Experimental and numerical evaluation of LTNE in saturated porous media under forced convection

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Convective-dispersion equation is formulated over a representative elementary volume (REV) in porous media, and local thermal equilibrium (LTE) is assumed so that the temperature of the solid and fluid phases are equal in the REV. In fact, however, the temperature of solid and fluid phases in the REV under forced convection are not the same all the time, and local thermal non-equilibrium (LTNE) occurred. Although previous research indicates that LTNE may have significant effects on heat transport simulation in porous media under forced convection, very few experimental studies on LTNE have been conducted. In this study, to investigate the effects of particle size and thermal properties of porous media on LTNE under forced convection, one-dimensional heat transport experiment using a column filled with uniform porous media consisting of glass spheres with a diameter of 3, 5 mm or polyoxymethylene (POM) with a diameter of 5 mm were conducted. Hot water was injected into the column at a constant flow rate during an experimental run for different four flow rates, and the temperature time series within the column were measured. To evaluate LTNE, separate measurements of the solid and fluid temperature were required. To meet this requirement, a thermocouple probe was designed to measure the temperature at the center of a particle (solid temperature) and fluid apart from particle surfaces (fluid temperature) separately. Obtained temperature time series of the solid and fluid phases were normalized by the initial and final temperatures, and a normalized-temperature difference (NTD) between the solid and fluid phases were calculated for the evaluation of LTNE. To validate the experimental results, numerical simulations using two-phase model considering LTNE were performed. When three parameters (Darcy flux, hydrodynamic thermal dispersion coefficient, and particle-to-fluid heat transfer coefficient) in the two-phase model were appropriately applied, the numerical solution could reproduce the experimental data for glass spheres of 5 mm and a Darcy flux of 0.0277 cm s^{-1}. Sensitivity analysis was performed to investigate the effects of the particle size and thermal properties on LTNE. The comparisons between the results of the heat transport experiments and sensitivity analysis revealed that the particle size and fluid velocity were dominant factors affecting LTNE rather than the thermal conductivity of solid.

Keywords: Porous Media, Local Thermal Non-Equilibrium, Forced Convective Heat Transport