R-VALUE AND THERMAL CONDUCTIVITY OF CROSSLINKED POLYETHYLENE (PEX) AND POLYETHYLENE OF RAISED TEMPERATURE (PE-RT) TUBING

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Foreword

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The purpose of this technical report is to report the test results for thermal conductivity and “R-value” of crosslinked polyethylene (PEX) tubing and polyethylene of raised temperature resistance (PE-RT) tubing.

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1.0 INTRODUCTION

Thermal conductivity through a homogeneous material such as the wall of crosslinked polyethylene (PEX) or polyethylene of raised temperature (PE-RT) pipe or tubing is a measurement of the rate at which heat transfers by conduction. It can be measured as the amount of heat, in British thermal units (BTUs) per hour, that will conduct through one square foot of one-inch-thick material, when the temperature differential across the material is one degree Fahrenheit[1].

Thermal conductivity is often denoted as ***k*** or ***k factor*** and is expressed as (BTU-in) / (ft^2-hr-°F). It can be converted to SI units as Watts per meter per degree Kelvin or W/(m-°K), where 1 (BTU-in) / (ft^2-hr-°F) = 0.1442279 W/(m-°K).[2]

Thermal resistance, or R-value, is a measurement used to compare the relative thermal resistance of materials used in the construction industry. For a flat surface, R-value is the reciprocal of ***k***, thus a lower R-value means greater heat conduction and vice versa. The letter “R” is placed before the numerical value, as in R19 or R-19[3].

In the process of designing a plumbing system or a radiant heating/cooling system or other application where PEX or PE-RT tubing is to be used, it is sometimes necessary to know the R-value of the tubing. In order to provide this information to interested parties, the Building and Construction Division of the Plastics Piping Institute undertook a test program to determine the thermal conductivity and R-value of PEX and PE-RT tubing.

2.0 OBJECTIVE

The objective of the test program was to determine the thermal conductivity of various PEX tubing materials. For completeness and comparison purposes, PE-RT tubing was also tested.

Samples were submitted of PE-RT and PEX tubing. The PEX samples were produced in accordance with ASTM F876 *Standard Specification for Crosslinked Polyethylene (PEX) Tubing* and included specimens representing all three common manufacturing methods (see PPI TN-17 *Crosslinked Polyethylene (PEX) Pipe & Tubing Systems* for more information on PEX manufacturing methods) and two colors of PEX. PE-RT tubing samples were produced in accordance with ASTM F2769 *Standard Specification for Polyethylene of Raised Temperature (PE-RT) Plastic Hot- and Cold-Water Tubing and*

[1] Olin, Schmidt, Lewis, revised Simmons, *CONSTRUCTION PRINCIPLES, MATERIALS, AND METHODS*, (New York: VAN NOSTRAND REINHOLD, 1994) p. 948.
[2] Taylor, *Guide for the Use of International System Units (SI) Special Publication 811,* (Gaithersburg, MD: National Institute of Standards and Technology, 1995) p. 46.
[3] Olin p. 949

Distribution Systems. The samples were flattened into disk form to accommodate the testing equipment.

3.0 TESTING

The tests were conducted in the summer of 2012 by The Dow Chemical Company.

The equipment used was a Hot Disk AB model TPS 2500 S which meets ISO Standard ISO/DIS 22007-2.2. ISO/DIS 22007-2.2 utilizes the “Transient Plane Source Method” to determine a material’s thermal conductivity. The data is comparable to that generated in compliance with ASTM D5930 which utilizes the “Transient Line Source Method”.

The test protocol includes tests at three temperatures: 73°F (23°C), 140°F (60°C), and 180°F (82.2°C). Samples were provided to the laboratory without brand or type identification (blind).

4.0 RESULTS AND CONCLUSIONS

Using the average of all PEX test samples at each temperature, the ***k factor*** results of 2.89, 2.88, and 2.82 (BTU-in)/(ft^2-hr-°F) were obtained. This is a narrow range, and the average ***k factor*** of 2.86 was used in the calculations of R-value for PEX.

