Thermal retardation and decay in fractured rock: theory and field measurements from joint heat and solute tracer tests

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ABSTRACT

Better understanding thermal transport processes in fractured rocks through experimental and modelling approaches is essential to predict and optimize deep geothermal system efficiency (Guo et al., 2016; Hawkins et al., 2017). The characterization of heat transfer in such media is particularly challenging as hydraulic and transport properties depend on a multiscale structure that is difficult to resolve (Klepikova et al., 2016). In addition to advection and dispersion, heat transfer is also impacted by thermal retardation and decay, which results from fracture-matrix thermal exchanges (shook, 2001). Here we derive analytical expressions for thermal retardation and decay in fractured media, which quantify the effect of fracture geometry on these key factors. We use the developed expressions to interpret the results of single-well thermal tracer tests performed in a crystalline rock aquifer at the experimental site of Ploemeur (H+ observatory network). Thermal breakthrough was monitored with Fiber-Optic Distributed Temperature Sensing (FO-DTS), which allows temperature monitoring at high spatial and temporal resolution (Read el al., 2013). The observed temporal scaling of the breakthrough peak thermal decay departs from the conventional parallel plate fracture model but is consistent with a channel model representing highly channelized fracture flow (see figure). These findings, which point to a strong reduction of fracture-matrix exchange by flow channeling, show the impact of fracture geometry on heat recovery in geothermal systems such as EGS. This study also highlights the advantages to conduct both thermal and solute tracer tests to infer fracture aperture and geometry.

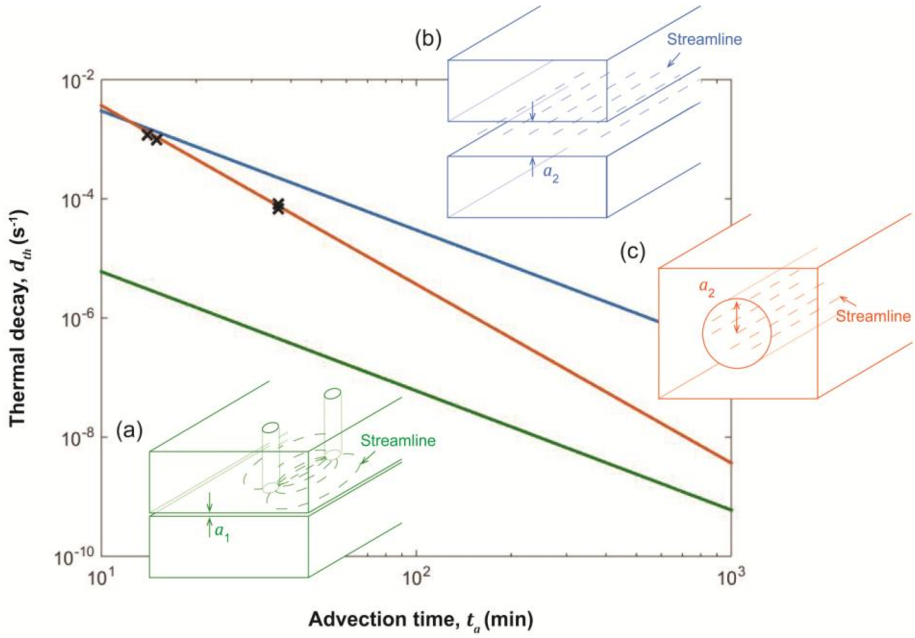

Figure. Thermal decay (d_{th}) as a function of the advection time (t_a, arrival time of the solute breakthrough peak) for thermal tracer tests performed with different flow rates (cross markers). Comparison with the analytical expression of d_{th} as a function of t_a for different fracture geometries and flow fields with (a) a parallel plate fracture in a dipole flow field of aperture a_1, the fracture aperture estimated from modelling of solute transport (green line), (b) a parallel plate fracture in a linear flow field of aperture a_2 (blue line) and (c) a channel in a linear flow field of aperture a_2 (orange line) (de La Bernardie et al., under review).

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