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Experimental Performance Enhancement of Thermal Storage with PCM

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ABSTRACT

In this paper, deals with the comparative heat transfer performance of shell and tube PCM (Phase Change Material) thermal energy storage unit. The present work influence of design on charging (melting) and discharging (solidification) of PCM in the storage unit. A thermal storage unit is designed with one central copper tube with a diameter of 0.0165m, four copper tubes distributed in the storage tank with a diameter of 0.01m and inside the shell diameter of 0.1m. An experimental test, charging and discharging process through four tubes is considered as setup 1 and charging through four tubes and discharging through one central tube is considered as setup 2. The experiment is carried out by setup 1 and 2 with different flow rates. Experimental results show that the performance of discharging through the central tube is slightly increased when to compare the discharging through the four tubes. The thermal efficiency is increased 5% in the setup 2 compare then the setup1.

Keywords: Experimental study, PCM, Charging and discharging.

1. INTRODUCTION

An energy storage (TES) is attained with greatly differing technologies that collectively accommodate the extensive range of needs. Phase Change Materials (PCMs) are more attractive for heating and cooling in building applications, solar applications, energy storage applications, and heat exchanger improvements. Thermal energy storage may be in the form of latent heat (heat of fusion), as sensible heat in the solid or liquid state, or as chemical energy. Garg et al. (1985) the 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. Mithat Akgun et al. (2007) presented an experimental investigation of melting and solidification characteristics of a phase change material as paraffin. The PCM is placed in an annular space between a tube in which the heat transfer fluid (here, water) is flowing and a concentrically placed outer shell. In order to enhance the heat transfer during the melting and freezing by tilting the outer surface of the storage container. Finally concluded that increase of the inlet temperature of the heat transfer fluid HTF is shown to decrease the melting time. For lower energy consumptions, lower values of the mass flow rate of the HTF are suggested. Vyshak and Jilani (2007) numerically analyzed the effect of different configurations of latent heat thermal storage (LHTS) systems which have the same volume and surface area of heat transfer. From results presented that the cylindrical containers take the least time for equal amounts of energy storage, and this geometric effect is more pronounced with an increase in the mass of the PCM. Jegadheeswaran and Pohekar (2010) numerically found the performance enhancement of a shell and tube LHTES unit dispersing high conductive particles in the PCM during charging process (melting). Both of them concluded that in dispersing high conductive material in PCM, the performance could be improved significantly. Ranjbar et al. (2011) investigated the effects of utilizing nanoparticles as an enhancement of heat transfer in a three dimensional cavity. They showed that the suspended nanoparticles substantially increase the rate of heat transfer. Hosseinizadeh et al. (2012) numerically investigated the melting of nano-enhanced phase change materials (NEPCM) inside a spherical container. The experiment included that a kind of paraffin (RT27) as a base material and copper particles as nanoparticles to improve the thermal conductivity of base material. The variation of PCM solid fraction with time is compared to cylindrical shells and rectangular storage arrangements, with the same volume and heat transfer surface area. The results indicated that the PCM solidifies more quickly in the cylindrical storage shell than in rectangular one. Hosseini et al. (2012) presented the experimental and numerical study of thermal and heat transfer characteristics of Paraffin during charging and discharging process inside a shell and tube heat exchanger. Various experiments are carried out to investigate the effects of increasing the inlet temperature of the heat transfer fluid (HTF) on the charging and discharging process of the PCM. As resulted that increasing the inlet temperature of HTF from 70 °C to 75 and 80 °C, an efficiency in charging and discharging process rises from 81.1% to 88.4% and 79.7% to 81.4% respectively. Gang Li (2015) presents the scope of various useful techniques adopted in detail for energy and exergy performance enhancements, and provides the perspectives for researchers and engineers to design more efficient latent TES systems. The influence factors include the HTF mass flow rate, HTF inlet temperature, PCM melting temperature, additives for PCMs, reference temperature, storage unit dimension, heat exchanger surface enhancement, and sensible heating and sub-cooling. From literature studies show that the geometrical design is more important to enhance the thermal energy storage. In order to enhance the storage performance, shell and tube heat exchanger is selected and also paraffin is considered as a storage medium. The present storage unit designed with the different diameter of copper tubes in the storage tank.

2. MATERIALS AND METHODS

Experimental setup: An experimental setup of present study consists of the hot water tank with thermostat controller, cold water tank, and PCM storage setup. The cylindrical storage unit consists of one central copper tube has 0.0165m diameter and 4 tubes of 0.01m diameter in shell of 0.1m diameter as shown in fig.1. The specification of the storage unit is given in table 1. Three thermocouples are placed at different places in the thermal storage tank to measure the temperature of PCM during charging and discharging process. In storage unit where the temperature of PCM at t_1, t_2 &t_3 are the locations of 0.03, 0.026 &0.15 respectively.

