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Investigation of convective-conductive heat transfer in geothermal system

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ABSTRACT

Geothermal energy is one of the well-known types of renewable energies that can be considered as a promising alternative to fossil fuels in order to mitigate the CO_2 emission in atmosphere. Geothermal energy has recently been used for heating and cooling systems in many countries of the world. Therefore, studying such kind of energy seems important and necessary. This paper studies the heat transfer processes in a borehole heat exchanger (BHE). The flow of fluid in a BHE has been considered with different geometries and heat transfer processes are modeled numerically and in a finite volume method through convection and conductivity. First, a single U-shaped BHE was modeled and its thermal properties were investigated and then other geometries were studied to obtain the best geometry and heat transfer efficiency. In order to increase the heat transfer in the inner part of the pipes, the fin with the given specifications was used and the modeling was carried out and the thermal parameters were compared for three BHE's with different geometries. In the final part, optimization results are presented, and the interaction of parameters on the Nusselt number and friction coefficient have been investigated. Also, the desirability of optimization and reliability is given to the results presented in percentage terms. Comparing the results of this article with the results of previous research shows a very good agreement and therefore the applied method is reliable and accurate.

Introduction

Fossil fuels mortality, diversification into energy sources, sustainable development and energy security and environmental problems caused by the use of fossil fuels on the one hand and clean and renewable sources of new energy such as the sun, wind and geothermal on the other hand has caused the world's attention to develop and expand use of renewable energy and increase the share of those resources in the global energy basket. Geothermal energy means energy from the internal origin of the earth. This energy emanates from the inner part of the earth, in the form of tangible heat and there are rocks and water in the gaps and pores inside the rock in the earth's crust. Over the life of the earth, this internal heat is slowly produced and kept within the ground. This has made it an important source of energy and is now being considered as a new energy source.

In geothermal systems, geothermal wells and heat pumps are commonly known as geothermal Borehole Heat Exchanger (BHE). To design geothermal BHEs, the thermal conductivity of the earth and the thermal resistance of the well are required. Usually, the above parameters are estimated using the experimental Thermal Response Test (TRT) which for first time was proposed by Mogensen [1]. Subsequently, supplementary guides of the TRT are suggested by Ashrae [2] and Sanner et al. [3].

The topic of geothermal heat pumps has attracted much attention as a renewable energy technology and has been used for heating and cooling [4–6]. Recent studies have been conducted to study the efficiency of geothermal heat pump systems [7–9]. Li et al. [10] experimentally investigated the efficiency of a U-shaped vertical BHE in which, temperature changes and thermal equilibrium of the system have been numerically simulated and analyzed. Those results indicated that the geothermal source could be used as a fountain or thermal well for the geothermal heat pump system to achieve higher returns and more energy storage.

Karabacak et al. [11] investigated the cooling performance of the geothermal heat pump system in Denizli, Turkey experimentally. They accurately showed that the relations of the coefficients of operation of the geothermal heat pump were proportional to the weathering information, including solar radiation, wind speed, relative humidity and external temperature. Michopoulos et al. [12,13] studied the performance of a system installed in Greece for heating and cooling. Ozyurt et al. [14] experimentally studied the performance of vertical geothermal heat pumps for the assessment of cold weather in Turkey and the coefficient of heat pump performance and system performance were calculated. Hwang et al. [15] examined the cooling performance of the geothermal heat pump system installed in the building of a school in

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Nomenclature

g	Grout
L	Borehole depth
u	Refrigerant velocity
ρ	Fluid density
c	Specific heat of the fluid
λ	Fluid thermal conductivity
λ_g	Grout thermal conductivity
c_g	Grout specific thermal capacity
$b_{\alpha\beta}$	Thermal coefficient between two components
f	coefficient of friction
P	stepping of Fin
Nu	Nusselt number
t	Pipe thickness
Re	Reynolds number
DR	Diameter rate
D	Distance of the center of the two pipes
d	Pipe diameter
d_g	Diameter of grout

South Korea. They discussed the system's performance and the effects of outdoor temperature. Li and colleagues [16] analyzed the thermal resistance of vertical U-shaped BHEs in the cold regions of China. They provided a new solution that reduced the thermal resistance of U-shaped BHEs and increased thermal efficiency. They considered the model once insulated and again without insulation at the bottom of the exhaust pipe and studied numerically. They examined the isolation effect of the tube on the outlet temperature, the soil temperature, and the heat transfer rate per unit length of the pipe.

Lei et al. [17] investigated the inhomogeneity of energy production under different working conditions in low dual enthalpy geothermal systems. They used finite element method to model fluid flow and heat transfer over time.

