First Thermal Response Test in Libya

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Abstract

The ground properties determination is of a significant challenge facing designers of ground source heat pump systems applied in air conditioning commercial buildings. The depth and the number of the boreholes are highly dependent on the ground thermal properties. In order to be able to predict ground thermal properties, an experimental apparatus setup has been built capable of imposing a heat flux on a test borehole and measuring its temperature response. The test is continuing for the specific time. The collected data is substituted into the equations of the line source theory to obtain the thermal conductivity of the soil and the thermal resistance of the borehole of the site. Performed test which is the first ever made in Libya were made at Al-Fateh University; Tripoli. The results show a thermal conductivity of 3.749 W/(mK) and a borehole thermal resistance of 0.18 K/(Wm). The site can be used as a ground heat exchanger coupled with a heat pump for air conditioning of buildings.

1. Introduction

Earth is already facing a global warming as a result of fossil fuel combustion. Fossil fuels are traditional and dominant in many countries. Oil, coal and natural gas are still something human beings can not live without.

However, due to a sharp increase in the use of fossil fuel, as a prime energy source for development, the researches in the world are continuing striving hard to make the renewable energy sources possible to use in order to meet the said challenge facing the human race.

In some countries utilizing the ground as heat exchanger systems have been gaining an increasing popularity for space air conditioning in the residential as well as in commercial buildings, this will contribute to the reduction of the global energy consumption. This system is environment friendly, causing less gas emission than the conventional energy sources.

2. Background

The underground thermal energy storage systems, is used as a heat exchanger devise for extraction or injection of heat from/into the ground to support a heat pump for domestic heating or cooling. However, the knowledge of the water temperature behavior leaves the ground loop heat exchanger, the thermal conductivity of the soil and the thermal resistance of the borehole is of importance before making any air conditioning system for buildings.

The above mentioned parameters are determining the efficiency of the heat storage. This can be done by determining in the site a thermal response test (TRT). Mogensen [1983] suggested a method to determine ground thermal conductivity and borehole thermal resistance in site. This can be done by extracting a constant heat flow rate from a borehole heat exchanger (BHE) and measuring the change in temperature of the fluid. The heat transfer in borehole and ground maybe evaluated using the equation of the line source theory. During the mid-nineties, in-site thermal response test equipment was developed by Eklof and Gehlin, [1996] and Austin, [1998] based on this method. Thermal response test is today the established method to determine ground thermal conductivity and borehole thermal resistance for borehole heat exchanger systems.

During a response test, the time duration to a heat carrier fluid circulation through the borehole installation is (50 to 72 hours), and the same time the inlet and outlet temperatures of the heat carrier fluid in the borehole are measured. The thermal response test can be done for extraction or injection of heat. TRT can also be conducted for one or more borehole. The power supply needed to be constant and is known (injection flow rate or extraction flow rate) throughout the thermal response test.

However, if the mean of the inlet fluid temperature (T_{in}) and outlet fluid temperature (T_{out}) into/ out of the borehole heat exchanger (^oC) is plotted against the logaritmic time, then one can determine the thermal conductivity and the thermal resistance.

3. Study objective

In this study, the experimental setup will be erected to test the soil of the site as a heat exchanger with a heat pump for the air conditioning buildings. The objective of this test is to evaluate the following properties:

- The ground thermal conductivity of the soil k.
- The thermal resistance R_b between the heat carrier fluid and the borehole wall.

4. Theory

The author is briefly introducing the theory to understand the response test. The transfer of heat to/from the boreholes causes a change in the temperature in the surrounding ground. The mathematics is described by Hellstrom (1994), Mogenson (1983) and Eskilson (1987) as presented below.

The temperature field as a function of time and radius around a borehole, described as a Kelvin Line Source Theory with a constant heat injection is known:

$$T_q(r,t) = \frac{q}{4\pi k} \int_{r^2/4\alpha t}^{\infty} \frac{e^{-u}}{u} du \tag{1}$$

where $$E_1\left(\frac{r^2}{4\pi\alpha}\right) = \int_{r^2/4\alpha t}^{\infty} \frac{e^{-u}}{u} du \quad \text{and} \quad \tau = \frac{r^2}{\alpha t}$$

