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THE EFFECT OF COMPRESSION ON THE MATERIAL R-VALUE OF FIBERGLASS BATT INSULATION*

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ABSTRACT

Fiberglass batt insulations intended for use in buildings are labeled with an R-value and a thickness at which the R-value is achieved. In some cases the insulation is installed in such a way that the label thickness is not achieved. The material R-value of fiberglass batts installed at less than full thickness will be less than the full-thickness R-value.

Results are presented for values measured in accordance with ASTM C 518 for commercially available fiberglass batts at full thickness and compressed to as much as 50% of full thickness. Thermal data and the resulting correlations are presented in this paper for six products manufactured in 1990.

KEY WORDS: R-value, Fiberglass, Insulation, Compression.

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INTRODUCTION

Commercially available fiberglass batts are labeled with an R-value that will be achieved at a stated thickness. Installation of the product can be done in such a way that the thickness stated on the label is not achieved. A common example of this situation is the installation of batts in wall cavities with stapling of support flanges inside of the cavity. Compression of insulating batts behind pipes, wires, or fixtures can also reduce the material R-value of the product. This study was undertaken to quantify the effect of compression on the R-value of fiberglass batts.

The thermal resistance (R-value) of fiberglass batt insulation depends on thickness (T) and apparent thermal conductivity (k). The apparent thermal conductivity at a specified average temperature, usually 75°F, is conventionally expressed in terms of density (D) as follows:

$$k = a + b \bullet D + c/D \qquad (1)$$

The constants a, b, and c in Equation (1) can be determined by the method of least squares if a set of (D, k) values are available. The R-value of an insulation is T divided by k. If the mass of an insulation specimen is constant then the density at a given T can be related to a reference value D_o, the density at label thickness, and the label thickness (T_o) by

$$D = T_o \bullet D_o/T. \qquad (2)$$

A combination of Equations (1) and (2) along with the identification of R_o as the R-value at thickness T_o and density D_o gives an expression for the ratio R/R_o in terms of T/T_o,

$$R/R_o = (F \bullet T_o/R_o)/(a + b \bullet D_o/F + c \bullet F/D_o) \tag{3}$$

where $F = T/T_o$.

A fiberglass batt at label thickness is represented by $F = 1$ in Equation (3) and $R = R_o$, the label value. If the batt is compressed then $F < 1$ and $R < R_o$. The evaluation of R/R_o requires values for the material specific constants a, b, and c.

The National Association of Home Builders, NAHB, [1] has published a few values for R/R_o, but the reference density (D_o) is not stated. Values for R/R_o calculated from data in the NAHB bulletin given in Table 1 show that R/R_o decreases as T/T_o decreases.

Table 1. The Reduction in R-Value for Two Fiberglass Batts Calculated from NAHB Data

	T/T_o	R/R_o
T_o = 3.5 inches	1.000	1.000
	0.857	0.900
	0.786	0.855
	0.714	0.809
	0.500	0.691
T_o = 6.5 inches	1.000	1.000
	0.917	0.932
	0.833	0.879
	0.667	0.774
	0.500	0.689

MATERIALS AND TEST METHOD

In the current study thermal resistance measurements were made on six commercially available fiberglass batt insulations in order to provide data like that shown in Table 1 for a range of D_o values. The six products tested had average D_o values ranging from 0.471 lb/ft^3 to 1.537 lb/ft^3. The batts were labeled with R_o-values ranging from 13.0 to 25.0 ft^2•h•°F/Btu.

Fiberglass batts manufactured by three companies were tested. Test specimens were taken from batts purchased at retail outlets or randomly selected from an insulation contractor's storage. Table 2 contains identifications that will be used to discuss the thermal test data. Three specimens of each of the first five products shown in Table 2 were tested. In the case of the test product F in Table 2 two specimens were cut and split into two sections of approximately 1/2 the full thickness of the batt. The batts were conditioned in the laboratory several days before testing. Weights and dimensions were obtained in order to determine the density at label thickness, and the initial density data are recorded in Table 3.

Thermal resistances were measured in accordance with ASTM C 518 [2] using apparatuses at Tennessee Technological University (TTU) and the Oak Ridge National Laboratory (ORNL). The specimens labeled (ORNL) in Table 3 were tested at Oak Ridge. All of the specimens were tested at TTU.

The heat-flow meter apparatus in operation at TTU is a R-Matic built by Dynatech Corp. in Cambridge, MA. It was calibrated using three 24 in. x 24 in. x 1 in.

specimens of NIST SRM 1450 b [3]. The three boards provided a calibration coefficient at 1.0, 2.0, and 3.0 inches of thickness and a mean specimen temperature of 75°F. The heat-flow meter apparatus in operation at ORNL is an advanced R-Matic built by

Table 2. Identification of Fiberglass Batt Products

Producer	Specimen Identification	Label R-Value R_o(ft^2•hr•°F/Btu)	Label Dimensions width (in)	thickness (in)
A	A-1,A-2,A-3	13	23	3.5
A	B-1,B-2,B-3	19	23	6.25
B	C-1,C-2,C-3	15	15.25	3.5
B	D-1,D-2,D-3	21	23.25	5.5
C	E-1,E-2,E-3	19	23.25	6.25
C	F-1A,F-1B,F-2A,F-2B	25	25.0	8.0

Holometrix, Inc. (formerly Dynatech), and was calibrated using NIST SRM 1451 [4] to provide calibration coefficients at 1.0, 3.0, and 6.0 inches of specimen thickness.

Test specimens were cut and initially tested at TTU. One specimen from sets A, B, C, D, and E was taken to ORNL for an additional sequence of measurements. Each specimen was tested at a thickness equal to or greater than the label thickness.

