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Research Article

MELTING OF PCM BY ELLIPTICAL AND CIRCULAR FINS IN THE CYLINDRICAL THERMAL ENERGY STORAGE

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ABSTRACT

The use of phase change materials (PCMs) is an effective method of storing thermal energy. The PCM used in the present study is paraffin wax and the heat transfer fluid (HTF) is water. A horizontal cylinder of 50 mm outer diameter with 3 mm thick and 1000 mm length is used as the thermal storage unit. A copper pipe of 16 mm outer diameter with 2 mm thick and 1000 mm length is kept inside the cylinder and HTF is passed through the copper tube. Experiments were performed for different inlet temperatures of HTF from 60°C to 80°C. The HTF mass flow rate are 2 – 10 kg/min. The melting time and charging efficiency are determined for the circular and elliptical fin profiles protruded into the PCM. The effect of the inlet HTF temperature and flow rate on the melting of PCM are studied. The elliptical fins provide the faster melting over the circular fins.

INTRODUCTION

The storage of thermal energy means to store thermal energy in a certain material for a period and to give an opportunity for using it later. Thelatent heat storage is a storage system that utilizes the change phase at almost constant temperature, and sensible heat storage which involves the temperature change of a material. A cylindrical thermal storage unit was investigated for the charging and discharging process (Robynne and Dominic, 2014; Robynne and Dominic, 2014). A shell-tube LHS system during phase change processes using pure paraffinand its composite PCMs was investigated for hot water (Xiao and Zhang, 2015; Xiao and Zhang, 2015). Every obstruction given by lateralfins reduces the melting and solidification velocity in direction to the outer shell (Heimo, *et al*., 2015).

Melting process involves the natural convection effect of the liquid phase. The transition temperature range of paraffin is 20–60°C withthe melting enthalpy of 140–280 kJ/kg. However,the low thermal conductivity and large volume change during phase change are the demerits. The melting rate in top half PCM was observed faster than the lower half of the cylinder. To enhance the PCM melting in the shell bottom, the arrangement of fins is concerted (Ramalingam and Marimuthu, 2016; Senthil R and Cheralathan, 2016; Senthil R and Cheralathan, 2016). The vertically oriented radial HTF tubes performed effective for the melting of surrounded PCM (Rabienataj, *et al*., 2016). The finned coil latent heat storage unit was investigated using paraffin wax (Guansheng, *et al*., 2017). Attaching the fins on the tubes surfaces with the different geometrical arrangement is investigated in this work.

EXPERIMENTAL SET-UP

The experimental setup used in the present work consists of water heating tank, test section, circulating pump and control valves. Hot water is used as a HTF which passes from the water tank into the test section coil to give heat to PCM, and then drawn back into the tank by the circulating pump. The test section can be considered as a shell and coil heat exchanger, the shell is a horizontal cylinder of an outer diameter of 50 mm and the height of 1000 mm and thickness of 3 mm. The shell is made of transparent acrylic tube. The coil is made from a copper tube which has an outer diameter of 16 mm, inner diameter of 12 mm

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and a length of 1000 mm. The entire cavity of test section is filled with paraffin wax which is used as phase change material (PCM).

Circular and elliptical fins of different geometries are arranged sequentially over the HTF tuble. The schematics of fins are shown in (Fig. 1 and 2). The locations of fins are arranged with constant intervals. Three thermocouples are located at the overhead tank, inlet of the copper pipe and outlet of the copper pipe respectively.

The thermos-physical properties of paraffin wax are given in Table 1.

The water flow rate through these test section is controlled via adjustable speed drive for single phase motor pump. The water in the tank is heated by means of electrical resistance heater of 7 kW. The water tank temperature is adjusted and controlled by using a thermal control unit.

The hot water flow rate is measured by flowmeter with stainless steel float, in a range of 2–10 kg/min with accuracy of ± 1% of reading. The varied parameters in the present study are the heat transfer fluid temperature during charge process 60°C, 65°C, 70°C, 75°C and 80°C and the volume flow rates of 2, 4, 6, 8 and 10 kg/min. These elements are interconnected via piping system which is made from propylene tubes of 25 mm diameter as shown in (Fig. 3).

