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Solute and Particle Transport in Complex Porous Materials

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Introduction

Transport of solutes and particles are important in many medical, natural, and industrial porous materials. For example, in the nature an increasing concentration of nano and colloidal particles is observed in soils and groundwater including micro-plastics, fuel additives, and particles used in pharmaceutical products.

We use invocative microfluidics (with a sizes of 10×10 mm^2) to directly observe and characterize transport of solute and particles in porous material. Emphasized is on dual-porosity material which are found in different types of porous materials in nature and industry.

Figure 1 shows the sample consist of solid grains and aggregated grains. Three types of samples are used: sample with no aggregate (S), samples with an inner void in the aggregate centre (H), and sample with fully filled aggregate grains (D).

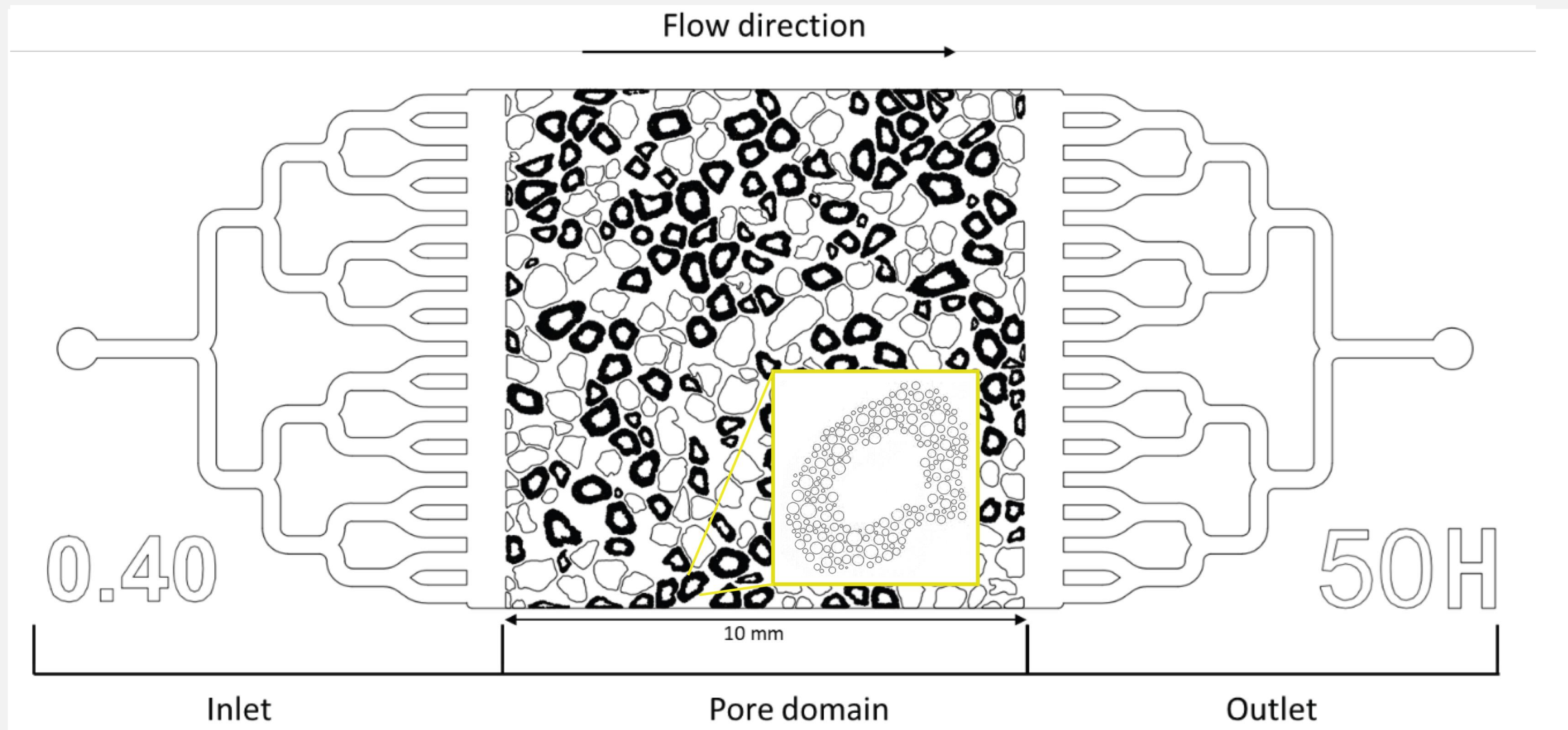

Figure 1: A microfluidic with grains, aggregates and a void space in the centre of aggregates. Porosity is 40%. The left and right channels are the inlet and outlet of the sample.

