CONF-8906031--57

K/QT-301

Thermal Properties Evaluation of Insulation in Overpack Containers for UF_6 Transport

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INTRODUCTION

Two types of insulation are currently in use in overpacks utilized to protect UF_6 during transport. Phenolic foam has been used in the family of UF_6 overpacks under U. S. Department of Transportation Specifications 20PF-1, 20PF-2, 20PF-3, 21PF-1, and 21PF-2 and modifications since the mid 1960s. Recently new generation overpacks have been developed which utilize polyurethane foam. A comparative analysis was made of the thermal characteristics of the phenolic foam with that of polyurethane in two different densities.

Thermal properties of materials vary with temperature with the relationship being a complex interaction of basic materials properties, processing variables, and environmental conditions. Typically, the thermal conductivity of a material increases with increasing temperature, and adequate thermal models of materials systems or structures require temperature dependent thermal properties such as conductivity. In the event of an overpack container exposed to a fire as a heat source, the thermal properties of the materials of construction will vary with temperature which varies with time. Environmental interactions will result in material properties changes which will be reflected in changes in thermal properties. Thus, analytical models that do not incorporate time, temperature dependent material thermal properties may not adequately evaluate a structural system thermal response.

The need to incorporate temperature dependent thermal properties into analytical finite element codes led to an experimental program to measure thermal properties, principally thermal conductivity, for the 21PF-1 overpack phenolic foam. The thermal conductivity-temperature relationship for this insulator has been measured from room temperature to over 1000F. An alternate UF_6 product cylinder overpack container has recently entered service; an overpack design incorporating polyurethane as the primary thermal resistance in place of the phenolic foam in a 2 1/2 ton cylinder overpack. Elevated temperature thermal properties measurements for the polyurethane material system are presented.

EXPERIMENTAL EVALUATION

The thermal conductivity and specific heat capacity properties of two grades of polyurethane foam were determined experimentally. The polyurethane materials available were FR-3708 and FR-3718 foams manufactured by General Plastics Manufacturing Company. The approximate material densities are $.13g/_{cm^3}$ and $.30g/_{cm^3}$ respectively for the FR-3708 and the FR-3718. Samples were sectioned from as received solid cylinders of polyurethane.

The thermal conductivity (dry nitrogen environment) was determined by means of a thermal comparator, where the temperature gradient across a known sample thickness was compared with the gradients across reference materials whose thermal conductivity-temperature relationship is established. The reference material used in determining the thermal conductivity of the polyurethane materials was Pyroceram 9606, a ceramic widely utilized as a comparative material. The polyurethane samples tested were nominally 5×10^{-2}m (2 in) diameter by 6.35×10^{-3}m (.25 in) thick. The Pyroceram reference disks (2) were each 5×10^{-2}m diameter by 1.27×10^{-2}m (0.5 in) thick. The test apparatus provided for essentially uniaxial heat flow through the heater reference sample stack with the heat flow normal to the disk surfaces. The test sample disk was placed between the reference disks in the vertical arrangement of the test assembly. Thermocouples were positioned in machined grooves in the sample and reference disks for temperature gradient measurements. Thermal conductivities were determined at the average temperature of the sample; the mid plane temperature of the sample assuming a linear gradient across the sample thickness. The thermal conductivities of Pyroceram 9606 in the temperature range investigated were obtained from Thermophysical Properties (TPRC) reference data. The thermal conductivity data for the FR-3708 material (low density) are presented in Figure 1 with the higher density FR-3718 material data plotted in Figure 2. The maximum average sample temperature achieved in this initial evaluation was approximately 475K with a hot surface temperature of 539K and a gradient across the sample thickness of 136K. Higher average sample temperature thermal conductivities could not be obtained with the comparator apparatus using the 6.35×10^{-3}m (0.25 in) thickness samples due to the initiation of material melting at a temperature of approximately 555K. One sample each of the two polyurethane materials have been tested to date for thermal conductivity. The direction of the thickness of the samples tested in this evaluation was parallel to the direction of rise of the pour. Samples were machined from discs sectioned along the length of the cylinder of material.

Figure 3 is a comparative plot of thermal conductivity temperature data for the polyurethane materials with phenolic foam material used as the thermal insulation for the 21PF-1 overpack container. The measured thermal conductivities for the denser polyurethane foam were lower than those determined over the same temperature range for the lower density polyurethane. The two polyurethane materials have higher thermal conductivities than the phenolic foam over the experimental temperature range. The measured thermal conductivities of the Fr-3708 and FR-3718 materials increase with temperature, with the effect being more significant for the lower density FR-3708 foam.

