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Original article

A new idea for improving the horizontal straight ground source heat exchangers performance

Rahim Hassanzadeh*, Mohsen Darvishyadegari, Samaneh Arman

Department of Mechanical Engineering, Urmia University of Technology, Urmia, Iran

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ABSTRACT

This paper presents a new idea for dissipating the higher amounts of thermal energy with enhanced horizontal straight ground source heat exchangers (GSHEs) comparing to the conventional GSHEs. For this purpose, the buried pipes were integrated with longitudinal galvanized bridges having the thickness and height of 2.5 mm and 117.5 cm within the ground, respectively. Several scenarios were examined in terms of the number and location of the bridges around the pipes. Attentions were attracted to three different soil types having thermal conductivities of 0.35 (soil I), 1.26 (soil II), and 2.60 (soil III) W/mK. On the other hand, different ambient air conditions on the ground were considered in order to extend the obtained results for various climates. It was found that once the buried pipes of GSHEs were equipped with galvanized bridges, the rate of heat transfer between the pipes and ground enhances significantly in comparison to the conventional GSHEs. It was demonstrated that the applied method for heat transfer enhancement was more effective for lower conductivity soils in comparison to soils with higher conductivities. Finally, maximum enhancements in the thermal energy dissipation of 90.46%, 28.84%, and 12.58% were determined for soil I, soil II, and soil III, respectively.

Introduction

After years, GSHEs are now the popular systems for heat extraction (or dissipation) in different thermal applicants. The idea behind the GSHEs is imagining of earth as an infinite heat source or sink. Although, among the different applications of GSHE, the heat pump is maybe the famous one, however, during the past decades, they found various industrial applications except the heat pumps. Certainly, the GSHEs will be found the other applications in near future due to restriction in fossil fuel resources, climate changes, carbon emission, and air pollution of current systems. The use of the GSHEs for heat extraction (or dissipation) is one of the ways that decreases the carbon emission along with minimum environmental effects. They are made in two different models, namely, horizontal and vertical GSHEs in which each of them has advantages and disadvantages compared with each other. Although, performing the horizontal GSHE is easier and cost effective compared with vertical one, however, the low capacity of such horizontal system is a great challenge for designers. In the past decade, numerous studies have been published on the horizontal GSHEs. Some of them will be reviewed in this section. Most of the previous researches regarding the horizontal GSHEs were on the pipe layouts and related material effects. For instance, Kim et al. [1] revealed that coil type horizontal GSHE has 10–11% higher thermal performance than the slinky type. In addition, the type of the GSHE and the soil conductivity plays important roles on the heat extraction rate, whereas the pipe diameter has not effective role in this process. Congedo et al. [2] found that the helical layout of the pipes has the best performance among the configurations under consideration such as the coil and straight ones. In addition, working fluid velocity and soil conductivity are the parameters which show important influences on the heat exchanger performance. Kupiec et al. [3] presented a research work on the heat transfer process in horizontal GSHEs. They indicated that after about 10 years operation, the ground temperature reaches a cyclic steady state condition. In another work, Dasare and Saha [4] confirmed that soil type and flow rate of the working fluid affect the GSHE performance while the installation depth (buried depth) has no effective role in heat transfer process. Yoon et al. [5] demonstrated that among the various configurations for GSHE pipes, "U" type shows a better thermal performance compared with the slinky and coil types. In a similar work, Wu et al. [6] compared two pipe layouts, namely straight and slinky types. They found that the specific heat of the straight heat exchanger after 140hr is more than that of the slinky one. However, the heat extraction per meter of the soil is significantly higher for slinky heat exchanger compared to the straight type. Li et al. [7] presented a sensitivity analysis and operation characteristics for spiral-coil type horizontal GSHEs. They indicated that among the effective parameters

* Corresponding author.
E-mail address: r.hassanzadeh@uut.ac.ir (R. Hassanzadeh).

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Nomenclature

c_p	Specific heat
D	Pipe diameter
E	Energy transferred per pipe length
h	Heat transfer coefficient
k	Conductivity
q	Heat dissipation flux
T	Temperature
TP	Thermal performance
R	Pipe inner radius
t	Time
x	Horizontal coordinate
y	Vertical coordinate

Greek symbols

α	Thermal diffusivity
ρ	Density

Subscripts

1	Pipe
2	Bridge
a	Ambient air
b	Conventional case (non-bridged scenario)
d	Bottom boundary
in	Inner surface
o	Outside
sw	Symmetric wall

on the GSHE performance, the soil conductivity as well as the pipes distance are main factors.

