Effect Of Newly Designed Coil Arrangements Slinky, Spiral, And U-Type On The Horizontal Ground Heat Exchanger Performance

Jaya Prakash Killi, V. Rambabu, Sanjay Kumar Gupta

Abstract:— In this work, a new coil arrangement ground heat exchanger unit is developed. The different coil arrangements i.e. slinky, spiral, and U-type have been arranged in series and formed one loop of horizontal ground heat exchanger. In this model, the copper material was used since copper show high thermal conductivity augmentation as compared to the extensively employed plastic resources. The prime objective of present work is to assess the thermal performance and parametric study of the developed horizontal ground heat exchanger. For that the ground heat exchanger experimentations were conducted in the developed experimental setup. In order to authenticate the obtained experimental results, the thermal performance characteristics corresponding to the same coil arrangement as obtained from the developed experimental set-up is compared with the published literature. After the validation, the effects of different operating parameters on ground heat exchanger performances are evaluated based on the experimental results. The thermal response tests (TRTs) were carried out for 10 h constantly to measure the rate of heat exchange for the ground heat exchanger at different inlet (fluid) temperatures (50°C, 45°C, and 40°C). The different working fluids like Distilled water, Ethylene Glycol+ Distillated Water, Methanol +Distillated Water were flowed through the ground heat exchanger loops. From the analysis, it is found that the maximum heat exchange rate is achieved with water at the inlet temperature of 50°C. The average fluid temperature for the water + methanol was higher than the other working fluids. It is consideration that heat is effectively flowed to the sand by the developed GHE with water as a working fluid, because of the better thermal and physical property of water.

Index Terms:— Thermal response tests, Ground heat exchanger, Heat exchange, Coil arrangement.

1 INTRODUCTION

The major challenge in this 21st century is to control the usage of fossil fuels: coal, oil, and natural gas has grown which emits the most CO2 gases cause damage to environment also leads to global warming. The fossil fuels extraction, transport, refinement, and burning consequence in the release of greenhouse gases (GHG). Usually, in developed countries, major part of energy is employed for cooling and heating of living spaces [1]. Hence, renewable energy sources required prevent these GHG threats, at present existing types of renewable energy sources are solar energy, Geo-thermal energy, wind energy, etc. Among all resources, the power generation from renewables is 1.5% and by geo-thermal energy is just 0.3% as compared to the solar, hydraulic energy, and wind. As geothermal energy is an abundantly available, stable natural resource, with no CO2 emission, has drawn more interest. The Earth's crust's temperature exceeds ~5800℃, and the stored energy inside the earth is infinite as compared to the other resources. Geothermal energy is a thermal resource where the depth in ground increases the temperature, where ground heat pump (GHP) is used for most effective space cooling and heating [2-7]. At a certain depth, the inside temperature of ground is always higher as compared to the atmospheric air temperature during the winter and is lower during the summer [8].

This difference in temperature can be employed as pre-heating in winter and pre-cooling in summer by working earth as a heat exchanger. Also, the GHP can be employed to remove heat from the comparatively warm ground in winter. It may be reversed during the summer. The ground heat exchanger (GHE) can be installed in two ways, namely, closed-loop and open-loop. In open-loop system, minimum two boreholes are employed: first one is for extraction of water and second one is for rejection of water. In closed -loop GHE, the heat exchanger is placed inside the ground by digging bore holes or in trenches. The working fluid is flowed in the coils, conveying heat from ground to GHP and vice versa [9]. The closed vertical GHEs are generally used for cooling and heating purposes. However, the major drawback of vertical borehole GHEs is high fitting costs (drilling operation). Therefore, the researchers are giving more preference to horizontal ground exchangers if the location has sufficient space [10-12]. Because of the lower fitting costs (drilling operation), the horizontal GHEs can offer an excellent realistic choice that attains a good cooperation between costs and efficiency. The heat transfer mechanism in horizontal GHEs includes different processes: first process is the conduction between the ground and pipes and second process is the convection between the pipe and the circulating working fluid. Since the Horizontal ground heat exchangers (HGHEs) are most commonly arranged in trenches at a depth of 0.9–1.8 m [13]. The rate of heat exchange was based on modeling and design of the GHE system. In recent researches, different parameters have been considered to design the GHE system, which influence the thermal efficiency. These parameters are grout thermal conductivity, pipe size, pitch distance, material used, and mass flow rate of working fluid. Knowledge of climate conditions and ground thermal properties are important in designing a GHE. Design of GHEs includes the modeling of heat exchangers coil arrangements (e.g., U-type, slinky-type and spiral-type). In this work, a new coil arrangement ground heat exchanger unit is developed. The different coil

