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A tri-phase phase-field model for precipitation and dissolution in partially saturated porous media

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We consider a porous medium where the pore space is completely filled by three different phases: two immiscible fluids like water and air or oil and a solid phase. The non-wetting phase contains no solute and has no interaction with the solid phase. The wetting phase contains dissolved ions, which can precipitate at the pore boundary to form the solid phase. The reverse process of dissolution, is also possible.

The precipitate has a non-negligible size when compared to the pore size. Therefore, precipitation and dissolution can lead to changes in the pore volume available to flow [1] and, at a larger scale, to changes in the porosity of the medium when interpreting the latter as the volume available strictly to fluids. Moreover, these changes are which are not known a priori.

Starting from a pore scale model that involves sharp interfaces between the three phases and incorporates the dynamics at the pore scale, we develop a diffuse interface approach that accounts for the evolution and the spatial distribution of the three phases and the overall concentration of the solute [4]. The model extends the ideas in [2], where only two phases (water and solid) are considered. Some properties of the model are discussed, including its convergence to the sharp interface model when letting the interface width parameter approach 0. Further, assuming that initially the porous medium consists of periodically distributed grains, we employ homogenization techniques to derive a two-scale model that is valid at the Darcy scale. The outcome is a parabolic reaction–diffusion system in a medium with variable, concentration dependent porosity. The evolution of the porosity is given by the phase field equations defined at the pore-scale.

Finally, an efficient numerical scheme for approximating the solution of the two-scale model is presented. This scheme builds on the algorithm in [3]. The numerical results show how the changes in the pore structure, which are due to precipitation and dissolution, and the evolution of the averaged, Darcy scale concentration of the dissolved ions in the wetting phase, influence each other.

References

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