Impact of fractures on diffusion dominated reactive transport in porous media: application to the study of a radioactive waste storage

Benjamin Delfino, Jean Raynald De Dreuzy, Jocelyne Erhel

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B. Delfino[a], J-.R. de Dreuzy[b], J. Erhel[c]

[a] *PHD student, Inria Rennes, Campus de Beaulieu, 263 Avenue General Leclerc, 35000 Rennes.*
[b] *Research scientist, Geosciences Rennes, Campus de Beaulieu, Avenue Charles Tillon, 35000 Rennes*
[c] *Research scientist, Inria Rennes, Campus de Beaulieu, 263 Avenue General Leclerc, 35000 Rennes.*

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Even in small numbers, fractures must be carefully considered for the geological disposal of radioactive wastes. They critically enhance diffusivity, speed up solute transport, extend mixing fronts and, in turn, modify the physicochemical conditions of reactivity around possible storage sites. Fractures occur at several places in the cement surrounding the containers and in the Excavation Damaged Zones (EDZ) of the galleries. They even occur in clays such as the French Callovo-Oxfordian formation mostly because of the de-saturation conditions induced in the operational time of the galleries.

Numerous studies addressing various applications (e.g. radioactive waste storage, CO_2 sequestration, geothermal storage, hydrothermal alteration) have shown that fractures cannot be simply integrated within an equivalent porous medium through a simple enhancement of its petro-physical properties (porosity and permeability). Fractures cannot either be accurately identified so that fully deterministic modeling approaches are precluded.

We propose a combined numerical and experimental approach to determine the influence on reactivity of typical fracture patterns classically found in radioactive waste applications. We investigate the possibility of applying simplified modeling frameworks on the basis of some key properties:

(i) transport is mostly diffusive and much faster in the fractures than in the porous matrix [1],

(ii) reactions occur predominantly in the matrix because of the large surface to volume ratio favorable to dissolution/precipitation processes,

(iii) the reactivity within the surrounding matrix is at equilibrium, or equivalently much faster than the diffusive transport. Reactivity is assumed transport-limited rather than rate-limited.

Based on the separation of the fracture and matrix domains, we develop a reactive transport model with diffusion conditions differing between the fracture and in the matrix, appropriate flow-rock interactions at equilibrium in the matrix and fracture-matrix exchange conditions at their interface. Using preferentially existing software, we propose simulation methods that comply with much faster diffusion in the fracture than in the matrix, and validate them against elementary fracture structures and a simplified reactivity.

We intend to use the developed methods on different fracture structures to simulate reactivity over long periods of time. We determine the possible relevance of the most classical simplified frameworks for fracture-matrix including:

(i) fully homogenized models with porosity, permeability and surface adapted to volume ratio to recover localization effects,

(ii) models with isolated fractures within "infinite matrix" assuming implicitly the localization of reactivity in the immediate vicinity of the fracture [2],

(iii) double porosity models characterized by single or multiple exchange coefficients[3].

Following the outcome of the numerical simulations, we will investigate experimentally the most critical limitation of reactivity. It might a priori be the fracture to matrix exchange law especially if the fracture is desaturated and the matrix saturated.

Within the radioactive waste framework, we aim at including fractures in the safety assessment workflow. We intend to determine to which extent fractures facilitate the access to reactive surfaces, the increase in bulk reactivity, the corrosion potential and the perturbation of the chemical conditions. We frame as much as possible the reference simulations in realistic physical and chemical conditions including the main operational phases of the radioactive waste repository. Results will be reported as comprehensive evolution scenarios.

References

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