ISSN: 0974-2115
www.jchps.com Journal of Chemical and Pharmaceutical Sciences

Experimental analysis of shell and tube thermal energy storage system with finned tube

V.Thirunavukkarasu*, **G. Balaji, M.Sornanathan**
School of Mechanical Engineering, SRM University, Kattankulathur
***Corresponding author: E-Mail: thirunavukkarasu.v@ktr.srmuniv.ac.in**

ABSTRACT

The enhancement of heat transfer characteristics of a shell and tube thermal energy storage system with finned tube is presented in this paper. Paraffin is used as the phase change chemical material, which fills the annular shell space around the tube, while the heat transfer fluid flows through the tube. The tube is externally finned to enhance the heat transfer to the PCM side. Experiments are conducted with bare tube as well as finned tube. The system is also tested with different number of fins to determine the effect of number of fins attached to the tube. The optimum number of fins is identified, beyond which there is no effect on the heat transfer characteristics.

KEY WORDS: Latent heat thermal energy storage unit, finned tube, heat transfer characteristics, phase change material.

1. INTRODUCTION

Thermal energy storage can be employed to balance energy demand between day time and night time. The latent heat storage method using phase change material (PCM) can store maximum thermal energy when compared to other methods. However, PCM storage technology is still not practical because it is difficult to find an ideal PCM that possesses certain desirable thermodynamic, kinetic, chemical, technical and economic characteristics, among which high thermal conductivity, large latent heat, low super cooling and good stability are the most important. To solve this issue various techniques has been used. Mixing of nano particles with PCM, nano coating on the TES, adding salts with PCM, using finned tubes. Out of these various techniques using finned tube or extended surface will be more efficient and economical.

A TES system which promises high efficiency for a minimum volume is the shell-and-tube type of exchanger with the PCM filling the shell-side while the heat transfer fluid (HTF) flows through the tubes and serves to convey the stored energy to and from the storage unit. The shell and tube heat exchangers can be charged by passing hot heat transfer fluid (HTF) through the tube and the discharging can be done by passing cold HTF.

Tehrani, (Saeed Mostafavi Tehrani, 2016) focussed on the optimum design and technical feasibility of a shell and tube LHTES unit that is suitable for use with concentrated solar technology tower and operates between 286 and 565°C. Gharebagi and Sezai (1997) had investigated the performance of rectangular PCM device with horizontal fins added to heated vertical walls. Lacroix and Benmadda (1997) did numerical studies on a rectangular enclosure with horizontal fins extending into the PCM from heated wall. Anica Trp (2005) analysed the latent TES system of shell and tube type during charging and discharging. The comparison numerical predictions and experimental data are good agreement for both paraffin non-isothermal melting and isothermal solidification. Zhongliang Liu, Xuan Sun, Chongfang Ma (2005) An experimental rig was set up to study the performance of a thermal storage unit using stearic acid as the heat storage medium. Lamberg (2004), had proven the natural convective effect by conducting an experimental and numerical study on melting performance of PCM in a rectangular enclosure, with and without natural convection effect. The results showed that PCM took double the time to reach the maximum temperature when natural convection effect was ignored. Jellouli (2007), also did a similar experiment on melting of PCM in rectangular enclosure but with heating at the bottom. Kristian Lenic, Anica Trp, Bernard Frankovic (2006) studied transient heat transfer phenomenon during charging and discharging of the shell and tube latent thermal energy storage system. Velraj (1997) analysed the effect of tube radius and number of fins on time required for inward solidification in the latent heat storage unit.

In this experimental study, heat transfer enhancement of shell and tube thermal energy storage system and also the effect of number of fins on the charging rate and discharging rate of phase change material is studied experimentally.

2. EXPERIMENTAL SETUP AND METHOD

The figure (1) depicts a schematic view of the experimental set up developed for testing the shell and tube thermal storage unit with finned tube. It consists of PCM storage container, HTF tube with annular fins, circulation pump, temperature measuring thermocouples, HTF storage tank and flow control valve. Water is the HTF used for study. PCM is kept in the space between inner tube and a concentrically placed outer shell. In this study, experiments are carried out with bare tube as well as finned copper tube inside the shell.

The shell used in this system is made of mild steel which has an inner diameter of 104 mm and outer diameter of 112 mm. Length of the tube is 1000 mm. Five holes are made in the shell at various locations for the purpose of inserting the thermocouples in order to measure the temperature of PCM at various locations. The tube used in the system is made of copper, inner diameter of 32 mm, outer diameter of 35 mm and length of 1200 mm. The thermal conductivity of the copper material is high (401W/mK). Copper annular fins are brazed in the copper tube in order to increase the heat transfer rate between the HTF and PCM. Thickness of fin is 1.5 mm. The heat transfer rate between the HTF and PCM is tested by varying the number of fins in the system.

