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MICROPOROUS FUMED-SILICA INSULATION BOARD AS A CANDIDATE STANDARD REFERENCE MATERIAL OF THERMAL RESISTANCE

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Microporous Fumed-Silica Insulation Board

as a Candidate Standard Reference Material

of Thermal Resistance

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Measurements of apparent thermal conductivity of microporous fumed-silica insulation board are reported in order to provide a basis for certifying it as a Standard Reference Material (SRM) of thermal resistance. These data, for a pair of specimens having a mean density of 301 kg/m^3, encompass a range of temperature from 321 to 723 K and environmental gas pressures at and below ambient atmospheric pressure (40 to 83.7 kPa). Detailed analyses and intercomparisons of previously published data are given. Correlations of thermal conductivity with temperature and with pressure are given which represent the data within a standard deviation of 0.2%. This fumed-silica material has a thermal conductivity of 19.68 mW/(m·K) at 300 K and is suitable for use as an SRM of very low conductivity from room temperature up to temperatures beyond 720 K (450 °C). Great care in handling this material is necessary because of its fragility.

Key words: apparent thermal conductivity; density; microporous fumed silica; pressure; Standard Reference Material; temperature; thermal insulation; thermal resistance.

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1. INTRODUCTION

The Office of Standard Reference Materials of the U.S. National Institute of Standards and Technology, NIST, (formerly the National Bureau of Standards, NBS) establishes Standard Reference Materials (SRMs) to improve reliability in measurement of physical properties. Specifically, SRMs of thermal resistance are used by industrial, academic, and government laboratories to verify the correct operation of guarded hot plates (GHPs) and to calibrate instruments such as heat-flow meters. These instruments measure the rate of heat flow under given temperature differences through specimens of known thickness. From such data one can obtain the thermal resistance (R-value) of the measured specimen, as well as the thermal conductivity (or its reciprocal, the resistivity) of the homogeneous material. SRMs can also be used to indicate the accuracy of measurement of apparent conductivity of thermally conducting materials over a range of parameters such as bulk density, temperature, and environmental air pressure. The Properties of Solids Group within the Chemical Engineering Science Division of NIST in Boulder, Colorado, (NIST/B) has participated for about 25 years in establishing SRMs of thermal resistance over a broad range of thermal conductivity, pressure, and temperature. The status of this effort has been summarized by Hust [1].

During the mid-1970's, the American Society for Testing and Materials (ASTM) recognized the great need for thermal insulation SRMs. Consequently, a task-group was established under the auspices of ASTM subcommittee C16.30 on thermal measurements. Recommendations for establishing thermal insulation SRMs were published in 1978 [2].

No SRM of thermal resistance for use at temperatures above 330 K is available at the present time from the Office of Standard Reference Materials of NIST in Gaithersburg, Maryland (NIST/G), in spite of the very strong need for such SRMs.

We report measurements of apparent thermal conductivity of one pair of specimens of microporous fumed-silica insulation board. This pair was obtained from the Heat Transfer Group of the Center for Building Technology at NIST/G, which is certifying one lot of this material as an SRM at room temperature. This material was investigated because of the recommendations of the ASTM C16.30 committee and of an advisory panel composed of representatives from government and industry. Additional measurements are currently being performed at NIST/B and NIST/G on several other specimen pairs of similar material, more fully to characterize its properties. Workers at NIST/G are measuring additional specimens with their 1-meter GHP, at environmental pressures very near 101.3 kPa, and at a temperature of 297 K. Work at NIST/B involves study of a selected subset of these specimens, with measurements of thermal conductivity performed over a greater range of temperature and pressure than is possible with the 1-meter apparatus.

2. CHARACTERIZATION OF MATERIAL

This insulation material is produced as rigid boards of bonded silica-aerogel composite made of very fine particles of synthetic amorphous silica, opacifier, fine ceramic fibers, and a binder [**3**,**4**]. The size of the silica particles has been reported by the manufacturer to be approximately 10^{-8} m. The fine ceramic fibers increase the cohesiveness of the board, and the binder cements the surfaces of the particles and fibers together into a cellular structure by sintering when the boards are cured at high temperatures (900°C). Ilmenite ($FeO \cdot TiO_2$) is the opacifier added to reduce radiative heat transmission through the board for use at high temperatures. The fractions of silica particles, opacifier, and ceramic fiber stand approximately in the ratios 60:35:5. All organic matter is burned out in curing.

Microporous fumed-silica insulation board in its raw-product form is very fragile and must be handled with great care. The edges of the slabs are easily chipped during installation and removal from the measurement apparatus. Boards having an edge dimension longer than about 30 cm are easily damaged during handling and shipping unless great care is taken to support them over a whole face and to protect them from localized impacts. However with proper cushioning of the specimens when they are packed for shipping, and with proper support of the broad faces when they are installed in an apparatus, a careful worker can probably measure them 20 or 30 times without significant degradation of their surfaces due to chipping or breaking. Great care will be necessary in handling these specimens.

An evaluation lot comprising 10 specimens of this material was originally obtained by NIST/G [**4**]. The specimens as received were about 2.5 cm in thickness and 60 cm square. After measurements of thermal conductivity were performed in the 1-meter GHP at NIST/G, a selected pair of specimens was cut into 30 cm squares and shipped to NIST/B. Two specimens for which thermal conductivity measurements are reported here had a mean density of 301 kg/m^3 (18.8 lbm/ft^3).

3. MEASUREMENTS

For brevity, we shall use the term "thermal conductivity" to denote the term "apparent thermal conductivity" in the following text. Analysis of our data in the following section suggests that radiative heat transfer in this microporous fumed-silica board is not negligible, but, near room temperature, contributes only a small amount in comparison to conductive heat transfer. Because of the density and microporosity of this material, convective heat transfer is totally negligible. Thermal conductivity is therefore an appropriate descriptor of the heat-transfer behavior of this material over the temperature range studied.

