Application of a flexible channel network model to understand flow, mass and heat transport in deep fractured formations

Benoît Dessirier, Uppsala University, Sweden
Chin-Fu Tsang, Lawrence Berkeley National Laboratory, USA and Uppsala University, Sweden
Auli Niemi, Uppsala University, Sweden

Key words: channel, network, semi-analytical

Deep fractured formations have potential for several applications such as geothermal energy production or geological storage. A successful operation requires correct understanding of the structure and physical properties of the targeted reservoir. Modeling is often used to synthesize, test and extend our knowledge and assumptions about the hydrogeological system. By comparing a model response to corresponding experimental data obtained through diverse types of field tests, one can assess the respective fitness of alternatives conceptualizations to capture some aspects of the system's behavior. This can also inform on relevant values for model parameters and on the relative sensitivities of model outcomes to these parameters which is very valuable information to set the focus of later investigations on the least understood processes or parameters. Modeling of flow and transport in deep fractured geological media is particularly challenging due to the intricacy between structure and hydraulics and to the extreme degree of heterogeneity and anisotropy in the system.

Flow and transport behaviors in fractured geological media are often determined by a dominating set of connected fractures at large scales. Furthermore, the local permeability, in a rough-walled fracture under high levels of mechanical stress typical of deep applications, is highly dependent on the local aperture. Both phenomena lead to the channeling of flow into pathways of least resistance [1]. The Channel Network approach (CN) has been developed to directly represent the combined effects of network-scale and in-plane channeling in deep fractured media by using long persistent one-dimensional "channels" as the support for flow and mass transport. It has been proposed and applied to examine the safety of radioactive waste disposal in sparsely fractured crystalline bedrock [2, 3] and to analyze tracer breakthrough and temperature forecast under production in deep geothermal reservoirs [4].

Analytical solutions in the Laplace domain are usually available for the single-phase flow, mass or heat transport equations in a one-dimensional channel, possibly even including the exchange with the surrounding relatively intact rock matrix. Combining mass balances at each channel intersection and using the aforementioned analytical solutions to express the flux terms yields a sparse linear system with a matrix dimension equal to the number of channel intersections, which can efficiently be solved by a conjugate gradient solver and an algebraic multigrid preconditioner for example. Once the solution over the network of channels has been calculated in the Laplace domain, one can numerically invert the Laplace transform at the points and times of interest in the system and obtain the time domain response. This approach includes the effect of structure via the connectivity of the channel network but does not require any discretization for each individual channel.

This contribution presents applications of a newly developed flexible channel network model for flow and transport simulation in fractured media. The emphasis is on the rapid development of alternative models and comparison with site characterization data such as transient pressure tests and tracer tests with multiple conservative or sorbing tracers. These calibration attempts with simple models can quickly inform and support early characterization and site model development and guide further testing and/or management.

References

[1] C-F. Tsang and I. Neretnieks. Flow channeling in heterogeneous fractured rocks. *Rev Geophys.* **36**(2), 275–98, (1998).
[2] Y.W. Tsang and C-F. Tsang. Channel model of flow through fractured media. *Water Resources Research*. **23**(3), 467-79 (1987).
[3] L. Moreno and I. Neretnieks. Flow and nuclide transport in fractured media: The importance of the flow-wetted surface for radionuclide migration. *Journal of contaminant hydrology*. **13**(1-4), 49-71 (1993).
[4] G. Axelsson, G. Björnsson and F. Montalvo. Quantitative interpretation of tracer test data. InProceedings world geothermal Congress 2005 Apr 24 (pp. 24-29).