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A stochastic analysis of the non-Newtonian hydraulic behavior of rough fractures

Tuesday, 1 June 2021 19:00 (1 hour)

Fluids involved in activities occurring in fractured underground reservoirs, either related to natural resource recovery (e.g., hydrofracturing, drilling, geothermal exploitation) or environmental remediation schemes, often exhibit complex rheology. The micro-structure of foams, muds, emulsions, or colloidal suspensions induces shear-thinning in the continuum scale mechanical behaviour, which can be described by the Ellis rheology. This three-parameter model has a Newtonian low-shear rate behaviour of apparent viscosity $_0$, a high-shear rate power-law trend with exponent n, and a transition between the two regulated by a characteristic stress $_{1/2}$. Such fluids often flow in rock fractures having rough walls characterized by long-scale correlations in the topography, i.e., a self-affine scale invariance at all scales. The facing walls of a given fracture are also mated at scales larger than a characteristic correlation length scale. Such geometries can be reproduced numerically utilizing an FFT-based algorithm. The fracture closure is then measured as the ratio of the aperture field's roughness amplitude to the mean fracture aperture. The investigation of the non-Newtonian hydraulic behaviour of such natural or artificial fractures implies a considerable mathematical and numerical effort to properly account for non-linearities and medium geometry. A full stochastic analysis of large fractures with a variety of statistical descriptive parameters via Monte Carlo simulations is almost prohibitive considering a fully 3-D simulation of the flow. The flow of a shear-thinning fluid through a variable aperture fracture can instead be described under the assumptions of the lubrication theory, a depth-averaged formalism that reduces the model formulation to a single two-dimensional non-linear PDE. A numerical code has been implemented adopting the finite volume method, with the fracture discretized on a staggered grid, defining the pressures at the centre of each finite volume and the aperture at each side. The system of non-linear equation is solved adopting the Newton-Krylov method, considering a continuation strategy to face strong non-linear cases (very low n values), and solving the linearized symmetric system of equations via variable-fill-in incomplete Cholesky preconditioned conjugate gradient algorithm. A Monte Carlo framework is adopted to study the influence of rheology, fracture dimension and pressure gradient on fracture hydraulic behaviour, generating $NMC = 1000$ realizations of the aperture field. The approach allows characterizing the hydraulic behaviour via ensemble statistics, such as the PDFs of the velocity fields and the dependence of the fracture transmissivity on fracture closure, and how it is impacted by the fluid's shear thinning behaviour. Fracture flow is mainly cocurrent, presenting narrow PDFs with nearly exponential decay. Evident channelling and localization effects are associated with strongly heterogeneous aperture fields and very shear-thinning fluids. In these cases, the probability distributions of velocity components PDFs show wide tails deviating from the exponential decay, and the fracture transmissivity is much higher compared with the Newtonian case of identical mean aperture.

Time Block Preference

Time Block B (14:00-17:00 CET)

References

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