The thermal conductivity data reported here were obtained with the high-temperature guarded hot plate described by Hust, Filla, Hurley, and Smith [5]. The diameter of this circular hot-plate stack is 25 cm (10 in), and the area of the metered main heater has a diameter of 12.5 cm (5 in).

The specimens were received as square slabs nominally 300 mm on a side. The measurement apparatus requires disks 250 mm in diameter, so disks were cut from the square slabs by using a bandsaw set to a low cutting speed. The material is very easily cut and the disk was not damaged during the cutting. The annular material making up the rest of the square is sometimes split during the cutting, however. Because the material generates air-borne dust during machining operations, prudence requires the use of a dust mask by the person cutting this material. Although the material from which the insulation is manufactured is not toxic, the dust is very fine and is borne by stray air currents over distances of several meters.

We measured the thickness of each specimen using a digital electronic caliper with a precision of 0.03 mm (0.001 in). Measurements of thickness were made at eight locations equally spaced around the perimeter of the disk, and the measurements were averaged. The standard deviation of the thickness measurements is 0.08 mm for a nominal specimen thickness of 25 mm (relative standard deviation of 0.3%).

Using a steel ruler that had a precision of 0.25 mm, we measured the diameter of each specimen along four different directions, and the results averaged. The standard deviation of these measurements was 0.8 mm for a nominal diameter of 255 mm (relative standard deviation of 0.3%).

Masses of the specimens were measured on a laboratory trip balance with a sensitivity of 0.1 g for a typical mass of about 400 g (relative imprecision of 0.03%).

The density can be determined from these measurements with a precision of $\pm$ 0.5%. The mass of each specimen decreased by about 3 g from conditioning in an oven at 90°C before the thermal conductivity was measured, and then increased by about 2 g during the measurement, as revealed by the mass of the specimen upon removal from the apparatus. These changes in mass due to the rigors of conditioning and measurement amount to about 0.8% uncertainty in the density.

After the specimens were installed in the apparatus they were heated to the highest temperature of measurement before the thermal conductivity was measured. There is no evidence in the thermal conductivity data that phase changes occur in the material below 475°C, the highest temperature to which the specimens (that is, their sides adjacent to the hot main plate) were exposed during measurements. There does seem to be some adsorption of moisture, which must be driven off before measurements are stable. We found it necessary to repeat measurements two or more times at a given mean temperature until the values obtained did not vary by more than the experimental reproducibility (0.5% for this apparatus).

The thermal conductivity of this pair of specimens was measured at mean temperatures up to 723 K (450°C) with air at ambient pressure and humidity in the environmental chamber. Absolute temperatures and temperature differences were stabilized and measured with a precision of 0.02%. The precision of the measurement of thermal conductivity was estimated to be 0.5% at 330 K, and 0.7% at 720 K. The bias was estimated to be 1.5% at 330 K and 2.5% at 720 K.

In table 1 we list 38 measurements of thermal conductivity for this pair of microporous fumed-silica insulation boards in air at a pressure of 83.6 kPa (627 Torr) and at mean temperatures varying from 321 to 723 K (48 to 450°C).

In order to obtain the effect of the environmental gas pressure on the thermal conductivity, we measured this pair at selected environmental air pressures evenly spaced over the range from 40.0 kPa (300 Torr) to 83.5 kPa (626 Torr). The measurements of thermal conductivity at these pressures were made at a constant mean temperature of 318 K (45°C). Gas pressure was measured with a precision of 0.13 kPa (0.1 Torr; a relative precision of 0.3% at the lowest pressure). The inaccuracy of pressure measurements is about 1%. The 20 measurements from these experiments are listed in table 2.

4. DATA ANALYSIS AND DISCUSSION

A. Thermal Conductivity as a Function of Temperature

The 38 data points in table 1 were analyzed to determine the correlation of thermal conductivity with mean specimen temperature. The thermal conductivity over the temperature range $321 < T < 723$ K, for the pair of specimens with a density of 301 kg/m^3 and in an environment of air at a pressure of 83.6 kPa and ambient humidity, was represented by

$$k = 18.46 + 2.283*10^{-3}\ T + 1.983*10^{-8}\ T^3, \qquad (1)$$

where k is in mW/(m·K) and T is in K. This correlation was obtained using a weighted least-squares fit and the thermal conductivity integral (TCI) method [6].

The curve in figure 1 representing the thermal conductivity as a function of temperature is seen to have very little curvature. Also, relatively small temperature differences were imposed on the specimens during these measurements. Thus it would not be necessary to use the TCI method to fit these data. The TCI method is indicated for use whenever measurements are made with large differences in the boundary temperatures of the specimen and with appreciable curvature in the thermal conductivity function over the included range of temperature. However, we always use the TCI method as a matter of course, whether or not the data seem to have enough curvature to require the method. This ensures that no additional errors are ever introduced by our fitting procedure due to nonlinearity in the fitted function.

The 38 thermal conductivity data k_{meas} used to determine this dependence of k on temperature are plotted as open circles in figure 1; the correlation given by eq(1) is plotted in figure 1 as the solid line. The deviations of the data from values of k_{calc} computed from eq(1) are plotted in figure 2 and are listed in the last column of table 1. The standard deviation of the data from the fitted curve is 0.21%.

The curvature of the solid line in figure 1 is correlated with the T^3 term in eq(1), which, being nonlinear, grows larger relative to the other two terms with increasing temperature. This T^3 term is related to the contribution of radiative heat transfer to the total heat transfer through the material. At 297 K the magnitude of this term is 0.5 mW/(m·K) out of a total apparent conductivity of 19.7 mW/(m·K), or 2.6% of the total. At 700 K the magnitude of the T^3 term is 6.8 mW/(m·K) out of a total of 26.9 mW/(m·K), or 25.3% of the total. Thus in this range of temperature, the radiative contribution to the total heat transfer is becoming appreciable.

