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Study on the influence of the identification model on the accuracy of the thermal response test

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ABSTRACT

A 3-D numerical heat transfer model of a ground-source heat pump thermal response test is established in this paper and verified by testing. The numerical model is used to simulate the thermal response test. The soil thermo-physical parameters are estimated based on the cylindrical heat source and the linear heat source theory and contrasted with the values setting in the numerical heat transfer model. The effect of the identification model of the in-situ thermal response on the accuracy of the identification results is studied under different soil thermal properties. The results show that there is an optimal time to identify the soil thermo-physical parameters based on the two models. Identifying the physical parameters at the non-optimal time points will produce a large error. Under the same conditions, the optimal identification time of the cylindrical heat source model is earlier than that of the linear heat source model and is also related to the soil physical properties. Therefore, the test time should be selected to ensure the accuracy of the results. Furthermore, there is no evident influence of the initial soil temperature on the identification accuracy of the two models. This paper offers a reference for improving the thermal response test of ground source heat pumps.

1. Introduction

The ground heat exchanger is an important part of a ground source heat pump (GSHP) system, and the heat transfer performance directly affects the system's efficiency, performance, and economic benefits. The accuracy of estimations of the soil thermo-physical parameters has a great impact on the design of a ground heat exchanger. It directly affects the quantity and depth of drilling and even affects the initial investment and operating performance of the GSHP system. Kavanaugh's (1998) studies show that if the test error of thermal conductivity is about 10%, the length design error of the borehole heat exchanger will reach 4.5–5.8%. Therefore, how to obtain the accurate thermal properties parameters of soil is very important and is also an urgent problem for GSHP technology.

Identification of soil thermal properties is an inverse problem of solving physical property parameters by applying heat transfer model. The ideal identification model should be accurate and applicability. However, the existing models (the linear heat source models and cylindrical heat source models) have some errors, which affect the accuracy of the identification results.

There are errors in the thermal response test (TRT) because the models make very specific assumptions concerning the process. In order to improve the accuracy of parameter identification, the model is modified based on some model assumptions. The actual soil is non-homogeneous, and the traditional heat transfer model based on the assumption of homogeneous soil can cause errors in the calculation of fluid temperature. Based on the superposition principle, Abdelaziz et al. (2014) proposed a linear heat source model for axial stratification in the heat exchange area. Bandos et al. (2016) developed an analytical cylindrical heat source model accounting for the effects of buried depth variations in the TRT, which was examined by the integral mean temperature method in a self-consistent approach. The traditional cylindrical heat source model just considers the heat transfer process along the radial direction. So Man et al. (2010) improved it by using the Green function method. The new model was also conducive to dealing with the short-term temperature response in boreholes. Available analytical models for the thermal analysis of GSHPs neglect either groundwater flow or axial effects. As a result, for Peclet numbers between 1.2 and 10, the combined effect of groundwater flow and axial effects had to be accounted for when evaluating the temperature response of a borehole heat exchanger (BHE) at the borehole wall, and thus Molina-Giraldo et al. (2011) proposed a moving finite line heat source model. Rivera et al. (2015, 2016) proposed a new form of moving finite linear heat source model that considered not only groundwater flow but also land surface effects on the ground heat transport of BHEs.

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Nomenclature

T	temperature (°C)
T_g	undisturbed ground temperature (°C)
Q	heat injection power (W)
H	active borehole length (m)
r_b	the radial coordinate (m)
τ	time (s)
ρ_s	soil density (kg/m^3)
c_s	ground heat capacity (J/(kg K))
γ	Euler's Constant
T_f	the average borehole wall temperature
R_b	pile thermal resistance (mK/W)
Fo	Fourier number
$G(\ldots)$	G-function
P	r/ro

Acronyms

GSHP	ground heat source pump
BHE	borehole heat exchanger
LHS	linear heat source
CHS	cylindrical heat source
3-D	three-dimensional

Subscripts

exp	experimental results
cal	calculated results
ide	identification
ini	initial temperature

