Study on finned pipe performance as a ground heat exchanger

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Abstract. The GHEs (ground heat exchangers) is an important element that determines the thermal efficiency of the entire ground-source heat-pump system. The aim of the present study is to clarify thermal performance of a new type GHE pipe, which consists straight fins of uniform cross sectional area. In this paper, GHE model is introduced and an analytical model of new type GHE pipe is developed. The heat exchange rate of BHEs utilizing finned pips is 40.42 W/m, which is 16.3% higher than normal BHEs, based on simulation analyses.

1. Introduction

In the recent decades, energy consumption for building sector has increased in multifold around the world [1]. Efforts are being made to develop alternate energy sources for meeting the demand of building heating and cooling loads. One of the best alternate ways is the use of nature source energy.

Geothermal energy is regarded as one of the most efficient forms of energy, and it has great potential as it is directly usable. At deeper layers, the ground temperature remains almost constant throughout the year and is usually higher than that of the ambient air during the cold months of the year and lower during the warm months, as shown in Fig.1.

A ground-source heat-pump (GSHP) system combined with GHEs (ground heat exchangers) absorbs and extracts geothermal energy for space heating and cooling. The GHE is an important element that determines the thermal efficiency and initial construction cost of the entire GSHP system. It is important to lower initial construction cost by improving thermal performance of GHE.

Heat transfer through GHE pipe is closely related to the heat transfer between the fluid that circulates within the GHE pipe and the complex medium (grout/ground).It is well known that the ground thermal conductivity and borehole thermal resistance are among the most important parameters in the design of a GSHP system.

The borehole thermal resistance can be decreased by increasing the thermal conductivity of the grout and the GHE pipe, and by optimizing the type of pipe used and the pipe configuration [2-3].

In the present study, the thermal performance of a new

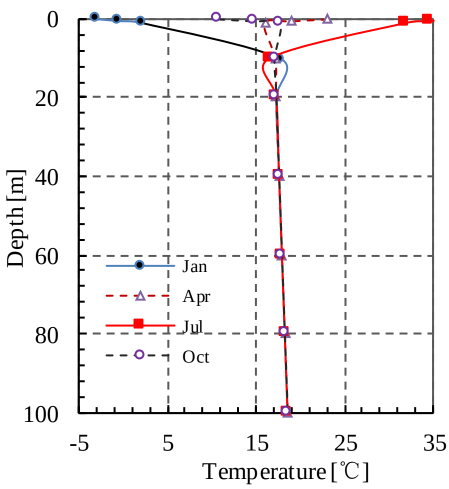


Fig.1 The he ground temperature distribution

type GHE pipe is clarified to determine its applicability as a ground heat exchanger. In this paper, the configuration of new type GHE and analytical model are introduced.

2. Configuration in borehole and model description

The new type GHE pipe is polybutylene (PB) consisting straight fins of uniform cross sectional area, and double U-tubes BHE is considered as shown in Fig.2. The depth of borehole is 80m.

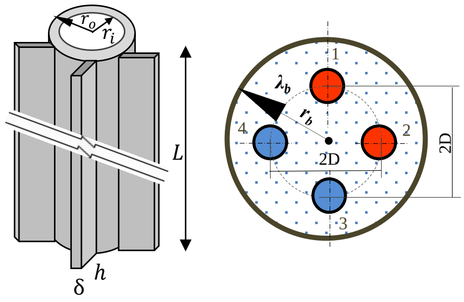


Fig.2 Configuration of doubles U-tubes in a borehole.

2.1. Model description

Quasi-Three-Dimensional model and finite line-source models are used in this study.In addition, fin efficiency methods is used to calculate heat conduction through fins of PB pipe, as shown in Table1.

The following assumptions are made:

- Soil is isotropic and homogeneous.

