Applied Thermal Engineering 107 (2016) 662–671

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Testing and analysis of the influence factors for the ground thermal parameters

Yingling Cai *, Hui Xu, Shuai Chen

College of Mechanical Engineering, Shanghai University of Engineering Science, Shanghai 201600, China

HIGHLIGHTS

- Three tests with different heating power and duration are investigated.
- The effect of water storage volume on the test results can be ignored.
- Increasing the heat transfer effect of GHE will has a great impact on the test results.

ARTICLE INFO

Article history:
Received 5 October 2015
Revised 10 May 2016
Accepted 30 June 2016
Available online 1 July 2016

Keywords:
Thermal response test
Influence factors
Thermal conductivity
Thermal resistance

ABSTRACT

To make full use of the ground heat exchanger, it is necessary to investigate the main factors affecting the thermal-physical property of soil. Thermal response tests (TRT) were conducted with different heating power and testing time in the same borehole in the present study. The results show that the change of the thermal conductivity is within 5% under different heating power. As some factors cannot be tested in practical engineering, a TRNSYS model of TRT was established based on duct ground heat storage model. The accuracy of the results from TRNSYS model was validated by testing. Changing the capacity of the water tank has little influence on the thermal conductivity, but affects the length of time heating fluid to reach the stable state. The rate of thermal conductivity change decreases gradually with the increase of the thermal conductivity of backfill material with constant borehole diameter. This indicates that the effect of backfill materials on the thermal conductivity of soil is limited. When the drilling depth is kept as constant, the borehole thermal resistance of double U-tube is reduced by nearly 70% compared to the single U-tube, while the thermal conductivity is increased by 8–10%.

1. Introduction

So far the ground-source heat pump (GSHP) technology has been widely used because of its low-carbon, environment-friendly and efficient characteristics. The design of the ground heat exchanger (GHE) is crucial to the GSHP system [1,2], and it should be carried out all-year hourly dynamic load calculation. The performance of GHE system mostly depends on the thermal response test to estimate the ground thermal parameters (i.e. conductivity and capacity) and the borehole thermal resistance. The ground thermal parameters and the specific heat capacity of the soil used for dynamic coupling design of GHE system could be obtained according to slope method or double parameters optimization method. Therefore, the accurate and effective ground thermal parameters play a key role in the long-term stable operation of the GSHP system [3–8].

Soil moisture content in different regions is related to the composition of soil. Even though in the same region, the composition and moisture content of soil at different depths are also different. Hence, there is no standard to illustrate or regulate the detailed thermal physical parameters of the soil in the region.

Further research on TRT is done by different data processing methods and practical cases. TRT is a relatively common and accepted method for thermo-physical property of soil, this method was firstly introduced by Mogensen [9] based on the infinite line source model, then it was widely promoted in European after Carslaw et al. [10] used for the first time. A comparison between conventional slope determination method, Geothermal Properties Measurement data evaluation software and two-variable parameter fitting were performed by Roth et al. [11] to calculate the thermal parameters. A test about a borehole's characteristics was performed by Georgios et al. [12] and two main factors affecting

* Corresponding author.
E-mail address: 01050209@sues.edu.cn (Y. Cai).

http://dx.doi.org/10.1016/j.applthermaleng.2016.06.186

Nomenclature

List of abbreviations

GSHP	ground-source heat pump
GHE	ground heat exchanger
TRT	thermal response test
DST	duct ground heat storage

List of symbols

d_b	outside diameter of the pipe, m
H	the depth of the borehole, m
q	heat flux per meter, W/m
Q	input power, W
r	radius, m
r_b	the radius of the borehole, m
r_i	inside radius of the pipe, m
r_o	outside radius of the pipe, m
R_b	borehole thermal resistance, m K/w
S	center-to-center distance of the pipe, m
T	time, s
T_0	undisturbed soil temperature, °C
$T_{cal,i}$	the average temperature by the heat transfer model in the *i* time, °C
$T_{exp,i}$	the actual measured mean temperature, °C
T_b	borehole wall temperature, °C
T_f	average temperature of fluid, °C
T_{in}	inlet temperature, °C
T_{out}	outlet temperature, °C