Here, E1 is called the exponential integral. For $\tau \geq 5$ there can be further simplifications:

$$E_t\left(\frac{\alpha t}{r^2}\right) \approx \ln\left(\frac{4\alpha t}{r^2}\right) - \gamma$$

γ = 0.577 is Euler's constant.
q = heat injection rate per unit length of borehole (W/m)
H = borehole length (m)
t = time after application of heat injection(s)
α = $k/\rho\, c_p$ thermal diffusivity (m^2/s)
r = radius from the borehole (m)

For the transient process, the temperature of the borehole can be formulated as follows.

$$T_b(r,t) = T_u + T_q(r,t) \qquad (2)$$

T_b (r, t) - the well temperature at time t
T_u - The undisturbed ground temperature
T_q(r, t) - Change in well temperature due to derivation from mean fluid temperature

Substituting Equation (1) into the equation (2)

$$T_b(r,t) \cong T_u + \frac{q}{4\pi k}\left[\ln\left(\frac{4\alpha t}{r^2}\right) - \gamma\right] \qquad (3)$$

The thermal characteristic of a borehole heat exchanger is determined by its effective borehole thermal resistance R_b, which defines the proportional relationship between the temperature difference fluid-ground on the borehole wall and the heat rate exchanged by the borehole.

$$T_f - T_b = R_b \times q \qquad (4)$$

where:

T_f = ((T_{in} +T_{out})/2), T_f denotes the arithmetic mean of the inlet fluid temperature (T_{in}) and outlet fluid temperature (T_{out}) of the borehole (^oC).

T_b Denote the average ground temperature on the borehole wall (^oC).

R_b is the thermal resistance of the heat carrier fluid and the borehole wall.

Substituting (3) into the equation (4)

$$T_f - T_u = \frac{q}{4\pi k}\left[\ln\left(\frac{4\alpha t}{r^2}\right) - \gamma\right] + qR_b \qquad (5)$$

The equation 5 can be simplified to a linear relation between T_f and ln(t).

$$T_f = a\ln(t) + m \qquad (6)$$

a, m are constants. a is estimated by plotting the mean heat carrier fluid T_f versus logarithm time ln(t) and k is calculated from the inclination of the graph as:

$$k = \frac{q}{4\pi a} \qquad (7)$$

Hence, the thermal conductivity can be determined from the slope of the line resulting when plotting the fluid temperature against ln(t).

The equation (5) can be rearranged as:

$$R_b = \frac{Q}{H}\left(T_f - T_u\right) - \frac{1}{4\pi k}\left[\ln\left(\frac{4\alpha t}{r^2}\right) - \gamma\right] \qquad (8)$$

5. An experimental setup

In order to conduct the thermal response test in the site, it is necessary to construct an experimental setup, which consists of two main components, test device and U-tubes buried into a borehole.

The test device consists of a water pump, a water heater, a tank, two sensors for measuring inlet and outlet temperatures and a logger to collect the data.

The U-tubes buried into the borehole are connected to the quick couplings of the pipe ends of the test device. The pipes are filled with heat carrier fluid from the tank and the fluid is pumped through the system via the pump. On its way, the fluid passes through the water heater that heats the fluid at constant power. As the fluid in the pipes passes the temperature sensors at inlet and outlet pipe, the temperatures are recorded by the logger. Time and inlet and outlet temperatures are logged at the selected time interval. The flow rate is measured using a flow meter.

In order to do that a well of a depth 23 meters and 250 mm diameter, was drilled in August 2007 outside the Air Conditioning Lab in the Mechanical and Industry Engineering Department, Faculty of Engineering, at Al-Fateh University in Tripoli-Libya. Figure 1 shows schematic diagram for the experimental setup in this study.

