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Optimizing the performance of solar water heater energy storage system using phase change materials

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Abstract

Phase change materials (PCMs) can be used in solar water heaters to store excess heat energy available during sunny hours. The purpose of this study is to investigate the performance of the solar water heater system with heat pipe, along with the energy storage system containing phase change materials (PCMs). In this study, a cylindrical galvanized tank with double spiral coil and containing PCM acts as a thermal energy storage unit. Paraffin is used as PCM and water is used as a heat transfer fluid (HTF) to transfer heat from the water heater tank to the spiral tubes and from there to the energy storage tank. The charging and discharging process tests are carried out on sunny days and in real operating conditions. The importance of temperature changes of HTF heat transfer fluid and PCM phase change material as well as the range of changes have been discussed. Functional variables of charge and discharge energy and thermal energy efficiency have been studied. The calculated charging efficiency, 75.7 %and the efficiency of the energy storage unit for the discharge process was 61.1 %. PCM saved 2700 kJ of heat in 70 minutes for 80 ° C during charging and 1650 kJ of heat in 50 minutes at 25 ° C and 42 liters per minute in storage, discharge. He made energy. From the tests, it was found that PCM improves the performance of the system by increasing the charging energy efficiency and the thermal efficiency of the hot water storage tank.

Keywords: solar energy, phase change material, water heater with heat pipe, energy storage tank, charge, discharge.

1. Introduction

A tank with a new design has been used to improve the performance of the solar water heater at night (Awani et al. 2021) [1]. This research estimates that about $4,265 in energy savings will be saved over 8 years. Since the high cost of energy in most parts of the world is one of the things that drives research into energy conservation, this innovation could work. PCM modules embedded in a spiral heat exchanger have been used in a solar water heater system (Fahad and Koc. 2022) [2]. The thermal performance of the system at sunset using PCM is improved by about 18% compared to when PCM is not used. The absorption performance of the absorber plate of a thermosyphon solar water heater with and without PCM storage was investigated (Siyahruddin et al. 2020) [3]. The results show that the use of paraffin as PCM inside the absorbent plate gives better performance compared to the absorbent plate without PCM. The performance of a V-shaped solar collector plate combined with stearic acid phase change material was investigated in comparison with a flat collector plate (Halim et al. 2020) [4]. The results showed an increase in performance of 3.7%, 9.9% and 11.3% for the flow rates of 0.5, 1 and 1.5 liters per minute of the V-shaped collector compared to the normal flat plate collector.

During the previous tests, it has been mentioned that an electric heater is usually used as a heat source to heat water during the performance studies of solar water heaters, which does not create real operating conditions. Also, in some cases, PCM material has been used as a module inside the water storage tank. So; In order to create real conditions, heat pipes have been used as a heat source to heat water during the experiments of this research. Also, the energy storage tank operates independently from the water storage tank. Charge and discharge tests with PCM have been done to study the system performance. Water cannot be removed from the cycle during the tests. The main objectives of this study are (a) to evaluate the thermal performance of the solar DHW system with a tank containing PCM using a heat pipe as a heat source, (b) to find the effect of the phase change material (PCM) in a solar water heater.

2- Methodology

The experiments were carried out in March in northeastern Iran, the city of Mashhad (longitude: 59.6042 east, latitude: 36.3069 north), which is located at an average height of 1050 meters above sea level. The average temperature is 25 to 35 ℃ in summer and 13 to 25 degrees Celsius in winter. A schematic diagram of the setup of the test device is shown in Figure (1). The setup of the device includes a stainless steel insulated cylindrical water tank, heating pipes, galvanized PCM tank, data logger or data recorder, thermocouples, inlet and outlet pipes and circulation pump.

The thermal energy storage tank is made of galvanized material with a capacity of 24 liters and is insulated with glass wool and foam. Heat transfer between PCM and HTF is done through double spiral copper pipes inside the energy storage tank. The water tank of the device with a capacity of 120 liters is able to supply water for a family of 4 people. The thermal energy storage tank is integrated with the HTF tank to transfer heat to the PCM.

When the solar radiation falls on the heat pipes, the heat pipes absorb the solar energy and the heat is transferred through the absorbent liquid inside the heat pipes which is indirectly connected to the tank containing HTF. It heats the water. Here, water is used as HTF to transfer heat to the energy storage tank. The hot water, which is located in the highest layer of the tank, enters the energy storage tank through the insulated pipes and with the pressure of the pump that is on the way, and after passing the path of the coil inside it, it goes down again. The first layer is entered from the tank.

PCMs fall into three categories: 1- hydrated salts, 2- paraffins and 3- non-paraffin organic substances. In this experiment, 58 grade paraffin was used as PCM, and its melting temperature is between 56 and 58 degrees Celsius. The reason for using paraffin is that it is easily available and usually cheaper than hydrated salts. Several works have been done to study the thermal properties of paraffin during melting and freezing processes. Paraffin is known as a non-toxic, attractive and chemically stable substance without destructive effects and has a high latent heat storage capacity in a low temperature range. PCM is placed in a galvanized column tank with an inner diameter of 210 mm and a height of 710 mm with a wall thickness of 2 mm. The PCM tank contains 12 kg of paraffin. The PCM was heated above its melting point before being placed in the tank, to avoid any problems that might arise due to volume expansion. PCM and HTF temperatures are recorded at 10-minute intervals using a HEATCON 8003/USB data logger, which can measure temperatures with an accuracy of 1℃. Also, the flow rate of HTF through the system is measured in a period of 10 minutes. Solar radiation has been measured using a TES-1333 radiation meter with an accuracy of ± 10W⁄m2.

