International Journal of Research in Engineering and Innovation (IJREI)
journal home page: http://www.ijrei.com
ISSN (Online): 2456-6934

ORIGINAL ARTICLE

An experimental study of geothermal heat exchanger

Rishav Ranjan, Nirdosh Nirala, Deepak Kumar Sharma, Dilip Kisku, Mukesh Kumar, Gaurav Kumar

Department of Mechanical Engineering, Vidya College of Engineering, Meerut, India.

Article Information

Received: 21 April 2022
Revised: 19 May 2022
Accepted: 06 June 2022
Available online: 08 June 2022

Keywords:

Geothermal energy
NTU
Effectiveness of GHE.
Heat Exchanger

Abstract

The prices and demand for electricity are growing steadily. Thus, everyone finds a way to live a continuous life. In this case, the Geothermal Heat Exchanger (GHE) is the best choice for the Heating Valuation and Air Conditioning center. In residential buildings, more than 40% of the electricity is required for heating and cooling purpose. To reduce the use of conventional natural resources or the burden on an efficient system, we have shifted to a renewable energy source. The Geothermal heat exchanger operates on the basic principle of heat transfer and uses geothermal energy as a source. With this, we can get HVAC or a cooling place at a meager cost with practical use anywhere. In calculating the length of GHE and the impact of speed on the effectiveness of GHE, we used the NTU method. This set method includes a 6m long Galvanized Iron tube placed at a depth of 1m and a width of 0.03m. The air is transported through a closed-loop system using a 250W blower. The experiment was performed in three different months and recorded a temperature drop of approximately 9°C.

1. Introduction

Worldwide, estimates say that residential buildings, offices, and shops use about 40% of our energy and 70% of our electricity. For residential, commercial, and industrial purposes, warming and cooling hold essentially the final amount of energy required. To reduce the burden on functional systems that convert renewable energy into thermal or electric energy, the first step is to use a complete combination of idle design techniques; most importantly, solar design techniques do not work. To our knowledge, Geothermal energy is a form of renewable energy source [1].

The Geothermal Heat Exchanger is an underground heat exchanger that can hold the heat down for heating purposes and release heat down for cooling purposes. In contrast, a typical heating and cooling system require a compressor, condenser, and evaporator setup.

The Geothermal Heat Exchanger is an intelligent way to use geothermal energy for our benefit, both in the heat and cooling within the local living space [2]. The Geothermal Heat Exchanger requires a fan to move air through all the settings of the indoor temperature switch. Heat is extracted or refined by a pipe fitted to the floor at a low level with airflow. This simple setup helps to reduce costs and energy consumption in the system. This system eliminates the cost of compressor, condenser, and evaporator by using geothermal power [3]. Ground Source Heat Pump systems are gaining popularity to reduce primary energy use and greenhouse gas emissions. The technology of burying heat exchangers in boreholes is a relatively new development, and its studies, whether theoretical, numerical simulation, or experimental, are pretty mature. The experiment investigation focused on the thermal response tests and thermal performance under various situations, such as backfills, tube materials, inlet water

Corresponding author: Gaurav Kumar
Email Address: gaurav.me86@gmail.com
https://doi.org/10.36037/IJREI.2022.6401

temperature, water velocity, heat exchanger types, and operation modes [4-6]. Theoretical work on exergetic modeling and performance evaluation and experimental work on solar-assisted ground-source heat pump systems were also presented [7]. In recent decades, energy geotechnical engineering has been developed and advocated to compensate for the limitations of borehole heat exchangers, namely, considerable initial investment and mostly occupied space. Energy geotechnical engineering is a system that saves energy by embedding the absorber tube loop directly in subsurface structures such as base slabs, piles, and diaphragm walls, establishing a heat exchanger with part of geotechnical engineering structures [8, 9]. From an energy-efficient standpoint, technology using the subsurface environment in architecture has been applied in numerous forms, such as the composition of space and elements for adapting to climate change. The ground source heat pump (GSHP), in particular, which uses a continuous layer of geothermal heat and water temperatures (100-200 m underground) inside the basement of structures, is commonly employed as a building heating and cooling system [10]. Because of its great benefits in utilizing renewable energy and high efficiency, the ground source heat pump system has grown at more than 10% per year in more than 30 nations over the last decade [11].

