Oscillatory Thermal Response Test (OTRT) - an Advanced Method for Gaining Thermal Properties of the Subsurface

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Abstract

Introduction
Thermal Response Tests (TRTs) are the state-of-the-art method to obtain the thermal conductivity of the subsurface in the nearby ambience of a borehole heat exchanger (BHE). The results of TRTs are used to determine the necessary depth of the borehole and to make long time predictions about the potential of heat extraction. For a TRT, a constant heat load is injected into the subsurface and the temperature development of the BHE working fluid is recorded. Using the analytical solution of a heated line source, the effective thermal resistivity of the system can be obtained by the slope of the temperature signal (Figure 1). We develop a method that promises exceeding information about the thermal properties. We consider a time dependent sinusoidal heat injection instead of constant heat injection. A similar method is used for determination of the thermal properties of small probes using an AC-Joule-heated wire, see e.g. [1], [2].

Use of COMSOL Multiphysics®
We used COMSOL Multiphysics® for the development of 3D BHE models that were validated with experimental data (see [3] and [4]). Standard TRTs are simulated by injecting a certain heat load q=q0 [W/m] into the subsurface. Defining a fluid flow rate in the pipes and fixing the temperature difference between inlet and outlet of the BHE determines the amount of injected heat. For this new approach we change the constant heat to an oscillating signal q=q0+sin(2*pi*f*t) with the frequency f. The BHE and the connected subsurface act as a linear time-invariant system and therefore the resulting fluid temperature (system response) is also a sinusoidal signal with the same frequency but phase delayed and amplitude damped, T=A*sin(2*pi*f*t+Phi)+T0. Phase and amplitude of the system response depend on the thermal transport parameters of the participating materials. In particular, the (specific) heat capacity can be obtained independently which is not possible in standard TRT evaluations.

Results
The typical illustrations for the responses of linear time-invariant systems are Bode diagrams, where the amplitude and phase of the response signal is plotted as a function of the logarithm of the period. Figure 1 shows Bode plots for a parametric sweep run with parameters of a real BHE system [5] in comparison with the response of a similar run with halved thermal conductivity of the subsurface. Differences of the responses occur for periods longer than about one hour, the

effect strikes broader in the phase shift. Figure 2 shows the results for a study with artificial gaps of different proportions (10m and 20m) in the borehole backfilling. The gaps are filled with water. The differences plots below show that there is a measurable difference in the system response.

The first simulation results of OTRTs show the potential of this novel technique. We intend to compare our results and further simulations with experimental data that will be gathered soon. We also intend to develop an inverse method to gain differentiated information about the thermal properties of the borehole and the subsurface vicinity from the system response. This method could be a useful addition to the conventional TRT practise.

Reference

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3. P. Oberdorfer et al., Comparison of Borehole Heat Exchangers (BHEs): State of the Art vs. Novel Design Approaches, Proceedings of COMSOL Conference Stuttgart (2011)

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Figures used in the abstract

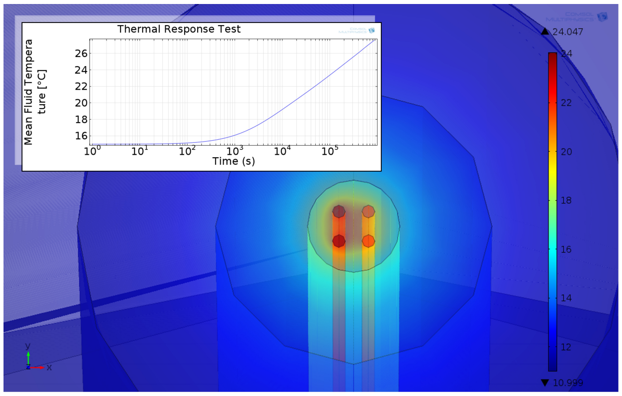

Figure 1: 3D Double-U BHE model and simulation result of a TRT. Colors indicate temperature.

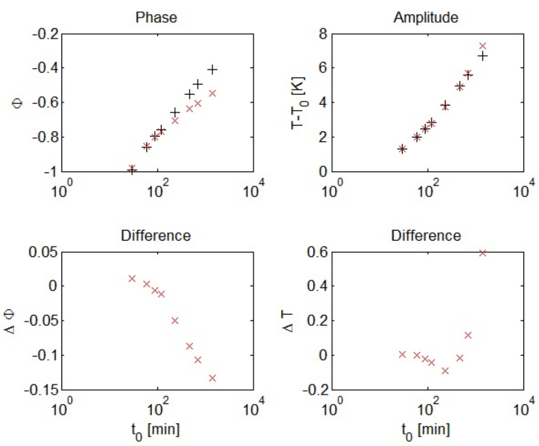

Figure 2: Top: Bode diagrams (phase and amplitude of system responses caused by a sinusoidal thermal excitation) for standard parameters (black,+) and halved thermal conductivity of subsurface (red,x). Bottom: Particular differences between both cases.

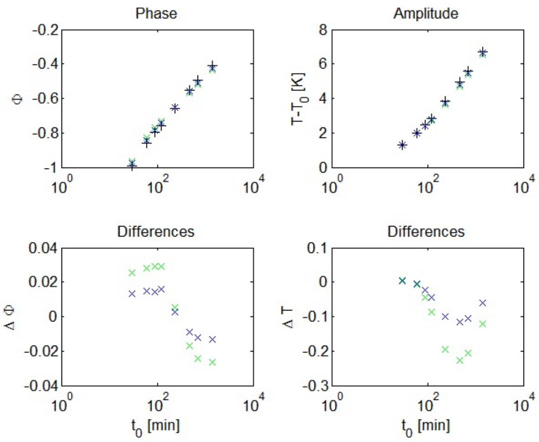

Figure 3: Top: Bode diagrams (phase and amplitude of system responses caused by a sinusoidal thermal excitation) for standard parameters (black,+) and a backfilling gap of 10m (blue,x) and 20m (green,x). Bottom: Particular differences between standard and modified cases.