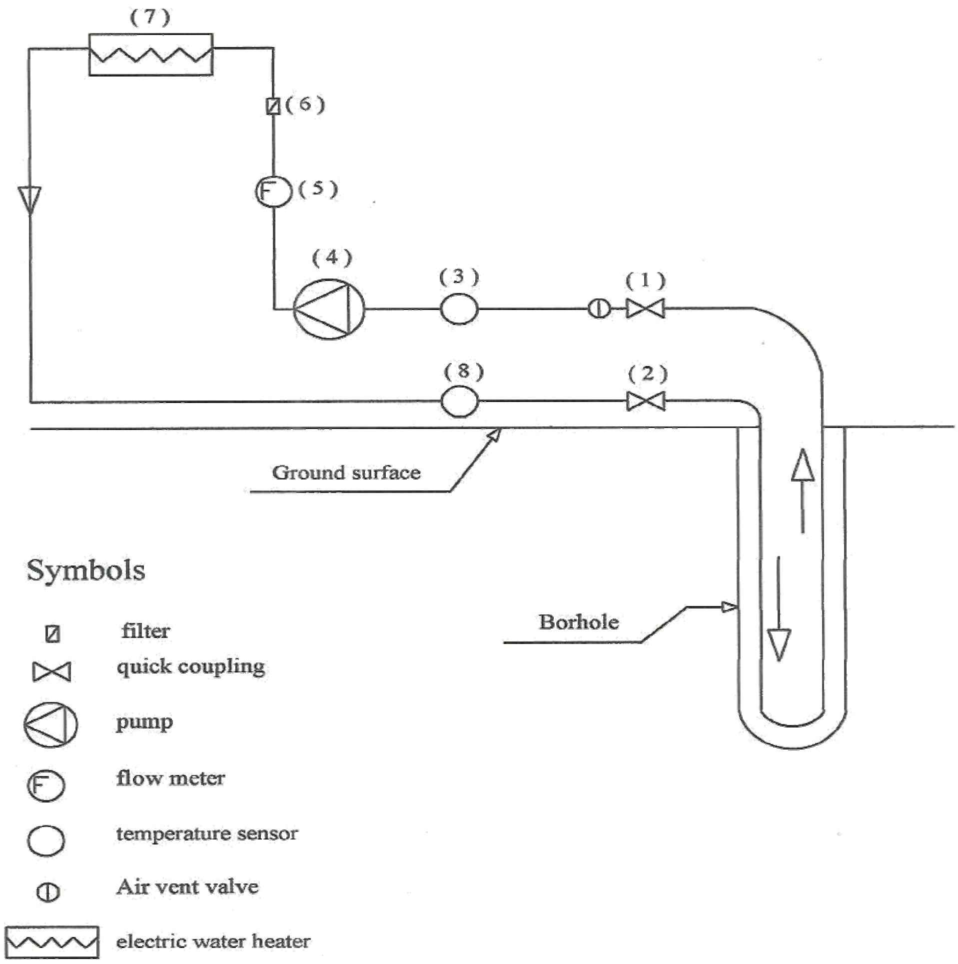

Figure 1 schematic a diagram of the experimental setup.

6. Results and discussion

6.1 Results

An experimental setup is constructed to test the ground of the site, where the ground is used as a heat exchanger with a heat pump. In this system, the electric water heater gives the heat carrier fluid a constant power supply of 4.5kW. The results obtained from the test using the line source theory, gives the behavior of the outlet temperature of the heat carrier fluid leaving the ground loop heat exchanger. The thermal conductivity of the soil and thermal resistance of the borehole wall are evaluated.

Equation 5 is used to evaluate the above-mentioned ground properties. In these equations, an approximation is made and the break time is introduced. In this chapter the break time (t_b) is defied as:

$$t_b = \frac{5r^2}{\alpha}$$

The error of the approximation in the equation (5) it is found to be less than 2% for $t_b \geq 5r^2/\alpha$.

Test site

The first measurements were performed at the borehole outside the Air-Condition Lab in the Mechanical Engineering Department of at Al-Fateh University, Tripoli- Libya. The borehole was drilled in August 2007. Several measurements are made at the borehole.

The borehole radius and depth are measured and suitable plastic loop is constructed for it. The borehole specifications are shown in table 1.

Table 1 Borehole specifications

Item	Description
U pipe polyethylene diameter	0.0254m
borehole Depth (h)	23m
borehole radius (r)	0.125m

The ground thermal conductivity depended on undisturbed ground temperature, which must be determined before the thermal response test starts.

In the first part of measurement the undisturbed ground temperature T_u is calculated from the average temperature of the heat carrier fluid and time, and is18.5°C.

A response test for determining the thermal conductivity and thermal resistance of the installation was performed on September 9th, 2007. Water is used as the heat carrier fluid for a borehole of 23 meter depth and 250mm radius. The constant power supply of 4.5kW is used throughout the test.

The break time is calculated, t_b =13h: 40min ($\ln(t_b)$=2.61). The linearized function of T_f (Figure 2) also shows the break time.

