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Non-Darcian effects in a rough fracture using lattice-Bolztmann methods

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Some natural fractures may be considered, at first order, as flat. However, looking at the influence of the fracture morphology in a geothermal background, it was shown that the complexity of the fracture topography changes the hydro-thermal flows which occurs when a cold fluid is injected into a hot fractured bedrock [1]. This was shown under lubrication approximations, which assumes that the fracture morphology varies in a smooth way, by solving Stokes equation and a bidimensional (integrated over the thickness) advection-diffusion equation. However, some features which are observed in the real world, like fluid recirculation, and time-dependent temperature at the pumping well, cannot be explained with this model.

We therefore wish to go beyond this lubrication assumption and be able to observe non Darcy effects, which may happen due to highly variable morphology of the fluid-rock interface.

Lattice-Boltzmann methods appear to be very suitable to implement this problem. Indeed, as the algorithms require only local operations, they can handle very well complex boundaries. We develop an algorithm which is based on two coupled lattice Boltzmann methods, allowing us to solve both the advective mass transport and the conducto-advective heat transport. No term are discarded in this solving: Navier-Stokes and the full advection-diffusion equations are solved in three dimensions in the fluid and solid. This allows us to observe how both the velocity and the temperature evolves with time and space, also possibly under a time variable pressure gradient. We investigate the effect of recirculation around sharp asperities and wedges along the fracture over the mass and heat transport. We observe that the velocity profile is far from a quadratic profile in the surrounding of sharp asperities: cold fluid may be first trapped into such zones showing a low velocity, and released later.

Note that this approach could also be used in any field requiring advection-diffusion solving, like the evolution of the concentration of a solute. By using suitable boundary conditions, it is also possible to implement fracture morphology evolution, for instance by considering chemical dissolution at the interface between fluid and rock.

[1] Neuville, A., Toussaint, R., and Schmittbuhl, J. (2010). Hydro-thermal flows in a self-affine rough fracture. Physical Review E, 82, 036317.