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U.S. DEPARTMENT OF COMMERCE/National Bureau of Standards

Standard Reference Materials:

Glass Fiberblanket SRM for Thermal Resistance

J.G. Hust

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Preface

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The 260 Series is dedicated to the dissemination of information on different phases of the preparation, measurement, certification and use of NBS SRM's. In general, much more detail will be found in these papers than is generally allowed, or desirable, in scientific journal articles. This enables the user to assess the validity and accuracy of the measurment processes employed, to judge the statistical analysis, and to learn details of techniques and methods utilized for work entailing the greatest care and accuracy. These papers also should provide sufficient additional information not found on the certificate so that new applications in diverse fields not foreseen at the time the SRM was originally issued will be sought and found.

Inquiries concerning the technical content of this paper should be directed to the author(s). Other questions concered with the availability, delivery, price, and so forth, will receive prompt attention from:

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Standard Reference Materials: Glass Fiberblanket SRM for Thermal Resistance

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The apparent thermal conductivity data that provide the basis for the certification of glass fiberblanket as an SRM of thermal resistance are reported and analyzed. Detailed analysis and intercomparisons of NBS and other published data are given. These data are represented by an equation describing the dependencies of the data on temperature and density. Certified values of thermal resistance are given for temperatures from 100 to 330 K and densities from 10 to 16 kg/m^3.

Key words: apparent thermal conductivity; density; glass fiberblanket; Standard Reference Material; temperature; thermal resistance

1. Introduction

The National Bureau of Standards (NBS) has an on-going program to establish physical property Standard Reference Materials (SRM's) as needed to improve measurement reliability. The Center for Chemical Engineering (CCE) has been active in a portion of this effort for about 20 years in establishing SRM's for thermal conductivity over a broad range of conductivities and temperatures. The status of this effort was recently summarized by Hust [1]. The Center for Building Technology (CBT) has supplied calibrated transfer specimens (CTS's) for thermal resistance of insulations for over 50 years.

During the mid 1970's, the American Society for Testing and Materials recognized the strong need for thermal insulation SRM's. As a consequence, a task group was established under the auspices of ASTM subcommittee C16.30 on thermal measurements. The recommendations for establishing thermal insulation SRM's was published in 1978 [2].

The purpose of the present publication is to describe the combined effort of CCE and CBT of NBS to establish the second of a series of insulation SRM's as recommended by the ASTM subcommittee. The first insulation SRM is a glass fiberboard material. It was established as an SRM of thermal resistance by Siu and Hust [3] for the temperature range 255 to 330 K in 1982, and was extended to 100 K in 1985 by Hust [4].

2. Material Characterization

In October 1979 two lots of 2.54 cm thick, glass fiberblanket insulation were purchased by the National Voluntary Laboratory Accreditation Program (NVLAP) and the Office of Standard Reference Materials (OSRM) both of NBS. The NVLAP lot was used for proficiency testing. Its density ranged from 8 to 19 kg/m^3. The OSRM lot, supplied as 61 x 61 cm square specimens, was to be used as SRM stock and the specimen densities ranged from 12 to 15 kg/m^3. The specimens were selected individually from a much larger lot on a criterion of uniformity of density over the center 36 x 36 cm square portions. The material consists of fibrous glass made into a low-density blanket bonded with phenolic resin. The fibers average about 5 μm in diameter and are oriented with their lengths extending primarily parallel to the face of the blanket. The binder content is reported to be about 6% by weight. The selection of this lot is described in detail in reference [14].

3. Measurements

The data used for certification of this material were obtained from two NBS apparatus:

a) The CBT 100 cm line source guarded hot plate with a 40 cm diameter meter area. It is described by Powell and Rennex [5]. A smaller version is described by Hahn [6].

b) The CCE 20 cm circular guarded hot plate with a 10 cm diameter meter area. It is described by Smith, Hust, and Van Poolen [7].

During 1980 and 1981 measurements were conducted at CCE on five pairs of specimens from the OSRM material at temperatures ranging from 100 K to 350 K. The test specimens were selected as follows: First, four 61 cm (24 in) squares were selected from the OSRM lot. These four pieces were chosen so their densities spanned the density range of the lot approximately uniformly. The specimen identification numbers wee 81614, 81356, 80156, and 85715. The densities of these specimens were 12.16 (0.759), 13.01 (0.812), 14.24 (0.891), and 14.91 kg/m^3 (0.931 lb/ft^3), respectively. These four pieces were cut into 11.7 cm (4.6 in) squares and the area density of each piece was determined. Five sets of matched pairs of specimens were selected from the 11.7 cm squares. This size was chosen so that the specimens spanned the gap between the meter and guard portions of the guarded hot plate. Guard frames were prepared from the same material to fill the remaining space between the hot and cold plates. These specimens ranged in density from 10.5 to 16 kg/m^3. The CCE measurements were conducted with various fill gases (air, nitrogen, argon, and helium) and over a range of fill-gas pressure from atmospheric pressure to high vacuum. The CCE measurements also involved a range of temperature differences between the hot cold plates from as small as 10 K to as large as 100 K. These variations in test conditions were helpful in separating the heat transfer mechanisms in this material. These data by CCE have been reported [8, 9, and 10]. The atmospheric pressure data with air as the fill-gas are listed in Tables 1 and 2.

More recently, CBT measured twenty-eight pairs of specimens from the OSRM lot using the 100 cm GHP [5]. These specimens included densities from 12 to 15 kg/m^3. All of the CBT measurements, listed in Table 3, were performed at 297 K with air as the fill-gas. The specimens were selected to span the entire density range of the lot. The densities given in Table 3 are for the entire 61 cm square specimens.

4. Data Analysis

This report serves as the basis of the certification of this SRM over the temperature range 100 to 330 K with air as the fill-gas at atmospheric pressure and a plate emittance of 0.8.

