A finite-volume based discrete fracture model for non-isothermal flow and transport in fractured porous media

Dennis Gläser, University of Stuttgart, Institute for Modelling Hydraulic and Environmental Systems (IWS),
Rainer Helmig (IWS),
Bernd Flemisch (IWS),
Holger Class (IWS)

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Introduction
Understanding and predicting the hydraulic response of fractured rock is of great importance in many geotechnical engineering applications such as e.g. geothermal energy or unconventional gas production. Numerical schemes used to simulate the underlying processes have to deal with the strongly discontinuous material properties of the involved geological porous media, and in addition to that, fracture networks of arbitrary geometries further complicate the problem. The fractures represent strong material discontinuities as well, however, their extent in normal direction is usually very small in comparison to the domain sizes considered. The combination of this discrepancy in scales paired with the large contrasts in properties makes it difficult for numerical schemes to treat the fractures accurately while maintaining efficiency. Many different approaches for single- and two-phase flow in fractured porous media have been proposed in the past, including e.g. dual- and multi-continuum approaches (see e.g. [1], [2]) or discrete fracture models (e.g. [3] or [4]).

In this contribution, we would like to present a discrete fracture model on the basis of a cell-centered finite volume approach, in which the fractures are treated as (d−1)-dimensional geometries embedded in a d-dimensional domain. Subsequently, we apply it to problems involving multi-phase, compositional and non-isothermal processes.

Numerical scheme
The finite-volume formulations of balance equations typically boil down to a control volume-wise equilibrium between storage and source terms within the control volume and flux terms across the facets of the control volume. By demanding grid conformity such that the facets of the d-dimensional grid for the porous matrix align with the (d−1)-dimensional fracture geometries, the matrix-fracture transfer fluxes can be evaluated explicitly and can be potentially different on the two sides of the fracture, which enables us to represent jumps in e.g. pressure and mass fluxes across the fracture. The fractures are treated as Robin-type interior boundary conditions for the matrix domain, which are derived analogously to those presented in [5]. The numerical scheme is implemented into the open-source simulator DuMu\(\times\) ([6]).

Preliminary results

In Figure 1 we show some preliminary results for two-dimensional simulations of single-phase flow and transport through a fracture network geometry that was taken from [7]. The scenario considers the injection...
of nitrogen-rich water into an initially water filled-domain, where nitrogen is transported subject to advective and diffusive mechanisms. The fluid system consisting of nitrogen and water has been chosen here due to the fact that an advanced implementation of the thermodynamic description of this mixture is available in DuMu², where the properties of the water phase (water being described after the IAPWS formulation [8]) are dependent on the mole fraction of dissolved nitrogen.

In the simulation shown in Figure 2, the nitrogen inflow into the domain is controlled via Dirichlet boundary conditions on the left side. In addition to the mass balances of the water phase and nitrogen that were solved in the above example, here, it is additionally solved for the energy balance of the porous medium accounting for non-isothermal effects. In both simulations, the hydraulic conductivity of the fractures was set to be several orders of magnitude higher than in the surrounding matrix, which explains the nitrogen transport being initially only concentrated along the fractures with a subsequent slow intrusion into the matrix.

![Temperature distribution](image)

*Figure 2: Temperature distribution after 1.5 days (left) and 5.25 years (right).*

For the contribution at the CMWR conference, we would like to present studies on the performance of the scheme for both single- and two-phase flow applications on simple geometries by comparing the results of the model to those obtained by an equi-dimensional discretization. Furthermore, we apply the model to geothermal energy production scenarios on realistic three-dimensional fracture network geometries.

References