Table 3. D_o Values for 17 Fiberglass Batt Test Specimens

Specimen	D_o (lb/ft^3)	$\bar{D}_o$ (lb/ft^3)
A-1	0.8163	
A-1 (ORNL)[a]	0.8097	
A-2	0.9662	
A-3	0.8479	0.8600 (σ = 0.0630)
B-1	0.4472	
B-1 (ORNL)	0.4510	
B-2	0.5190	
B-3	0.4082	0.4564 (σ = 0.0399)
C-1	1.5407	
C-2	1.5407	
C-2 (ORNL)	1.5185	
C-3	1.5504	1.5365 (σ = 0.0134)
D-1	0.9372	
D-2	0.9797	
D-3	0.9360	
D-3 (ORNL)	0.9170	0.9425 (σ = 0.0229)
E-1	0.4845	
E-3[b]	0.5089	
E-4	0.4463	
E-4 (ORNL)	0.4447	0.4711 (σ = 0.0270)
F-1	0.5372	
F-2	0.5325	0.5349 (σ = 0.0024)

(a)Selected specimens were tested at Oak Ridge National Laboratory.

(b)E-2 became wet during testing so the data were discarded.

Then R-values were obtained at reduced thicknesses without removing the insulation specimen from the test apparatus.

DISCUSSION OF THE THERMAL TEST RESULTS

The measured k-values for the six products are shown as a function of test specimen density in Figures 1-6. The individual test sequences are indicated by symbols in the figures and a curve representing a least-squares correlation of the data is shown in each figure. The thermal test data from each of the six products were used to obtain the a, b, and c needed to calculate R/R_o. These values are listed in Table 4. Table 4 also contains two measures of the goodness-of-fit of the curve to the data. An average absolute percent difference, E, is listed and the standard deviation, σ, of the experimental data from the curve is shown. The E was less than 2% in all cases and less than 1% in two cases.

The parameters in Table 4 were used to calculate R/R_o using Equation (3). The results are shown in Table 5 for T/T_o from 1.0 to 0.5. The correlations were also used to calculate the R-value at the label thickness, R_o. The measured R_o and the label value, R_o (label), are also shown in the table.

The R/R_o in Table 5 demonstrate the decrease in R as fiberglass batts are compressed. The R_o in this discussion is the measured R-value at label thickness. An interesting comparison between the ratios in Table 5 and the ratios in Table 1 can be made at $T/T_o = 0.5$. The present results show R/R_o ranging from 0.55 to 0.65 at $T/T_o = 0.5$ while Table 1 shows R/R_o is near 0.69. The agreement between the two tables is

Table 4. Thermal Test Summary and Values for a, b, and c for Six Products

Specimen	Number of Data	Density Range (lb/ft^3)	a	b	c	$E^{(a)}$ %	$\sigma^{(b)}$
A	24	0.81 - 2.84	0.17894	0.47422×10^{-2}	0.69600×10^{-1}	0.51	0.171×10^{-2}
B	26	0.38 - 0.91	0.18421	-0.79912×10^{-2}	0.67139×10^{-1}	1.90	0.736×10^{-2}
C	23	1.50 - 5.18	0.19946	-0.11693×10^{-2}	0.60994×10^{-1}	0.87	0.277×10^{-2}
D	34	0.87 - 3.66	0.18645	0.13054×10^{-2}	0.71670×10^{-1}	1.00	0.327×10^{-2}
E	33	0.44 - 2.69	0.19675	-0.50767×10^{-3}	0.62969×10^{-1}	1.81	0.664×10^{-2}
F	26	0.40 - 1.98	0.14698	0.19720×10^{-1}	0.76598×10^{-1}	1.91	0.639×10^{-2}

[a] E is the average absolute difference between experimental and calculated k values.

[b] σ is the standard deviation of the data about Equation (1). The units are $Btu \cdot in/ft^2 \cdot hr \cdot {}^\circ F$.

Table 5. R/R_o as a Function of T/T_o for Six Fiberglass Batt Products

Specimen/	A	B	C	D	E	F
D_o (lb/ft^3)	0.86	0.46	1.54	0.94	0.47	0.53
R_o [a]	13.3	19.1	14.7	20.9	18.9	26.6
R_o	13	19	15	21	19	25
T/T_o (F)	R/R_o	R/R_o	R/R_o	R/R_o	R/R_o	R/R_o
1.00	1.000	1.000	1.000	1.000	1.000	1.000
0.95	0.964	0.972	0.958	0.964	0.970	0.971
0.90	0.927	0.944	0.916	0.926	0.938	0.941
0.85	0.888	0.913	0.873	0.888	0.905	0.909
0.80	0.849	0.882	0.829	0.848	0.871	0.876
0.75	0.808	0.848	0.784	0.807	0.835	0.840
0.70	0.765	0.813	0.740	0.765	0.797	0.803
0.65	0.721	0.777	0.693	0.721	0.758	0.763
0.60	0.676	0.738	0.647	0.678	0.716	0.720
0.55	0.629	0.697	0.599	0.629	0.673	0.675
0.50	0.580	0.654	0.550	0.581	0.628	0.627
α	0.700	0.524	0.824	0.706	0.579	0.536
β	0.278	0.332	0.150	0.261	0.328	0.415
σ	0.4×10^{-3}	0.8×10^{-3}	0.4×10^{-3}	0.8×10^{-3}	0.5×10^{-3}	0.1×10^{-2}

[a] The units for R in this table are ft^2•hr•°F/Btu. R_o refers to the measured value at label thickness. R_o (label) is the R-value stated on the label.

best for fiberglass batt insulation specimens B, E, and F.

