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Hydrology and Earth System Sciences Discussions

Interactive comment on "Time dependent dispersivity behavior of non-reactive solutes in a system of parallel fractures" *by* G. Suresh Kumar et al.

G. Suresh Kumar et al.

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Title: Time dependent dispersivity behavior of non-reactive solutes in a system of parallel fractures.
Authors: Suresh Kumar G., Sekhar, M. and Misra, D.

The response to the comments of *anonymous referee#1* are provided below:

Referee's Concern#1:

From a general point of view, I do not see any "practical" aspects into studying solute transport in fractured media by means of spatial moments, unless the Authors suggest

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how is it possible to monitor solute propagation into fractured systems.

Author's Reply:

It is well known that dispersivity, which controls mechanical dispersion, is a function of the size of the domain, due to the random deviation of velocities from its mean value, caused by the heterogeneities. In a heterogeneous formation like fracture-matrix coupled system, the breakthrough curves along the fracture are generally characterized by long tails and also the shapes of the solute front are skewed in contrast to the traditional Gaussian type symmetric Breakthrough Curves (for a typical ADE). In such cases, analysis of concentration (history) profiles with space and time is not sufficient and the use of method of moments, like zeroth, first and second moments provide a better means of understanding the anomalous behavior of solute transport arising from the concept of non-Fickian behavior. For example, under skewed concentration profiles, it is difficult to estimate the spreading behavior of solutes in a fracture-matrix coupled system, while the first and second spatial moments provide a reasonable estimate of solute mobility and spread characteristics. Thus, the method of moments provides a better way to study the behavior of solute propagation in a heterogeneous fracture-matrix coupled system, in contrast to the traditional Fickian behavior.

Referee's Concern#2:

To my opinion the Authors did not go deeply through the literature, since I believe that most of the aspects they tried to investigate have been already considered in the past (see e.g. Cvetkovic and co-authors).

Author's Reply:

Dagan and Cvetkovic (1993) used the method of spatial moments to analyze the transport behavior of solutes for kinetically sorbing solutes, with special emphasis on heterogeneous conductivity.

Berglund and Cvetkovic (1996) studied the contaminant displacement behavior in

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aquifers. Their focus was on the coupled effect of flow heterogeneity and non-linear sorption.

Andricevic and Cvetkovic (1998) analyzed the behavior of relative dispersion for solute flux in aquifers.

Cvetkovic et al., (1999) studied the transport of reactive tracers in rock fractures.

However, none of the above studies by Cvetkovic analyze the time dependent behavior of dispersivity in a fracture-matrix coupled system.

Also, it is well known that the mass transport processes in a classical Advection-Dispersion Equation (ADE) is controlled by 2 basic mechanisms, viz. Advection and Dispersion. Without any fundamental modifications, ADE can treat other processes like matrix diffusion. However, since the dispersive transport in a fracture-matrix coupled system, particularly at an early stage, can not be represented by Fick's law due to the involvement of two distinguished homogeneous system, the dispersive process, and in turn, the dispersivity behavior becomes critical in such cases. The present problem has been attempted to explore the conceptual difficulties of ADE in terms of Time Dependent Dispersivity at the Pre-Asymptotic Regime, with matrix diffusion as an additional process to the basic ADE.

References:

Andricevic, R. and V. Cvetkovic. (1998). Relative dispersion for solute flux in aquifers. Journal of Fluid Mechanics, v. 361, pp. 145-174.

Berglund, S. and V. Cvetkovic. (1996). Contaminant displacement in aquifers: Coupled effect of flow heterogeneity and non-linear sorption. Water Resour. Res, v. 32, pp. 23-32.

Cvetkovic, V., Selroos, JO., and H. Cheng. (1999). Transport of reactive tracers in rock fractures. Journal of Fluid Mechanics, v. 378, pp. 335-356.

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Dagan, G. and V. Cvetkovic. (1993). Spatial moments of a kinetically sorbing solute plume moving in a heterogeneous aquifers. Water Resour. Res. V. 29, pp. 4053-4061.

Referee's Concern#3:

The Authors use a numerical approach; however, at the first glance, such type of transport appears to be solvable in analytical form by means of the Laplace transform (for instance, they could look at the approach developed by Leij in order to analyze similar problems). To my opinion, the use of numerical tools in those cases in which the problem being studied is analytically solvable is not correct.

Author's Reply:

Analytical model to describe solute transport in a system of parallel fractures has been published in the literature (eg. Sudicky and Frind, 1982). The analytical solution for this problem was arrived assuming that the set of fractures has a uniform fracture aperture. However, in the present problem the parallel fractures with varying fracture apertures have also been studied.

Leij et al (1991) analyzed solute movement analytically in semi-infinite porous system under equilibrium conditions. Leij et al (1993) analyzed solute movement analytically in an isotropic soil where the transport parameters namely velocity and dispersion coefficient were assumed to be constant with both space and time. However, the present work differs from the above work, in the sense that, the dispersivity parameter is studied as a time dependent parameter, and that too, for the cases including parallel fracture apertures of different thicknesses. For such system, we are not aware of any analytical solutions so far.

References:

Leij, F.J., Skaggs, T.H. and van Genuchten, M.Th., (1991) An analytical solutions for solute transport in three-dimensional semi-infinite porous media. Water Resour. Res., 27: 2719-2733.

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Leij, F. J., N. Toride, and M. Th. Van Genuchten. (1993). Analytical solutions for non-equilibrium solute transport in three-dimensional porous media. Journal of Hydrology, v. 151, pp. 193-228.

Sudicky, E. A., and Frind, E. O. (1982). “Contaminant transport in fractured porous media: Analytical solutions for a system of parallel fractures.” Water Resour. Res., 18, 1634-1642.

Referee’s Concern#4:

I do not believe that “general properties” can be assessed by using “empirical formulas” as the Authors state.

Author’s Reply:

The empirical expressions deduced in this work provide an idea about the growth of quantum of dispersivity values at an early stage for a system of parallel multiple fractures. Though, the simulated values correspond to an ideal single fracture-matrix system, it provides the magnitude of dispersivity values at pre-asymptotic regime. It is generally difficult to obtain the long time (when fracture and matrix act as a single entity) asymptotic values of dispersivity in a fractured formation, particularly, in the field. Also, in a fractured formation, when matrix diffusion is considered, the values of dispersivity becomes critical even for a smaller distance between source and outlet as the extent of solute velocity retarded is several orders of magnitude smaller than that of water velocity. In such cases, empirical values of dispersivity would be of help for preliminary studies, where the time frame involved in conducting experiment, even in the pre-asymptotic regime is quite significant

Referee’s Concern#5:

The Authors use a particular model to account for the mass transfer diffusion from/toward fractures. How does this model fit with the more classical first order linear kinetics? Is it consistent? The Authors should clarify on physical grounds.

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Author's Reply:

The diffusive mass transfer model describing the dual porosity concept has earlier been studied along with linear reaction kinetics. For example, Steefel and Litchner (1998) studied the behavior of reaction front geometry of multi-component reactive transport in discrete fractures by applying the dual porosity concept, while simultaneously considering linear reaction kinetics represented by fracture and matrix rate constants and concentrations. In such studies, kinetic rate law is based on the assumption that the rate law is surface reaction-controlled. Thus, the present diffusive mass transfer model could very well be fitted to study the first order linear reaction kinetics.

Reference: Steefel, C. I., and P. C. Litchner. (1998) Multicomponent reactive transport in discrete fractures: 1. Controls on reaction front geometry. Journal of Hydrology, v. 209, pp. 186-199.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 3, 895, 2006.

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