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arrangements i.e. slinky, spiral, and U-type have been arranged in series and formed one loop of HGHEs. In this model the copper material was used since copper show high thermal conductivity augmentation compared to the extensively employed plastic. The prime objective of this work is to assess the thermal performance and parametric study of the HGHEs. For that, the GHE experimentations were conducted in the developed experimental setup. In order to authenticate the obtained experimental results, the thermal performance characteristics corresponding to the same coil arrangement as obtained from the developed experimental set-up is compared with the published literature [41]. After the validation, the effects of different operating parameters on ground heat exchanger performances are evaluated based on the experimental results. The responsible heat exchanging mechanisms for enhanced thermal performance of ground heat exchanger are also identified. The corresponding discussions on these aspects are presented in the subsequent sections of this chapter.

2 Materials And Methods

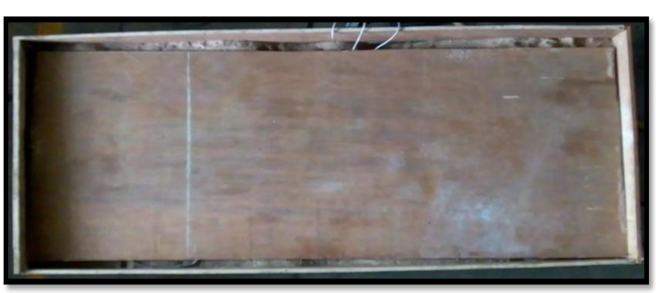
The experimental investigation has been carried out to obtain ground heat exchanger data with different coil arrangement (slinky+ spiral+ U-type). The different coil arrangements i.e. slinky, spiral, and U-type have been arranged in series and formed one loop of horizontal ground heat exchanger. The detail of experimental setup is discussed in this chapter.

2.1 Description of ground heat exchanger coil arrangement

In this designing process, initially a wooden box is prepared (64 cm ×129 cm ×31 cm). Later, the copper tube was designed individually like slinky, spiral, and U-type with known pitch, diameter and center-to-center distances with known lengths. They are connected and assembled each other as per the design structured by the copper bends and gas welded for the formation of single HGHE model and that model is placed inside the soil in wooden box as shown in Fig.1.

***Fig. 1**. Heating coil arrangement (Slinky+Spiral+U-type)*

***Fig. 2.** Wooden box*



Different components are used for different purposes like water heater for heating the inlet fluid, water pump to circulate the fluid into the heat exchanger coil, flow meters to measure the flow rates, PID temperature controller to control the inlet fluid temperature, thermo couples to measure the temperatures at inlet (T1), outlet (T2), average soil temperatures, 8- channel data scanner to record the corresponding temperatures. The working fluids, water, Ethylene Glycol+ Distillated Water and Methanol +Distillated Water, are flowed through the ground heat exchanger loops. The brief explanation is given in Table 1. After the setup of coil loops in wooden box, the thermocouples and flow meters are connected at inlet and outlet of the Heat exchanger model. The PVC pipe lines and pressure release valve were connected to the water motor pump. The developed heat exchanger coil is placed horizontally inside the wooden box and filled with sand. After that, the three thermocouples (T3, T4, T5) are placed inside the sand at a distance of 2 mm. Now the top part of wooden box is covered by wooden plywood in order to insulate from environment and to make it is a closed insulated box. The water sump tub (water reservoir) is arranged to maintain continuous water supply in to the heat exchanger.

***Table-I**: Brief explanation of components*

Components	*Usage*
Copper coil tubes (15 meters)	*Formation of these structural coil loops like slinky, U-type and spiral coils making it is used.*
Copper bends	*assembling for connection of each ends of joints and later gas welded.*
K-Type thermocouples	*Used for measuring the temperatures.*
8 channel data scanner	*To record the temperature readings.*
PID Temperature controller	*To control the inlet fluid temperature*
Water Pump (0.5 H)	*To achieve respective mass flow rate and pressure*
Flow Meters	*Measurement of mass flow rate*
Water heater	*Used for heating the working fluid at inlet.*
Anti-Freeze Coolants (Ethylene Glycol, Methanol)	*These are water-mixed anti-freeze coolants which used as a working fluid.*
Water sump	*It acts as source and sink of water which store's the water.*
PVC Pipes, bends and Valve	*For fluid flow rate and excess pressure control by removal of stagnated water.*

