MEASUREMENT OF THE PARAMETERS OF EXTERNAL HEAT TRANSFER BY DILATOMETRY

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UDC 536.2.023

The results of a study of the effective heat-transfer coefficient during the turbulent flow of gas streams over a surface in the region of elevated and high temperatures are described.

The study of the temperature fields of a surface and of a stream interacting with it is an obligatory and very laborious procedure for studying the parameters of external heat transfer in the region of elevated and high temperatures during steady heat exchange between solid surfaces and gas streams (both under conditions of subsonic and supersonic flow over the surface) [1].

The specifics of the thermal interaction of a stream and a surface with cylindrical symmetry of the aerodynamic characteristics and, in particular, heat transfer to pipes of circular cross section must be considered with complete justification as the most common conditions of heat exchange in practice. The total power Q of heat exchange between a stream and the lateral surface of a cylinder of length l and radius R, pertaining to convective heat transfer, depends on the concrete temperature distribution T(x) along the length of the pipe and the effective heat-transfer coefficient α in accordance with the well-known Newtonian law [2]

$$Q = 2\pi R\alpha \int_0^l [T(x) - T_1]\,dx, \tag{1}$$

where T_1 is the average-integral stream temperature (which can also be a constant, depending on the circumstances [3]).

Despite the fact that the factors of radiant heat exchange begin to play an ever more important role with an increase in the surface temperature, the determination of the parameter α can be accomplished in this case by resorting to the new dilatometric method [4], which provides for conducting the experiment so that all the parameters of the thermal interaction of the body with the surrounding medium except for the factor of convective heat exchange can be eliminated from the results of the measurements.

The main theoretical premise of the use of dilatometry to study the properties of convective heat exchange under steady-state conditions is the fact that the absolute increment Δl in the length of a body of cylindrical shape and constant cross section with an initial longitudinal dimension l is proportional to the increment in the average-integral temperature and the coefficient of thermal expansion β of the material of the specimen when the temperature field is axisymmetric [4]:

$$\Delta l = \beta \int_0^l [T(x) - T_1]\,dx. \tag{2}$$

Under conditions when the standard specimen, made from a metal with known properties, is heated to an equilibrium state through the direct transmission of a known electric power (the strength I_1 of the heating current and the voltage drop U_1 over the specimen were re-

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All-Union Scientific-Research Institute of Bioengineering, Moscow. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 33, No. 1, pp. 116-119, July, 1977. Original article submitted June 17, 1976.

corded) in the absence of the stream being studied, the energy balance between the specimen and the surrounding medium corresponds to a certain value of the average-integral temperature [2]

$$c_V \frac{d}{dt}\left[\int_0^l (T(x) - T_1)\,dx\right] = I_1U_1 - q = 0, \tag{3}$$

where q is the total power of the heat losses of all types, both contact (such as from the ends of the cylinder) and noncontact (particularly thermal radiative losses); c_V is the heat capacity per unit volume.

If, having recorded the equilibrium value of the elongation Δl, one now places the specimen in thermal contact with the test gas stream, which has a temperature equal to the initial (constant) temperature T_1 of the specimen, then the intensification of the heat losses owing to convective heat transfer from the lateral surface changes (toward a decrease in the given case) both the equilibrium value of the average-integral temperature and the absolute elongation of the specimen corresponding to it. However, if in the presence of the test stream one increases the power of the equilibrium electric heating to the values of the current strength I_2 and voltage drop U_2 at which the elongation Δl takes the original value (2), then this means that the newly obtained value of the average-integral temperature coincides with that which occurred in the absence of the test gas stream. Two important consequences emerge from this fact:

1) The concrete values of all the physical properties of the specimen (primarily the coefficient of thermal expansion, the electrical resistance, and the integral emissivity) which are determined only by the average-integral temperature are the same in the two cases;

2) the requirement that the property (2) be satisfied means that, despite the difference in the functions T(x) in the two cases, the flux q of heat losses is the same in each of them; in other words, the equality

$$I_2U_2 = q + Q \tag{4}$$

is valid, illustrating the fact that the sole cause producing an increase in the equilibrium power of electrical heating upon the addition of the factor of convective heat exchange to the external conditions (and the simultaneous maintenance of the value of the average-integral temperature) can only be heat transfer to the test gas stream.

From Eqs. (1)-(4) we get the equation for the calculation of α:

$$\alpha = \beta\,\frac{I_2U_2 - I_1U_1}{2\pi R\Delta l}\,. \tag{5}$$

An indisputable advantage of Eq. (5) consists of the fact that the procedure for measuring all its component quantities is not only free from a determination of the temperature field and heat fluxes at the surface of the specimen but also allows one to isolate the factor of convective heat losses without any appreciable complication of the experimental embodiment of the dilatometric method used earlier [6].

Under the experimental conditions the specimen temperature can reach very considerable values (above 800-1000°C), and therefore it is desirable to keep the ends of the cylinder at room temperature so as not to take special measures for the thermal insulation of the dilatometer units. The most successful version of the practical realization of the method described proved to be the study of gaseous coolants interacting with surfaces heated to high temperatures. The test medium was air flowing with velocities of 100-550 m/sec through a stainless steel nozzle 25 mm in diameter and 200 mm long. A cylindrical molybdenum rod 1 mm in diameter and 50 mm long, heated from an alternating-current generator with a power of 32 kW, was chosen as the standard (dilatometric) body. The current strength and voltage drop (recording the power with a wattmeter) were measured with an accuracy of 1.5%, while the absolute elongation of the rod was recorded on a lever—optical dilatometer with a relative error of not over 0.5%. Special slots were provided for the ends of the standard specimen to emerge from the nozzle, and the ends were cooled with oil [6].

The measurement data revealed a tendency of the coefficient α to grow with an increase in the (average) velocity of the air stream with longitudinal flow over the cylindrical surface in accordance with the law $\alpha \sim \sqrt{v}$ (Table 1).

TABLE 1. Dependence of Heat-Transfer Coefficient α [kcal/(m$^2\cdot$h$\cdot$deg)] on Flow Velocity v (m/sec)

v	100	150	200	240	290	330	360	400	550
α	350	430	490	560	590	630	680	710	820

The data obtained agree well with the empirical dependence $\alpha \sim v^{0.6}$ found earlier [7].

NOTATION

α, heat-transfer coefficient; c_V, heat capacity per unit volume of specimen material; β, coefficient of thermal expansion; t, time; l, length of cylindrical specimen; R, radius of cylinder; q, total power of heat losses; T(x), temperature field along specimen; I, current strength; U, voltage drop over specimen; Δl, limiting absolute elongation of specimen.

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COMPRESSION MECHANISM FOR TWO-COMPONENT LOOSE MEDIA MODELED BY SPHERICAL PARTICLES

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UDC 531.731

The packing density coefficient of two-component granular media, modeled by steel spheres, is investigated for a change in the fractional and concentration compositions of the mixture in a broad range of ratios between the diameters of the particles being mixed.

The mixing of bodies differing sharply in size results in a perceptible rise in the packing density coefficient (K) of a loose mass. In fact, the minimal porosity ($\Pi = 1 - K$) of large volumes filled by irregular compacted identical spherical particles is independent of the particle size and equals $\Pi_0 \approx 0.36$ [1]. The minimum porosity of a binary loose mixture with sharply differing component sizes is achieved by filling all the pores between the large spheres with fine fractions. Hence, the latter occupy 64% of the total volume

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