International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 5 May 2023, pp: 975-982 www.ijaem.net ISSN: 2395-5252

Design and Fabrication of Earth Tube Heat Exchanger

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Date of Submission: 15-05-2023 Date of Acceptance: 30-05-2023

ABSTRACT: The Earth Tube Heat Exchanger is a specialized equipment designed to leverage the thermal properties of the ground for efficient heating and cooling applications. It is referred to by various terms such as "Earth Tube Heat Exchangers," "Ground-To-Air Heat Exchangers," "Ground Pipe Heat Exchangers," and "Soil Heat Exchangers." Extensive research has been conducted to determine optimal parameter values for improved performance based on location and other factors. These studies assess performance by taking into account elements including material choices, ground level, the velocity of winds, and tube dimensions. At a certain depth, the earth maintains a distinct temperature from the ambient air, being cooler in the summer and hotter in the winter. The use of ground-level temperature variations for heating as well as cooling reasons may be explored in further research. It is crucial to prioritize alternative energy sources due to limited energy resources, preserving conventional fuels, and saving space. Ground-to-air heat exchangers, which use fans to move ambient air into the pipes, are a practical option for heating or cooling buildings. Heat transfer occurs based on temperature differences, necessitating a well-designed system to maximize efficiency. The effectiveness of the system can be influenced by various factors, such as the cross-sectional dimension and material of the pipe, wind velocity also the characteristics of the soil. This technology serves as a means to reduce pollution, decrease reliance on conventional energy, and utilize environmentally friendly, renewable power sources.

Keywords:
Earthtubes,COP,Soilproperty,Coolingcapacity,Ambientair

I. INTRODUCTION

Buildings are account for nearly 30% of all energy-related emission of greenhouse gases and about forty percent of all worldwide energy use. Almost a third of the energy used in the building sector is for heating and cooling interior areas in buildings. However, using traditional heating and cooling systems has negative energy and ecological consequences, such as raised carbon emissions, accelerated climate change, exacerbated urban heat islands and greenhouse gas effects, increased highest electricity demand, and lowered the condition of indoor air. In the past few years, the technological and research community has created significant efforts to investigate energy-based cooling and heating options based on renewable energy resources that can contribute to energy conservation as well as sustainability.

The earth tube heat exchanger works by utilizing the natural thermal properties of the earth. Underground, temperatures remain relatively constant throughout the year, usually between 50°F and 60°F (10°C to 15.5°C) depending on the region. This temperature stability provides an ideal heat source in winter and a cooling source in summer. Earth Tube Heat Exchangers (ETHE) are systems which utilize number of underground tubes for circulate ambient or indoor air. In summer season, they transfer heat to the soil from the air, while in the colder month, they extract heat from the soil to warm the air. These systems make efficient utilization of as a heat sink and source. Inside the building or greenhouse, air is combined with the air flowing through the pipes. This paper aims to study and compare the performance of an earth tube heat exchange using the materials copper and GI at different velocity ranges (4, 8, 12, and 16 m/s).

II. DESIGN PARAMETERS

The following factors are important for designing ETHE.

1. **Tube material**: When selecting the material for the ETHE tube, considerations such as cost, durability, corrosion resistance, and strength are important. Researchers worldwide have explored various pipe materials to investigate their impact on the system's functionality. However, no significant effect on the outlet air temperature has been observed. Both steel and PVC pipes have shown limited influence on the thermal performance of ETHE. For our project, we opted for copper tubing due to its higher thermal conductivity and satisfactory corrosion resistance.
2. **Tube length:** When it comes to heat transfer, the tube's length is quite important**.** A longer length translates to a larger surface area, facilitating faster heat transmission and increased efficiency. However, beyond a certain length, the heat transfer becomes negligible. It is essential to find the optimal length that balances heat transfer and avoids unnecessary pressure drops, which can lead to increased fan energy consumption. In our project, we have chosen a 10-meter tube length.
3. **Tube diameter**: The diameter of the tube affects airspeed and heat transmission. Larger diameters result in reduced airspeed and heat transfer, while smaller diameters cause greater pressure drops. Optimal thermal performance is achieved with smaller diameters due to improved heat transfer efficiency.
4. **Tube depth**: Understanding the temperature distribution at the earth surface and its deviation with depth is crucial for designing an effective ETHE system. Factors such as ground structure, physical characteristics, and ground cover significantly impact the heating of the ground. To maximize the system's effectiveness, the pipe should be buried at an appropriate depth below the surface.
5. **Flow and thermal properties of air**: The characteristics of the air, including temperature, flow rate, and relative humidity, are key factors influencing the performance of the ETHE system. Extensive research has been conducted to explore how air properties affect the system's effectiveness. The temperature difference between the air and underground soil determines the rate of heat transfer. Furthermore, increased air velocity in the pipe below the soil surface decreases the overall temperature differential between the inlet and outlet air, impacting the performance of the ETHE system.

