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Thermal Performance Evaluation of a Double Tube Ground Coupled Heat Exchanger in the Climate of Bangladesh

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ABSTRACT
The ground-coupled heat exchanger (GCHE) is used in space heating and cooling systems to exchange heat with ground soil as a heat source/sink to reduce energy consumption. An experimental investigation is performed in this work to assess the thermal performance of a double tube ground coupled heat exchanger in the climate condition of Bangladesh. A double tube heat exchanger is fabricated using two PVC pipes of different diameter and inserted into 9.14 m depth of the ground. To measure the performance of the heat exchanger, water is circulated through the heat exchanger and temperatures and flow rate of the circulated water are measured. By altering the flow rate, the heat exchanger's rate of heat transfer can be determined. For a period of 12 hours, the water flow rates were 3 lit/min and 5 lit/min. The experiment shows that a flow rate of 3 lit/min gives a higher heat transfer rate per unit length than a flow rate of 5 lit/min. The average rate of heat transfer for the double tube GCHE was 82.36 W/m and 93.28 W/m for the flow rate of 5 lit/min and 3 lit/min, respectively, for the duration of 12 hours.

Keywords: Heat exchanger, GCHE, Heat transfer rate, flow rate.

1. Introduction

A ground-coupled heat exchanger (GCHE) is a type of heat exchanger which exchanges heat with underground soil. The atmospheric temperature is higher than the soil temperature in summer and the atmospheric temperature is lower than the soil temperature in winter. A ground-coupled heat pump releases heat during the summer and draws heat from the ground during the winter. A ground-coupled heat exchanger can be buried horizontally or in vertical boreholes. All over the world, 35% of energy is consumed in building sector for HVAC and heating water [1]. Ground-coupled heat exchanger is mainly used for HVAC and other heating and cooling purpose such as ground-coupled heat pump (GCHP), cooling/melting ice, industrial uses, drying in the agricultural sector, greenhouse heating, space heating, aquaculture pond, and raceway heating, etc. [2].

Geothermal direct utilization had a total installed capacity of 48,483 MWt as of the end of 2009, an increase of 72% from 2005 to 2010 at an annual compound rate of 11.4%. With a compound annual growth rate of 9.2% from 2005 to 2010 [2], the total annual energy consumption is 423,968 TJ (117,778 GWh).

The ground-coupled heat pump is the most efficient heating and cooling system compared to other heating and cooling systems. This system is described as an energy star by the U.S. Environmental Protection Agency [3]. With the help of nature, the ground-coupled heat pump offers efficient, clean, and year-round heating and cooling. GCHPs conserve natural resources by using less energy than other heating and cooling systems. In order to reduce emissions of harmful gases like carbon dioxide, sulfur dioxide, and nitrogen oxides, these technologies are essential.

Heat pumps powered by hydropower or renewable energy, for example, reduce emissions significantly more than heat pumps powered by oil, natural gas, or coal power plants. The GCHP system can reduce CO_2 emissions from 15 to 77 in buildings that are both commercial and residential. GCHP has better efficiency compared to an air-to-air heat pump and other systems [4].

In the field of ground-coupled heat exchangers many pieces of research have been done by researchers all over the world. A 3D vertical GCHE model had been analyzed by Ozudogruet [5]. A new numerical methodology was introduced for the analysis of the geothermal down-hole heat exchanger. This model helps to properly exploit low-enthalpy geothermal reservoirs [6]. Rui et al. [7] had previously investigated how well a geothermal heat exchanger performed when groundwater advection and heat conduction were coupled.

Many experimental works have been done in this field all over the world. The thermal performance of a horizontal-coupled slinky GSHP was tested in the U.K. climate by Yupenget [8]. In a passive house ventilation system, a GCHE experimental measurement and CFD simulation had been done in a cold climate. The mean value of coverage from December to April was 15% of the heat for heating the ventilation air, and in February the GCHE provided 24% of the heat for that purpose [9].

Performance and economic installation of a GCHE greatly depend on the environmental condition, soil temperature, soil properties, pressure drop, flow rate, length and diameter of the heat exchanger, etc. Ali et al. [10] numerically optimized the double tube heat exchanger based on pressure drop.

