Technical Report

Measuring the R-Value of Thermal Insulation at Various Temperatures

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Introduction

Insulation materials of all types provide building owners with resistance to heat flow, called thermal resistance or R-value, to reduce energy costs. In the USA, insulation manufacturers, code officials, building owners and occupiers, etc. have relied on standard test methods for evaluating the effectiveness of insulation materials. These standard test methods allow all interested parties to compare the performance of different insulation technologies on an even baseline.

All insulation materials that claim an R-value are required to declare the R-value at the same temperature, 75°F, according to federal law. All commonly used methods for evaluating insulation require there to be a temperature difference from one side of the insulation to the other to create a heat flow, called the heat flux, that can be measured. The R-value is reported at the average of the hot and cold side temperature, 75°F in most cases. However, all insulation products show changes in thermal resistance (R-value) with changes in temperature. R-value is determined from thickness, L, and a physical property called "apparent thermal conductivity", k_a, using the equation:

$$\boldsymbol{R\ value = \frac{L}{k_a}}$$

It is common for insulation materials, such as polyisocyanurate foam board, to be described by the thermal resistivity, or the R per inch (R/in) of material manufactured. The smaller the apparent thermal conductivity, k_a, the larger the potential R-value. The property k_a generally becomes smaller as the mean temperature decreases. This means that generally, a reduction in mean temperature results in an increase in R-value.

The variation of R-value with temperature can be complex. The relationship of R-value and temperature for some insulation materials is often linear, meaning that the change in R-value changes at a constant rate over the temperature range common in building applications. Compared to the R-value at 75°F, the R-value at lower temperatures will be higher and the R-value at higher temperatures will be lower. If the change in temperature results in physical or chemical changes the changes in thermal resistance can be non-linear. For closed cell foams like polyiso, extreme temperatures can impact the dimensional or cell-gas composition which changes the thermal resistance.

R-value measurements

Heat flow meters (HFM) are commonly used to evaluate the R-value of thermal insulations. Heat flow meters operate under the guidelines of standard test method ASTM C518, "Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus". The overall process of arriving at R-value involves two steps. The HFM is used to measure the heat flux that results from a temperature difference across

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the insulation. Then, the HFM data are analyzed to arrive at values for k_a, R/in. and R-value. The data from a test in the HFM allows the user to determine the R-value of the insulation at the specific test conditions, how large the temperature difference is across the insulation, what the mean temperature is during the test, and the direction of heat flow. There is an infinite combination for the determination of R-value at different mean temperatures, temperature differences and heat flow directions.

There are two options to characterizing the R-value over the range of use for an insulation material. The first option is to measure a material at all possible combinations of mean temperatures and temperature differences. This is difficult due to the amount of time and effort it would take to accomplish. The second option is to use the data that comes from the HFM to calculate the R-value for a range of temperatures. Using selective measurements from the HFM, the material R-value is calculated using ASTM C1045, "Standard Practice for Calculating Thermal Transmission Properties Under Steady-State Conditions".

Calculating R-Value

ASTM C1045 is the uniform procedure for calculating all thermal properties regardless of the test method used to obtain the test data.

There are two common methods for calculating the R value of insulation materials.

1. The commonly used method includes analysis that is valid when the variation of k_a with temperature is linear. This involves making a minimum of two measurements at the upper and lower temperature use range, fitting the data with a linear curve fit and solving for the equation. Generally, additional measurements are made within the temperature range to prove that the variation of k_a is linear for the material and to improve the quality of the data fit. It is recommended that a minimum of four R-value measurements be made for this approach. This is a simplified approach because a linear variation of k_a is valid for many insulations.

2. The second approach allows the user to solve for more complicated equations that describe the changes in thermal performance when the changes in k_a are non-linear over the temperature range. This method of calculating thermal performance is known as the "Thermal Conductivity Integral (TCI) Method". Any combination of temperature differences and average temperatures can be captured using the TCI method. Additional measurements are required to improve the quality of the fit of the equation to the material thermal performance.

ASTM C1045 recognizes that the HFM determines the average value for k_a over the temperature range T_{cold} to T_{hot}. This fact can be used to describe how R value varies with temperature and an equation that provides the average R value for a range of temperatures. The equation used to describe the temperature dependent R-value when the change in R-value is not linear can be a polynomial equation.

