Design-The Key to Vacuum Insulation Value

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ABSTRACT

Vacuum insulation has potential to greatly impact performance because of its four to seven times greater thermal resistance per inch. However, the detail designs of a refrigerator or other appliance greatly affects the thermal benefit and cost effectiveness obtained from vacuum insulation. This paper covers (in a generic way due to secrecy requirements) the successful design strategies that we have used during this last year on several different projects involving the use of vacuum insulation. Both calorimetry thermal testing and Finite Element Analysis (FEA) techniques are described. Some generic examples of the performance that can be obtained are covered in the paper. Also described is the use of vacuum insulation to enable the design of new beneficial features. The paper concludes by forecasting vacuum insulation's future cost, performance, and application.

VACUUM INSULATION PERFORMANCE

Vacuum insulation has made significant advances during the last several years. The new core materials and barrier films have resulted in insulation products that are lower cost with proven performance. Typically, vacuum insulation thermal resistance is 25 to 30 R/inch. This compares to typical urethane foams of about 7 R/inch. However, we have seen many people incorporate vacuum insulation into their products and not obtain the large benefit that they expected. This situation occurs whenever a new high performance material is introduced. We have seen this same effect when high performance composites were introduced. The rules of good design change when such a large performance change occurs. This large a performance change requires the designers to recalibrate themselves. By comparison to vacuum insulation, urethane foam is a poor insulator and can significantly reduce the performance of vacuum insulation if heat is allowed to flow through the urethane foam instead of the vacuum insulation. Also, small thermal shorts in the thermal envelope will be very significant when incorporating vacuum insulation. If there is a 15% thermal short (penetration, etc.) in a one inch thick urethane foam wall and a one inch thick vacuum insulation is substituted in the same wall, the thermal short has now increased to about 40% of the heat flow. Thus the overall performance has been significantly reduced. <u>Detail in design is everything with vacuum insulation</u>. With careful design, vacuum insulation can for refrigerators/freezers reduce energy consumption, increase internal volume or allow special features. Examples of special features are recessed handles, lights, or ice makers or provide local increase in volume such as increased door storage in front of the vegetable pan. For shipping containers, vacuum insulation can provide longer time in transit, reduced use of dry ice (an important environmental consideration), reduced shipping container size, or more uniform interior temperature.

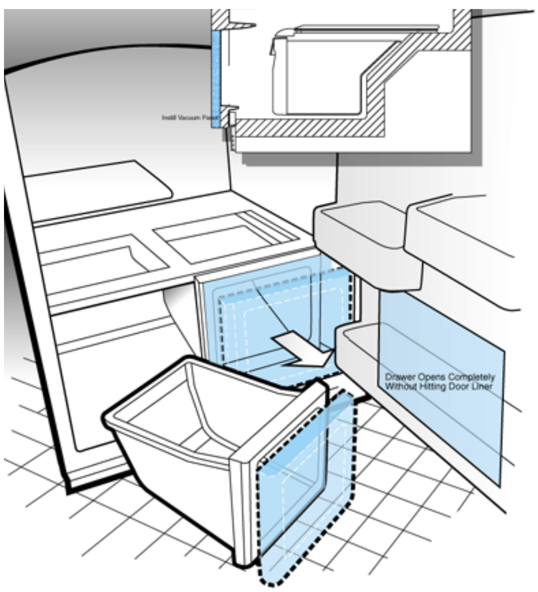

Figure 1. Vacuum panel in door to increase vegetable pan volume.

DESIGN TOOLS

We have designed many products incorporating vacuum insulation and have found that detailed thermal analysis is required. We typically perform Finite Element Analysis (FEA) of every thermal discontinuity in the thermal envelope of the product. To produce an accurate model it is important to model the details. We do **not** suggest that the vacuum insulation be modeled as an average R that incorporates edge effect of the boundary of the panel. We recommend that the vacuum insulation is modeled as the core and an element of the FEA model is the barrier film. Many barrier films incorporate highly conductive layers, which can significantly reduce the installed performance. This is particularly true if the conductive layer in the barrier film thermally couples with the outer steel case. It should be noted that some newer barrier films are substantially less conductive which reduces this problem.

One of the advantages of building the FEA computer model is the ability to separate the overall energy use into a quantitative estimate of each component's contribution. Thus, we know how much energy is going through the door, gasket area, each wall, etc. This detailed information can then help identify the major areas for energy reduction. The results from each thermal discontinuity FEA model are combined with the ideal envelope heat gain to obtain the total heat gain. The thermal FEA model can also provide insight into the identification and quantification of thermal shorts and surface temperatures. Surface temperatures are important in making sure there are no condensation problems. Vacuum insulation with careful design can sometimes eliminate the need for local heating for condensation control, which saves energy and the cost of the heater.

The computer models can then be used to rapidly study the effect of design changes. A cost performance trade-off study can then be performed and the design direction selected to reach the goal at the lowest cost.

