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Unifying Pore Network Modeling, Continuous Time Random Walk (CTRW) Theory and Experiment to Describe Impact of Spatial Heterogeneities on Solute Dispersion at Multiple Length-scales

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This talk will describe and highlight the advantages offered by a novel methodology that unifies pore network modeling, CTRW theory and experiment in description of solute dispersion in porous media.

Solute transport in a porous medium is characterized by the interplay of advection and diffusion (described by Peclet number, Pe) that cause dispersion of solute particles. Dispersion is traditionally described by dispersion coefficients, D, that are commonly calculated from the spatial moments of the plume. Using a pore-scale network model based on particle tracking, the rich Peclet-number dependence of dispersion coefficient is predicted from first principles and is shown to compare well with experimental data for restricted diffusion, transition, power-law and mechanical dispersion regimes in the asymptotic limit. In the asymptotic limit D is constant and can be used in an averaged advection-dispersion equation. However, it is highly important to recognize that, until the velocity field is fully sampled, the particle transport is non-Gaussian and D possesses temporal or spatial variation.

Furthermore, temporal probability density functions (PDF) of tracer particles are studied in pore networks and an excellent agreement for the spectrum of transition times for particles from pore to pore is obtained between network model results and CTRW theory. Based on the truncated power-law interpretation of PDF-s, the physical origin of the power-law scaling of dispersion coefficient vs. Peclet number has been explained for unconsolidated porous media, sands and a number of sandstones, arriving at the same conclusion from numerical network modelling, analytic CTRW theory and experiment.

The length traveled by solute plumes before Gaussian behaviour is reached increases with an increase in heterogeneity and/or Pe. This opens up the question on the nature of dispersion in natural systems where the heterogeneities at the larger scales will significantly increase the range of velocities in the reservoir, thus significantly delaying the asymptotic approach to Gaussian behaviour. As a consequence, the asymptotic behaviour might not be reached at the field scale. This is illustrated by the multi-scale approach in which transport at core, gridblock and field scale is viewed as a series of particle transitions between discrete nodes governed by probability distributions. At each scale of interest a distribution that represents transport physics (and the heterogeneity) is used as an input to model a subsequent reservoir scale. The extensions to reactive transport are discussed.