Solute Transport

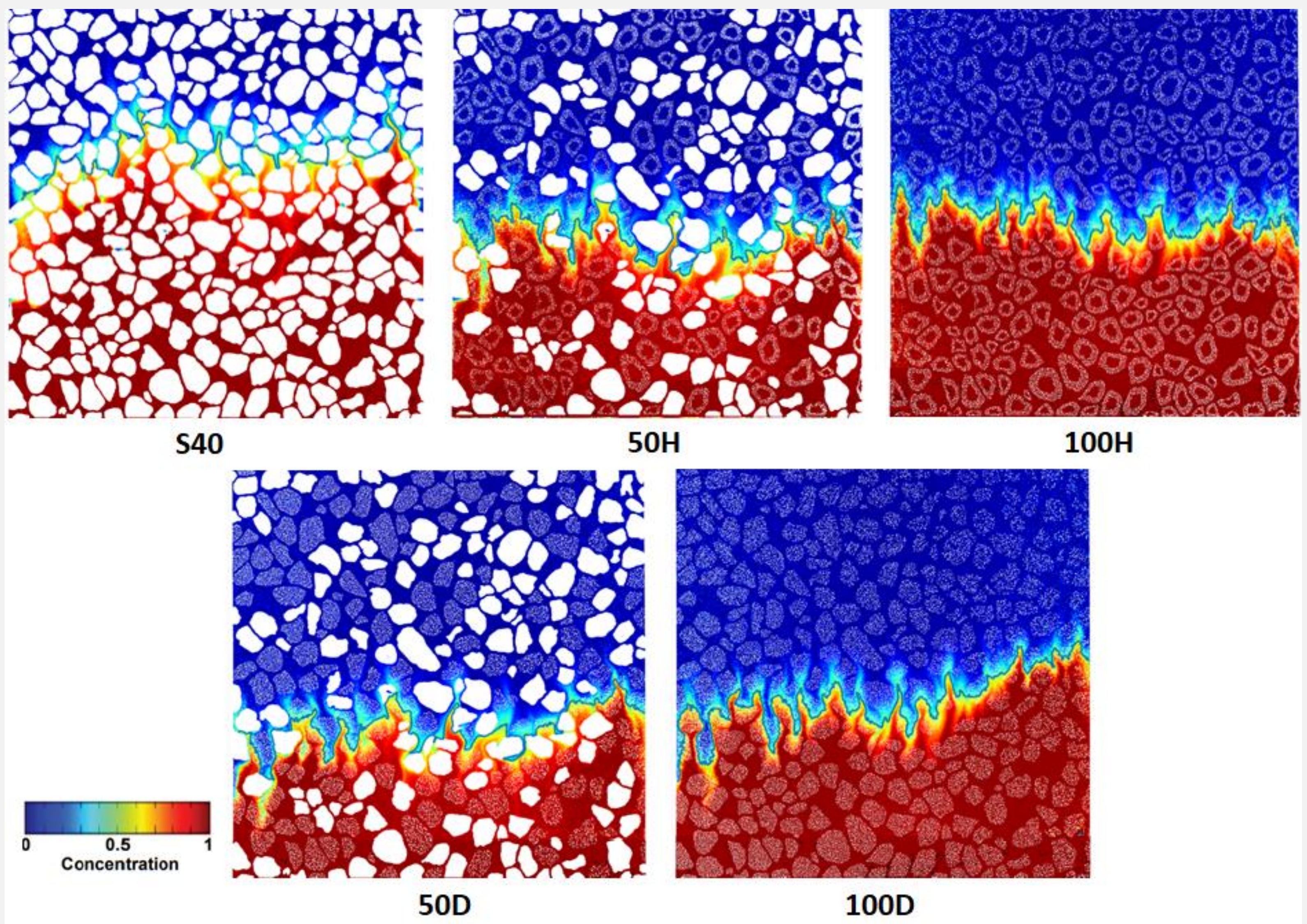

Figure 2: Solute concentration distributions in different samples (S40, 50H, 100H, 50D, and 100D) after injection of 0.5 pore volume (PV) solution. The average water velocity is 20 m/day. Flow direction is upward.