Heat capacities for the polyurethane materials and the 21PF-1 overpack phenolic foam were determined by means of differential scanning calorimetry (DSC). The comparative data are presented in Figure 4. The differential scanning calorimetry data indicated a glass transition temperature (Tg) in the range of 393K to 423K for the polyurethane materials.

CONCLUSIONS

The measured thermal conductivities of the two polyurethane materials increase with temperature over the range of room temperature to the materials melting points. The measured thermal conductivities of the polyurethane foams exceed the conductivities of the phenolic foam currently utilized in the 21PF-1 overpack over the experimental temperature range. The polyurethane materials began melting in the thermal comparator apparatus at a temperature of approximately 555K; whereas, the phenolic foam insulation is capable of sustaining temperatures of approximately 1100K, charring when exposed to air. The measured thermal conductivities of the denser Fr-3718 material were lower than the conductivities of the FR-3708 polyurethane material. The measured thermal conductivities by means of the thermal comparator have an estimated accuracy of ± 15 per cent. The Pyroceram 9608 reference material utilized in the comparator to obtain the thermal conductivities of the polyurethane materials has a large conductivity relative to the polyurethane. The mismatch in thermal conductivity between the reference material and the polyurethane materials tested contributes significantly to be estimated measurement error. Measurement error can be reduced by employing an absolute method such as the ASTM C177 guarded hot plate technique. The experimentally determined thermal conductivities and heat capacities along with the known material densities can be used to compute thermal diffusivity values.

FUTURE MATERIALS EVALUATION

Conduct additional tests with the thermal comparator to establish statistical variance in the measured thermal conductivity of the polyurethane materials. Conduct tests of material samples sectioned perpendicular to the direction of rise of the pour in order to measure material anisotropy with respect to thermal conductivity and heat capacity. Perform ASTM C-177 guarded hot plate tests of polyurethane samples to establish error bounds for the comparator apparatus, which is a simpler, less expensive method than the absolute method of the guarded hot plate.

