PERSISTENCE OF INCOMPLETE MIXING IN HETEROGENEOUS POROUS MEDIA

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Local full mixing is often a key assumption that is needed in dispersion and reactive transport models. Complete mixing implies a loss of memory of Lagrangian velocities along particle trajectories. Thus, reaching this state is the main condition for Fickian dispersion. The existence of a locally fully mixed scale, which we call here mixing scale, is also required for defining the concept of local concentration and thus for using the mass action law for chemical reactions at local scale. The existence of this scale of homogenization can be assumed by invoking diffusive mixing. In this case, the mixing scale is identified to the characteristic diffusion scale. Yet, in heterogeneous velocity fields, where shear may act at all scales, the definition of the scale where elements are fully mixed is not obvious. Experimental observations of anomalous dispersion and chemical kinetics in heterogeneous porous media suggest that incomplete mixing at different scales may be at the root of these non classical behaviors.
In order to investigate this we define a local mixing scale as the largest volume which can be considered as fully mixed and propose a method for estimating it from particle separation statistics (Le Borgne et al., Phys Rev. E, 2011). In homogeneous media, local mixing is ensured by diffusion and the mixing scale grows like the square root of time. In heterogeneous velocity fields, the growth of homogenized areas is limited by the shear action of the velocity field. Hence, for strong heterogeneities, we find that the mixing scale grows subdiffusively, implying the persistence of incomplete mixing over long time scales. As the latter implies a significant correlation of Lagrangian velocities, we show that this subdiffusive scaling of mixing is related to a superdiffusive scaling of plume dispersion. Using different examples, we discuss how the analysis of the dynamics of local mixing can be used for understanding global dispersion and chemical kinetics laws.
Le Borgne T., Dentz M., Davy P., Bolster D., de Dreuzy, J. R. and Bour O. (2011) Persistence of incomplete mixing: A key to anomalous transport Phys. Rev. E Rapid Communication, 84, 1