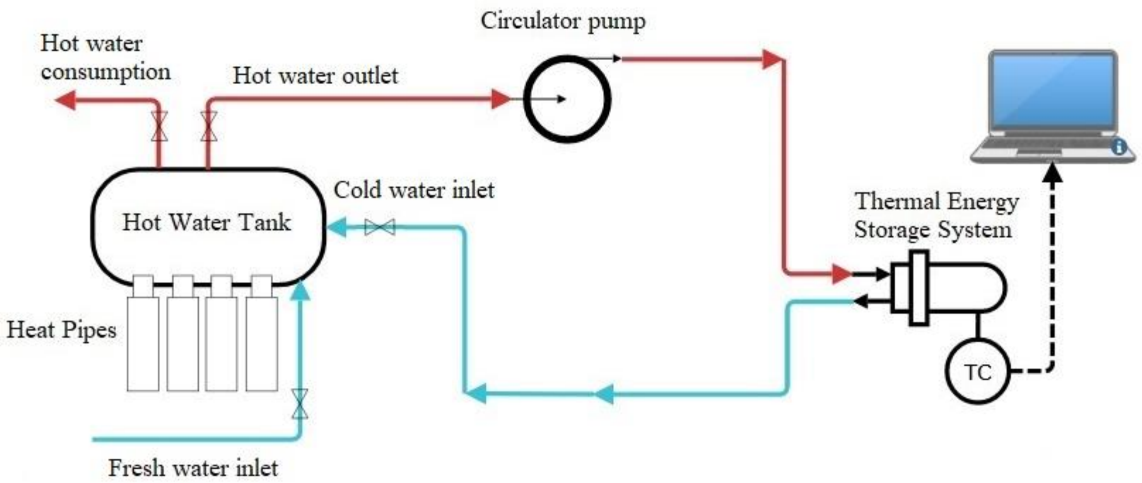

Figure (1): Schematic of the test device

3- Tests results

In this section, the results obtained for charging and discharging processes are presented separately. Charging and discharging tests have been carried out for volumetric flow rates of 14, 21, 42 L⁄min on three different days.

3-1 Charging process

The charging process starts at 10 am on three different days when the HTF temperature in the tank reaches 80 degrees Celsius. During the charging process, the compensatory cold water inlet and hot water outlet of the tank are closed. The reason for this is the better control of the tank temperature at 80 degrees in order to provide better charging conditions for the PCM tank.

3-1-1 Charging efficiency

The power of HTF charging energy ($\dot{Q}_{c,HTF}$) is calculated from the following equation [5,6]:

$$\dot{Q}_{c,HTF} = \dot{m}_{HTF} C_{p,HTF} (T_{in} - T_{out}) \quad (1)$$

As a result, the total energy of HTF ($Q_{c,HTF}$) can be calculated by adding the power given during charging [5,6]:

$$Q_{c,HTF} = \sum_{t=0}^{t_c} \left(\Delta t_c \dot{Q}_{c,HTF} \right) \quad (2)$$

Here Δt_c is the time interval (s) between both stages and t_c is the melting time. During the charging process, the PCM stores about 2700 kJ of heat. However, the total heat given by HTF for charging 2700 kJ of heat in the storage unit, which was calculated using equation (2), was equal to 3567 kJ. The charging energy efficiency (η_c) of the storage unit can be defined as the ratio of the stored energy of the PCM to the total energy provided by the HTF [6,7]:

$$\eta_c = \frac{m[C_{ps}(T_s - T_{ini}) + L_f + C_{pl}(T_f - T_l)]}{Q_{c,HTF}} \quad (3)$$

where T_f is the final temperature of the PCM. Therefore, the calculated charging efficiency is 75.7%.

3-2 Discharging process

The process of energy discharge starts when the HTF temperature inside the tank reaches 25℃, from 6:00 PM and on three different days. To reach the temperature of the water in the tank to 25 ℃, after the completion of the charging process, the inlet and outlet of the energy storage tank were first closed, and then about 40 liters of hot water was consumed in the tank every hour and replaced with the same amount of cold water. During the energy discharge process, the compensatory cold water inlet and hot water outlet of the tank are closed. The reason for this is the better control of the tank temperature at 25 ℃ in order to provide better conditions for PCM tank energy discharge.

3-2-1 Discharging efficiency

Similar to the charge energy efficiency, the discharge energy efficiency of the energy storage unit can be defined as the ratio of the heat received (recovered) by the HTF during the discharge process to the heat stored in the unit [27,26,23]:

$$\eta_d = \frac{Q_{d,HTF}}{m[C_{ps}(T_s - T_{ini}) + L_f + C_{pl}(T_f - T_l)]} \quad (4)$$

Using equation (4), the efficiency of the energy storage unit for the discharge process is 61.1%.

4- Discussion

In this research, the melting and freezing behavior of paraffin in a heat exchanger with a double horizontal spiral coil was investigated during the melting and freezing processes. The influence of the operating parameter of the HTF flow rate was studied in detail and the physics of heat transfer during the paraffin phase change process was explained. The low thermal conductivity of PCM caused significant thermal resistance to heat transfer in PCM. Therefore, changing the flow rate was effective to overcome the thermal resistance of PCM. It was found that the charging time of PCM decreases with the increase of HTF input speed due to the increase in displacement and the large temperature difference between PCM and HTF. The flow rate had a significant effect on the PCM solidification process; Because discharge was mainly controlled by conduction. It was observed that the discharge time was affected by the HTF flow rate, and a higher flow rate resulted in a shorter discharge time. The PCM stored 2700 kJ of heat in 70 minutes for an HTF inlet temperature of 80°C during charging, and 1650 kJ of heat in 50 minutes at an HTF inlet temperature of 25°C and 42 L/min in the storage, discharge unit. Energy did. The results of this analysis are expected to be applicable to the design of latent heat storage spiral heat exchangers, especially for solar heating applications.

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