B. Thermal Conductivity as a Function of Pressure

The correlation of thermal conductivity with pressure P was obtained from the 20 data points listed in table 2, for a mean specimen temperature of 318 K (45°C), a temperature difference within the specimen no greater than 30 K, and a density of 301 kg/m³. By use of a weighted least-squares fit the correlation was represented by

$$k = 9.337 + 0.17436\ P - 5.6095 * 10^{-4}\ P^2 \qquad (2)$$

where k is in mW/(m·K) and P is in kPa; this relation is valid over the range of pressure from 40 to 83.5 kPa. Because the pressure is constant throughout the specimen, it is not necessary to use the TCI method to fit this correlation with pressure. For the relatively small temperature difference used (30 K), any error made by associating the thermal conductivity with the mean temperature of the specimen is inappreciable.

The thermal conductivity data used to determine this dependence of k on pressure are plotted as open squares in figure 3; the correlation given by eq(2) is plotted in figure 3 as the solid line. Deviations of the data from values of k_{calc} computed from eq(2) are plotted in figure 4 and are also listed in the last column of table 2. The standard deviation of the data from this curve is also 0.21%.

The maximum value of k_{calc}, 19.98 mW/(m·K), given in table 2, represents the value of thermal conductivity k_B at the ambient atmospheric pressure at Boulder, Colorado. At this elevation, approximately 1650 m, or 5400 ft, above sea level, the atmospheric pressure is 83.3, with normal fluctuations, due to local weather, of $\pm$ 0.5 kPa. By extrapolation of eq(2) to a condition of one standard atmosphere of pressure, 101.3 kPa (corresponding to sea level), the thermal conductivity k_{sl} is estimated to be 21.245 mW/(m·K). This value is compared with the data for pressure dependence by representing it as the circle in figure 5. This value is 6.3% higher than the value k_B = 19.98, obtained for our laboratory in Boulder. That is, the ratio of the two values is $k_{sl}/k_B = 1.063$. This factor will be of use in the next section comparing these data with the results of measurements on this same lot of material by workers at NIST/G, at sea level.

Because the form of the k dependence given by eq(2) is nonlinear (quadratic dependence on P), the rate of change of k with pressure changes with pressure. Figure 2 shows that the slope of k versus P is steeper at lower pressures and less steep at higher pressures. For this fumed-silica insulation the rate of change of k with pressure P, or slope of the k(P) function plotted in figure 2, is given by the mathematical first derivative of the k(P) function:

$$dk/dP = 0.17436 - 2 * 5.6095 * 10^{-4}\ P. \qquad (3)$$

At sea level, where P_{sl} = 101.325 kPa, the rate of change of k with pressure takes the value 0.0607, which is also the slope of the k(P) relation, eq(2), at P_{sl}. At the elevation of our laboratory at Boulder, where the pressure is P_B = 83.5 kPa, the rate of change of k with pressure is 0.0807, which is the slope of the k(P) relation, eq(2), at P_B. But because these slopes are different, neither of them is valid for extrapolating values of k to a different range of pressure. Rather, the k(P) relation itself, given by eq(2), should be used.

5. COMPARISONS

A similar microporous material of low thermal conductivity, with a nominal density of about 310 kg/m³, was studied by Tye [7]. Its thermal conductivity ranged from 26.5 mW/(m·K) at 25°C to 48.5 mW/(m·K) at 650°C. He recommended in 1970 that it be considered as a possible SRM.

Microporous fumed-silica insulation board has been investigated for use as a possible SRM of low thermal conductivity by Rennex, Somers, Faison, and Zarr [3], and by Zarr, Somers and Ebberts [4] at NIST/G. All but two of the latter set of measurements were performed at a mean specimen temperature of 297 K (24°C) and at a pressure of 101.33 kPa (760 Torr), on specimens having densities ranging from 310 to 333 kg/m³. The apparatus used at NIST/G, a GHP with a diameter of 1 m, is enclosed in a rectangular environmental chamber with dimensions larger than 1 m. Thus this apparatus is limited by its size and geometry to a very small range of environmental gas pressure, around ambient barometric pressure, that can be safely used within it. The present measurements extend the range of correlation of thermal conductivity for microporous fumed silica insulation to the temperature interval from 318 to 723 K (45 to 450°C). The correlation is also extended to environmental gas pressures over the range from 40 to 83 kPa (300 to 626 Torr).

The microporous insulation material had a somewhat lower conductivity than that of the material studied by Tye. Rennex, Somers, Faison and Zarr [3], found that the thermal conductivity of this material at a temperature of 297 K could be represented by the correlation

$$k = 21.94 + 0.03076\,(D-301.4) + 0.09936\,(P-101.33) \qquad (4)$$

where k is conductivity in mW/(m·K), D is density in kg/m³, and P is pressure in kPa.

The coefficient, 0.09936, of the pressure term in eq(4), is the rate of change of thermal conductivity with pressure, or slope of a plot of k versus P, for a specimen at a temperature of 297 K and an environmental gas pressure of 101.3 kPa. This coefficient was obtained over the range of pressures from 99.3 to 101.2 kPa. This value compares with the value of 0.0607 obtained by extrapolating eq(3), the relation for the slope of k against P, to P_o = 101.3 kPa. A full understanding of the disagreement between the two slopes of k(P) obtained by the two different laboratories has yet to be obtained. According to the NIST/G group, however, moisture content has a slight but measurable effect on thermal conductivity at 297 K, and this variable was not controlled by either lab for the results reported here.

However, extrapolating eq(1) to a value of T = 297 K, only slightly below the lowest temperature used by us in obtaining this correlation, we estimate that k = 19.66 mW/(m·K) is the value of thermal conductivity for our fumed-silica specimens at 297 K, that would be measured in the Boulder lab. We estimated in the previous section that the effect of increasing the environmental air pressure on these specimens to that at sea level (the air pressure at NIST/G) would be to increase k by a factor of 1.063 from the values measured at the elevation of Boulder. Combining these two results, we estimate that k_B^* = 1.063 * 19.66 = 20.9 mW/(m·K) for a temperature of 297 K and an ambient environmental pressure equal to that at sea level. Under the same conditions, Rennex, Somers, Faison and Zarr [3] found k_G = 21.8 mW/(m·K) at an environmental air pressure of 100.1 kPa and a temperature of 297 K, for specimens having a density of 301 kg/m^3. The difference is about 1.9% and is less than the combined estimates for the experimental biases of the NIST/B ($\pm$ 1.5%) and NIST/G ($\pm$ 0.9%) apparatus. This agreement is satisfactory. Recent work by NIST/B, to be published separately, indicates that the different densities used in this comparison have little or no effect on the conclusion.

