Contribution ID: **154** Type: **Oral Presentation**

Dispersed two-phase flow for mixing enhancement in porous media

Wednesday 21 May 2025 09:20 (15 minutes)

Efficient solute mixing in porous media is crucial for various natural processes and industrial applications, such as nutrient transport in biological systems, groundwater bioremediation, carbon dioxide-enhanced oil recovery, and packed-bed reactors. The effectiveness of solute mixing directly influences the rates of biological and chemical reactions in these scenarios. While turbulence is commonly used to enhance mixing due to its transient and chaotic flow dynamics, its effectiveness in porous media is constrained by the extensive solid boundaries that suppress turbulence. Alternatively, dispersed two-phase flows, which feature transient flow behavior [1] and are more feasible to porous media, offer a promising strategy for improving mixing efficiency.

The current understanding of solute mixing driven by dispersed two-phase flow remains incomplete. Research on enhancing mixing through these flows has largely concentrated on simple systems [2], such as uniform channels or bulk fluids, without considering the complexities of porous media. On the other hand, most investigations into solute transport within porous media under two-phase flow conditions assume static phase interfaces [3]. However, dispersed two-phase flows are inherently characterized by dynamic and evolving phase interfaces. This gap in knowledge regarding the performance and mechanisms of dispersed two-phase flow on solute mixing within porous media hinders a comprehensive understanding and modulation of its behavior.

This study investigates transverse mixing driven by dispersed two-phase flow in porous media using pore-scale direct numerical simulation. Results indicate that dispersed two-phase flow exhibits transient features, such as the formation of vortices, which are absent in single-phase flow. These transient characteristics, particularly the vortex structures, significantly enhance transverse solute mixing. The efficiency of mixing is evaluated using the mixing volume ratio, defined as the proportion of the volume where solute concentrations range between 0.01 and 0.99 relative to the total solvent volume. At identical total injection flow rates, the mixing volume ratio for dispersed two-phase flow is approximately twice that of single-phase flow. These findings offer novel insights for enhancing mixing in porous media.

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Session Classification: MS08

Track Classification: (MS08) Mixing, dispersion and reaction processes across scales in heterogeneous and fractured media