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Experimental Performance Study of Helical Coil Thermal Storage Unit Filled with PCM

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Abstract : The present work is an experimental performance of helical coil thermal storage unit filled with phase change material (PCM). Paraffin is considered as a storage material. An experimental testis conducted in order to study the characteristic of PCM during charging and discharging process at various parameters such as inlet heat transfer fluid temperature and volume flow rate of heat transfer fluid (HTF) as water. The temperature of the PCM measured and examine the charging and discharging process of PCM. The effect of inlet HTF temperature, volume flow rates and the thermal effectiveness are analyzed. The result of the present study is concluded that the volume flow rate is not much effect on the discharging phase compared to the charging phase.
Keywords : Helical coil thermal storage unit, PCM, Melting and solidification.

1. Introduction

The demand for alternative energy solutions in recent years has increased by leaps and bounds as a means for reducing pollution and consumption of petroleum products. Another equally important need is to develop energy storage devices which can store and convert energy in the required form, and achieving this is challenge. In most of the resent research on energy storage with phase change problems investigated within the temperature range of 0–100 C suitable for heating and cooling applications. Most of the energy storage analysis used common PCMs such as paraffin, fatty acids, stearic acid, n-octadecane and salt hydrides. The PCMs are used based on their thermo-physical properties[1,2]. A PCM is a material that stores and supplies heat at its solidification and melting temperature (known as charging and discharging) using its high thermal energy storage density per unit volume by its latent heat, which is much higher than the sensible heat[3].The phase change materials including organic, inorganic, eutectic and ionic liquids are reviewed with respect to their thermal energy storage capacity. Finally summarized, melting temperature range of -10°C to 100°C is selected the most popular applications and the out of the materials, melting in this temperature range, those with highest heat of fusion and density are shortlisted[4]. Energy storage not only provides continuous supply but also conserves energy by improving the reliability and performance of energy systems. A waste heat recovery system with a TES tank is fabricated to improve the heat recovery by using PCM. In the study a shell and tube heat exchanger and a PPCM based TES tank were designed and fabricated and tested with a diesel engine. The investigation is concluded that the maximum heat extracted and stored and also heat recovery increased by using proper insulation[5]. The PCMs used as a storage material results in long heat absorption and especially long heat removal periods of a PCM storage container, because natural convection does not aid the solidification process[6]. An experimental study is conducted in order to investigate the melting and solidification processes of paraffin as a phase change material (PCM) in a tube in shell heat exchanger system. The results evaluated and concluded that an increase of the inlet temperature of the HTF is shown to decrease the melting time and for lower energy consumptions, lower values of the mass flow rate of the HTF are suggested[7]. The heat storage applications used as a part of solar water-heating systems, solar air heating systems, solar cooking, solar green house, space heating and cooling application for buildings, off-peak electricity storage systems, waste heat recovery systems. That paper also presents the melt fraction studies of the few identified PCMs used in various applications for storage systems with different heat exchanger container materials[8]. The use of phase change materials in solar domestic hot water system would improve the performance of the system due to high energy storage density and isothermal operation. PCMs can improve the thermal stratification of energy storage tanks. The experimental observations concluded that the usage of different combinations of PCMs with design modifications, PCM container and the performance enhancement of solar water heating systems[9]. The studies show that commercial grade paraffin wax and other pure paraffin have stable properties after 1000–2000 cycles. Paraffin wax did not show regular degradation in its thermal properties after repeated melting/freezing cycles. They are compatible with all metal containers and easily incorporated into heat storage systems and care should be taken when using plastic containers as paraffin have a tendency to infiltrate and soften some plastics[10]. In the helically-coiled-tube heat exchanger, the secondary flow is induced mainly by the centrifugal force (centrifugal range), the buoyancy force (buoyant range), or by both (composite range), according to operating conditions[11]. An experimental setup is designed for simultaneous charging and discharging thermal energy in the storage unit. Three different cases are studied; initially unstratified and stratified storages units, and initially unstratified storage unit at the top and stratified at the bottom. These three cases indicate that water can be boiled within 2 hours of the charging/discharging cycle and a sufficient amount of energy can be stored[12]. The effects of naturally available heat transfer improvement methods for the melting and solidification behavior of PCM are discussed. The thermal conductivity enhancement techniques in the PCM are metal foam, expanded metal mesh, expanded graphite, the addition of fins and nanoparticles to the PCM[13]. From literature studies shows that the suitable heat exchanger with PCM is gives better performance for thermal storage tank. The aim of this study is to investigate the effect of inlet temperature and flow rates of HTF and effectiveness of PCM. The storage geometry is the cylindrical tube filled paraffin wax with helical coil through which the HTF is flowing. In order to investigate the thermal performance of the PCM during the melting and solidification processes, an experimental study is performed.

