INTERPRETATION OF THERMAL RESPONSE TESTS USING THE FIBER OPTIC DISTRIBUTED TEMPERATURE SENSING METHOD

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ABSTRACT

The thermal conductivity of the ground is an important parameter to calculate the total length of borehole heat exchangers (BHEs) in a geothermal heat pump (GHP) system. Thermal response test (TRT) determines the thermal conductivity of the ground. We conducted TRTs with the fiber optic distributed temperature sensing (DTS) method and applied this new method to interpret the TRT. First, the total depth was sliced into several layers and the cylindrical source function was applied to calculate the heat conduction behavior in each layer. The calculated thermal conductivities of each layer were compared with the results of laboratory tests on rock core samples. Calculated outlet water temperatures of BHE reasonably matched with vertical temperature profiles in the TRTs. Estimated thermal conductivity profile was found to be in good agreement with core data, but it has weak relationship with water injection test data.

1. BACKGROUND

The thermal conductivity of the ground can be measured by conducting TRTs. In the design of a geothermal heat pump system, the thermal conductivity of the ground is an important parameter to calculate the total length of borehole heat exchangers. It was undertaken prior to installing a closed loop geothermal heat pump system. Well estimated thermal conductivity of the ground can prevent oversized system design and enable an economical GHP system. The optimal design of a borehole heat exchanger system will guarantee the performance and the functionality of the GHP system.

The Kelvin’s line source solution has been applied in the interpretation of a TRT as a conventional analysis method. It is valid for the constant heat flux case and the average thermal conductivity of the ground can be estimated. The average of inlet and outlet temperatures of the circulation fluid in a U-tube is used as ground temperatures for the method (Sanner et al., 2005). However, geological structures are generally heterogeneous and in-situ thermal conductivity of the ground varies according to well depth. A new interpretation method of TRTs using optical fiber sensors was developed by Fujii et al. (2006). In the method, the total depth of the ground was sliced into several layers and the cylindrical source function was applied to calculate the heat conduction of each layer.

The thermal properties of cores were measured and hydraulic tests were conducted in the study area (Fig. 1). We carried out TRTs using TRT equipment and a fiber optic DTS system.
The distribution of apparent thermal conductivities estimated by the new method was compared with the hydraulic characteristics of the ground, the thermal conductivity estimated by the line source solution and core data.

Fig. 1. Schematic of the installed BHEs (a) and three dimensional fracture image detected by televiewer logging (b) at a 300-m deep observation borehole.

2. THERMAL RESPONSE TESTS

We carried out a TRT in a borehole heat exchanger (BHE) and the well is located at the Korea Institute of Geoscience and Mineral Resources (KIGAM) in Daejeon, Korea (Shim et al., 2006). Figure 2 shows the schematic of the BHE and vertical thermal conductivity distribution measured using core samples. The measured thermal conductivities ranged from 2.50 to 3.63 W/m/K and the arithmetic mean was 2.95 W/m/K. A double U-tube and an optical fiber sensor cable were installed at the center of the BHE. The borehole was filled with bentonite, silica sand and water mixed grout (Fig. 2). The geology consisted of soil and weathered granite above 10 m and fresh granite below 10 m. Twenty nine BHEs were installed at the site for the GHP system.

The ground temperatures in the BHE were measured using the optical fiber sensor during fluid circulation and after the end of circulation. In conventional TRTs, the temperatures of circulation fluid as heat medium are usually measured only during the circulation period. In the case of using optical fiber sensors, the measured temperatures are not always representative during the fluid circulation, because the measured temperatures were strongly affected by the location of the sensors. The temperatures in the BHE were measured for 72 hours during the water circulation in the U-tubes and the measurement continued for 240 hours even after the end of circulation. During the circulation, we supplied a constant heat load of 10 kW and maintained a flow rate of 38 l/min.
3. ANALYSIS MODEL OF TRT

The new developed analytical interpretation method is based on the cylindrical source function. The total depth was sliced into several layers and the cylindrical source function was applied to each layer to calculate heat exchange rate between the ground and heat exchangers (Fig. 3). The nonlinear regression method was used to estimate the vertical distribution of thermal conductivities of the each layer.

Figures 4(a) shows the history matching results between measured and calculated outlet temperatures. The calculated temperature distribution agreed well with the measured
temperatures in the TRTs. Figures 4(b) show the matching of the temperature distribution of the BHEs after the circulation in the TRTs.

For the interpretation of the TRTs, the temperature distribution of the ground was calculated using the data of 48 hours after the circulation. The calculated temperature distribution of the TRTs shows a good match with the measured distribution at 24 and 48 hours after the circulation as shown in Fig. 4(b).

Fig. 4. (a) History matching result of TRTs and (b) matching of the temperature distributions of BHE after the circulation.

4. RESULTS AND DISCUSSION

Figures 5(a) shows the vertical distribution(s) of the estimated thermal conductivities and core data. The thermal conductivity was calculated at every 5 m depth slice with the fiber optic DTS method using borehole temperatures in the recovery period. Also, it was agreed well with the distribution of the thermal conductivity measured using core samples by fresh method (Parker et al., 1961). We compared the calculated thermal conductivity distribution with measured thermal conductivity with the core. The large differences between the calculated thermal conductivity distribution and measured values were found at the depth intervals from 40 to 70 m and from 130 to 140 m. In the first interval the high hydraulic conductivities were determined but in the second interval high hydraulic conductivities were not measured. The distribution of the thermal conductivity and hydraulic conductivity shows a weak relationship. The average value of the thermal conductivity was 2.80 W/m/K using the optical fiber sensors, 2.75 W/m/K by Kelvin’s line source theory and 2.95 W/m/K measured by cores using the fresh method, respectively.
Fig. 5. Distribution of (a) estimated thermal conductivity and (b) hydraulic conductivity by injection tests.

5. CONCLUSIONS

Calculated outlet water temperatures of BHE were reasonably matched with measured temperatures in the TRTs. The estimated thermal conductivity using line source theory agreed well with the calculated average thermal conductivity by the fiber optic DTS method. The thermal response test using the optical fiber DTS method was effective for the estimation of the vertical distribution of the thermal conductivity in a BHE. Estimated thermal conductivity profile by the new interpretation method has a close relationship with core data, but the relationship with injection test data is limited.

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REFERENCES