Crooijmans et al. [18] studied the thermal efficiency of a BHE with centrifugal tubes. They calculated the distribution of fluid temperature and investigated the effect of the discharge flow of the inlet fluid, as well as the effect of the filler materials on the fluid temperature.

BniLam et al. [19] simulated the heat transfer in a U-shaped BHE, and analyzed it analytically. They performed discretization in the time domain and studied the effect of friction at different flow rates and in different viscosities. Akbar et al. [20] studied numerically the unstable flow of high enthalpy fluid in a geothermal BHE. They solved the governing equations with finite element method and investigated important physical phenomena along wells including phase change, compressibility and thermal interaction.

Regarding to the review of the research carrying out on the current subject matter and its applications in heating systems, electricity gen-

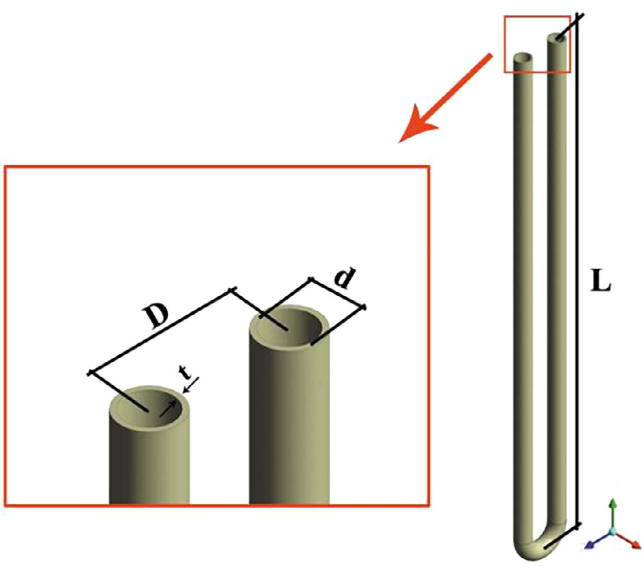

Fig. 1. U-type BHE geometry.

Table 1
U-type BHE dimensions.

Characteristic	Symbol	Size (mm)
Pipe Depth	L	1000
Inner pipe diameter	d	26
Distance of the center of the two pipes	D = 3d	78
Pipe thickness	t	2.9

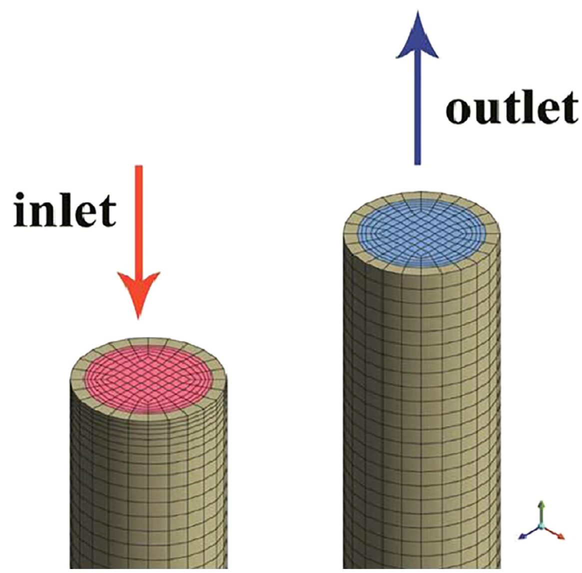

Fig. 2. Structured mesh used in the fluid and pipe area.

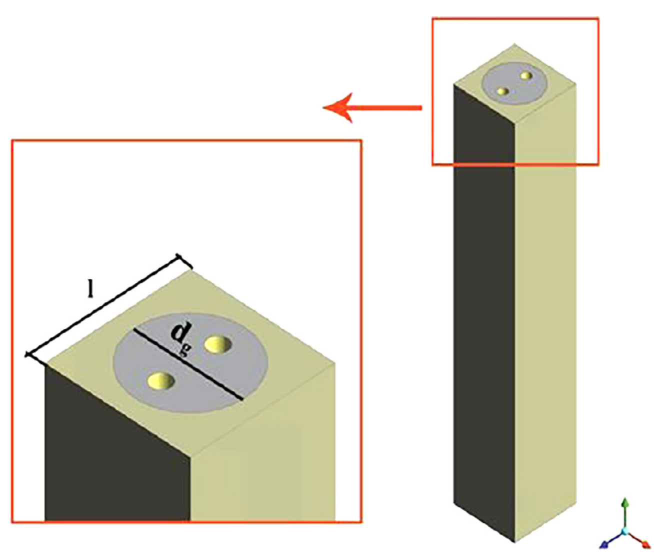

Fig. 3. Geothermal BHE, considering the parts of the grout and the surrounding soil.