Table 1. CCE thermal conductivity data for glass fiberblanket (Set 1).

T_{mean} (K)	T_{hot} (K)	T_{cold} (K)	Density (kg/m^3)	Thickness (cm)	λ_{obs} ($mW \cdot m^{-1} \cdot K^{-1}$)	Percent Deviation
299	311.448	286.362	14.75	2.5892	39.970	-1.15
299	311.453	286.427	14.75	2.5892	40.356	-0.20
299	311.368	286.439	14.75	2.5892	40.484	0.14
249	260.599	238.257	14.76	2.5874	31.205	1.82
100	108.943	91.068	14.79	2.5824	10.250	-4.07
97	108.753	84.785	14.79	2.5823	10.255	-0.79
97	108.866	84.326	14.79	2.5823	10.370	0.49
111	123.378	98.174	14.79	2.5828	11.753	-0.89
111	123.287	98.269	14.79	2.5828	11.931	0.62
124	136.242	111.392	14.79	2.5832	13.386	0.18
136	148.977	123.504	14.79	2.5835	14.940	0.49
149	161.313	135.979	14.78	2.5839	16.588	1.00
162	174.164	149.286	14.78	2.5844	18.106	0.01
174	186.811	161.806	14.78	2.5848	19.696	-0.28
187	199.531	174.611	14.78	2.5852	21.366	-0.37
187	199.399	174.010	14.78	2.5852	21.275	-0.56
200	212.040	187.211	14.77	2.5856	23.012	-0.57
212	224.628	199.894	14.77	2.5861	24.853	-0.20
225	237.177	212.043	14.77	2.5865	26.673	-0.09
237	249.758	225.170	14.77	2.5870	28.793	0.42
250	262.310	237.589	14.76	2.5874	30.910	0.58
251	261.442	239.802	14.76	2.5874	31.068	0.74
262	274.855	249.807	14.76	2.5879	33.145	0.67
275	287.504	262.484	14.76	2.5883	35.618	0.78
288	300.073	275.064	14.76	2.5888	38.048	0.32
300	312.537	287.671	14.75	2.5893	40.858	0.39
313	325.127	300.282	14.75	2.5898	43.680	0.02
325	337.512	312.764	14.75	2.5903	47.052	0.55
336	350.058	322.678	14.75	2.5907	49.957	0.35
350	362.512	337.764	14.74	2.5913	54.043	0.71
315	335.306	294.375	14.75	2.5899	44.380	0.27
330	362.339	297.060	14.75	2.5904	48.243	0.10
357	362.637	350.773	14.74	2.5915	56.191	1.12
350	356.040	344.026	14.74	2.5913	53.903	0.56
338	349.850	325.269	14.74	2.5908	49.172	-1.92
337	349.523	325.165	14.74	2.5907	51.708	3.20
313	325.093	300.323	13.67	2.7938	44.886	-0.05
325	337.730	312.757	13.67	2.7944	48.037	-0.41
338	350.061	325.083	13.67	2.7949	51.555	-0.29
350	362.525	337.771	13.67	2.7954	55.430	-0.04
300	309.293	290.863	13.68	2.7933	41.650	-0.21
350	362.489	338.093	13.81	2.7954	55.705	0.83
325	337.504	313.172	13.81	2.7944	48.261	0.41
300	312.496	288.474	13.82	2.7933	41.956	0.61
149	161.174	136.068	13.85	2.7875	16.208	-1.18
149	161.936	136.427	13.85	2.7876	16.938	2.75
162	174.180	149.132	13.85	2.7880	18.289	0.96
174	199.768	149.231	13.84	2.7885	19.900	0.62
187	224.455	149.024	13.84	2.7889	21.533	0.72
195	241.527	149.199	13.84	2.7892	22.763	0.82
199	249.525	149.056	13.84	2.7894	23.312	0.70
212	274.651	149.271	13.84	2.7898	25.314	0.62
244	299.737	187.458	13.83	2.7910	30.361	-0.78
262	324.765	199.559	13.83	2.7918	33.962	-1.01
275	349.719	199.809	13.82	2.7923	36.605	-1.81

Percent Deviation = $(\lambda_{obs}-\lambda_{calc})100/\lambda_{calc}$

Table 2. CCE thermal conductivity data for glass fiberblanket (Set 2).

