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Coupling Numerical Modelling with Flow Experiments to Optimize Fabrication of Microfluidic Devices for Transport in Porous Media Applications

Amir Jahanbakhsh*, Krystian L. Wlodarczyk*, M. Mercedes Maroto-Valer*, Duncan P. Hand, Robert R. J. Maier, William N. MacPherson

*Research Centre for Carbon Solutions (RCCS)

School of Engineering and Physical Sciences, Heriot-Watt University, UK

Investigating the mechanisms that govern flow of fluids at the pore-scale are the cornerstone of understanding multiphase flow in porous media for a wide range of applications, including hydrocarbon recovery, CO₂ sequestration and contaminant hydrology.

Microfluidic devices, coupled with visualization techniques allow us to study pore-scale processes [1, 2]. Glass substrates are often preferred over silicon and polymers for the manufacturing of microfluidic devices because of their high transparency, thermal stability, hardness and chemical resistance. However, conventional manufacturing of glass-based microfluidic devices is time consuming, expensive, complex and multistep [3]. We have recently developed a novel and relatively inexpensive laser-based process that can be used for the fabrication of microfluidic devices using glass substrates [4]. Features generated on the glass surface by using a picosecond laser beam enable more complex surface features than those produced by more conventional photolithography and etching. Laser-generated micro-channels have a limited aspect ratio (typically < 4:1), much higher surface roughness than etched micro-channels, and angled walls with a rounded bottom, rather than steep, vertical walls with a flat bottom. However, these characteristics do not limit the ability to closely simulate real porous materials relevant to applications such as CO₂ sequestration, hydrology or hydrocarbon recovery.

Designing of appropriate micro-structures for specific fluid flow experiments most often requires performing numerical simulations to predict fluid flow behaviour and conducting flow tests on the fabricated micromodels to validate the simulation results.

We have coupled micromodel flow experiments and pore-scale numerical simulations to investigate fluid flow behaviour in micro-structures under various experimental conditions. Simulations are particularly useful for guiding the prototyping of micro-models, since the geometry, physical dimensions, and surface properties of micro-channels and pores in the structure have a significant effect on fluid flow dynamics. In this research, we will pinpoint critically important parameters that have an impact on the fluid flow at pore-scale, which should be considered in the fabrication of micromodels. We investigate the fluid displacement front, saturation distribution, and the influence of the micromodel imperfections on the bulk flow will be evaluated [5,6]. We utilize a commercially available computational fluid dynamics (CFD) code in this work.

Additionally, a set of dynamic flow tests will be performed on the fabricated micromodels to obtain valuable qualitative and quantitative data. This will allow the comparison between the measured experimental data after performing fluid flow tests on the fabricated micromodels with the results of pore-scale numerical simulations.

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