Contribution ID: **354**

Type: **Oral Presentation**

Fingering Instability During Mixing-Driven Precipitation Flow: Experiments and Simulations

Monday, 13 May 2024 13:55 (15 minutes)

Reactive flows in porous media that results in precipitation of solids are ubiquitous in a wide range of applications. Laboratory studies focusing on microscopic changes of the porous media have elucidated the complexity of the precipitation patterns due to the highly nonlinear coupling between advection, diffusion, reaction, and the intrinsic heterogeneity of the pore geometry and mineralogy. Here, we study the displacement of aqueous solutions of calcium chloride by sodium carbonate in a Hele–Shaw cell where the two fluids react, upon mixing, to form calcium carbonate precipitates. We examine the case of equal reactant concentrations in detail via high-resolution imaging, which reveals a variety of precipitation patterns at different injection rates and reactant concentrations. We find that reaction along the moving fluid–fluid interface forms a precipitation band in the form of particle suspensions, whose width and particle concentration are controlled by the injection rate. This injection rate dependent behavior arises due to particle–particle agglomeration in the precipitation band. Higher injection rates generate larger particles and lower suspension mobility, resulting in miscible viscous fingering at the precipitation band. Critically, fingering has important control over the growth of precipitation amount in time, which is diffusive with time in the absence of fingering but is linear with time in the presence of fingering. Furthermore, we show that the precipitates uniformly deposit onto the top and bottom surfaces of the Hele–Shaw cell as a thin particle layer at low injection rate, but they form large particle islands at high injection rates. We develop a novel reaction-diffusion-convection model that not only captures the phenomenology of the precipitation and deposition process, but also the scaling of the temporal precipitation amount.

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Session Classification: MS08

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