Table.1 Simulation models

$$\left.\begin{aligned}
-Mc_p\frac{dT_{f1}(z)}{d(z)} &= \frac{T_{f1}(z)-T_b(z)}{R_{11}^{\Delta}}+\frac{T_{f1}(z)-T_{f2}(z)}{R_{12}^{\Delta}}+\frac{T_{f1}(z)-T_{f3}(z)}{R_{13}^{\Delta}}+\frac{T_{f1}(z)-T_{f4}(z)}{R_{12}^{\Delta}}\\
-Mc_p\frac{dT_{f2}(z)}{d(z)} &= \frac{T_{f2}(z)-T_{f1}(z)}{R_{12}^{\Delta}}+\frac{T_{f2}(z)-T_b(z)}{R_{11}^{\Delta}}+\frac{T_{f2}(z)-T_{f3}(z)}{R_{12}^{\Delta}}+\frac{T_{f2}(z)-T_{f4}(z)}{R_{13}^{\Delta}}\\
Mc_p\frac{dT_{f3}(z)}{d(z)} &= \frac{T_{f3}(z)-T_{f1}(z)}{R_{13}^{\Delta}}+\frac{T_{f3}(z)-T_{f2}(z)}{R_{12}^{\Delta}}+\frac{T_{f3}(z)-T_b(z)}{R_{11}^{\Delta}}+\frac{T_{f3}(z)-T_{f4}(z)}{R_{12}^{\Delta}}\\
Mc_p\frac{dT_{f4}(z)}{d(z)} &= \frac{T_{f4}(z)-T_{f1}(z)}{R_{12}^{\Delta}}+\frac{T_{f4}(z)-T_{f2}(z)}{R_{13}^{\Delta}}+\frac{T_{f4}(z)-T_{f3}(z)}{R_{12}^{\Delta}}+\frac{T_{f4}(z)-T_b(z)}{R_{11}^{\Delta}}
\end{aligned}\right\}\quad(1)$$

$$\left.\begin{aligned}
R_{11} &= \frac{1}{2\pi\lambda_b}\left[\ln\left(\frac{r_b}{r_o}\right)-\frac{\lambda_b-\lambda_s}{\lambda_b+\lambda_s}\ln\left(\frac{r_b^2-D^2}{r_b^2}\right)\right]+R_p\\
R_{12} &= \frac{1}{2\pi\lambda_b}\left[\ln\left(\frac{r_b}{\sqrt{2}D}\right)-\frac{\lambda_b-\lambda_s}{2(\lambda_b+\lambda_s)}\ln\left(\frac{r_b^2+D^2}{r_b^4}\right)\right]\\
R_{13} &= \frac{1}{2\pi\lambda_b}\left[\ln\left(\frac{r_b}{2D}\right)-\frac{\lambda_b-\lambda_s}{\lambda_b+\lambda_s}\ln\left(\frac{r_b^2+D^2}{r_b^2}\right)\right]\\
R_P &= \frac{1}{2\pi\lambda_p}\ln\left(\frac{r_o}{r_i}\right)+\frac{1}{2\pi r_i h_f}+\frac{1}{2\pi r_i h_s}
\end{aligned}\right\}\quad(2)$$

$$\left.\begin{aligned}
&R_{ij}^{\Delta}=R_{ji}^{\Delta},\ R_{ii}^{\Delta}=R_{jj}^{\Delta}\,(i,j=1,2,3,4)\\
&R_{11}^{\Delta}=R_{22}^{\Delta}=R_{33}^{\Delta}=R_{44}^{\Delta}=R_{11}+R_{13}+2R_{12}\\
&R_{12}^{\Delta}=R_{21}^{\Delta}=R_{14}^{\Delta}=R_{41}^{\Delta}=R_{23}^{\Delta}=R_{32}^{\Delta}=R_{34}^{\Delta}=R_{43}^{\Delta}\\
&=\frac{R_{11}^{\ 2}+R_{13}^{\ 2}+2R_{11}R_{13}-4R_{12}^{\ 2}}{R_{12}}\\
&R_{13}^{\Delta}=R_{31}^{\Delta}=R_{24}^{\Delta}=R_{42}^{\Delta}\\
&=\frac{(R_{11}-R_{13})(R_{11}^{\ 2}+R_{13}^{\ 2}+2R_{11}R_{13}-4R_{12}^{\ 2})}{R_{13}^{\ 2}+R_{11}R_{13}-2R_{12}^{\ 2}}
\end{aligned}\right\}\quad(3)$$

$$\left.\begin{aligned}
-Mc_p\frac{d\theta_1(z)}{d(z)} &= \frac{\theta_1(z)}{R_{11}^{\Delta}}+\frac{(R_{12}^{\Delta}+R_{13}^{\Delta})}{R_{12}^{\Delta}\bullet R_{13}^{\Delta}}(\theta_1(z)-\theta_3(z))\\
+Mc_p\frac{d\theta_3(z)}{d(z)} &= \frac{\theta_3(z)}{R_{11}^{\Delta}}+\frac{(R_{12}^{\Delta}+R_{13}^{\Delta})}{R_{12}^{\Delta}\bullet R_{13}^{\Delta}}(\theta_3(z)-\theta_1(z))
\end{aligned}\right\}\quad(4)$$

