AUTOMATED SYSTEM FOR SCIENTIFIC INVESTIGATIONS
OF THERMOPHYSICAL PROPERTIES OF DISPERSED MATERIALS

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Theoretical and experimental research into industrial procedures for processing or making products in the form of dispersed materials is closely related with the problem of studying how thermophysical material properties change in the course of chemical, physical, microbiological and other transformations. In developing and utilizing methods and means for measuring these properties, the problems of automating the measuring operations and processing experimental data are important. These can be solved most completely by designing a specialized automated system for scientific investigations of thermophysical properties.

At TIKhMe, such a system was designed for measuring 1) the thermal conductivity, the heat-transfer coefficient, and the volume heat capacity of monolithic and bulk dispersed materials; 2) a set of potential-dependent characteristics of heat and moisture transfer in bulk materials (the diffusion coefficient, the relative coefficient of thermal diffusion, and the degree of phase transition); and 3) the determination of the shear-rate dependence of the thermal conductivity and the heat-transfer coefficient of paste and liquid dispersed materials.

The system includes a personal computer; a connection unit of a personal computer with measuring devices of the CAMAC standard; measuring devices designed for experimental determination of the thermal conductivity, the heat transfer coefficient, the volumetric heat capacity, the diffusion coefficient, and other properties of dispersed materials; and also auxiliary devices (power supplies, thermostats, pumps, etc.).

Depending on the user's requirements, the system can be used in conjunction with various measurement devices.

The first type of measurement device was designed to measure the thermal conductivity, the heat transfer coefficient, and the volumetric heat capacity of monolithic, bulk, paste, and liquid materials. The mathematical model of this device has the following form:

$$\frac{\partial T(x, \tau)}{\partial \tau} = \frac{\partial^2 T(x, \tau)}{\partial x^2}; \quad a = \frac{1}{\rho c_p}; \quad \tau > 0, \quad 0 < l_1 < l_2 < x < l_3;$$

$$\lambda = \begin{cases} \lambda_s & \text{for } 0 < x < l_2, \\ \lambda_s & \text{for } l_2 < x < l_3; \end{cases} \quad a = \begin{cases} \alpha_s & \text{for } 0 < x < l_2, \\ \alpha_s & \text{for } l_2 < x < l_3; \end{cases}$$

$$c_p = \begin{cases} \rho c_p & \text{for } 0 < x < l_1, \\ \rho c_p & \text{for } l_1 < x < l_3; \end{cases}$$

$$T(x, 0) = 0, \quad T(0, \tau) = 0, \quad T(l_1 - 0, \tau) = T(l_1 + 0, \tau);$$

$$\frac{\partial T(l_1 - 0, \tau)}{\partial x} = \frac{\partial T(l_1 + 0, \tau)}{\partial x} = q(\tau);$$

$$T(l_2 - 0, \tau) = T(l_2 + 0, \tau); \quad \lambda_s \frac{\partial T(l_2 - 0, \tau)}{\partial x} = \lambda_s \frac{\partial T(l_2 + 0, \tau)}{\partial x}; \quad T(l_3, \tau) = 0,$$

where $T(x, \tau)$ is the material temperature at coordinate $x$ at time $\tau$; $\lambda$ is the thermal conductivity; $a$ is the heat transfer coefficient; $c_p$ is the volumetric heat capacity; $q$ is the...
specific power of the heat source; the subscript "s" refers to a standard material; and the subscript "x" refers to the material being investigated.

Solution of (i) with the use of the Laplace transform

\[ T^*(x, p) = \int_0^\infty e^{-pt} T(x, \tau) d\tau; \quad q^*(\rho) = \int_0^\infty e^{-\rho \tau} q(\tau) d\tau \]

yields functions \([1, 2]\) for determining \(\lambda_T, \alpha_T, \) and \(c_T\rho_T\) from experimental information on the specific power \(q\) of the heat source and the temperature \(T(\ell_1, \tau)\) in the plane where the heat source is mounted (here \(p\) is the Laplace transform variable).

