MEASURING THE THERMAL CONDUCTIVITY OF IRRADIATED FOAM-TYPE INSULATION MATERIALS

E. T. Smith and R. E. Miller

General Dynamics/Fort Worth
Fort Worth, Texas

INTRODUCTION

The development of a flight-qualified nuclear-rocket propulsion system has progressed rapidly during the past three years. Space missions requiring this propulsion system are being evaluated and planned. The reliability and operating characteristics of these systems cannot be assessed, however, without a thorough knowledge of the effects of radiation in combination with other environments on the materials and components making up the systems. Organic materials are particularly vulnerable to radiation and deserve special attention. Insulating materials and insulation systems, because of the importance of their functions, are prime candidates for early assessment.

Tests were therefore conducted to measure the effects of nuclear reactor radiation on the thermal conductivity of four foam-type insulations at room, liquid-nitrogen, and liquid-hydrogen temperatures. Unirradiated control data were also obtained at these temperatures to compare with those reported by the manufacturers, as well as to demonstrate the effects of radiation. The manufacturers' designations for the foams tested were CPR-200-2, H-1502, EFS-175, and CPR-1021-2.

EXPERIMENTAL DESIGN

For the experiment reported herein, a cylindrical geometry was used in the thermal-conductivity test units. The heat source was placed in a central core, and radial heat flow was maintained from the heater, through a cylindrical test specimen of foam insulation material, to an outer aluminum container. The basic equation for the heat-transfer rate $q$ in a cylindrical geometry system of this type is

$$q = \frac{2\pi \kappa (t_1 - t_2)}{\ln(D_2/D_1)}$$

where $\kappa$ is the thermal conductivity of the cylinder material, $h$ is the length of the cylinder, $t_1$ is the inner temperature of the cylinder, $t_2$ is the outer temperature of the cylinder, $D_1$ is the inner diameter of the cylinder, and $D_2$ is the outer diameter of the cylinder.

Figure 1 consists of vertical and horizontal cross-sectional views of the actual test unit used in this experiment. As can be noted, heat from the central heater core flows radially out through two concentric cylinders, namely, the thick-walled cylinder of...
test foam material and the thin-walled outer container. A rigorous analysis of this test arrangement would thus show a heat-transfer rate in the form

\[ q = \frac{2\pi h(t_1 - t_3)}{(1/k_m)[\ln(D_2/D_1)] + 1/k_m[\ln(D_3/D_2)]} \]  

(2)

where \( k_m \) is the \( k \) for the test foam cylinder, \( k_m \) is the \( k \) for the outer container, \( D_1 \) is the inner diameter of the test foam cylinder, \( D_2 \) is the outer diameter of the test foam cylinder (or inner diameter of the outer container), \( D_3 \) is the outer diameter of the outer container, \( t_1 \) is the inner temperature of the test foam cylinder, and \( t_3 \) is the inner temperature of the outer container.

Considering the materials involved, it is obvious that \( k_m \) is much greater than \( k_m \) (an approximate value of \( k_m/k_m = 10,000 \)). For Fig. 1, the ratio \( D_3/D_2 \) is approximately unity; thus, the term \( 1/k_m[\ln(D_3/D_2)] \) can be dropped. Also, for all practical purposes, \( t_3 \) in (2) is equal to \( t_2 \) in (1). Therefore (2) reduces to

\[ q = \frac{2\pi h(t_1 - t_2)}{(1/k_m)[\ln(D_2/D_1)]} \]  

(3)