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Upscaling of two-phase flow processes in CO_2 geological storage

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Only few current multiphase flow and reactive transport models take into account the impact of heterogeneity on front spreading and mass transfer between high and low permeability zones of the heterogeneous medium and the impact of physical heterogeneity and chemical heterogeneity on chemical reactions rates. Effective equations are available for single-phase conservative and reactive transport and under development for multiphase flow.

In the present work, we aim specifically at the upscaling of the two-phase flow dynamics related to processes of CO_2 geological storage. The impact of heterogeneity on the two-phase flow dynamics can be quantified in the framework of a multi-continuum approach. This approach allows for the quantification of mass exchange between mobile (background material) and immobile (inclusions) zones of the medium. In this way it accounts systematically for local scale non-equilibrium and thus for the complex flow dynamics in highly heterogeneous and fractured media. The mass exchange between mobile and immobile zones is taken into account by a Multi-Rate Mass Transfer (MRMT) model.

Effective equations were formulated in order to describe the impact of spatial heterogeneity on the large-scale two-phase flow behavior. The model was implemented into a MatLab code. Heterogeneity in the hydraulic conductivity of the storage aquifer was accounted through a Gaussian random field. Numerical simulations of 2D two-phase flow through this heterogeneous media were run to obtain the evolution of the actual CO_2-rich phase saturation distribution. An equivalent effective model of 1D two-phase flow in homogenous media with MRMT was used to describe the 2D heterogeneous results.

The numerical simulations show that a simple 1D homogeneous model with MRMT, capillarity at mobile-immobile interface and in the mobile zone is able to describe two-phase flow in heterogeneous media. However, gravity and macrodispersion terms still have to be included. Extension to heterogeneous multiphase flow is straightforward. The present methodology could contribute significantly to the quantification of the heterogeneity-induced uncertainty of the predicted large-scale multiphase flow and transport behavior in CO_2 geological storage.