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METHOD OF ANALYZING AND GENERALIZING EXPERIMENTAL DATA ON THE FREE MOTION OF TOLUENE

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An equation describing the heat transfer in the free motion of toluene about a horizontal tube and at supercritical pressures is proposed.

The results of analyses of experimental data by various authors show that the laws of convective heat transfer in free convection at supercritical pressures of the heat carrier differ from the laws of heat transfer in the subcritical region of states of the material. In a series of works, the influence of individual factors on the heat-transfer coefficient has been noted [1, 2]. Therefore, generalization of experimental data at supercritical pressures of different heat carriers by means of a single critical equation with free convection is very difficult. The basic difficulties are associated with taking account of the influence of change in physical properties of the given fluid on the heat-transfer coefficient. The means of taking account of this phenomenon adopted by individual researchers have been different. Many have taken the well-known relations obtained for the Nusselt number (Nu_0) and added corrections that take account of the variability of the physical properties.

At present, there exist a series of critical relations for calculating the heat-transfer coefficient with free convection at supercritical pressures. One was proposed in [3] on the basis of the results of investigating the heat transfer of carbon dioxide with free convection in horizontal tubes, in the form

$$Nu = 0.152\, Ra^{1/3} (Pr_c/Pr_f)^{0.25}. \quad (1)$$

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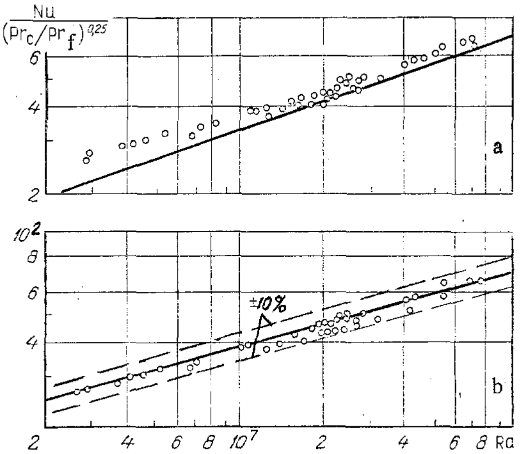

Fig. 1. Curves of the dependence $Nu/(Pr_c/Pr_f)^{0.25} = f(Ra)$: a) calculated according to [3]; b) from Eq. (2).

This equation describes the heat transfer with an error of ±20%. The Nusselt and Rayleigh numbers were determined from the following expressions: $Nu = \alpha d/\lambda$ and $Ra = g\rho(\rho_f - \rho_c)d^3 Pr/\mu^2$. In determining λ, ρ, μ, Pr, the mean temperature of the moving layer was adopted, i.e., $t = (t_c + t_f)/2$.

In [3], it was noted that Eq. (1) is valid for $Ra = 10^7$-10^{10} and for $Pr_c/Pr_f = 0.5$-3.0. The experimental data of [1, 2], obtained for Rayleigh numbers in the range 10^6 to 10^8, may be compared with the given dependence. From the results of the calculations, curves of the dependence $Nu/(Pr_c/Pr_f)^{0.25} = f(Ra)$ have been plotted in logarithmic coordinates (Fig. 1a). It is evident from Fig. 1a that, with decrease in the Rayleigh number from 10^7, the error increases and reaches 20% and above. When $Ra > 10^7$, the maximum error is 13%. In this treatment, the basic mass of experimental points from [1, 2] lie above the calculated curve in the whole range of Rayleigh numbers. This is mainly associated with the choice of the constants (c and n) appearing in Eq. (1). It is known from the classical literature that, with free motion of the fluid at subcritical pressures around horizontal tubes and at $10^3 < Gr_{f,d}Pr_f < 10^8$, c = 0.50 and n = 0.25 [4]. Since the experimental data of [1, 2] were obtained at $10^6 < Ra < 10^8$, they were generalized by the criterial relation

