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In-Suit Testing and Analysis of Thermal Properties of the Ground Formation in Zhejiang, China

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Abstract. The borehole exchanger (BHE) exchange heat with the surrounding ground, which is the core heat exchange component of Ground source heat pump(GSHP). The thermal properties of the surrounding rock, soil and backfill in the borehole have a great impact on the performance of the BHE. Ensure thermal properties' accuracy could facilitate GSHP's design and reduce investment. The data of thermal properties measured in laboratory do not comply the in-situ conditions. To get the more accurate data of the thermal conductivity (λ) of the ground formation in the vicinity of a BHE, and the effective thermal resistance (R_b) of this latter, in-situ thermal response test can be the best choice. In this paper, we use in-suit TRT method get the thermal response of BHE in Shaoxing City, Zhejiang Province, China. And the λ and R_b of borehole are measured as $2.27 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$ and $0.123 \text{ (m} \cdot \text{K} \cdot \text{W}^{-1})$.

1. Introduction

GSHP system have many advantages over other air conditioning system.^[1-2] The temperature in the deep layer of the ground higher than the outdoor temperature in winter and lower than the outdoor temperature in summer, GSHP is a natural heat source. In addition, it has many advantages such as low noise, small floor space, low operating and maintenance costs, and long life. However, there are many factors that affect the performance of GSHP. Such as the heat pump characteristics, BHE's thermal process in the ground and so on. BHEs usually contain a closed U-loop, which undertakes the main task of heat transfer. And BHE should be designed to meet the heat requirements of the required transmission. In our county, depending on different energy requirements and underground conditions, BHE with a depth of 80-150m and a diameter of 15-20 cm can meet the needs of ordinary residential buildings. If the physical parameters are not accurate enough, the designed system may not meet the load requirements, or the scale may be too large, thus greatly increasing the initial investment.

Pribnow and Huenges^[3-4]'s experiments show that the data obtained in the laboratory experiments usually not the same with the engineering sites. The real-world engineering problems tend to span broad activities and require consideration of multiple aspects. From now on, in-suit TRT is an effective way to measure the ground thermal conductivity. With a known thermal load applied to BHE and measure the inlet and outlet temperature over time, we could complete a thermal analysis of borehole. A few requirements should be followed to obtain the accurate data. First: power load is as stable as possible. Second: Keep at least 48 hours of testing time. Third: record BHE inlet and outlet temperature changes over the time.



The earliest TRT system designed by Mongensen^[5] is immovable. It has been welcomed by the majority of researchers after being improved from Sweden^[6-7] and The USA.^[8] And this test is also uses mobile devices.

In this study, the TRT means in-situ measurements of the heat transfer capacity of boreholes for energy injection. The purpose of test is to get the effective ground thermal conductivity (λ), and the effective thermal resistance (R_b) of the BHE.

2. Field experiment

From 15 December to 17 December 2016, the TRT was lasted two days. The in-situ device includes a pump, a borehole collector and a cross-flow heater. The in-situ device is installed on a mobile trailer, water is circulating by pump to the borehole and cross-flow heater to finish a heat exchange circulation. The heating power of cross-flow heater is in the range of 9.56 and 9.89 KW. A thermistors measure the inlet and outlet temperature of the borehole, which accuracy is $\pm 0.15^\circ\text{C}$. A logger is used to record the temperature and flow rate at a 60s interval. And the circulation pressure of flow is 2~3 bar. The main structure of TRT is shown in Figure 1.

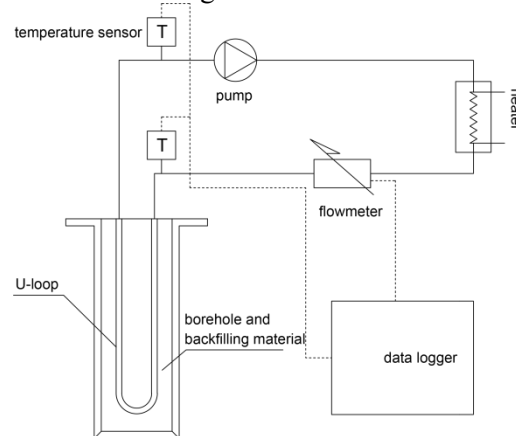


Figure 1. The main structure of TRT

We drilled two single boreholes for TRT in this study, and the boreholes have 100m depth and 0.13m diameter. Surrounding mud and soil was used as backfilling. With the 32mm diameter and 3mm thickness, polyethylene U-loop (SDR-11) was chosen to install in the boreholes. The general characteristic of high-density polyethylene tube is shown in Table 1.

Table 1. Main characteristic of U-loop

Catalog	Parameter
Melting temperature	130°C
Working temperature	90°C
Peak temperature	125°C
Internal diameter	26mm
External diameter	32mm
Density	0.96 g/cm ³
Thermal conductivity	0.4 W·m ⁻¹ ·K ⁻¹
Thermal resistance	0.0815 m·K·W ⁻¹

In order to determine the actual injected power, recording the power supply is critical. Preheating for 20~30 minutes is essential to get an accurate undisturbed initial ground temperature. After that, we can start measuring up to 48 hours. To facilitate the calculation of the actual thermal load injected to the hole, the flow rate should be keep at 1.2m³/h. And Figure 2 shown a 50-h measurement record.

