Geophysical Research Abstracts
Vol. 14, EGU2012-11216-1, 2012
EGU General Assembly 2012
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Hydro-thermal exchanges in rough fractures: solving the equations with or without lubrication approximations?

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The characteristics of the hydro-thermal flow which occurs when a cold fluid is injected into a hot fractured bedrock depend on the morphology of the fracture [1]. This was shown under lubrication approximations – which assume 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 on the field, like time-dependent temperature during pumping, cannot be explained with this model. To go beyond these lubrication assumptions we have developed a full tridimensional (3D) lattice Boltzmann (LB) code. These simulations establish the validity range of the lubrication approximation, and they may be compared to a new set of experiments based on infrared photography.

In these LB simulations, two sorts of fictitious particles are used: one to solve the mass transport, and the other one for the energy transport. These particles move respectively on a four-dimensional hypercubic face centered lattice and a 3D simple cubic lattice: using these special lattices, we can simulate 3D mass transport, and 3D heat advection-diffusion. As a first step, we study the hydrothermal exchanges into fracture morphologies which are invariant along one dimension. We investigate the effect of recirculation around a sharp cavity perturbing an otherwise flat fracture, at fixed low Reynolds number. Beyond some critical slope for the boundaries, we observe that the velocity profile is far from a quadratic profile in the surrounding of the sharp asperity: the fluid within the cavity moves very slowly. The cold fluid may be trapped into such zones, where heat conduction is dominant over heat convection. By exploring a range of cavity shapes, we identify when the cavity has a negligible effect on the hydrothermal exchange, i.e. when it is possible to simply ignore the cavity, as if it were filled with rock. Within this fictitious flat geometry the lubrication approximation can, in this case, be used. The lubrication approximation also holds when the cavity has gentle slopes, so that the fluid flows in the cavity with a smooth quadratic profile across the full aperture. We also compare some lengths (apertures) characterizing respectively the fracture geometry, the permeability and the heat transfer; those lengths being obtained with and without lubrication approximations, or within a flat fracture. Doing so, we determine the range of validity of the approximations often used in geothermal models: the parallel plate approximation, and the lubrication approximation. Beyond some critical slope for the boundaries, 3D effects become important and require to go beyond these approximations to be properly modeled.

Finally we also present an experimental setup that we want to use to further investigate and calibrate our simulations. An infrared camera monitors the temperature field in space and time of cold water injected through a rough fracture, composed by a rough wall, and a flat germanium plate.

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