The linearized function of T_f is used as an approximation of T_f=a ln(t)+m. where, a and m are constants and both can be obtained from the equation of the plotted experimental collected results during the test as presented in Figure 2.

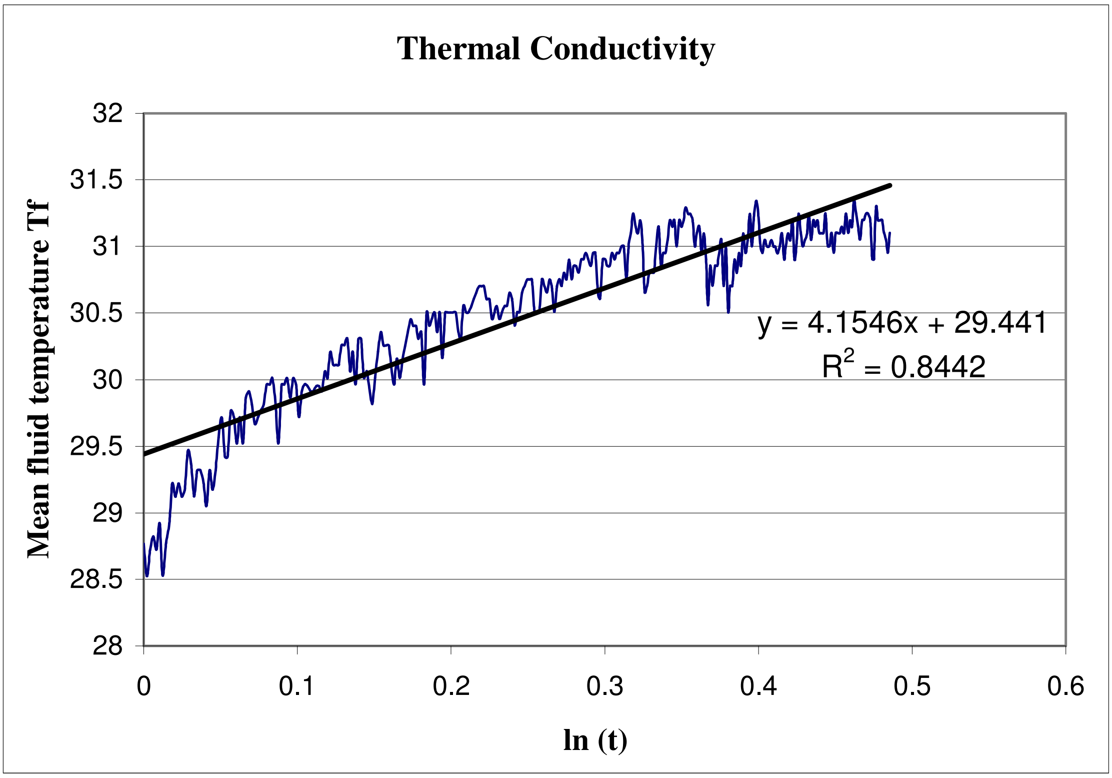

Figure 2 linearized function of the Mean Fluid Temperature (T_f) versus Logaritmic time ln(t)

The equation shown in the Figure 2 can be compared with the equation $T_f = a \ln(t) + m$, to determined the constants a=4.1546 and m=29.441. Therefore, the thermal conductivity k can be found by plotting the mean temperature of the heat carrier fluid T_f versus Logaritmic time ln(t).

Using the given parameters in Table 5.1 for the borehole specifications and the value constant a=4.1546 in to the equation (7).Thus, the thermal conductivity of soil k at the break time t_b is determined as 3.7494 (W/m. K).

Determination of the borehole thermal resistance (R_b)

The effective borehole thermal resistance is defined as proportional relationship between the heat flow rate by the borehole and the temperature difference between the circulating fluid and the borehole wall.

Using the data obtained from the response test and parameters for the borehole specifications, the relation between the thermal resistance (R_b) and the time (t) can be plotted as shown in Figure 3.