***Fig. 3**. Components used in present work*

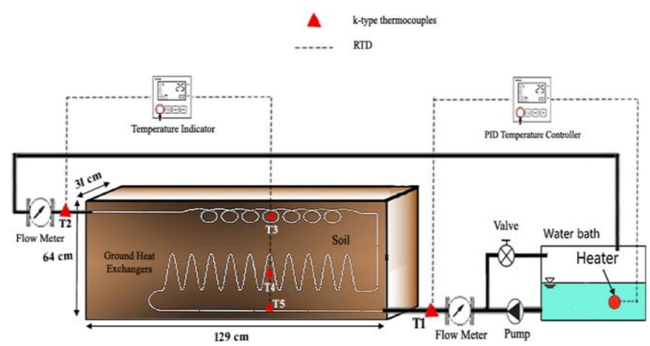


Fig. 4. *Schematic diagram of Horizontal Ground Heat Exchanger*

2.2 Experimental Procedure

From the reservoir, the different working fluids like (Water, Ethylene Glycol+ Distillated Water, Methanol +Distillated Water) with a ratio of 6:1 are flowed through the HGHE copper loops. The inlet temperatures (40℃, 45℃, 50℃) of working fluids are controlled by the PID controlled water heater, which is installed in the water reservoir. The flow rate of water at inlet can be adjusted by using a PVC valve installed before inlet, which releases excess pressure created by working fluid and by pass the excess water into the reservoir. The three thermocouples (T2, T3, T4) were placed in the soil over the GHE coils at a distance of 2cm. The average soil temperature can be determined and the outlet temperature can be measured by the outlet thermocouple (T5). All the thermocouples (T1, T2, T3, T4, T5) temperatures are recorded by 8- channel temperature scanner.

2.3. Equations

The total length of U-type coil L1=1.2065

The total length of spiral-coil-type is calculated by:

$$\mathbf{L_2} = \mathbf{h}\sqrt{\boldsymbol{\omega}^2 * \mathbf{r_0}^2 + 1}$$

where, $\boldsymbol{\omega} = \frac{2\pi N}{h} = \frac{2\pi * 10}{0.01} = 6283.18531\ \mathrm{m}$

$$L_2 = 0.01 = \sqrt{(6283.18531)^2 \times (0.0127)^2 + 1} = 6.28391\mathrm{m}$$

The total length of slinky-type GHE is calculated by:

$$\mathbf{L_3} = \mathbf{NL_1} + \mathbf{2PN} + \frac{\pi d}{2} + \mathbf{d}$$

$$L_3 = (7) * (0.7747) + 2 * (0.1143) * (7) + \frac{\pi(0.0127)}{2} + 0.0127 = 7.05574$$

Total length of coil L =L1+L2+L3.

L = 7.05574+6.2839+1.2065=14.53 meters.

The heat exchange rate can be calculated by:

$$Q = mc(Tin - Tout)$$

3 Sections Results and Discussions

Section 2 enumerates the development of ground heat exchanger unit with new coil arrangement and its working procedure. The different coil arrangements i.e. slinky, spiral, and U-type have been arranged in series and formed one loop of horizontal GHE. The prime objective of this section is to assess the thermal performance and parametric study of the horizontal GHE. For that the GHE experimentations were conducted in the developed experimental setup, discussed in section 2. In order to authenticate the obtained experimental results, the thermal performance characteristics corresponding to the same coil arrangement as obtained from the developed experimental set-up is compared with the published literature [41]. After the validation, the effects of different operating parameters on ground heat exchanger performances are evaluated based on the experimental results. The responsible heat exchanging mechanisms for enhanced thermal performance of ground heat exchanger are also identified. The corresponding discussions on these aspects are presented in the subsequent sections of this chapter.

