OPTIMIZATION OF THERMOPHYSICAL PROPERTIES OF INSULATION MATERIALS MEASURING BY THE METHOD OF IMPULSE FLAT HEAT SOURCE

S.V. Ponomarev, E.V. Bulanov, V.O. Bulanova, A.G. Divin

Abstract: Using the developed mathematical models of errors in measuring thermal conductivity and the coefficient of thermal diffusivity of heat-insulating materials, a method for choosing the following optimal parameters was proposed: 1) the value of the duration of the heat pulse; 2) the main structural dimension of the measuring device; and 3) the conditions for implementing the algorithm for experimental data processing.

Key words: heat conductivity, thermal diffusivity, measurement, error minimization, optimal conditions for experimental data processing, the rational value of the structural size, duration of the thermal pulse.

Introduction

The need for information on thermophysical properties (TPP) of thermally insulating materials arises during the design of new technological processes, during product quality control in real-time operating production processes, as well as in mathematical modeling and in solving problems of optimizing modernized industries [1-6]. The main approach to obtain knowledge about TPP of new substances and materials is the experimental measurement [7].

Relations for calculating estimates of root-mean-square relative errors in TPP measurements

A mathematical model of the temperature field $[T(x,\tau) - T_0]$ is formulated in a flat semi-infinite sample, to which a constant heat flux $q_c = const$ is applied in the plane $x=0$ for a time interval $0 \le \tau \le \tau_u$. Based on this model, taking into account the introduced dimensionless parameter

$$\gamma = (T(x,\tau) - T_0)/(T_{max} - T_0), \qquad (1)$$

the following ratios are obtained for calculating the measured (desired) values of the thermal diffusivity

$$a = x^2/(4\,\tau(U(\tau'))^2), \qquad (2)$$

and the heat conductivity

$$\lambda = [(q_c x)/(T(x,\tau(\gamma)) - T_0)]F(\gamma), \qquad (3)$$

where x, τ - the spatial coordinate of the sample and the time; T_0 - the initial temperature of the material (at time $\tau = 0$), taken as the origin of the temperature scale in each experiment, that is, $T_0 = 0$;

$$U(\tau') = x/(2(a\tau')^{1/2})$$

$$F(\gamma) = \Phi[U(\tau'), \tau_u, \tau'] = ierfc[U(\tau')]/U(\tau') - -ierfc[U(\tau')(\tau'/(\tau' - \tau_u))^{1/2}]/[U(\tau')(\tau'/(\tau' - \tau_u))^{1/2}],$$

- the values of analytical functions at the time $\tau' = \tau'(\gamma)$, depending on the dimensionless parameter γ(1), which is the ratio of the current value of the temperature difference $[T(x,\tau) - T_0]$ at the time τ to the maximum value $T_{max} - T_0$ of this difference at the time τ_{max}; τ_u – is the duration of the thermal pulse.

In accordance with the recommendations of the theory of errors of physical quantities measurement and based on the dependencies (2) and (3), the relations for the calculation of estimates of root-mean-square relative errors for the measurement of the thermal diffusivity has been obtained as follows

$$(\delta a)_{ск} = (4(\delta a)^2 + [\Delta T/(\tau'\{d[T(x,\tau) - T_0]/d\tau'\})]^2 + [(1/U')(dU'/d\gamma)(\gamma+1)^{1/2}\,\delta(T_{max} - T_0)]^2)^{1/2} \qquad (4)$$

and for the thermal conductivity

$$(\delta\lambda)ск = [(\delta qc)^2 + (\delta x)^2 + \{[1/F(\gamma)][\partial F(\gamma)/\partial\gamma][1+\gamma^2]^{1/2}\,\delta(T_{max} - T_0)\}^2 + (\Delta T/(T(x,\tau) - T_0))^2]^{1/2} \qquad (5)$$

The following symbols are used in the ratios (4) and (5):

$\delta x = \Delta x/x$, $\delta\tau' = \Delta\tau'/\tau'$, $\delta U(\tau') = \Delta U(\tau')/U(\tau')$ – the relative errors for determining the corresponding physical quantities x, τ, $U(\tau')$; ΔT – the absolute error in measuring the temperature differences; $\delta(T_{max} - T_0)$- the relative error in measuring the maximum value of the temperature differences $(T_{max} - T_0)$.

Results

Using ratios (4) and (5), the following findings have been obtained.

1. To minimize errors $(\delta a)_{ск}$ during the thermal diffusivity a measurement, the experimental data processing should be carried out at the values of dimensionless parameters in the range $0{,}45 < \gamma \le 0{,}47$, and the values of the main structural size of the measuring device should be chosen within a range of $4{,}0\ mm < x \le 4{,}5\ mm$.

2. The minimum values of root-mean-square relative errors $(\delta\lambda)_{ск}$ of the heat conductivity measurement λ occur at $0{,}95 < \gamma \le 1{,}0$ and

4,0 *mm*<*x*≤4,5 *mm*

3. The smallest sum of root-mean-square relative errors $[(\delta\lambda)_{ск} + (\delta\lambda)_{ск}]$ is achieved when the duration of the thermal pulse lies within $19 < \tau < 23$ seconds.

The use of the proposed approach for the selection of the optimal dimensionless parameter value γ, the rational structural size x of the middle plate of the sample material and the duration of the thermal pulse τ_u – reduces the measurement error of the thermal diffusivity a and heat conductivity λ from 12…14% to 5…7 %.

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Acknowledgments

The results of the study were obtained with the financial support of the Ministry of Education and Science of the Russian Federation (the unique identifier of the project RFMEFI57716X0214).

Information about the Authors:

Sergey Vasilievich Ponomarev. Tambov Institute of Chemical Engineering (1972). D.Sc. (1995), Professor (1996). Scientific interests: thermophysical measurements, quality control and management. Workplace - Tambov State Technical University, Institute of Automation and Information Technology, Department of Mechatronics and Technological Measurements. 392000 Russia, Tambov, Sovietskaya St., 106.

Web: *www.tstu.ru , e-mail: svponom@yahoo.com*

Evgeny Vladimirovich Bulanov. Tambov State Technical University (2011). Scientific interests: heat-insulating materials Workplace - postgraduate student, Tambov State Technical University, Institute of Automation and Information Technology, Department of Mechatronics and Technological Measurements. 392000 Russia, Tambov, Sovietskaya St., 106.

Web: *www.tstu.ru, e-mail: evgenbull@gmail.com*

Valentina Olegovna Bulanova. Tambov State Technical University (2012). Scientific interests: heat-insulating materials Workplace:. postgraduate student, Tambov State Technical University, Institute of Automation and Information Technology, Department of Mechatronics and Technological Measurements. 392000 Russia, Tambov, Sovietskaya St., 106. Web: *www.tstu.ru, e-mail: valyabulanova@gmail.com*

Aleksandr Georgievich Divin. Tambov Institute of Chemical Engineering (1985), Doctor of Technical Sciences (2011), Associate Professor (2000). Scientific interests: automation of thermal control. Workplace - Tambov State Technical University, Institute of Automation and Information Technology, Department of Mechatronics and Technological Measurements. 392000 Russia, Tambov, Sovietskaya St., 106.

Web: *www.tstu.ru, e-mail: agdv@yandex.ru*