T_{mean} (K)	T_{hot} (K)	T_{cold} (K)	Density (kg/m^3)	Thickness (cm)	λ_{obs} ($mW \cdot m^{-1} \cdot K^{-1}$)	Percent Deviation
112	124.141	99.248	10.65	2.5828	11.976	2.95
149	161.282	136.046	10.64	2.5839	16.843	1.94
199	212.049	186.900	10.64	2.5856	24.175	-0.37
250	262.297	237.813	10.63	2.5874	33.316	-0.95
300	312.381	287.707	10.62	2.5893	45.406	-1.64
111	123.599	98.585	11.65	2.5828	11.777	1.39
149	161.547	137.084	11.65	2.5840	17.043	2.98
200	212.028	187.237	11.64	2.5856	24.100	0.84
250	262.157	237.405	11.63	2.5874	33.079	1.30
300	312.516	287.932	11.62	2.5893	44.767	0.65
111	123.154	98.367	15.95	2.5828	11.881	-0.84
149	161.604	136.697	15.94	2.5840	16.785	1.53
200	212.063	187.456	15.93	2.5856	23.020	0.05
250	262.271	237.740	15.92	2.5874	30.738	1.55
300	312.432	287.704	15.91	2.5893	40.290	1.39
112	123.844	100.088	13.67	2.5828	11.659	-1.89
149	161.690	136.757	13.66	2.5840	16.427	-0.31
200	212.038	187.418	13.65	2.5856	23.238	-0.53
250	262.292	238.163	13.64	2.5874	31.600	0.79
301	312.705	289.380	13.63	2.5893	41.740	-0.72
325	337.474	312.600	13.63	2.5903	48.794	1.15
325	337.396	312.691	13.63	2.5903	48.603	0.75
325	337.363	312.854	13.63	2.5903	48.256	0.01
325	337.354	312.857	13.63	2.5903	48.280	0.06
325	337.351	312.858	13.63	2.5903	48.288	0.07
325	337.349	312.856	13.63	2.5903	48.288	0.08
325	337.357	312.848	13.63	2.5903	48.256	0.01
325	337.343	312.850	13.63	2.5903	48.287	0.08
200	212.220	188.514	13.65	2.5857	23.334	-0.51
200	212.263	188.482	13.65	2.5857	23.200	-1.10
200	212.272	188.540	13.65	2.5857	23.247	-0.91
200	212.253	188.592	13.65	2.5857	23.317	-0.62
200	212.274	188.583	13.65	2.5857	23.228	-1.01
200	212.303	188.594	13.65	2.5857	23.209	-1.11
200	212.249	188.551	13.65	2.5857	23.220	-1.03
200	212.272	188.544	13.65	2.5857	23.192	-1.15
200	212.268	188.545	13.65	2.5857	23.196	-1.14
325	336.894	313.263	13.63	2.5903	48.103	-0.29
325	336.831	312.958	13.63	2.5903	47.966	-0.47
325	336.939	313.594	13.63	2.5903	48.233	-0.12
325	337.035	313.292	13.63	2.5903	48.136	-0.27
326	337.398	313.676	13.63	2.5903	48.472	0.21
151	163.891	137.402	13.66	2.5840	16.623	-0.24
351	362.502	338.916	13.62	2.5913	56.480	1.36
325	336.865	314.109	13.63	2.5903	47.087	-2.69

Percent Deviation = $(\lambda_{obs} - \lambda_{calc})100/\lambda_{calc}$

Table 3. CBT thermal conductivity data for glass fiberblanket.

T_{mean} (K)	T_{hot} (K)	T_{cold} (K)	Density (kg/m^3)	Thickness (cm)	λ_{obs} ($mW \cdot m^{-1} \cdot K^{-1}$)	Percent Deviation
297	311.00	283.20	14.90	2.540	39.06	-1.86
297	311.00	283.20	12.20	2.540	42.24	-1.06
297	311.00	283.20	13.80	2.540	40.13	-1.70
297	311.00	283.20	13.30	2.540	40.83	-1.26
297	311.00	283.20	14.90	2.540	39.70	-0.21
297	311.00	283.20	13.90	2.540	40.94	0.56
297	311.00	283.20	12.90	2.540	41.76	-0.10
297	311.00	283.20	12.80	2.540	42.24	0.75
297	311.00	283.20	12.30	2.540	42.60	0.11
297	311.00	283.20	13.20	2.540	41.43	-0.06
297	311.00	283.20	12.60	2.540	42.25	0.19
297	311.00	283.20	12.80	2.540	41.86	-0.15
297	311.00	283.20	12.70	2.540	42.52	1.12
297	311.00	283.20	13.20	2.540	41.71	0.61
297	311.00	283.20	14.30	2.540	40.68	0.88
297	311.00	283.20	13.10	2.540	42.24	1.59
297	311.00	283.20	12.80	2.540	41.57	-0.85
297	311.00	283.20	12.70	2.540	41.97	-0.18
311	321.03	301.03	13.18	2.528	43.86	-2.81
297	307.03	287.03	13.18	2.539	41.35	-0.51
273	283.15	263.15	13.18	2.535	35.30	-2.36
273	283.15	263.15	13.18	2.558	35.60	-1.50
311	320.96	300.96	12.15	2.543	46.81	0.51
297	307.04	287.04	12.15	2.541	42.65	-0.46
273	283.21	263.21	12.15	2.570	36.38	-2.01
311	321.02	301.02	14.86	2.532	43.82	1.55
297	307.06	287.06	14.86	2.551	40.19	0.72
273	283.12	263.12	14.86	2.580	34.73	-0.47

Percent Deviation = $(\lambda_{obs} - \lambda_{calc})100/\lambda_{calc}$

To facilitate comparison of the data and to provide a basis for the certification, a model was selected and optimized to represent the data. A variety of models from the literature were examined for this purpose. None of them proved adequate for the entire temperature range of this certification. As a consequence, modification of the form presented for the certification of the glass fiberboard SRM [4] was used. This model described the 128 GHP data points from CCE and CBT with no systematic deviations either as a function of temperature (from 100 to 350 K) or a function of density (from 10.5 to 16 kg/m^3). The model is given by equation (1).

$$\lambda(T,\rho) = a_1 + a_2\rho + a_3T + a_4T^3/\rho + a_5\exp -[(T-180)/75]^2 \qquad (1)$$

where the values of the parameters, a_i, are a_1 = -0.1059, a_2 = 0.1378, a_3 = 0.07714, a_4 = 8472.10^{-9}, and a_5 = 1.339, ρ is the bulk density in kg/m^3, T is temperature in K, and $\lambda(T,\rho)$ is the apparent thermal conductivity in mW$\cdot$m$^{-1}\cdot$K^{-1}

The deviations of the data from this model are shown in figure 1 as a function of temperature, and in figure 2 as a function of bulk density. The two standard deviation values computed from the residuals of the fit is 2.1%. For illustration, values of $\lambda(T,\rho)$ are calculated and plotted in figure 3 as a function of temperature at a density of 13 kg/m^3, and in figure 4 as a function of density at a temperature of 300 K.

Although the deviations shown in figures 1 and 2 appear random, systematic differences between the CCE and CBT data as a function of temperature are noted. A similar difference in the slope as a function of temperature was noted in the data for the glass fiberboard SRM 1450b [4]. The source of this systematic difference is unknown, but it is less than the overall scatter of the data sets.

