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EXPERIMENTAL STUDY OF THE TRANSIENT REGIME IN A THERMOPILE WITH ADDITIONAL HEAT REMOVAL

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Experiments have shown that additional heat removal makes it possible to eliminate overheating of the leg of a thermopile and significantly increase the speed of its response. A description is given of the experimental method used.

It was shown in [1] that the use of additional removal of heat from the lateral surface of the leg of a thermopile makes it possible to improve the dynamic characteristics of the latter.

The thermal scheme of a thermopile may be modified differently than in [1], such as by removing heat from the cross section of the leg [2]. Some results of study of such thermopiles were reported in [3].

Here, we generalize results of an experimental study of a transient in cooling thermopiles both with additional heat removal from the cross section and with the conventional design (with heat removal only from the end of the leg). In making the test thermocouples, we used legs with a current height of 4.6 and 8 mm and a diameter of 3 and 2 mm.

The results reported here were obtained from testing thermopiles consisting of several thermocouples. This is in contrast to those studies in [4, 5], which consisted of a single thermocouple.

The unit used in the tests consisted of the radiators of the hot junctions 1, two thermopiles 2, and the object being cooled 3. The cooled object was a copper plate. The heat capacity of the plate was roughly five times greater than the heat capacity of the switching elements. Flowing water served as the heat carrier in the radiators and in the additional cooling device 4.

Temperature was measured with copper—constantin thermocouples attached to the center of mass of the cooled object I, to the heat-absorbing II and heat-emitting III junctions, to the additional cooling device or to a point corresponding to its position in a conventional thermopile, and to two points over the height of the leg V.

The measurement thermocouples on the junctions and in the additional cooling element were soldered in an opening having a diameter twice as great as the diameter d of the thermocouple electrode, while the measurement thermocouple of the leg was glued into a hole having a depth equal to roughly half the cross section of the leg. The diameter of the electrode

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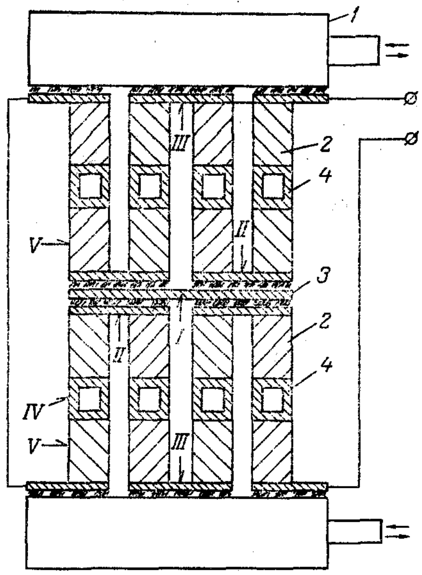

Fig. 1. Diagram of the experimental unit.

of this thermocouple was 2d. The thermocouple was glued in the hole with a composition which conducts heat well.

To evaluate the effect of the heat flows in the thermocouple leads, we compared the maximum gradients ΔT_{max} developed by the thermopiles before and after connection of the thermocouples. Connection of the thermocouples led to a reduction in ΔT_{max} by an amount on the same order of magnitude as the error of the measuring instrument. This allowed us to ignore the effect of heat flow along the leads on the temperature field.

The estimates obtained show that the maximum absolute temperature measurement error was no more than 0.2 K. The maximum relative error of measurement of the electrical quantities, in accordance with the nominal data of the instruments, was no more than 0.5%. The time intervals were measured to within 0.1 sec.

The unit was insulated with a layer of wool, while the tests were conducted at atmospheric pressure and room temperature. At the same time we connected the electric power supply and started the stopwatch, we began synchronous measurements of temperature at all of the above points. These measurements were made every 20 sec until the steady state was reached. The regime was considered to be a steady state when the signals from the measurement thermocouples in 10-15 successive measurements differed by no more than the error of the measuring instrument.

Tests were conducted for different supply currents which were constant over time. Figure 2 shows the results of tests in which a thermopile with additional cooling and a conventional thermopile were supplied with the same current. In both cases, the current was optimum for the regime in which the cooling capacity of the conventional thermopile is maximal $\max Q_x$. The thermopile with additional cooling was also studied with the supply of current characteristic of its natural operating regime $\max Q_x$ [3].

The tests were conducted with a broad range of supply currents and showed that the leg of a conventional thermopile undergoes appreciable overheating during service, especially during the initial moments of the transient regime when the temperature gradient between the junctions is relatively small (Fig. 2a). This overheating of the leg of a conventional thermopile has been noted by other authors [5], albeit only in the one regime corresponding to ΔT_{max}.

The authors of [5] attribute the overheating of the leg seen at the initial moment of the transient regime merely to a time lag in the effect of Peltier heat on the temperature field of the leg. It is difficult to accept this explanation. At the initial moment of the transient regime, when the gradient between junctions is near or equal to zero, it follows from the theory of heat conduction that internal heating in the leg (the Joule effect) results in overheating near the middle of the leg [6], regardless of the supply current. The amount of overheating will be greater, the greater the supply current.

