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Characteristics of ground thermal properties in Harbin, China

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ABSTRACT

Eleven representative sites were selected in this study to present the characteristics of ground thermal properties in Harbin, China. The initial ground temperature field was measured, and the temperature ranges of the solar warming, constant temperature, and increasing temperature layers were determined. The 22 thermal response tests (TRTs) for 11 boreholes were examined with two heating powers (4.2 kW and 6.5 kW). Analysis of thermal properties was performed in the laboratory. A total of 337 representative samples of rock and soil were analyzed, and their thermal properties were measured in laboratory tests, and the results of these tests are not consistent with those of TRTs. The overall characteristics of ground thermal conductivity are determined according to overall distribution.

1. Introduction

The global energy crisis and environmental pollution have caused frequent resource shortage, such as oil and electricity shortage; thus, the development and utilization of renewable energy is an urgent issue.

Shallow geothermal energy refers to energy at a certain depth below the ground surface (generally, the depth is from constant temperature zone to 200 m) whose temperature is below 25 °C. The development and utilization of geothermal energy is valuable for savings of energy costs under current technological and economic conditions [1]. Ground source heat pump (GSHP) can maximize the relatively stable temperature of the ground, which is proposed in the last decade, and there are different kinds of GSHPs using vertical or horizontal heat exchangers. Some researchers pay attention to horizontal ground heat exchangers [2–5], but the most spread ones are closed loop, ground coupled with vertical heat exchangers for the efficiency. In the system, a borehole heat exchanger (BHE) is utilized to facilitate the exchange of heat within the underground environment and to provide cooling and heating during summer and winter [6]. Shallow geothermal energy is new, renewable and can be utilized extensively. This type of energy has received increasing interest in many countries, such as Germany [7–9,28], Italy [5,10], Japan [11–13], Turkey [3,4,14–16,30,31], Sweden [17,25], Argentina [18] and USA [19,20,27]. Many researchers in China also studied some of the problems caused by the use of shallow geothermal energy, including change in ground temperature field [21], effect of groundwater seepage and heat transfer model [22,23], and so on.

However, geothermal energy is not only restricted by the heat power of the ground but is also affected by the thermal properties of rock and soil in the process of the development and utilization with GSHP technology. A method to determine such influence has been established, which is thermal response test (TRT). The first TRT was conducted by Mogensen [24] with a stationary test facility. Afterward, mobile TRT facilities were developed by many researchers for estimating ground thermal properties in different regions of the world, including Sweden [25], Canada [26], USA [27], Germany [28], Cyprus [29,46], Turkey [30,31], Korea [32], China [33–35] and elsewhere. The effective ground thermal conductivity (λ_s), effective thermal resistance (R_b), and specific heat capacity (c_s) values of boreholes with different depths can be obtained through TRTs.

The behavior of the thermal properties of the ground must be determined to evaluate the effectiveness of the GSHP system that utilizes shallow geothermal energy in Harbin. However, such properties have not been sufficiently studied. The information on the design of BHEs available at present is not applicable to Harbin, which cannot be compared with other regions. Thus, the characteristics of the thermal properties of the ground in 11 representative areas of Harbin are evaluated in this study according to data obtained from 22 TRTs. The shallow geothermal energy of the region is also evaluated, focusing on the analysis of the initial temperature field of the region and the overall conditions of

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Nomenclature

c_s	the mean specific heat capacity of the ground surrounding BHE [J/(kg K)]
d_i	the inside diameter of the pipe (m)
d_o	the outside diameter of the pipe (m)
d_b	borehole diameter (m)
K	the heat convection coefficient between the circulating medium and internal pipe wall [W/(m^2 K)].
R_1, R_2	the thermal resistance values of the borehole wall and the two BHEs, respectively (m K/W)
R_{12}	the thermal resistance between the two BHEs (m K/W)
R_p	the thermal resistance of the borehole wall (m K/W)
R_f	the thermal resistance of heat convection between the pipe wall and circulating medium (m K/W)
T_{f1}, T_{f2}	the fluid temperatures of the two BHEs, respectively (°C)
T_b	the temperature of the borehole wall (°C)
T_{ff}	undisturbed ground temperature (°C)
T	time (s)
λ_p	the thermal conductivity of the pipe [W/(m K)]
λ_b	the thermal conductivity of the grout [W/(m K)]
λ_s	the thermal conductivity of the ground surrounding the borehole [W/(m K)]
ρ_s	the mean density of the ground surrounding BHE (kg/m^3)

comprehensive ground thermal conductivity. This study provides a starting point for the future development of geothermal energy research and will be favorable for the further utilization of GSHP system in Harbin.

