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Fast method for simulation of radionuclide chain migration in dual porosity fracture rocks

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Abstract

In fractured rocks with a porous rock matrix such as granites, radionuclides will flow with the water in the fracture network. The nuclides will diffuse in and out the rock matrix where they can sorb and be considerably retarded compared to the water velocity. A water parcel entering the network will mix and split at the fracture intersections and parts of the original parcel will traverse a multitude of different fractures. The flowrates, velocities, sizes and apertures of the fractures can vary widely. Normally one must solve the transport equations for every fracture and use the effluent concentration as inlet condition to the next fracture and so on. It is shown that under some weakly simplified conditions it suffices to determine one single parameter group containing information on the flow wetted surface that a water parcel contacts along the entire path. It is also shown how this can be obtained. Then, solving the transport equations only once for time and location along the path gives the concentration and nuclide flux of every nuclide in the chain everywhere along a path. The same solution actually is valid for every path in the network. This dramatically reduces the computation effort. The same approach can be used for models based on streamtubes.

Keywords: Radionuclide chain decay; Fracture networks; Radionuclide migration; Matrix diffusion; Flow Wetted Surface; Dual porosity

1. Summary

Radionuclides moving with the seeping water in fractured rocks decay and generate daughters, which in turn decay. Radionuclide decay chains of interest can consist of four or more nuclides. The nuclides are retarded by sorption and diffusion in and out of the rock matrix. The nuclides are

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carried by water in the complex network of fractures, which can split at fracture intersections and parts can end up in many different locations. Along the flowpaths the fracture properties and the water velocity in the fractures can vary considerably.

Numerical and semi-analytical computation schemes that are used to simulate the transport and fate of the nuclides usually are based on models that assume at least piecewise constant properties and velocities. In numerical methods applied to solute transport problems with matrix diffusion the changing solute concentration in the mobile water as well as in the rock matrix has to be followed over time. For a nuclide chain where the nuclides have different sorption properties and decay constants the discretisation needs of a fracture network and its matrix can put severe demands on computer memory and computation time. In the computations with semi-analytical models the effluent from one fracture is used as input to one or more intersecting fractures. This often entails the need to solve the equations repeatedly along every fracture in the path in addition to computing a large number of different paths or to use some average values for the properties along the flowpath.

For some important cases the computations can be considerably reduced, subject to some simplifying conditions. Many of the important nuclides in the decay chains are retarded so much by the interaction with the rock matrix that their residence time is so dominated by these effects that the water residence time has a negligible influence. The "dispersion" caused by the different residence times in different paths is often so much larger than that due to dispersion in the individual paths that the latter also can be neglected. A further condition is that the matrix interaction properties for each nuclide are the same along the whole path.

Under these simplifying conditions it is found that it is not necessary to solve for each fracture. It suffices to determine the magnitude of one parameter group, A_q/q, containing the ratio of the flow wetted surface to the flowrate along the whole path that a water parcel traverses. This information is sufficient to determine the concentration evolution of the nuclides in the chain along the whole path and the equations need to be solved once. Further, the same solution is valid for every path, only accounting for the differences of A_q/q in the different paths.

As, typically, hundreds to thousands or more of different paths have to be followed in a fracture network with hundreds of thousands of fractures the computing effort is considerably decreased if only one solution is needed for all the hundreds to thousands of pathways each consisting of hundreds of individual fractures.

The simplifying assumptions needed for this approach are stated and discussed. For illustrative purposes the analytical solution for one stable solute is shown and based on this a method to assess when the main simplifying condition is valid is proposed. A method to determine A_q/q in the different paths in the network is shown. A field tracer test with sorbing nuclides simulated with this method is discussed.

2. Introduction

In many countries work is in progress to design geologic repositories for nuclear waste. Some geologic media that are considered are fractured rocks with low hydraulic conductivity. Flow in such rocks takes place mostly in the fractures that form complex networks of conducting paths in the fractures. An overview can be found in Tsang and Neretnieks (1998). The porous rock matrix commonly has a low hydraulic conductivity that transport by flow in the matrix is negligible compared to transport by molecular diffusion. In such cases the system is commonly modelled as a dual porosity medium with flow in one and only diffusion in another direction. The channels in the fractures carry the flowing water and the dissolved nuclides. The nuclides in the flowing water