5. Comparisons

It is desirable to compare equation (1) to the results from other measurements on similar materials. It is most convenient to make these comparisons of $\lambda(T,\rho)$ through the use of the models. The baseline for these comparisons will be the values as calculated from equation (1).

The most direct comparison that can be made is with respect to the recently completed round robin on low-density glass fiberblanket materials as reported by Hust and Pelanne [11]. Part of these measurements were performed on the NVLAP material obtained from the same supplier as was the OSRM material. The data used to develop the model reported by Hust and Pelanne [11] included temperatures from 255 to 330 K, and densities from 11 to 35 kg/m^3. The comparison of the two models as a function of temperature for a density of 13 kg/m^3 is shown in figure 5. The comparison as a function of density at a temperature of 300 K is shown in figure 6.

Systematic differences between the two equations of as much as 2% are noted at the lower densities. The agreement is excellent at the higher densities. Since part of the material used in the round robin was similar to the material

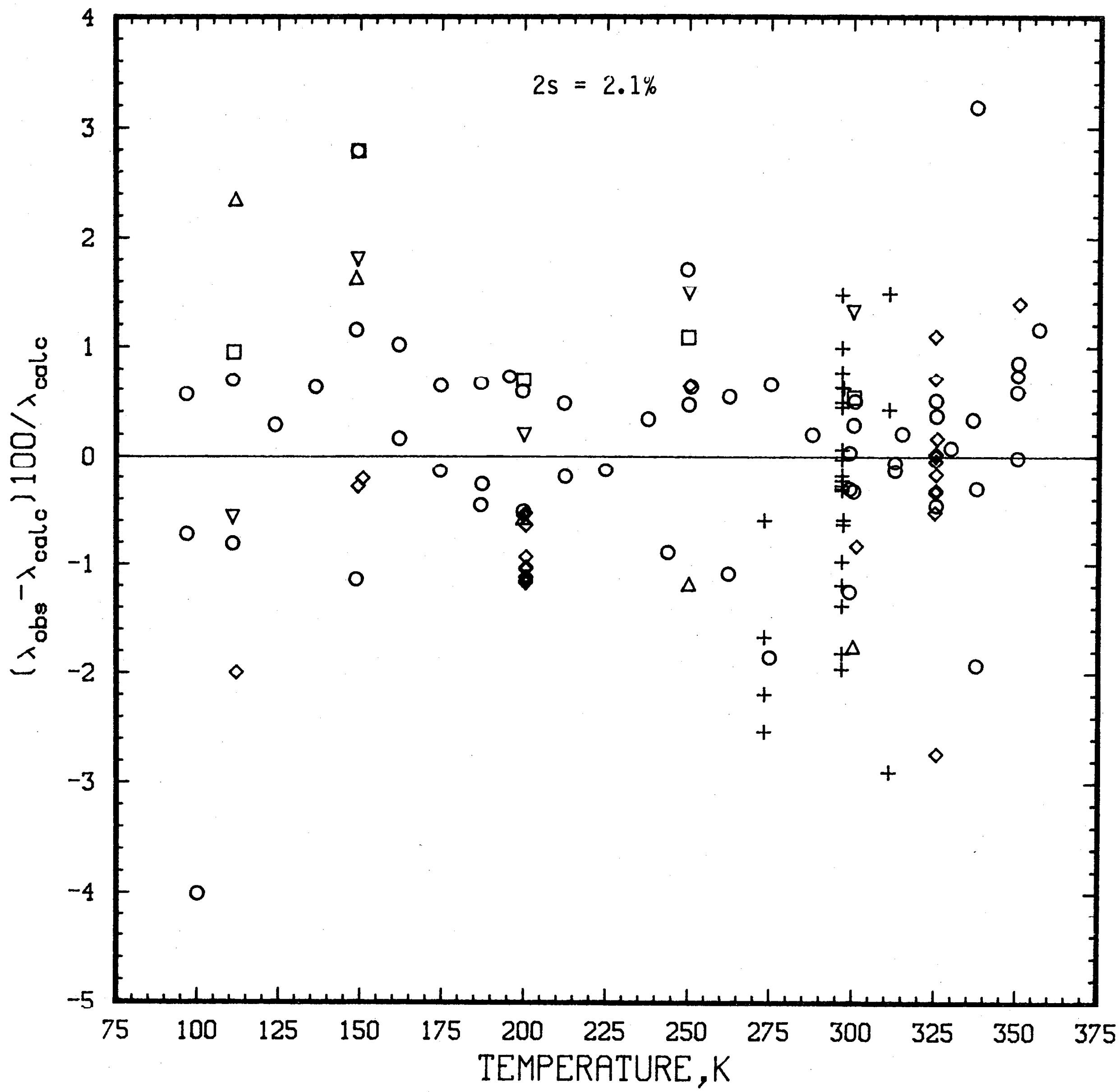

Figure 1. Deviations of measured apparent thermal conductivities from values calculated with equation (1) versus the mean temperature of the measurements at densities from 10.5 to 16 kg/m^3.

