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MELTING AND SOLIDIFICATION OF PARAFFIN WAX IN A CONCENTRIC TUBE PCM STORAGE FOR SOLAR THERMAL COLLECTOR

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ABSTRACT

A double tube phase change material (PCM) storage is investigated. The thermal energy storage (TES) contains a polycarbonate shell filled with paraffin wax and a copper tube to carry heat transfer fluid (HTF).The fusion takes place radially outwards from the center. Ineffective melting of wax was observed in bottom due to temperature gradients. An increase in HTF inlet temperature by 5°C reduces the melting time by 6.2% and increases the efficiency by 3.9%. Effect of mass flow rate of HTF is comparatively lower than HTF inlet temperature towards complete melting of PCM.

Key words: Latent heat storage, Concentric tube, Solar thermal collector, Paraffin wax.

INTRODUCTION

A thermal energy storage is an essential part of solar thermal applications. PCM has more energy density. A significant natural convection during melting resulted in more molten PCM at the top of the container during charging. But it was found negligible during solidification[1,2]. The natural convection currents were enhanced by moving inner tube downwards[3,4]. A shell-tube LHS system during phase change processes using pure paraffin and paraffin/expanded graphite composite PCMs was investigated by[5,6]. Thermal performance enhancers for PCM were reviewed and improved the solar receiver productivity by integrating PCM in the receiver by[7-9]. Solar desalination and solar pond were experimentally investigated by[10,11]. The integration of PCM on external wall is used to reduce the heat flux entry the building[12]. The integration of PCM on external wall is used to reduce the heat flux entry the building[13]. The effect of recirculation of heat transfer fluid in solar thermal collector was investigated by Senthil and Cheralathan[14].

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From the literature review, it was found that paraffin wax was extensively used as PCM for hot water applications. The thermal performance of double tube PCM storage with the effects of HTF inlet temperature and mass flow rates are experimentally investigated and reported in this article.

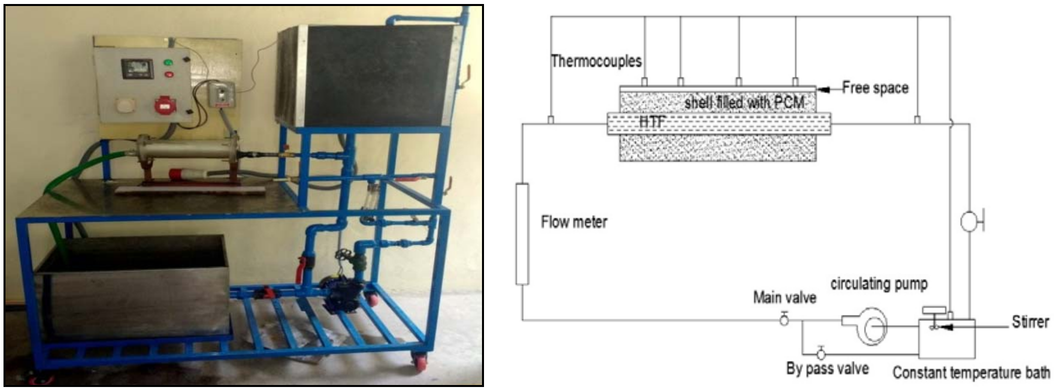
EXPERIMENTAL

Materials and methods

The TES consists of PCM filled polycarbonate shell, copper tube, variable speed pump, constant temperature bath and a flow meter. The length and diameter of the copper tube are 500 mm 25 mm, respectively. The inner diameter of the shell is 100 mm. Thermocouples are inserted to measure the temperature field inside the PCM. To provide a desired HTF inlet temperature, a constant temperature bath is used.

Table 1: Thermo-physical properties of Paraffin wax

Properties	Values
Phase change temperature (Melting point) (°C)	58
Density (kg/m^3)	810 (Liquid), 910 (Solid)
Thermal conductivity (W/m-K)	0.25 (Liquid), 0.228 (Solid)
Latent heat (kJ/kg)	204
Specific heat (kJ/kg-K)	2.1 (Liquid), 2 (Solid)
Flash point (°C)	113



(a) (b)

Fig. 1: Experimental setup: (a) Photographic view (b) Schematic diagram

A pump circulates the flow of HTF. The flow of the HTF is measured by a rotameter with a maximum capacity of 10 kg/min. Water flows through the copper tube along shell axially. Paraffin wax is selected due to its suitability for the domestic hot water. Table 1 shows the thermo-physical properties of paraffin wax. Fig. 1 shows the schematic of the experimental setup. The shell and the total piping system are insulated with 30 mm thick styro-foam layer to avoid heat losses. The charging process is done with hot water to flow through the HTF tube. For the discharging process, cold water is passed through the HTF tube.