Experiment set-up
We developed a Fluorescence Recovery After Photobleaching (FRAP) setup to track solute transport. The micromodel is saturated with a fluorescent solution and the photobleaching is done by a high-intensity laser beam. After bleaching, the recovery is recorded and imaged (Figure 2). For all five samples, the experiment is carried out at four different flow speeds varying from 20 to 2 m/day. Data are analysed to obtain breakthrough curve of concertation at the outlet of the sample (Figure 3).

Conclusions
The reference micromodel S40 show the fastest arrival time, and other samples show enhanced spreading of solute due to transport in small pores.

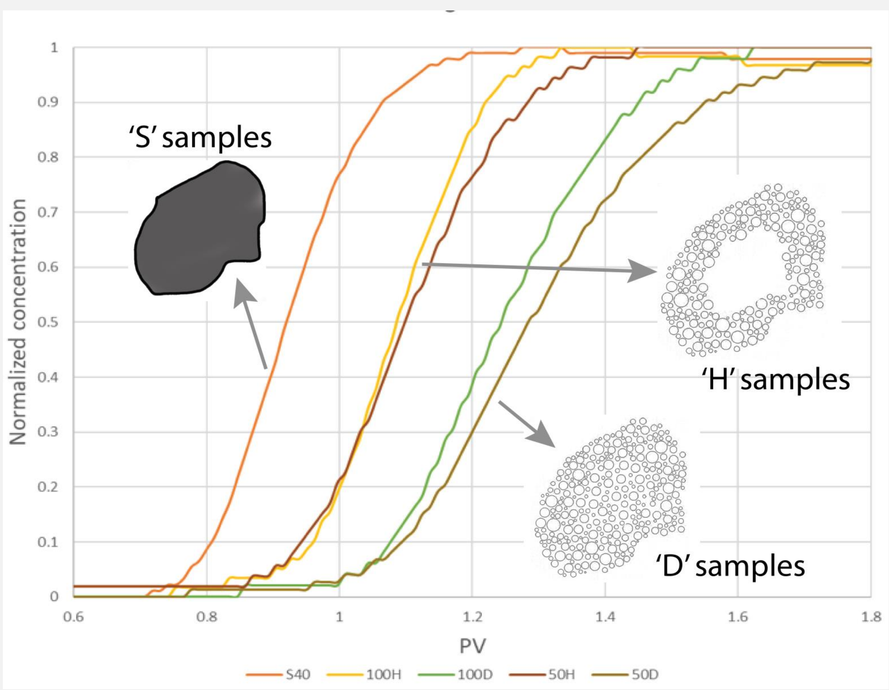

Figure 3: concentrations at the sample outlet for water velocity of 5 m/day.

Particle Transport

Experiment set-up
The aggregates can change flow velocity to cause more attachment/detachment of particles, probably creating a longer tail in the breakthrough curve (BTC)[1]. Two different particle sizes (1.5 and 4.3 µm) are used in each samples, leading to a total of 10 experiments. The different colloid sizes are used to acquire data on the effect of colloid sizes and their attachment/detachment behaviour in the dual-porosity media.

Fluorescent colloids are used and fully tracked within water-saturated samples using an in-house optic setup. Flow rate is 12 m/day. The trajectories of the colloids are analysed using a tracker in ImageJ (Figure 4). Based on these tracks, different colloid transport mechanisms (attachment, detachment, remobilization) are detected and breakthrough curve at the outlet of the sample is measured to calculate transport parameters like spreading and retardation.

Conclusion
The full transport path of particles are observed, showing an increased attachment rate for particles in samples with aggregates and the exact location of the attachment.

