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Ground water level influence on thermal response test in Adana, Turkey

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SUMMARY

For optimum design of borehole thermal energy storage (BTES) and ground sources heat pump (GSHP) applications, determination of underground thermal properties is required. The design and economic feasibility (number and depth of boreholes) of these systems need thermal conductivity of geological structure, λ (W m^{-1} K^{-1}), and thermal resistance of ground heat exchanger, R (K W^{-1} m). Thermal properties measured in laboratory experiments do not coincide with data of *in situ* conditions. Therefore, *in situ* thermal response test equipment has been developed and used in Canada, England, Germany, Norway, U.K., U.S.A. and Sweden to ensure precise designing of BTES systems.

This paper describes the results and evaluations of the Adana continual thermal response test measurements. Copyright © 2007 John Wiley & Sons, Ltd.

KEY WORDS: borehole thermal energy storage; thermal response test; thermal conductivity; thermal resistance

1. INTRODUCTION

Underground thermal energy storage (UTES) technologies are renewable, reliable, energy-saving and environment friendly systems for air conditioning in buildings, telecom stations, industrial cooling and heating process and also agricultural applications. After the first oil crisis in the 1970s, the expertise on UTES has developed within the International Energy Agency (IEA) energy conservation through energy storage (ECES) implementing agreement (IA) program.

In UTES technology underground is used as a storage medium. Aquifers (ATES), underground pools (CTES) and also ground itself (borehole thermal energy storage, BTES) can be used for storage. During winter excess cold from the surface water or from the air can be stored in different ways and during summer this cold could be used for cooling. Heating can also be done in a similar way.

Knowledge of the thermal conductivity of the ground surrounding the well is crucial for the proper dimensioning of an underground thermal energy system. By measuring the ground thermal response of a well, the effective *in situ* thermal conductivity of the system must be estimated. Field tests are done in Çukurova University

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Campus Area Adana, Turkey with a mobile thermal response test apparatus.

The research area which is located at 36 S 0710563 UTM 4100897 is in the campus of Çukurova University. A thick terrace–calichie (approx. 30–40 m) mixture exists on the Handere Formation around the well location. BTES was installed as the Seyhan dam lake site to be able to use Seyhan lake as a cold source in winter for further field test.

2. METHOD

Turkish mobile thermal response test equipment has been donated by Luleå University of Technology, Sweden.

The *in situ* equipment is installed on a mobile trailer and consists of a 1 kW pump circulating the heat carrier fluid (water) through the borehole collector and through a cross-flow heater with adjustable and stable heating power in the range of 3–12 kW. Fluid temperature is measured at the inlet and outlet of the borehole with thermistors, with an accuracy of ±0.2°C. A data logger records the temperatures at a set time interval. The equipment is powered by 16 A electricity [1]. Figure 1 shows the TRT flow diagram.

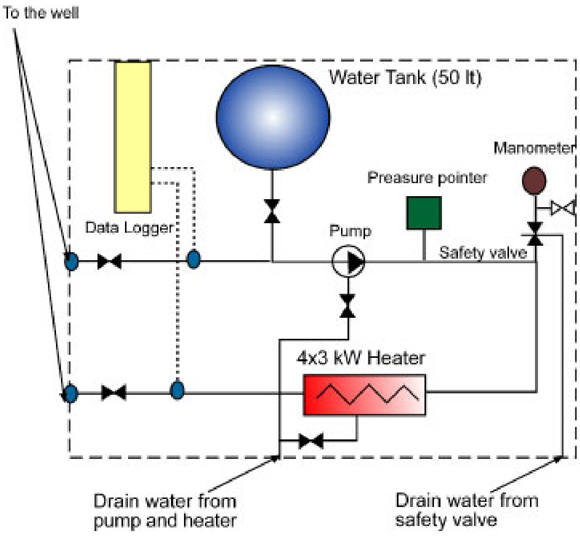

Figure 1. TRT flow diagram.

