard cylinder. The whole thermal unit is placed in a heat insulator 10 consisting of two separable halves. When the specimens are replaced the upper half, together with the symmetrical heating unit, is raised and opens to give access to the specimens.

To maintain the required heating conditions the calorimeter contains a unit for setting the thermal conditions by means of which the necessary rate of heating is established and the temperatures of the symmetrical heater and the heater of the guard cylinder are controlled. We used an automatic potentiometer with a preamplifier and a unit for switching the measured signals as the measuring instrument. The instrument enables one to simultaneously record the temperature of the specimen and the temperature drops in the specimen and the heat standard.

The calorimeter was investigated using specimens of polymethylmethacrylate and polytetrafluorethylene at heating rates from 1°K/min to 3°K/min. The specimens were in the form of cylindrical disks of diameter 35 mm and thickness 5 mm. From tests with both specimens we found the temperature dependence of k_T of the heat standard from Eq. (10) using known values of the thermal conductivity [3, 4]. The disagreement between the values obtained using the different specimens was not greater than 4%. This agrees with the theoretical value of the error obtained from (11), since the difference in the heat capacities of the specimens in these measurements was about 25%, while the ratio of the heat capacities of the specimen and the heat standard was 2:5.

The mean-square spread in the results obtained on the same specimens in different experiments was 2%, despite the fact that the surface of the specimens was not given any special processing. This slight effect of the contact thermal resistances is due to the fairly large thickness of the specimens and the absence of a thermal flux at the center of the composite place where the junction of the differential thermocouple measuring the temperature drop in the specimen is placed.

Using this calorimeter we measured the thermal conductivities of different polymer materials at temperatures from −100 to 300°C.

NOTATION

λ_0, λ_T, a_0, a_T, thermal conductivities and thermal diffusivities of the specimen and heat standard, respectively; q_0, q_T, heat fluxes applied to the specimen and the heat standard; b, rate of heating; R_0, R_T, thicknesses of the specimen and the heat standard; k_T, l_T, constants of the heat standard; C_T, ρ_T, specific heat capacity and density of the heat standard; C_0, C_T, total heat capacities of the specimen and the heat standard; θ_0, θ_T, temperature drops in the specimen and the heat standard; t, temperature.

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EXPERIMENTAL INVESTIGATION OF THE TEMPERATURE DEPENDENCE OF THE ACCOMMODATION COEFFICIENTS FOR THE GASES He, Ne, Ar, AND Xe ON A Pt SURFACE

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This paper presents measurements of accommodation coefficients for the gases He, Ne, Ar, and Xe on a Pt surface in the temperature range 100-500°K. An improved unsteady hot-wire method at low pressure is used.

The experience of thermophysical investigations in gases has pointed out the need to study phenomena occurring at the gas−solid interface and adjacent to it. An important factor in the study of these phenomena is knowledge of the energy accommodation coefficients for gas molecules on the surface of solids, particularly on the surface of metals. The accommodation coefficient describes the degree of energy exchange of the gas molecules and the solid surface and is given by the expression [1]

$$\alpha_E = \frac{E_i - E_r}{E_i - E_w}, \tag{1}$$

where E_i is the energy arriving with the incident molecules; E_r is the energy carried away by reflected molecules; and E_w is the energy which would be carried away by reflected molecules if they acquired the surface temperature.

Expression (1) is valid only when the incident molecule temperature differs very little from the surface temperature.

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