A MULTI-RATE DUAL POROSITY MODEL FOR IMPROVED SIMULATION OF IMMISCIBLE DISPLACEMENT AND COMPONENT TRANSFER IN HIGHLY HETEROGENEOUS AND FRACTURED MEDIA

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To predict the displacement of carbon dioxide and its dissolution in brine involves often modelling of flow and component transport in fractured rock or highly heterogeneous media. To capture the detailed structure in a numerical model is often not feasible, although information about heterogeneous structure, such as fracture geometry and connectivity might be available.
Often, flow and transport in strongly heterogeneous or fractured media is modelled using a dual-porosity approach, which assumes that the high-permeability parts (such as fractures) are mobile and low-permeability part (such as rock matrix) is immobile. A single transfer function is used to model the rate of mass exchange between mobile and immobile domain. However, the typical time behaviour of capillary driven flow into and out of the low-permeable part is not fully described by a single rate transfer function. Also, as shown in many numerical, laboratory, and field experiments, a wide range of transfer rates occur between the immobile matrix and mobile fractures. These arise, for example, due to the different size of matrix blocks (yielding a distribution of shape factors) or different porosity types (vugs and matrix). Accurate models are hence needed that capture all the transfer rates between immobile and mobile regions, particularly to predict late-time behaviour. If component mass transfer between the displacing fluids is involved, the transfer depends on the macroscopic interface between the fluids, which depends on the heterogeneous medium structure.
Upscaled models for displacement processes can be derived with homogenization theory. Based on this approach, a multi-rate mass transfer model for two-phase flow can be formulated, which describes the flow in the mobile (fracture) domain. By linearizing the capillary flux, the model can be parameterized by a memory function, which captures the exchange between mobile and immobile domain. It extends the standard (single-rate) dual-porosity model in that it allows to simulate the wide range of transfer rates occurring in naturally fractured multi-porosity rocks. The multi-rate mass transfer formulation allows for an estimation of the macroscopic interface between the fluids in the immobile domains. The interface at the displacement front in the mobile domain can also be estimated depending on the heterogeneous structure of the medium. Based on this, an estimation of the total mass transfer between the fluids can be estimated. Using high-resolution numerical simulations of displacement of oil by water in highly heterogeneous porous media at the grid-block scale we demonstrate that the multi-rate model captures the time behaviour of the large scale fluid content. We further show how tracer tests can be used to calibrate the multi-rate dual porosity model before applying it to two-phase flow applications. We also discuss the limits of the proposed model.