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A simplified model to evaluate the effect of fluid rheology on non-Newtonian flow in variable aperture fractures

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Modeling of non-Newtonian flow in fractured media is essential in hydraulic fracturing operations, largely used for optimal exploitation of oil, gas and thermal reservoirs. Complex fluids interact with pre-existing rock fractures also during drilling operations, enhanced oil recovery, environmental remediation, and other natural phenomena such as magma and sand intrusions, and mud volcanoes. A first step in the modeling effort is a detailed understanding of flow in a single fracture, as the fracture aperture is typically spatially variable.
A large bibliography exists on Newtonian flow in single, variable aperture fractures. Ultimately, stochastic modeling of aperture variability at the single fracture scale leads to determination of the flowrate under a given pressure gradient as a function of the parameters describing the variability of the aperture field and the fluid rheological behaviour. From the flowrate, a flow, or 'hydraulic', aperture can then be derived.
The equivalent flow aperture for non-Newtonian fluids of power-law nature in single, variable aperture fractures has been obtained in the past both for deterministic and stochastic variations. Detailed numerical modeling of power-law fluid flow in a variable aperture fracture demonstrated that pronounced channelization effects are associated to a nonlinear fluid rheology. The availability of an equivalent flow aperture as a function of the parameters describing the fluid rheology and the aperture variability is enticing, as it allows taking their interaction into account when modeling flow in fracture networks at a larger scale.
A relevant issue in non-Newtonian fracture flow is the rheological nature of the fluid. The constitutive model routinely used for hydro-fracturing modeling is the simple, two-parameter power-law. Yet this model does not characterize real fluids at low and high shear rates, as it implies, for shear-thinning fluids, an apparent viscosity which becomes unbounded for zero shear rate and tends to zero for infinite shear rate. On the contrary, the four-parameter Carreau constitutive equation includes asymptotic values of the apparent viscosity at those limits; in turn, the Carreau rheological equation is well approximated by the more tractable truncated power-law model. Results for flow of such fluids between parallel walls are already available.
This study extends the adoption of the truncated power-law model to variable aperture fractures, with the aim of understanding the joint influence of rheology and aperture spatial variability. The aperture variation, modeled within a stochastic or deterministic framework, is taken to be one-dimensional and perpendicular to the flow direction; for stochastic modeling, the influence of different distribution functions is examined. Results are then compared with those obtained for pure power-law fluids for different combinations of model parameters. It is seen that the adoption of the pure power law model leads to significant overestimation of the flowrate with respect to the truncated model, more so for large external pressure gradient and/or aperture variability.