The principle of the thermal response test is to inject a known amount of power into the energy well over a certain period of time (> 50 h), by letting a heat carrier fluid circulate through the energy well piping system while a certain power rate is transferred to the fluid. The temperature response of the ground is measured by recording the inlet and outlet temperatures. The thermal properties of the ground and collector installation are proportional to the temperature change in the ground over the measurement period (Figure 2).

A single borehole which has 2.4 m^3 volume with 75 m depth and 0.2 m radius is drilled. The geological formation consists of mainly terrace–calichie. A single polyethylene U pipe (DN 40) was installed in the borehole (Figure 3). The pipe diameter is 32 mm and its wall thickness

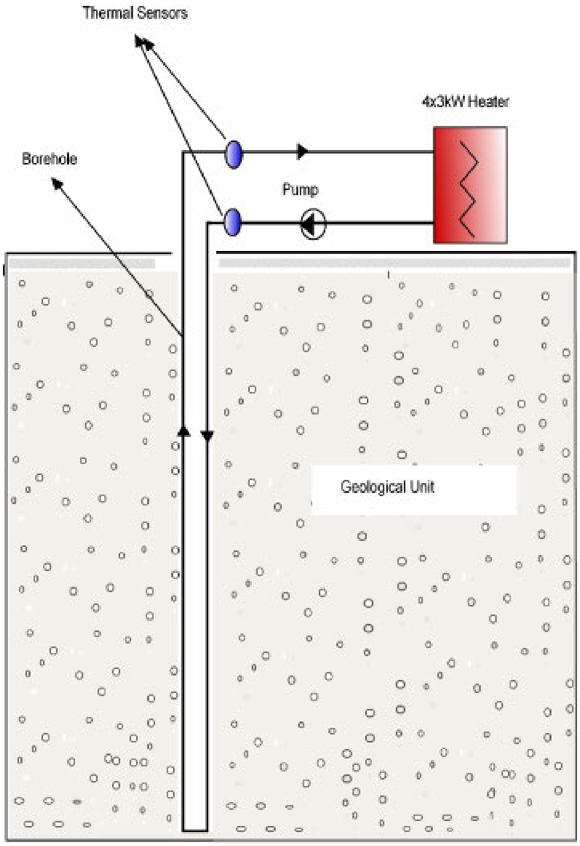

Figure 2. Cross section of the well and U-pipe.

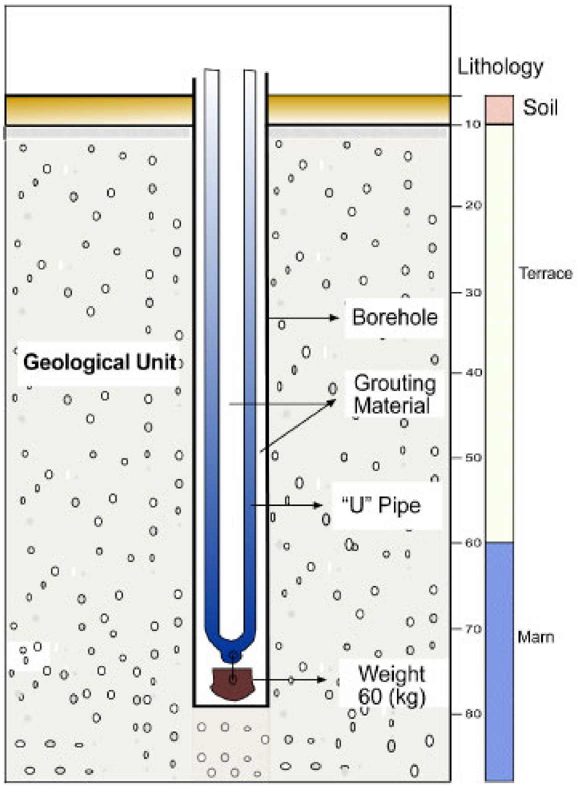

Figure 3. Cross section of a ground heat exchanger.

is 2.4 mm. Thermal conductivity of the pipe is 0.4 $\mathrm{W\,m^{-1}\,K^{-1}}$ and the density is 3.29 $\mathrm{g\,cm^{-1}}$.