2. Experimental Setup

In order to evaluate the performance of the TES unit is constructed and an experimental system set up as shown in fig.1. Experimental setup consists of hot water tank, cylindrical thermal storage unit with helical coil and temperature controller with display setup.

Fig 1. Photographic view of experimental setup

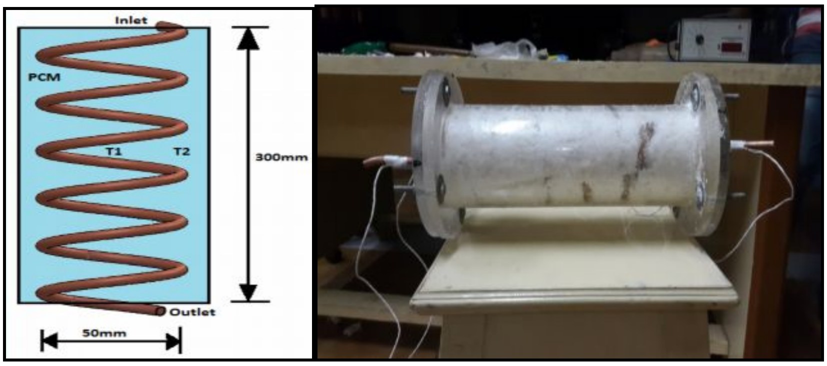

Fig 2. Positions of thermocouples and Acrylic storage cylinder filled with PCM

Thermal storage unit is a cylindrical transparent acrylic chamber filled with PCM as shown in fig.2. The hot water flows the constant temperature bath to the single tube helical coil which is made of copper with a diameter of 50 mm.

In the first step the acrylic chamber is filled with lab grade PCM and the properties of PCM is given in table 1. Three thermocouples are used in the chamber for measuring the temperatures of the PCM, while melting and solidification of PCM. Initially the charging process took place in which the hot water is passed through the coil at a constant temperature of 70 and 75°C.The charging process continued till outlet heat transfer fluid attained same as inlet fluid temperature and in the next step the discharging process takes place in which constant temperature of cold water s passed through the coil at 30°C. Three different volume flow rates (78l/h,80l/h&82l/h) are used to perform the experiment. The temperature variation of the water and PCM during charging and discharging process are noted every 20 min in all five thermocouples.

Table 1. Properties of Phase Change Material

Storage material (PCM)	Melting temperature (°C)	Density (kg/m^3)	Thermal conductivity(W/mK)	Specific heat (kJ/kg K)	Latent heat (kJ/kg)
Paraffin	55-60	900	205	1.469	256

3. Results and discussion

In this work presents the results of PCM temperature distribution and experimental results obtained with various heat transfer flow rates of 78, 80 and 82 l/h respectively. The paraffin wax is heated during charging process and cooled during discharging period at constant temperature of heat transfer fluid.

3.1 Effect of PCM temperature

In fig. 3, 4 and 5 shows the temperature variations of the PCM and the hot water during charging and discharging process for 78, 80 and 82 l/h respectively. During charging process initially, the temperature of the PCM was equal to the room temperature but as the time increase the temperature of the PCM increases. Initially, the change in phase occur symmetrical across the chamber but due to the position of the coil the melting process near the coil was higher. The difference between the values of these temperatures lies in the heat storage process of the PCM, which differs from a position to another due to the natural convection phenomenon. After 100 min, the paraffin is completely melted and the charging process stopped when the inlet and outlet temperatures are same.

