Comparison of axial and radial soil temperature distribution in U-tube and coaxial borehole heat exchangers

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ABSTRACT

Dynamic variation of surrounding soil temperature in axial (depth) and radial directions of vertical type geothermal heat pump (GHP) heat exchangers are investigated here. This soil temperature distribution for borehole heat exchangers (BHE) plays an important role in thermal operation, electricity consumption and coefficient of performance of geothermal heat pump. Thus the transient 3 dimensional numerical modeling of U-tube and coaxial borehole heat exchangers are investigated to find the temperature distribution around the buried pipes. The simulation is performed using ANSYS FLUENT 16.0 software based on the finite volume method. The effects of various parameters are studied and modeling results for the cooling application of heat pump are obtained for different mass flow rates of condenser cooling water. Results show that the injection heat transfer rate to the ground in summer, in the coaxial borehole heat exchanger (CBHE) at mass flow rates of 0.8, 1, 1.2 kg/s are 5.34%, 11.9%, 16.5% higher than U-tube borehole heat exchanger (UTBHE) respectively. Moreover, after 93 days, the vertical temperature distribution of the soil for U-tube heat exchanger shows a significant variation mainly at depths less than 36.6 meters while the coaxial heat exchanger greatly affects the soil temperature distribution even in higher depths.

KEYWORDS

Borehole heat exchanger, U-tube heat exchanger, Coaxial heat exchanger, Geothermal heat pump, Soil temperature distribution

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1. Introduction

BHEs play an important role in the performance of GHPs and they are manufactured in two forms of horizontal and vertical structures. The former is more stable and have better performance compared to the latter. The most common types of BHEs with vertical structure are UTBHE and CBHE.

The temperature distribution in the surrounding soil has an important role in the performance of the BHEs and the GHP combined with it; because when the fluid flows through the BHE and exchanges heat with the ground, the temperature distribution in the surrounding soil varies gradually. This leads to gradual saturation of the ground and the reduction of heat transfer rate between the fluid and ground which cause an increase in the fluid temperature leaving the BHE at cooling mode. Finally, this temperature variation has an adverse effect on the coefficient of performance and the GHP performance. Moreover, the radius of ground affected during heat transfer is an important factor in determining the distance of the installation wells from each other and their arrangement; Therefore, the investigation of the soil temperature distribution around the BHEs are of great importance. A number of studies have been investigated the radial distribution of the temperature in the soil surrounding the BHEs [1, 2]. Comparison of soil temperature distribution around both CBHE and UTBHE has not been studied so far, so in this paper, first, considering the initial temperature profiles for the ground in summer, the effects of both intended BHEs on soil temperature distribution have been studied and compared, and parameters such as soil temperature distribution in both horizontal and vertical directions, depth and radius of effect of two BHEs in the soil and their impact on the positioning of installation wells relative to each other and the ground temperature variation are also studied. The results of this simulation can be used as a guideline for selecting the right BHE.

2. Simulation of fluid flow in UTBHE and CBHE

The high density polyethylene tubes and of SDR 11 type have been chosen for both BHEs whose dimensions are based on the DIN8074 standard [3] as described in Table 1 with other required parameters.

Table 1. Parameters of CBHE and UTBHE

Parameter	value
Outer pipe of CBHE	160×14.6 mm
Inner pipe of CBHE	50×4.6 mm
Pipe of UTBHE	50×4.6 mm
Shank spacing	55 mm
BHE depth	100 m
Thermal conductivity of pipe	0.44 W/(m. K)
Thermal conductivity of grout	1.6 W/(m. K)
Thermal conductivity of ground	2.8 W/(m. K)
Inlet temperature	307.2 K
Inlet mass flow rate	0.8,1,1.2 kg/s

3-D transient simulation for both vertical tube configurations is conducted based on the control volume method. In this study, fluid flow is considered turbulent, so the Navier-Stokes equations with the k-ε turbulence model are solved that are expressed in Eqs. (1) to (5).

$$\frac{\partial \overline{u_i}}{\partial x_i}=0 \qquad (1)$$

$$\frac{\partial \overline{u_i}}{\partial t}+\overline{u_j}\frac{\partial \overline{u_i}}{\partial x_j}=-\frac{1}{\rho}\frac{\partial \overline{P}}{\partial x_i}+\nu\nabla^2\overline{u_i}-\frac{\partial(\overline{u_i^{'}u_j^{'}})}{\partial x_j} \qquad (2)$$

$$\frac{\partial \overline{T}}{\partial t}+\overline{u_j}\frac{\partial \overline{T}}{\partial x_j}=\alpha\nabla^2\overline{T}-\frac{\partial(\overline{u_j^{'}T^{'}})}{\partial x_j} \qquad (3)$$

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho k\overline{u_i})}{\partial x_i}=\frac{\partial}{\partial x_j}[(\mu+\frac{\mu_t}{\sigma_k})\frac{\partial k}{\partial x_j}]+G_k+G_b-\rho\varepsilon+S_k \qquad (4)$$

$$\frac{\partial(\rho\varepsilon)}{\partial t}+\frac{\partial(\rho\varepsilon\overline{u_i})}{\partial x_i}=\frac{\partial}{\partial x_j}[(\mu+\frac{\mu_t}{\sigma_\varepsilon})\frac{\partial \varepsilon}{\partial x_j}]+G_{1\varepsilon}\frac{\varepsilon}{k}(G_k+G_{3\varepsilon}G_b)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}+S_\varepsilon \qquad (5)$$

The inlet boundary condition (BC) for the fluid flow is assumed as Mass flow inlet, and for the outlet boundary condition as the pressure outlet.

