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EXPERIMENTAL INVESTIGATION OF AIR COOLING OF A CONDUCTIVE CALORIMETER

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The spatial inhomogeneity of thermal fluxes on the surface of the heat-dissipation unit of a KTS-2 calorimeter and a system consisting of an additional thermistor and stepped turbulizers for equalization and intensification of the heat transfer are investigated experimentally.

The KTS-2 conductive calorimeter [1], designed for measurement of the heat of combustion of fuel, is convenient in operation, is automated, and, as opposed to conventional water calorimeters, does not require the use of distilled water as the working body or flowing water for cooling and does not require a special room with a stable microclimate. In the KTS-2 calorimeter (Fig. 1a) combustion of the fuel sample takes place in a calorimetric bomb 1, and the heat liberated is transferred via a thermometric shell 2 to a massive cylindrical heat-dissipating unit 3 whose surface is thermostated at a temperature of +40 °C using controlled electric heating. Excess heat is removed by forced air cooling. An air flow with a velocity of 3–3.5 m/sec is generated in a concentric channel between the surface of the heat-dissipation unit 3 and the casing 4 using a built-in blower 5.

High heat-liberation energies (20–40 kJ) are characteristic of bomb calorimeters designed for measuring the heat of combustion of a fuel, and the instability of maintaining the temperature of the device casing should not exceed 10^{-2}–10^{-3} K [1]. Therefore, massive heat-dissipation units with a high heat capacity, protective heat shields, and water cooling are used, as a rule, in devices of this type. Air cooling used in the KTS-2 improves the operating parameters of the device; however, its metrological parameters (measurement error and range) depend on the intensity and spatial inhomogeneity of the heat transfer.

A thermal boundary layer is formed at the surface of the heat-dissipation unit, which results in substantial spatial inhomogeneity of the local coefficient of convective heat transfer [2]. The inhomogeneity of the temperature field induces a shift in the calorimeter "base line" as a result of distorting thermal fluxes through the calorimetric cell and can lead to the appearance of small oscillations in the thermostatic-coontrol system, which degrades the metrological parameters of the device.

A theoretical analysis of the spatial distribution of local values of the convective heat transfer coefficient for the case under consideration is substantially hindered due to the external-turbulization effect and twisting of the air flow by the blower and certain construction elements of the calorimeter body. The most reliable information on the character of the thermal-field inhomogeneity is provided by direct measurement of local heat-flux densities. The experiment is carried out using a set of eight flexible thermoelectric auxiliary-wall-type heat-flux transducers (HFTs) with close metrological parameters. Each HFT is a galvanically produced bimetallic thermobattery [3] with a 40 × 40 mm thermally sensitive zone, a thickness of 1 mm, and a thermal resistance of up to 0.001 $m^2 \cdot K/W$. The metrological characteristics of the HFTs were determined on a graduated radiation facility with an error not exceeding ±3%. The residual flexibility of the relatively thin HFTs allows tight fitting of them on the cylindrical surface of the heat-dissipation unit of the calorimeter using a heat-conducting lubricant, and the low thermal resistance of the HFTs introduces virtually no distortions into the thermal process under investigation. The HFTs are installed along a generatrix of the heat-dissipation unit in the form of a thermometric straightedge 6.