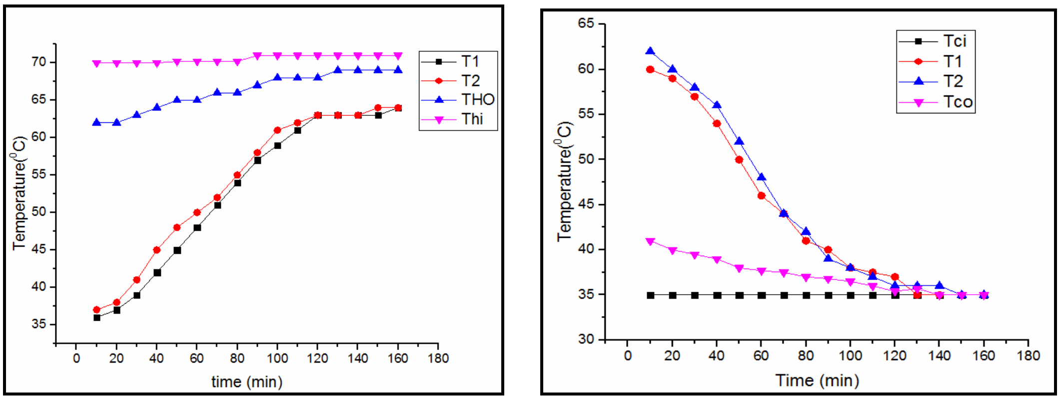

Fig 3. Charging and discharging processes for 78 l/h

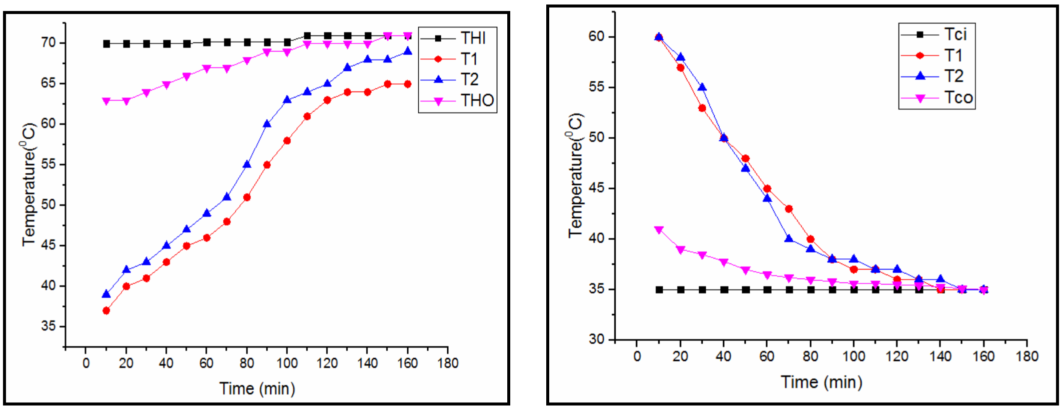

Fig 4. Charging and discharging processes for 80 l/h

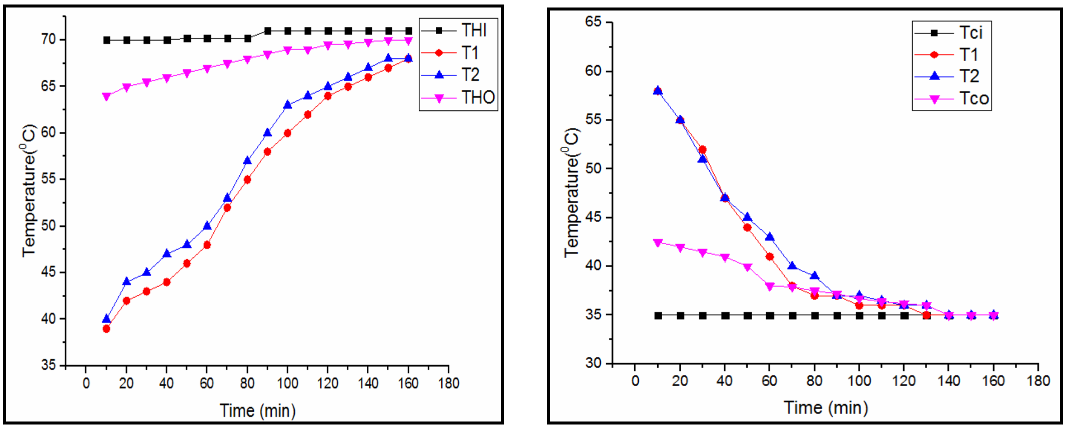

Fig 5. Charging and discharging processes for 82 l/h

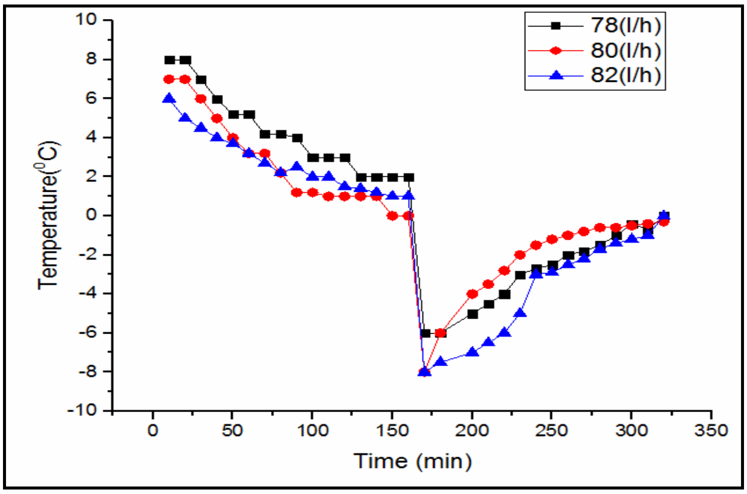

Fig 6. Effect of volume flow rate on the water temperature difference using PCM

3.2 Effect of HTF temperature

In Fig. 6 shows the evolution of the water temperature difference between outlet and inlet for different volume flow rate at the beginning of the charging phase. The temperature difference is higher for higher mass flow rate and after 50 min it is abruptly decreased. During the discharging phase, the water outlet temperature becomes more crucial than the inlet one, the temperature difference becomes negative. In complete values, the temperature difference is maximum at the beginning of the discharging phase and decreases exponentially with some fluctuations. A fluctuation appearing on the temperature difference curves reflects the complicated phenomenon of the phase change that implies conduction and natural convection which their predominance varies in time, absorption and liberation of the latent heat at the phase change front.

3.3 Effect of volume flow rate of HTF

