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Minimal Surfaces in Mixed-Wet Bead Packs: Insights from 3D X-Ray Imaging

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The interfacial curvature of immiscible fluids within porous media is critical for the comprehensive understanding of multiphase fluid, impacting capillary pressure, relative permeability, saturation distribution, and the formation of preferential flow paths. Despite many studies that have been made demonstrating that interfacial curvature is strongly affected by wettability, there are still some fundamental questions that remain unresolved. In this work, we employed three-dimensional (3D) X-ray imaging techniques combined with automated interfacial curvature analysis to examine the minimal surfaces under mixed wettability conditions, using random arrangements of spherical glass beads, which are hydrophilic, and plastic beads, which are hydrophobic. Our findings confirmed the existence of mean curvatures approaching zero (minimal surfaces), suggesting optimal conditions for the simultaneous flow of two connected phases. This work provides insight into the ideal wettability conditions for enhancing oil recovery, CO2 sequestration, hydrogen storage, groundwater remediation, optimizing water management in polymer electrolyte fuel cells, and designing microfluidic devices.

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Primary authors: Ms LI, Min (Dalian University of Technology); Ms GOODARZI, Sepideh (Imperial College London); Prof. ZHAO, Jiafei (Dalian University of Technology); Dr BIJELJIC, Branko (Imperial College London); Prof. BLUNT, Martin (Imperial College London)

Presenter: Ms LI, Min (Dalian University of Technology)

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