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Hydro-thermal flows in a rough fracture

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Heat exchange during laminar flow is studied at the fracture scale on the basis of the Stokes equation. The aperture is obtained from a self-affine geometrical model shown to be a realistic description of a natural fracture. We study the influence of the fracture roughness on the heat flux through the fracture sides when a cold fluid is injected and we estimate at which distance the fluid reaches the rock temperature. As a first step, the rock temperature is considered as constant (in time and space). We show that at a coarse grained scale, the basic equation for heat flux is identical to the one for parallel plates, but with a different characteristic thermal length, which depends on the details of the morphology of the fracture.

Our model also illustrates that the fracture roughness potentially induces channeling effects in hydraulic and thermal flows. As the fracture roughness is shown to induce a large variability of behaviors, we made statistical computations of the hydraulic aperture and thermal length, which are relevant quantities to characterize hydraulic transmissivity and thermal fields at the fracture scale. Then we compare these values to what is obtained with flat parallel plates. The hydraulic aperture of rough fractures can be higher or lower than the one of parallel plates having the same mean mechanical aperture: when the fracture is longer in the flow direction, the morphology tends to induce fences perpendicular to the flow providing small hydraulic apertures (small flow); whereas the opposite aspect ratio tends to favor channels in the main flow direction and large hydraulic apertures (large flow). Comparing two fractures having the same hydraulic aperture, one with a constant aperture and the other being rough, our model shows that the thermal equilibration is more likely to be reached at

a longer characteristic thermal length for the rough one. By filtering the aperture, we also show that the largest scales dominate the hydraulic and thermal flows; however, more Fourier modes are necessary to describe the thermal behavior. A boundary element model describing how the fracture elastically closes is used in order to introduce the study of the hydro-thermo mechanical coupling of a rough fracture. Application to the Soultz-sous-Forêts geothermal project is discussed.

Most results presented here come from hydrodynamic flows in the Stokes regime, using a lubrication approximation. These bidimensional (2D) flows and 2D temperatures field are computed thanks to finite difference scheme combined with a biconjugate gradient method. These equations have also been implemented on a different numerical solver, which is shown to give similar results.

In a forthcoming step, we will address the influence of departures from the lubrication approximation due to highly developed morphology, and to the impact of oscillating flows on the heat exchange on rough fractures. We will show through preliminary results, how these problems can be addressed using a Lattice Boltzmann cellular automaton.