$$Nu = 0.50\, Ra^{0.267} (Pr_c/Pr_f)^{0.25}, \tag{2}$$

in which the physical parameters were chosen in accordance with the determining temperature, analogously to [3]. The results of calculations by Eq. (2) are also shown in the logarithmic coordinates $Nu/(Pr_c/Pr_f)^{0.25} = f(Ra)$ (Fig. 1b). It is evident from Fig. 1b that, when $Ra < 1.2 \cdot 10^7$, the experimental points lie on the calculated curve with a maximum error of ±2.5%, while when $Ra > 1.2 \cdot 10^7$ the spread of the experimental points reaches ±10%. This equation for toluene according to the data of [1, 2] has been verified in the wall temperature range from room temperature to 723°K.

Thus, on the basis of the Beschastnov–Petrov equation, criterial Eq. (2) has been proposed, and may be recommended for calculating the heat transfer in the range $Ra < 10^8$.

NOTATION

Nu, Ra, Pr, Gr, Nusselt, Rayleigh, Prandtl, and Grashof numbers; α, heat-transfer coefficient, $W/m^2 \cdot °C$; λ, thermal conductivity, $W/m \cdot °C$; ρ, density, kg/m^3; μ, dynamic viscosity, $N/m \cdot sec$; d, tube diameter, m.

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DETERMINATION OF THE TEMPERATURE-DEPENDENT VARIATION OF THE THERMAL CONDUCTIVITY OF A COMPOSITE MATERIAL FROM THE DATA OF A NONSTATIONARY EXPERIMENT

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We consider the construction of an iteration algorithm for reconstructing the temperature-dependent variation of the thermal conductivity in the generalized energy equation from the data of temperature measurements at one or more points in the interior of the body.

In investigating the thermophysical characteristics of composite materials, it often becomes necessary to use new methods for the analysis and processing of experimental data. These methods must provide a possibility of processing the results of a nonstationary thermal experiment and obtaining the maximum amount of reliable information concerning the material under study when the accuracy characteristics of the measurement systems are limited [1].

The intensive development of the theory and the expansion of the fields of practical application of methods for the solution of inverse problems in heat exchange have led to their widespread use in thermophysical investigations.

A particularly timely use of the inverse-problem apparatus is its application to the investigation of the thermophysical characteristics of high-temperature composite materials under nonstationary conditions. Such an approach enables us to eliminate the problem of simulating the structure of the material and the character of the internal processes under nonstationary thermal influences. Furthermore, in this case there is a possibility of considering the problem of thermophysical investigations as a complex problem in the simultaneous determination of many interrelated characteristics.

Inverse problems usually belong to the class of ill-posed problems of mathematical physics [2]. In solving boundary-value and coefficient-type inverse problems in heat conduction, iterative methods have been found to be very effective [3-5].

The basic purpose of the present study is to investigate the possibilities of constructing iteration algorithms of the gradient type for reconstructing the thermophysical characteristics of a composite material from the solution of a coefficient-type inverse problem for the nonlinear generalized heat-conduction equation. We analyze a mathematical model which takes account of the processes of thermal decomposition and filtration [1].

We shall consider the following problem. For a given mathematical model of the process of heat and mass exchange during the intense heating of a composite heat-shielding material and known boundary conditions, it is required to reconstruct the temperature-dependent variation of the thermal conductivity $\lambda(T)$ and the temperature field $T(x, \tau)$ from the data of temperature measurements at one or more interior points of the body under investigation. The mathematical model of the process being investigated has the following form:

$$c(T)\frac{\partial T}{\partial \tau} = \frac{\partial}{\partial x}\left(\lambda(T)\frac{\partial T}{\partial x}\right) - m_g\frac{\partial h_g(T)}{\partial T}\frac{\partial T}{\partial x} - \frac{\partial m_g}{\partial x}h_g(T),$$

$$0 < x < b,\ 0 < \tau \leqslant \tau_m, \tag{1}$$

$$T(0,\ \tau) = f_1(\tau), \tag{2}$$

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