This analysis has assumed that the pressure dependence of the thermal conductivity, given by eq(2) and obtained for a specimen temperature of 318 K, was valid for estimating the pressure dependence of k at 297 K in order to compare results obtained by different labs at different environmental pressures. While the two temperatures used are not very different, so the comparison made should be valid, the effect of temperature on the k(P) correlation is presently under investigation.

6. RECOMMENDATIONS

The thermal conductivity of this material is somewhat lower than that of the presently established SRM 1450b (fibrous glass board with organic binder), and the material can withstand much higher temperatures. The limiting high temperature used in this study was set by the apparatus and not by the physical properties of this material. When a suitable apparatus becomes available this material should be characterized at even higher temperatures.

The most serious disadvantage of this material in its proposed use as an SRM is its high mechanical fragility. If this material is adopted as an SRM, users will have to be cautioned to exercise great care in handling it when measuring its mass and physical dimensions, when conditioning it to proper moisture content, and when installing it in, and removing it from, measurement apparatus. The material is made from extremely fine particles, and fine airborne dust is easily generated during sawing or other machining operations. Use of a dust mask should be required of those machining the material when preparing to install it into a measurement apparatus.

The relatively low thermal conductivity of this material, its apparent stability under exposure to temperatures as high as 500°C, its freedom from phase changes, and its inorganic composition are useful and desirable properties for a new SRM. While the correlation of thermal conductivity with temperature seems to indicate the presence of some radiative heat transfer, this radiative component seems to be relatively small in comparison to the total apparent thermal conductivity. This suggests that the total heat transfer is due mostly to conduction through the microporous solid and the entrapped gas within the pores.

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Table 1. Thermal conductivity of a pair of microporous fumed-silica insulation boards with a mean density of 301 kg/m , at mean temperatures from 321 to 723 K (48 to 450 °C). Measurements were performed in air at ambient humidity and at a pressure of 83.6 kPa (627 Torr), using the high-temperature guarded hot plate at the National Institute of Standards and Technology in Boulder, Colorado. Temperature differences through the specimens were chosen to be about 10 percent of the value of the mean temperature within the specimens. The bias in values of Kmeas is estimated to be 1.5 percent at 330 K and 2.5 percent at 720 K. Deviations compare measured thermal conductivity to values of Kcalc computed from eq(1).

Thi (K)	Tlo (K)	Tmean (K)	Kmeas mW/(m•K)	Kcalc mW/(m•K)	Deviation (Percent)
443.256	403.184	423.220	20.999	20.932	0.32
441.168	405.093	423.131	20.926	20.930	-0.02
443.168	403.099	423.134	20.953	20.931	0.11
445.166	401.159	423.163	20.950	20.932	0.09
603.281	543.078	573.180	23.604	23.512	0.39
708.294	637.800	673.047	25.958	26.058	-0.38
758.146	688.102	723.124	27.713	27.625	0.32
737.959	658.086	698.023	26.779	26.819	-0.15
735.060	661.128	698.094	26.855	26.818	0.14
733.157	663.205	698.181	26.860	26.818	0.15
713.031	633.139	673.085	26.058	26.064	-0.02
711.104	635.156	673.130	26.071	26.063	0.03
708.141	638.187	673.164	26.085	26.061	0.09
706.160	640.261	673.211	26.061	26.061	0.00
681.099	615.150	648.125	25.364	25.351	0.05
653.024	593.135	623.080	24.651	24.689	-0.16
653.150	593.229	623.190	24.625	24.692	-0.27
653.151	593.201	623.176	24.687	24.692	-0.02
628.057	568.134	598.096	23.998	24.078	-0.33
605.207	541.133	573.170	23.523	23.513	0.04
603.127	543.159	573.143	23.521	23.511	0.04
601.125	545.221	573.173	23.534	23.511	0.10
578.078	518.148	548.113	22.962	22.986	-0.10
550.107	496.166	523.137	22.431	22.500	-0.31
548.151	498.170	523.161	22.509	22.499	0.04
546.152	500.169	523.161	22.551	22.498	0.23
523.120	473.165	498.143	21.992	22.054	-0.28
500.134	446.159	473.147	21.650	21.647	0.02
498.134	448.130	473.132	21.652	21.645	0.03
496.097	450.108	473.103	21.621	21.644	-0.11
391.242	355.150	373.196	20.375	20.344	0.15
393.187	353.153	373.170	20.312	20.345	-0.16
395.141	351.120	373.131	20.364	20.345	0.09
418.205	378.168	398.187	20.693	20.623	0.34
341.115	306.888	324.002	19.788	19.875	-0.44
339.181	307.182	323.182	19.806	19.868	-0.31
340.177	306.394	323.286	19.898	19.869	0.14
337.172	305.412	321.292	19.886	19.852	0.17

Standard Deviation = 0.21

Table 2. Thermal conductivity of a pair of microporous fumed-silica insulation boards with a mean density of 301 kg/m , at a mean temperature of 318 K (45 °C). Measurements were performed in air at ambient humidity and at pressures ranging from 40 to 83.5 kPa (626 Torr) using the NIST/B high-temperature guarded hot plate. Temperature differences through the specimens were chosen to be about 10 percent of the value of the mean temperature within the specimens. The bias in values of kmeas is estimated to be 1.5 percent at 330 K. Deviations compare measured thermal conductivity to values of Kcalc computed from eq (2). The highest pressure (83.5 kPa; 626 Torr) is the local ambient atmospheric pressure at Boulder, Colorado.