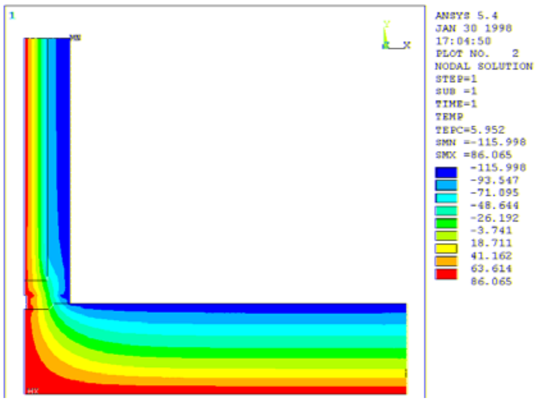

Figure 2. FEA thermal cross-section plot.

Another consideration when incorporating vacuum insulation is the structural design of the application. Often insulation provides more than thermal control. It provides much of the structure in many applications. We recommend that FEA structural models be used to evaluate the new design structure.

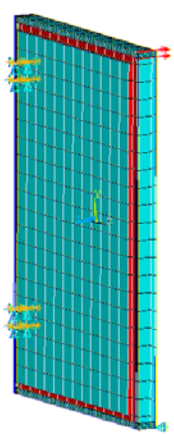

Figure 3. FEA structural model of a door under a racking load.

Figure 3, is an example of a structural analysis of a door which incorporates vacuum insulation under a racking load.

Vacuum insulation can be part of the overall structure. However often vacuum insulation allows the wall thickness to be reduced, this can lead to significantly less stiffness if the design has not been adjusted to accommodate the change.

Another design tool that we recommend is the use of calorimetry testing. Calorimetry testing involves testing the refrigerator or freezer in a temperature controlled room with resistance heaters inside the unit. This reverse heat flow test allows easy measurement of the thermal envelope performance by measuring the electrical wattage used by the heaters. This type of testing separates the performance of the thermal envelope from the cooling equipment performance. The calorimetry testing should be used to characterize the performance of any baseline design and is used to validate the computer modeling results. If the results of the calorimetry test and the computer modeling are not in agreement, it means there is an effect that is not identified or understood. That is the time to work hard and determine the cause of the difference. This situation can lead to very valuable fundamental knowledge building.

PRODUCT EXAMPLES

Presented below are some generic examples that are based on real designs incorporating vacuum insulation that we performed during this last year. Computer thermal modeling of an existing refrigerator/freezer design, which was thermally a fairly poor design, was performed. This existing design was then modeled with incorporation of full coverage of vacuum insulation without changing the design. The study showed energy savings of 15%. When a complete redesign was performed, the energy was cut to 25% of the original (a 75% energy savings). Calorimetry testing showed slightly greater savings. The vacuum insulation was not responsible for all the savings. However, once the whole design was improved, the vacuum insulation could provide its maximum benefit. This example is an extreme case but we have seen the general conclusions repeated over and over. Careful design is required to obtain maximum benefit from vacuum insulation.

Another example is the redesign of an insulated shipping container. The original design had exterior dimensions of 22.5 x 19.25 x 19.5 inches with 1.5-inch thick urethane walls. Forty eight pounds of coolant provided 120 hours of endurance. An optimized vacuum insulated container contained the same items being shipped but had exterior dimensions of 13 x 18 x 11 inches with 1.0 inch thick vacuum insulation walls. Fifteen and a half pounds of coolant provided 200 hours of endurance. Thus, the optimized vacuum insulation design reduced container volume (based on exterior dimensions) by 70% and at the same time reduced the required coolant by 68% and increased the endurance by 66%.

Still another example shows how the detailed design when incorporating vacuum insulation is critical. To identically sized containers with the same payload and five pounds of dry ice and two-inch thick vacuum insulation walls (about 55 R's) gave the very different performance shown in figure 4. Detail is everything.

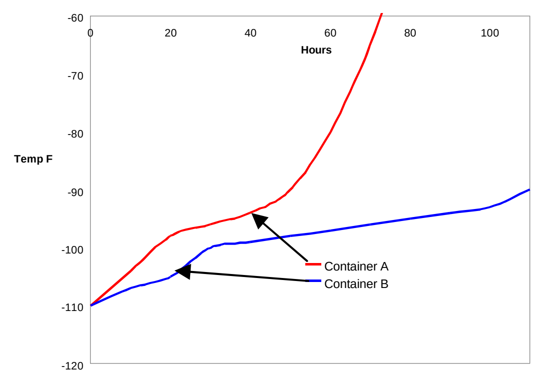

Figure 4. Two vacuum insulated containers.

FUTURE OF VACUUM INSULATION

The performance of vacuum insulation will continue to improve as better core materials, barrier films, and getter technology develops. Thermal resistance values will climb to well over 30 R/inch. The vacuum level required to obtain the high performance will be less severe. As the sales volumes increase, the cost will significantly decrease. Costs will continue to drop until within five years or less the cost will be half of what they are today. However, the real key to expansive use of vacuum insulation is the incorporation of the technology into new product designs that allow full benefit of the technology including new and previously unobtainable design features.