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Solute transport in a plane horizontal fracture: influence of density contrasts and fracture-matrix exchange

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Fractures are preferential paths for fluids and solutes inside hard rock formations in the Earth's upper crust. We address the advective and dispersive transport of a buoyant solute in a horizontal fracture with no wall roughness, under laminar flow conditions. Our reference configuration is that with impervious fracture walls an no density-driven coupling between flow and transport; it gives rise to the classic one-dimensional longitudinal Tayor-Aris dispersion process. In reality the solute usually has a negative buoyancy, so that the fluid density is spatially distributed according to the solute concentration field, which induces significant perturbations to the Poiseuille flow inside the fracture. We study this impact of density constrasts on the longitudinal dispersion, using a two-dimensional finite elements numerical simulation [1]. The asymptotic Taylor–Aris effective dispersion coefficient is observed to be reached eventually, but buoyancy effects at short and moderate times are responsible for a systematic retardation of the asymptotic mean solute position with respect to the frame moving at the mean fluid velocity, as well as for a time shift in the establishment of the asymptotic dispersion regime. We characterize these time delays as a function of the Péclet number and of another non-dimensional number that quantifies the ratio of buoyancy to viscous forces. Depending on the Péclet number, the asymptotic dispersion is measured to be either larger or smaller than what it would be in the absence of buoyancy effects. Breakthrough curves (an important measurement in hydrogeological applications) measured at distances larger than the typical distance needed to reach the asymptotic dispersion regime are impacted accordingly. We also discuss conditions under which density effects related to fracture wall roughness are likely to be significant, or not.

Another effect that can strongly influence the transport process is the small but finite porosity of the rock matrix, which allows part of the solute present in the vicinity of the fracture wall do diffuse into the matrix. We carry an experimental study of this effect [2]. The analog fracture model consists of a $1000 \times 50 \times 5$ mm^3 plexiglass box with a porous lower wall made of 1mm-large glass beads. A permanent laminar water flow is forced through the fracture at controlled mean velocity ($\simeq$ 1 mm/s). A dye (patent blue) injection system simulates a point source of contaminant along the center plane of the experimental fracture. The two-dimensional equivalent longitudinal concentration field is measured as a function of time using a visualization system based on 4 cameras positioned side by side. Mass transfer between the fracture and the bounding porous matrix is measured at different volumetric flows and for various concentrations of the injected dye, and this in different geometries (roughness) of the fracture-matrix interface. Here also, buoyancy effects play a significant role in the trapping of the solute in the vicinity of the porous wall.

[1] J. Bouquain, Y. Meheust and P. Davy, J. Contam. Hydrol., in press (2010)
[2] L. Michel, PhD thesis, Université Rennes 1 (2009)