Thi (K)	Tlo (K)	Tmean (K)	Kmeas mW/(m•K)	Kcalc mW/(m•K)	Pressure (kPa)	Deviation (Percent)
331.151	305.119	318.135	20.070	19.982	83.5	0.44
333.152	304.224	318.688	20.047	19.982	83.5	0.32
334.130	304.259	319.195	19.972	19.982	83.5	-0.05
331.143	305.150	318.147	19.913	19.950	83.1	-0.19
331.095	305.076	318.086	19.626	19.696	80.0	-0.35
332.209	304.294	318.252	19.099	19.107	73.3	-0.04
333.133	304.090	318.612	19.054	19.107	73.3	-0.28
334.140	304.205	319.173	19.089	19.107	73.3	-0.09
335.229	304.469	319.849	18.447	18.468	66.7	-0.11
332.142	304.149	318.146	17.811	17.779	60.0	0.18
331.164	305.155	318.160	17.083	17.041	53.3	0.25
332.147	304.151	318.149	17.059	17.041	53.3	0.11
331.167	305.178	318.173	17.016	17.041	53.3	-0.14
332.141	304.142	318.142	16.275	16.252	46.7	0.14
331.121	305.109	318.115	16.245	16.252	46.7	-0.04
332.185	304.187	318.186	15.443	15.414	40.0	0.19
333.123	303.818	318.471	15.376	15.414	40.0	-0.25
332.142	304.138	318.140	15.395	15.414	40.0	-0.12
331.152	305.167	318.160	17.768	17.779	60.0	-0.06
332.125	304.120	318.123	17.801	17.779	60.0	0.12

Standard Deviation = 0.21

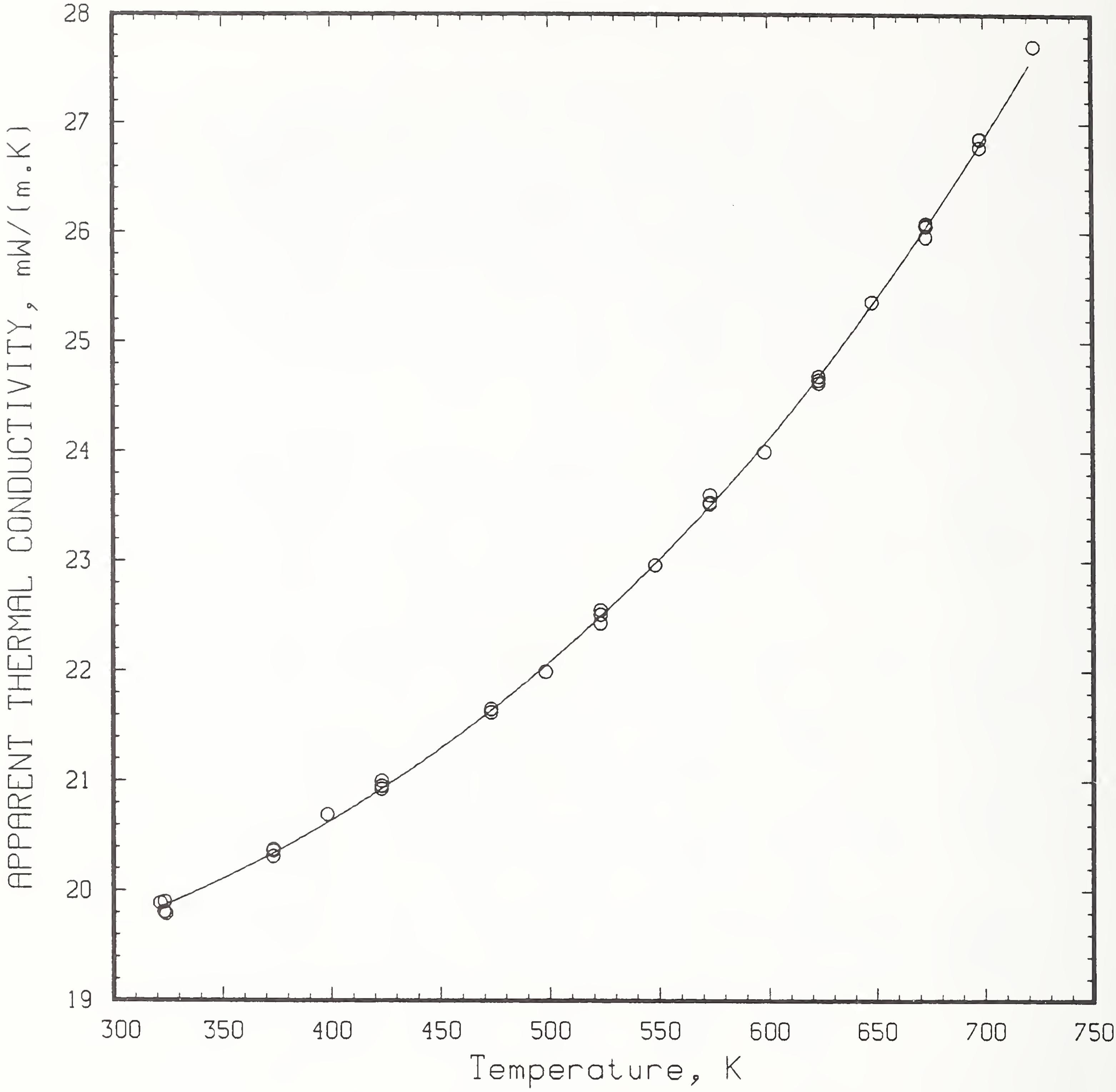

Figure 1. Thermal conductivity of a pair of microporous fumed-silica insulation boards with a mean density of 301 kg/m3, at mean temperatures from 321 to 723 K (48 to 450oC). Measurements were performed in air at ambient humidity and at a pressure of 83.6 kPa (627 Torr) using the NIST/B high-temperature guarded hot plate. The measurement bias in values of Kmeas is estimated to be 1.5% at 330 K, and 2.5% at 720 K. The solid curve represents values of Kcalc, obtained using eq(1).

