Modeling variable-density groundwater flow and solute transport in discretely-fractured porous media: Numerical solution for a single inclined fracture

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1 Introduction

Many countries (e.g., Canada) plan to dispose of their radioactive waste in low-permeability hard rock formations, such as the Canadian shield. Groundwater at depths up to 1000 m (e.g., at Cameco) exists. Thus, the transport behavior is greatly affected by fluid density differences. Acute safety questions regarding radioactive waste repository area due to the presence of fractures where flow velocities are typically very high.

Therefore, it is important to understand the movement of contaminants in fractured media under the influence of fluctuating fluid density.

In the past, variable-density transport has been intensely investigated in homogeneous and in heterogeneous porous media (Bear, 1988).

In fractured media, exploring density effects was initiated to the use of simplified fracture networks (C. Shilue et al., 1998).

Since the simulations carried out by Shikaze et al. (1998) for inclined and horizontal fractures, it still remained unknown how dense plumes will migrate in fractures of arbitrary inclination (G).

To address this question, the HydroSphere model (Therrien and Sudicky, 1998), which solves 3D vertically saturated flow and solute transport in discretely-fractured porous media, has been modified.

2 Model Development

Discretizing inclined fractures

In HydroSphere, vertical and horizontal fractures are incorporated into the grid by superimposing individual fracture elements onto the grid, consisting of regular block elements. Two-dimensional faces represent the fracture whereas three-dimensional blocks denote the porous matrix, in order to fully couple the fracture with the porous matrix, faces and blocks where common nodes along the fracture walls.

The fracture nodes between $i$ and $j$ are selected using a simple least difference criterion: for every node that sets up the fracture, the distance of all three neighbor nodes of $P$ to the undeformed fracture is calculated. The neighbor node whose distance to this fracture is the smallest is selected as a fracture node and becomes point $P$ for the next step. Initially, $P$ is identical to $W$. This process is repeated until the point $P$ meets the end point $E$.

Discretized inclined fractures are combinations of horizontal, inclined and vertical 2D elements.

3 Model Verification

Porosity media

Density effects were validated in three dimensions, based on experimental simulation results (Glowatzki and Künsch, 2004).

Inclined fractures

With HydroSphere, two scenarios were simulated where the inclined fracture was discretized differently. In order to account for the longer path in scenario 2, fracture velocities were corrected. The results of the two scenarios were quantitatively compared and very good agreement was obtained.

Additionally to isochlor matching, the following quantitative indicators were used to objectively compare the simulation results.

Simulation results using a single inclined fracture

With the appropriate grid level 5, a numerical simulation of HydroSphere also provides a 3D Random Fracture Generator where network properties (fracture trace, aperture, and orientation) follow statistical distributions.

Further investigations will show the impact of parameter variations on the simulation result in fractured geological media.

4 Results and Conclusion

Grids of different discretization levels were generated to investigate the effective grid size density.

The grid of level 1 can be characterized by 400 $^\circ$ identical squares elements with $h = 1 m$. The domain size is $L = 12 m$, $L = 8 m$.

Grid convergence was achieved for grid level 5 when simulating scenario 1.

Several simulations were carried out where a single fracture of different incline was used. It was demonstrated that the simulated density effects on an inclined fracture approach those in fractures at the limits of the incline. As the fracture becomes steeper, the observed results do approach the ones calculated correctly at the fracture inclination limits.

Therefore, it is important to understand the movement of contaminants in fractured media under the influence of fluctuating fluid density.

5 References