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Reactive transport in fractured porous media

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Reactive flow through geological formations occurs in many situations due to human intervention or during natural processes. For instance, chemical dissolution and precipitation play a major role in diagenesis or in the formation of karsts. The quantitative description of the injection of a reacting fluid from a well into a fractured porous medium is also a subject of high interest. It can be provoked, as in the acidization stimulation technique for increasing well productivity, or accidental, in CO_2 sequestration. Ideally, one wishes to analyze the improvements or damages caused by the fluid to the well itself and to its immediate surroundings.

To this end, a coupled system of equations has to be solved. It includes the description of the flow in the porous matrix and in the fracture network by Darcy-like equations, and the description of the reactive solute transport and of the reactions which occur in the two structures. In addition, constitutive equations are required for the evolution of these two structures, such as evolution laws for permeability and reactivity as functions of porosity.

Our discrete fracture numerical model involves three major steps. First, an unstructured tetrahedral mesh of the fractures and of the porous matrix is built. Second, the Darcy equations are discretized and solved, in a finite volume formulation. Third, the evolution of the solute concentration has to be calculated. This is the most difficult point if one wants to avoid numerical diffusion and accurately describe the transfers between the fractures and the matrix. A non linear flux limiting scheme of the Superbee type coupled with a systematic use of triple control volumes proved to be the most efficient.

Various simple model situations have been considered, for validation purposes or to illustrate some physical points. In particular, it is shown that even when the matrix permeability is small and the flow is predominantly carried by the fracture network, convective exchanges still exist between the fractures and the matrix which can widely exceed diffusive ones and strongly affect the solute transport and its residence time distribution.

Finally, simulations of passive and reactive solute transport have been performed in large samples containing percolating or non percolating fracture networks. Various parameters have been systematically investigated, including the transmissivity of the fractures, the flow regime characterized by Péclet numbers in the fractures and in the matrix, and the Damköhler numbers of the reaction process in the matrix and fractures. The passive transport behavior and the effect of the gradual clogging of the fractures and/or matrix pore space in the case of a precipitation process are analyzed.