EXPERIMENTAL STUDY TO DETERMINE THE THERMAL CONDUCTIVITY OF BROMIDED FREONS F-113 V2 AND F-114 V2

Z. I. Geller, V. Z. Geller, and V. P. Éizenveis

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A test cell is described which has been designed on the principle of coaxial cylinders and with which the thermal conductivity of bromided Freons F-113 V2 and F-114 V2 has been determined experimentally.

Bromided Freons are used in centrifugal-type air conditioning compressors, as the refrigerant in single-stage compressors, as flame quenching media, as inhibitors of spontaneous combustion of hydrazine in nitrogen dioxide [1], as the compensating and as the hydraulizing fluid in instruments, as an anesthetic, and in the chemical industry for producing fluoroorganic compounds. Since with fluoroethers they form heterogeneous azeotropic compounds with a high heat of evaporation and a low compressibility, which would make them very effective refrigerants, bromided Freons may have potential applications in thermoenergy apparatus.

In view of this, we made an experimental study to determine the thermal conductivity of Freons F-113 V2 and F-114 V2 over the temperature range from −60 to +80°C under atmospheric pressure. The absolute method with coaxial cylinders was used for the measurements.

One of the test cells designed by us is shown schematically in Fig. 1. The inner cylinder 7 was made of grade M-1 copper with an axial bore hole 3 mm in diameter, into which a 24 W electric heater 6 was installed. This heater consisted of a size 0.12 mm (diameter) manganin wire insulated with heat resistant enamel and wound bifilarly on a porcelain bobbin. In order to reduce the heat dissipation in current and voltage leads, the latter were made of size 0.12 mm and size 0.1 mm wire, respectively. The outer cylinder 8 was also made of copper. The active surfaces of both cylinders were carefully polished. The geometrical dimensions of the cylinders, measured on a model IZA-2 horizontal comparator table, are given in Table 1.

The active segment of the device was contained between two Teflon washers 5, 12, 0.01 mm thick and tightened through copper seals, 3, 4 and 11, 13 with nuts at the cylinder ends. The cylinders were aligned coaxially by means of set screws 10 with Textolite spacers 2 mm in diameter. The eccentricity measured on the comparator did not exceed 0.005 mm, allowing the correction to the test value for λ to be reduced to 0.01%.

The temperature difference across a layer of test substance was measured with a differential three-junction copper–constantan thermocouple 9 made of size 0.1 mm (diameter) thermoelectrode wire. The thermocouple junctions were installed in holes 2 mm in diameter and 90 mm deep, spaced at 120° around the circumference. A preliminary calibration of the thermocouple against a standard PTS-10 resistance-type platinum thermometer made at the VNIIFTRI ensured a reliable measurement of temperature drops in the clearance within a ±0.001°C accuracy.

Since heat leakage from the end surfaces of the cylinders would cause large errors in the measurement of λ with a coaxial cell [2, 3, 4], special precautions were taken to ensure isothermal conditions

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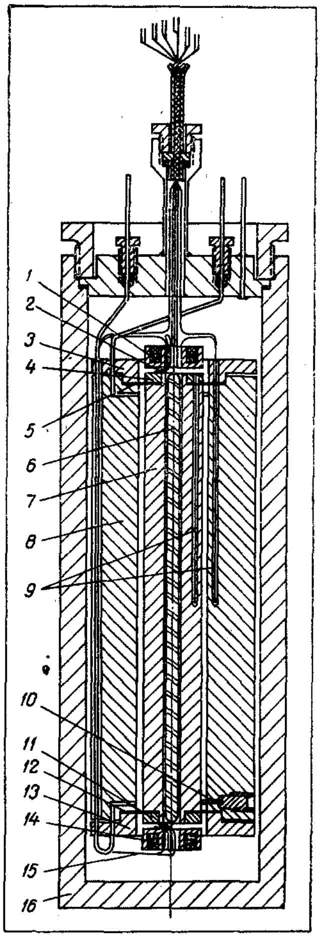