A mixture of bentonite and cement was used as grouting material in the field test. The composition of the grout pumped to the borehole is 74% water, 2.4% cement, 0.2% bentonite and 23% dried mud or soil. During the tests, equipment is connected to the borehole collector pipes and the heat carrier fluid is pumped through the system in a closed loop. The injection power used 3 kW × 2 = 6 kW during the test. The fluid passes through the heater before going into the loop. Inlet and outlet fluid temperatures and also outdoor temperatures are recorded every 10 min by the data logger. The power supply is also recorded during measurement in order to determine the actual injected power. To estimate undisturbed ground temperature, the heat carrier is initially circulated through the system without heating approximately for 20 min. After this procedure, the heater is switched on and the measurements are continued for minimum 48 h.

3. DATA CALCULATION

The theoretical basis for this experiment is cited at length in [1, 2]. The evaluation method is called 'line source modelling'. Hence six different evaluation models have been reported to date including the line sources model. The equation for the temperature field as a function of time and radius around a line source with constant heat injection rate may be used as an approximation of the heat injection from borehole heat exchanger [1].

Here, it is considered sufficient to quote the two formulae used to analyze the data. In Equation (2): *k* is determined from the slope of the line in the plot of ln time *versus* mean fluid temperature. All equations used to calculate thermal conductivity (λ) and thermal resistance (R_b) are as follows:

$$T_\mathrm{f} = k\ln(t) + m \tag{1}$$

$$\lambda = \frac{Q}{4\pi k H} \tag{2}$$

$$m = \frac{Q}{H}\left(\frac{1}{4\pi\lambda}\left(\ln\left(\frac{4a}{r_\mathrm{b}^2}\right) - \gamma\right) - R_\mathrm{b}\right) + T_\mathrm{sur} \tag{3}$$

$$T_\mathrm{f} = \frac{Q}{4\pi\lambda H}\ln(t) + \left[\frac{Q}{H}\left(\frac{1}{4\pi\lambda}\left(\ln\left(\frac{4a}{r_\mathrm{b}^2}\right) - \gamma\right) + R_\mathrm{b}\right) + T_\mathrm{sur}\right] \tag{4}$$

where λ is the thermal conductivity ($\mathrm{W\,m^{-1}\,K^{-1}}$), Q the injected heat power (kW), T_f the heat carrier mean fluid temperature (K), r_b borehole radius (m), T_sur the undisturbed initial temperature in borehole, a the thermal diffusivity ($\mathrm{m^2\,s^{-1}}$), H the effective borehole depth (m), t the time from start, R_b the thermal resistance ($\mathrm{K\,W^{-1}\,m}$), γ the Euler's constant (0.5772).

The slope of the mean temperature data *versus* the natural log of time in seconds given in Figure 4 is proportional to the thermal conductivity of the

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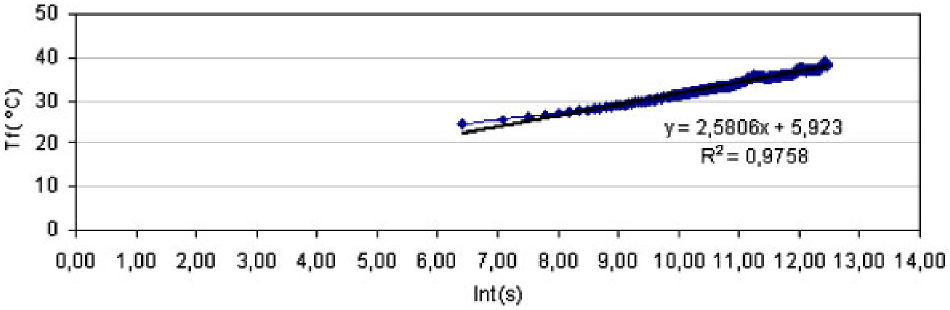

Figure 4. Mid to late stage time/temperature data for the experiment. Slope (k) of linear relationship is 2.5806. This value is substituted into Equation (1).

