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Morphology Engineering of Porous Media for Enhanced Solar Fuel and Power Production

Silvan Suter, Sophia Haussener*

Laboratory of Renewable Energy Science and Engineering, Institute of Mechanical Engineering, Ecole Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland

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The favorable transport properties of porous media such as large specific surface area, variable permeability, and volumetric radiation absorption make them particularly suitable components of reactors used for solar fuel processing and power production. The morphology of the porous media significantly influences the performance of the process in which they are used. The directed engineering of the porous media's morphology can significantly improve the performance of these reactors.

We used a multi-scale approach to demonstrate and quantify the significant changes in performance of exemplary photoelectrochemical and solar thermal processes using porous media as multi-functional component, i.e. absorber, heat exchanger, charge conductor, and reaction site. The applied methodology uses imaging-based direct numerical simulation techniques and digital image processing in combination with volume averaging theory to characterize the transport in porous media with varying morphology (fibrous vs. foam) and varying morphological size range (mm-scale vs. μm-scale), each with porosity between 0.46 and 0.84. The obtained effective transport properties were subsequently used to quantify the performance in continuum-scale models of a 1D multi-functional porous slab used for solar fuel processing via photoelectrochemical processes and power production via solar thermal processes.

The results showed that the changes in base morphology (fibrous vs. foam), characteristic morphological sizes (original vs. shrunken foam), and porosity significantly affect the process efficiency. The two exemplary continuum scale applications required different morphologies for increased performance. When applied to photoelectrochemical hydrogen generation, the maximal efficiency increased by a factor of 23 when using a low porosity foam sample of μm-size instead of a high porosity fibrous sample of μm-size. The minimal required sample thickness to reach the absorption limited efficiency was reduced by a factor of 2 when using the foam sample instead of the fibrous sample at porosity of 0.46. When applied to solar thermal power production, the maximal efficiency increased by a factor of 1.2 and the required slab thickness was reduced by a factor of 12 when using a highly porous fibrous sample of μm-size range instead of a low porosity foam sample of mm-size range.

The applied multi-scale investigation provides a pathway towards pore-engineering of the reactor components for enhanced reactor performance.

Keywords: solar fuels, morphology, porous media, direct numerical simulations, micro tomography