The R/R_o in Table 5 can be described analytically by

$$R/R_o = 1 - \alpha(1\text{-}T/T_o) - \beta(1\text{-}T/T_o)^2 = 1 - \alpha(1\text{-}F) - \beta(1\text{-}F)^2. \quad (4)$$

Least-square values for α and β are shown in Table 5 along with the standard deviation of the "data" points about the curve. The parameters α and β can be expressed as linear functions of D_o to provide an expression for R/R_o as a function of T/T_o (or F) and D_o

$$R/R_o = 1 - (0.4268 + 0.2726\ D_o)(1\text{-}F) - (0.4690 - 0.2103\ D_o)(1\text{-}F)^2. \quad (5)$$

Equation (5) was used to calculate R/R_o for comparison with ratios in Table 5 that were used to develop the expressions for α and β. The results are shown in Table 6.

The entries in Table 6 show that Equation (5) describes the smoothed R/R_o in Table 5 to better than 3.50% for all six products compressed to as much as 50% of label thickness. In four of the six cases, the description is better than 2%. The average deviations between test data and Equation (1) were less than 2% is all 6 cases. The maximum uncertainty in R/R_o calculated with Equation (5) for $0.5 < F < 1.0$ and $0.45 < D_o < 1.54$ is 5 to 6%.

Figure 7 shows R/R_o as a function of T/T_o for the six insulation products that were tested. This figure is a graphical representation of the R/R_o given in Table 5. Equation 5 is shown graphically in Figure 8 for D_o values of 0.4, 0.8, 1.2, and 1.6 lb/ft^3. This figure shows the ordering of the R/R_o curves with D_o. The curve for D_o of 1.6 lb/ft^3 decreases more rapidly with T/T_o than the curve for D_o of 0.4.

Table 6. A Comparison of R/R_0 Calculated with Equation (5) and the R/R_0 from the Correlation of Thermal Test Data

Product Diff.[c]	% Diff. at T/T_0 = 0.8[a]	% Diff. at T/T_0 = 0.65[b]	Ave %
A	0.88	3.00	1.30
B	0.77	3.50	1.43
C	0.52	1.72	0.78
D	0.53	1.61	0.73
E	0.40	0.39	0.33
F	0.51	0.45	0.56

[a]absolute value of the percent difference

[b]absolute value of the percent difference

[c]average percent difference for T/T_0 = 0.975 to T/T_0 = 0.500 (20 points).

CONCLUSIONS

Thermal measurements show that the thermal resistance of six commercially available fiberglass batts decreases as the batts are compressed. The measured R-values at the label thickness agreed with the label R-values to within the experimental uncertainty of the thermal measurements. The measured R-values at label thickness exceeded the label R-value in three of six cases while the measured R-value at label thickness was 2% below the label R-value in one case. The decrease in R-value with compression was greatest for the highest density product and least for the lowest density product. Equation 5 describes the R/R_o values calculated from the thermal data to better than 3.5% over the range of thicknesses and densities studied. A correlation for the ratio R/R_o in terms of T/T_o and D_o describes the data set to better than 6% for $0.5 < T/T_o < 1.0$ and $0.45 < D_o < 1.54$ when both experimental uncertainty and data smoothing are taken into account.

The measurements reported in this paper show that material R-values shown on the insulation product labels are achieved if the insulation is installed at the thickness stated on the label. Installations that result in batt thicknesses less than the label thickness can have substantially lower material R-values.

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4. J. G. Hust, "Glass Fiberblanket SRM for Thermal Resistance," NBS SP 260-103, NIST, September 1985.

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Figure 1. Apparent Thermal Conductivity as a Function of Density for Specimen Set A. (○ = A_1, ● = A_1(ORNL), Δ = A_2, and □ = A_3)

Figure 2. Apparent Thermal Conductivity as a Function of Density for Specimen Set B.

(○ = B_1, ● = B_1(ORNL), Δ = B_2, and □ = B_3)

Figure 3. Apparent Thermal Conductivity as a Function of Density for Specimen Set C.

(○ = C_1, ● = C_1(ORNL), Δ = C_2, and □ = C_3)

Figure 4. Apparent Thermal Conductivity as a Function of Density for Specimen Set D. (○ = D_1, ● = D_1(ORNL), Δ = D_2, and □ = D_3)

Figure 5. Apparent Thermal Conductivity as a Function of Density for Specimen Set E.

(○ = E_1, ● = E_1(ORNL), Δ = E_2, and □ = E_3)

Figure 6. Apparent Thermal Conductivity as a Function of Density for Specimen Set F.

(○ = $F_{1\text{-}a}$, ● = $F_{1\text{-}b}$, Δ = $F_{2\text{-}a}$, and ▲ = $F_{2\text{-}b}$)

Figure 7. The Thermal Resistance Ratio (R/R_o) as a Function of the Fraction of Label Thickness (T/T_o).

Figure 8. The Thermal Resistance Ratio Calculated at D_o = 0.4, 0.8, 1.2, and 1.6 lb/ft^3 Using Equation 5.

