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Conduction-radiation Heat Transfer in Closed-cell Polymer Foams

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Extended Abstract

Rigid polymer foams are one of the most used materials for building heat insulation. Due to their chemical composition and inner structure, they provide excellent resistance to convection, conduction and also radiation. After the ban of fluorocarbons, pentane, carbon dioxide and air are the most commonly used blowing agents. However, all of them have larger thermal conductivity than fluorocarbons. Thus, new ways how to decrease foam conductivity are sought.

Currently, the most promising results show foams with cell size lower than 1 μm. In these foams, larger amount of phase interfaces leads to more scattering and decrease of radiative heat flux. Moreover, when the cells are so small, their size becomes comparable to the mean free path of gas molecules. Therefore, the mechanism of heat conduction changes from diffusive to Knudsen mode, which leads to reduced gas conductivity.

To theoretically estimate heat insulating properties of polymer foam we created a Fortran program simulating heat transfer in computer reconstructed three-dimensional foams. We solve coupled conduction-radiation equations directly in the two-phase domain (Ferkl et al., 2014). Since we don't treat foam as a homogeneous material, we are able to avoid the calculation of its effective radiative properties (Placido et al., 2005; Coquard et al., 2009). The heat conduction is governed by Fourier law, in which the gas conductivity depends on the cell size. We use the so-called P_1-approximation to describe the heat radiation and derive appropriate boundary conditions, which consider partial photon reflection on phase interfaces. Moreover, the reflectivity of phase interfaces accounts for wave interference phenomena in the thin polymer walls. Overall, our model doesn't use any empirical correlations, only input parameters are the foam microstructure and physical properties of pure phases.

Using this model, we can find optimal porosity, cell size, wall thickness and content of polymer in the struts. Moreover, we show that for certain types of foams, the equivalent conductivity depends on the total foam thickness and that reduction of cell size doesn't necessarily lead to improvement of heat insulating properties.

References

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