○ - CCE Spec. 1
△ - CCE Spec. 2
□ - CCE Spec. 3
▽ - CCE Spec. 4
◇ - CCE Spec. 5
\+ - CBT

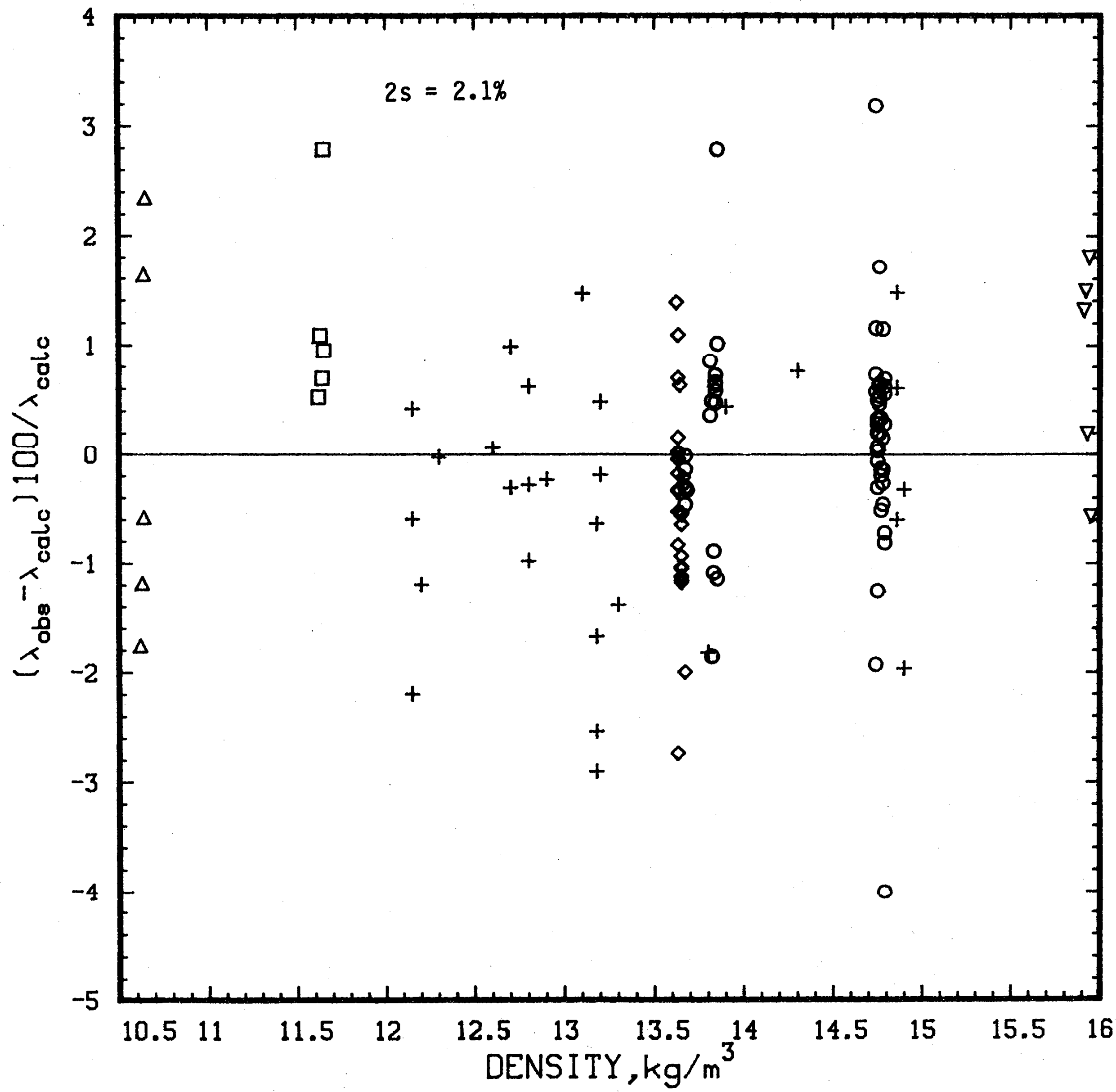

Figure 2 Deviations of measured apparent thermal conductivities from values calculated with equation (1) versus the bulk density of the specimens at temperatures from 100 to 360 K.

○ - CCE Spec. 1
△ - CCE Spec. 2
□ - CCE Spec. 3
▽ - CCE Spec. 4
◇ - CCE Spec. 5
+ - CBT

