THERMAL RESPONSE TEST WHILE DRILLING

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1. BACKGROUND

Knowledge of the ground thermal conductivity is of importance when designing borehole heat exchanger (BHE) systems. As thermal conductivity for any specific rock type varies due to its mineral content, porosity, pore fluid and anisotropy, it is preferable determined in-situ. Choudhary (1976) suggested a method for determining the thermal conductivity which analysed the heat transfer during the thermal recovery after drilling. A numerical model of the heat transfer was compared to temperature-time loggings along the borehole. By knowing the change in temperature with time, the ground thermal conductivity could be calculated for different depths.

Mogensen (1983) suggested a method to determine ground thermal conductivity and borehole thermal resistance in situ. By extracting a constant heat rate from a BHE and measuring the temperature change in the fluid, the heat transfer in borehole and ground may be evaluated by e.g. the line source model. During the mid-nineties, in-situ thermal response test (TRT) equipment was developed (Eklöf and Gehlin, 1996 and Austin, 1998) based on this method. TRT is today the established method to determine ground thermal conductivity and borehole thermal resistance for borehole heat exchanger systems.

In most TRT measurements, energy is injected into the borehole by circulating a heated fluid in the collector. The thermal response is measured as the change of fluid inlet and outlet temperature over time. Borehole mean values of the effective ground conductivity and the borehole thermal resistance, i.e. thermal resistance between fluid and borehole wall, are evaluated from this data. Swedish tests are usually performed on one or two boreholes for approximately 72 hours for design of larger BHE systems. Because of the heat released during drilling, the test should be performed a few days after the drilling to ensure thermally undisturbed ground.

In 2003, Tuomas et al. suggested a method for TRT while drilling (TRTWD), which would simplify the evaluation of the ground properties. In this method, heat transfer from the heat released during drilling is analysed. Measurements of required parameters are made during the drilling. A major advantage compared to standard TRT is that this method would give a continuous thermal conductivity along the borehole instead of a mean value. The disadvantage is that the borehole thermal resistance is not evaluated, instead is a standard value used for the given borehole configuration. Since evaluation may be performed straight after the drilling this method also results in time savings.

2. THERMAL RESPONSE TEST WHILE DRILLING

Thermal response test while drilling (TRTWD) uses the same basic principle as standard TRT measurement. A known constant heat power is injected into the borehole and the thermal response of circulating fluid is measured. Instead of heating the circulating fluid by an electrical heater, heating is caused by heat dissipation from drilling work. The heat will transfer to drilling fluid and to bedrock formation. The energy transport depends on circulating drilling fluid, drilling process and bedrock properties. Performed work considers TRTWD with a water-driven down-the-hole (DTH) hammer. The hammer tool and drilling process are described in detail by Tuomas, 2004.

In DTH drilling, the hammer tool is located at the bottom of the borehole. Drilling energy is supplied through the drill string by pressurized fluid which will dissipate into heat in the hammer tool. The water temperature at the outlet of the drill string depends on inlet water temperature, flow velocity, heat release in hammer tool, and heat transfer in water and bedrock. No measurement equipment has been developed yet, but by measuring flow velocity, power injection, inlet and outlet temperatures during the drilling, as in the standard TRT, the bedrock thermal conductivity ought to be estimated.

If there are any discontinuities in the bedrock during the drilling, the heat transfer will change depending on these new conditions and result in changes in the measured return fluid temperatures. It would therefore theoretical be possible to detect larger fractures, fracture zones or other changes in the bedrock properties with this method. Such information could result in a more thorough design of the BHE system or be used for geological mapping.

3. MODEL DESCRIPTION

A numerical two-dimensional axisymmetric model was constructed in MathCAD 2001i Professional [MathCad, 2001] to theoretically investigate the TRTWD method. Figure 1 outlines the model when the drill has reached the depth $z = z_d$.

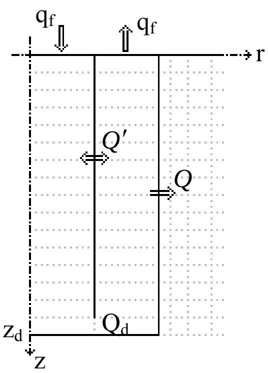

Figure 1: Outline of numerical model

The drilling fluid flows inside the drill string, q_f [m^3/s], changes direction at the bottom and flows upwards outside the drill string in direct contact with the bedrock. As the fluid passes the hammer tool in the bottom a constant heat power Q_d [W] raises the fluid temperature. Heat is transferred between inner and outer channel, Q', and between outer channel and bedrock wall. The inlet temperature, T_{in}, and the initial ground temperature, T_{init}, are assumed to be equal, 10°C, since drilling water is taken from the ground. The drill moves downwards with a penetration rate of 0.5 m/min and the fluid flow rate is 300 l/s. The injected heat is 150 kW from the drill.

