Continuous-Time Random-Walk Analysis of Dual-Permeability Fractured Media

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RESEARCH OBJECTIVES

Reliable prediction of fluid and solute movement in fractured porous formations is of paramount importance in many practical applications. Fracture networks and the surrounding porous (and permeable) matrix are not hydraulically independent domains—they interact by exchanging solutes at their interface. Solute particles traveling on fast flow paths in the fractures can be retarded by solute exchange with the porous matrix, a diffusive or advective process depending on matrix properties. These retardation effects are extremely difficult to model in a classical transport framework. The objective of this research is to apply the continuous-time random-walk (CTRW) transport theory to the analysis of dual-permeability fractured media, to characterize transport by means of probabilistic distributions of the solute retention times.

APPROACH

In the CTRW approach, the interaction between the fractured and porous rock domains is modeled by a transition time probability distribution function (pdf), which characterizes the retention time inside the fractured medium. In our research, this approach is validated numerically through the analysis of discrete numerical solutions of tracer transport in idealized dual permeability fractured media. A numerical inversion procedure identifies the transition time pdf from the analysis of the BTCs.

ACCOMPLISHMENTS

We applied the CTRW analysis to a series of synthetic breakthrough curves (BTC) obtained by means of a standard finite element code, on a finely gridded 2-D geometry consisting of a regular arrangement of fractures (oriented at a 45° angle with respect to the direction of the mean flow) in a permeable porous domain (see Figure 1). By changing matrix permeability over a wide range (from representing rather permeable sandstone on one end of the spectrum to almost impermeable granites or shales on the other), we have considered various fracture-to-matrix permeability contrasts, which reflect typical values of densely fractured geological formations.

SIGNIFICANCE OF FINDINGS

Our results indicate that a CTRW analysis can completely characterize transport in dual-permeability fractured media by means of a probabilistic distribution function (pdf) of solute retention times. The pdf can be obtained from an analysis of the macroscopic (experimental) BTCs and contains all the necessary information for predicting the solute behavior at different times and sections. In the CTRW model, the transport velocity can be estimated from the composite porosity of the dual permeability medium. Furthermore, the classical dispersivity parameter, an essential component of any advection-dispersion based model, does not scale with the distance of the observation, but rather stays constant and relatively small. These findings indicate the CTRW method is an important and valuable alternative to more complex model approaches for fractured porous formations, such as discrete models or dual-permeability formulations.

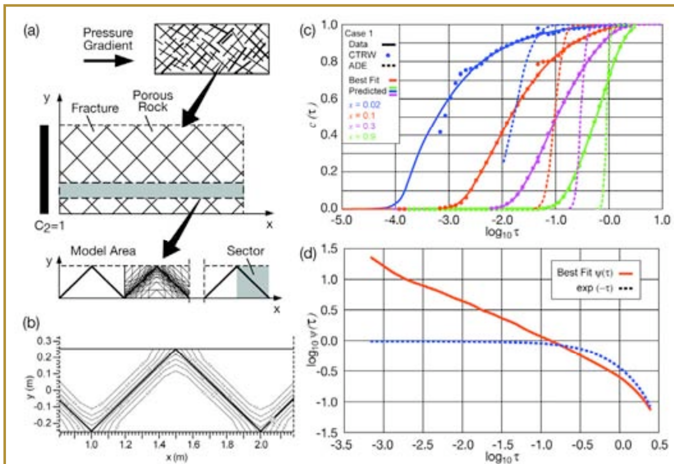

Figure 1. (a) Fractured domain under study (b) Discrete finite-element solute-transport simulations for a permeability contrast of approximately 12,000. (c) Breakthrough curves at four different sections. Discrete simulations are solid lines; CTRW predictions are circles; advection dispersion equation (ADE) predictions are dashed lines. (d) Probabilistic distribution of the solute residence times from CTRW analysis (red line), and comparison with the decaying exponential distribution (ADE model).

RELATED PUBLICATIONS

Cortis, A., Peclet-dependent memory kernels for transport in heterogeneous media. Phys Rev. E, 2007 (submitted).

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