The wall thickness of PEX is less than 1 in. and varies by its nominal size. To provide additional information specific to nominal SDR9 PEX sizes, Table 1 shows the R-value by nominal size:

Table 1: R-Value of SDR9 PEX tubing per Nominal Tubing Size

Nominal Tubing Size	1/2	3/4	1	1 1/4	1 1/2	2
R-value	0.028	0.038	0.049	0.060	0.072	0.093

Note 1: The R-value was calculated based on the ***k factor*** for PEX at 73°F (23°C), 140°F (60°C), and 180°F (82°C) and dimensions found in ASTM F876.

The following equation was used:

R = r2-ln (r2 / r1) / k [4]

Where:

- r1 = inside radius (in.)
- r2 = outside radius (in.)
- k = thermal conductivity (BTU-in)/(ft^2-hr-°F)
- ln = natural logarithm

[4] The simple relation for flat sheet conductivity does not hold true when looking at cylindrical pipe. For cylindrical geometry, heat flow is not the simple straight through heat flow found in flat surface material, but rather radial heat flow. This reasoning is based on the fact that the inner radius surface area is much smaller that the outer radius surface area.

Two colors of PEX were tested, and little difference was noted. Therefore, the color of PEX appears to be insignificant in determining *k factor* and R-value.

For reference and comparison purposes, Table 2 lists the thermal conductivity of PEX (from above), PE-RT (also tested as part of this project)[5] and copper[6].

Table 2: Thermal Conductivity of PEX, PE-RT, and Copper Tubing

Material	Thermal Conductivity BTU-in/(ft²-hr-°F)	Thermal Conductivity W/(m-°K)
PEX	2.86	0.41
PE-RT	3.15	0.46
Copper	196	28

[5] There was variation between PE-RT and PEX from various sources. Actual thermal conductivity values may vary from the average values reported by +/- 5%.
[6] Copper Development Association Inc., *Properties of Wrought and Cast Copper Alloys – Physical Properties,* Alloy C12200 http://www.copper.org/resources/properties/db/CDApropertiesselectionservlet.jsp?mode=basic, July 2013.

Appendix

Results of the testing at each of the three temperatures are detailed in the following tables[7]:

Table 3: Testing Results at 73°F (23°C)

Sample	Material	Temperature °F (°C)	Thermal Conductivity BTU-in/(ft^2-hr-°F)	Thermal Conductivity W/(m-°K)	Std. Deviation
1	PEX	73 (23)	3.029	0.437	2.59E-03
3	PEX	73 (23)	2.821	0.407	6.19E-04
3a	PEX	73 (23)	2.994	0.432	3.57E-04
5	PEX	73 (23)	2.792	0.403	2.84E-04
5a	PEX	73 (23)	2.830	0.408	4.55E-04
6	PE-RT	73 (23)	3.266	0.471	3.88E-04
6a	PE-RT	73 (23)	3.050	0.440	8.52E-04

PEX Avg. 2.893

Table 4: Testing Results at 140°F (60°C)

Sample	Material	Temperature °F (°C)	Thermal Conductivity BTU-in/(ft^2-hr-°F)	Thermal Conductivity W/(m-°K)	Std. Deviation
1	PEX	140 (60)	3.004	0.433	4.64E-04
3	PEX	140 (60)	2.841	0.410	7.49E-04
3a	PEX	140 (60)	2.937	0.424	3.36E-04
5	PEX	140 (60)	2.789	0.402	1.14E-03
5a	PEX	140 (60)	2.830	0.408	6.02E-04
6	PE-RT	140 (60)	3.266	0.471	3.88E-04
6a	PE-RT	140 (60)	3.163	0.456	3.55E-04

PEX Avg. 2.880

Table 5: Testing Results at 180°F (82°C)

Sample	Material	Temperature °F (°C)	Thermal Conductivity BTU-in/(ft^2-hr-°F)	Thermal Conductivity W/(m-°K)	Std. Deviation
1	PEX	180 (82)	2.968	0.428	1.55E-04
3	PEX	180 (82)	2.760	0.398	3.35E-04
3a	PEX	180 (82)	2.864	0.413	1.44E-04
5	PEX	180 (82)	2.740	0.395	1.82E-03
5a	PEX	180 (82)	2.754	0.397	1.97E-03
6	PE-RT	180 (82)	3.227	0.465	1.02E-03
6a	PE-RT	180 (82)	2.949	0.425	2.43E-04

PEX Avg. 2.817

[7] Sample 2 was omitted from the results because it had been prepared in a different manner and might not be representative.