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The Impact of Conduction Shape Factor in Volume-Averaged Calculations of Heat Transfer in Permeable Porous Materials

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Extended Abstract

Porous materials like metal and graphitic foams are seeing increased use in heat transfer devices due to their high solid-phase conductivity and area-to-volume ratios. The internal structures of these materials can be extremely complex, but accurate characterization of the foam properties in terms of permeability, inertial losses, interstitial exchange and effective conductivity are critical for being able to consider such materials in design and application. Recent literature exists for characterizing permeable porous materials by conducting pore-level simulations on idealized geometric models [1-2] or geometric models generated by scanning samples of the porous media [3-4]. In such cases, a given geometric structure is discretized and simulations are conducted to obtain direct solutions to the mass, momentum and energy equations under laminar or turbulent flow conditions. These simulations can be used to obtain integral quantities characterizing the resistance to fluid passage, convective exchange and thermal dispersion, all of which are required for analogous simulations conducted using the volume-averaged (porous-continuum) approach. In addition to flow resistance and interstitial heat exchange, accurate information must be provided to characterize the solid phase conduction, which because of the complex shape, is a function of both solid-phase conductivity and a conduction shape factor, which characterizes the departure of the conduction path from being straight and of uniform cross-section [5-6].

In the present study, spherical-void-phase representative elemental volumes developed using the Discrete Element approach described in Dyck & Straatman [7] were produced over the range of porosities $0.70 \leq \varepsilon \leq 0.85$ and for pore diameters of 400 μm and 800 μm. Simulations of conduction-only through the solid domain were then conducted using the commercial software CFX to establish conduction shape factors using the approach of Fleet and Straatman [6]. Simulations of conjugate heat transfer were also conducted to provide validation for similar simulations conducted using the porous continuum (volume-averaged) approach. The volume-averaged simulations were conducted using an in-house, conjugate domain, thermal non-equilibrium CFD code described in Betchen et al. [8], but modified to include the conduction shape factor (F). The simulations including F are shown to be in excellent agreement across the full range of heating and Re_D considered. The results also show that without including F, the volume-averaged simulations over-predict the heat transfer by as much as 40% owing to the over-estimation of the effective solid-phase conductivity. Of important note is that pore-level calculations of conjugate heat transfer require more than 25 times the CPU effort compared to those conducted using the volume-averaged approach with F, which illustrates the important utility of volume-averaged heat transfer calculations in porous materials.

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