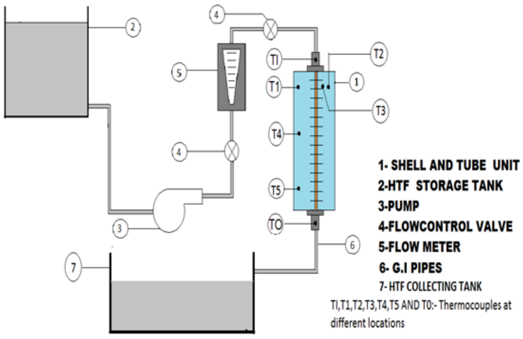

Figure.1.Schematic diagram of experimental set up

Paraffin is a chemically stable as well as nontoxic material with good availability. Its thermophysical properties like melting point, latent heat, specific heat capacities were measured by DSC analysis. The properties of the paraffin wax used in the present study are given in table (1).

The pump of capacity 1.35 litres/sec and head 12 m is used in the system in order to supply the HTF (constant flow) through the shell and tube system. J type thermocouples are used to measure the temperature of the PCM at different radial and axial locations.

Table.1. Thermophysical properties of paraffin wax

Melting point	**331K**	
Density	905 kg/m^3 (solid)	795kg/m^3 (liquid)
Specific heat capacity	1.8 KJ/KgK(solid)	2.4 KJ/KgK(liquid)
Thermal conductivity	0.18 W/mK (solid)	0.21W/mK (liquid)

Figure.2. HTF Finned tube

Figure.3. Insulated shell and tube

Various locations at which the thermocouples were identified so that the temperature variation both in the axial direction and radial direction are obtained. The radial distance mentioned in the table is from the centre part of the shell and tube system. The axial distance is measured from the end of shell body. The thermocouple locations are given in table (2).

Table.2. Location of thermocouples

Thermocouples	**Axial locations(mm)**	**Radial locations (mm)**
T1	250	41
T2	250	33
T3	250	26
T4	500	41
T5	750	41

Glass wool of the low thermal conductivity of 0.04 W/mK is used as the thermal insulator in the shell and tube setup in order to avoid the heat loss. Experiments are conducted for both charging and discharging period, first with bare tube and then with finned tube. To study the effect of number of fins, experiment is conducted first with 7 fins, then with 13 fins and finally with 25 fins. Charging the PCM is done with the help of a electric heater of capacity 1.5 kW. Discharging is done by circulating water at a constant flow rate of 0.017 kg/s. The temperature variation of PCM were recorded at various locations at an interval of one minute and heat transfer rate has been calculated.

3. RESULTS AND DISCUSSION

Melting characteristics of the TES system during charging period has been done. Temperature at each thermocouple has been noted for an interval of 1 minute. Comparison of temperature distribution in the PCM with different number of fins at locations T1, T2 and T3 are obtained. Variation of temperature at one location (T1) is represented below.

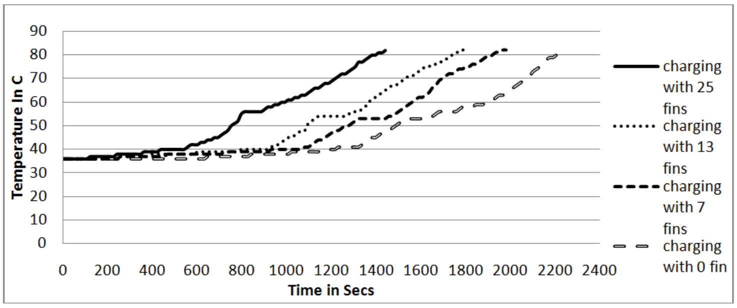

Figure.4. Comparison of temperature variation at location T1 while charging

From figure (4), it is clear that the temperature of the PCM increases constantly at each location followed by phase change and then heating of liquid PCM. Conduction dominates during the heating of PCM in the solid state and convection dominates in the liquid phase. In both the phases, temperature increase is observed to be more for finned tube. During melting convection starts and the effect of fins is more visible at this convection process. For charging the system with 25 fins took 24 minutes to reach 82 ^{0}C at location T1. Likewise charging with 13 fins took 30 minutes, charging with 7 fins took 33 minutes and charging with bare tubes took 37.5 minutes to reach 82^{0}C at same location mentioned above.

Solidification characteristics of the TES system have been done by circulating the HTF through the tube and with the heated PCM surrounding the tube. Temperature at each thermocouple has been noted for an interval of 1 minute. Temperature vs time graphs for different number of fins and bare tube has been given below. Comparison of temperature distribution with different number of fins at locations T1, T2 and T3 are obtained and graph for one location (T1) is represented in figure(5).