III. EXPERIMENT DETAILS

Table 1- Experiment Details

Location	9.9782° N, 76.2772° E
Conducted experiment on	12/04/2023,13/04/2023 &14/03/2023
Velocity Ranges	4,8,12 &16 (m/s)
MATERIALS USED	
Copper Pipe (Thermal conductivity 385 W/m K) & GI Pipe (Thermal conductivity 15 W/ m K)	Diameter- 1 ½ inch Length - 10 meter
Blower	550 W Variable speed control, Blow rate – 2.3 m^3/min

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IV. OBSERVATION TABLE

Table 2 – Observation Table of the experiment

Time (Hour)	Avg. Inlet Temp. (℃)	Material	Outlet Temp. of Air (℃) at,			
			4 m/s	8 m/s	12 m/s	16 m/s
9	30.8	copper	27.6	28.1	28.3	29
		GI	28	28.4	28.7	29.3
10	32.7	Copper	29.2	29.7	30.3	30.5
		GI	29.8	30.1	30.4	30.9
11	34.3	copper	29.6	30.3	31	31.9
		GI	30.1	30.9	31.5	32
12	36.5	copper	31	31.7	32.5	33.2
		GI	31.6	32	32.9	33.4
13	37.8	copper	31.7	32.4	33.3	34.8
		GI	32.2	32.8	33.9	35
14	38.9	copper	31.9	32.8	33.1	34.6
		GI	32.7	33.3	33.9	35
15	38.1	copper	31.7	32.5	33.2	34.9
		GI	32	32.9	33.8	35.1
16	37.2	copper	32.1	32.9	33.7	34.6
		GI	32.6	33.4	34	34.9

V. TIME VS OUTLET TEMPERATURE

Based on the observation table, the time vs. outlet temperature was plotted on a graph for the different velocity ranges. The variation of the outlet temperature for the two different materials (copper and GI) can be identified from the graphs. The blue line represents the outlet air temperature for GI pipe and the black line for copper pipe.

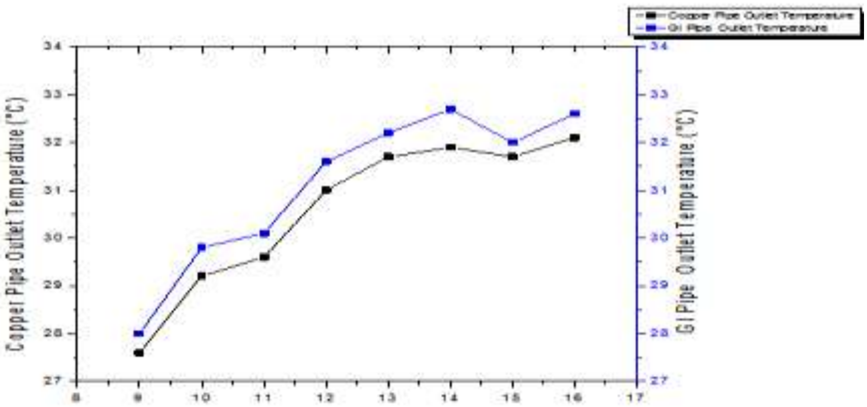

Fig. 1 (a)

The first graph, Figure 1(a), represents the time vs. outlet temperature of the two materials at 4 m/s. From the graph, the outlet temperature of the air for copper pipe is lower than that of GI pipe.

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The maximum temperature drop for each pipe was observed at 2 p.m.

Figure 1 (b) represents the time vs. outlet temperature at 8 m/s.As compared to the first graph, the outlet temperature of air slightly increased, and the maximum temperature drop was at 2 p.m. for each pipe.

