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Analysing Thermal Response Test Data Affected by Groundwater Flow and Surface Temperature Change

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Tests that record the underground temperature variation due to a constant heat injected into a borehole (or extracted from it) by means of a carrier fluid are routinely performed to infer subsurface thermal conductivity and borehole thermal resistance, which are needed to size geothermal heat pump systems. The most popular model to analyse temperature-time curves obtained from these tests is the infinite line source (ILS). This model gives appropriate estimations of thermal parameters only if particular hydro-geological conditions are fulfilled. Several flaws can however affect data interpretation with ILS, which is based on strong assumptions like those of a purely conductive heat transfer regime in a homogeneous medium, no vertical heat flow and infinite length of the borehole. Other drawbacks can arise from the difficulty in the proper thermal insulation of the test equipment, and consequently with oscillations of the carrier fluid temperature due to surface temperature changes. In this paper, we focused on the treatment of thermal response test data when both advection and periodic changes of surface temperature occur. We used a moving line source model to simulate temperature-time signals under different hypothesis of Darcy velocity and thermal properties. A random noise was added to the signal in order to mimic high frequency disturbances, possibly caused by equipment operating conditions and/or geological variability. The subsurface thermal conductivity, the Darcy velocity and the borehole thermal resistance were inferred by minimising the root mean square error between the synthetic dataset and the theoretical model. The optimisation was carried out with the Nelder-Mead algorithm, and thermal and hydraulic properties were determined by iterative reprocessing according to a trial-and-error procedure. The inferred thermal and hydraulic parameters are well consistent with the "a priory" values, and the presence of noise in the synthetic data does not produce instability. The same optimisation procedure was also applied to interpret the synthetic signal with the ILS model. In case of Darcy velocity of the order of 10^{-6} m s^{-1}, ILS largely overestimates thermal conductivity. The optimisation analysis was then applied to real thermal response tests carried out in boreholes drilled in sedimentary formation aquifers, whose volume heat capacity was assumed to be known. These data showed a periodic offset in the recorded temperature-time series. A Fourier analysis allowed the recognition of harmonic contributions with period of about 12 and 24 hours. These oscillations appeared to be coherent with the data of air temperature change recorded at the test sites. The temperature-time curves were then filtered to remove the disturbing spectral components associated to a non-optimal thermostatic behaviour of the apparatus. This produced reliable estimates of thermal conductivity, Darcy velocity and borehole thermal resistance. The magnitude of the inferred groundwater flow was also checked by means of an independent method based on the analysis of temperature-depth logs recorded prior to the thermal tests, under thermal equilibrium conditions.