In Fig. 7 shows the effect of the volume flow rate of water (78, 80 and 82 l/h) on the different temperature of the PCM at T_1. The heating of PCM is accelerated by increasing the volume flow rate. Fig. 8 shows that the same thermal behaviour is observed at T_2. Thus, the increasing of the HTF flow rate accelerates the charging process in all positions. By increasing the volume flow rate of hot water the supplying heat increases, and thus the stored thermal energy. This action is observed from the graph that as the mass flow rate of the HTF increases the temperature during the charging increases. However, it is vise-versa for discharging process.

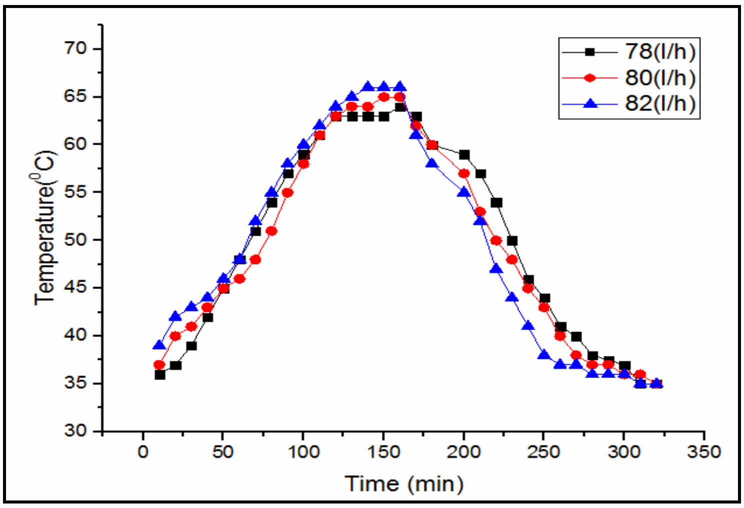

Fig 7. Effect of volume flow rate on the temperature evolution of PCM at 70 °C.

3.4 Effectiveness

The PCM storage unit can be analysed as a heat exchanger where heat is transferred between the HTF and the PCM. The effectiveness of this process is equal to the ratio of the actual heat transfer to the maximum possible heat transfer, as presented in equation (1). Where T_{in} and T_{out} represent inlet and outlet temperatures of the HTF and T_m is the phase change temperature of the PCM.

$$\varepsilon = \frac{T_{in} - T_{out}}{T_{in} - T_m} \qquad \text{------ (1)}$$

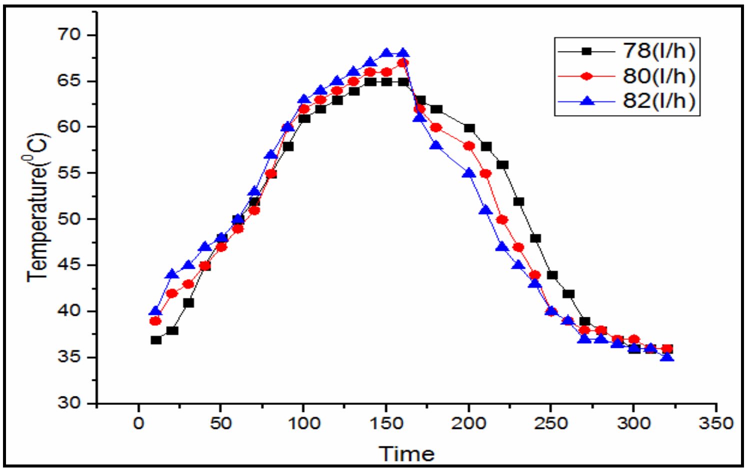

Fig 8. Effect of volume flow rate on the temperature evolution of PCM at 75°C. of solidification, the effectiveness decreases for flow rates.

