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Modeling of Solute transport in a fractured rock zone at KURT

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1. Introduction

A solute transport model has developed to simulate migration of tracers which has tested in KURT. KAERI built an underground research laboratory so called KURT, which stands for Korea Underground Research Tunnel. Dipole tests has performed with some nonradioactive conservative tracers in a fractured zone which having a single fracture at KURT. The objectives of this study are not only developing a migration model of solutes for in-situ open environments but also validating the model by comparing and estimating experimental results.

2. Hydrology modelling

The fracture zone is described as a two dimensional geometric field in the simulation with a variable aperture channel model. The fracture field is divided into NxN (transversal x longitudinal flow direction) subsquares. A two dimensional distribution of the aperture field for the whole fracture zone was generated by a geostatistical treatment based on the sample coring results at the test site. The simulated fracture field is well developed and there is no local closed zone. The mean aperture value was calculated as 0.02 *cm,* the standard deviation is 0.7, the correlation length is 0.9.

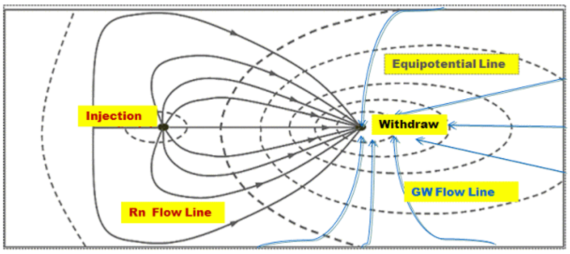

Fig.1 Flow field around dipole test zone

The flow system in the zone is assumed as a point source-in and a point flow-out system, that is, a point source solution contacts at a certain point in the flow field and flows out the other point of the fracture zone as shown in Fig.1. The distance between the inlet and the out let is about 2.5 m.

A governing equation and boundary conditions were set for the flow system which consisted of 100*100 subsquares like the finite difference meshes. The fluid flow through the fracture was then calculated for a constant flow rate as well as for constant pressure conditions.

The volumetric flow rate, Q_{ij}, at a subsquare ***i*** may be written as:

$$Q_{ij} = C_{ij} (P_i - P_j) \qquad (1)$$

where P_i is the pressure at node *i*, Node *i* implies an index of the ith subsquare in a fracture surface. C_{ij} is the flow conductance between nodes *i* and *j*.

The mass balance at each node may be written as:

$$\sum_j Q_{ij} = \sum_j C_{ij} (P_i - P_j) = E_i \qquad (2)$$

where E_i is the injection rate or elution rate at node *i*. The subscript *j* stands for the four facing nodes of the surrounding subsquares to node *i*. By rearranging the above equation for each node, a system of linear equations in the following form can be obtained,

$$[B]\,[P] = [E] \qquad (3)$$

where ***[B]*** is a coefficient matrix describing the flow conductance. The matrix ***[P]*** is an array describing the pressure distribution and ***[E]*** is an array describing the net flow rates. Except for the nodes at the boundaries, the pressure at each node can be solved by an iteration method. The flow between adjacent nodes can be calculated by using equation (2). After obtaining the flow vectors at all the nodes, a solute transport can be simulated in this flow field.

3. Modelling of solute transport

A two-dimensional random-walk particle tracking algorithm is used to simulate a solute transport through the flow fields. Four kinds of transport processes are considered : advection, longitudinal dispersion, diffusion into the rock mass, and a sorption. Particle displacements in each time step consisted of an advective displacement based on the local velocities calculated by using the pressure field, random diffusive displacement, and retardation by a sorption. Particles, which represented the mass of a solute contained in a defined volume of the fluid, moved through the fracture with two types of a motion. One motion is with the mean flow along the stream lines and the other is a random motion, governed by a scaled probability for a matrix diffusion and a sorption. At the inlet, a certain amount of the particles is introduced and distributed at each node between the flow channels with a probability proportional to the flow rates. Particles are then advected and retarded by discrete steps from node to node until they reach the outlet node at which point their arrival time is recorded. This procedure is repeated for all the particles to obtain a stable probability distribution which in turn can be regarded as an elution concentration. The residence time of a particle along each path is obtained by a sum of the residence times in all the subsquares through which a particle has passed. The migration plum can be obtained by checking the positions of the particles in the fracture surfaces at a certain time. Fig.2 shows a migration plume of a nonsorbing tracer at 1 hour after injection. The plume exists in a wide region around straight line between the inlet and the outlet.