The energy equations for the ground, grout and pipes is expressed by Eq. (6)

$$\frac{\partial T}{\partial t}=\alpha\nabla^2 T \qquad (6)$$

The temperature distribution shown in Fig. 1 is considered as the far-field BC of the ground.

The simulation of CBHE and UTBHE is carried out as axisymmetric and symmetry, respectively. The realizable model and standard wall function are used for solving the k-ε equations. The SIMPLE scheme is considered for coupling of velocity and pressure fields. The pressure and momentum equations are discretized using the second order and second order upwind schemes, respectively, and first order upwind scheme is applied for discretization of the equations related to the turbulent kinetic energy and turbulent dissipation rate. The convergence criterion value for the energy equation is assumed to be 10^{-6}, and 10^{-3} for the continuity, momentum, and k-ε equations. Finally, the equations are solved based on finite volume method in the transient and implicit mode for 93-day period.

3. Results and discussion

3.1. Ground temperature variation from the surface to 100 m depth

Fig. 1 shows the soil temperature distribution within a distance 0.5m from the center of the BHEs considering the mass flow rate of 0.8 kg/s. In some areas of radial distance, the rise in the temperature of the Ground has reached more than four degrees. By comparing the effect of both heat exchangers on soil temperature distribution, it is observed that the CBHE has more tangible effects on augmentation of the ground temperature, especially in the deep regions, but UTBHE shows a significant variation mainly at depths less than 36.6 meters.

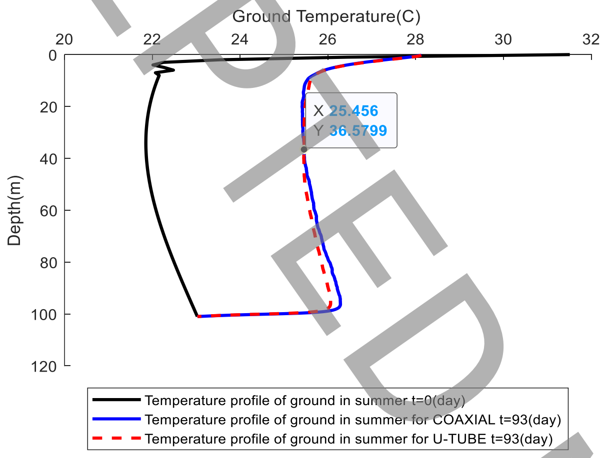

Fig 1. Temperature distribution of soil from surface to 100 m depth

3.2. Ground temperature variation at depth 20m from the surface in radial direction

Fig. 2 shows the distribution of the soil temperature at a depth of 20 m from the ground surface at different times. As shown in Fig. 2, the areas close to the BHEs are more affected by heat transfer, so they have higher temperature. As we get away from the BHE, the effect of the BHE on the distribution of the soil temperature is reduced. Over time the temperature of the points in the vicinity of the well wall increases and changes in the distribution of the soil temperature gradually decreases, but the radius of the ground that is affected by heat transfer increases. It is observed that at a certain time, the soil temperature distribution for the UTHE reaches higher values in comparison to that of the CBHE.

3.2. Ground temperature variation at depth 80 from the surface in radial direction

Fig. 3 shows the distribution of the soil temperature at a depth of 80 m from the ground surface at different times. It is observed that at a certain time, the soil temperature distribution for the CBHE reaches higher values in comparison to that of the UTHE.

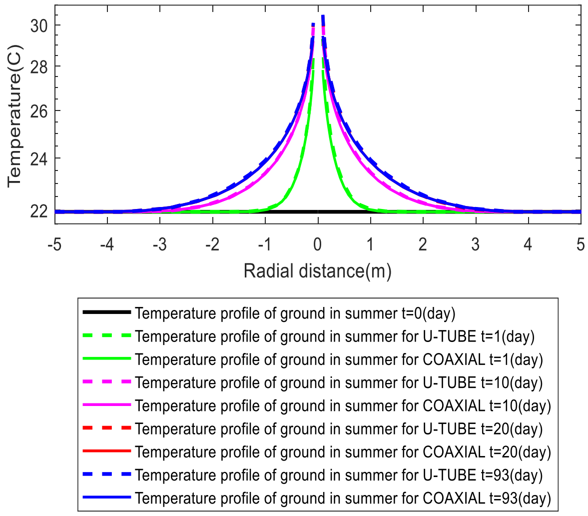

Fig 2. Temperature distribution of soil at depth 20 m

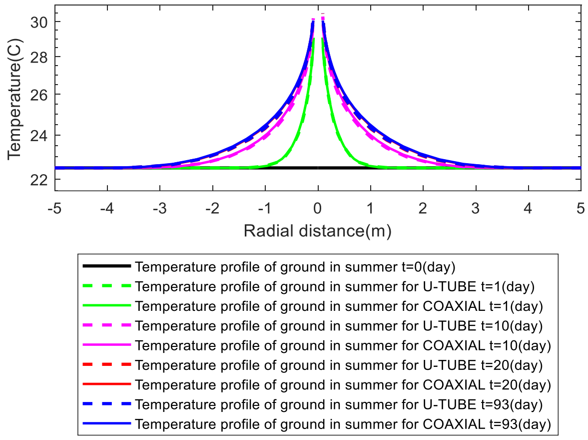

Fig 3. Temperature distribution of soil at depth 80 m

4. Conclusion

After 93 days, the vertical temperature distribution of the soil for UTBHE shows a significant variation mainly at depths less than 36.6 meters while the vertical temperature variation with CBHE is significant even in higher depths. As the radius of the ground is affected by two BHEs is almost identical, so the distance and the arrangement of wells to install these two types of BHEs will also be the same.

5. References

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