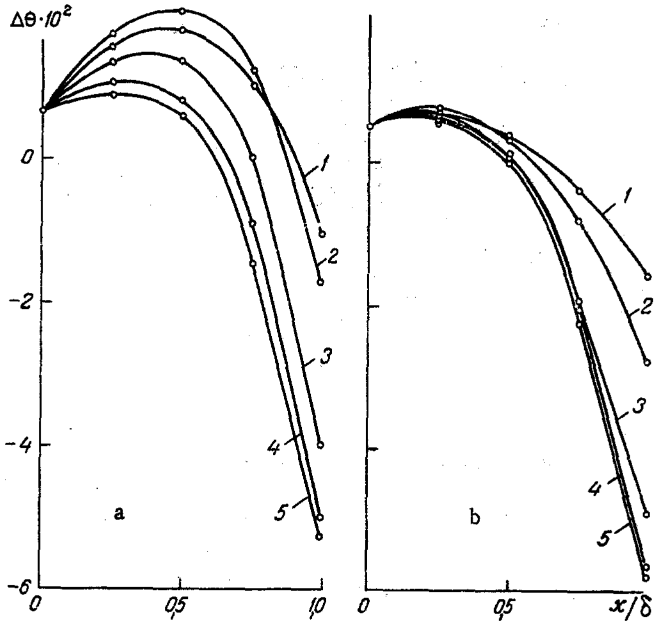

Fig. 2. Distribution of temperature along the current height of the leg of a conventional thermopile (a) and a thermopile with an additional cooling element (b), j = 0.5, η = 15.3: 1) Fo = 1.63; 2) 3.26; 3) 9.77; 4) 26.06; 5) 50.

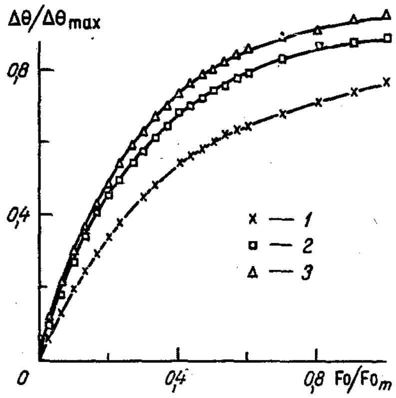

Fig. 3. Dependence of the relative cooling depth on relative time for a thermopile with η = 15.3; 1) conventional design, j = 0.5; 2, 3) design with additional cooling, j = 0.5 and 0.7, respectively.

In the maximum cooling-capacity regime at the optimum supply current, the amount of overheating is $0.25\Delta T_{max}$, as was shown in [7]. With an increase in the temperature gradient, the overheating point is shifted toward the heat-emitting junctions and the amount of overheating decreases (Fig. 2b). Thus, it is obviously necessary to eliminate the overheating. This can be done only by removing additional heat from the overheated part of the leg.

As shown by Fig. 2b, the use of additional cooling for the design being examined eliminates overheating of the leg. In turn, the elimination of overheating leads to an increase in unit cooling capacity. This was demonstrated in [1, 7], for example.

An increase in the instantaneous cooling capacity in the transient regime makes it possible (Fig. 3) to use additional cooling to increase the speed of response of a thermopile.

NOTATION

$\Theta = zT$, dimensionless temperature at the measured point; $\Delta\Theta = \Theta - \Theta_0$, dimensionless temperature gradient between the measured point over the height of the leg and the cooling medium; Θ_0, dimensionless temperature of the medium; x, coordinate at the measured point; δ, current height of the leg (m); $\Delta\Theta_x = \Theta_0 - \Theta_x$, dimensionless cooling depth; Θ_x, dimensionless temperature of the heat-absorbing junctions; ΔT_{max}, $\Delta\Theta_{max}$, dimensional and dimensionless maximum cooling depth of a conventional thermopile; $z = E^2/(4\rho\lambda)$, Q factor of the thermocouple (T^{-1}); E, total thermo-emf (V/K); ρ, mean electrical resistivity of the thermocouple ($\Omega \cdot m$); λ, mean thermal conductivity of the thermocouple ($W/(m \cdot K)$); $j = (2E\delta I)/(\lambda f)$, dimensionless current density; I, supply current (A); f, cross-sectional area of leg (m^2); $Fo = (at)/(4\delta^2)$, Fourier criterion; a, mean diffusivity (m^2/sec); t, time (sec); $\eta = G_d/G_s$, relative heat content of the thermal load; G_d, heat capacity of the thermal load (J/K); G_s, total heat capacity of the semiconductor thermopile (J/K); Fo_m, Fourier criterion, determining the dimensionless time over which a conventional thermopile attains the maximum cooling depth; d_s, diameter of the semiconductor leg; max ΔQ, maximum cooling capacity of the thermopile.

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VIRIAL COEFFICIENTS OF METHANE, ETHANE, AND PROPANE AT TEMPERATURES UP TO 1500°K

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The second and third virial coefficients are calculated for the (12-7, δ) model pair potential. With their help the fourth virial coefficient is determined from the experimental data for p, $\tilde{V}$, and T. The limit of applicability of the equation of state obtained is indicated.

The second and third virial coefficients of monoatomic (neon, argon, krypton) and diatomic (nitrogen, oxygen, air) gases were previously calculated in [1, 2] for temperatures up to 3000°K. With their help the fourth virial coefficient was determined from the experimental data on p, $\tilde{V}$, and T. The equation of state obtained describes with high accuracy the data on the thermodynamic properties of these gases tabulated in handbooks [3-6].

In this paper we present the virial coefficients of three polyatomic gases, whose molecules have the most diverse symmetry. As previously, the (12-7, δ) model pair potential, proposed in [7]

$$\varphi(r) = \begin{cases} \infty, & r \leqslant r_e, \\ 5{,}1042\varepsilon\left[\left(\dfrac{\sigma^2 - r_e^2}{r^2 - r_e^2}\right)^6 - \left(\dfrac{\sigma^2 - r_e^2}{r^2 - r_e^2}\right)^{7/2}\right], & r \geqslant r_e \end{cases} \quad (1)$$

(where ε is the depth of the potential well; σ is the "diameter;" and r_e is the "core" of the molecule) was employed in the calculations. The application of this potential to gases consisting of polyatomic molecules with arbitrary symmetry was impeded by the uncertainty in the size of the molecular "core."

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