Fig.1.Storage tank configuration

During charging, the constant temperature of HTF is passed through the inlet of the thermal storage tank and outlet of the thermal storage tank is connected to the bottom of a cold water storage tank. Initially, stir the water from hot water tank to cold water tank with the help of pump to get the stable temperature. After getting the stable temperature open the shut-off valve at the inlet of the thermal storage tank and set the flow rate required. Digital thermometers are used at the inlet and outlet of the thermal storage tank to know the amount of heat absorbed. During discharging process, the hot water valve is closed and then the bottom cold water tank is filled with cold water. The cold water is circulated through the thermal storage tank to absorbing the heat energy of the PCM. During the test, charging and discharging process through four tubes is considered as setup 1 and charging through four tubes and discharging through one central tube is considered as setup 2. T_1 and T_2 is the mean temperature of the setup 1 and 2 respectively.

Table.1.Specification of thermal storage tank

Specimen	Material	Diameter (mm)	Length (mm)	Thickness (mm)
Storage tank	Acrylic	100	300	5
Central tube	Copper	16.5	300	0.405
Tubes	Copper	10	300	0.205

Thermal analysis: The thermal performance of the PCM storage unit is analyzed by the heat energy absorbed by PCM during charging and discharging process and efficiency of heat exchanger setup 1 and setup 2. The volume of the shell is initially found to determine the maximum capacity of PCM. Thermal instantaneous power (q) and cumulative energy gained by the water (Q_{ch}/ Q_{ds}) during charging/ discharging can be expressed as below:

$$q_{ch} = \dot{m}C_p(T_{in} - T_{out}) \tag{1}$$

Where, $\dot{m}$ is the mass flow rate, C_p is the specific heat, T_{in} and T_{out} are the inlet and outlet temperature of HTF(water). Varying heat power (q) and aggregated energy given by HTF during charging and discharging can be expressed:

$$Q_{ch\&\mathrm{dis}} = \sum q_{ch\&dis} \tag{2}$$

Heat absorption by the heat exchanger material can be expressed:

$$Q_{HE,ch} = M_{HE}C_{p,HE}(T_{end} - T_{\mathrm{int}}) \tag{3}$$

$$Q_{HE,\mathrm{dis}} = M_{HE}C_{p,HE}(T_{\mathrm{int}} - T_{end}) \tag{4}$$

$$Q_{HE,ch\&\mathrm{dis}} = \sum q_{HE,ch\&dis} \tag{5}$$

Where, M_{HE} is the mass of the sole device, $C_{p,HE}$ is specific heat for heat exchanger and T_{int} & T_{end} are the PCM temperatures at initial and end of the process. The following expression can calculate the cumulative energy charged by PCM (Q_{PCM}):

$$Q_{\mathrm{PCM,ch\&dis}} = Q_{ch\&dis} - Q_{ch\&dis} \tag{6}$$

The maximum theoretical energy absorbed ($Q_{\max}$) by the PCM during charging and discharging can be calculated as below:

$$Q_{\mathrm{max,ch}} = M_{PCM}\left[C_{p,PCM}(T_{\mathrm{ini}} - T_{solidus} + LH + C_{p,PCM}(T_{end} - T_{liquidus}\right] \tag{7}$$

$$Q_{\mathrm{max,dis}} = M_{PCM}\left[C_{p,PCM}(T_{\mathrm{ini}} - T_{liquidus} + LH + C_{p,PCM}(T_{end} - T_{solidus}\right] \tag{8}$$

Where the M_{PCM} is the mass of PCM. In order to evaluate the effects of inlet HTF temperature on the thermal performance of the latent heat storage units, the efficiency of setup1 and 2 can be calculated as below:

$$\eta = \frac{Q_{PCM,ch\&dis}}{Q_{\max,ch\&dis}} \qquad (9)$$

3. RESULTS AND DISCUSSION

The experimental investigation is carried out to analysis the performance behavior of PCM in the thermal storage unit. The procedure described above, the experimental tests are carried out to investigate the behavior of paraffin wax during charging and discharging process.