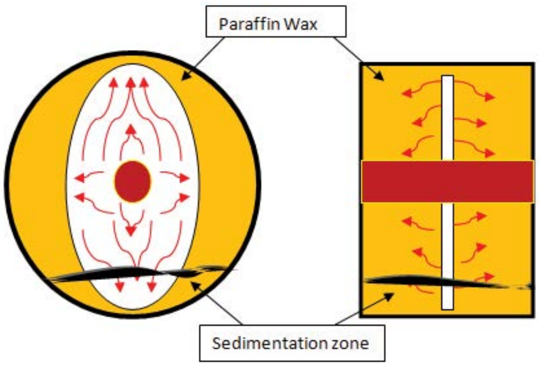

Fig. 1 Pictorial representation of heat transfer in elliptical fins.

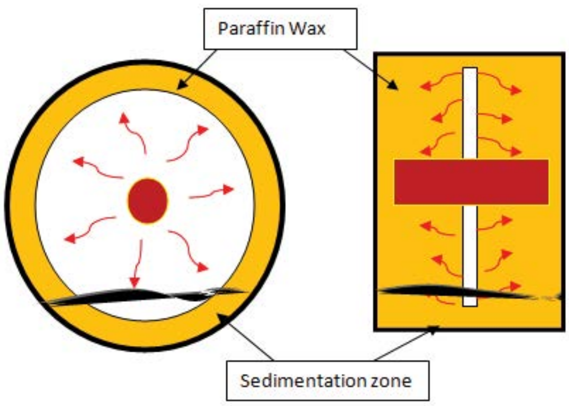

Fig. 2 Pictorial representation of heat transfer in circular fins.

The heat transfer rate can be improved by optimizing the geometry of shell and tube arrangement, thereby aiding natural convection and by improving the thermal conductivity of PCM using circular and elliptical fins geometries. Heat transfer rate can be increased by enlarging the convection dominated zone by making small changes in the geometry of the system.

Heat absorbed by heat transfer fluid is given by

$$Qu = mCp\ (Ta\text{-}Ti) \tag{1}$$

Thermal efficiency of absorber given by the following relation.

$$\eta_i = \frac{m_f C_p (T_o - T_i)}{I_b A_a} \tag{2}$$

The overall efficiency of the system is evaluated by the given expression as,

$$\eta_o = \frac{Q_u}{Q_{in}} = \frac{m_f C_p (T_o - T_i)}{I_b A_a t \eta_{op}} \tag{3}$$

where m_f is the mass flow rate of water (kg/min),

Table 1. Properties of paraffin wax

Thermal Conductivity	0.21 W/m·K
Heat Capacity	2.5 kJ/kg·K
Density	900 kg/m³
Enthalpy of Fusion	174 kJ/kg
Melting Temperature	58°C

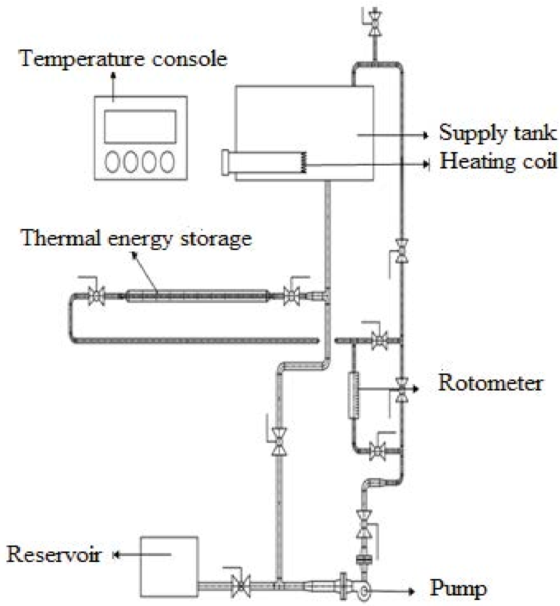

Fig. 3 Experimental setup for thermal storage.

C_p is the specific heat of water (J/kg-K) and (To - Ti) is the temperature difference of HTF in the absorber inlet and outlet.