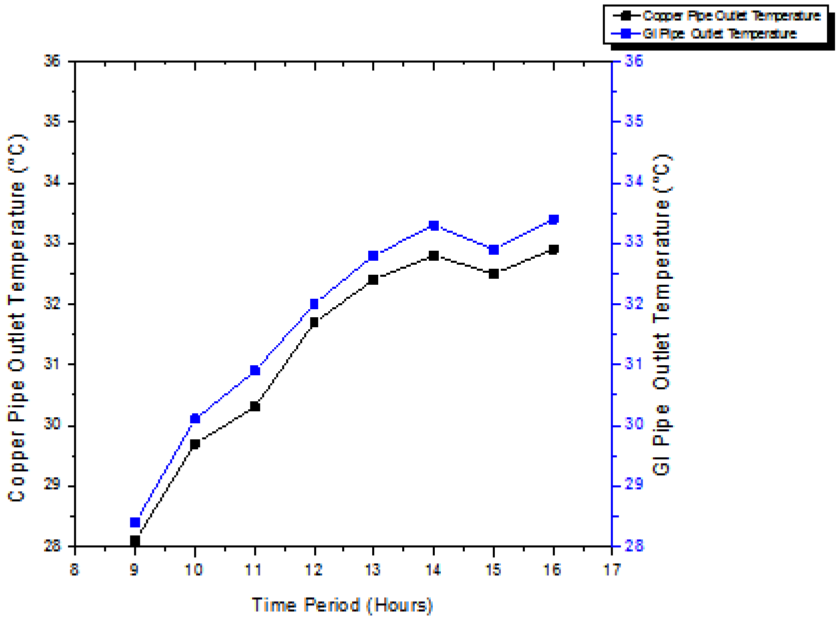

Fig. 1 (b)

Figure 1 (c) For 12 m/s, the outlet temperature further decreases as the inlet velocity of air increases. At 10 a.m., the outlet temperature for each pipe is almost the same. The figure 1 (d), is for the 16 m/s inlet air velocity. From the graph, it can be understood that the outlet temperature for each material is almost similar at each time period, so that through these graphs we can conclude that, as the inlet air velocity increases, the temperature drop for the pipes decreases, and at some periods it is showing the same outlet temperature for each pipe.

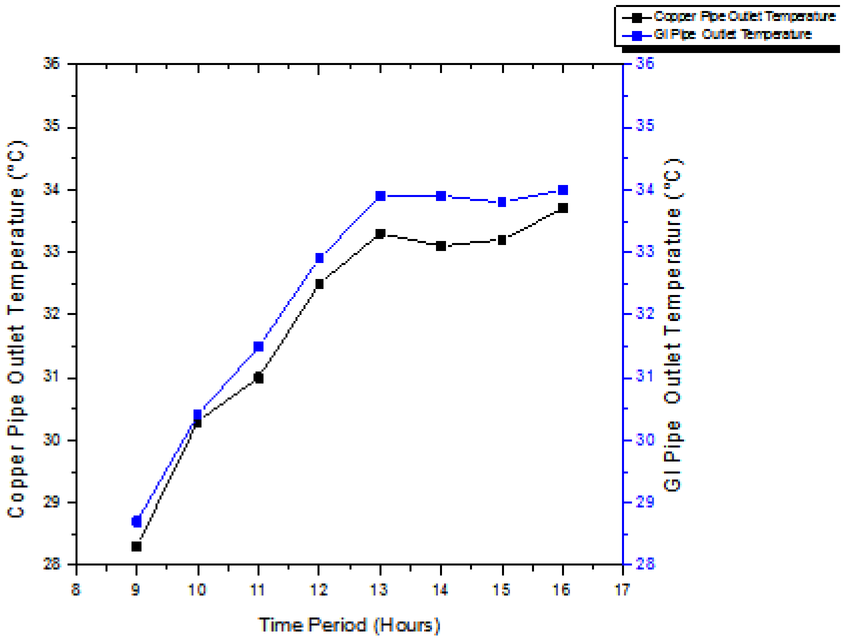

Fig. 1(c)

