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Buoyant Fluid Flow in Inclined Fractures

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Natural and injected fluids in the subsurface often vary in composition and have different physical properties such as density and viscosity. It is well known that fracture aperture distributions control flow, transport, and mixing of fluids within a fracture. In this study, the effect of fracture orientation on fluid mixing is examined for two cases with a density contrast (1) between miscible fluids, and (2) between miscible reactive fluids that form precipitates.

Fractures with uniform apertures (~2mm) were formed from transparent acrylic plates (50 mm in thickness). The transparency of the samples enabled imaging of the flow and transport within the fracture to study fluids and precipitation distribution development during the pumping of two solutions. The two solutions were Na2CO3 and Na2CO3 + NaCl solutions in miscible nonreactive case; and Na2CO3 and CaCl2 solution in reactive miscible case. The reaction for forming CaCO3 precipitate in reactive case is as follows:

CO32- + Ca2+ ⟶ CaCO3(s).

Solutions were dyed with pH indicators (Bromocresol green or purple) to help distinguish them. The solutions were introduced through two separate ports using a dual-syringe pump (constant flow rate). Fracture inclination angles were set to be 0o,15o,30o,45o,60o,75o,90o to investigate the different distributions of fluids and precipitation.

The experimental observations found very different distribution of fluids, as well as precipitation, that depended on the inclination of the fracture plane. In the miscible nonreactive experiments, when the fracture is horizontally oriented (inclination angle is 0o), stratification of flow occurred with the lighter solution flowing on top of the heavier solution. Mixing occurred across the entire fracture. When the fracture was vertically oriented (inclination angle is 90o), a mixing interface arose from the bottom of the fracture. The lighter solution formed a continuous narrow flow path from the inlet to the middle of the fracture. Halfway up the fracture plane, a few instabilities occurred resulting in discontinuous bubble-like transport to the outlet. In the miscible reactive experiments, when the fracture is vertically oriented, precipitates only formed along the narrow flow path of the lighter solution. When a fracture was horizontally oriented, precipitate distribution was thick and covered the entire fracture plane. Fracture orientation affects the spatial distribution of precipitate because the mixing interface location is dominated by gravitational effects.

The potential to improve caprock integrity through induced mineral precipitation must account for gravity-driven chemical dynamics that can result in differences in the amount and spatial distribution of precipitates depending on fracture orientation.

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References

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