Thermal instantaneous power and cumulative energy given by water during phase change can be expressed as below:

$$q_{ch} = \dot{m}c_p(T_{in} - T_{out}) \qquad \ldots(1)$$

$$q_{dis} = \dot{m}c_p(T_{out} - T_{in}) \qquad \ldots(2)$$

$$Q_{ch} = \sum q_{ch}\Delta t,\ Q_{dis} = \sum q_{dis}\Delta t \qquad \ldots(3)$$

Where $\dot{m}$ is the mass flow rate,

C_p is the specific heat capacity,

T_{in} and T_{out} are the inlet and outlet temperatures of the HTF.

Heat lost to the heat exchanger can be expressed as –

$$Q_{H.E,\,ch} = M_{H.E}C_{PH.E}\ (T_{end} - T_{ini}) \qquad \ldots(4)$$

$$Q_{H.E,\,dis} = M_{H.E}C_{PH.E}\ (T_{ini} - T_{end}) \qquad \ldots(5)$$

Where $M_{H.E}$ is the mass of heat exchanger

$C_{PH.E}$ is the specific heat for heat exchanger

T_{ini} and T_{end} are the PCM temperatures at start and end of the process.

The cumulative energy exchanged with PCM can be calculated by –

$$Q_{PCM,\,Ch\,\&\,dis} = Q_{ch\,\&\,dis} - Q_{H.E,\,ch\,\&\,dis} \qquad \ldots(6)$$

Theoretical efficiency can be calculated by –

$$\text{Theory} = \frac{Q_{PCM,ch\&dis}}{Q_{max,ch\&dis}} \qquad \ldots(7)$$

The theoretical maximum amount of energy during phase change processes can be determined by –

$$Q_{max,ch} = M_{PCM}\,[C_{P,PCM}\,(T_{ini} - T_{solid}) + L + C_{P,PCM}\,(T_{end} - T_{liq})] \qquad \ldots(8)$$

$$Q_{max,dis} = M_{PCM}\,[C_{P,PCM}\,(T_{ini} - T_{liq}) + L + C_{P,PCM}\,(T_{liq} - T_{solid})] \qquad \ldots(9)$$

Where M_{PCM} is the mass of PCM, $C_{p,PCM}$ is the PCM specific heat, T_{solid} and T_{liq} are the PCM phase change interval and L is the PCM phase change enthalpy.

RESULTS AND DISCUSSION

Experiments were conducted to study the melting and solidification behavior of PCM for HTF inlet temperature of 65, 70, 75, 80°C and mass flow rates of 2, 4, 6, 8 kg/min. Experimental results for HTF inlet temperature 80°C and mass flow rate 8 kg/min are discussed. The other values of inlet temperature and mass flow rates were observed with similar trends. It is observed that melting starts in the regions closer to outer wall of HTF tube. PCM at a radial distance 14 mm reached a higher temperature than that of 28 mm as it is nearer to outer wall of HTF tube. Discharging experiments are conducted for same mass flow rate and HTF inlet temperature. The increase in inlet temperature of HTF from 65 to 80°C increases the efficiency from 66.8% to 78.4%.

