An Experimental of Enhancement Heat Exchanger (Shell And Coil) by Different Types of Soil

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Abstract. Soil is one of the sources of energy conservation, accordingly, the present work aims to enhance the thermal storage efficiency and the thermal behavior for a heater system integrated with a helical coil cylindrical system. The helical coil, combined with a tank having a cylindrical shape, has a diameter of (250) mm and a height of (600) mm, placed under the electric heater. In the experimental study, latent heat storage materials (soil, sand and their mixture) having a high specific heat were used to raise the thermal storage. Different cases under a constant temperature hot water (80 °C) from an electric heater with 100 W/m² were considered. In the first case, the helical coil was immersed in pure sand in the cylindrical tank, and in second case, the helical coil was immersed in compound (50% sand and 50% soil) in the cylindrical tank, while in third case, the helical coil was immersed in pure soil in the cylindrical tank. These cases were verified for both natural and forced convection with different mass flow rates (0.008 and 0.016 kg/sec). For the forced convection with (0.008 kg/sec), the results indicated that the compound (sand and soil) compared with pure sand gave the best thermal storage duration by approximately (36.84%). There was an increase in the outlet water temperature by (8%), and an increase in the mass flow rate to (0.016 kg/min). The duration was (37%), with an increase of (5.84%) in temperature. The increase of the rate of mass flow led to a reduction in time of the outlet water temperature of discharge process.

Keywords. Soil, Heat exchanger, Thermal storage, Helical coil

1. Introduction
Ongoing requirements to the use of uncomplicated methods in providing cooling energy were applied. Vitkovic et al. [1] studied two cycles in the cooling tower. The first cycle was a natural cooling tower, and the secondary recycling was carried out to moisturize the dry section of the hybrid cooling tower. Somwanshi and Sarkar [2] proved that the cooling strength increases when the cooling towers enter the wet position. The design and analysis work was conducted, using two cycles in a hybrid air cooling. The heat extracting cost via utilizing the suggested process was around 88% less than by electricity. Karthik et al. [3] used two suitable methods; Log Mean Temperature Difference (LMTD) and an Effectiveness-Number of Transfer Units (ε-NTU), to help in maximize the performance and the heat exchanger cost. Mudawar et al. [4] developed the subsequent cooling technologies for hybrid vehicle electronics. The recent models have a methodology for predicting the cooling performance of pressure spray nozzles.
Neuberger et al. [5] prepared the temperature changes in soils “slinky”-type through heat flows, where the horizontal heat exchangers are intricate but they require to be recognized when the robust quantification has to be performed. Analysis of the specific heat flows and the system of thermal energy are within the soil. Sipio and Bertermann [6] presented the parameters that affect the thermal efficiency of the horizontal-ground heat exchangers. Monthly, the field test was monitored to measure thermal conductivity, the moisture content of air, the ground temperature (inside and outside each helix), and the meteorological and ground volumetric water content (VWC) were continuously recorded in the data acquisition. Žandeckis et al. [7] obtained solutions for the energy efficiency and the sustainable heating of ventilation air. The energy balance results in the building and the exchange of air were prepared in an organized way, including the design, the strategy of control and the recovery of heat, and the utilization of the renewable energy sources. Mohammad et al. [8] presented the experimental performance of a direct evaporative cooler operating in humid and hot areas. The output temperature, saturation efficiency, and cooling capacity were used to evaluate the performance of the evaporative cooler. The performance characteristics of a hybrid cooling system were analyzed by Yoon et al. [9], depending on the cooling pad and the evaporator. It was found that the hybrid cooling system is more economic, and determining the cooling capacity from the cooling pads is possible due to the major obtained results. Tu et al. [10] conducted an experiment and modeling of the thermal performance of a ground-heat exchanger in the freezing soil circumstances. They found references and operations for the cold and severe cold climate zones to analyze the future GHEs performance with the phase change processes. Asfand et al. [11] considered the thermodynamic performance and water consumption of the hybrid cooling system configurations for the concentrated solar power plants. The wet cooling utilization in the (CSP) plants has a tendency to be an unfavorable option in the areas where water is scarce owing to the high water needs of process. The balanced process was the generation of power with an increment of (3.2%) and (30%) consumption of water in comparison with the merely wet cooling option. Erkek et al. [12] performed the thermodynamic performance upon a water source heat pump in various working circumstances. The analysis of the energy and exergy from the cycle was found for the obtained measured factors. The outputs were presented to give the power calculation quantity and construction about the components of the system and the cycle. Bell et al. [13] studied experimentally the influence of a specific fouling on the heat transfer of a heat exchanger, and the airside pressure drop of a hybrid-dry cooler. A 50% increase in the heat transfer was shown and was found under a heavy fouling. As well, utilizing the wetting water for washing the coil (plumps fouling off) was studied and determined to be of some usefulness.