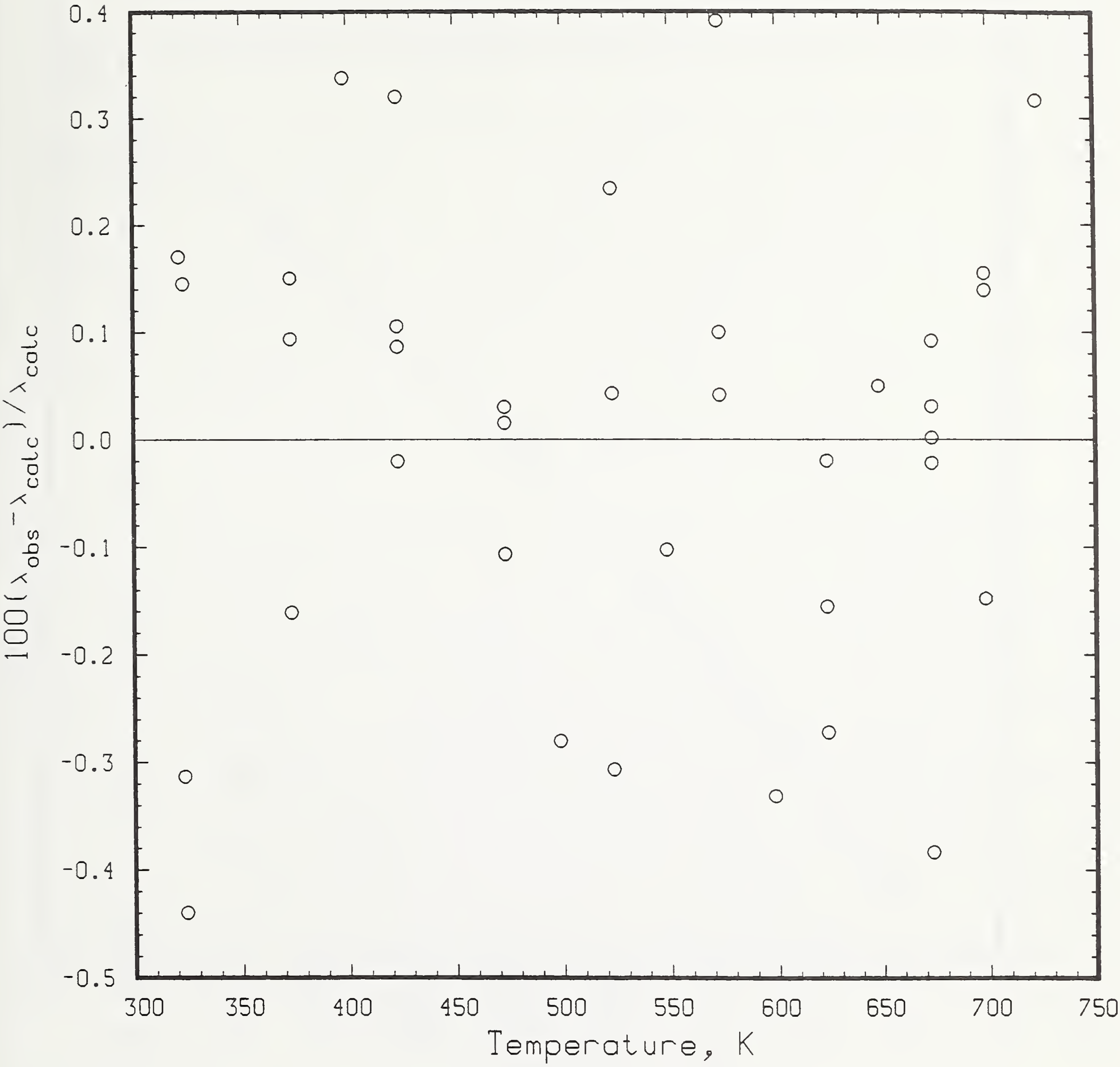

Figure 2. Deviations of thermal conductivity of microporous fumed-silica specimens from values calculated with eq(1).