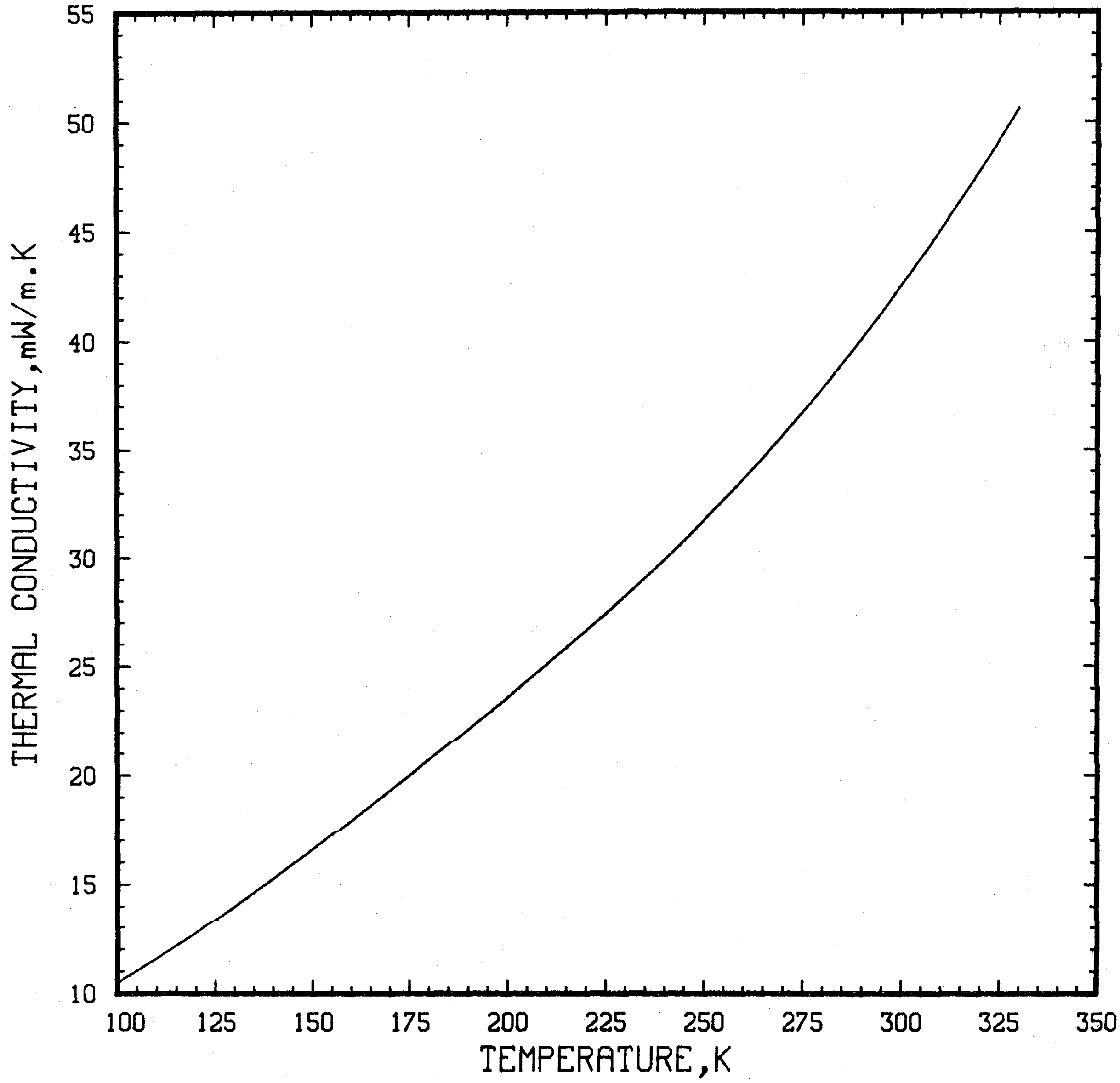

Figure 3 Thermal conductivity as a function of temperature at a density of 13 kg/m^3 as calculated from equation (1).

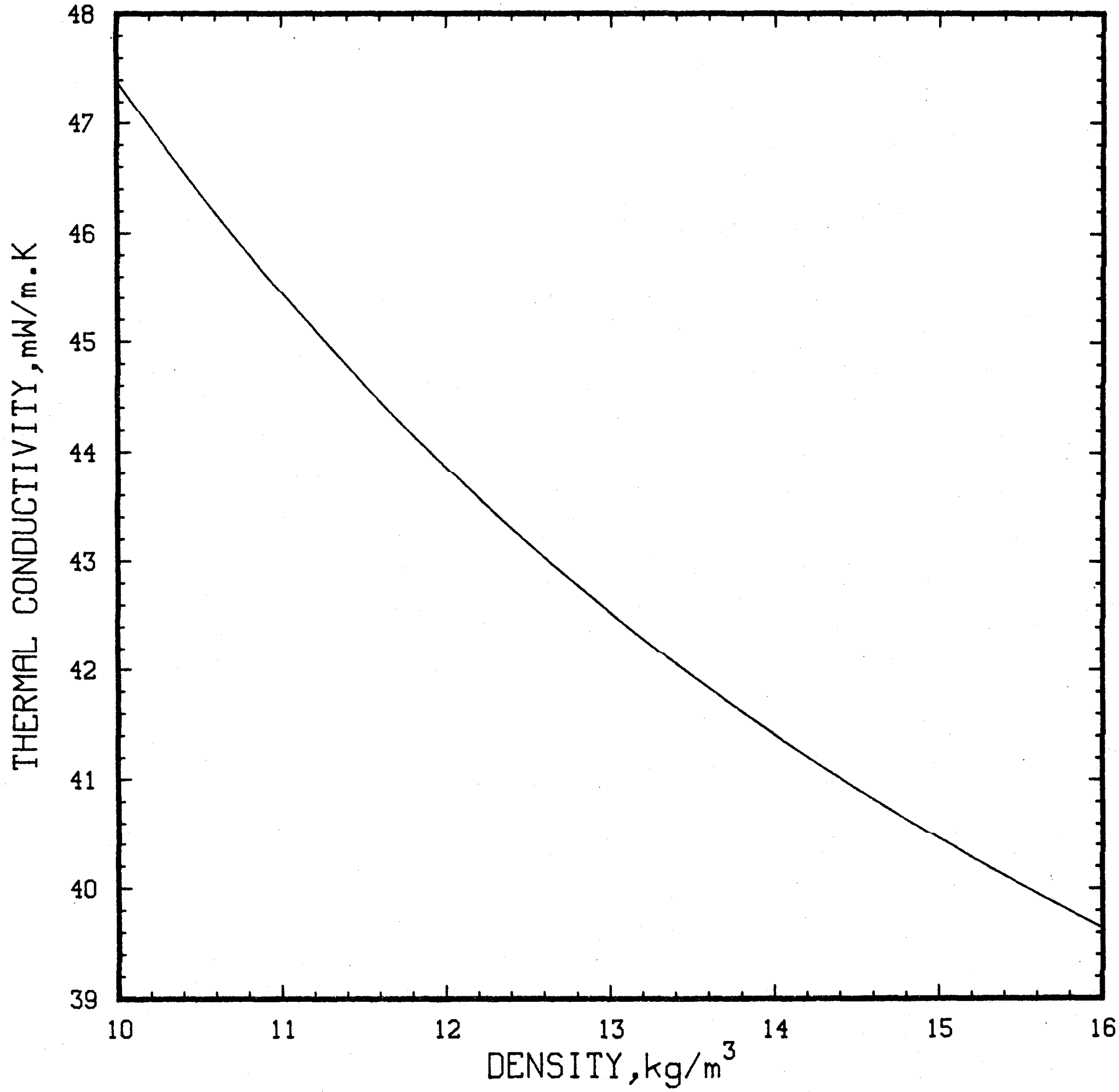

Figure 4 Thermal conductivity as a function of bulk density at a temperature of 300 K as calculated from equation (1).

