Characterization of fractured porous rock aquifers using a combined solute - heat tracer test approach

Motivation

Characterization of solute transport in fractured porous media, as chalk aquifers, remains a challenging problems in hydrogeology, as combined effects of matrix and fractures induce different complex transport mechanisms (Bodin, 2003). Investigations of subsurface transport often rely on applied tracer experiments. Cross-borehole tracer tests generally involve the injection of solutes into one or more injection wells, and monitoring of tracer recovery in groundwater produced from observation wells. However, due to different overlying transport mechanisms occurring in fractured porous media, tracer breakthrough curves (of concentration versus time) often exhibit 'anomalous' behavior showing very high velocity of tracers, longer recorded transit time or multiple concentration peaks (Dassargues et al., 2011). In order to interpret measured breakthrough curves it is particularly important to infer the underlying processes and to delineate conceptual model. However, simple study of breakthrough curves does not generally allow knowing which mechanisms are dominant (Sanchez-Vila, 2004). In the field, a better understanding of the transport behavior in chalk can be obtained by performing tracer tests under different flow and transport conditions (varying tracer velocities, pumping conditions, and distances) (Becker and Shapiro, 2003; Brouyère, 2006). Moreover, different types of data, such as reactive solute and heat tracer tests, can be used to provide additional constraints on the transport processes.

In order to understand and interpret tracer test data, two large classes of numerical approaches have been developed based on different conceptual approaches: continuum and discrete fracture models (Berkowitz, 2002). Continuum approaches, such as dual-porosity model, dual-permeability models, allow the contaminant retardation due to immobile water effects to be taken into account (Brouyère, 2006), but they may provide unrealistically low values for the effective porosity in the fracture zones (Dassargues et al., 2011). On the other hand, discrete fracture approaches account explicitly for the effects of individual fractures on fluid flow and solute transport, but they require detailed field data.

Calibration of these models against directly measured flow and transport properties provides estimation of transport parameters. The characterization of transport patterns from tracer tests at the field-scale is a strongly under-constrained inverse problem, and it remains a challenging research area. This project aims to develop new inverse approaches that are adapted for fractured porous media, and that take advantage of different types of data such as reactive solute and heat tracer experiments.

Strategy

A set of multiple tracer tests were conducted at different locations in the Hesbaye chalk aquifer located near the city of Liège (a full description of the aquifer can be found in Brouyère et al., 2004). 35 tracer tests distributed between 11 sites were conducted with the main objective of studying the local transport of solute contaminants. Measured concentrations show different behaviors linked to the coexistence of a porous matrix and fractures in the chalk aquifer. A preliminary work that consisted in the manual calibration of some of the data using the HydroGeoSphere software has demonstrated that the approach is promising to delineate transport patterns [Dassargues et al., 2011]. Data from these numerous tracer tests offer a great and unique opportunity to explore the potential contribution of one or multiple tracer tests for imaging of porous fractured media.

In the first time, we plan to explore different conceptual models to represent the double porosity and fractured media. Using the capabilities of the HydroGeoSphere code (Therrien et al., 2010, Therrien and Sudicky, 1996; Sudicky and McLaren, 1992), two possibilities, including dual continuum models and discrete fracture models can be investigated. Then, based on the best conceptualization, we will develop an automatic inverse approach in order to interpret the existing salt and dye tracer tests results in the chalk of Hesbaye.

Furthermore, the contribution of different types of data will be assessed. Recent reviews demonstrate that temperature data may have a good potential for providing new constraints on flow heterogeneity (Anderson, 2005, Saar, 2011). We will then investigate the interest of using heat as a tracer in fractured porous media. The fundamental difference between solute and heat transport is that heat diffusion in rocks is large compared to molecular diffusion, implying that fracture-matrix exchange is much significant for heat than for solute tracers. Thus, one can expect that matrix diffusion will control breakthrough tailing, and diffusive transport can be constrained (Becker and Shapiro, 2000). During the project, we are planning to design,prepare and perform a new heat tracer test in the fractured-chalk of Hesbaye at the Bovenistier experimental site (Brouyère et al. 2004) in order to improve the understanding of transport processes by combining heat and solute tracer data.

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