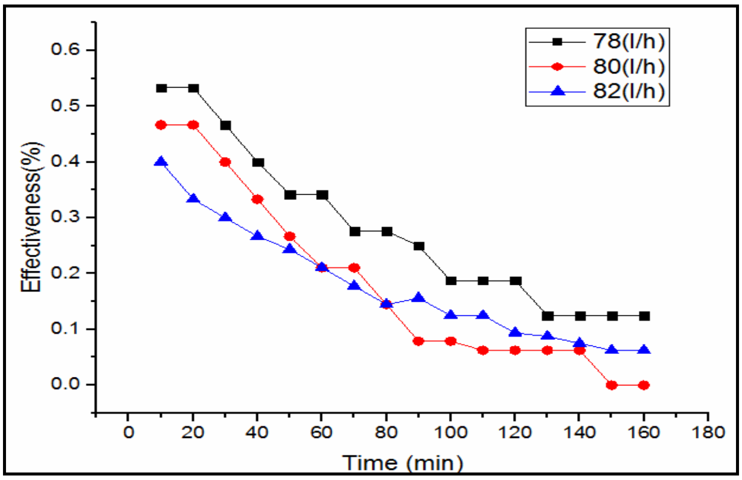

Fig 9. Effectiveness of the PCM during charging process for different volume flow rate.

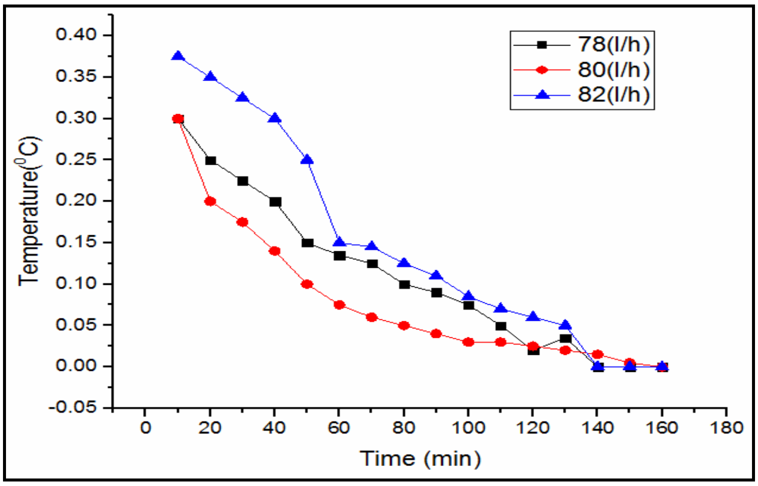

Fig 10. Effectiveness of the PCM during discharging process for different volume flow rate.

In Fig. 9shows the effectiveness of the PCM storage unit during charging process for different volume flow rate and inlet temperature. At the beginning, the effectiveness is maximum and during the melting transition the effectiveness remains almost constant and decreases slowly to reach. Indeed, the PCM makes it possible to offer an almost constant outlet temperature during the phase change period; the exchanger effectiveness becomes almost constant. Overall, the figure shows that the effectiveness decreases with increasing the volume flow rate of HTF. Increasing the flow rate involves the reduction of HTF temperature difference between inlet and outlet, the effectiveness decreases. It observes that the effectiveness can increasing by decreasing the mass flow rates of HTF by eight times. In Fig. 10shows the effectiveness of the PCM storage unit during discharging process for different volume flow rate and inlet temperature.

4. Conclusion

The present work has been conducted to study the melting and solidification characteristics of a PCM as paraffin. During the charging process, the melting transition develops symmetrically due to the presence of the heat conduction that dominates heat transfer and deforms thereafter due to natural convection occurs and gradually dominates heat transfer compared to the conduction. During discharging process, the solidification transition progresses from the bottom this behaviour is due to the presence of the natural convection in the liquid phase, which promotes the dissipation of heat upwards. While increasing the mass flow rate from 78l/h to 82l/h there was an accelerated charging process for all the temperature points while during discharging it decreased from 78l/h to 82l/h.As increasing the mass flow rate from 78l/h to 82l/h there was decrease in the temperature difference as the values changes exponentially. Volume flow rate of 78 l/h ensures a better charging and discharging processes. A high inlet temperature leads to a better thermal dynamic of the charging and discharging processes. However, a low inlet temperature leads to a uniform charging and discharging processes.

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