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Quantifying the contribution of advection in thermal response tests

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Precise knowledge of thermal properties of the ground is crucial for reliable and sustainable operation of geothermal applications, such as ground source heat pump (GSHP) systems. The thermal response test (TRT) is a field investigation technique used to determine subsurface heat transport parameters. It is comparable to a hydraulic pumping test. However, instead of the hydraulic head, here, the temperature of the subsurface is disturbed and the thermal response is recorded. The TRT uses an installed borehole heat exchanger (BHE) to exchange heat with the subsurface by circulating a heat carrier fluid through the U-tubes embedded in the BHE. Commonly, during a TRT, heat is introduced in the subsurface for several days. The time-dependent change of the temperature of the heat carrier fluid is recorded and, for the standard case, evaluated to estimate the thermal conductivity of the subsurface and the borehole resistance of the BHE. For this, Kelvin's infinite line source equation is calibrated to the measured temporal temperature development. This evaluation customarily assumes pure conductive heat transport, and ignores advective provision of heat to the BHE. If advection, however, is present, the obtained thermal conductivity represents an apparent parameter and is interpreted as an "effective thermal conductivity". Advective heat transport increases the extractable amount of thermal energy from the ground in comparison to systems with conduction only. Consequently, the standard TRT evaluation is not suitable for aquifers with high Darcy velocity, where the discrepancy between true and effective thermal conductivity is substantial. To extend the application window for the TRT, we developed a procedure that separates the advection and conduction components during analysis of the recorded temperature time series. It is based on the moving line source equation, which considers both advective and conductive heat transport in a homogenous porous media. In order to account for heterogeneity effects from grouted BHEs, a correction function is determined. This new approach is successfully validated with laboratory and field-based test cases with ground thermal conductivities ranging between 1.5 and 3.0 W/(mK) and a Darcy velocity varying from 0 to 1 m/day. For this application window, the developed approach provides realistic estimates of both ground thermal conductivity and Darcy velocity. However, for high Darcy velocity, the evaluation results in a wide range of equally possible parameter combinations