Fig. 1

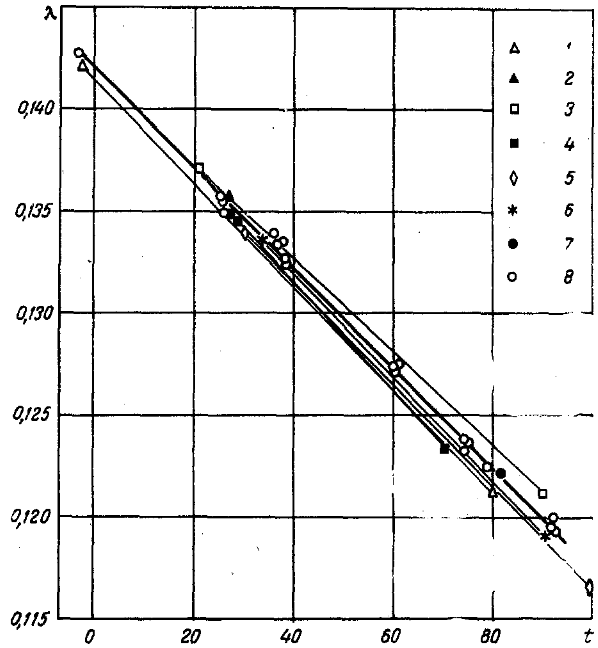

Fig. 2

Fig. 1. Schematic diagram of the test cell with protective heaters.

Fig. 2. Comparison of test data on the thermal conductivity of toluene: 1) according to the data in [5]; 2) the data in [6]; 3) the data in [7]; 4) the data in [8]; 5) the data in [9]; 6) the data in [10]; 7) the data in [11]; and 8) the data obtained by the authors in this study; λ, W/m·deg; t, °C.

throughout the length of the device. At the end surfaces of the test cell were placed protective heaters 1, 14 whose power was regulated by means of an electronic heat control circuit responding to the indications of differential two-junction copper–constantan thermocouples 2, 15. Thus, the temperature difference between the active cell segment 7 and the protective heaters never exceeded 0.005°C.

Calculations have shown that any error in the λ-measurement which is due to the heat loss at the end surfaces can be eliminated almost completely by the use of protective heaters.

The thermal conductivity, on the basis of the configuration with coaxial cylinders, is defined as follows:

$$\lambda = \frac{\ln d_2/d_1}{2\pi l} \cdot \frac{Q}{\Delta t_{\text{true}}}, \tag{1}$$

where

$$\Delta t_{\text{true}} = \Delta t_{\text{meas}} + \Delta t_{\text{diss}} - \Delta t_{\text{tc}}.$$

The temperature drop Δt_{diss} represents the error in measuring Δt_{true} which is due to the heat dissipated through the end surfaces of the cell and the centering screws.

The basic source of error in the determination of λ with a cell shown in Fig. 1 is the heat lost through the centering screws. According to calculations, however, the maximum error here does not exceed ±1%.

TABLE 1. Geometrical Dimensions of the Test Cell

Parameter	Cell with protective heaters
Diameter of inner cylinder d_1, mm	12,974±0,003
Inside diameter to outer cylinder d_2, mm	14,484±0,003
Length of active segment l, mm	178,05±0,01
Eccentricity e, mm	0,005

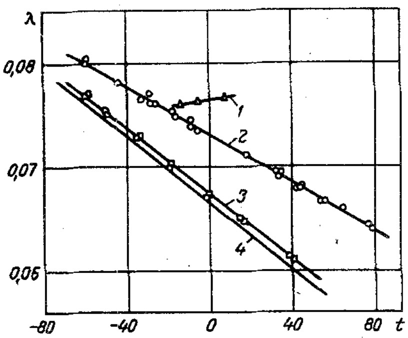

Fig. 3. Test values for the thermal conductivity of bromided Freons: 1) Freon F-114 according to the data in [13]; 2) Freon F-113 V2 according to our data; 3) Freon F-114 V2 according to our data; 4) Freon F-114 V2 according to the data in [12]; λ, W/m · deg; t, °C.