The objective of the present work is to use a passive method in which available materials (soil, sand and their mixture) are used to improve the heat transfer since these materials possess the capability to save the energy through utilizing the property of a good thermal conductivity.

2. Experimental setup

In the presented model, the water pumps were first operated to obtain a low temperature to be utilized for cooling the helical coil, and the heater was then run. When the heat was transferred by the water passing inside the tube, water became hot, and the heat exchange occurred between the helical coil and water through the soil. Thermocouples (type K) were located on different places (inside and outside tank 1, on the coil surface, in the inlet and outlet of coil, and at the shell) to measure the temperatures. Figure 1 depicts the schematic diagram of the test rig. The cylindrical coil of tank 2 acts as a magnet when carrying hot water and the shell are formed. The helical coil of the heat exchanger is made of copper tubes. Care was taken to locate the coil on the periphery of the inner shell where it was full of soil. The exchanger was manually assembled and connected with the tank, where it had a heater and a thermometer to heat the water, the tank 2 made of galvanized steel was used as an insulation shell for the heat exchanger. The tank 2 is getting cooled by the water coming from down to up, where the process for continuing the experiment is by controlling temperature. The heat transfer between tank 1 and tank 2 is by thermosyphone. Various components have been used in the test apparatus, for example, the use of a turbocharger (model: LZM-15,
0.2e2 GPM) to measure the rate of flow inside the tank, K thermocouples are installed in the coil entry and exit point (i.e. T1 and T2). Thermocouples were jammed into small fleabags made in input and output tubes from the tank 1 of the coil and sealed to stop any leakage. Two points on the input and output from tank 2 (T3 and T4) of the coil surface and two points of the porous medium (i.e. T5 and T6) were used. First, small channels were made carefully, and then each thermocouple was imbedded in the channels and attached to the coil's surface. Two different points of the tank 2 (i.e. T7 and T8) were utilized to measure the temperature every minutes of the water in the tank 2.

3. Mathematical analysis

The primary energy balance equation for a thermal system in a zero capacitance model, in which the effect of storage capacitance is on a save temperature and the ambient temperature, is neglected and considered to be in environmental equilibrium, is given by:

Useful energy gain = (Heat removal factor absorbed by helical coil) – (Heat losses due to connection, convection, and conduction). The balanced energy from the side of both the helical coil and soil can be found by the following equation:

\[ Q = \dot{m}_w \times C_p \times (T_2 - T_1) \]  

(1)

The heat flux per unit area for flows in a coil of heat exchanger is calculated from:

\[ A_0 = \pi \times d_o \times l \]  

(2)

\[ LMTD = \frac{\Delta T_A - \Delta T_B}{\ln(\frac{\Delta T_A}{\Delta T_B})} \]  

(3)
Where; $\Delta T_A = T_1 - T_2$, $\Delta T_B = T_4 - T_3$ as shown in Fig. 1.

$$q = U \times A \times LMTD$$  \hspace{1cm} (4)

$q$ is the exchanged heat duty (watts), $U$ is the heat transfer coefficient (watts per kelvin per square meter), $A$ is the Tank 2 area, $A_o$ is the coil area, $d_0$ is the diameter tube, $L$ is the long tube and $LMTD$ is defined by the logarithmic mean.