$$\left.\begin{aligned}
-\frac{d\theta_1(z)}{d(z)} &= A\theta_1(z)+B(\theta_1(z)-\theta_3(z))\\
\frac{d\theta_3(z)}{d(z)} &= A\theta_3(z)+B(\theta_3(z)-\theta_1(z))
\end{aligned}\right\}\quad(5)$$

$$A=\frac{1}{R_{11}^{\Delta}\bullet Mc_p},\ B=\frac{(R_{12}^{\Delta}+R_{13}^{\Delta})}{(R_{12}^{\Delta}\bullet R_{13}^{\Delta})\bullet Mc_p}$$

$$\eta_f=\frac{th\left(mh_f\right)}{mh};\quad m=\sqrt{\frac{h_f U}{\lambda A_L}};\quad U=2\left(L+\delta\right);\ \ A_L=L\delta;$$

$$R_{P\_f}=\frac{1}{2\pi r_i h_f}+\frac{1}{2\pi\lambda_p}\ln\left(\frac{r_o}{r_i}\right)+\frac{1}{[(2\pi r_i-n\delta)+\eta(2n(h+\delta/2))]h_s}$$

r_i, r_o : *Inner radius of U-tube, Outer radius of U-tube.* $[m]$

r_b : *Borehole radius.* $[m]$

$2D$: *U-tube spacing.* $[m]$

λ_s : *Thermal conductivity of soil.* $[W/(m\,K)]$

λ_b : *Thermal conductivity of backfill material.* $[W/(mK)]$

λ_p : *Thermal conductivity of U-tube.* $[W/(m\,K)]$

h : *Convective heat transfer coefficient.* $[W/(m^2\,K)]$

h_s : *Heat transfer coefficient at outside of U-tube.* $[W/(m^2\,K)]$

M : *fluid mass flow rate in U-tube.* $[kg/s]$

c_p : *Heat capacity of circulating water.* $[J/(kg\,K)]$

R_{p_f} : *thethermal resistance of finned pipe.* $[W/mK]$

R_p : *thethermal resistance of pipe.* $[W/mK]$

n : *the number of fins*

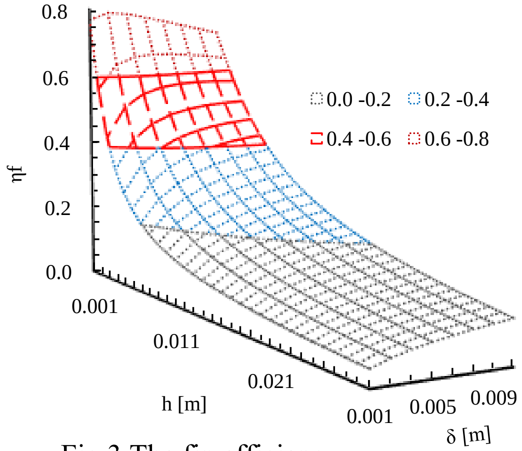


Fig.3 The fin efficiency.

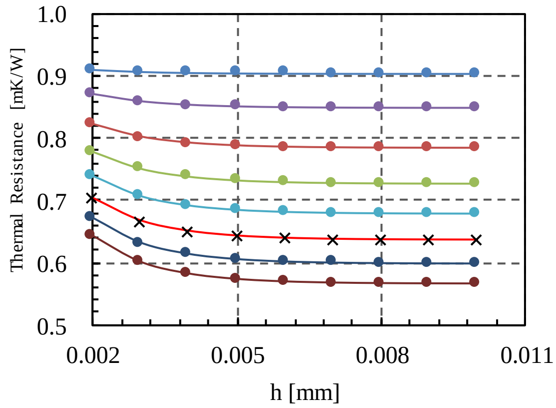


Fig.4 The thermal resistance of finned pipe Rp_f

Table.2 Geometrical parameters and properties of materials

ri	13	[mm]	*λs*	2.07	[W/mK]
ro	16	[mm]	*λp*	0.05	[W/mK]
rb	300	[mm]	*λb*	2.34	[W/mK]
M	0.3	[kg/s]			