The device is made in the form of two plane heat exchangers, through which a working fluid flows from a thermostat. The primary measurement transducer is made in the form of an electric heater and a resistance thermometer, placed in a single plane on the base of a standard material, which is fastened to the top of the heat exchanger. In order to assure direct contact of the investigated material with the electric heater and the resistance thermometer, the thermometer is covered by a thin sleeve of the same material as the base. The investigated dispersed material (monolithic, bulk, paste, or liquid) is placed in an open cuvette, which is mounted in the lower heat exchanger. The primary measurement transducer is placed in the cuvette with the investigated material. After a steady-state thermal regime is attained, a constant electrical power is fed to the heater and the temperature change of the heater is recorded over time. The experimental data is processed to determine the values of the desired thermophysical properties.

A second type of measuring device is designed for experimental determination of a set of potential-dependent characteristics of heat and moisture transfer: the diffusion coefficient \(a_m\), the relative thermal diffusion coefficient \(\delta\), and the degree of phase transformation \(\varepsilon\). The mathematical model of this device is written for a semifinite sample in the following form:

\[
\frac{\partial T}{\partial \tau} = \frac{1}{\alpha} \frac{\partial}{\partial x} \left( \lambda \frac{\partial T}{\partial x} \right) + \varepsilon \frac{\partial U}{\partial \tau}, \quad \tau > 0, \quad x > 0; \\
\frac{\partial U}{\partial \tau} = \frac{1}{\alpha} \frac{\partial}{\partial x} \left( a_m \frac{\partial U}{\partial x} \right) + \frac{\partial}{\partial x} \left( a_m \frac{\partial T}{\partial x} \right), \quad \tau > 0, \quad x > 0; \\
T(x, 0) = T_0, \quad U(x, 0) = U_0, \quad T_0, U_0 \text{ --- const}; \\
T(0, \tau) = T_c, \quad U(0, \tau) = U_c, \quad T_c, U_c \text{ --- const}; \\
\frac{\partial T(\infty, \tau)}{\partial x} = \frac{\partial U(\infty, \tau)}{\partial x} = 0,
\]

where \(U(x, \tau)\) is the moisture content of the investigated bulk material at coordinate \(x\) and time \(\tau\) and \(r_m\) is the heat of vaporization.

Here \(r_m = \text{const}\), \(c = c(T, U)\), and \(\lambda = \lambda(T, U)\) are known; and \(a_m = a_m(T, U)\), \(\delta = \delta(T, U)\), and \(\varepsilon = \varepsilon(T, U)\) are to be determined.

By using the Boltzmann substitution \(\xi = x/2\sqrt{\tau}\), the model (2) is reduced to a system of differential equations, whose solution yields [1] functional relationships for calculating the desired quantities \(a_m\), \(\delta\), and \(\varepsilon\). The design and operational principles of this measurement device have been described [1].

In a series of cases, the initial raw materials for making granulated products are paste or liquid. Therefore, the measurement system includes devices for measuring the thermophysical properties of pastes and liquids. These devices are of interest because in the past decades theoretical and experimental investigations have been done on the effects of heat-transfer anisotropy during plastic flow of materials.

A third type of device is designed for measuring the heat transfer coefficient \(a_x\), the thermal conductivity \(\lambda_x\), the volumetric heat capacity \(c_x\rho_x\), and the parameter \(\mu_x/\lambda_x\) for plastic flow of a dispersed paste, which is placed in the gap between two coaxial cylinders. A heater and a resistance thermometer are placed in the inner cylinder. Measurements are conducted both for constant power to the heater and for no heat loss. In this case the heat comes from dissipating the mechanical energy from rotating the outer cylinder, due to the viscous friction of the dispersed paste in the narrow gap between the cylinders. The mathematical modeling of the temperature field \(T(r, \tau)\) of the material in the gap has the following form: