Applied Thermal Engineering 85 (2015) 252–263

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research paper

Numerical study of horizontal ground heat exchanger for high energy demand applications

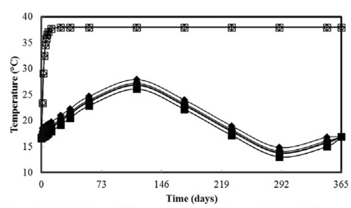
Ranjeet R. Dasare, Sandip K. Saha*

Department of Mechanical Engineering, Indian Institute of Technology, Bombay, Mumbai 400076, India

HIGHLIGHTS

- Design methodology of ground heat exchanger for high energy-demand applications.
- Heat transfer fluid velocity affects the amount of heat exchanged with soil.
- Installation depth negligibly affects thermal performance of ground heat exchanger.
- Distance between two layers of double layered heat exchanger affects performance.
- Combination of horizontal-vertical ground heat exchanger design concept introduced.

GRAPHICAL ABSTRACT



Legends: (a) ◊: D_l= 1 m, d_s= 0.1 m, p= 0.1 m, u_{in}= 1 m/s; □: D_l= 1 m, d_s= 0.2 m, p = 0.2 m, u_{in}= 1 m/s; Δ: D_l= 1.2 m, d_s= 0.1 m, p=0.2 m, u_{in}= 1 m/s; ×: D_l= 1.2 m, d_s= 0.1 m, p= 0.2 m, u_{in}= 0.5 m/s; o: D_l= 1.2 m, d_s= 0.1 m, p= 0.2 m, u_{in}= 0.25 m/s; +: D_l= 1.2 m, d_s= 0.2 m, p= 0.2 m, u_{in}= 1 m/s; •: D_l= 1.2 m, d_s=0.2 m, p= 0.3 m, u_{in}= 1 m/s; ♦: D_l= 1.2 m, d_s=0.2 m, p= 0.3 m, u_{in}= 0.25 m/s; ■: D_l= 1.5 m, d_s= 0.2 m, p= 0.2 m, u_{in}= 1 m/s

Figure: Midpoint temperature between two layers for a year of operation for different double helical ground heat exchanger temperature variation with time

ARTICLE INFO

Article history:
Received 31 October 2014
Accepted 4 April 2015
Available online 18 April 2015

Keywords:
Horizontal ground heat exchanger
Design methodology
Double layer
Ground heat exchanger

ABSTRACT

In this paper, a method of designing horizontal ground heat exchanger for high energy demand applications is presented as the role of ground heat exchangers on the performance of the ground source heat pumps (GSHP) is very critical. A numerical model was developed and validated to predict the thermal performance of various types of ground heat exchangers. A parametric study was performed to identify the important factors affecting the thermal performance of the ground heat exchanger. It was found that thermal conductivity of soil plays a vital role in the heat transfer process. The heat transfer fluid velocity, thereby mass flow rate was an important parameter affecting the amount of heat exchanged with soil. The depth of installation was found to have negligible effect on the thermal performance of ground heat exchangers. A novel design concept was introduced for designing ground heat exchanger for high energy applications for given foot print area and the mean thermal energy dissipation with low cost of installation. The new configuration can be considered as the combination of horizontal and vertical ground heat exchanger.

1. Introduction

In today's world, the use of fossil fuel energy resources has degrading effect on earth's atmosphere resulting from their combustion. This adds to the greenhouse gases apart from the expenses incurred towards the fuel. In order to overcome these drawbacks, it is imperative to invent alternative technologies which can generate energy in more efficient and clean way. Typically, in developed countries, major portion of energy is consumed for heating and cooling of living spaces [1]. This impacts the total energy demand in greater depth and thus adds to total pollution [1]. In this context, renewable energy is considered to be one such

* Corresponding author. Tel.: +91 22 25767392; fax: +91 22 2572 6875.
E-mail address: sandip.saha@iitb.ac.in (S.K. Saha).

http://dx.doi.org/10.1016/j.applthermaleng.2015.04.014
1359-4311/

Nomenclature

a	half difference between the maximum and minimum temperature on the soil surface in the year, °C
d	pipe diameter, m
d_s	spire diameter, m
d_p	depth of ground heat exchanger, m
D_l	distance between two layers, m
DT	amplitude of annual surface temperature, °C
E_{mte}	mean thermal energy, kWh
H	height, m
L	length, m
Re_d	Reynolds number based on pipe diameter
c_p	specific heat, J/kg K
EWT	entry water temperature, °C
k	thermal conductivity, W/m K
$\dot{m}$	mass flow rate of heat transfer fluid, kg/s
p	pitch, m
P	pressure, Pa
q''	heat flux, W/m^2
T	temperature, °C or K
T_{in}	heat transfer fluid inlet temperature, °C
T_∞	soil temperature, °C
T_{out}	heat transfer fluid outlet temperature, °C
T_M	annual average soil surface temperature, °C
t	time, s or days
t_M	time at which maximum temperature occurs on the ground, s or days
u_i	velocity components in x, y and z directions
u_{in}	inlet velocity of heat transfer fluid, m/s
W	width, m
x, y, z	coordinate axes