Charging: During the charging process, thermal path is maintained constant for inlet heat transfer fluid (HTF) in the thermal storage unit. Initially, paraffin wax in the thermal storage tank is at room temperature when the HTF of hot water passing through the thermal storage tank, increases the paraffin temperature near the coil. The temperature variations of paraffin wax inside the storage observed for every 15 minutes and also obtained the mean temperature by measuring inlet and outlet temperature of HTF. The paraffin wax in the thermal storage is start getting heated, and the average temperature of the PCM is reached 43^{0}C where it raised 10^{0}C in the thermal storage tank. After 30 minutes mean temperature of PCM reaches to 53^{0}C where it increases 10^{0}C from previous reading at this point the PCM around the copper tubes partially melted. After 45 minutes, rapid change in the state of PCM where the temperature of the PCM raises to the 60^{0}C where it is near to the melting point of the PCM which is 58^{0}C. After 60 minutes approximately 75% of PCM is melted and the inside temperature is 63^{0}C, where the PCM is keep melting and absorbing heat energy. After 75 minutes, the decrease in the rise of the internal temperatures of the PCM inside the storage tank and it can observe 95% of PCM melted that the temperature after 90mins is changed the only 5^{0}C in the mean temperatures of the storage tank when to compare to the previous reading. After 90 minutes, the remaining small amount of PCM takes a large amount of time to melt when to compare to the whole process of charging. At 105 minutes the internal temperatures are almost equal but still a little amount of PCM have to melt even the rise of the internal temperatures decreases a lot. At 120 minutes the whole PCM in the tank has melted and the inlet and outlet temperature of the water are equal and there is no heat absorption by the PCM. Below fig.2 shows that the melting of PCM at 15, 60, 90 and 120 minutes.

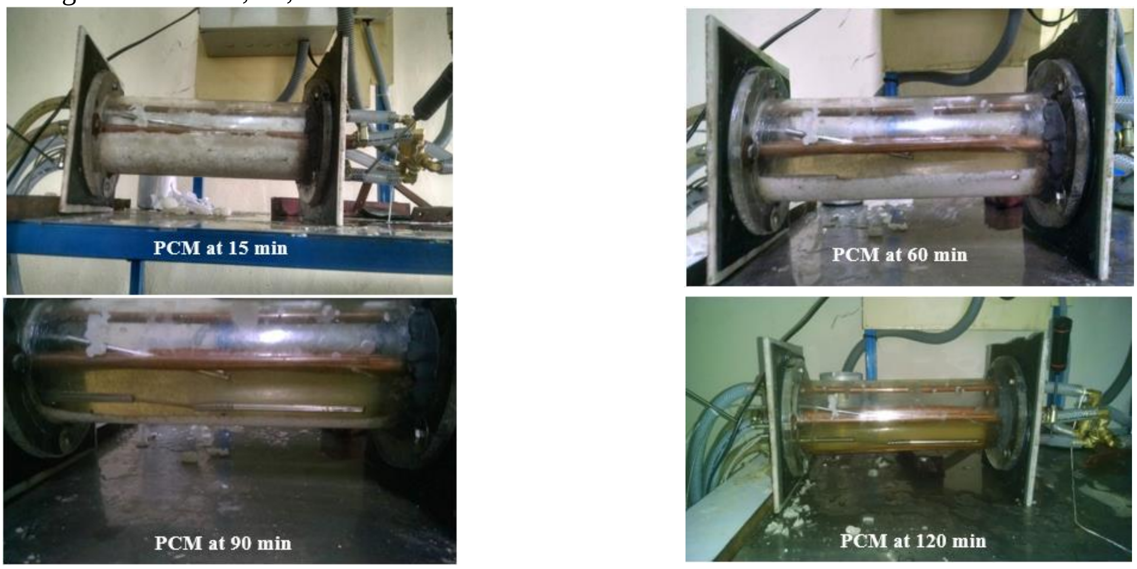

Fig.2.Melting of PCM during charging process

Discharging: Initially, discharging process is carried out through four tubes where the PCM mean temperature is 66^{0}C, which loses the little amount of heat while preparing the setup of discharging process. Discharging through the central tube is carried out after charging from the four tubes where the process is started at 60^{0}C, and it took 165min to get an almost stable state. At 45 min PCM in the tank is partially solidifies forming a transparent layer and the heat absorbed by the water is more when to compare to the discharge from four tubes. After 75 min of discharging the process PCM in the tank solidifies more when to compare to before but there is no difference in the heat transfer rate to the fluid. Below fig.3 shows that the solidification of PCM at 45 and 90 minutes.

Behavior of PCM temperature: In fig. 4 shows that the temperatures of three thermocouples (t_1, t_2 &t_3) while charging and discharging of PCM from four tubes and fig.5 indicates that the charging and discharging of PCM from four tubes and central tube, where it observed that the change of state of PCM with respect to time. And also it shows that there is the great increase of three temperatures after 60 min and 60^{0}C and the lines reach the peak and they start to fall down when the discharging process has started as that there is the standard decrease in internal temperatures so the discharging line is so stable. Where three temperatures are peak there is the full melting of PCM in the tank takes place.

