Convective mixing in confined porous media

Marco De Paoli, CJ Howland, R. Verzicco, D. Lohse (Univ. Twente, Physics of Fluids)

Abstract:

We consider the process of convective dissolution in a homogeneous and isotropic porous medium. The flow is unstable due to the presence of a solute that induces a density difference responsible for driving the flow. The mixing dynamics is thus driven by a Rayleigh-Taylor instability at the pore scale. We investigate the flow at the scale of the pores using experimental measurements, numerical simulations and physical models. Experiments and simulations have been specifically designed to mimic the same flow conditions, namely matching porosies, high Schmidt numbers, and linear dependency of fluid density with solute concentration. In addition, the solid obstacles of the medium are impermeable to fluid and solute. We characterise the evolution of the flow via the mixing length, which quantifies the extension of the mixing region and grows linearly in time. The flow structure, analysed via the centre-line mean wavelength, is observed to grow in agreement with theoretical predictions. Finally, we analyse the dissolution dynamics of the system, quantified through the mean scalar dissipation, and three mixing regimes are observed. Initially, the evolution is controlled by diffusion, which produces solute mixing across the initial horizontal interface. Then, when the interfacial diffusive layer is sufficiently thick, it becomes unstable, forming finger-like structures and driving the system into a convection-dominated phase. Finally, when the fingers have grown sufficiently to touch the horizontal boundaries of the domain, the mixing reduces dramatically due to the absence of fresh unmixed fluid. With the aid of simple physical models, we explain the physics of the results obtained numerically and experimentally. The solute evolution presents a self-similar behaviour, and it is controlled by different length scales in each stage of the mixing process, namely the length scale of diffusion, the pore size, and the domain height.