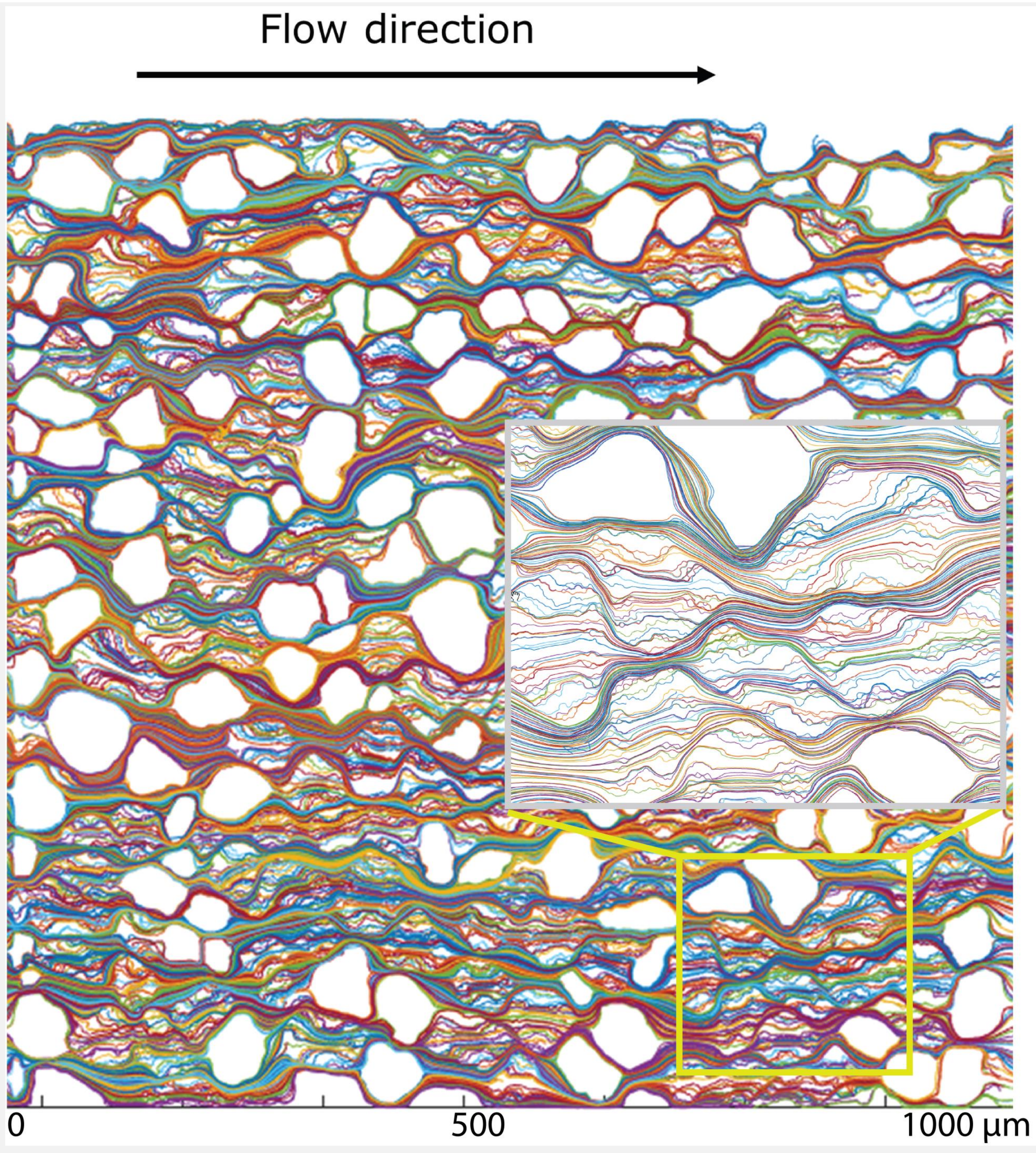

Figure 4: Full trajectories of particles in sample 50H using 1.5 µm colloids.

References
1. Mehmani, A., & Prodanović, M. (2014). The effect of microporosity on transport properties in porous media. Advances in Water Resources, 63, 104–119. https://doi.org/10.1016/j.advwatres.2013.10.009
2. De Vries, E. T. (2021). Transport of Solutes and Colloids in Multi-Scale Porous Media Under Single and Multi-Phase Flow. https://doi.org/10.33540/746