A REDUCED-ORDER MODEL OF FLUID MIXING IN STRONGLY HETEROGENEOUS POROUS MEDIA

Birendra Jha, Massachusetts Institute of Technology, 650-766-1732, bjha@mit.edu

1. Birendra Jha, Massachusetts Institute of Technology
2. Luis Cueto-Felgueroso, Massachusetts Institute of Technology
3. Ruben Juanes, Massachusetts Institute of Technology

We characterize the evolution of fluid mixing in strongly heterogeneous porous media using stochastic modeling of the concentration variance and the mean scalar dissipation rate. Transport through a heterogeneous medium exhibits nonlinear, long-correlation features such as channeling through high permeability zones, hold-up in low permeability zones, and longitudinal and transverse spreading due to local variations in fluid velocity. We develop a macroscopic model of mixing in porous media following a similar approach to that of [1], but where now the primary source of disorder in the fluid velocity is the permeability heterogeneity and not a hydrodynamic instability. It is well known that heterogeneity enhances (non-Fickian) dispersion and also that it exerts a fundamental control on mixing during solute transport. Although spreading and mixing are intricately linked, it is not possible to predict the degree of mixing from plume spreading. We use a higher-order perturbation expansion and ergodic theory to model mechanical dissipation rate as a function of the underlying permeability field. We model the evolution of the scalar dissipation rate obtained from the stochastic transport equation for the concentration fluctuations. Based on the high-resolution simulations, the advective and diffusive contributions in the model equation are approximated in terms of the spectrum of the permeability field, concentration variance, and mechanical dissipation rate. Our two-equation ODE model captures the nonmonotonic dependence of the degree of mixing on the level of heterogeneity: moderate levels of heterogeneity enhance mixing, but extreme heterogeneity leads to channeling, which inhibits fluid contact and fast mixing.

[1] B. Jha, L. Cueto-Felgueroso, and R. Juanes. Fluid mixing from viscous fingering. Phys. Rev. Lett., 106, 194502 (2011).