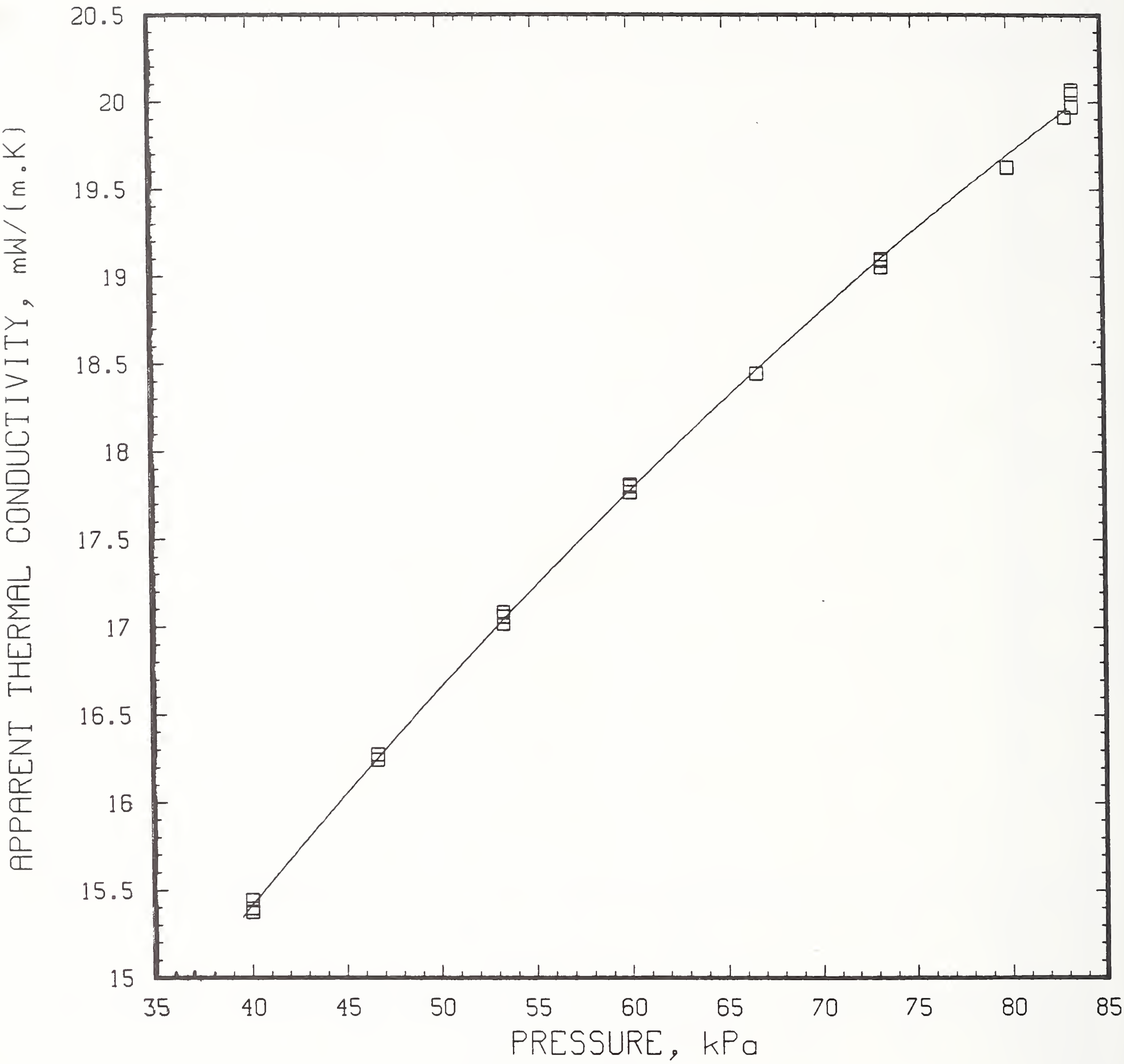

Figure 3. Thermal conductivity of a pair of microporous fumed-silica insulation boards with a mean density of 301 g/m3, at a mean temperature of 318 K (45°C). Measurements were performed in air at ambient humidity and at pressures varying from 40 to 83.5 kPa (300 to 626 Torr). The solid line was calculated from eq(2).

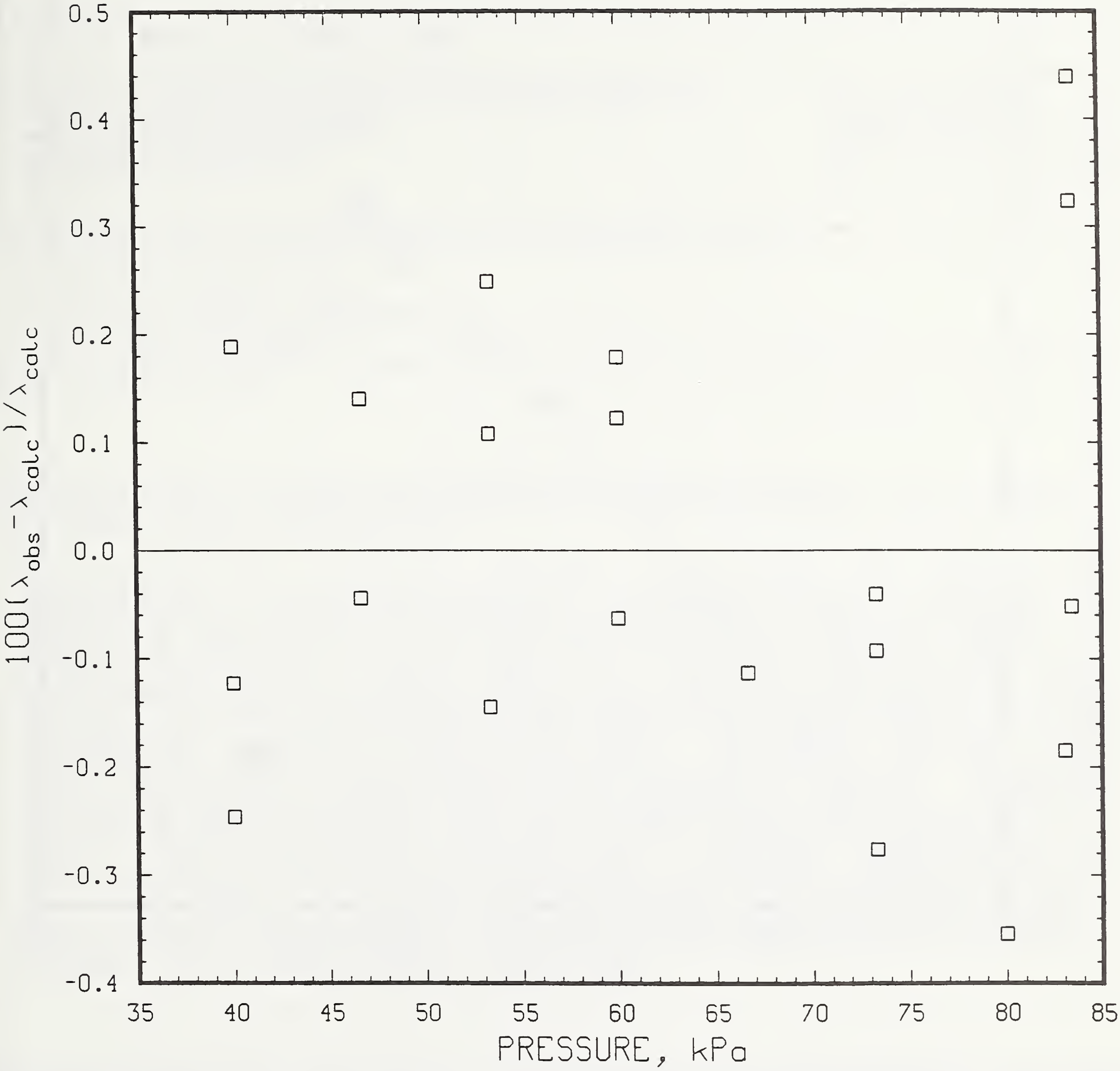

Figure 4. Deviations of thermal conductivity of microporous fumed-silica specimens from values calculated with eq(2).