Park et al. (2016) and Tye-Gingras and Gosselin (2014) were also concerned with groundwater seepage factors and made some relevant contributions. The traditional models are invalid for the first several hours of GSHP operation due to the thermal capacity of the grout, U-pipe, and fluid. As a result, a new transient quasi-3D entire timescale line heat source model was proposed by Zhang et al. (2016); it was an effective method for the prediction of fluid and ground temperature and might offer a theoretical basis for system control and borehole distance determination. In addition, scholars have also made other improvements, for example by taking into account the interference of environmental conditions (Bandos et al., 2009, 2011; Yu et al., 2013), the time scale term (Li and Lai, 2012; Choi and Ooka, 2015), or the heat transfer in different stages (Woods and Ortega, 2011).

Although the above mentioned models only study the unilateral influence factors, the improved model is more complex and the computation is large. Therefore, it has not been applied in practical engineering. Based on the traditional identification model for measuring thermo-physical parameters, the results contain errors that have not been quantified and evaluated, and the accuracy of the improved model is no guarantee. In conclusion, the improvements have led to a large amount of computation, which is difficult to apply to practical engineering. In practice, the traditional linear heat source model and cylindrical heat source model are still used (e.g., Shim and Park, 2013; Hu et al., 2014; Marcotte et al., 2010). Therefore, on the basis of the usefulness of the traditional model, it is necessary to find the change rule of the error itself and improve the accuracy of the identification. The objective of this study was to seek another method of reducing errors based on the traditional models.

In this paper, a numerical simulation model was established to simulate the TRT. The thermo-physical parameters are estimated, respectively, based on cylindrical heat source and linear heat source theory and contrasted with the values setting in the numerical model, and the identification errors and change rules of different thermos-physical parameters and initial temperature are obtained. The achieved results can provide references and analytical analyses for the in-situ TRTs of practical projects.

2. Simulation model

The physical model consists of four parts: the circulating fluid, heat exchanger, backfill material, and soil. The parameters of each part of the model are as follows: The external diameter of the U-tube is 32 mm, the spacing of the pipe is 80 mm, the well depth is 63m, and the drilling radius is 0.24m.The mesh of the numerical model is shown in Fig. 1.

The heat transfer process in the TRT is convective heat transfer between the water and the backfill material and the heat transfer of the backfill material and the partial heat of the soil. The kinetic properties of the fluids in the ground heat exchanger tube can be depicted by partial differential equations including the mass conservation equation (continuity equation), the momentum conservation equation, and the

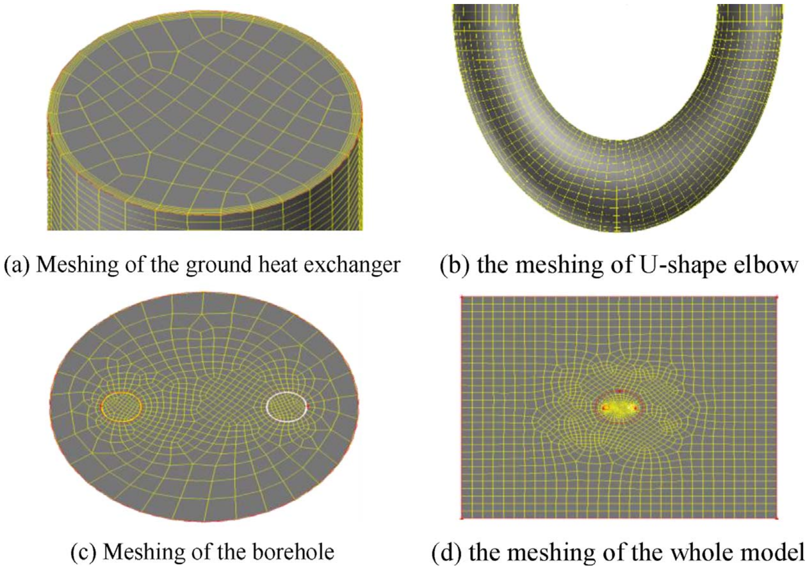
(a) Meshing of the ground heat exchanger
(b) the meshing of U-shape elbow
(c) Meshing of the borehole
(d) the meshing of the whole model

Fig. 1. Schematic of the meshing.

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