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Thermal retardation in fractured media: theory and field measurement from joint heat and solute tracer test experiments

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The characterization of flow and transport in fractured media is particularly challenging because hydraulic conductivity and transport properties are often strongly dependent on the geometric structure of fractures at different scales. In addition to advection and dispersion, heat transfer is also affected by thermal retardation and damping, which results from fracture-matrix diffusion. Here, we derive analytical expressions for thermal retardation and damping for different fracture geometries and we show, from modeling and field experiments, that estimation of thermal retardation and damping may provide new constraints on fracture geometry. 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 is monitored with Fiber-Optic Distributed Temperature Sensing (FO-DTS), which allows the temperature monitoring with high spatial and temporal resolution. We demonstrate that the observed thermal response indicates that heat transfer is controlled by a channel fracture of large diameter rather than by a parallel plate fracture. These results point to a strong reduction of fracture-matrix exchange by flow channeling. These findings, which bring new insights on the effect of flow channeling on heat transfer in fractured rocks, show how heat recovery in geothermal systems may be controlled by fracture geometry. This highlights the interest of thermal tracer tests as a complement to solute tracer tests to infer fracture aperture and geometry.