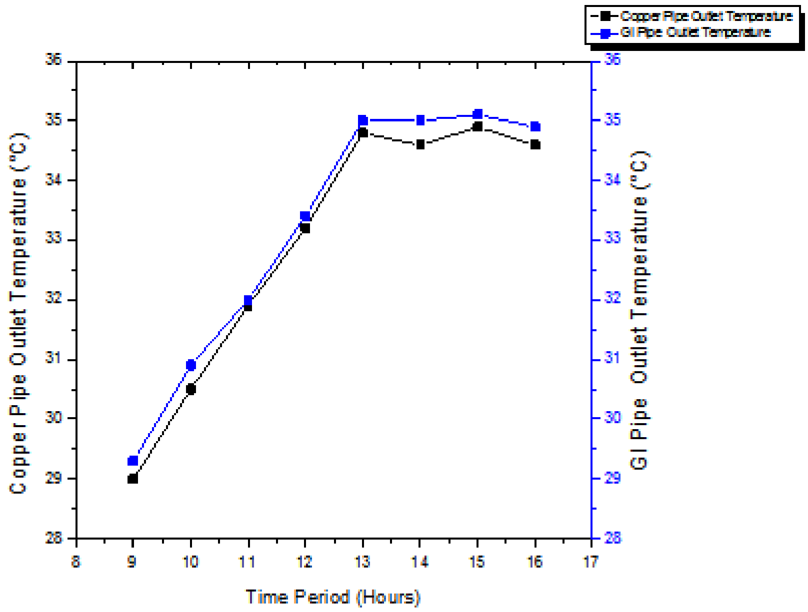

Fig. 1 (d)

CALCULATIONS

Calculations for the 4 m/s flow velocity is given below:

1. <u>Mass flow rate</u>

$m = \rho A v$

Where, ρ = Density of air = $1.164 \frac{Kg}{m^3}$

A = Area $= \frac{\pi}{4} \times d^2 = \frac{\pi}{4} \times (3.81 \times 10^{-2})^2 = 1.14 \times 10^{-3} m^2$

v = Velocity of air = 4 m/s

$$\therefore m = 5.308 \times 10^{-3} \frac{Kg}{sec}$$

2. <u>Reynolds Number</u>

$Re = \rho v d/\mu$

Where, $\mu = 1.872 \times 10^{-5} \frac{m^2}{s}$

$\therefore R_e = (1.164 \times 4 \times (3.81 \times 10^{-2}))/1.872 \times 10^{-5} = 9476.15$

3. <u>Prandtl number</u>

$Pr = \mu C_P/k_a$

Where, k_a = Thermal conductivity of air = 0.0266W/m K

C_P = is the specific heat of air = 1006 (J/kg-K)

$\therefore Pr = (1.872 \times 10^{-5} \times 1006)/0.026 = 0.7243$

4. <u>Friction Factor</u>

$f = (0.79 \ln Re - 1.64)^{-2}$

$= (0.79 \ln (9476.15) - 1.64)^{-2}$

= 0.03196

(Reference: Bisoniya, T. S. (2015). Design of earth–air heat exchanger system. Geothermal Energy, 3, 1-10.)

5. <u>Nusslet Number</u>

For $0.5 < Pr < 2000$ and $2300 < Re < 5 * 10^6$

$$\mathrm{Nu} = \left(\left(\frac{f}{8}\right) \times (\mathrm{Re}-1000)\mathrm{Pr}\right) / \left(1+12.7\left(\frac{f}{8}\right)0.5(\mathrm{Pr}0.66-1)\right)$$

$$= \frac{\left(\frac{0.03196}{8}\right)\times(9476.15-1000)0.7243}{1+12.7(0.031968)^{0.5}(0.7243^{0.66}-1)} = 29.03$$

6. Convective Heat Transfer coefficient

$h = Nuk_a/d$

$$h = 29.03\times\frac{0.026}{3.81}\times 10^{-2} = 19.81\ \mathrm{W/m^2K}$$

7. Overall Heat Transfer Coefficient

$U = 1/R_{total}$

Where, $R_{total} = R_{soil} + R_{pipe} + R_C$

$R_C = 1/2\pi r_i l_p h$

$$= \frac{1}{2\pi\times3.51\times10^{-2}\times10\times19.81} = 0.022890\ \mathrm{K/W}$$