Fig 1

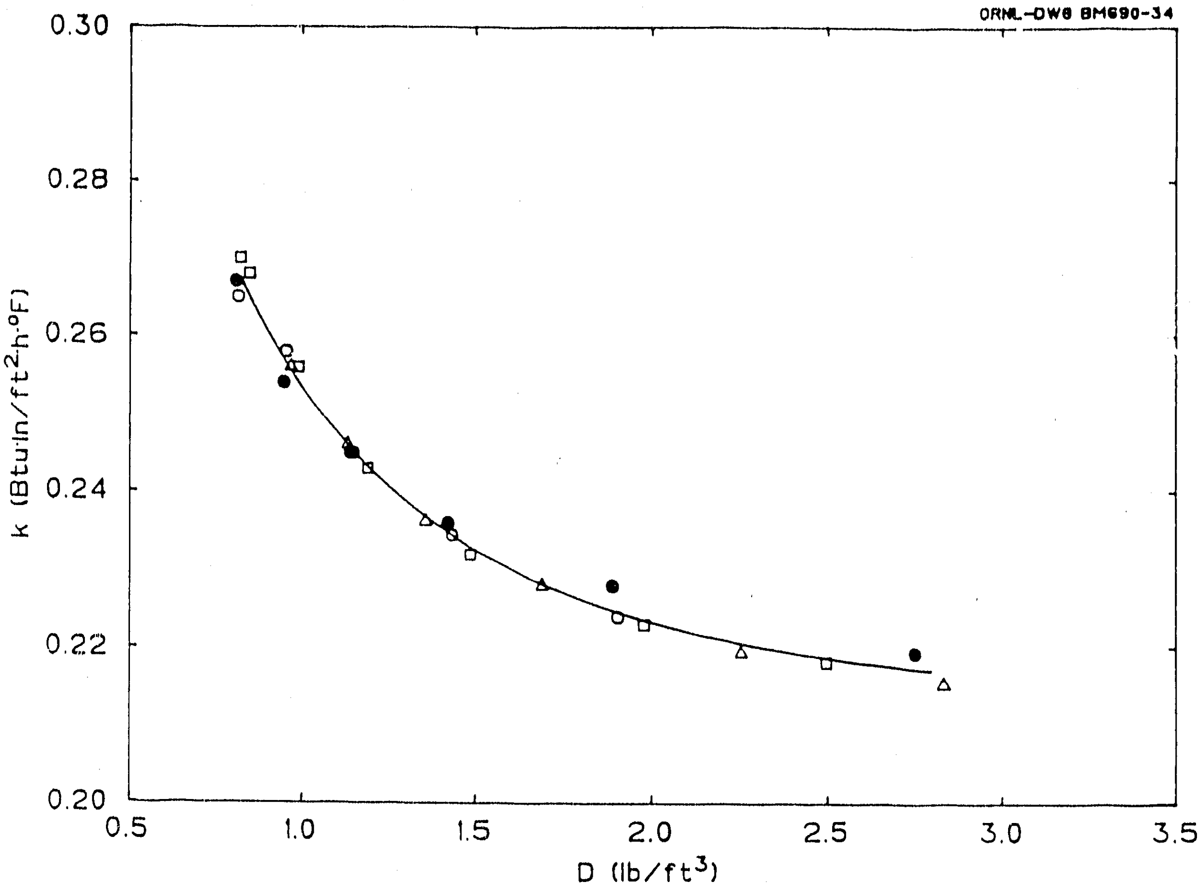

ORNL-DWG 8M690-34
0.30
0.28
0.26
0.24
0.22
0.20
k (Btu·in/ft²·h·°F)
0.5
1.0
1.5
2.0
2.5
3.0
3.5
D (lb/ft³)

Fig 2

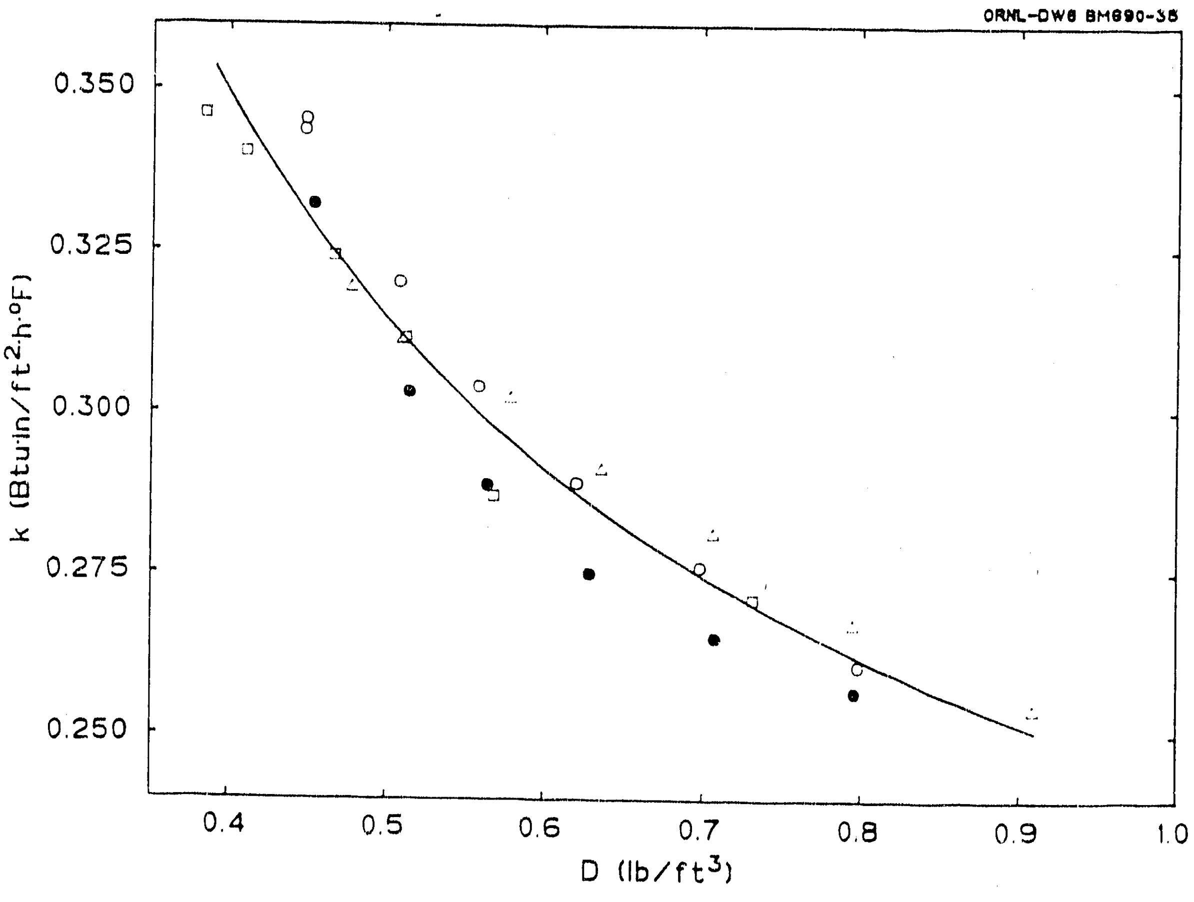

ORNL-DWG 8M690-35
0.350
0.325
0.300
0.275
0.250
k (Btu·in/ft²·h·°F)
0.4
0.5
0.6
0.7
0.8
0.9
1.0
D (lb/ft³)