Ground-coupled heat exchangers are using significantly all over the world. Geothermal district heating capacity has been steadily rising in China, up about 10% yearly. Over the past 15 years, the number of geothermal heat pumps installed in the United States has steadily increased; in 2009, an estimated 100,000 to 120,000 equivalent of 12 kWt units

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were installed. The majority of the installations, at least one million units, have been made.

However, compared to other countries, there is no significant research work being performed in Bangladesh about ground-coupled heat exchangers (GCHE). Bangladesh is situated in the tropical monsoon region and its climate is characterized by high temperature and high humidity. The GCHE-based heat pump has high COP and lower energy consumption. GCHE with a cooling system may significantly reduce the energy consumption of cooling devices as cooling demand is increasing day by day. Using the ground-coupled cooling system, a large amount of energy may be saved in Bangladesh.

Therefore, in this work, an experimental study is performed to investigate the performance of a double-tube ground-coupled heat exchanger in the Bangladeshi climate.

2. Experimental Procedure

A double tube ground coupled heat exchanger is designed using two pipes of different diameters as shown in Fig. 1. The inner tube is 0.0508 meters in diameter, while the outer tube is 0.1016 meters in diameter. Two PVC pipes are used to construct the heat exchanger as shown in Fig. 2. The thickness of the inner and outer pipes is 0.0046 m and 0.00275 m, respectively. The length of the tubes inside the soil is 9.144 m. At the end side of the tubes, a cap is attached. The outer tube is used as the inlet and the inner tube is used as the outlet for the heat exchanger.

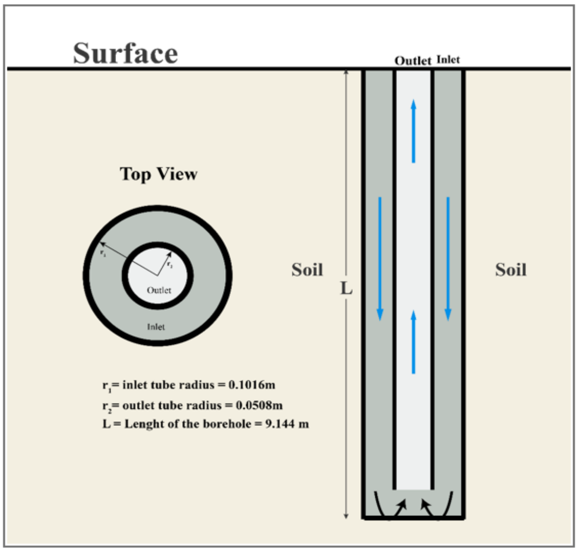

Fig. 1 Schematic diagram of double tube GCHE

An experimental setup is constructed to measure the performance of the GCHE as shown in Fig. 3. Inlet and outlet of the GCHE are connected with a constant temperature water bath. A pump is used to circulate the water through the heat exchanger. A flow meter is used to measure the flow rate and the valve has been used to control the flow rate. Two thermocouples are connected with a double tube inlet and outlet to get the inlet and outlet temperatures. To record all the data, a data logger is connected to each thermocouple. A USB-B cable is used to connect the flow meter to the Arduino board, which is then connected to a computer.

