A Triple-Continuum Model for Flow and Transport Processes in Fractured Rock

Yu-Shu Wu, Hui-Hai Liu, and G. S. Bodvarsson
Contact: Yu-Shu Wu, 510-486-7291, YSWu@lbl.gov

RESEARCH OBJECTIVES

The objectives of this study are (1) to explore a triple-continuum concept for studying the effect of small-scale fractures on flow and transport processes in fractured rock, (2) to develop a methodology for determining the model input parameters of the proposed model, and (3) to show how the proposed model can apply to site characterization of the Yucca Mountain unsaturated zone (UZ). In particular, we investigate the triple-continuum behavior of flow and transport processes in the fractured Yucca Mountain UZ, using both numerical and analytical solutions.

APPROACH

As conceptualized, the triple-continuum media consist (as the name implies) of three continua: a single porous-medium rock matrix and two types of fractures: (1) "large" fractures globally connected and (2) "small" fractures locally connected to the "large" fractures and the rock matrix. This concept is a natural extension of the dual-permeability or double-porosity models, in that it treats small-scale fractures as an additional connection between large fractures and the matrix. With this triple-continuum approach, flow and transport processes in fractured rocks are described using a triplet of governing equations for the two fracture and matrix continua. This conceptualization results in a set of partial differential equations for flow and transport in each continuum, which are in the same form as that for a single porous medium.

We have developed both analytical and numerical approaches to the triple-continuum model. Analytical solutions are obtained under single-phase flow and simple flow-geometry conditions only, while numerical implementation of such a triple-continuum model is based on the TOUGH2 framework, i.e., the mass- and energy-conservation equations are discretized in space using an integral finite-difference method, and the resulting discrete nonlinear equations are solved using a Newton iteration scheme.

ACCOMPLISHMENTS

Our new triple-continuum conceptual model, developed for modeling flow and transport through heterogeneous fractured rock, has been implemented into both analytical and numerical approaches. The model has been used for performing theoretical studies characterizing transient flow behavior in a triple-continuum formation. In field applications, the triple-continuum model has been employed in a sensitivity study of flow and transport in the Yucca Mountain UZ. This new conceptual model was first used to estimate model-related fracture-matrix parameters from field observation data using an inverse-modeling approach. Then, the estimated parameters were incorporated into the triple-continuum model for 3-D site-scale flow and transport simulations. The triple-continuum modeling results have indicated that small fractures may have a significant impact on radionuclide transport in the Yucca Mountain UZ system, as shown in Figure 1.

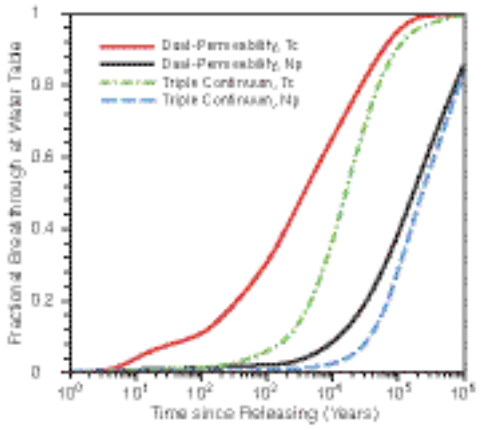

Figure 1. Comparison between cumulative breakthrough curves at the water table, simulated for conservative (Tc) and reactive (Np) tracer transport from the repository with dual-permeability and triple-continuum 3-D models, respectively

SIGNIFICANCE OF FINDINGS

This study shows that small fractures may have an important effect on radionuclide transport within Yucca Mountain, and provides a new capability in modeling flow and transport through heterogeneous fractured rock. As an extension of the dual-continuum concept, the triple-continuum model, with its analytical solution and numerical approach, will find further applications in the analysis of flow and transport through multifractured reservoirs, which typically contain a large number of small fractures, cavities, and different-scale heterogeneities. In general, such fractured reservoirs cannot be described using conventional dual-continuum models. In addition, the methodology developed in this study for determining model properties with the triple-continuum model, using observed data, will prove to be useful for parameter estimation in application.

RELATED PUBLICATION

Wu, Y.S., H.H. Liu, and G.S. Bodvarsson, A triple-continuum approach for modeling flow and transport processes in fractured rock. Journal of Contaminant Hydrology, 73, 145–179, 2004. Berkeley Lab Report LBNL-48875.

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