Fluid flow along a rough fracture: impact on hydraulic diffusivity

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Fluid flow along fractures or in fractured rock is of great importance in Enhanced Geothermal System, since natural fracture networks generally affect the permeability of the reservoir rocks and therefore the hydraulic performance. The cubic law commonly estimates the permeability of a single fracture, which is only valid for the flow through two smooth parallel plates. In fact, the flow performance is strongly influenced by the aperture fluctuations, which are related to the fracture surface roughness, the fluid-rock interaction process, and the amount of flow exchange between the matrix and the fracture itself, etc.

To quantify the hydraulic performance and get the better knowledge of the more real fracture flow, we conduct numerical simulations of fluid flow in a fracture-rock system hosting one single rough fracture from laboratory to field scales. As an example, a 2D self-affine rough surface is synthetically generated (Candela et al, 2012), with two anisotropic roughness exponents $H_{//}=0.6$ along the slip direction, $H_{\perp}=0.8$ in the perpendicular direction and a RMS amplitude of 0.1m at the 512m scale. Based on this surface generation, the opening geometry of a rough fracture is obtained as an input structure for finite element mesh generation. On one hand, we apply a lubrication approximation and limit the fracture opening to spatially variable 2D features with lower-dimensional element embedded in a saturated porous. On the other hand, we consider the full 3D features of the fracture opening as the space between two surfaces symmetrical about the mean fracture plane. The simulations are performed in the framework of the Multiphysics Oriented Simulation Environment (MOOSE) combined with a MOOSE-based application GOLEM dedicated to modeling coupled Thermal-Hydraulic-Mechanical (THM) process in fractured geothermal reservoirs.

For the lubrication case, the mass balance equation for a saturated porous medium is described in terms of volumetric averaged mass conservation equations for the fluid phase, with Darcy’s law governing the momentum conservation equation. For the 3D fracture case, the incompressible Navier-Stokes equation is solved for the dynamic pressure and the velocity field inside the fracture only.

We compare the 2D and 3D cases and assess the effects of the nonlinear inertial term $(\mathbf{u} \cdot \nabla) \mathbf{u}$ in 3D case especially when the Reynolds number is high. The objective is to evaluate the large-scale hydraulic diffusivity of the fractured domain and its anisotropy owing to the strong contrast between the fluctuating fracture opening, and the homogeneous bulk porosity. The results show
that the long-range aperture variations significantly affect the fluid flow, like the channeling effect and the hydraulic diffusivity anisotropy (i.e., along and perpendicular to the fault), which may have strong implications on the spatial distribution of fluid-induced seismic events in faulted reservoir.