Thermal Considerations for Overpack Designs in Drum Packages

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ABSTRACT

The design of the overpacks in drum packages, both in terms of thickness and materials of construction, greatly impact the ability of the package to accommodate heat source contents. The optimum overpack thermal protection needed is that which results in the lowest containment vessel temperature during both Hypothetical Accident Conditions (HAC) and Normal Conditions of Transport (NCT). For heat source packages, the use of very good or high efficiency insulating materials such as fiberboard and polyurethane results in high containment vessel temperatures during both NCT and HAC. Using a more modest or low efficiency insulating material would reduce the NCT and HAC containment vessel temperatures significantly. A material such as oak (low efficiency) would maintain a containment vessel with a content of 100 watts at a fraction of the temperature reported for very good or high efficiency insulating materials. Four inches of oak can prevent the containment vessel from exceeding 500°F during both NCT and HAC with 100 watts of contents, whereas using a high efficiency material the vessel would exceed 1000°F.

I. INTRODUCTION

There currently are no drum type packages in the DOE complex which are certified to transport over 30 watts of material. A need exists in the DOE complex for drum type packages which can be used to transport contents which generate well over 30 watts. Such a package would result in fewer shipments to transport large quantities of heat generating materials. Fewer shipments reduces cost and increases safety.

Overpacks for drum packages have historically been relatively thick (greater than 5 in.) and made of a very good insulating material such as cane fiberboard or polyurethane. These designs are quite adequate for low heat source contents (less than 20 watts). The overpacks insulate too well to allow for higher heat source contents. As an example, the 9972-75 drum packages, which are constructed of cane fiberboard, must operate below 20 watts because of excessive internal temperatures during NCT.

This work investigates various insulating materials for their suitability as drum overpacks. The effects of both overpack thickness and sensitivity to internal heat source strength were studied. Three analyses were made for each material: non-solar NCT, solar NCT, and HAC fire. The NCT analyses were all steady-state calculations. The HAC fire analyses did not include solar heating after the fire and did not consider the out-gassing associated with some of the materials.

The present study does not consider the structural performance of the overpack materials. A similar structural study would be required to completely evaluate the materials and optimize the overpack design.

II. COMPUTATIONAL ANALYSES

The generic drum package investigated contained a single containment vessel 3/8 in. thick made of stainless steel. The vessel was 12 in. high and 6 in. in diameter. A 4 in. thick overpack was chosen as the baseline design (see Figure 1). For NCT analyses the drum surface had an emissivity of 0.5, and during HAC the emissivity was 0.8. The insulators investigated and their thermal properties are presented in Table 1.

The non-solar NCT case is simply the drum standing upright in a 100°F ambient. The
solar NCT case is identical to the non-solar NCT case except 800 W/m² of insolation is applied to the drum top surface, and 400 W/m² of insolation is applied to the outer curved surface of the drum. The bottom surface receives no solar flux. In both NCT cases heat is dissipated to the ambient via radiation and natural convection from the exposed surfaces to the 100°F ambient. A steady-state analysis was used to compute the package response to the NCT solar loading.

The non-solar NCT solution is used as an initial condition for the HAC fire case. A fire of 1475°F with an emissivity of 0.9 is applied to the exposed drum surfaces for 30 minutes. Heat is also convected from the fire to the exposed drum surface via natural convection (forced convection was not included). After 30 minutes the exposed drum surfaces dissipated heat to a 100°F ambient via radiation and natural convection. The result of interest from the HAC fire computations is the peak vessel temperature which often occurs from 2 to 8 hours after the end of the 30 minute fire.

The computer code SCANS developed at LLNL was used to perform the computations. As already mentioned, three separate conditions were analyzed for each material (non-solar NCT, solar NCT, and HAC fire). Heat generation rates of zero, 25, 50, and 100 watts were investigated. The internal heat source was applied on the inner vessel surface as a uniform heat flux.

All materials were evaluated using a 4 in. thick overpack. Additionally, the oak and fiberboard materials were analyzed at 6 and 8 in. thicknesses.

III. RESULTS

The result of interest in these computations is the maximum vessel temperature. The results are presented in Figures 2 through 8. In Figures 2 through 6 the vessel temperature is plotted against the conductivity of the overpack material for various internal heat source loadings. In Figures 7 and 8 the peak vessel temperature is plotted against the thickness of the overpack for various internal heat source loadings.