Greek symbol:

α	thermal diffusivity, m^2/day
ρ	density, kg/m^3
ϕ	phase angle
ν	kinematic viscosity, m^2/s
ω	frequency, radian/s
τ	period under consideration

important resource which can be used to generate electric power, heating and cooling of living spaces etc. [1]. In the area of heating and cooling of buildings, the alternate way to increase COP and reduction in greenhouse gases is by utilizing the heat storing capability of the ground [2]. Ground source heat pump system (GSHP) is a very efficient relatively newer technology that uses less variable soil temperature to provide efficient living space conditioning. The device, known as ground heat exchanger, through which heat is exchanged with the ground is of typical interest to the researchers today since it offers cost effective performance of the system [1]. To bring this technology into actual practice, the study of ground heat exchanger began by installing the first prototype in 1945 in USA [1]. This model was successful in showing the advantages of such innovative ways of energy savings. In the ground heat exchanger application, the heat storage capability of soil is exploited to increase the efficiency of the traditional heating, ventilation and air conditioning (HVAC) systems. This was demonstrated by many research works either experimentally or numerically [3].

The different types of GSHPs are open loop and closed loop heat exchanger, ground coupled or direct expansion loop configurations. The heat exchanger could be vertical or horizontal, however the most widely used are closed loop, ground coupled with vertical heat exchangers [4]. The vertical heat exchangers are expensive and drilling costs vary depending on the soil composition although they are very efficient. Hence a compromise is made between higher efficiency and cost in horizontal ground heat exchangers [5]. In horizontal heat exchangers embedded in soil, long pipes are installed at a depth of 1–2 m through which heat transfer fluid (HTF) flows and exchanges heat to or from soil [6].

The GSHPs are used in buildings to provide heating in the cold seasons mostly in North America (USA and Canada) and North Europe [7]. In some European countries like Italy, such systems are yet to gain the importance even if they can be convenient in both summer and winter seasons for respective applications with substantial savings on energy and reduction in pollution [8]. Congedo et al. [5] studied the thermal performance of different horizontal ground heat exchangers for a year comprising of summer and winter considering the climate condition of the city of Lecce (Italy). They conducted a detailed parametric study and concluded that the thermal conductivity of soil and velocity of heat transfer fluid are key factors affecting the thermal performance of ground heat exchanger. They found that the thermal performance of helical geometry is the best among all the configurations. While studying the ground heat exchangers for a cold country, it is required to ensure that such systems could be operated in both hot and cold seasons to maintain an annual ground thermal balance, instead of using heat transfer in one direction only. For Indian conditions, the use of GSHPs would be mostly considered during summer in most parts of India. However, the use of the GSHP as heating system during winter will make it a better investment option [9–12].

In the developed countries where population density is considerably low, horizontal ground heat exchangers (HGHEs) is extensively used as the heat source for GSHP. HGHEs are an economical choice for ground heat exchangers if there are no major limitations on land usage since the excavation cost of horizontal trenches is significantly lower than vertical drilling of boreholes. However, several countries like Japan where the population density is high, limited land space in residential or commercial areas restrict the use of HGHEs.

Most of the literature in this field suggest that the numerical model can predict realistic results if properly developed and simulated with the appropriate parameters. However, the configuration of ground heat exchanger changes and thus its performance depending on the application. The situation worsens for high energy demanding applications which requires large ground area to transfer heat to or from soil. The land generally comes with a premium and if the design of ground heat exchanger is not optimized for a particular application, then the total installation cost will increase. Hence in this work, a systematic approach is adopted for evaluating the thermal performance of various types of horizontal ground heat exchangers numerically. A numerical model is developed for this purpose and validated with results from the existing literature. Further important parameters affecting the thermal performance of HGHEs are identified. Based on these findings, a suitable ground heat exchanger is designed for a high-energy application in a given foot print area for years of operation with a minimum installation cost. This study corresponds to the scenario exists in large auditoriums in Pune, India where the requirement for energy exchanged to soil is high.