Fig 3

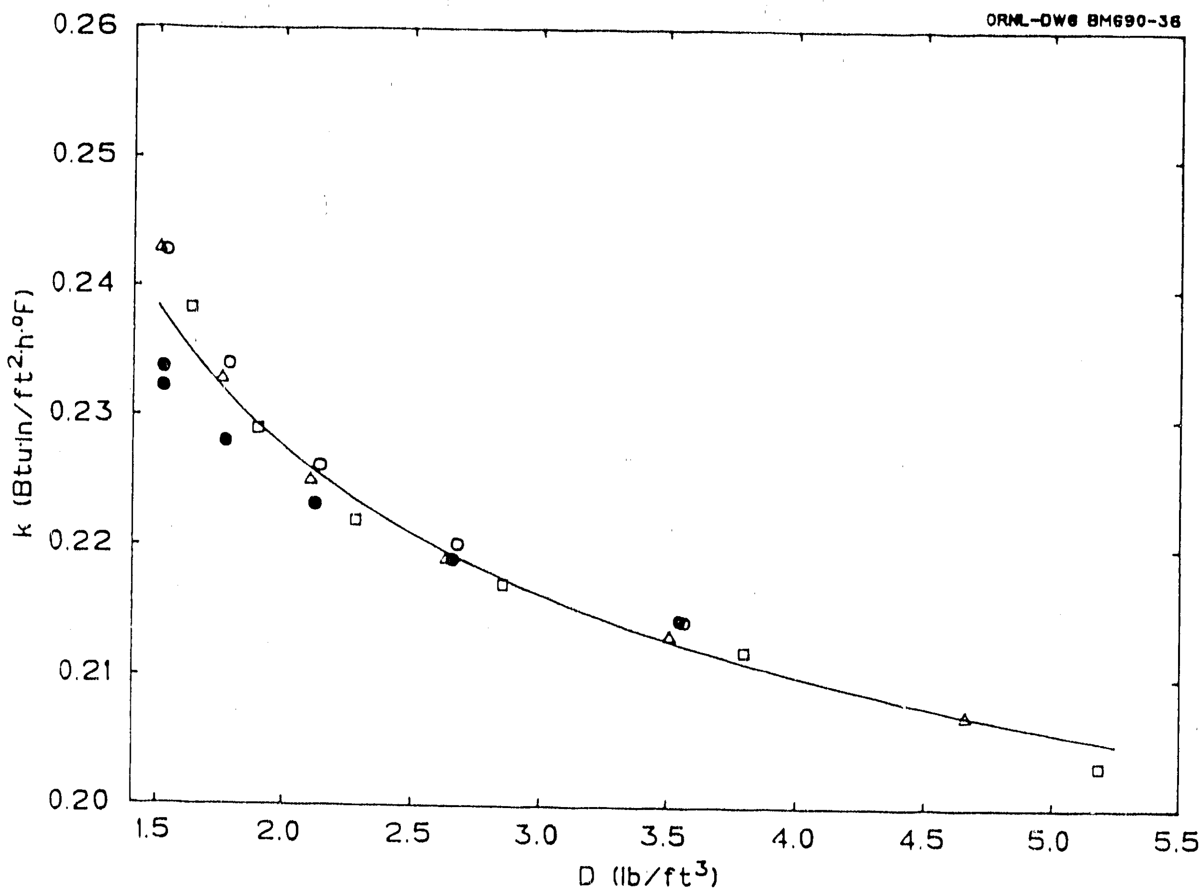

ORNL-DWG BM690-36
0.26
0.25
0.24
0.23
0.22
0.21
0.20
k (Btu·in/ft²·h·°F)
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
D (lb/ft³)