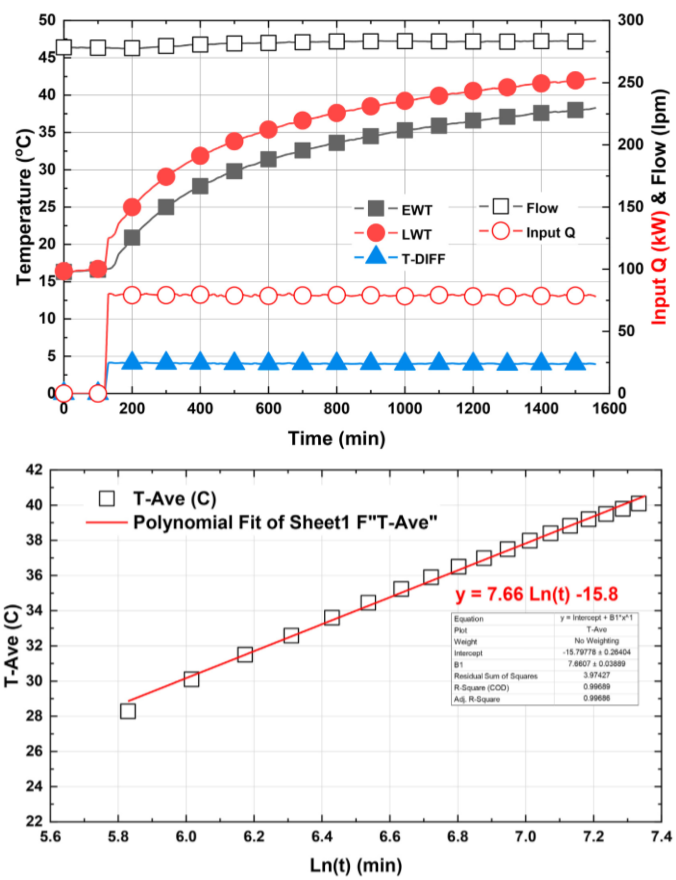

Figure 1: Characteristics on the thermal performance of SCW geothermal heat exchanger, (a) inlet and outlet recirculation water temperature, recirculation water rate and heat injection, (b) slope of K [12].

Fig. 1 depicts the evaluation of the thermal performance of the soil utilizing the Standing column well and balancing well geothermal heat exchangers. The results of assessing the thermal performance of the earth using the present Standing column well approach are shown in Fig. 1. The k value of in the line-source approach is represented by the slope of the graph in Fig. 1(b). The present Standing column well underground heat exchanger's effective heat transmission can be obtained [12].

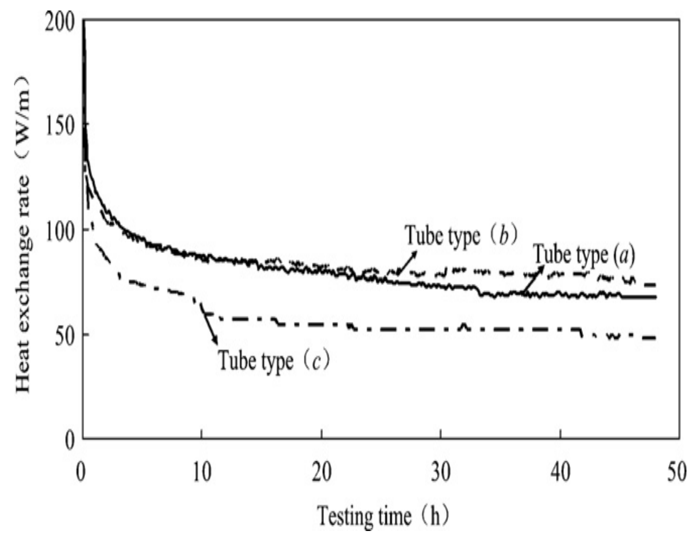

Figure 2: Relationship curves of heat exchange rate and time under different types of heat exchangers [13]

The greater the distance, the less interaction there is, and consequently, the more significant the heat exchange rate. Unlike borehole heat exchangers, the distance between the two branches of U-shaped tubes in the diaphragm walls can vary from several millimeters to dozens of centimeters. As a result, increasing the distance between the two branches of U-shaped tubes in diaphragm walls is an excellent technique to improve heat transfer performance. Fig. 2 depicts the heat exchange rate and time relationship curves for several heat exchangers [13]. The energy pile has piqued the interest of these energy geotechnical engineering members. Its thermal performance and some influencing elements such as inlet water temperature, water velocity, tube kinds, and operation modes were investigated and tested [14-19]. The embedding of heat exchangers in diaphragm walls is a novel and expanding area of energy geotechnical engineering. Using this technology, absorber tubes are buried in diaphragm walls by attaching them to the reinforcing cage. However, applications and research on heat exchangers buried in diaphragm walls are uncommon. In Austria and Switzerland, absorber tubes were first placed in diaphragm walls as a heat exchanger in 1996 [20-22].

2. Design parameters

The GHE design should be based on the following parameters:

2.1 Tube Material

When choosing a GHE tube material we must consider the properties provided such as strength, corrosion resistance, durability, and material cost.

2.2 Tube length

Heat transfer depends on the surface area. The surface area of the pipe depends on: (a) Width, (b) Height. Therefore, in the Heat & Mass Transfer concept the increase in length leads to an increase in heat transfer rate and produces higher efficiency. After, for a certain length no significant heat transfer occurs. Therefore, prepare the length. Increasing lengths also cause a decrease in pressure. Thus, increase fan power [3].

2.3 Width of tube

A smaller range provides better thermal performance but results in a greater decrease in pressure which results in a decrease in air velocity and heat transfer [2].

$$\mathrm{Nu}_D = \frac{(f/8)\,(\mathrm{Re}_D - 1000)\,\mathrm{Pr}}{1 + 12.7(f/8)^{1/2}\left(\mathrm{Pr}^{2/3} - 1\right)}$$

2.4 Depth of Tube

Low temperature is affected, (a) Outdoor weather, (b) Shape of the Earth, (c) Water Content, (d) Tropical buildings [3]. Low temperatures fluctuate over time, but the amplitude of fluctuations decreases with depth. Burying pipes / tubes as deep as possible would be fine. Generally, 4-5m below the surface of the earth significantly reduces oscillation [21].

3. Objective

The Geothermal Heat Exchanger is the best and most modest way to use global warming power for our own good or for our own good. The main purpose of this project is outlined below:

- Find another solution for effective heating and cooling system such as air conditioning, heater [3].
- Continuity of renewable energy source [2].
- Utilize geographically compatible technologies [2].
- Reduce energy consumption by heating and cooling the system [23].

This project aims to design a heating and cooling system based on global warming. In this project, we explained about the key parameters when designing GHE.

4. Tube material selection

The key component of GHE is tube and its material. Following factors are considered for selection of tube material: (a) Good Thermal Conductivity, (b) High Corrosion Resistance

Table 1: Different materials and its thermal conductivity

S. N	Materials	Thermal Conductivity (W/mk)
1.	PVC	0.19
2.	Galvanized Iron	55.3
3.	Iron	79.5
4.	Brass	109
5.	Aluminum	205
6.	Copper	385

As per table 1 GI has been selected as tube material due to its good thermal conductivity and low cost [24].

5. Design calculation

Listed below is a list of formulas we consider when calculating geothermal temperature change and the same efficiency at different speeds [24].

Mass flow rate = m = $(v \times \rho \times \pi \times D_i^2)/4$

Prandtl Number: (Pr) = $\mu Cp/Ka$

Reynolds Number: (Re) = $\rho v Di/\mu$

Nusselt Number:

Convective Heat Transfer Coefficient: $h = \frac{N_u k_{air}}{D_0}$

Heat Transfer Co-efficient: $U_t = [\frac{1}{h_c} + \frac{1}{2\pi k_t}\ln\frac{r_o}{r_i}]^{-1}$

NTU = $UtA/maC_p = Ut\pi DiL/maC_p$

NTU = $-\ln(1 - \varepsilon)$

Total Heat Transfer: $Q = m\,C_p\,(T_o - T_i)$

Effectiveness: $\varepsilon = (T_o - T_i) / (T_{wall} - T_i)$

$\varepsilon = 1 - e^{-NTU}$

Co-efficient of Performance

COP = Total Heat Transfer/ Energy input

By using above these formulas, we found out the length of GHE. Calculation results are given below [25].

Table 2: Input parameters

Used Parameters	Value in unit
Velocity of the air (V)	3, 3.56 m/s
Density of the air (ρ)	1.1465 Kg/m^3
Outer dia. of the pipe (Do)	0.03 m
Inner dia. of the pipe (Di)	0.028 m
Outer radii of the pipe (Ro)	0.015 m
Thermal Conductivity of the Air (k air)	0.0266 W/mK
Thermal Conductivity of the pipe (k pipe)	55 W/mK

Thermal Capacity (Cp)	1.006 kJ/KgK
Viscosity (μ)	1.84 X 10^{-5} N/ms
Pipe wall Temp. (Twall)	22°C
Length of Tube (L)	6 m
Inlet Temperature (Ti)	28°C

Table 3: Dimensions of Experimental Setup

S. No.	Depth	Breadth	Length(pipe)
1.	1m	0.6m	6m

6. Length of geothermal heat exchanger

The length of GHE was calculated by taking 10°C minimum temperature drop and input parameters and dimension of experimental setup is given in table 2 and 3.

Mass flow rate (m) = 0.06Kg/sec
Reynolds number (Re) =28039.4022
Prandtl number (Pr) =0.6959
Nusselt number (Nu) = 55.3627
Convective heat transfer coefficient per unit length (h) = 9.8069 W/m^{2}K
Overall heat transfer (Ut) = 9.7933
NTU = 1.2
Tube Length = 6m
Effectiveness = 0.7

A temperature drop of 8°C was attained by taking GHE of length. Results for change in outlet Temp with change in velocity and COP are given in Table 4.

Table 4: Change in Temperature, Velocity and COP.

Velocity (m/s)	3	3.56
m	0.0608	0.081
Re	28039	37385.9
Pr	0.6959	0.6959
f	0.024	0.0224
Nu	66.363	82.8448
h	9.8069	14.6911
Ut	9.7933	14.6605
NTU	1.5	1.032
€	0.7	0.6
Tout	29.5°	31°
Q (w)	642.23	733.374
Q(ton)	0.183	0.209
COP	2.5	2.9

7. Result and discussion

Following are the findings of experimental study:

- The setup for experiment is consist of a GI tube which is 6m long and buried 1m below the ground surface having the diameter of 0.03m and a blower of 250W is used for the purpose of circulation of air inside the system.
- The experiment has been performed in three different months and we recorded that temperature is varying approximately 9°C.
- Observation depicts that as the velocity of fluid increases the rate of heat transfer across the heat exchanger decreases and at the minimum heat transfer rate decrease in temperature drop is seen also as compared to the fluid of low velocity.
- All the theoretical calculations are carried out at different velocity of fluid, that are 3m/sec and 3.56m/sec respectively.
- We used GI as a tube material because it is easily available in our workshop.
- Table 5 displays the outlet temperature recorded over three different months i.e. January, March and May at three different season with different earth temperature and inlet temperature but main point of concern is that temperature is dropping in all three months and Mean of temperature difference is 9.33°C. Below given Graph 8.1 also displaying the same temperature drop of three different months.

Table 5: Outlet temperature of three different months

Months	Earth Temperature	Inlet Temperature	Outlet Temperature
21 Jan,2022	19°C	29°C	21°C
13 March 22	23°C	38°C	27°C
5 May,2022	23.2°C	43°C	34°C

Mean (temperature difference) = (8+11+9)/3 = 9.33°C

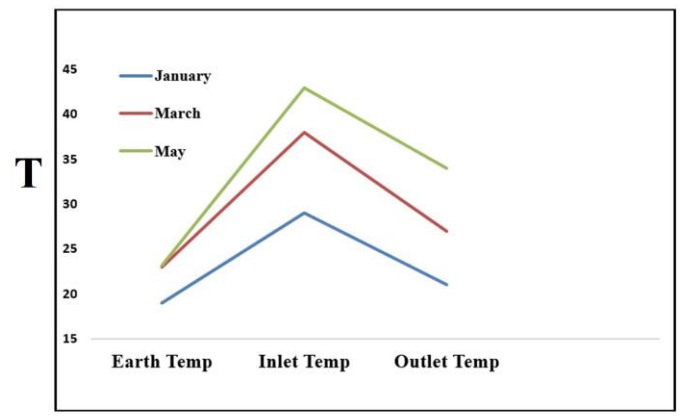

Figure 3: Temperature Difference in different months

8. Conclusions

All tests were conducted on the Vidya Knowledge Park campus, the longitudinal extent was 28.97498 DD (Degree Decimals), and the latitudinal extent was 77.62494 DD in January, March and May 2022. This paper draws a geothermal heat exchanger (GHE) and analytical model. The test set included a 6m GI tube length and 0.03m wide. The NTU method is used in the calculation of theory.

Experiments were performed at three different months, and we recorded that the temperature varied about 9° C. Observation depicts that as the velocity of fluid increases, the heat transfer rate across the heat exchanger decreases and at the minimum heat transfer rate decrease in temperature drop is also seen as compared to the fluid of low velocity. Therefore, this program should be used because it is cheaper and more effective than our research work.

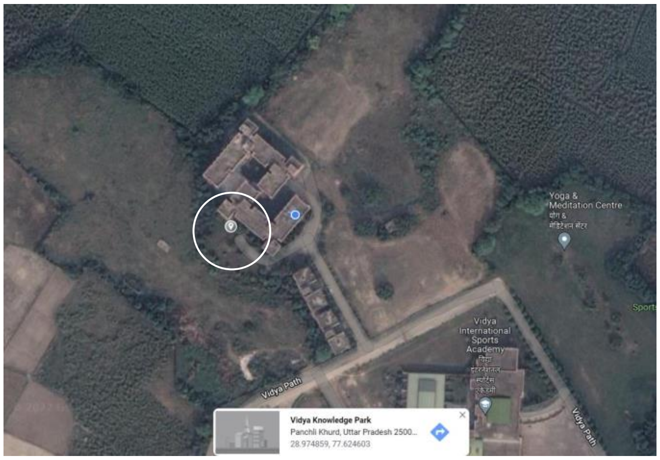

*Figure 4: Satellite image of Project Site (i.e. Meerut, India) *source(Google)*

References

[1] Saman Rashhidi, Naser Bakshi & Roohollah Rafee (2021). Problems and challenges of Helical Shaped Geothermal Heat Exchanger, volume-28 pages 28965-28992.

[2] Nethra, MR, Kalidasan(2021). Earth tube heat exchanger design for efficiency enhancement of PV panel, volume-45,part 2, pages 587-591

[3] Lamrani, M., Laaroussi, N., Khabbazi, A., Khalfaoui, M., Garoum, M., &Feiz, A. (2017). Experimental study of thermal properties of new ecological building material based on peanut shells and plaster. Case studies in construction materials, 7, 294-304.

[4] H. Esen, M. Inalli, In situ thermal response test for ground source heat pump system in ElazIg, Turkey, Energy and Buildings 41 (2009) 395–401.

[5] A. Hepbasli, O. Akdemir, E. Hancioglu, Experimental study of a closed loop vertical ground source heat pump system, Energy Conversion and Management 44 (2003) 527–548.

[6] X.G. Li, Y. Chen, Z.H. Chen, J. Zhao, Thermal performances of different types of underground heat exchangers, Energy and Buildings 38 (2006) 543–547.

[7] K. Lim, S. Lee, C. Lee, An experimental study on the thermal performance of ground heat exchanger, Experimental Thermal and Fluid Science 31 (2007) 985–990.