THERMAL CONDUCTIVITY
POLYURETHANE FOAM
LOW DENSITY MATERIAL

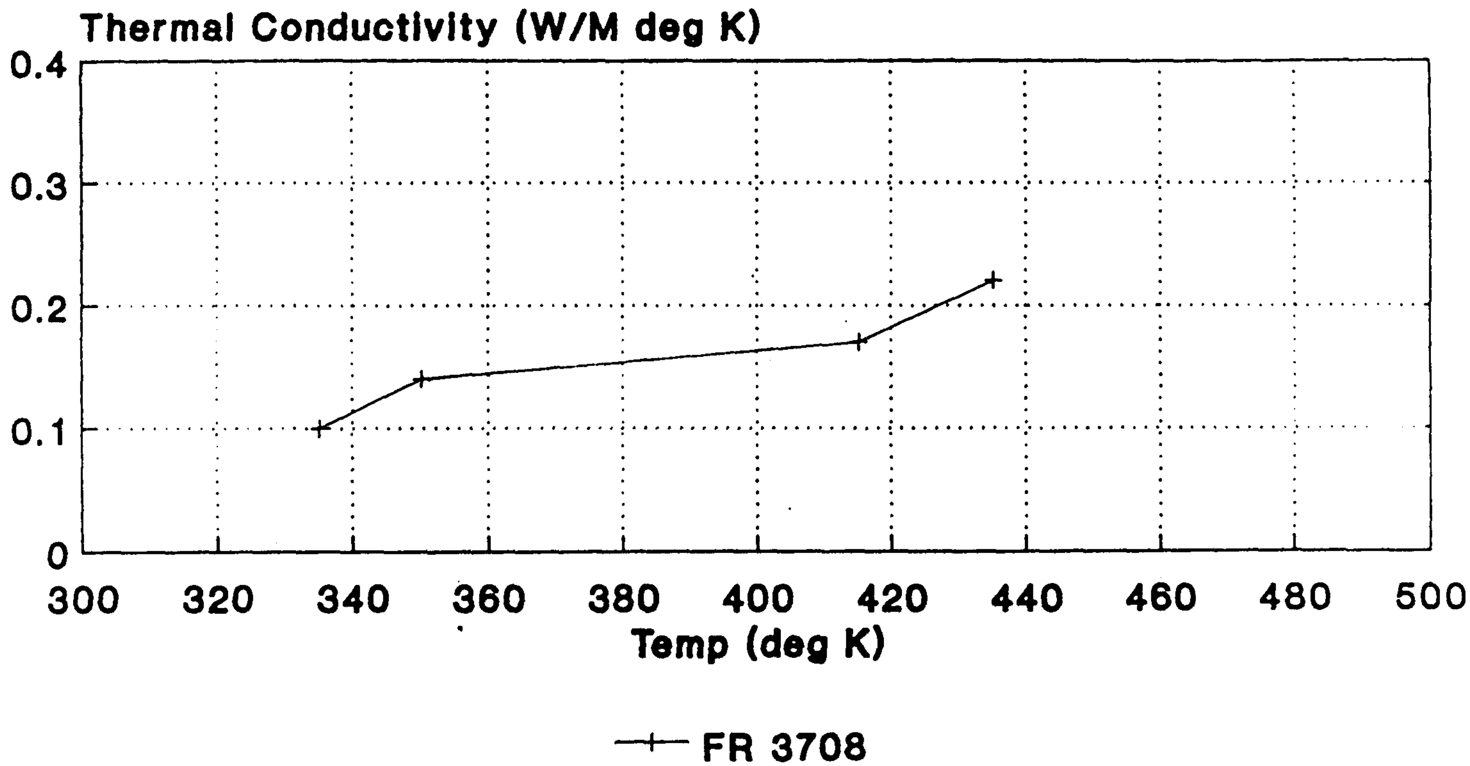

FIGURE 1

THERMAL CONDUCTIVITY
POLYURETHANE FOAM