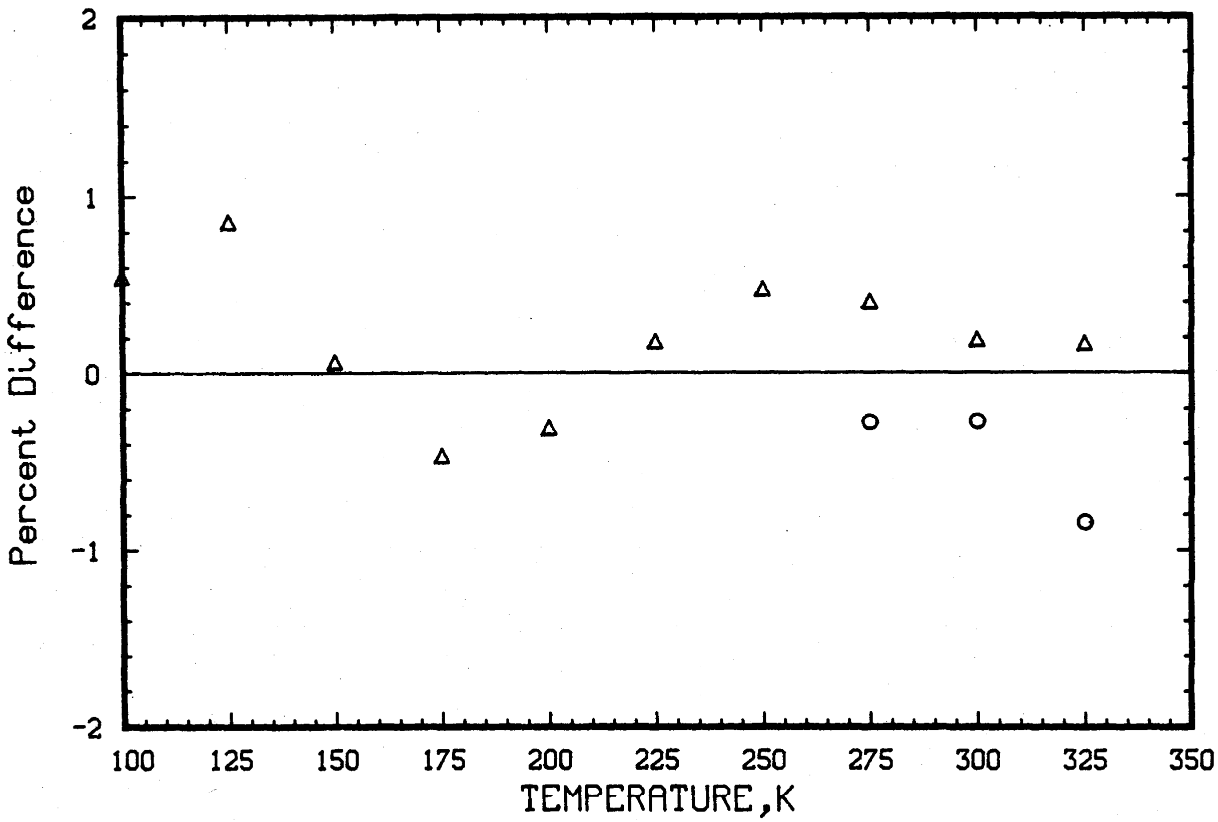

Figure 5 Comparison of equation (1) to previously published equations as a function of temperature at a density of 14.75 kg/m^3. Percent Difference = $(\lambda_i - \lambda_{eq.1})100/\lambda_{eq.1}$.

o - Round Robin Model [11]
Δ - Smith and Hust [9,10]

