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C1Or4A-01: Validating effective thermal conductivity of glass microspheres in cryogenic storage insulation via finite element analysis

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In this work we consider multi-mode, multi-scale heat transfer within a cryogenic storage system and demonstrate the importance of using gaseous conduction functions derived from low pressure gas theory in converging to published experimental data. Through validation of modeling data against experimental cryostat data available in the academic literature, we develop the framework for extrapolating such an analysis to large scale cryogenic storage container systems. An accurate estimation of the effective thermal conductivity of these insulation materials is essential in the evaluation of heat leak and boil-off rate from liquid hydrogen storage tanks. Heat transfer through evacuated packed beds of microspheres for cryogenic storage applications is primarily driven by a combination of solid conduction, radiation, and gaseous molecular transport. In the practical range of interest of cold vacuum pressure between approximately 100 and 1000 mTorr for tank insulation conditions, this study finds that the intra-sphere gaseous molecular transport begins to deviate from the diffusive regime into quasi-ballistic behavior. We further corroborate a size effect fitting parameter through a Monte Carlo ray tracing analysis to calculate the ballistic transport length distribution.

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