and characteristic times; m and d, dimensionless longitudinal and transverse particle velocities; P, pressure; F_M, Magnus force; Fr, Froude number; U_{dr}, particle drift velocity; α and β, dimensionless parameters.

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NONSTEADY HOT-FILAMENT METHOD USING AN RC OSCILLATOR TO INVESTIGATE HEAT EXCHANGE IN RAREFIED GASES

Yu. G. Semenov, B. A. Kalinin,
S. F. Borisov, and P. E. Suetin

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A device which realizes the nonsteady hot-filament method using an RC oscillator is discussed, along with the results of its testing in the measurement of the thermal conductivity of the gases Ar, N_2, and CO_2 and their mixtures under standard conditions.

The experimental investigation of heat exchange in rarefied gases in the presence of solid surfaces has acquired ever greater importance in recent years. The complex physicochemical processes taking place at the gas – solid boundary have a considerable effect on processes of heat transfer in gaseous media, requiring the introduction into heat-conduction theory of the concepts of a temperature jump and of coefficients of energy accommodation [1]. This imposes higher demands on the experimental technique also. The effort to satisfy these demands led us to the creation of a device based on the nonsteady hot-filament method using an RC oscillator as the recorder of the filament temperature.

A whole series of methods exist which permit one to investigate the thermophysical properties of a gaseous medium with a high degree of accuracy. The steady-state research methods have obtained the greatest development. Devices based on these methods possess a high measurement accuracy, but they have a number of fundamental drawbacks reducing the value and reliability of the results obtained. First of all one must note the presence of a constant temperature drop in the investigated gases, which leads to such undesirable phenomena as convection and thermodiffusion. The large value of this drop, reaching tens of degrees, hinders the one-to-one correlation between the results obtained and the temperature of the investigated gas. The time consumed in performing the measurements is long.

Devices based on nonsteady methods have not obtained wide application because of their low accuracy, which is due mainly to the difficulty in the recording of a rapidly varying temperature. All the same, nonsteady devices allow one to avoid the indicated defects of steady-state devices, and they considerably simplify and speed up the measurement process.

To increase the accuracy of nonsteady devices we used a high-frequency RC oscillator as the temperature recorder. A circuit diagram of the device is shown in Fig. 1. The electronic circuit built on the transistors T_1 and T_2 together with the detector D form an RC oscillator whose negative feedback circuit is frequency-setting and is built in the form of a 2T bridge.

S. M. Kirov Ural Polytechnic Institute, Sverdlovsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 37, No. 2, pp. 269-272, August, 1979. Original article submitted October 2, 1978.

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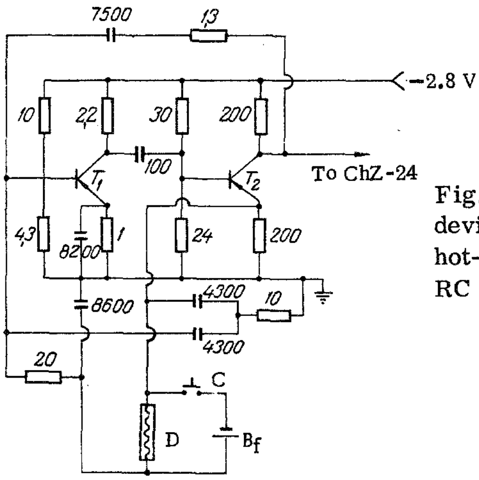

Fig. 1. Circuit diagram of a device realizing the nonsteady hot-filament method using an RC oscillator. R, kΩ; c, pF.

The detector D is a structure consisting of a metal filament stretched along the axis of a copper cylinder in whose internal cavity the investigated gas is located. (The construction is described in detail in [2].) As shown in Fig. 1, the filament of the detector D is included as one of the elements of a frequency-setting circuit and affects the frequency of the RC oscillator through its active electrical resistance. A change in the resistance of the filament leads to a change in the oscillator frequency. The filament of the detector D is connected through the contact C with the filament battery B_f.

The electrical resistance of the metal filament was 20-30 Ω for the given circuit.

In the electronic circuit we used GT-308 V transistors. The RC oscillator is supplied from two batteries of the Baken type with a total voltage of 2.8 V. The working oscillator frequency of $1.2 \cdot 10^6$ Hz is recorded by a ChZ-24 electronic-counter frequency meter. The voltage of B_f is 1.5-3 V.