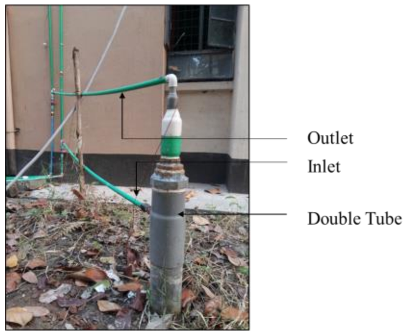

Fig. 2 Constructed view of double tube GCHE

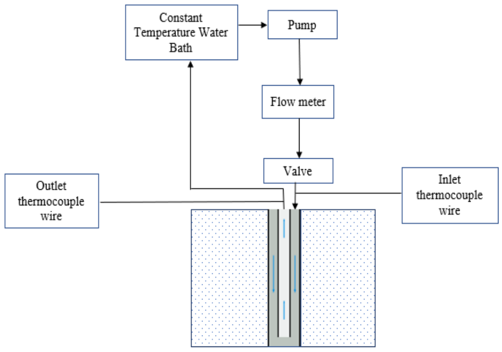

Fig. 3 Block diagram of the experimental setup

3. Results and Discussions

Heat transfer rate per meter tube length was considered for the performance test of a double tube ground-coupled heat exchanger. Two flow rates of 3lit/min and 5lit/min were considered for the flow duration of 12 hours. The inlet and outlet temperatures of GCHE were measured. Fig. 4 shows variation of inlet and outlet temperatures for the flow rate of 5 lit/min with respect to time for the duration of 12 hours. First, inlet and outlet temperature differences are higher, and after some time, it was decreased and became steady. Typically, a 2°C temperature difference was found between the inlet and outlet.

Fig. 5 shows the inlet and outlet temperatures for the flow rate of 3 lit/min with respect to time. First, inlet and outlet temperatures were low and after some time, inlet and outlet temperature were increased and become steady. The temperature difference between inlet and outlet is much higher than that of flow rate of 5 lit/min. Here, an average of 3.83°C difference in temperature was observed between the inlet and outlet.

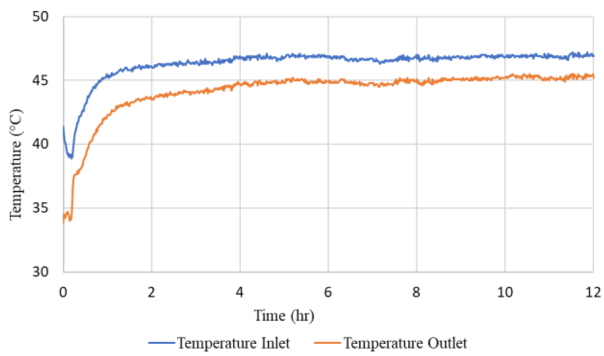

Fig. 4 Temperature changes at the inlet and outlet over time for a flow rate of 5 lit/min

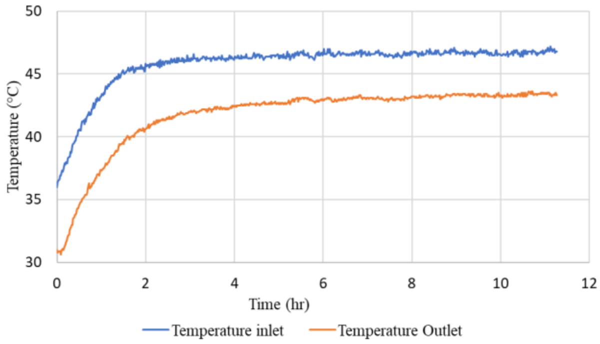

Fig. 5 Temperature changes at the inlet and outlet over time for a flow rate of 3 lit/min

Fig. 6 depicts the heat transfer rate per meter (W/m) over time for a flow rate of 5 lit/min. Initial heat transfer rate per meter seem to be higher; then it gradually decreases and becomes horizontal, and remains that way. The average rate of heat transfer per unit meter is 82.36 W/m.

For a flow rate of 3 lit/min, Fig. 7 depicts the rate of heat transfer per meter with respect to time. The initial rate of heat transfer per meter is high, then it gradually declines and eventually becomes horizontal. 93.28 W/m is the average rate of heat transfer per unit meter.

For flows of 5 and 3 liters per minute, the rate of heat transfer per meter over time is shown in Fig. 8. At a flow rate of 5 lit/min, the rate of heat transfer per meter is lower than it is at a flow rate of 3 lit/min. This is so that heat can be effectively dissipated at lower flow rates.

