Contribution ID: **643**

Type: **Oral Presentation**

Experimental validation of a graph-based model to represent colloid transport and fracture-matrix transport processes

Wednesday, 21 May 2025 12:50 (15 minutes)

Fractures are voids in rock, defined by rough surfaces in partial contact, that often create complex flow and transport networks. Flow and transport in fractured systems is complicated by coupled processes such as colloid transport, water-rock interactions, and geomechanics. Understanding these coupled processes is essential for permeability and injectivity management in oil and gas operations, carbon dioxide injection, geothermal reservoirs, and managed aquifer recharge. Despite the significance of fractured systems, challenges persist in quantifying coupled transport processes given the opaque nature of rocks and limitations of traditional experimental techniques. This study overcomes these challenges by using a combination of pulse-tracer experiments with positron emission tomography (PET) and reduced physics flow and transport models to characterize (1) colloid transport and (2) fracture-matrix interactions in rock cores with mechanically generated fractures.

In the first set of experiments an aqueous pulse of suspended radiolabeled kaolinite (64Cu2+) is injected into a 5.08 cm diameter fractured Sierra granite core under single-phase flow conditions. Flow-through experiments are conducted under varying flow rates to evaluate hydrodynamic effects on colloid retention and breakthrough behavior. A second set of experiments was performed that use a conservative radiotracer ([18F]-FDG) +) injected into a 5.08 cm diameter fractured Berea sandstone core under single-phase flow conditions. Berea sandstone is used because it has high matrix porosity and allows for the quantification of solute transport through both matrix and fracture. Simultaneous PET imaging during both experiments allows for high-resolution, in-situ visualization and quantification of solute and colloid distributions at the millimeter scale.

The PET imaging experiments provide spatially resolved data and traditional coreflooding provides bulk-scale breakthrough, enabling the testing for reduced-physics models to accurately capture coupled flow and transport processes in fractured rock. Prior work has shown that graph-based, random-walk particle tracking techniques accurately model conservative solute transport in fractured cores (Sutton & Zahasky, 2025. Here, that algorithm is modified based on first-order kinetics (Liu et al., 2022) and is used for colloid transport and diffusion into a porous matrix. The model is validated against experimental data, demonstrating its ability to characterize colloid tailing behavior and attachment dynamics as well as transport in a fracture with adjacent porous matrix. This work demonstrates that graph-based modeling of fractures can effectively capture complex processes, offering computationally efficient modeling approaches without requiring explicit geometric definitions. While previous studies have shown that graph-based approaches accurately quantify conservative solute transport in a single fracture, this is one of the first studies to validate this modeling approach for coupled transport processes.

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References

Sutton, C. R., and C. Zahasky (2025), A laboratory-validated, graph-based flow and transport model for naturally fractured media, Geophysical Research Letters, 52, e2024GL112277, https://doi.org/10.1029/2024GL112277.
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Session Classification: MS03

Track Classification: (MS03) Flow, transport and mechanics in fractured porous media