Hydro-thermal coupling in a rough fracture
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ABSTRACT
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 geometric 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 matrix when a cold fluid is injected and we estimate at which distance the thermal equilibrium between the fluid and the rock temperature is reached. We show that at a coarse-graded scale, the basic equation for heat flux is identical to the one for parallel plates, but with a different characteristic thermal length. Statistical computations and comparisons with flat parallel plates are made for the hydrothermal and thermal results. The aperture of rough fractures can be higher or lower than the one of parallel plates having the same mechanical aperture (or geometric aperture). The aspect ratio of the fracture appears to be an important parameter. One result also shows that the fracture roughness induces channeling effects in hydrothermal and thermal flows. Although fracture roughness is shown to induce a large variability of behavior, the thermal equilibrium is often reached within a higher characteristic thermal length than for a system with parallel plates having the same hydraulic aperture. A boundary element model describing how the fracture energetically changes is used to introduce the study of the hydro-thermal-mechanical coupling of a rough fracture.

METHOD
HYDRAULIC FLOW

- Aperture:
  \[ A(x,y) \]
- Coarse-grained aperture:
  \[ A^*(x,y) \]
- Flow:
  \[ \dot{Q}(x,y) \]
- Energy conservation:
  \[ \rho C_p \dot{T} + \nabla \cdot (\dot{Q} + \rho \dot{u} \cdot \nabla T) = 0 \]

2D-THERMAL LAW

- Energy conservation:
  \[ \rho C_p \dot{T} + \nabla \cdot (\dot{Q} + \rho \dot{u} \cdot \nabla T) = 0 \]

RESULTS ILLUSTRATION

- Aperture:
  \[ A(x,y) \]
- Coarse-grained aperture:
  \[ A^*(x,y) \]
- Flow:
  \[ \dot{Q}(x,y) \]

ENERGY CONSERVATION

- Conduction:
  \[ \rho C_p \dot{T} + \nabla \cdot (\dot{Q} + \rho \dot{u} \cdot \nabla T) = 0 \]
- Convection:
  \[ \rho C_p \dot{T} + \nabla \cdot (\dot{Q} + \rho \dot{u} \cdot \nabla T) = 0 \]

3D-TEMPERATURE LAW

- Energy conservation:
  \[ \rho C_p \dot{T} + \nabla \cdot (\dot{Q} + \rho \dot{u} \cdot \nabla T) = 0 \]

BIBLIOGRAPHY