Jalaluddin et al. [11, 12] experimentally and numerically tested the performance of double tube ground coupled heat exchanger in Japanese climate. The diameters of the outer and inner tube were 130 mm and 40 mm respectively. The materials of the outer and inner tube were PVC and stainless steel. The length of the heat exchanger was 20 m. The average heat transfer rates for 2, 4 and 8 lit/min were 36.9, 49.6 and 54.8 W/m respectively, for 24 hours continuous operations with inlet temperature of 300K. Ali et al. [10] also tested the performance of double tube ground coupled heat exchangers with similar climate conditions and obtained similar performance. Heat transfer rate of the present investigation is higher than these results in Japanese climate. However, soil type, duration of operation, inlet temperature, flow rate, heat exchanger type and material have significant impact on the performance of the ground coupled heat exchangers.

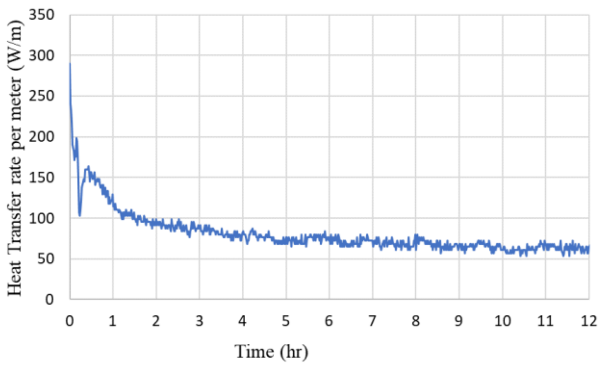

Fig. 6 Variation in the rate of heat transfer per meter over time for a flow rate of 5 lit/min

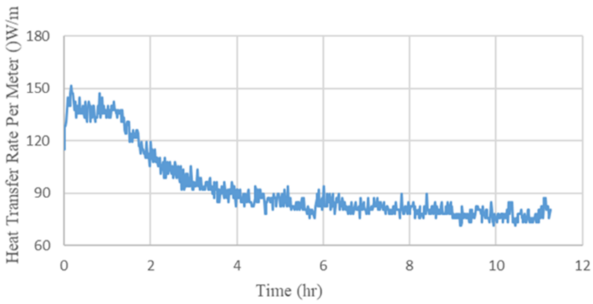

Fig. 7 Variation heat transfer rate per meter with time for the flow rate of 3lit/min

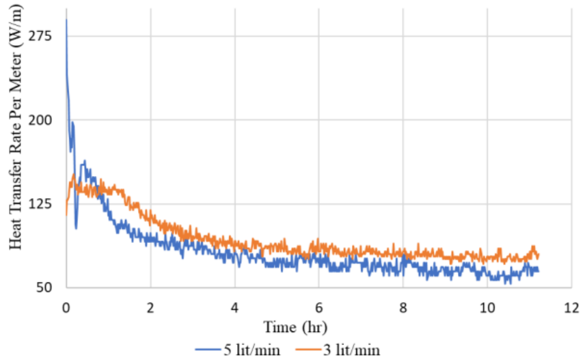

Fig. 8 Heat transfer rates per meter for flows of 3 lit/min and 5 lit/min

The temperature difference between surrounding soil and heat exchanger is higher. For this reason, the heat transfer rate is higher initially. After dissipating heat to the surrounding soil, the temperature difference between the surrounding soil and heat exchanger is decreased. For this reason, heat transfer rate decreased and became steady. Initially the temperature difference between surrounding soil and circulated water was high and showed high rate of unsteady state heat transfer. That is why the heat transfer rate per meter for flows of 5 lit/min has huge spike in the beginning as is shown in Fig. 8.

4. Conclusion

The performance of a double tube GCHE has been tested in this work in the climate condition of Bangladesh. The GCHE was inserted 9.14 meters into the ground. Heat transfer rate is calculated from the measured temperatures and flow rate. From the experiment, the following results can be concluded:

a. The initial rate of heat transfer is higher and gradually becomes steady for both flow rates and durations.
b. The average heat transfer rate per meter length for the GCHE was calculated over a 12-hour period to be 93.28 W/m for a flow rate of 3 lit/min.
c. Over the course of 12 hours, a flow rate of 5 lit/min resulted in an average heat transfer rate per meter length of the GCHE of 82.36 W/m.

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