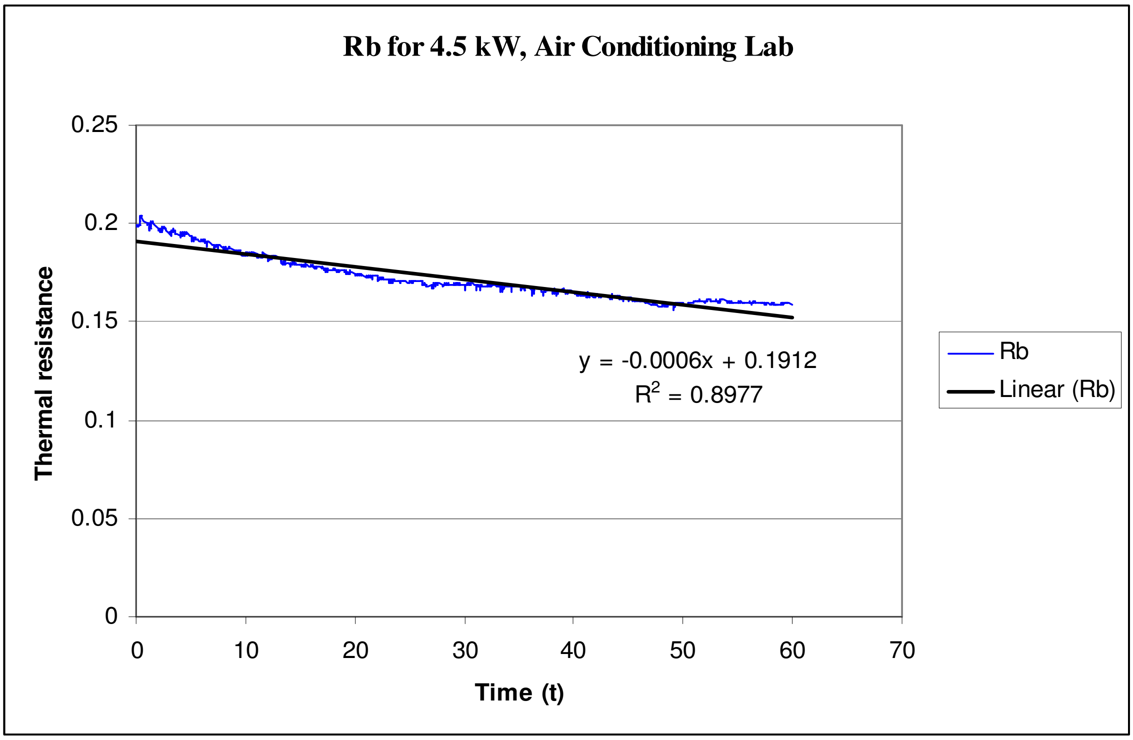

Figure 3 Thermal Resistances (R_b) as a function of Time (t)

If one is looking at the thermal resistance of the borehole that the responses test will give equation (8) and it is now can be used for determining R_b. Using the given parameters for the borehole specifications and inserting the thermal conductivity calculated above, the thermal resistance Rb is determined as 0.18 K/ (W m).

6.2 Discussion

With a thermal response test one can measure the ground temperature, evaluate the thermal conductivity of the ground and the thermal resistance between the heat carrier fluid and borehole wall. Table 2 shows the response test results at the break time t_b=13h: 40min.

Table 2 Response test results:

Break time t_b	Mean ground temperature T_u	Thermal conductivity k	Thermal resistance R_b
13h:40min	18.5°C	3.749 W/(m K)	0.18 K/(Wm)

7. Conclusion and recommendation

7.1 Conclusion

In this study, the experimental setup is erected to test the soil of the site as a heat exchanger with a heat pump for air conditioning of buildings, the test is called thermal response test. During the test a constant power supply is injected to the ground by circulating a heat carrier fluid through the vertical ground loop heat exchanger. The length of test is about 60 hours. From the obtained results of response test on the site one can conclude the following:

- The thermal conductivity of the soil is 3.749 W/ (m. K)
- The thermal resistance is 0.18 K/ (Wm) between the heat carrier fluid and the borehole wall.

Therefore, from the obtained range of the results as mentioned the selected site, at Al-Fateh University, Tripoli- Libya area can be use as heat exchanger with a heat pump for air conditioning of buildings.

7.2 Recommendation

- Further investigation is required for ground horizontal loop heat exchangers experimentally and modeling for air conditioning building.
- Further studies are needed to evaluate the economics of the underground thermal energy systems.
- A similar experimental setup and modeling are required for a high depth borehole, more than 50 meters.

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