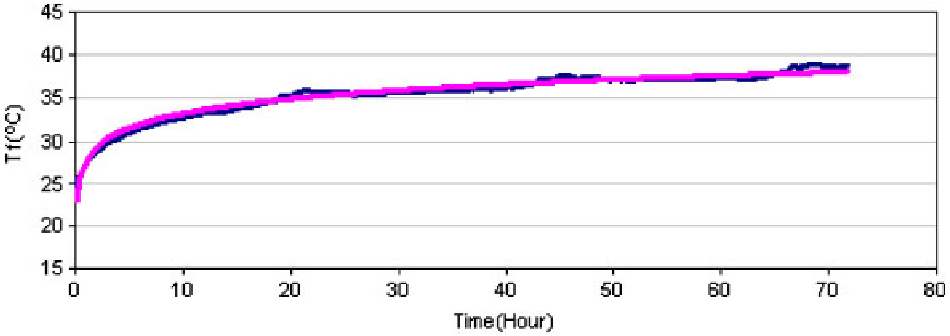

Figure 5. Mean fluid temperature from response test on U-pipe collector fitted to Equation (4). $\lambda = 2.2\ \mathrm{W\,m^{-1}\,K^{-1}}$, $R_b = 0.06\ \mathrm{K\,W^{-1}\,m}$.

rock and filled material through which the heat is transferred. According to the line sources model for these measurements, thermal conductivity (λ) and thermal resistance (R_b) are calculated with an iterative approach where λ is given an initial estimated value and R_b is calculated from Equation (4). The iteration is continued until calculated fluid temperature distribution fits the experimental distribution minimum for two days in each measurement. Figure 5 shows the best iterative approach for thermal conductivity (λ) and thermal resistance (R_b) for September measurements. The same model has been applied for each monthly measurement.

4. RESULTS AND DISCUSSION

Table I. Monthly TRT results from measurements carried out in Adana.

Month	Thermal conductivity λ ($\mathrm{W\,m^{-1}\,K^{-1}}$)	Thermal resistance R ($\mathrm{K\,W^{-1}\,m}$)	Duration of the test (h)
July	2.5	0.09	50
August	2.1	0.05	76
September	2.2	0.06	72
October	2.2	0.06	53

Monthly results of the continual *in situ* thermal response test are given in Table I. Test duration as recommended by Gehlin [1, 2] has been selected over 50 h as given in Table I. Additionally monthly levels of Seyhan dam lake are given in Table II. Thermal conductivity of the ground decreases due to drop of water level. Hence, λ value of the ground increases when the water level rises. The most striking result is that Seyhan dam lake water level is directly effective on the TRT results. Otherwise thermal conductivity has to be constant and/or similar in each measurement. In addition to this, each experiment has been done in same

Table II. Seyhan dam lake level during months.

Months	Depth (m)
January	58.15
February	59.3
March	61.09
April	64.65
May	65.19
June	65.5
July	64.06
August	61.58
September	59.04
October	58.66
November	60.67
December	60.47

borehole, pipe installation, geological formations and test equipment. However, thermal conductivity is reduced in the months of August, September and October compared with July result. In July, Seyhan dam lake level reached 64.65 m level (see Table II). In the same month TRT result is shown 2.5 W m^{-1} K^{-1} (see Table I). After this month, dam lake level starts to decrease due to seasonal and climatic reason. And TRT test result also shows that within the dam lake level also thermal conductivity of the ground decreases 2.1–2.2 W m^{-1} K^{-1} level (see Table I). As estimation, ground thermal conductivity of BHE above ground water level is about 2 W m^{-1} K^{-1}. Also below ground water table it is about 2.6 W m^{-1} K^{-1}. Owing to Seyhan dam lake surface water movement thermal conductivity and resistance of the BHE change between 2 and 2.6 W m^{-1} K^{-1}. Hence dam lake surface water directly affects the ground water table, and ground water table affects the thermal conductivity and resistance of ground.

Finally, it may be stated that thermal response measurements with mobile equipment may have many potential applications in the future for Turkey; for example, geothermal mapping of Turkey [3], testing of new U-pipe materials, quality control and certification of borehole thermal energy storage (BTES) applications, and *in situ* pre-investigation of thermal properties for large BTES systems. As a result of measurements in Adana, it is recommended that the effect of solar radiation has to be taken into consideration in evaluating TRT results [4].

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