HIGH DENSITY MATERIAL

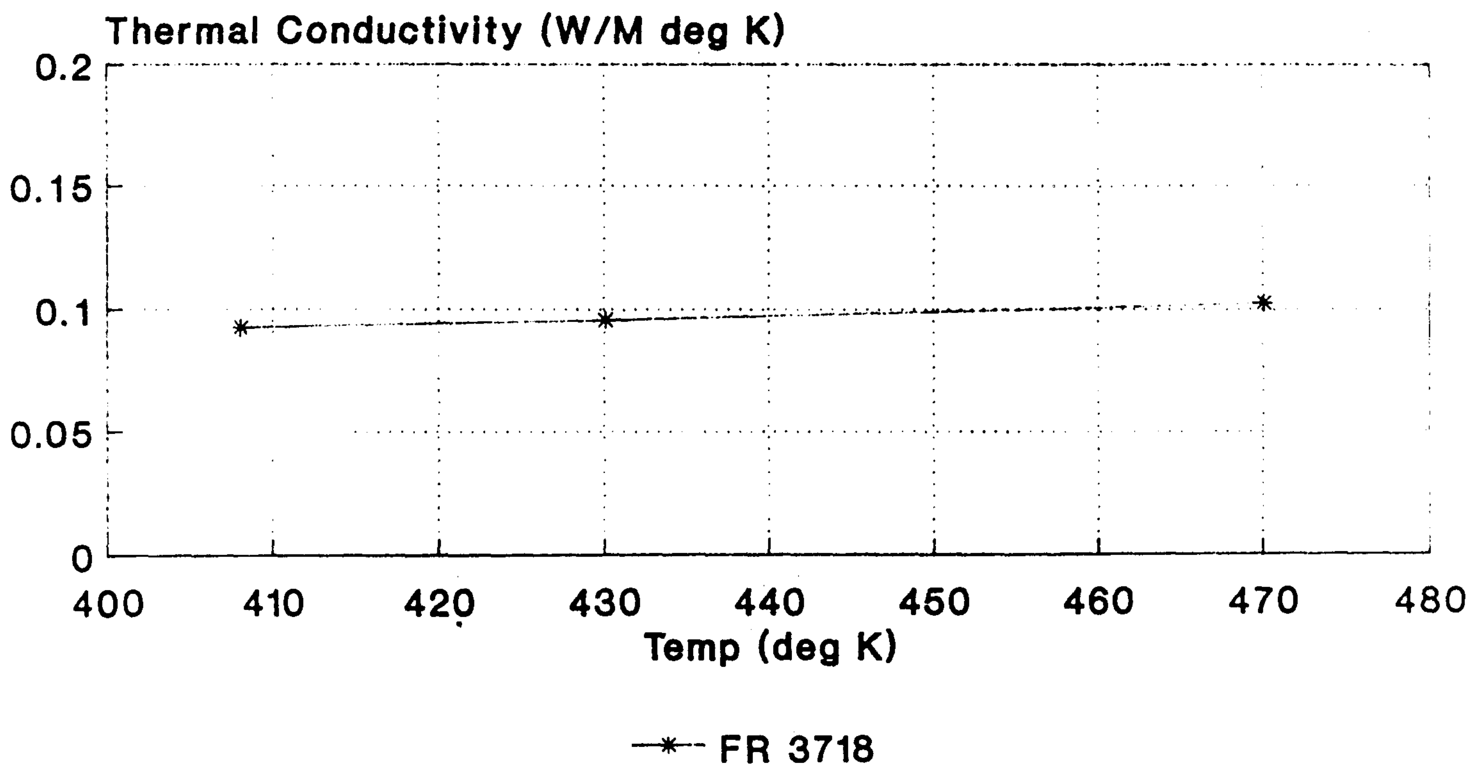

Figure 2

THERMAL CONDUCTIVITY
PHENOLIC FOAM AND POLYURETHANE