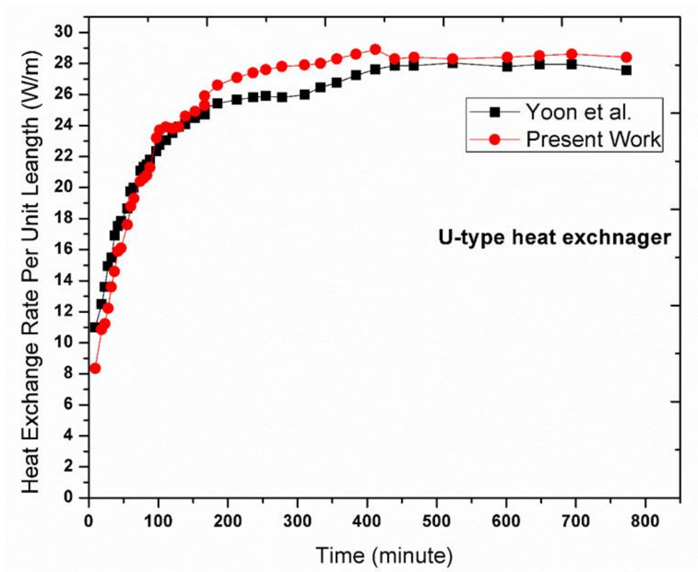


Fig. 5*. Validation of experimental setup*

3.1 Validation of Ground Heat Exchanger Experimental Results

The outcome of the present work solely depends upon the accuracy of the obtained results from the developed experimental setup. In order to authenticate the obtained experimental results, the heat transfer (heat exchange) curve generated from experimentations is necessarily to be validated with some standard published data [41]. For that three repeated test runs were performed with U-type coiled heat exchanger at a time interval of 20 hours in the developed experimental setup to generate the heat exchange curve. The deviations among the three runs, though nominal (~4%), the average values were considered to generate the heat exchange curve. This heat exchange curve corresponding to the time was then compared with Yoon et al. [41]. In order to have a comparative assessment, the heat exchange curve generated from the experimental results and that obtained from the Yoon et al. [41] are presented in Fig. 5. A good accuracy between the present experimental heat exchange curve and that obtained from the Yoon et al. [41] has been observed. The maximum variation in heat flux has been found to be ±8.6%. Based on this authentication, the thermal performance experiments were extended for the developed ground heat exchanger unit.

