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Numerical modeling of multiphase flow in rough and propped fractures

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crystalline rocks. The detailed pattern of flow paths and effective fracture conductivity are largely dependent on the level of confining stresses and fracture wall roughness, which both determine the shape and distribution of fracture apertures and contact areas. The distribution of proppant grains, which are used to maintain apertures of hydraulic fractures, is a key factor governing fracture flow in industrial applications. The flow of multiphase fluids in narrow apertures of rock fractures may substantially differ from the flow of a single-phase fluid. For example, multiphase flow effects play an important role during all stages of unconventional reservoir life cycle. Multiphase flow conditions are also expected to prevail in high temperature geothermal fields and during the transport of non aqueous phase liquid contaminants in groundwaters.

We use direct numerical simulations to study single- and multiphase flow in rough and propped fractures. We compute the fluid flow using either the finite element or the lattice Boltzmann method. Body-fitting, unstructured computational meshes are used to improve the numerical accuracy. The fluid-fluid and fluid-solid interfaces are directly resolved and an implicit approach to surface tension is used to alleviate restrictions due to capillary CFL condition. In FEM simulations, the Beltrami-Laplace operator is integrated by parts to avoid interface curvature computation during evaluation of the surface tension term.

We derive and validate an upscaled approach to Stokes flow in propped and rough fractures. Our upscaled 2.5D fracture flow model features a Brinkman term and is capable of treating no-slip boundary conditions on the rims of proppant grains and fracture wall contact areas. The Stokes-Brinkman fracture flow model provides an improvement over the Reynolds model, both in terms of the effective fracture permeability and the local flow pattern. We present numerical and analytical models for the propped fracture permeability as a function of proppant concentration. Front dynamics of invading non-wetting and wetting fluids is systematically studied as a function of fracture aperture, proppant concentration, fluid viscosity ratio and capillary number.