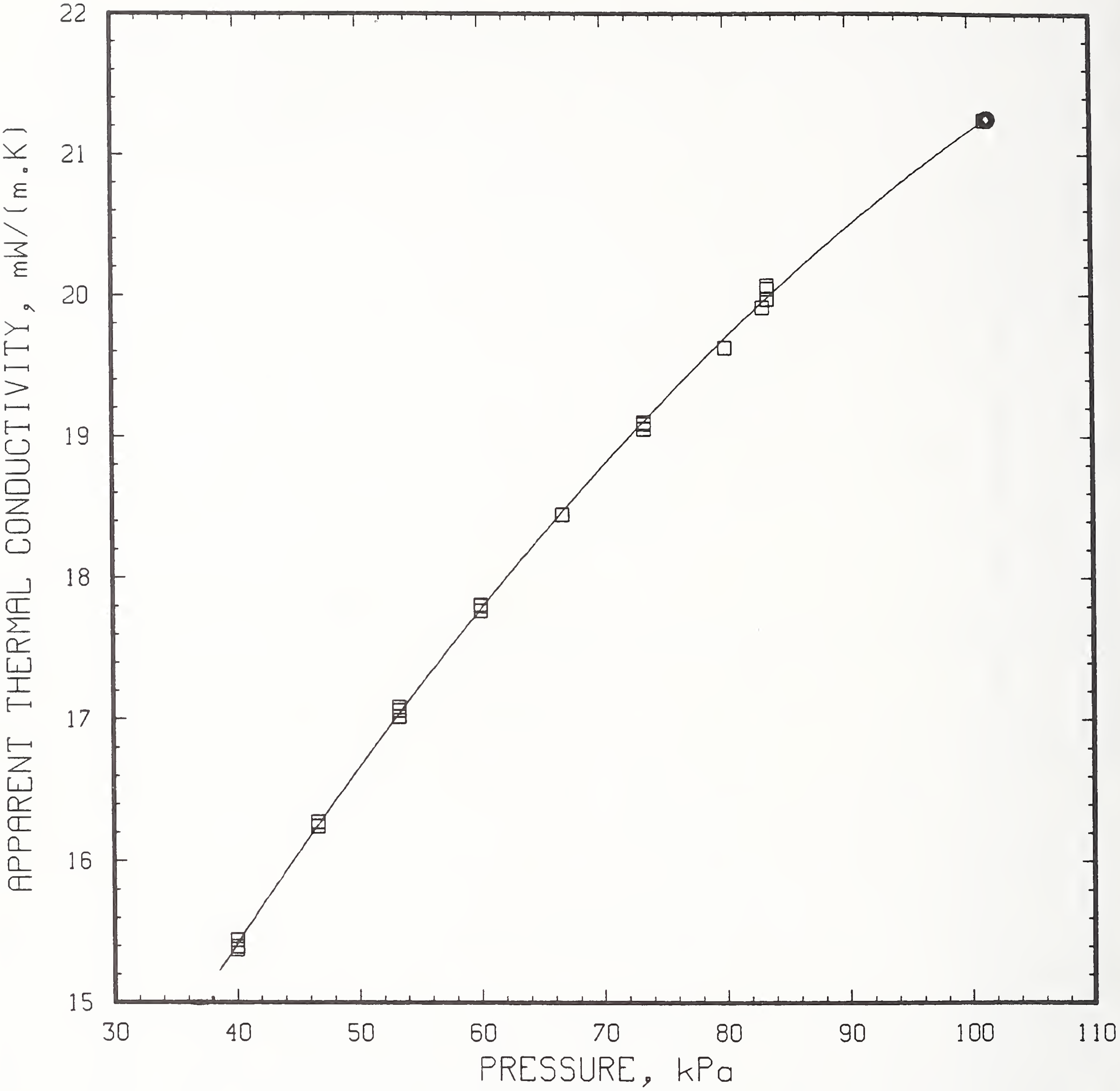

Figure 5. Extrapolated correlation of thermal conductivity with with pressure, eq(2), estimating thermal conductivivity of microporous fumed-silica insulation at sea-level atmospheric pressure (101.3 kPa) as indicated by the open circle at the top. Mean temperature of specimens is 318 K.

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MICROPOROUS FUMED-SILICA INSULATION BOARD AS A CANDIDATE STANDARD REFERENCE MATERIAL OF THERMAL RESISTANCE

5. AUTHOR(S)

DAVID R. SMITH and JEROME G. HUST

6. PERFORMING ORGANIZATION (*If joint or other than NBS, see instructions*)

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (*A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here*)

Measurements of apparent thermal conductivity of microporous fumed-silica insulation board are reported in order to provide a basis for certifying it as a Standard Reference Material (SRM) of thermal resistance. These data, for a pair of specimens having a mean density of 301 kg/m^3, encompass a range of temperature from 321 to 723 K and environmental gas pressures at and below ambient atmospheric pressure (40 to 83.7 kPa). Detailed analyses and intercomparisons of previously published data are given. Correlations of thermal conductivity with temperature and with pressure are given which represent the data within a standard deviation of 0.2%. This fumed-silica material has a thermal conductivity of 19.68 mW/(m·K) at 300 K and is suitable for use as an SRM of very low conductivity from room temperature up to temperatures beyond 720 K (450 °C). Great care in handling this material is necessary because of its fragility.

12. KEY WORDS (*Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons*)

apparent thermal conductivity; density; microporous fumed silica; pressure; Standard Reference Material; SRM; temperature; thermal insulation; thermal resistance.

13. AVAILABILITY

[XX] Unlimited

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