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Heat transfer performance of buried extremely long ground-coupled heat exchangers with concentric pipes

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Abstract

This study focuses on the heat transfer between the vertical concentric tubes buried underground and the medium-deep rock-soil geothermal energy. The numerical simulation based on an in-house FORTRAN computation program was performed to analyze the mechanism of heat exchange underground. The program was shown to predict the test results of outlet water temperature and heat gain very well under the corresponding operating conditions when engineering data of an actual geothermal well were obtained to validate the numerical scheme. The effects of inlet water temperature and flow rate on the heat exchanger performance were also analyzed in detail. The comparison indicated that the present numerical scheme is able to predict the heat transfer performance of extremely long ground-coupled heat exchanger subject to various geothermal conditions.

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Keywords: Heat transfer performance; Concentric tube heat exchanger; FORTRAN program; Geothermal

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1. Introduction

As an important renewable resource, geothermal energy has drawn more and more attention due to its characters of clean and non-polluting (Capozza, et al., 2012). The investigation on the ground-coupled heat exchangers for the heating application has become a popular research topic. However, current works mainly focus on heat exchangers utilizing shallow geothermal (Li and Lai, 2015). When the depth increases, the concentric pipe heat exchanger allows water to flow in and out vertically to absorb heat from deep soils and rocks, which will be beneficial to saving space in the horizontal direction occupied by heat exchangers (Yang, et al., 2010) and the outlet water temperature could be increased for heat pumps and other applications. The extremely long ground-coupled heat exchanger obtains the heat mainly from deeper rock layer, which does not affect the balance of medium-deep geothermal storage (Soni, et al., 2015). Thus, it is necessary to study the heat transfer performance of concentric pipe heat exchangers for utilizing the medium-deep geothermal energy.

In this system, water is pumped into the outer pipe to absorb the heat from surrounding soils and rocks, which results in a temperature rise of the pumped water. The heated water returns to the ground through the inner pipe, which can be used as the heat source for various facilities such as heat pumps, as shown in Fig. 1. During the operating process, the outlet temperature of the water and the heat exchange between the tube and the rock-soil, which are the most concerned results in practical application, are affected by various parameters such as, the inlet water temperature, the flow rate of the water, operating method, size and thermal properties of the pipe, the environmental conditions and even the thermal properties and initial temperature distribution of the rock-soil. This study mainly focuses on evaluating the first three factors.

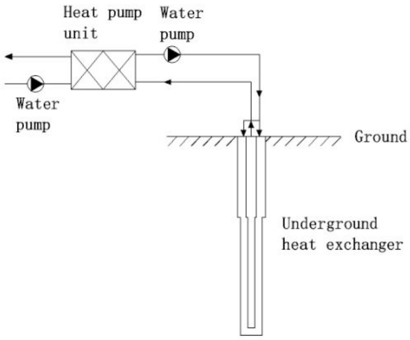

Fig. 1. Schematic diagram of the heat exchange system.

The heat transfer of ground-coupled heat exchanger involves in complex influential factors (Zhuang, et al., 2016). There is significant study and development in this field. Mei and Fischer (1983) did an experimental and analytical project to study the design of vertical concentric pipe ground-coupled heat exchanger. The length of the pipe was 47.7m and the diameter of the well was 0.2m. At the same time, a mathematical model was established and converted into FORTRAN computation program to simulate the operation of the system. After verifying its accuracy and reliability, the program was then used to study the effects of different variables on the performance of the heat exchanger. The results show that increasing the flow rate, the diameter of the outer casing and the length of the heat exchanger contributes to the design of a relative higher heat exchange, i.e., improve the heat exchange between the heat exchanger and the surrounding rock-soil.

2. FORTRAN computation program

There are several analytical approaches to study the thermal performance of the ground–coupled heat exchanger, including Kelvin's line-source model, infinite cylindrical source model and so on (Carotenuto, et al., 2014). In this study, a FORTRAN computation program was written to solve the model of the heat exchanger numerically. The program mainly contains four parts, whose contents and functions are introduced as following.