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# Project Summary

# Literature Review: Heat Transfer Through Two-Phase Insulation Systems Consisting of Powders in a Continuous Gas Phase

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**This review of the literature on heat flow through powders was motivated by the use of fine powder systems to produce high thermal resistivities (thermal resistance per unit thickness). The term "superinsulations" has been used to describe this type of material, which has thermal resistivities in excess of 20 ft²·h·°F/Btu (3.52 K·m²/W) per in. (2.54 cm) of insulation thickness. The report is concerned with superinsulations obtained using evacuated powders.**

**The literature review shows that the calculation of heat flow through gas-powder systems is highly developed. One major weakness in the calculational procedures is the absence of structural features for the powders, which are invariably characterized as regular arrays of spheres or cubes rather than random irregularly shaped particles. The effect of particle size distribution on the shape and size of void spaces is not modeled, although it affects the thermal conductivity of the gas. Calculations of thermal performance based on simplified descriptions of the porosity distribution can be used to show the dependence of thermal resistance on interstitial gas pressure. The literature reviewed in this report provides a basis for predicting the interstitial gas pressure at which thermal conductivity begins to increase. The objective is to design filler material for powder insulation systems with ultrafine void spaces that will permit pressure increases without dramatic thermal conductivity increases.**

***This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).***

An effort is underway at the Oak Ridge National Laboratory (ORNL) to facilitate the use of evacuated powder insulation in appliances such as refrigerators and freezers and in selected building applications. The objective of the effort is to produce and demonstrate performance and durability of very high thermal resistivity systems to replace closed-cell foam products containing environmentally unacceptable chemicals. Important tasks associated with the objective include cost effective minimization of the heat transfer through a layer of fine powder with low interstitial gas pressure and demonstration that the low interstitial pressure, which is a major factor in the thermal performance, can be maintained for extended periods. In the case of building insulation, the service life should be at least 25 years and perhaps as much as 50 years.

Interest in two-phase dispersed systems dates back at least 100 years. The early work focused on solid mixtures, but the resulting theory is applicable to systems in which the continuous phase is a noncondensible gas or, more precisely, a gas above its critical temperature. The transport of heat by the gas in a gas-solid composite can be a significant part of the total heat flow. If the composite is to be used as an insulator, the gas phase conduction can be reduced by lowering the pressure (evacuation) and/or reducing the dimensions of the gas-phase regions (use fine powders).

The motivation for this literature review was the use of evacuated fine powder systems to produce high thermal resistivities (thermal resistance per unit thickness) or low thermal conductivities. The term "superinsulations" has been used to describe this type of material, which has thermal resistivities in excess of 20 $ft^2 \cdot hr \cdot °F/Btu$ (3.52 $m^2 \cdot °K/W$) per in. (2.54 cm) of insulation thickness.

The use of evacuated powders is one method of producing a superinsulation. Multi-layer evacuated insulation made from high-reflectance/low-emittance foils is another, and evacuated fibrous insulations represent a third. This report is concerned with superinsulation obtained using evacuated powders.

The transfer of heat through a particulate bed containing a stagnant gas is generally discussed in terms of three mechanisms: (1) radiation through the void fraction, (2) conduction through a series of solid and gas elements, and (3) conduction through the solid phase. The three mechanisms are taken to result in additive heat flows, although this is not totally consistent. Radiative heat transport through the solid particles (as well as the void space) occurs, and the steady-state heat flow across planes perpendicular to the overall heat flow direction is not distributed among the mechanisms the same way for every plane. However, most of the theoretical discussion of heat flow across gas-solid systems involves a calculation of a heat flow that depends on the thermal conductivities of the two materials with an added term for radiation. The radiative term then must include radiation across voids and radiation through particles.

The literature review shows that the calculation of heat flow through gas-powder systems is highly developed. One major weakness in the calculational procedures is the absence of structural features for the powders, which are invariably characterized as regular arrays of spheres or cubes rather than random irregularly shaped particles. Radiative transport calculations are approximate. Particle-to-particle contact resistance is treated empirically. The effect of particle size distribution on the shape and size of void spaces is not modeled, although it affects the thermal conductivity of the gas. Calculations of thermal performance based on simplified descriptions of the porosity distribution can be used to show the dependence of thermal resistance on interstitial gas pressure. The high thermal resistance that can be achieved with evacuated powders has been clearly demonstrated. Calculations of thermal performance based on simplified descriptions of the porosity or void-space distribution can be used to show the dependence of thermal resistance on interstitial gas pressure. The challenge for bringing powder-filled evacuated panels to commercialization lies primarily with the development of a packaging system that will maintain the required low pressures for many years. The developmental work then should concentrate on barrier material air-permeability and vacuum sealing technology.

The development of advanced filler materials would help provide panels that will exhibit high thermal resistance even though air leakage has occurred. The literature reviewed in this paper provides a basis for predicting the interstitial gas pressure at which thermal conductivity begins to increase. The objective is to design filler material for powder insulation systems with ultrafine void spaces that will permit pressure increases without dramatic thermal conductivity increase.

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*The complete report, entitled "Literature Review: Heat Transfer Through Two-Phase Insulation Systems Consisting of Powders in a Continuous Gas Phase," (Order No. DE93-014387; Cost: $17.50; subject to change) will be available only from:*
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