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Probing Transport in Geologic Porous Materials by Fast X-ray Micro-Computed Tomography

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Understanding the time evolution of solute transport at the pore scale in geologic porous media is crucial in many subsurface engineering applications, including underground gas (e.g. H2 and CO2) storage. While transport processes in rocks can be investigated by dynamic 4D imaging, such as X-ray and neutron-based computed tomography, most of the observations so far have been limited to the continuum scale (image resolution approx. 1 mm and above). These observations have improved our understanding of non-Fickian transport in rocks [1]. Yet, the lack of spatial resolution of these methods precludes the unambiguous interpretation of the transport mechanisms at play, because the relevant mixing processes initiate at the pore scale. Recent advances involve the uses of fast X-ray micro-computed tomography (fast μCT), which allows direct micron-scale imaging of fluid transport at a time resolution on the order of tens of seconds.

Here, we analyse a comprehensive data set of 4D imagery acquired by fast μCT available on the Digital Rocks Portal [2,3]. The dataset consists of dynamic images of solute transport during miscible displacement in three porous media (diameter: 6 mm, and lengths: 16 or 20 mm), namely sintered beadpack, Bentherimer sandstone, and Savonnières limestone. Tracer tests were performed at various Péclet numbers, covering the range Pe = 2 –20. In each test, fast μCT scans were continuously acquired at the sample inlet with the field of view of 8.8 (H) x 8.8 (W) x 5.0 (L) mm, and at spatial and time resolutions of 14 μm and 12 s, respectively. We have analysed this rich dataset by applying the concept of residence time (RT) at different length-scales and by considering its spatial variability within the sample. Specifically, we computed RT curves for individual pore volume elements (PVE) in the sample (> 100 curves) and identified variations with both size and spatial location of the PVE. The strength of pore-scale heterogeneity is thus quantified by comparing the experimental RT with the theoretical counterparts. To quantify the degree of non-uniformity of the concentration field, we also examined the extent of mixing within individual PVE using various metrics, including the dilution index, the intensity of segregation and the spreading length.

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References

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