[8] B. Sanner, G.Hellstrm,J. Spitler, S. Gehlin, Thermal response test – current status and world-wide application, in: Proceedings of Word Geothermal Congress 2005, Antalya, Turkey, 2005, pp. 24–29.

[9] H.J. Wang, J. Zhao, L. Shen, Experimental investigation on long-term performance of ground source heat pump system, Journal of North China Electric Power University 34 (2007) 52–54 (in Chinese).

[10] J. Lund, G. Sanner, L. Rybach, R. Curtis, G. Hellstrom, Geothermal (ground- € source) heat pumps: a world overview, Geo-Heat Cent. Q. Bull. 25 (2004).

[11] L. Rybach, The advance of geothermal heat pumps-worldwide, IEA Heat Pump Center News Letter 23 (4) (2008). No. 2.

[12] Myungkwan Lim, Changhee Lee, An experimental study on thermal performance evaluation and effectiveness of geothermal heat exchange system in various standing column well types, Renewable Energy 179 (2021) 1049e1064.

[13] CaichuXia, MengSun, GuozhuZhang, SuguangXiao, YichuanZou, Experimental study on geothermal heat exchangers buried in diaphragm walls, Energy and Buildings 52 (2012) 50–55.

[14] Y. Hamada, H. Saitoh, M. Nakamura, H. Kubota, K. Ochifuji, Field performance of an energy pile system for space heating, Energy and Buildings 39 (2007) 517–524.

[15] L. Laloui, M. Moreni, L. Vulliet, Behavior of a dual-purpose pile as foundation and heat exchangers, Canadian Geotechnical Journal 40 (2003) 388–402.

[16] L. Laloui, M. Nuth, L. Vulliet, Experimental and numerical investigations of the behaviour of a heat exchanger pile, International Journal for Numerical and Analytical Methods in Geomechanics 30 (2006) 763–781.

[17] J. Gao,X. Zhang,J. Liu,K.S. Li,J.Yang, Thermal performance and ground temperature of vertical pile-foundation heat exchangers: a case study, Applied Thermal Engineering 28 (2008) 2295–2304.

[18] A. Miyara, K. Tsubaki, S. Inoue, K. Yoshida, Experimental study of several types of ground heat exchanger using a steel pile foundation, Renewable Energy 36 (2011) 764–771.

[19] K. Morino, T. Oka, Study on heat exchanged in soil by circulating water in a steel pile, Energy and Buildings 21 (1994) 65–78.

[20] K. Nagano, Energy pile system in new building of Sapporo City University, in: H.O. Paksoy (Ed.), Thermal Energy Storage for Sustainable Energy Consumption, Springer, Netherlands [s.n.], 2007, pp. 245–253.

[21] J. Zhao, H.J. Wang, Numerical simulation on heat transfer characteristics of soil around compact pile-buried underground heat exchangers, Heating, Ventilating & Air Conditioning 36 (2006) 11–14 (in Chinese).

[22] J. Zhao, T. Wu, Q. Zhu, Y.L. Gong, Thermal simulation on the steady heat transfer of the U-pipe pile heat exchanger, Acta Energiae Solaris Sinica 26 (2005) 59–62 (in Chinese).

[23] AkshayM.Pudke, KartikS.Shire, YogeshR.Borkar (2017), Comparative Study on Passive Solar Building, IARJSET AGNI-PANKH 16, Vol.4, Special issue.

[24] Tarigh, A. D., Tarigh, F. D., &Nikranjbar, A. (2012). A Survey of Energy-Efficient Passive Solar Houses. IPCBEE© IACSIT Press, Singapore, 27, 18-25.

[25] Jannot, Y., Remy, B., &Degiovanni, A. (2009). Measurement of thermal conductivity and thermal resistance with a tiny hot plate. High Temperatures-High Pressures, 39(1), 1-21.

Cite this article as: Rishav Ranjan, Nirdosh Nirala, Deepak Kumar Sharma, Dilip Kisku, Mukesh Kumar, Gaurav Kumar, An experimental study of geothermal heat exchanger, International journal of research in engineering and innovation (IJREI), vol 6, issue 4 (2022), 204-208. https://doi.org/10.36037/IJREI.2022.6401.