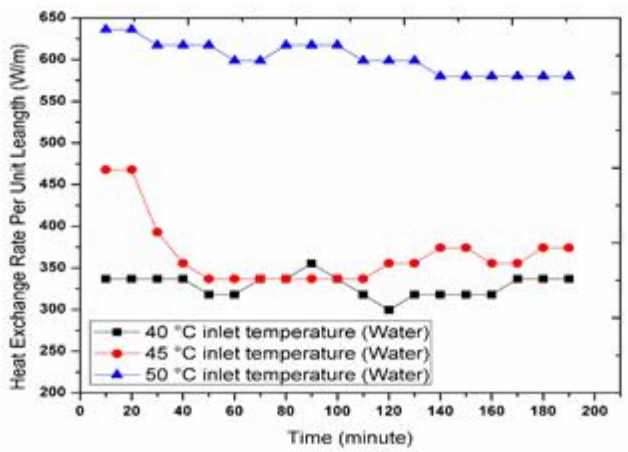


***Fig. 6**. Heat exchange rate for water at different inlet temperatures*

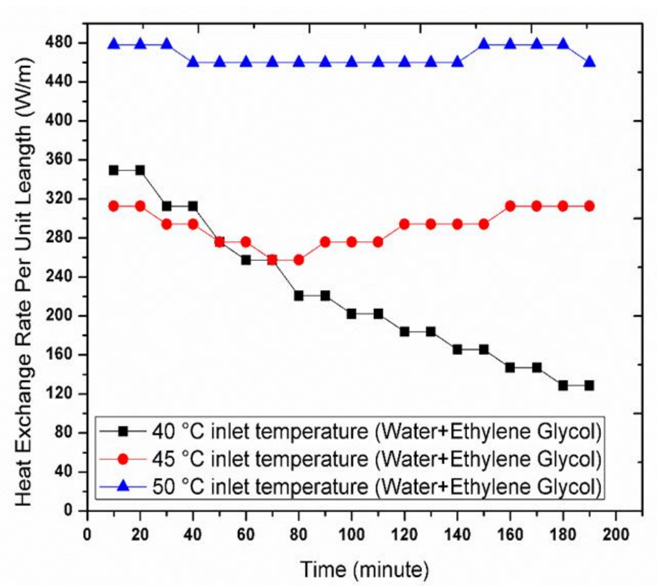


***Fig. 7.** Heat exchange rate for Water + Ethylene Glycol at different inlet temperatures*

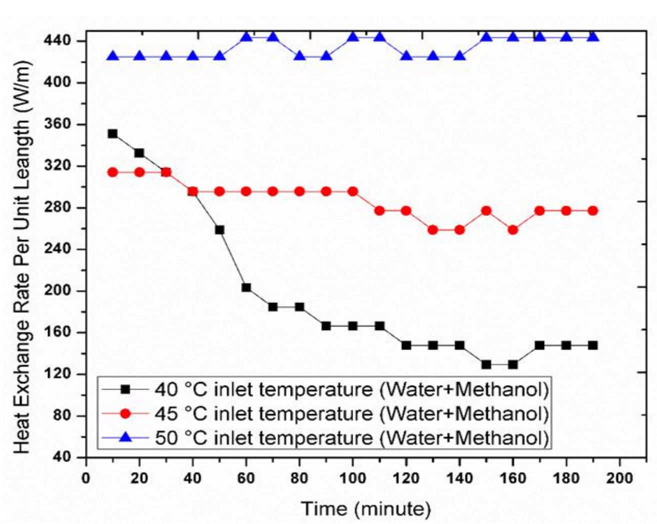


***Fig. 8**. Heat exchange rate for Water + Methanol at different inlet temperatures*

3.2. Thermal Performance of HGHE

The thermal response tests (TRTs) have been carried out for 10 h continuously to compute the rate of heat exchange for the GHE at different inlet fluid temperatures (50°C, 45°C, and 40°C). The different working fluids like Distilled water, Ethylene Glycol+ Distillated Water, Methanol +Distillated Water were flowed through the ground heat exchanger loops. The steady state in circulating water temperature was reached after 2 h in the TRT. Initially, the sand temperature was found to be 22–23°C, and the mass flow rate of working fluid was maintained to be 4 lpm. The heat transfer rate per unit pipe length of horizontal GHE for different working fluids at various inlet temperatures are shown in Figs. 6 -8. Figs. 9 -11 show the average fluid-temperature distribution of horizontal GHE for different working fluids at various inlet temperatures. For water, the average heat transfer rates for the GHEs were 4893 W, 6797 W, and 9244 W at the inlet temperature of 40°C, 45°C, and 50°C, respectively. The corresponding average rates of heat transfer per unit pipe length for the water were 337 W/m, 468 W/m, and 636 W/m at the working fluid inlet temperature of 40°C, 45°C, and 50°C, respectively. For Water + Ethylene Glycol, the total average rate of heat transfer for the GHEs were 5076 W, 4542 W, and 6947 W at the working fluid inlet temperature of 40°C, 45°C, and 50°C, respectively. The corresponding average heat transfer rates per unit length of pipe for the Water + Ethylene Glycol were 349 W/m, 313 W/m, and 478 W/m at the working fluid inlet temperature of 40°C, 45°C, and 50°C, respectively. For Water + Methanol, the total average heat transfer rates for the GHEs were 5102 W, 4565 W, and 4250 W at the inlet temperature of 40°C, 45°C, and 50°C, respectively. The corresponding average heat transfer rates per pipe length for the Water + Methanol were 351 W/m, 314 W/m, and 425 W/m at the inlet temperature of 40°C, 45°C, and 50°C, respectively. From the above analysis, it is found that the maximum heat exchange rate is achieved with water at the inlet temperature of 50°C. The minimum and maximum average fluid temperature for water were 31°C at 40°C inlet temperature and 35.5°C at 45°C inlet temperature. On the other hand, the minimum and maximum average fluid temperature for Water + Methanol was 36°C at 40°C inlet temperature and 38°C at 45°C inlet temperature. The average temperature for the Water + Methanol was higher as compared to the other working fluids, and it is consideration that heat was effectively flowed to the sand by the GHE with water as a working fluid, because of the better thermal and physical property of water.