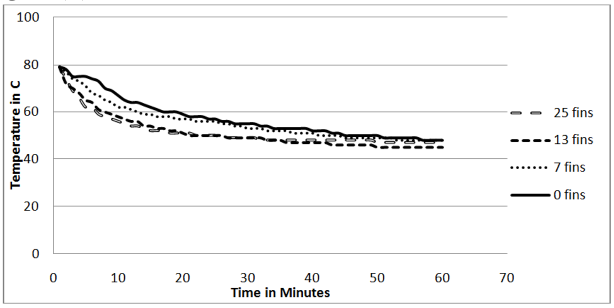

Figure.5. Comparison of temperature variation at location T1 while discharging

The discharging process of system up to one hour has been done and its characteristics are studied. It is observed that the temperature variations at location T2 and T3 are almost same. After a particular time temperature at each locations of the PCM become same and the heat energy discharging rate decreases. When the inlet and outlet temperature of HTF become same the discharging process will come to an end. Temperature variation by adding more number of fins is not in a proportional manner, a considerable difference in temperature variation between 7 and 13 fins system at each location can be observed. The difference in temperature variation between 25 and 13 fins are not high compare to that of 7 and 13. During the initial stage of discharging the heat transfer is high and while time increases the heat transfer reduces.

The heat transfer rate to the HTF is calculated by the following equation.

$$Q = mC_p\Delta T \quad (1)$$

where Q is the heat transfer rate, m is the mass flow rate of HTF, Cp is the specific heat and ΔT is the temperature difference of HTF between outlet and inlet of the TES system. The heat transfer characteristics of the system while discharging is studied and represented graphically in figure (6). The difference in using bare tubes and finned tubes can be observed from the graph. At the initial stage of discharging heat transfer is maximum and heat transfer reduces gradually. When comparing 7 and 13 finned tubes there is a difference in heat transfer rate. But when comparing the result of tube with 13 and 25 fins the difference in heat transfer rate is less than that of the tube with 7 and 13 fins. So the difference in heat transfer between 25 fins and 13 fins are not significant.

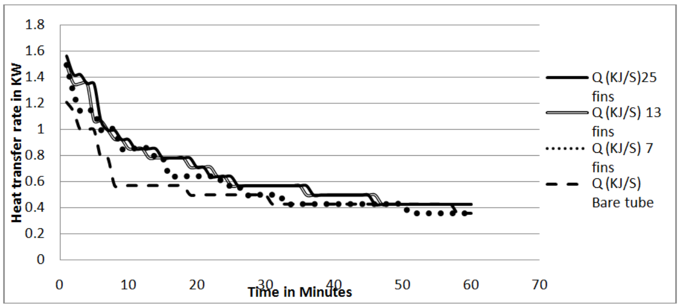

Figure.6.Heat transfer vs time during discharging process

4. CONCLUSION

The temperature variation and heat transfer characteristics of the shell and tube TES system with finned tube have been obtained. On comparing the charging process for tube with 25, 13, 7, 0 fins, we can see that the heat transfer rate is more for finned tube system than the bare tube system. Heat transfer rate increases as the number of fins increases. But rate of increase is not appreciable after thirteen number of fins. Thus it can be concluded that the drawback of PCM is its lower thermal conductivity (lower thermal diffusivity), which can be rectify by adding extended surfaces with the tubes in a shell and tube TES system. It is observed from the experiment that optimum no. of fins should be chosen which should be according to the amount of heat to be transferred and the size of storage tank. Selection of number of fins is an important criterion for making the system more efficient and more economical.

REFERENCES

Anica Trp, An experimental and numerical investigation of heat transfer during technical grade paraffin melting and solidification in a shell and tube latent thermal energy storage unit, Solar energy, 79, 2005, 648-660.

Gharebagi M, Sezai I, Enhancement of heat transfer in latent heat storage modules with internal fins, Numerical Heat Transfer Part A, 53, 1997, 749-765.

Jellouli Y, Chouikh R, Guizani A, Belghith A, Numerical study of the moving boundary problem during melting process in a rectangular cavity heated from below. Am J. App Science 4, 2007, 251-256.

Kristian Lenic, Anica Trp, Bernard Frankovic, Analysis of the influence of operating conditions and geometric parameters on heat transfer in water paraffin shell and tube latent thermal energy storage unit. A.Trp, / Applied Thermal Engineering, 26, 2006, 1830-1839.

Lacroix M, Benmadda M, Numerical simulation of natural convection-dominated melting and solidification from a finned vertical wall, Numerical Heat Transfer Part A-Appl. 31, 1997, 71-86.

Lamberg P, Siren K, Numerical and experimental investigation of melting and freezing processes in phase change material storage, Int J. Thermal Science, 43, 2004, 277-287.

Saeed Mostafavi Tehrani S, Robert A Taylor, Pouya Saberi, Gonzalo Diarce, Design and feasibility of high temperature shell and tube latent heat thermal storage system for solar thermal power plants, Renewable energy, 96 2016, 120-136.

Velraj R, Seeniraj RV, Hafner B, Faber C, Schwarzer K. Experimental analysis and numerical modelling of inward solidification on a finned vertical tube for a latent heat storage unit. Solar Energy, 60(5), 1997, 281–290.

Zhongliang Liu, Xuan Sun, Chong fang Ma, Experimental investigations on the characteristics of melting processes of stearic acid in an annulus and its thermal conductivity enhancement by fins Z, Liu, / Energy Conversion and Management 46, 2005, 959–969.