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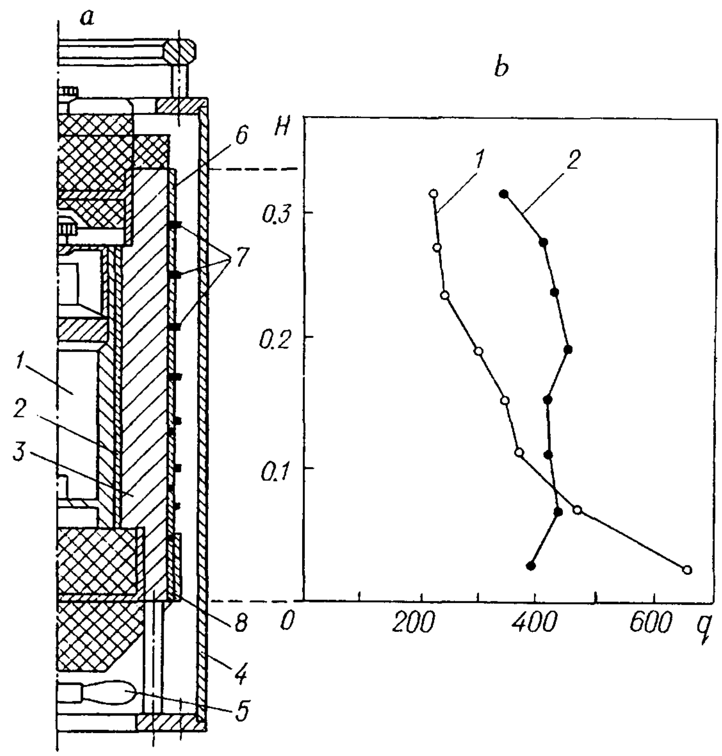

Fig. 1. Schematic of the thermal unit of the calorimeter (a) and distribution of the heat-flux density q (W/m^2) along the height H (m) (b).

To measure the temperature needed for calculation of the heat-transfer coefficients, a band-shaped Chromel-Alumel thermocouple is mounted on the surface of each HFT, and the free junction of the thermocouple is placed in the air flow near the blower. Detection and processing of signals from the primary transducers were carried out using an information-gauge system coupled to a personal computer. Obtained local values of the heat-flux density along the height of the heat-dissipation unit in the case of the smooth channel are presented in Fig. 1b (curve 1). As is evident from the plot, these values change along the generatrix of the thermal unit by a factor of almost three. The local coefficient of convective heat transfer calculated from experimental data takes on values between 35.9 at the lower edge and 8.0 W/(m^2·K) at the upper edge of the heat-dissipation unit. The temperature of the cooling air in the experiments was 25 °C.

The spatial inhomogeneity of the thermal flux can be equalized by various methods, e.g., by introducing additional finning that varies along the height of the device, nonuniform electric heating, etc. The most technologically effective method consists in introducing additional thermal resistance and using turbulizers for intensification of local heat transfer.

Additional thermal resistance was introduced by covering the cylindrical surface of the unit with a cotton cloth, with the number of cloth layers varying along the calorimeter height proportionally to the heat flux measured. By this means, we managed to obtain a rather uniform (within the limits of ±5%) distribution of heat flux. However, this reduced the efficiency of the air cooling.

We carried out a series of experiments aimed at finding an efficient method of equalizing the heat flux by means of additional turbulization of the air flow using ring-shaped turbulizers mounted on the unit and the inner surface of the casing. Spiral and stepped turbulizers were tested. The former turned out to be inefficient for solving the problem posed, since they led to formation of local air counterflows and reduced the mean air velocity in the channel.

Stepped turbulizers 7 (see Fig. 1a) with a height of 4–5 mm separated by a distance of 35–45 mm from one another demonstrated the highest efficiency. Turbulizers with a larger height led to a decrease in the mean air velocity in the channel, which resulted in a reduced cooling efficiency. The results obtained correspond to experimental data [2] from which it follows that a turbulizer substantially enhances heat transfer in a zone exceeding its height by a factor of 8–12. In the lower portion of the unit, where the local heat transfer coefficient has the highest value, a cord-cloth ring 8 with a thermal resistance of about 0.02 $m^2 \cdot K/W$ is mounted to provide a decrease in the heat flux. Measured values of the heat-flux density are represented in Fig. 1b by curve 2. The inhomogeneity of the heat-flux density in the central portion of the unit does not exceed ±7%, and a decrease in the heat flux at the upper and lower edges with respect to the mean value is substantiated by the necessity of compensating the heat removal via the structural elements situated there.

As a result of the improvement of the air cooling of the KTS-2 calorimeter carried out in this work, the shift of the "base line" of the device decreased from 25–30 to 10–15 mW, and the instability of the temperature of the unit decreased from 0.005 to 0.002 K, which corresponds to a decrease in the measurement error due to the nonuniformity of the thermal field of the device by a factor of 2.5.

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