Application of the horizontal GSHEs for large amount of heat exchange rate needs a huge area to bury the required pipes. This restriction causes that the application of the horizontal GSHEs becomes impossible, especially in urban environments for large thermal systems. There are some restricted attempts which try to improve the thermal performance of the horizontal GSHEs. For example; Gao et al. [8] used rainwater harvesting techniques for improving the horizontal GSHEs performance. Their method was based on the increasing the moisture level within the ground at which the GSHE was constructed. Bassiouny et al. [9] used a new idea for enhancing the thermal performance of the GSHEs. They used aluminum wires in the conventional polyethylene pipe thickness. The number and diameter of applied wires were investigated in their works. It was demonstrated that maximum 25% and 150% enhancements were obtained for equivalent thermal conductivity of the polyethylene pipes with 2 mm and 3 mm wires, respectively. Selamat et al. [10] compared different pipes for a horizontal GSHE and found that copper pipe has 16% higher efficiency than that of the conventional polyethylene pipe.

This paper presents an innovative method for enhancing the rate of heat transfer between the buried pipes and the ground. The idea is exerting the galvanized bridges around the pipes in order to increase the thermal diffusion within the ground. Certainly, due to small dimension and inexpensive material of the applied bridges, this idea can be as a cost effective method in comparison to the total cost of the GSHEs. There are different ways for polyethylene pipe-galvanized bridges connection in the soil, but, this study is not considered the methods of this issue. Therefore, theoretically, it was assumed that there is the thermal equilibrium in connection points. For convenience, the computations are performed in two-dimensions since the scope of the present study is focusing on the rate of thermal diffusion in the ground from the buried pipes of horizontal GSHEs. In fact, this paper is an attempt to reduce the needed ground area with a new method in which the polyethylene pipes equipped with galvanized thermal bridges will be assessed and compared with that of the conventional GSHE made with polyethylene pipes. It is hoped the obtained results arouse interest among the GSHEs designers since it enhances significantly the rate of the heat exchange in horizontal straight GSHEs.

Problem description and analysis procedure

In this study, a two-dimensional numerical method based on the finite volume approach was performed for analysis the thermal performance of a horizontal straight GSHE with and without the thermal bridges. For this purpose, a computational domain as Fig. 1 was defined for the problem. The computational media was consisted of a polyethylene pipe with 5 cm nominal diameter and 0.5 cm thickness. The installation depth of the pipe was 1.2 m from the ground surface and the distance from the pipe center to the bottom boundary was 2.8 m [6]. Furthermore, the center to center distance between the two neighboring pipes was set to 2.4 m. A layer of asphalt with thickness of 5 cm was considered on the ground surface. In order to show the effects of soil conductivity on the performance of enhanced horizontal straight GSHE, three various soils having the thermal conductivities of 0.35, 1.24, and 2.60 W/mK were considered in the present work. Table 1 indicates detail of the applied materials in this investigation. The all applied galvanized bridges were same in dimensions and properties with 2.5 mm thickness and 117.5 cm length. The first challenge in the implementation of the thermal bridge was the location of the bridge around the pipe within the soil. Hence, several scenarios were considered for the number and location of the bridges around the buried pipe. Fig. 2 illustrates the various scenarios under consideration. The red colored sections indicate the existence of the thermal bridges. Therefore, in the case-0, there was no bridge around the pipe and indicates the conventional horizontal GSHE system. This case was considered only for comparison purposes. In the case-1, case-2, and case 3, only a single thermal bridge was located in the upper, lower, and lateral side of the pipe, respectively. The double-bridge scenarios were seen in

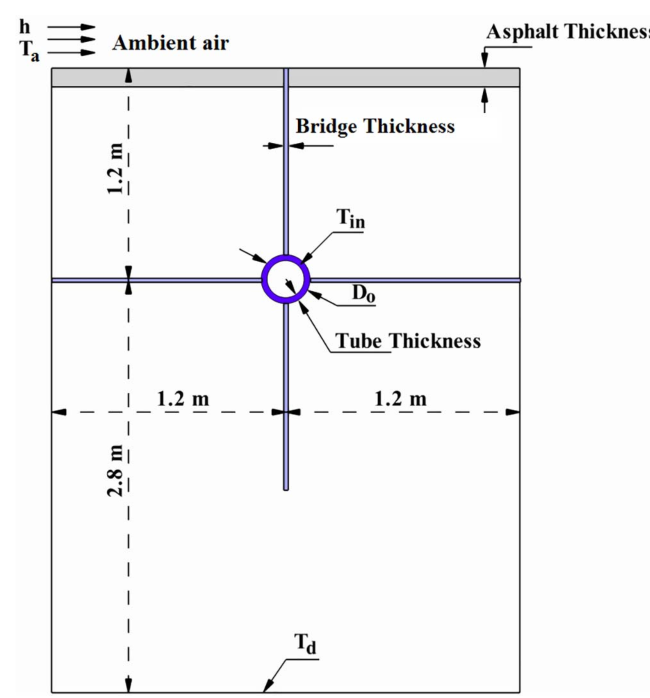

Fig. 1. The computational domain applied in the present study.