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Heat transport by flow through rough rock fractures

Maria Klepikova[1], Yves Méheust[1], Clément Roques[2], and Niklas Linde[3]
[1]Rennes 1, Géosciences Rennes (UMR CNRS 6118), Rennes, France (maria.klepikova@univ-rennes1.fr)
[2]Centre for Hydrogeology and Geothermics (CHYN), University of Neuchatel, Switzerland
[3]Institute of Earth Sciences, University of Lausanne, Switzerland

Fracture surface topography exhibits long-range spatial correlations resulting in a heterogeneous aperture field. This leads to the formation, within fracture planes, of preferential flow channels controlling flow and transport processes. We have investigated numerically the influence of the statistical properties of the aperture field and upscaled hydraulic behavior on heat transport in rough rock fractures with realistic geometries. Similarly to the rough fracture's hydraulic behaviour, we find that its heat transport behaviour deviates from the conventional parallel plate fracture model with increasing fracture closure and/or decreasing correlation length. We demonstrate that the advancement of the thermal front is typically slower in rough fractures compared to smooth fractures having the same mechanical aperture. In contrast with previous studies that neglect temporal and spatial temperature variations in the rock matrix, we find that the thermal behavior of a rough-walled fracture can, under field-relevant conditions, be predicted from a parallel plate model with an aperture equal to the rough fracture's effective hydraulic aperture. The practical implication of our finding is that thermal exchanges at the scale of a single fracture is controlled by the effective hydraulic transmissivity. Provided that thermal properties of the host rock are known, this implies that (1) geothermal efficiency can be computed at field sites using hydraulic characterization alone, and predicted using well-known low-dimensional hydraulic parameterizations in terms of effective hydraulic properties and (2) heat tracer tests are reliable for inferring effective fracture transmissivity.