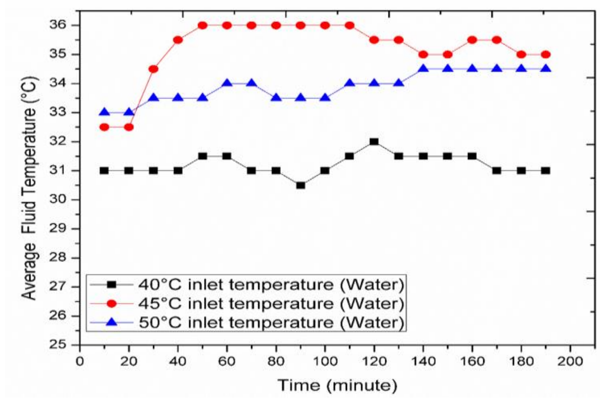


Fig. 9. *Average fluid temperature for water at different inlet temperatures*

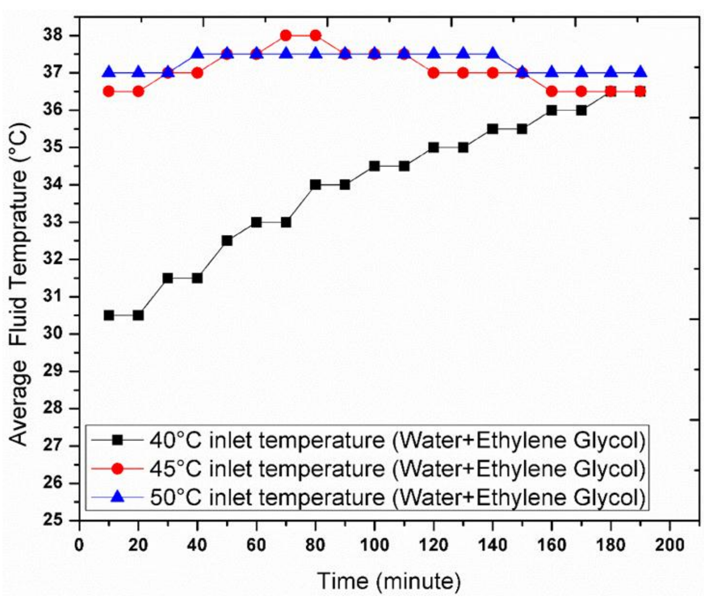


Fig. 10. *Average fluid temperature for Water + Ethylene Glycol at different inlet temperatures*

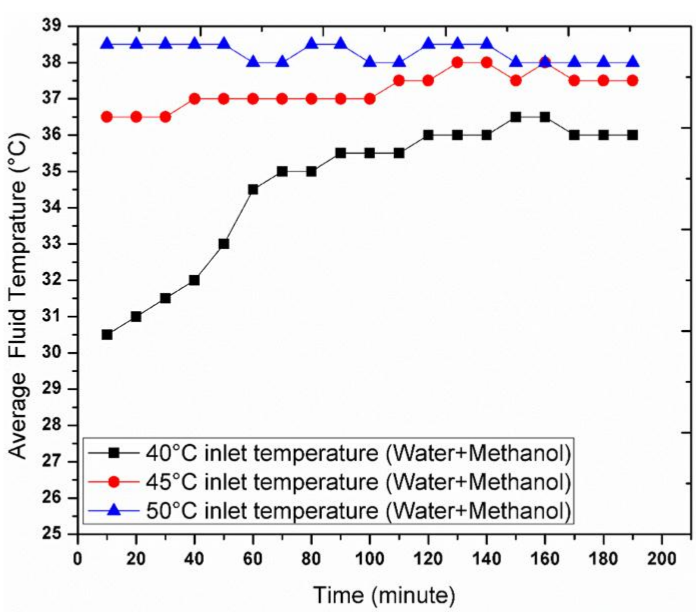


Fig. 11. *Average fluid temperature for Water + Methanol at different inlet temperatures*

4. Conclusion

In this work, a new coil arrangement ground heat exchanger unit is developed. The different coil arrangements i.e. slinky, spiral, and U-type have been arranged in series and formed one loop of horizontal ground heat exchanger. In this model the copper material was used since copper show high thermal conductivity augmentation compared to the extensively employed plastic resources. The prime objective of this work is to assess the thermal performance and parametric study of the developed HGHE. For that the ground heat exchanger experimentations were conducted in the developed experimental setup. In order to authenticate the obtained experimental results, the thermal performance characteristics corresponding to the same coil arrangement as obtained from the developed experimental set-up is compared with the published literature [41]. After the validation, the effects of different operating parameters on ground heat exchanger performances are evaluated based on the experimental results. The thermal response tests (TRTs) were carried out for 10 h constantly to calculate the heat exchange rates for the ground heat exchanger at different inlet fluid temperatures (50°C, 45°C, and 40°C). The different working fluids like Distilled water, Ethylene Glycol+ Distillated Water, Methanol +Distillated Water were flowed through the ground heat exchanger loops. From the analysis, it is found that the maximum heat exchange rate is achieved with water at the inlet temperature of 50°C. The minimum and maximum average fluid temperature for water were 31°C at 40°C inlet temperature and 35.5°C at 45°C inlet temperature. The average temperature of working fluid for the water + methanol was higher as compared to the other working fluids, and it is consideration that heat was effectively flowed to the sand by the GHE with water as a working fluid, because of the better thermal and physical property of water.

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