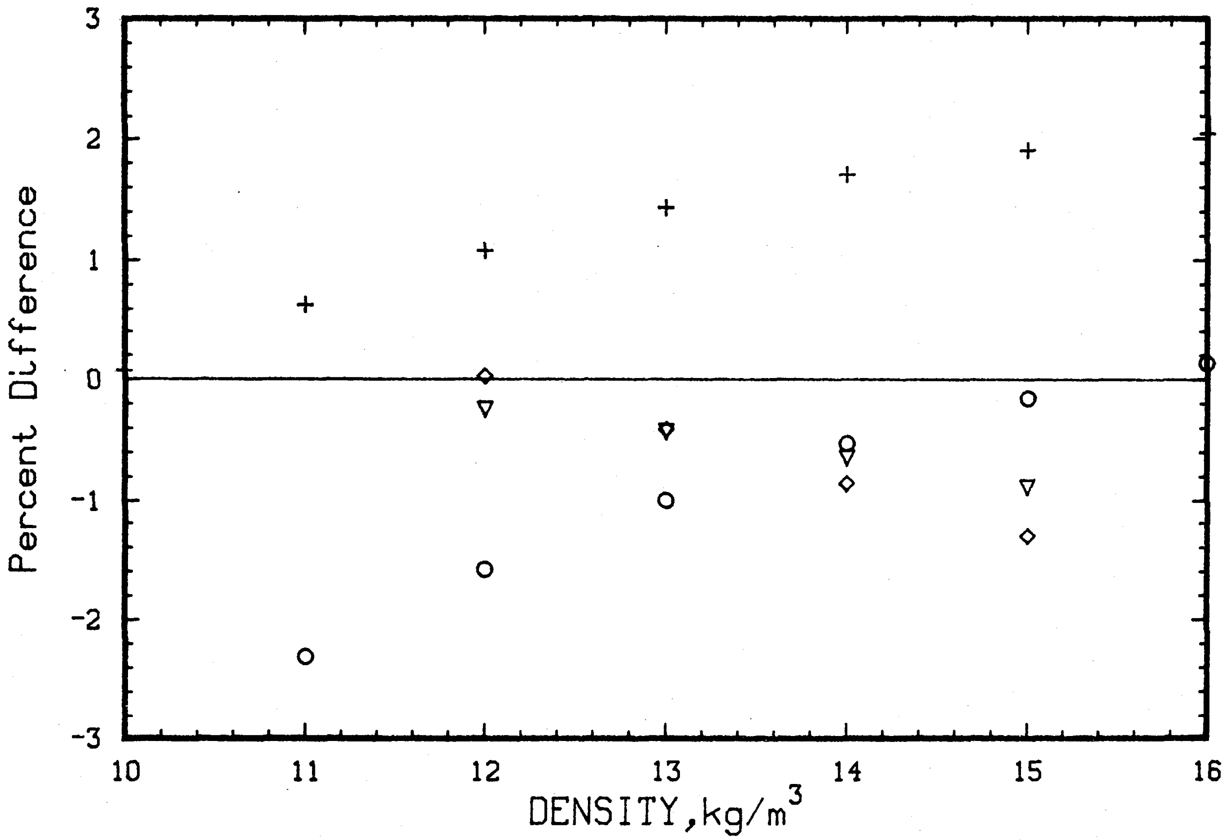

Figure 6 Comparison of equation (1) to previously published equations as a function of density at a temperature of 297 K. Percent Difference $= (\lambda_i - \lambda_{eq.1})100/\lambda_{eq.1}$.

o - Round Robin Model [11]
∇ - GHP [12]
◇ - HFM [12]
+ - HFM [14]

used for this SRM, the difference as a function of density is probably an indication of measurement uncertainty.

The supplier of this material performed numerous characterization measurements at a temperature of 297 K using heat flow meter apparatuses of various sizes. They reported that the following equation described their apparent thermal conductivity values as a function of density, ρ, within the imprecision of the data: $\lambda = 28.57 + 179.6/\rho$ where λ is in $mW \cdot m^{-1} \cdot K^{-1}$ and ρ is in kg/m^3. Calculated values from this equation are compared to equation (1) in figure 6. This curve is nearly parallel to the curve for the round robin equation [11]. Since the round robin equation is based on NBS data, a systematic difference between the supplier's measurements and NBS measurements is noted.

Another comparison that is useful for SRM utilization is with respect to the equation presented by Rennex [12], $\lambda = 25.3 + 212/\rho$, for the CBT GHP data at a temperature of 297 K. Figure 6 shows that the equation presented by Rennex differs by less than 1% from equation (1).

The NBS-HFM apparatus with plate dimensions of 61 x 61 cm (24 x 24 in) and meter dimensions of 25 x 25 cm (10 x 10 in) was used to measure 75 specimens from this lot at 297 K. Rennex [12] reported these data and an equation describing the data to within about ±2%. This equation, $\lambda = 24 + 229/\rho$, is compared to equation (1) in figure 6. The deviations of the two equations are well within 1% at the low density end, but exceed 1% at the higher densities.

6. Certified Values

For certification purposes, values of thermal resistance, R, are desirable. Values of R at a thickness of 2.54 cm (1 in), R_0, calculated from equation (2) are listed in Table 4 in units of $m^2 \cdot K \cdot W^{-1}$.

$$R_0 = 0.0254/\lambda(T,\rho) \qquad (2)$$

The as-tested thickness will most likely be slightly different from 2.54 cm. The R values at different thicknesses, L, are calculated from

$$R = R_0 L/0.0254 \qquad (3)$$

where R is the thermal resistance at the tested thickness, and R_0 is the certified value interpolated from the table or calculated from equation (2).

It should be noted that this material is certified only for thicknesses within the range of the tests reported, nominally 2.54 cm (1 in). The specimens should be in good contact with the apparatus plates, but compression to a thickness less than 2.4 cm should be avoided. Reference 13 may aid the user in connection with the compression properties and homogeneity of this material.

Values of thermal resistance of this SRM are expected to be within 3% of the computed values at temperatures from 250 to 330 K, and increasing to 5% at 100 K. These estimates are based on the experimental data and include both material variability and measurement uncertainty.

Table 4. Certified Values of Thermal Resistance of a 2.54 cm Thick Specimen, R_o, as a Function of Density and Temperature. (These values have been corrected for the thermal expansion of the measurement plates.)

	Density ($kg \cdot m^{-3}$)			
Temperature (K)	10	12	14	16
100	2.475*	2.443	2.403	2.358
110	2.219	2.202	2.176	2.144
120	2.000	1.995	1.979	1.957
130	1.812	1.816	1.809	1.795
140	1.649	1.661	1.661	1.654
150	1.508	1.526	1.532	1.530
160	1.386	1.409	1.420	1.422
170	1.279	1.306	1.321	1.328
180	1.185	1.216	1.234	1.244
190	1.102	1.136	1.157	1.170
200	1.027	1.064	1.088	1.104
210	0.960	0.999	1.026	1.043
220	0.898	0.939	0.968	0.988
230	0.842	0.884	0.914	0.936
240	0.789	0.832	0.864	0.887
250	0.739	0.783	0.816	0.841
260	0.693	0.737	0.771	0.796
270	0.650	0.694	0.728	0.754
280	0.609	0.653	0.688	0.715
290	0.571	0.615	0.649	0.677
300	0.536	0.579	0.613	0.641
310	0.503	0.546	0.580	0.607
320	0.472	0.514	0.548	0.575
330	0.444	0.485	0.518	0.545

*R_o values are in units of $m^2 \cdot K \cdot W^{-1}$

7. Summary

Measurements and data analysis are presented to establish a lot of glass fiberblanket as an SRM of thermal resistance for temperatures from 100 to 330 K and densities from 10 to 16 kg/m^3. A model is presented that describes the data over the above temperature and density range to within the imprecision of the data. Comparisons to previously published values for similar material are presented.

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