4. Results and discussion

The experimental investigation was done in an invariable condition with a constant power of 1000 W, natural and forced convection during the charge and discharge process. Figure 2 reveals the outlet water temperature for the sensible heat storage material and natural convection. In the charge process, the compound (sand and soil) gives a higher outlet temperature compared with pure sand and pure soil. That is caused by increasing the thermal conductivity of the compound which leads to increased heat absorption. In the discharging process, the compound (sand and soil) gives the best results in comparison with others; the compound (sand and soil) gives heat during (10 min), but pure sand gives heat after (25 min) and pure soil after (50 min). In forced convection with (0.5 kg/min), the compound (sand + soil) gives the heat after the charging process during (3600 sec), (2160 sec) for pure sand, and (1440 sec) pure soil. When the mass flow rate of water increases to (0.016 kg/sec), the compound (sand + soil) gives the heat during (2160 sec), (1860 sec) for pure sand and (1320 sec) for pure soil. Figure 3 shows the effect of the mass flow rate on the outlet water temperature for the sensible heat storage materials (pure sand and pure soil) and the compound sensible heat storage materials (sand + soil) in the forced convection. The experimental results show that the outlet water temperature period time decreased when the mass flow rate of water increased due to the increased heat exchange process between the cylindrical capsule surface and water layers. Figure 4 illustrates the thermocouple reading fixed in the center of cylindrical capsule (charge and discharge process) in the forced convection. In the charge process, pure sand gives a higher temperature compared with others. That is caused by the high thermal conductivity of the pure sand compared with the compound (sand + soil) and pure soil, which leads to increasing the heat absorbed. In the discharging process (after 70 min), the compound (sand + soil) gives a higher temperature for a long duration time. Figure 5 represents the dimensionless temperature variation versus the length of the heat of water in the natural forced convection for pure sand. The dimensionless temperature gradient was used to define the temperature of sand along the heat of water, and it can be observed that the dimensionless temperature increases along Tank 1 heater for the forced convection with 0.5 kg/min. Figure 6 clarifies the useful heat gain for the sensible and compound sensible and the latent heat storage materials in forced convection with 0.008 kg/sec. In the charge and discharge process, the compound (sand + soil) gives the best results compared with the pure sand and pure soil. In the discharge process, specifically in the period from (3000-6000) second, pure sand gives good results, but rapidly dropped and gave the final value in (1740 sec). When the rate of mass flow raises, the beneficial heat gain time decreases as shown in figure 7 for the same sensible and compound heat storage materials. Figure 8 illustrates the system thermal storage efficiency behaved in forced convection with water mass flow rate of 0.008 kg/min. During the discharge process, pure sand exceeded the other materials and gave a pick value of (77%) and reached its final value after (1680 sec). But the compound (sand + soil) gave the best performance for a longer time and reached its final value after (2520 sec). The compound (sand + soil) gave its final value after (40 min). This experimental result was expected as a result of adding the porous media (glass) with pure sand, which operated to increase the thermal conductivity and increase the specific heat for the compound heat water soil mass. This means that the increase of the susceptibility of these materials is to store thermal energy. As the mass flow rate increases, the thermal storage efficiency time decreases, as demonstrated in figure 9.
Figure 2. Outlet water temperature in natural convection versus time with various heat storage materials.

Figure 3. Outlet water temperature in forced convection (0.008 kg/sec) versus time with various heat storage materials.

Figure 4. Outlet water temperature in forced convection (0.016 kg/sec) versus time with various heat storage materials.
Figure 5. Effect of mass flow rate on the outlet water temperature for pure sand.

Figure 6. Effect of mass flow rate on the outlet water temperature for pure soil.

Figure 7. Effect of mass flow rate on the outlet water temperature for compound (50% sand + 50% soil).
Figure 8. System thermal storage efficiency versus time in forced convection (0.008 kg/sec) with various heat storage materials.

Figure 9. System thermal storage efficiency versus time in forced convection (0.016 kg/sec) with various heat storage materials.

5. Conclusions

1. The compound material (50% sand and 50% soil) gave the best thermal storage time of (2280 sec) during the discharging process of forced convection with (0.008 kg/sec) and (2100 sec) for the forced convection with (0.016 kg/sec) in comparison with that for the pure sand (1440 sec) and (1320 sec) for the forced convection with (0.008 kg/sec) and (0.016 kg/sec), respectively.

2. The increase of the rate of mass flow led to a reduction in time of the outlet water temperature of discharge process.
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