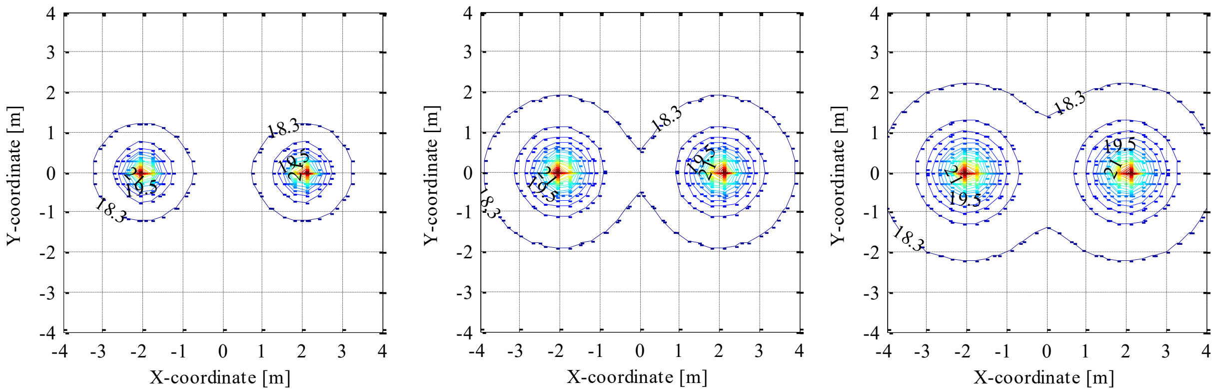
- The effects of groundwater movement have been assumed as insignificant.
- The temperature distribution along the vertical direction has a negligible influence.
- There is no contact resistance between the boreholes and the ground.
- The fluid temperature in the BHEs is determined as average of inlet and outlet temperature.
- A uniform initial temperature of 18.2 Degree C is equal to the undisturbed ground temperature.

Table.2 shows the Geometrical parameters and properties of materials and so on.

3. Results and conclusions

3.1. Optimizing fin size for GHE pipe

Fig.3 shows the fin efficiency of PB pipe at various fin length h and thickness δ. Out radius of Pipe r_o is16 mm, λ_p=0.05 W/mK. It is clearly seen that the fin length affects the fin efficiency is stronger than fin thickness. It is noticed that increment of fin length causes rapid decrement on the fin efficiency of pipe. Fig.4 shows the relationship between the thermal resistances of finned pipe Rp_f and the number



a (2days) b (5days) c (7days)

Fig.5 Comparison of temperature distribution at various times for 2 BHEs with fined pips of fins, under the condition of fin thickness 3mm. It is clear that increment of fin number causes lower thermal resistances.

The fin length 5mm,fin thickness 3mm and the fin's number 20 are selected, the fin efficiency of pipe is 0.57, considering manufacturing process requirements, in this paper.

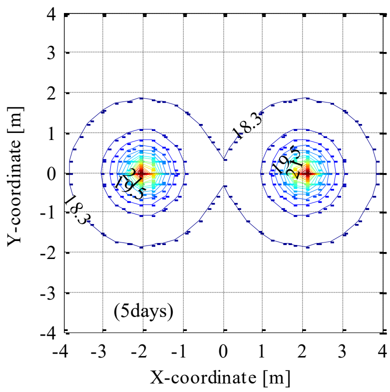


Fig.6 Temperature distribution for 2 BHEs without finned pips

3.2. Temperature distribution around 2BHEs at various times

Fig.5 shows the temperature distribution for 2 BHEs with finned pips in the ground at the end of 2, 5,7days under condition of inlet temperature 35 degree C and ground temperature 18.2 degree C.

It is obvious from these figures that the ground temperature is raised by the time. It can also be noticed that the temperature response at any location keeps rising. The heat exchange rate is 40.42 W/m.

Fig.5 (b) shows the temperature distribution in the ground for 2 BHEs with finned pipes after 5days. Comparing to Fig.6, It is clearly seen that the configurations which utilize finned pipes with the same distance have more thermal interaction between boreholes. The reason is that the heat exchange rate of BHEs with finned pips is 40.42 W/m, which is 16.3% higher than normal BHEs.

Acknowledgment

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