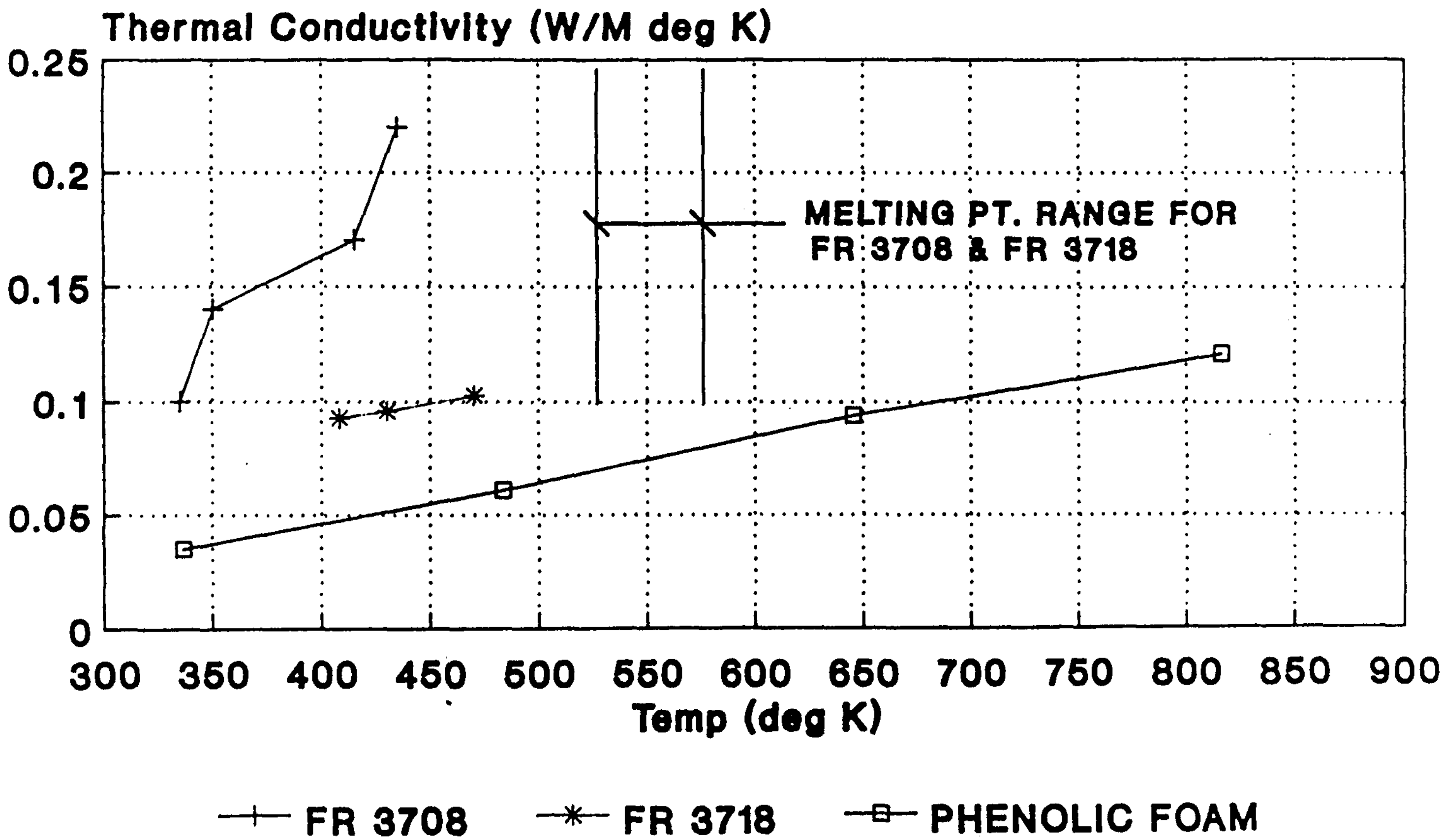

Figure 3

SPECIFIC HEAT CAPACITY
POLYURETHANE AND PHENOLIC FOAM

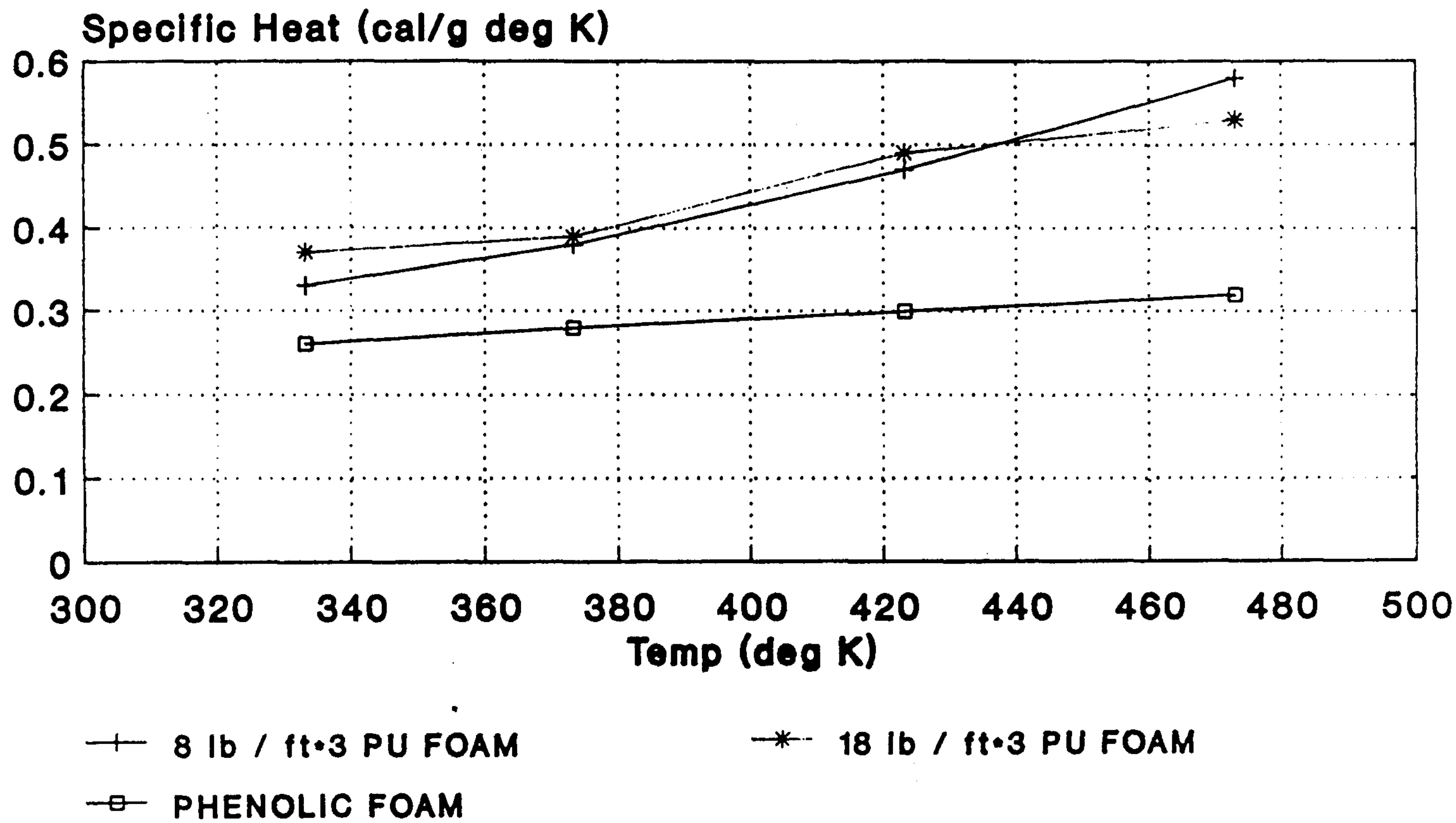

Figure 4