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Numerical Simulation of Soil Thermal Response Test with Thermal-dissipation Corrected Model

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Abstract

Based on the duct ground heat storage model on TRNSYS software, a thermal-dissipation-corrected transient model which takes the heat dissipation from ground and testing tube surfaces into consideration is established. An experimental platform is built for in-situ thermal response test (in-situ TRT) in Shandong Province, China. The presented model is verified by in-situ TRT with similar inlet and outlet temperatures of borehole heat exchanger (BHE). Furthermore, the key parameters, such as injected heat power, circulation flowrate, etc. are analyzed to study the influences on identified soil thermal conductivity, borehole thermal resistance and heat flow per unit length of BHE. It is showed that test duration has the largest impact on identified soil thermal conductivity, followed by injected heat power, abandoned initial hours, the circulation flowrate and backfill material conductivity; injected heat power has the largest influence on heat flow per unit length of BHE.

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Keywords: Thermal response test; TRNSYS; Thermal-dissipation-correction; Borehole heat exchanger; Thermal physical property; Numerical simulation

1. Introduction

Ground-source heat pumps (GSHPs) have been widely used to provide space heating and cooling as well as domestic hot water (Bandos et al. 2011). Compared with other energy supply forms, they offer high energy efficiency, reduced noise levels, savings of greenhouse gas emissions and comfort. The design of borehole heat exchanger (BHE) is very crucial to GSHP system. BHE is responsible for a major part of the initial cost of the whole system and accurate

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design procedures are needed to ensure the higher efficiency and better economy (Cai et al. 2016).

The performance of the BHE mostly depends on TRT used to estimate the ground thermal parameters, borehole thermal resistance and heat flow per unit length of BHE. According to Zhang (2009), if there is 10% error on soil thermal conductivity, the relative difference of designed length of BHE will be about 4.5-5.8% and the largest and smallest temperature differences of U-pipes are about 1.1°C-1.2°C and 0.3°C-0.4°C respectively. This will result in 1% change in heating or cooling capacity and increase on initial cost. Besides, the economic advantages of GSHP will be lost once the deviation between required and designed length of BHE reaches 10%-33% (Zhao 2013). Therefore, the accurate and effective ground thermal properties play a key role in the long-term stable operation of the GSHP system.

Several methods can be used to estimate ground thermal properties, including soil and rock identification, steady heat flow experimental testing of drill cuttings, in-situ probes and inverse heat conduction methods (Zhang et al. 2014). The parameter determination methods of TRT include slope method or double parameters optimization method which base on the Infinite Line Source Model (ILSM) introduced by Ingersoll (1948) and Mogensen (1983). In addition to analytical calculation, there are numerical simulation models in recent years. The most typical models are Eskilson heat-transfer model (Eskilson 1988) and Hellström duct storage system (DST) model (Thornton et al. 1997). The former has been applied to business software GLHEPRO and GLD while the latter has been applied to TRNSYS.

In this paper, in-situ TRT has been conducted in Zhaotong Village of Binzhou area, Shandong Province in China. Then combining the experimental data and TRNSYS software, a thermal-dissipation-corrected model has been proposed. Furthermore, with the indoor soil test results and experimental data, the new model is verified and key parameter (i.e. injected heat power, circulation flowrate, etc.) influence studies on the identified soil thermal conductivity, borehole thermal resistance and heat flow per unit length of BHE are simulated. The results of the study provide feasible suggestion for the application and promotion of GSHP system.

2. System description

2.1 General situation for testing region and experimental set up

The in-situ TRT is located in Zhaotong Village on the downstream of The Yellow River in Binzhou Area of Shandong Province in China. Geographic coordinate of Zhaotong Village is 117.94°E, 37.32°N in the southeast of Binzhou. Testing area is covered by Quaternary with the depth of 250-400 m and on the top of Minghuazhen formation. The main structures of the geology are sandy conglomerate, mudstone and sand-shale stone. Cohesive soil is the major component with the thermal conductivity of 1.67-1.97 W/(m·K).

Fig.1 The physics appearance of TRT apparatu

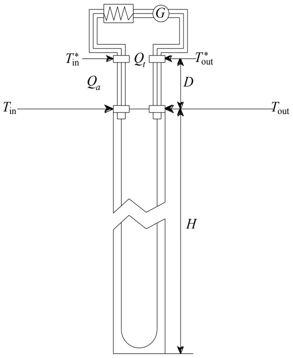

Fig.2 Schematic diagram of in-situ TRT apparatus

The testing device is a vehicle-mounted shallow geothermal energy TRT tester. The main components of the TRT apparatus are as follows: data acquisition system, thermal storage water tank, electric auxiliary heater, temperature sensor (Pt100), variable speed pump, electromagnetic flowmeter, flow control valve, pressure sensor, etc. The maximum test error of TRT system is ±0.20%. Fig.1 and Fig.2 show the physical appearance and schematic diagram of in-situ TRT apparatus respectively.

2.2 Experimental results

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