To be able to compare the two methods, standard TRT and TRTWD, calculations simulating a TRT measurement were performed with a two-dimensional axisymmetric numerical model constructed by Hellström, 2001. The model simulates a 150 m deep groundwater-filled borehole with a single U-pipe collector. Undisturbed ground temperature is set to 10ºC in this model to. The heat transfer is by conduction even though the borehole is filled with water.

4. COMPARISON BETWEEN THE TWO METHODS

There are two obvious differences between the two methods. Firstly, in the standard TRT the borehole thermal resistance is evaluated. Secondly, the TRTWD evaluates the effective bedrock conductivity along the borehole instead of a mean value. In everyday usage of the methods there are also some differences. Standard TRT often requires an additional partner in the project since drilling companies rarely have the equipment or the knowledge of performing the test. If the TRTWD could be integrated in already existing measurement while drilling (MWD) equipment, the measurement data could simply be transferred to a design program or to the system designer for evaluation. This would result in time savings.

In Figure 2, results from TRT and TRTWD simulations are shown. For both methods calculations of mean fluid temperature, $\Delta T_f = (T_{inlet} + T_{outlet})/2$, were made for three different bedrocks with conductivity λ_1 = 2 W/m,K, λ_2 = 3 W/m,K and λ_3 = 4 W/m,K. In the TRT model borehole thermal resistance was chosen to 0.07 Km/W in all simulations. The major difference between these methods is then that the TRTWD method requires a higher accuracy and precision in the temperature measurements than TRT.

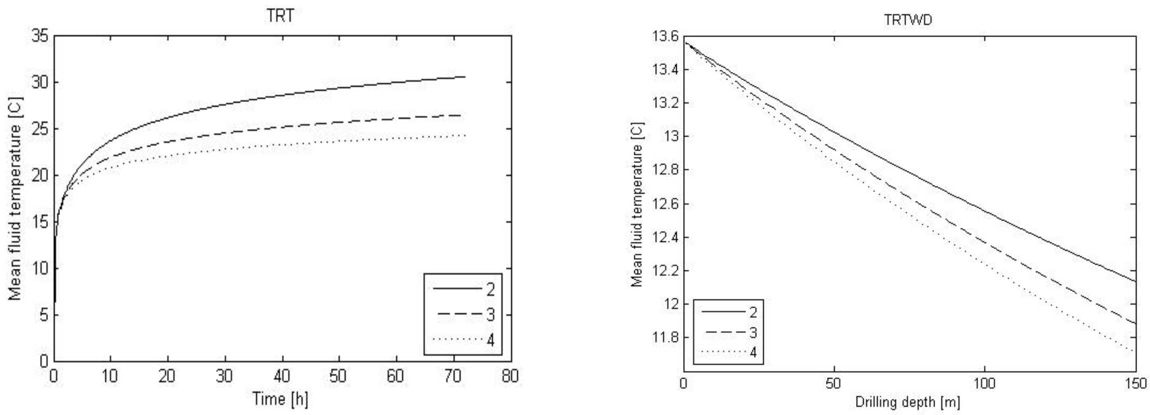

Figure 2: Simulation results for a) TRT measurement and b) TRTWD measurement for three different bedrock conductivities; λ_1 = 2 W/m,K, λ_2 = 3 W/m,K and λ_3 = 4 W/m,K.

The difference between e.g. a bedrock conductivity value of 3 W/m,K and 4 W/m,K for the TRTWD method results in 0.17ºC difference for a 150 m deep drilling. For the TRT method after 72 hours of measurement the difference in temperature is 2.2ºC. The reason is that the fluid is recirculated in the TRT method. Figure 3 shows the calculated difference in the response for conductivity 3 and 4 W/m,K for the two methods, i.e. $T_f(\lambda = 3)$-$T_f(\lambda = 4)$.