RESULTS AND DISCUSSION

The heat transfer rate and time taken for charging and discharging is the main factors considered. The melting time is observed for various temperature of water and flow rate through the HTF tube. Heat transfer happening at the top and bottom tip of fins to enhance and ensure total melting of paraffin wax inside the thermal storage system. The slower phase change problem in the bottom of the tube shall be overcome by fins. This is applicable to both charging and discharging periods.

From (Fig. 4), the increase in the HTF flow rate from 2 kg/min to 10 kg/min, the charging time reduces by 5.33% for the elliptical fins when compared to circular fins.

From (Fig. 5), an increase in inlet temperature of water from 60 to 80°C, the melting time reduces by 7% for the elliptical fin profiles when compared to the circular profile.

The charging efficiency varies from 72% to 78% for the circular fins whereas 73% to 81% for the elliptical fins. There is an increase of the charging efficiency of 2.2% for the same operating inlet temperature for the elliptical fins (Fig 5 and 6).

Much recent research shows additives to be added in the PCM to increase the heat conduction. The best cost effective method is fins in the HTF tube to conduct the heat transfer to PCM. The melting time of PCM is considered as one of the requirement for both the fin configurations. The surface area and number of fins are the same.

The elliptical fins are observed with more heat transfer rate in elliptical fin geometry than circular fin geometry. The selection of an elliptic fin is beneficial for the maximum heat transfer at a particular fin volume.

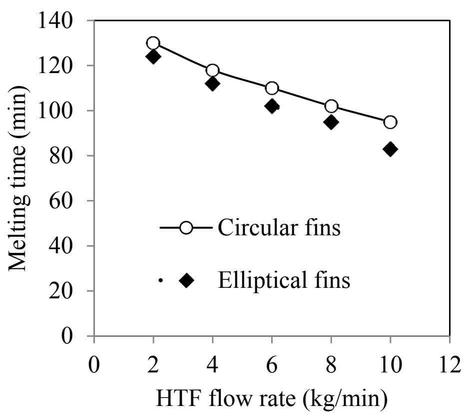

Fig. 4 Effect of HTF flow rate on melting of PCM.

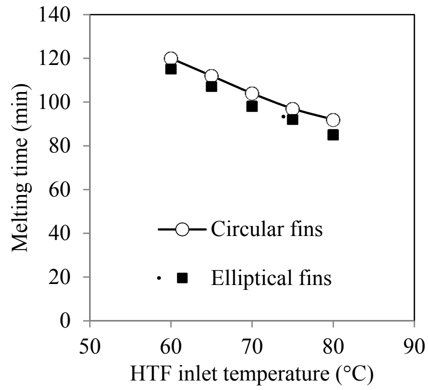

Fig. 5 Effect of HTF inlet temperature on melting of PCM.

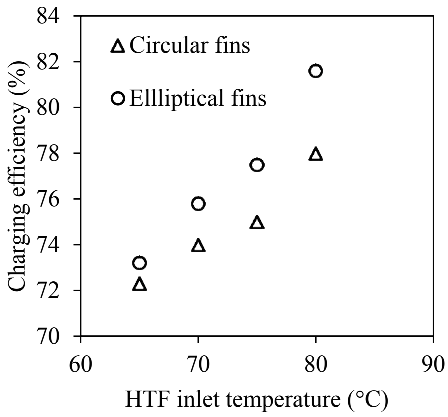

Fig. 6 Effect of circular and elliptical fins on charging efficiency of PCM.

The uncertainty of melting efficiency is determined through root mean square method as 1.2% and this shows that the measurement errors are within a significant level.

CONCLUSION

The circular and elliptical fin profiles are tested for the melting time and charging efficiency with the different HTF inlet temperature and mass flow rates. The elliptical fin profile is found effective when compared to circular fins by melting the PCM settled in the bottom of the shell. PCM in the elliptical melts 5.3% to 7.03% faster. The quick charging process makes the storing energy at a faster rate. The effect of HTF inlet temperature and flow rate on the discharge process will be studied in the future study.

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