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Quantification of variable-density groundwater flow and solute transport in fractured rock: a modification of the Tang et al. [1981] problem

T. Graf (1) and C.T. Simmons (2)

(1) Center of Geosciences, Georg-August-University Göttingen, Goldschmidtstr 3, 37077 Göttingen, Germany (tgraf@gwdg.de / Fax: +49 551 399379 / Phone: +49 551 397919), (2) School of Chemistry, Physics and Earth Sciences, Flinders University, GPO Box 2100 Adelaide, SA 5001, Australia

Variations in fluid density can greatly affect solute transport and must be accounted for in hydrogeological situations including, amongst others, geothermal reservoirs, deep hazardous waste disposal, or inland salinity. Fractures play a major role in solute transport because fractures represent preferential pathways for solutes. They are also expected to be an important control on variable density groundwater flow processes (Graf and Therrien, 2007). Tang et al. (1981, WRR) provided the analytical solution for constant-density solute transport in a single fracture embedded in a porous rock matrix. The Tang et al. analytical solution is useful because it provides a simple method for predicting fracture concentration in space and time $C(z,t)$for any given groundwater flow speed, influent groundwater concentration, and fracture properties. It has also been used in numerous previous studies of fractured rock transport processes – irrespective of the density of the invading fluid. The present paper assesses the applicability of the Tang et al. analytical solution to mixed convective transport problems (where both variable-density and advective transport occur) in fractured porous media. The variable-density HydroGeoSphere model (Therrien et al., 2008) is used to carry out a series of numerical simulations of a variable-density modification of the Tang et al. (1981) problem for different mixed convection numbers, M (=variable-density transport / advective transport). For a given set of transport parameters (matrix porosity, matrix tortuosity, fracture dispersivity, molecular diffusion, relative fluid density, hydraulic gradient), the deviation between variable-density solute transport and constant-density solute transport was found to be 0% for M <0.1 and 28% for M=1. The applicability of the constant-density Tang et al. analytical solution to variable-density problems for varying transport parameters was also verified. It was found that the applicability of the Tang et al. analytical solution to variable-density problems increases with decreasing matrix porosity, decreasing matrix tortuosity, decreasing molecular diffusion, and increasing fracture dispersivity. Finally, it is shown that the Tang et al. solution can be applied to mixed-convective transport problems for any M by accounting for fluid density in the calculation of the groundwater flow velocity in the fracture.