List of Greeks

c_s	heat capacity, J/kg K
α_s	ground thermal diffusivity, m^2/s
ρ_s	soil density, kg/m^3
γ	Euler's constant
κ_s	ground thermal conductivity, W/m K
κ_b	ground thermal conductivity, W/m K
κ_p	thermal conductivity of pipe, W/m K

List of subscripts

1, 2, 3, 4	pipe sequence in borehole
b	borehole
f	fluid
s	soil

the accuracy of the collected data were analyzed: the daily flux penetration through the ground and a variation of the heating coil injection rate per active length of the borehole. Austin et al. [13] investigated the length of test required, the number and the type of parameters to estimate and the initial number of data hours to ignore, which indicated the length of test should be no less than 50 h to obtain a valve of group thermal parameters. Li et al. [14] discussed some aspects of parameters estimation used in-situ TRT of GHEs, their results presented that the uncertainty of borehole size might be very sensitive to the thermal conductivity of the soil, and initial temperature of ground and heating power were the most sensitive parameters. Hu et al. [15] analyzed the influence of duration of TRT and specific heat capacity of soil and rock on the results of test, which indicated that 70 h was indispensable for the TRT and the influence of the specific heat capacity of soil to the results can be ignored. Yang et al. [16,17] proposed an updated method, which developed an analytical heat transfer mode for GHE with considering the variation of fluid temperature along borehole length and thermal interference. Shonder et al. [18] proposed a new method based on a one-dimensional numerical heat transfer model, which used parameter estimation to determine ground thermal parameters.

Various models have been developed to determine the performance of GHE. Four two-variable parameter estimation models were compared and three TRTs were tested for thermal parameters by Signhild et al. [19], which indicated that minimum response test duration of 50 h is recommended from the model comparison. As an improved method of TRT, vertical temperature profiles were obtained using retrievable optical fiber sensors by Fujii et al. [20]. Signorelli et al. [21] compared the results from a 3-D finite-element numerical model with those of a simple analytical line-source solution, and the results emphasizes the importance of using more sophisticated numerical methodologies in interpreting thermal response test data. Lee et al. [22] developed a numerical model using three-dimensional implicit finite difference method with rectangular coordinate system. Onder et al. [23,24] developed a model from daily fluctuations in air temperature using a sinusoidal function of time and depth to improve a model predicting daily soil temperature. Zhang et al. [25] presented a system model of TRT based on the DST model of vertical U-tube GHE for determining ground thermal parameters, and the results showed that the temperature difference quadratic sum corresponding to the DST model was minimum.

However, the numerical models cited above are relatively complex. At the same time, user will also consume a large of time to adapt the numerical model when the parameters are changed, and thus are not very fit for engineering design. DST model, which is different from the line source model and the cylindrical source model, will be used as a whole for the heat transfer inside and outside of the borehole, using explicit finite difference method (FMD) and heat transfer analytical solution to solve the ground heat exchanger temperature variation. Moreover, compared with the above mentioned GHE models in practical engineering for determining the ground thermal parameters, TRNSYS TRT model not only consider the ground heat exchanger model, but take into account the external influence factors (such as water tank volume, the heating power) on the actual test in this paper. The process of the calculation is simple relatively, and more applicable to engineering test.

In the present study, one TRT project was conducted to obtain the thermal physical parameters in the mountain. It is difficult to obtain relatively accurate thermal physical parameters, mainly because of the measurement of thermal physical parameters, which may be affected by many factors. Therefore, it is necessary to study the main factors (i.e. heating power, length of testing) affecting the results on the TRT. Meanwhile, the TRNSYS software was employed to simulate some factors which is difficult to achieve in the field test, including the water tank volume, the borehole depth, the type of U-tube and the backfill materials on the results of TRT. The results of TRT provide a lot of feasible suggestions for the application and promotion of GSHP system.

2. System description

2.1. Experimental set up

This project is located in a Resort Villas, Deqing County, Zhejiang Province. The vertical typical U-tube GHE was used for this project according to the field investigation and the permission of