Fig 4

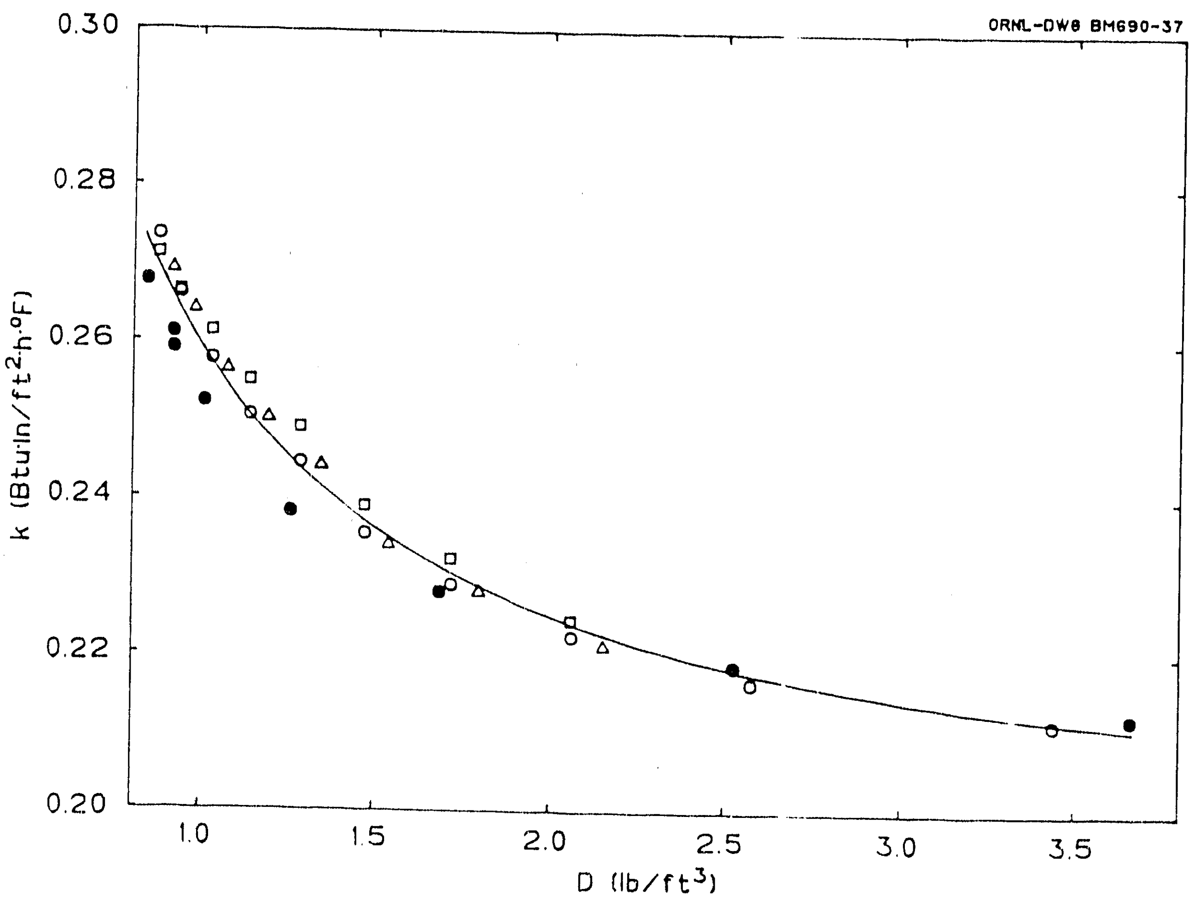

ORNL-DWG BM690-37
0.30
0.28
0.26
0.24
0.22
0.20
k (Btu·in/ft²·h·°F)
1.0
1.5
2.0
2.5
3.0
3.5
D (lb/ft³)

Fig 5

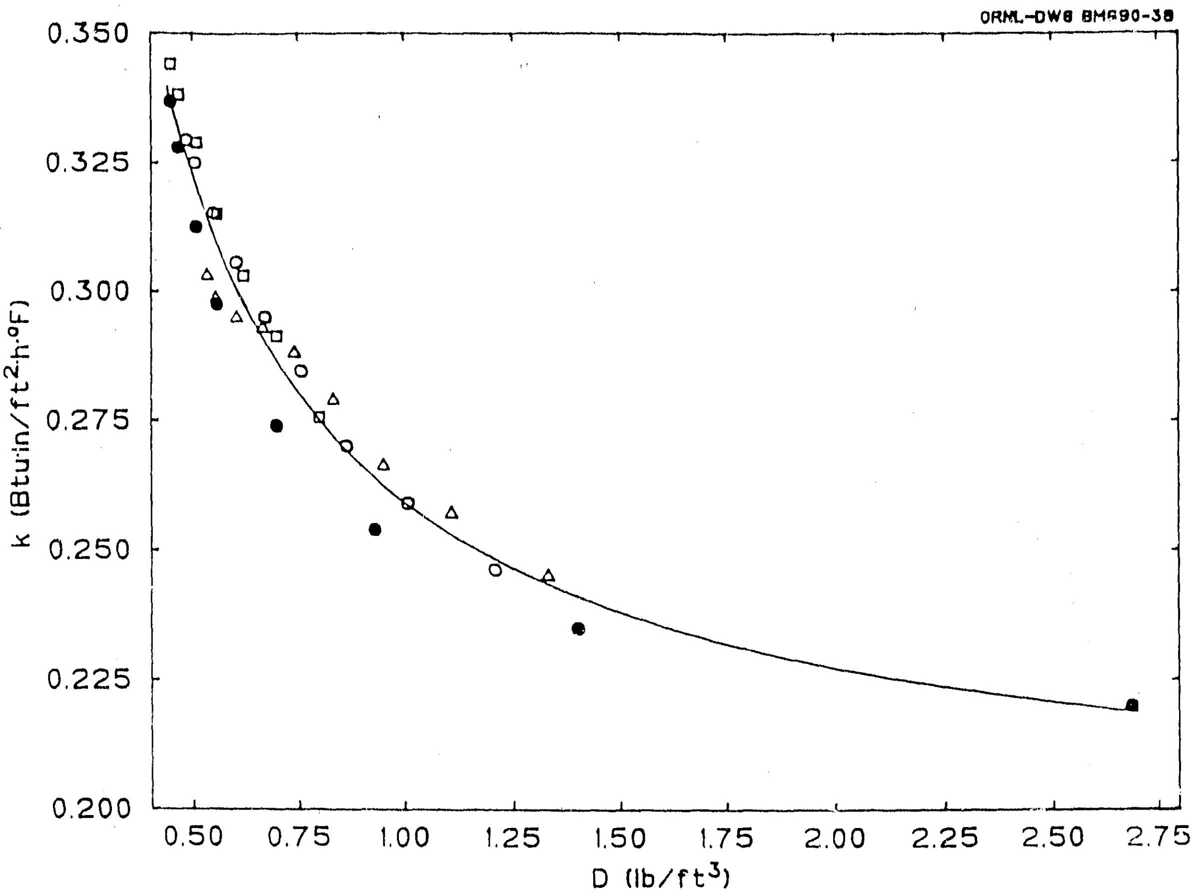

ORNL-DWG 8M690-38
0.350
0.325
0.300
0.275
0.250
0.225
0.200
k (Btu·in/ft²·h·°F)
0.50
0.75
1.00
1.25
1.50
1.75
2.00
2.25
2.50
2.75
D (lb/ft³)