Figure 2 is a plot of the peak vessel temperature against conductivity of the overpack material for the NCT non-solar case with 25, 50 and 100 watts of internal heat source. The overpack was 4 inches thick. The non-solar NCT case serves as the initial condition for the HAC fire case. The important features of this plot is the non-linear response to decreased conductivities of the overpack material.

Figure 3 is a plot of the peak vessel temperature against conductivity of the overpack material for the NCT case with insolation. The overpack was 4 inches thick, and internal heat sources of zero, 25, 50, and 100 watts were investigated. The high efficiency insulating materials such as polyurethane, cork, alumina-silica, and fiberboard have great difficulty conducting 25 watts through the overpack. The two lower efficiency materials oak and pine would easily accommodate a 100 watt drum package design with a 4 inch overpack.

In Figure 4 the peak vessel temperature during HAC as a function of overpack conductivity is presented for a 4 inch overpack with zero, 25, 50, and 100 watts of internal heat source. The low conductivity materials such as polyurethane and fiberboard are again limited to low wattage contents. In general, vessel temperatures are significantly greater for the low conductivity overpacks compared with the higher conductivity materials such as oak and pine.

The source of the higher vessel temperature for the lower conductivity materials during HAC is the higher initial NCT non-solar temperature. In Figure 5 the vessel temperature rise during the HAC fire is plotted against the overpack conductivity for 4 inch overpacks with 25, 50, and 100 watt contents. As expected, the polyurethane, cork, alumina-silica, and fiberboard materials protect the vessel from the fire better than the pine and oak. However, the pine and oak have significantly lower HAC peak vessel temperatures due to the lower initial temperature as shown in Figure 2. Another interesting point is the insensitivity of the temperature rise of the vessel to the internal heat source wattage. For 4 inch overpacks the peak vessel temperature is roughly 50°F greater than the NCT non-solar value for very good insulators and 90°F for moderate materials regardless of the content heat source wattage.

An interesting comparison for drum packages is the peak vessel temperature for solar NCT and the HAC fire. In Figure 6 the difference between these vessel temperatures is plotted against overpack conductivity for 25, 50 and 100 watts of content heat. Again, all computations are
for a 4 inch overpack thickness. The low conductivity materials all show the vessel temperature to be greater during solar NCT, while the higher conductivity materials show higher temperatures during the HAC fire. The effect of content wattage is minimal, which was already illustrated in Figure 5.

The effects of overpack thickness were also investigated. In Figure 7 the vessel temperature as a function of overpack thickness is plotted for the NCT solar and the HAC fire cases. Oak was used as the overpack material. The optimum thickness is about 5.75 in. and is independent of content wattage.

A similar plot for fiberboard is presented in Figure 8. It appears that the optimum fiberboard thickness is less than 4 inches. Note the vessel temperature is significantly higher for fiberboard as compared with the oak.

IV. CONCLUSIONS

Ten different materials were investigated as potential overpacks for drum packages. Low conductivity or high efficiency overpack materials such as polyurethane and fiberboard are acceptable for low wattage contents but insulate too well for contents of 20 watts or more. In fact, these low wattage materials result in the containment vessel temperature being greater during the solar NCT than the HAC fire.

Higher conductivity or low efficiency materials work well for contents above 20 watts. A low efficiency material such as oak would provide excellent performance for contents up to 100 watts. The optimum material thickness of 6 inches should also provide very good resistance to impact damage. The study was simplified in that all out gassing effects of the overpack materials during the HAC were not included in the analyses, and the insolation after the fire now required in the regulations was neglected.

Other results of interest were the striking similarity between the curves depicting vessel temperature versus conductivity for NCT and HAC, and the temperature rise of the vessel during HAC is essentially independent of the material studied. These conclusions may not be valid outside of the range of materials studied or thickness analyzed. Lastly, the peak wattage values can be increased over 25% if the aspect ratio (height to diameter) of the containment vessel was increased from 2.0 to 3.0.

V. ACKNOWLEDGMENTS

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VI. TABLES AND FIGURES

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*conductivity is in Btu/hr.-°F
**diffusivity is in ft.²/hr.

Figure 1
Difference in Vessel Temperature Between HAC-Fire and NCT Solar

**Figure 6**

Optimized Thickness For Fiberboard

**Figure 8**

Optimized Thickness For Oak

**Figure 7**