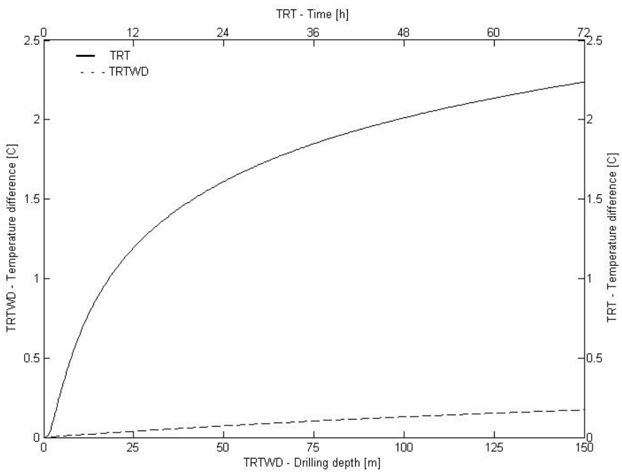

Figure 3: Temperature difference between simulations with conductivity
3 W/m,K and 4 W/m,K, $T_f(\lambda = 3)$-$T_f(\lambda = 4)$, for the TRT and TRWD.

An occurring change in the bedrock thermal properties will be visible in measured thermal response for the TRTWD method. For example if the bedrock will transfer away more heat at a section, a lower outlet temperature will be the result. With high enough measurement accuracy and precision fractures or other bedrock formation changes may be detected in the data analysis. In Figure 4a the mean fluid temperature of a 40 m drilling is shown for two bedrocks, one with two layers and one with conductivity 3 W/m,K for the whole formation. The layered bedrock have bedrock conductivity λ_1 = 3 W/m,K for the first 20 m and thereafter λ_2 = 4 W/m,K. The shift in inclination is visible when comparing the two results but harder to detect just showing the layered curve. Looking at the drilling depth derivative for the mean fluid temperature, $d(\Delta T_f)/dz_d$, for the layered ground in Figure 4b, the occurring shift is clearly visible. It requires though that the temperature precision is in order of 0.001ºC.

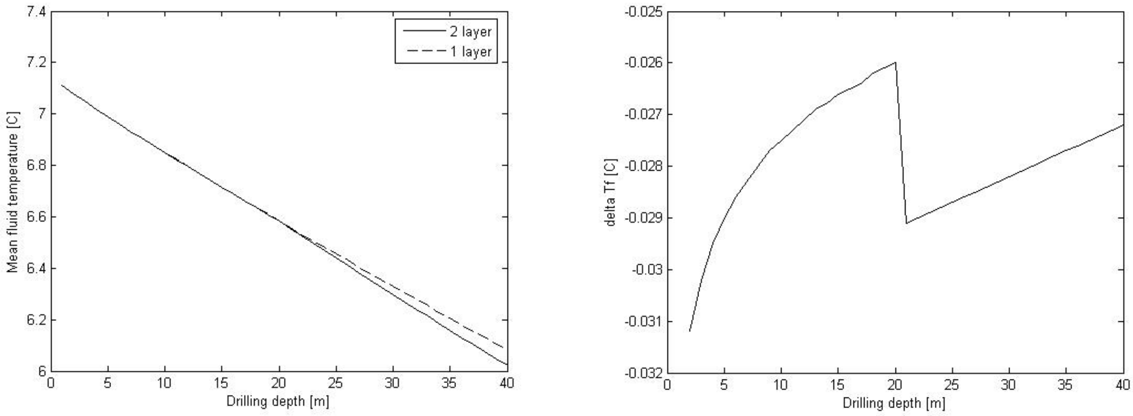

Figure 4: a) mean fluid temperature for two different bedrocks, layered (λ_1 = 3 W/m,K and λ_2 = 4 W/m,K) and non-layered (λ = 3 W/m,K) b) drilling depth derivative of mean fluid temperature for the layered bedrock.

5. CONCLUSION

Thermal response test while drilling is a theoretically interesting method to determine bedrock conductivity during the drilling. Besides being a less time-consuming method, TRTWD gives the continuous ground conductivity along the borehole. All boreholes are evaluated instead of one or two, as in the standard TRT. However, the method requires high accuracy temperature measurements to distinguish between the different thermal responses of bedrocks.

By analysing the varying differences in fluid temperatures between drill string inlet and outlet with drilling depth, bedrock anomalies can be distinguished. A change in ground thermal properties is reflected by a corresponding change in the temperature difference. Such anomalies, e.g. fracture zones, can be of importance in designing BHE systems.

In this paper, a 2D numerical model of the TRTWD method has been used to evaluate the heat transfer during the drilling. The model assumes a tight bedrock formation where fluid penetrates the formation. In fractured rock, during a drilling, drilling fluid is pressed out in connecting fractures, resulting in an enhanced heat transfer in the formation. This has to be experimental investigated and possibly incorporated in the model.

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