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Numerical Study of Mass Transfer Characteristics in a Structured Packed Bed of Porous Spherical Particles for Use in Solar Thermochemical Reactors

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Thermochemical reactors use concentrated solar radiation as the energy source to drive endothermic reactions to produce synthetic fuels, commodity chemicals, and to drive energy-dense thermochemical storage processes. A promising approach to accomplish the thermochemical cycle in a solar reactor is to use a heterogeneous reacting medium with a high specific surface area (SSA) to promote efficient solid–gas reactions while simultaneously achieving desired transport characteristics. An efficient reacting medium is reuquired to have low optical thickness to enable volumetric radiative absorption, and hence, pores in mm-range are desired. However, the reacting medium also needs to have large SSA to enhance reaction kinetics, and therefore, pores in µm-range are desired. Recently, in light of the apparent trade-offs between rapid reaction kinetics and efficient radiative heat transfer, dual-porosity structures have been engineered. They are capable of combining both of the desired properties, a low optical thickness and high SSA. Investigations are required to understand the transport phenomena in dual-porosity structures to improve the conversion efficiency of the solar thermochemical reactors equipped with such media. However, experimental investigation of transport through such novel porous media is inherently difficult due to the lack of optical access. Therefore, multi-scale numerical modelling can be useful to investigate the transport phenomena in such media.

In this study, a structured packed bed of porous spherical particles is considered as a medium with two levels of porosity. The inter-particle region represents the macro-pores (mm-size range), while micro-pores (µm-size range) exist within the spherical particles, named as intra-particle pores. The structured packed bed under study is formed by a three-dimensional array of identical micro-porous spheres with simple, body-centred and face-centred cubic arrangements. Mass and momentum transfer characteristics of the structured packed bed are numerically investigated for use in solar thermochemical applications. For the inter-particle region, continuum mass and momentum conservation equations are solved for the flow of an inert sweep gas. Volume-averaged equations for mass and momentum are solved to model the transport phenomena in the intra-particle pores. Interface conditions are applied between the homogenous fluid flowing in the interstitial space and the porous spheres. The effects of particle permeability and Reynolds number on the pressure drop are investigated for different packing forms. The mass transfer characteristics of packed beds of solid particles reported in the literature are compared with those of the packed bed of porous particles.