TABLE 2. Adjusted Values for the Thermal Conductivity of Bromided Freons

Temperature, °C	Thermal conductivity λ, W/m · °C	
	of Freon F-113 V2	of Freon F-114 V2
—60	0,0799	0,0767
—50	0,0788	0,0752
—40	0,0777	0,0736
—30	0,0766	0,0721
—20	0,0754	0,0706
—10	0,0743	0,0690
0	0,0731	0,0675
10	0,0720	0,0600
20	0,0709	0,0644
30	0,0698	0,0629
40	0,0687	0,0616
50	0,0676	—
60	0,0664	—
70	0,0653	—
80	0,0641	—

The test cell was placed inside a thin-walled aluminum autoclave 16 immersed in a thermostatic fluid inside a TS-24 thermostat. The thermostat temperature was maintained constant within ±0.01°C by means of an electronic regulator and, because of the thermal inertia of the autoclave–airgap–cell system, no temperature fluctuations were obtained in the cell. The temperature gradient along the autoclave which was determined in special tests with a differential copper–constantan thermocouple, did not exceed 0.02°C. In order to reduce the convective heat dissipation from the ends of the device, the latter were filled with wooly glass fiber. The test substance was then injected with hypodermic instruments through thin-walled copper capillaries into the active gap region. The heater was energized through a U 1136 dc voltage stabilizer connected to the power line through an S-0.750 stabilizer. All electrical measurements were made with a class 0.015 R-306 potentiometer and an F 116/2 microvoltammeter.

In order to check the performance of the apparatus, we ran control tests in which the thermal conductivity of toluene was measured. Inasmuch as toluene has properties which make it suitable as a reference substance for checking the calibration of thermal conductivity meters, its thermal conductivity was examined with special care. We used for the test a toluene of the "Scintillation Toluene, Extra Pure" grade in accordance with the GOST (Government Standards) 11144-65. Twenty test values for λ were obtained within the temperature range from –4 to +95°C. In Fig. 2 we compare our data with those obtained by other authors [5-11] by the method of coaxial cylinders. An analysis of calculations shows that the discrepancies between the most reliable data on λ of toluene and our test values are within 1-2%.

For measuring the thermal conductivity of bromided Freons we used grade F-113 V2 and F-114 V2 specimens which had been purified chromatographically at the State Institute of Applied Chemistry. The content of these specimens was 99.97% pure. All measurements were performed at various temperature differences across the liquid layer (from 1 to 4°C) and at products of Gr Pr ≪ 1000, signifying the absence of convective heat transmission. In calculating λ we added corrections for the eccentricity of the cylinders, for the heat leakage through the centering screws, for changes in the geometrical dimensions due to temperature changes, and for the presence of thermocouples.

The test values for the thermal conductivity of bromided Freons F-113 V2 and F-114 V2 are shown in Fig. 3, the adjusted values are listed in Table 2.

The temperature-dependence of the thermal conductivity can be described, within a ±1% accuracy, by the following linear equation:

$$\lambda_t = \lambda_{30}[1 - \alpha(t - 30)], \tag{2}$$

where α is equal to $1.6088 \cdot 10^{-3}$ deg^{-1} and $2.4387 \cdot 10^{-3}$ deg^{-1}, respectively.

Our test values for the thermal conductivity of Freon F-114 V2 agree closely with the test values obtained by Tauscher [12] (the difference does not exceed 1.2%), but differ considerably from those obtained by Powell et al. [13], according to which the temperature coefficient of thermal conductivity is positive.

The Freons in [13] were measured by the relative method with a plane layer, with the thickness of the Freon layer in different configurations varying from 10 to 25 mm and with the temperature drop up to 42°C in some tests. Under these conditions, evidently, convection took place causing the thermal conductivity of Freons to appear higher and, in some cases, causing the temperature coefficient to become positive. Thus, for example, the values for the thermal conductivity of Freon F-113 at 10°C are 8% higher in [13] than the reliable values in [14].

The thermal conductivity of Freon F-113 V2 had been measured earlier.

NOTATION

Q	is the quantity of heat supplied by the heater, W;
Δt_{true}	is the true temperature drop across the layer, °C;
Δt_{meas}	is the measured temperature drop across the layer, °C;
Δt_{diss}	is the correction for heat dissipated through the end surfaces, °C;
Δt_{tc}	is the correction for the thermocouple installation, °C;
d_2	is the diameter of the outer cylinder, m;
d_1	is the inside diameter of the outer cylinder, m;
l	is the length of the active segment, m;
λ	is the thermal conductivity, W/m·deg.

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