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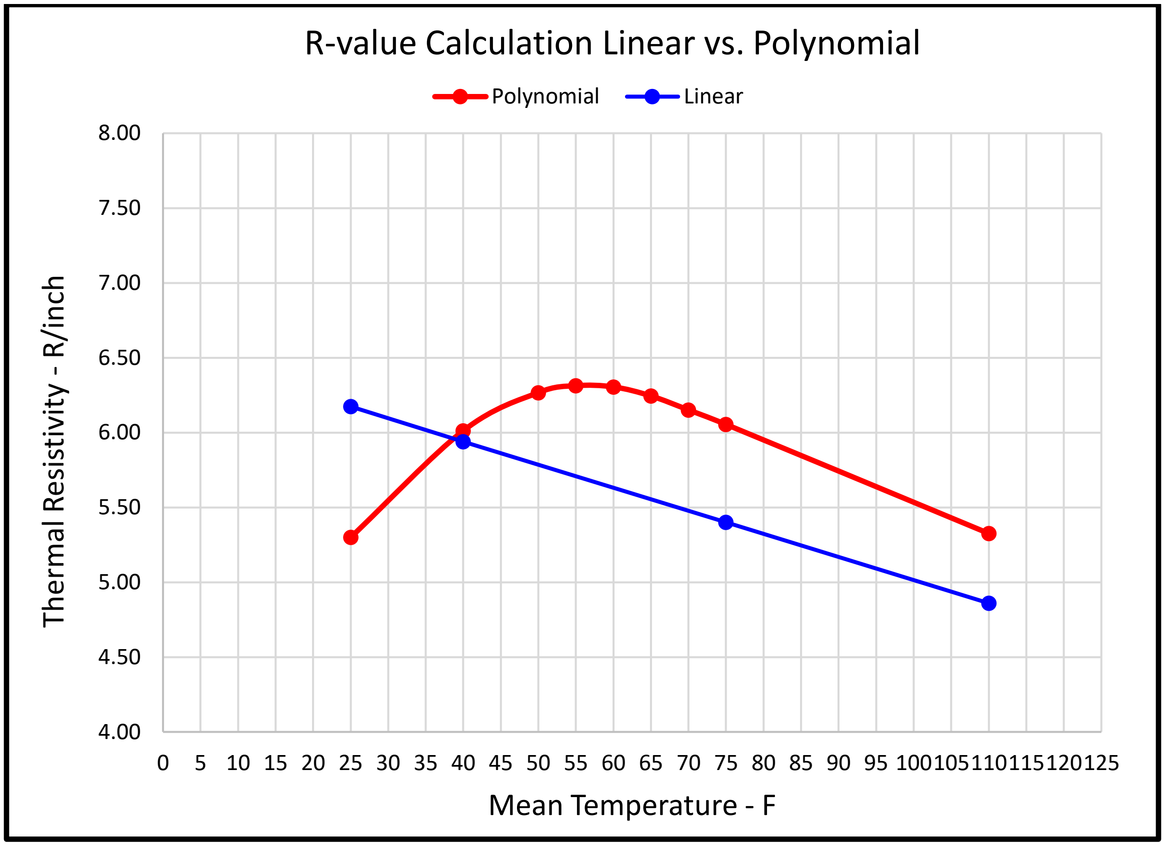
The two methods for calculating R-value described above are shown in Figure 1. The blue data points and line in Figure 1 describes a material where the change in R-value over the temperature range is linear. The red data and curve in Figure 1 describes a material where the change in R-value over the temperature range is non-linear. Both materials had measurements performed according to ASTM C518 and the thermal data was evaluated using ASTM C1045.



Conclusion

Insulation materials are evaluated for thermal performance using widely accepted consensus measurement techniques and are reported in accordance with federal law. All insulation materials have varying thermal performance as the temperature changes. These changes can be linear with respect to temperature where there are no chemical or physical changes or these changes can be more complex when chemical or physical changes do occur. ASTM C1045 is used to calculate the range of thermal performance for all measurement and material types.

ASTM C518 "Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus
ASTM C1045 "Standard Practice for Calculating Thermal Transmission Properties Under Steady-State Conditions"