Fig 6

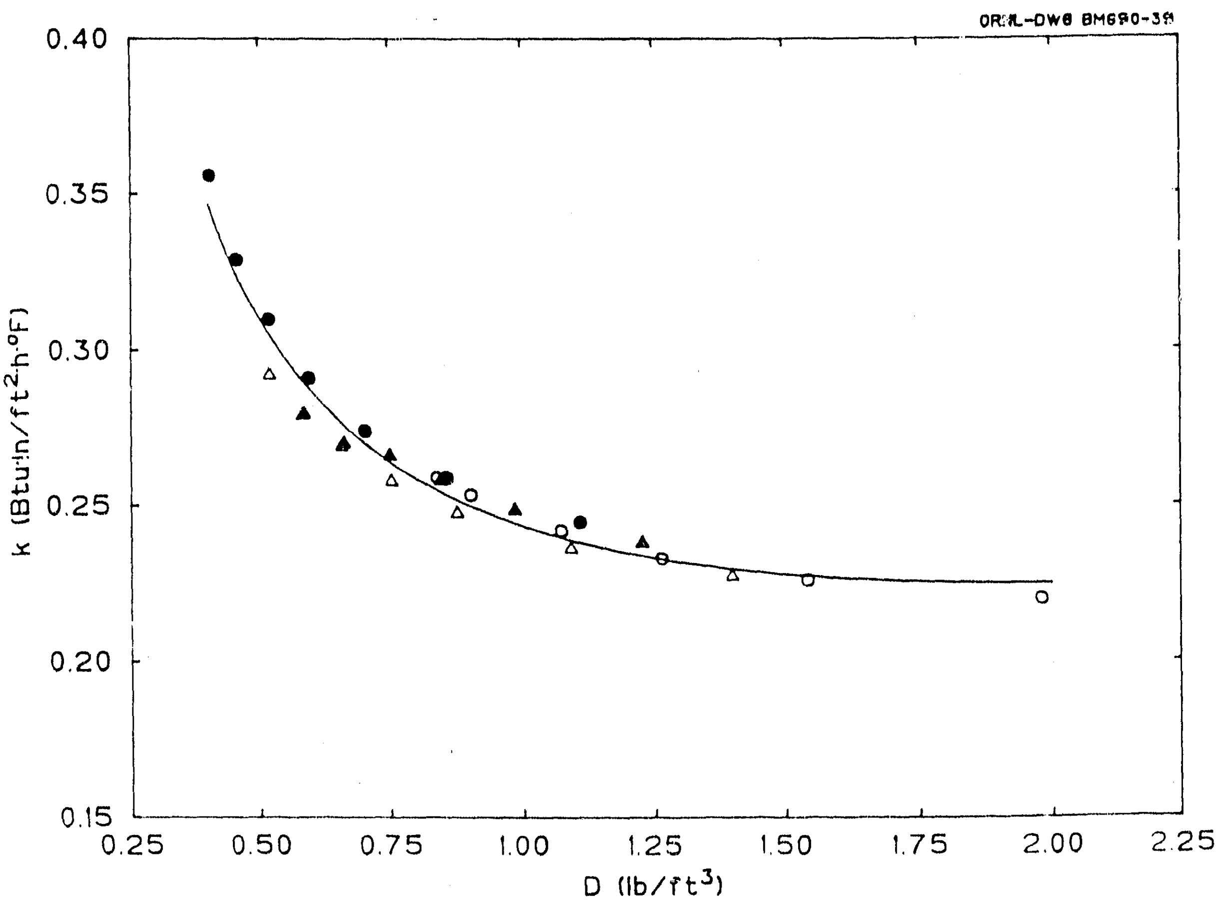
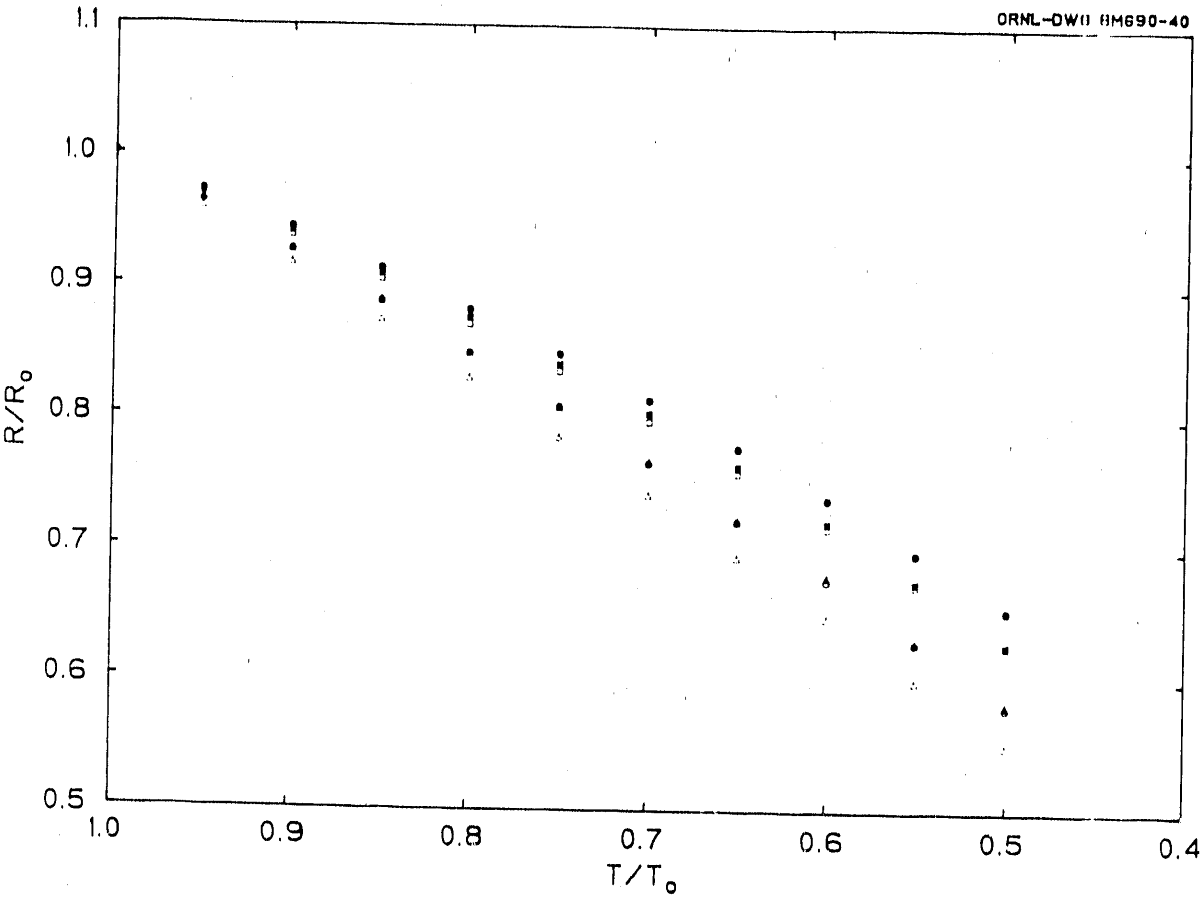
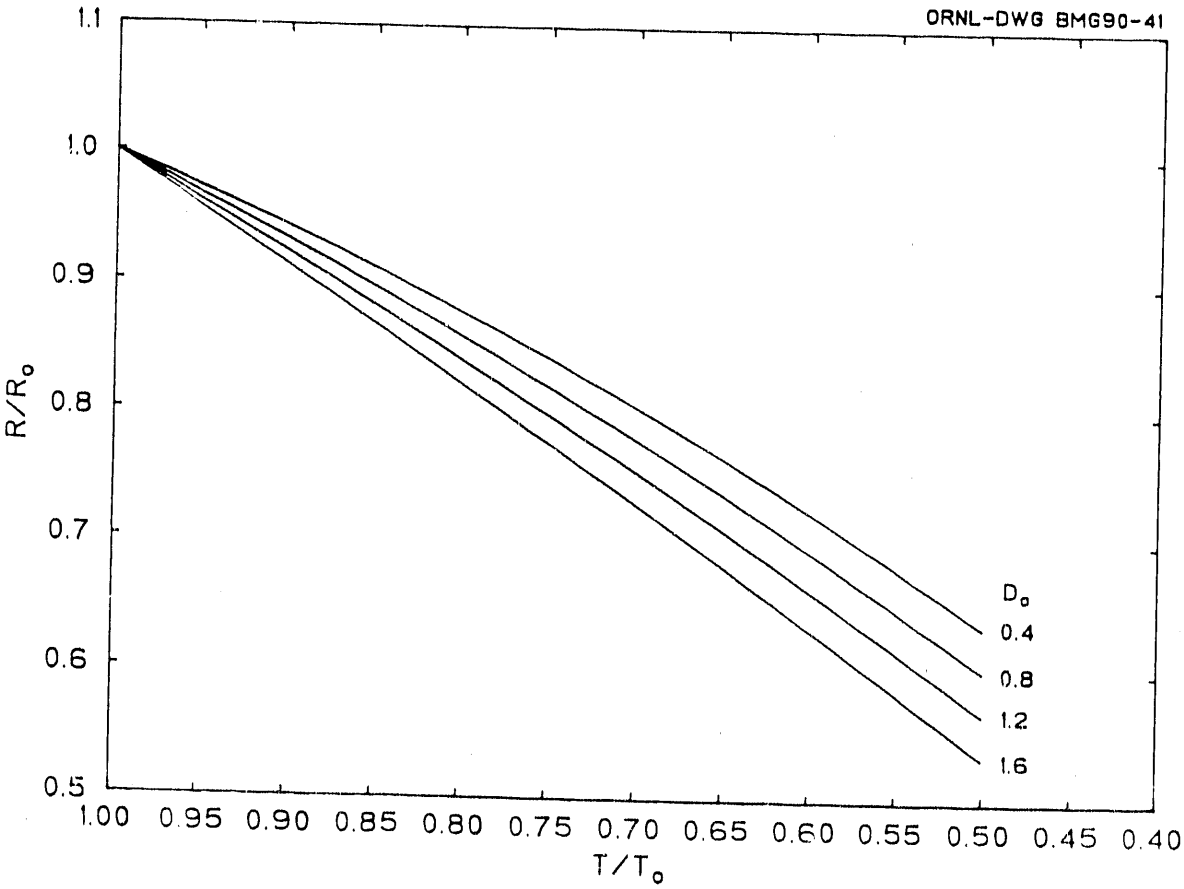

ORNL-DWG 8M690-39
0.40
0.35
0.30
0.25
0.20
0.15
k (Btu·in/ft²·h·°F)
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
2.25
D (lb/ft³)

Fig 1



ORNL-DWG 8MG90-40
1.1
1.0
0.9
0.8
0.7
0.6
0.5
R/Ro
1.0
0.9
0.8
0.7
0.6
0.5
0.4
T/To

Fig 8



ORNL-DWG 8MG90-41
1.1
1.0
0.9
0.8
0.7
0.6
0.5
R/Ro
Do
0.4
0.8
1.2
1.6
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
T/To

END

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