2. In-situ TRT in Harbin

2.1. Study region introduction

Harbin City is located in southwest of Heilongjiang Province of China and is the capital of the province. The geographic coordinates are longitude of 42′E-130°10′E and latitude of 44°04′N-46°40′N (Fig. 1).

The study region is marked in red in Fig. 1, and the land area is 1006 km^2. Based on exploration data, the ground layer mainly consists of silty clay, silt, fine sand, mudstone, and so on [36]. The groundwater aquifer system mainly consists of quaternary loose pore water system.

2.2. Boreholes distribution

In this study, 11 representative sites were selected to conduct TRT. The boreholes distribution is shown in Fig. 2. Two boreholes are 200 m deep, and nine boreholes are 110 m deep. All BHEs utilize U type pipes. Five boreholes utilize double-U pipes, and the others are single-U pipes. The annular space was grouted with a Bentonite–sand mixture. The pipes are made of high-density polyethylene (HDPE) materials. Shank spacing (distance between BHE pipes) is 12 cm. The physical and thermal properties of the HDPE pipes and the Bentonite–sand mixture utilized in the BHE installation are shown in Table 1.

2.3. TRT equipment

The equipment for TRT is certified by China Geological Survey. Fig. 3 shows the composition of the testing apparatus, including control host and testing system. The apparatus employs constant heat power to perform tests and a coil heater for heating. Constant heat flux is applied with BHE to the borehole while the data acquisition system records the inlet and outlet temperature of the pipe fluid, flow rate, and heating power at a certain time interval

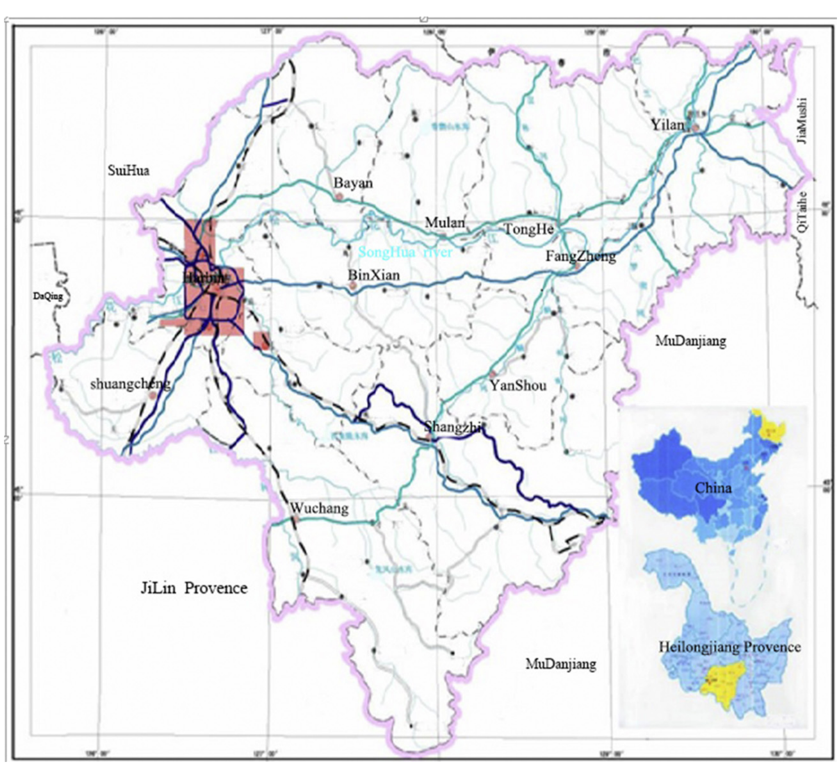

Fig. 1. Study region location.