Experimental measurement of the heat transfer coefficients for gas flow through granular porous media

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1 Abstract

Heat transfer phenomena through granular porous media is widespread in industrial fields e.g. energy storage technology and thermal process engineering. Numerous research focused on a uniform temperature distribution within the solid phase with small Biot numbers (Bi), see [1] for a review. The volumetric heat transfer coefficient (Hv) is used to represent the internal heat exchange between the fluid and solid phases. Here we obtained Hv and the solid effective thermal conductivity for large Biot numbers ($Bi \gg 0.1$) by using an inverse analysis [2] of experimental results with well designed simulations. The experiment was conducted using a transient technique in a 1 m long, 194 mm diameter iron tube filled with uniformly sized glass spheres ($d = 16$ mm). The temperatures inside the iron tube are measured at seven central axis locations (x =5, 15, 25, 35 , 45, 65, 85cm) and three radial locations. The wall surface temperature is also measured at four axial locations (x =5, 35, 65, 90cm). The inlet boundary condition for the pressure is calculated based on the velocity measured at the outlet assuming a constant mass flow rate in the porous sample. The inlet mass flow rate is variable in order to obtain a range of Reynolds (Re) in the experiment. The flow inside the granular porous medium is considered compressible, the coupling between gas density and temperature is implemented in the mass conservation equation. The velocity field is modeled by the Darcy-Forchheimer equation based on the Reynolds number ($Re \gg 10$). Heat transfer is described using a local thermal non-equilibrium (LTNE) model in which there is conduction in both phases and convection in fluid phase. The governing equations are solved in the Porous material Analysis Toolbox based on OpenFoam (PATO) [3]. Hv is calculated and optimized based on the Wakao correlations [4] between the Nusselts (Nu), Prandlt (Pr) and Re numbers in which a new coefficient f has been added , $Nu = 2 + f \cdot Pr^{1/3} Re^{0.6}$. The effective solid conductivity is treated as an anisotropic tensor due to the flow. The results show that Hv is a function of space and time within granular porous media. The distribution of Hv is consistent with the gas temperature distribution e.g., where the gas temperature is high, Hv is also high. The factor f in the Nu correlations will increase with the increase in the Re. The inverse analysis can be used to obtain Hv and effective solid conductivity in uniform sized spheres and random shape granular porous media.

Keywords :granular porous media ; high Biot number ; inverse analysis ; volumetric heat transfer coefficient

Références

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