The device works in the following way: the investigated gas or gas mixture is placed in the cavity of the detector D. The contact C is closed and a heating current pulse from the battery B_f is applied to the detector filament. Then the contact C is opened and the detector filament, having obtained some store of heat, starts to cool, dissipating the heat into the gas. In the process the filament temperature decreases, which leads to an increase in the frequency of the RC oscillator owing to the decrease in the resistance of the cooling filament. The oscillator frequency is recorded by the frequency meter over different time intervals from the moment of opening the contact C until the complete cooling of the filament. The rate of cooling of the detector filament is determined from the readings of the frequency meter.

Following [2, 3], we can connect the filament cooling rate with the coefficients of energy accommodation and thermal conductivity of the investigated gas. The coefficient of thermal conductivity λ and the coefficient of energy accommodation α_E are connected with the filament cooling rate m by the equations

$$\lambda = \frac{1}{2} \rho c_p \left(m - \frac{\omega \pi^2}{\rho c_p l^2} - \frac{8 \gamma \Phi T^3}{\rho c_p R_1} \right) R_1^2 \ln \frac{R_2}{R_1} ; \tag{1}$$

$$\alpha_E = \frac{c_p \rho R_1 m \left(2\pi\mu / N_0 kT \right)^{1/2}}{2P \left(c_v \mu / N_0 + k/2 \right)} . \tag{2}$$

The connection between the cooling rate and the measured frequencies of the RC oscillator is expressed by the equation

$$m = \frac{1}{t} \ln \frac{F - F_0}{F_f - F_0} . \tag{3}$$

The device for investigating heat exchange using an RC oscillator was initially tested in a study of the temperature dependence of the coefficients of energy accommodation of a number of inert gases at the surface of a platinum filament. We published data on these investigations in [3].

In the present work we measured the thermal conductivities of the gases Ar, N_2, and CO_2 and their mixtures at a temperature of 15°C and atmospheric pressure. The results are given in Table 1.

In tests of the device its following positive characteristics were revealed:

1) the digital data output (the frequency meter is a digital printer);

TABLE 1. Measured Values of Thermal Conductivity of the Gases Ar, N_2, and CO_2 and Their Mixtures Taken in a Ratio of 50:50 at Atmospheric Pressure and a Temperature of 15°C

Gas	$\lambda \cdot 10^4$, W/m·deg	$\Delta\lambda/\lambda$, %	$\lambda \cdot 10^4$, W/m·deg [4]
Ar	159	1,1	160
N_2	238	1,3	240
CO_2	153	0,9	152
Ar—N_2	230	1,0	—
Ar—CO_2	164	0,8	—
N_2—CO_2	165	0,8	—

2) the high stability (no worse than 10^{-6}) and high temperature sensitivity (10^3 Hz/deg) of the RC oscillator permit the creation of an initial temperature drop of less than 1°C in the device, which assures a high certainty in the mean temperature of the measurements, eliminates convection, and permits work with gas mixtures, since thermodiffusion is practically absent;

3) the high speed of the measurement system makes it possible to conduct measurements even when the temperature and pressure of the investigated gases vary continuously;

4) the use of an electronic-counter frequency meter to measure the frequency assures the recording of the time coordinate of the process with an accuracy determined by the quartz oscillator ($\pm 10^{-7}$).

NOTATION

α_E, coefficient of energy accommodation, a dimensionless quantity; λ, thermal conductivity of investigated gas, W/m·deg; m, filament cooling rate, 1/sec; ρ, density of filament material, kg/m^3; c_p, heat capacity, J/kg·deg; ω, thermal conductivity, W/m·deg; γ, emissivity, dimensionless; l, length of filament, m; R_1, its radius, m; R_2, inner radius of cylinder, m; μ, molecular weight of gas, kg/mole; c_V, heat capacity of investigated gas at constant volume, J/kg·deg; P, gas pressure, N/m^2; T, mean filament temperature, °K; k, Boltzmann constant, J/deg; N_0, Avogadro's number, 1/mole; Φ, Stefan – Boltzmann constant, J·deg^{-3}/m^2·sec; F_i, initial frequency of RC oscillator measured at time of opening of contact C, Hz; F_0, oscillator frequency upon complete cooling of filament, Hz; F, oscillator frequency measured in the process of cooling of filament, Hz; t, time when frequency F is measured, reckoned from time of measurement of frequency F_i, sec.

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