$R_{pipe} = \ln(r_o/r_i)/2\pi l_p k_p$ (since r < L)

$R_{soil} = \ln(r_{soil}/r_o)/2\pi l_p k_{soil}$

$= (\ln(5.715/3.81))/(2\pi \times 10 \times 0.9651) = 6.686 \times 10^{\wedge}-3$

$R_{total} = 0.022890 + 6.686 \times 10^{\wedge}-3 =$

$0.029576\ \mathrm{K/W}$

$U = 1/0.029576$

$= 33.81\ \mathrm{W/m^2\ K}$

8. Number of transfer units (NTU)

$NTU = hA/mc_p$

$$= \frac{19.81\times\pi\times3.81\times10^{-2}\times10}{5.30\times10^{-3}\times1006} = 4.44$$

9. Effectiveness of ETHE

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

$\varepsilon = 1 - e^{-4.44} = 0.98$

The effectiveness of an earth-air heat exchanger is influenced by the dimensionless parameter NTU. The effectiveness of the earth-air heat exchanger varies depending on the Number of Transfer Units.

10. The cooling potential of ETHE system

or copper pipe:

$Q = mc_p (T_{ai} - T_{ao})$

$= 5.30\times 10^{-3} \times 1006 \times 7 = 37.32$ W

For GI pipe:

$Q = mc_p (T_{ai} - T_{ao})$

$= 5.30\times 10^{-3} \times 1006 \times 6.2 = 33.05$ W

11. Efficiency of ETHE System

For copper pipe:

$$\eta = \frac{\mathrm{OUTPUT}}{\mathrm{INPUT}} = \frac{37.32}{55}\times 100 = 67.85\%$$

For GI pipe:

$$\eta = \frac{\mathrm{OUTPUT}}{\mathrm{INPUT}} = \frac{33.05}{55}\times 100 = 60\%$$

VI. RESULTS

The results of the experiment conducted for different velocity ranges are given in the following table 3.

Table 3- Experiment Results

v (m/s)	4	8	12	16
m (kg/s)	5.30×10^{-3}	0.0106	0.016	0.0212
Re	9476.1	18952.3	28428.4	37904.6
Pr	0.7243	0.7243	0.7243	0.7243
f	0.03196	0.02650	0.02395	0.02235
Nu	29.03	50.16	68.71	85.82
h (W/m^2K)	19.81	34.23	46.89	58.56
NTU	4.44	3.84	3.48	3.28
ε	0.98	0.97	0.96	0.96
Q (W) Copper	37.32	65.04	93.35	91.70
Q (W) GI	33.05	59.71	80.48	83.17
η (%) Copper	67.85	59.12	56.5	41.68
η (%) GI	60	54.28	48.77	37.80

VII. CONCLUSIONS

By conducting the Earth Tube Heat Exchanger experiment on two different materials at different velocity ranges the following conclusions are made:

- The rate of decrease of outlet air temperature was high when the inlet temperature increases.
- The cooling performance of an ETHE was high at low velocity (due to higher temperature difference) but with the increase in the velocity the heat transfer rate increases and then decreases (due to increase in the mass flow rate and low temperature difference).
- The efficiency of the ETHE is higher at lower velocity and the efficiency decreases with increase in temperature.
- The Reynolds number increases with an increase in velocity, which means more turbulent flow inside the pipe.
- The Nusselt number (Nu) and the convective heat transfer coefficient (h) increase with the velocity of the inlet air, so the convective heat transfer is higher as compared to the conductive heat transfer.
- By comparing the performance using copper and GI pipes, copper shows a better performance

SCOPE OF THIS PROJECT

- Earth tube heat exchangers are poised to potentially replace conventional ac units in the future, offering greener as well as more sustainable alternative. By doing so, they contribute to reducing the release of harmful gases such as chlorofluorocarbons (CFCs) and hydrofluorocarbons (HFCs), which are responsible for global warming and ozone depletion.
- It uses the surrounding environment and ground temperature.
- It can make the transition to a sustainable energy source.
- Address environment ally sustainable technology.
- This heating/cooling system is also inspiring and motivating numerous researchers in the field of environmental conservation, as they recognize its potential for advancing sustainable practices and addressing the challenges of climate change.

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