3. Data calculation and test evaluation

At present, the mature models for calculating heat transfer between geothermal heat exchanger and surrounding rock and soil are Linear heat source model and Cylindrical heat source model.^[9-10]

We choose the linear heat model for this test, which mainly depends on the thermal conductivity of the surrounding soil and the fluid-to-soil thermal resistance. The data measured from the TRT is also based on the linear heat source model. The data error after 10 hours is less than 2% with the apply of a logarithmic approximation to the exact solution. The theoretical basis of the thermal response test is presented by Hellstrom^[11], Gehlin^[12] and Kavanaugh and Rafferty^[13]. Different types of BHEs were investigated to determine the borehole thermal resistance^[14].

In linear heat source model, Three formulates are sufficient to analyze the data. In Eq. (1), 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 follow

$$T_f = k \ln t + m \quad (1)$$

k and m are constants.

$$\lambda_s = \frac{Q}{4\pi k H} \quad (2)$$

$$R_b = \frac{H}{Q} (T_f - T_0) - \frac{1}{4\pi\lambda} \left[\ln \left(\frac{4\alpha t}{r^2} \right) - \gamma \right] \quad (3)$$

λ -the thermal conductivity ($\text{W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$),

Q-the injected heat power (W),

T_f - the heat carrier mean fluid temperature (K),

r-the borehole radius (m),

T_0 -the denotes the undisturbed initial ground temperature (K) in borehole,

α -the thermal diffusivity ($\text{m}^2\cdot\text{s}^{-1}$),

H -the effective borehole depth (m),

t -the time from start,

R_b - the thermal resistance ($\text{m}\cdot\text{K}\cdot\text{W}^{-1}$),

γ -the Euler's constant (0.5772).

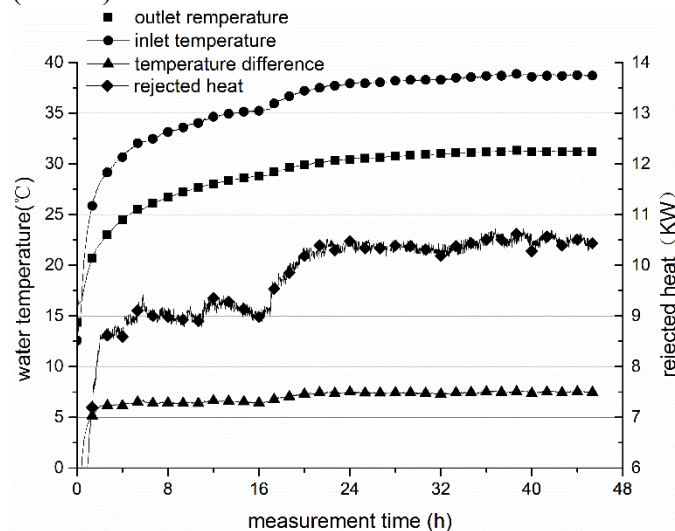


Figure 2 . Measurement records development

The slope of the mean temperature versus the log of time in seconds given in Figure 3 is proportional to the thermal conductivity of the backfilling material. λ and R_b can be calculated by iterative approach on the base of linear heat source model, where λ is given an initial estimated value and R_b is calculated from Eq. (3). TRT parameters of Shaoxing measurement status are shown in Table2.

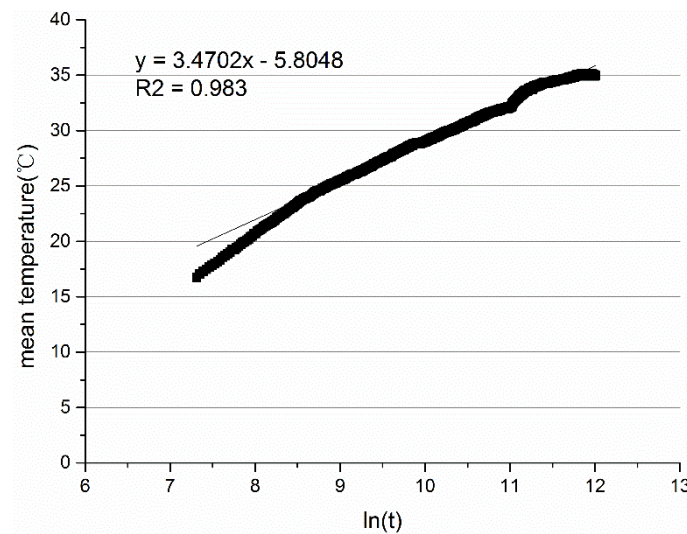


Figure 3. Log time plot of the mean temperature for the test length

Table 2. Parameters of Shaoxing measurement state

Catalog	Parameter
Undisturbed ground temperature	18.51 °C
Depth of borehole	100m
Test duration	48h
Power of heater	9.3kW
Injected heat per meter	86.39 W·m ⁻¹
Thermal diffusivity	1.15×10 ⁻⁶ m ² ·s ⁻¹
Thermal conductivity (λ)	2.27 W·m ⁻¹ ·K ⁻¹
Thermal resistance (Rb)	0.123 m·K·W ⁻¹

4. Conclusions

The thermophysical parameters required by the GSHP design obtained by the in-suit TRT are relatively accurate. Based on the experience and the results obtained, we can draw the following conclusions:

- (1) Through the in-suit testing, the effective values of the thermal conductivity λ and borehole thermal resistance R_b are determined as $2.27 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$, $0.123 \text{ m} \cdot \text{K} \cdot \text{W}^{-1}$ respectively in Shaoxing, City, Zhejiang Province China.
- (2) Careful complication with measurement rules will be conducive to the accuracy of measurement data.
- (3) Although there are many areas to be improved, such as standardization, What is certain is that TRT has great development potential in our country.

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