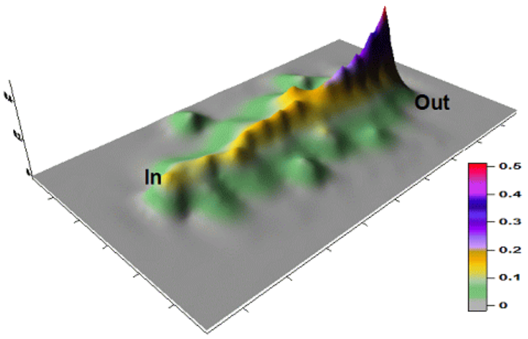

Fig.2 Migration plume of the trace at 1 hr

Fig.3 shows simulated elution curves of nonsorbing tracers according to its migration characteristics at the KURT dipole field. When the tracer moves only by advection without any interactions with the fracture surface, the peak appears after 1 hour and C/Co is 0.00175. After 3 hours some minor peaks appear, which implies tracers move through multi-paths in the dipole field. In order to examine the matrix diffusion effect, elution curves are plotted together in Fig.3 when D_e=3x10^{-12}m^2/s and D_e=3x10^{-11}m^2/s. The elution curves show larger dispersion effects and longer tails. And the magnitude of the peak of the elution curve reduces to 0.001. Fig.4 shows cumulative elution curves of the nonsorbing tracer by integrating the elution curves with time. When the tracer moves only by advection, the recovery percentage becomes 0.9, while when D_e=3x10^{-12}m^2/s, it becomes 0.82, and when D_e=3x10^{-11}m^2/s, 0.75. That is, the larger matrix-diffusion gives the lower recovery rate. This phenomenon means the tracer diffuses into the rock matrix and diffuses back slowly. On the other hand, the experimental curves of uranine and eosine show 0.0017 of peak magnitude, long tails, and small multi-peaks after 30 hours. It implies that the tracer does not move through a straight flow path, and some portion of the tracer move along detour courses slowly. The recovery percentages of the experiments are less than 0.47. It suggests some portion of the tracer could be captured to outer flows or background flows and could not come into the withdrawal pole.

4. Conclusion

The developed variable aperture channel model is applied successfully to characterize a flow field in a fractured zone, and also the particle tracking scheme is described well for a migration of tracers through a fractured zone. The solutes in the experiment did not move through the straight line between the inlet and the outlet in the fracture, rather they move along the tortuous paths by following the least flow resistance region.

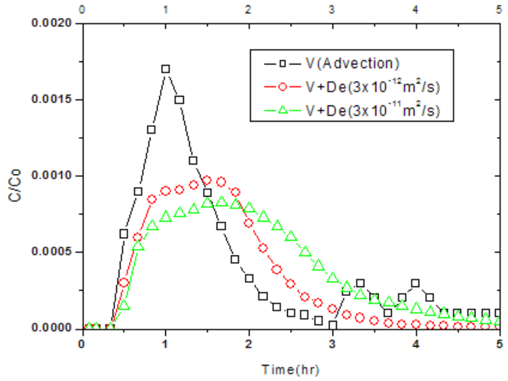

Fig.3 Simulated elution curves of nonsorbing tracers

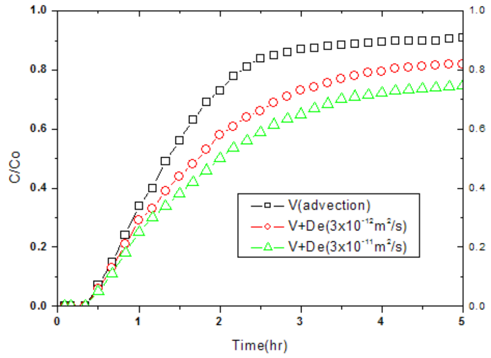

Fig.4 Simulated cumulative elution curves of nonsorbing tracers

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