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Visualizing Mass Transfer Across Fluid-Fluid Interfaces

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When a nonwetting fluid is forced to flow through an otherwise water-saturated porous solid medium (e.g. as occurs in geologic CO_2 sequestration and underground hydrogen storage projects), the movement and ultimate fate of that nonwetting phase is dictated by a range of physio-chemical interactions; including trapping within pore spaces due to capillarity, mobilization via viscous or buoyant forcing, and dissolution and subsequent flow within the aqueous phase. Previous studies have constrained these transport processes, often using the explicit assumption that capillary trapping (or mobilization) and dissolution are distinct mechanisms, occurring on disjoint length and time scales. However, our recent experiments [1] suggest that there exists a strong coupling of these processes: dissolution shrinks ganglia and changes bubble morphologies; and it may also induce a concentration gradient near the ganglion interface that locally decreases the fluid-fluid interfacial tension. We observed that these impacts frequently destabilized previously trapped ganglia, ultimately inducing buoyant displacement upwards [1].

To further explore this coupled transport behavior, we have designed and deployed a novel experimental protocol which allows us to visualize dissolution mass transfer across fluid-fluid interfaces at the pore-scale. Here, we present preliminary results for CO_2 gas bubbles dissolving within a 3D packing of spherical beads, refractive-index matched to water. The water phase is doped with pH-sensitive fluorescent indicator. Once a CO_2 bubble is introduced and capillary trapped within the system, we apply Planar Laser Induced Fluorescence (PLIF) to visualize the pore-scale evolution of aqueous pH (i.e., aqueous CO_2 concentration) during the dissolution process. Our results demonstrate the variability of dissolved gas concentration at the pore-scale, and the influence of the fluid-fluid interface on the dissolution process. This study thus builds on the foundational work of Prof. Dorthe Wildenschild: focusing on interfacial dynamics of multiphase systems, and highlighting potential impacts to the long-term behavior of capillary trapped ganglia.

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References

[1] Huang, R., Herring, A. L., & Sheppard, A. (2023). Investigation of supercritical CO_2 mass transfer in porous media using X-ray micro-computed tomography. Advances in Water Resources, 171, 104338. https://doi.org/10.1016/j.advwatres.2022.1043

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