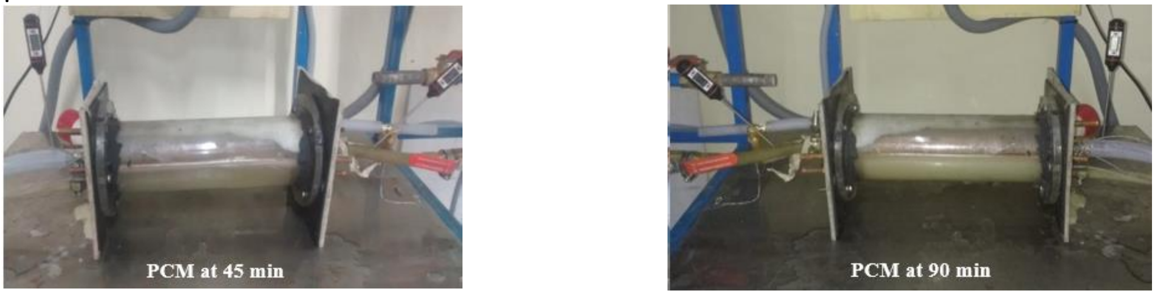

Fig.3.Solidification of PCM during discharging through central tube

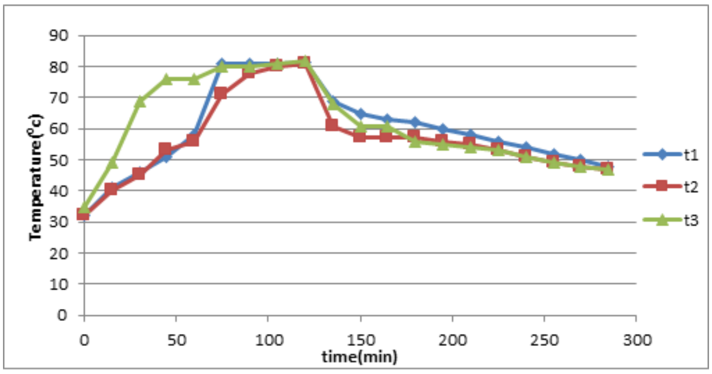

Fig.4.Charging and discharging time from four tubes on temperature of PCM

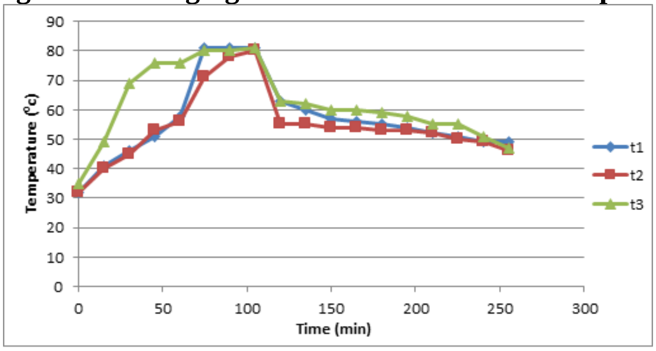

Fig.5charging through four tubes and discharging through central tube on temperature of PCM

Fig. 6 shows the comparison between the mean temperatures of the total process with respect to time. Results show that the charging process is same for both the process, there is no change in the charging process, but where comes to discharging process, it varies and the central tube loses energy little fast when compare to the four tubes because there is more heat transfer while discharging through the central tube when compare to the four tubes.

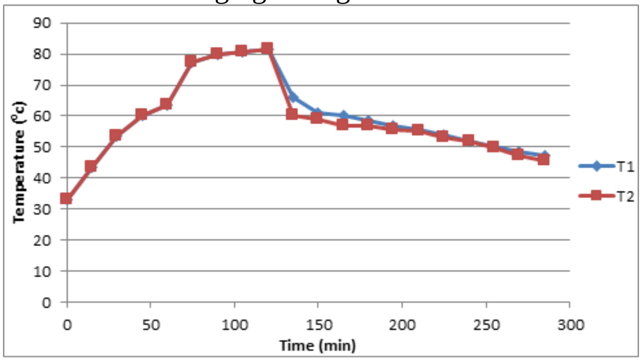

Fig.6.Comparison of effect of mean temperatures in both setups

4. CONCLUSION

The discharging process from the central tube has more heat transfer rate than the discharging from the four tubes. There is heat loss while discharging from the same four tubes which are used to charge the PCM in storage tank which causes the less heat transfer rate than the discharging from the central tube. The time of discharge is similar for both because while discharging from the central tube there is heat loss occurs while whole heat reaching the central tube from all sides of the tank. The efficiency of discharging through the central tube is slightly increased when compare to the efficiency of the discharging through the four tubes. Therefore, having different inlet and outlet for charging and discharging is the beneficiary. The discharge time for both the processes have almost same due to different types heat loss.

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