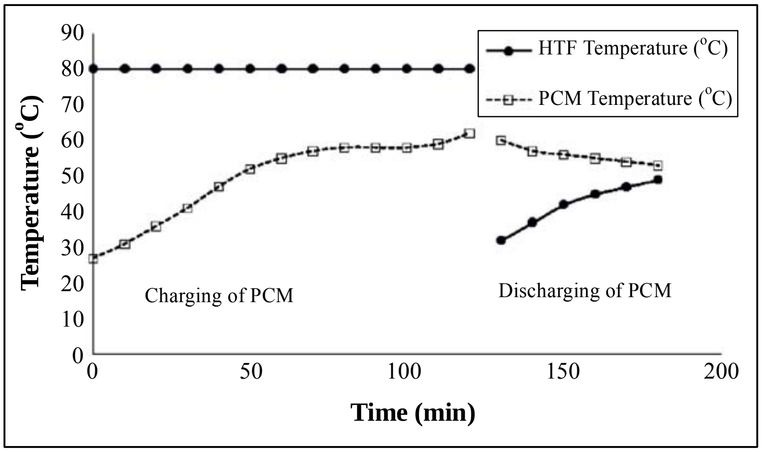


Fig. 2: PCM Charging and discharging behavior

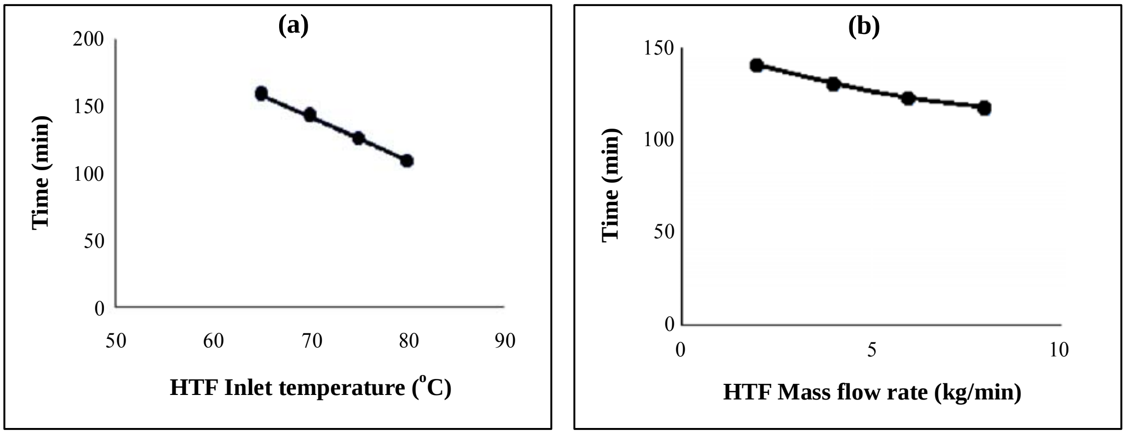


Fig. 3: Melting time of PCM (a) HTF inlet temperature; (b) HTF flow rate

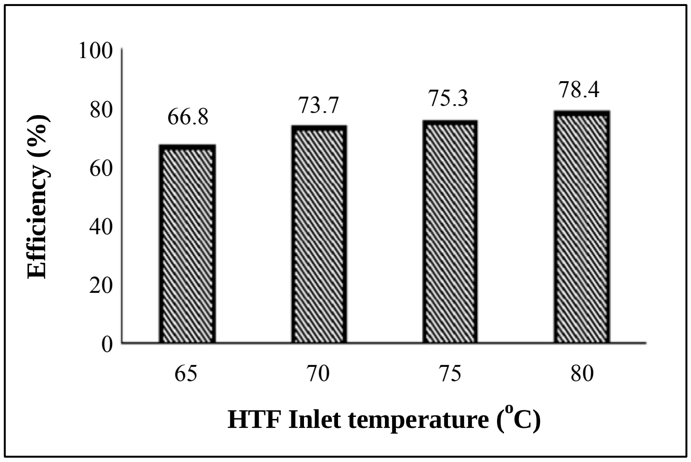


Fig. 4: Effect of inlet temperature on efficiency

The higher HTF inlet temperature increases the melting rate and energy stored. An increase in inlet temperature beyond the certain level may degrade the performance due to more heat losses. Fig. 3 shows the effect of HTF inlet temperature on melting time. The increase in inlet temperature from 65°C to 80°C reduces the melting time by 30.81%. Mass flow rate of HTF increases the melting rate (Fig. 3).

The increase in mass flow rate from 2 kg/min to 8 kg/min reduces the melting time just by 16.31%. A sharp rise in the temperature of PCM was observed at top section because of effect of buoyancy. PCM in bottom takes more time to melt as most of the heat is transferred to the top section. Though conduction heat transfer takes place at the starting time, it is dominated by convection heat transfer. The melting rate in bottom is slower when compared to the top and right section. Discharging process is done for HTF inlet temperature 26°C and mass flow rate 8 kg/min. Experiments done for other parameters showed similar results.

The temperature measurements were measured using K-type thermocouples (accuracy ± 1%), mass of PCM was measured using a digital balance (accuracy ± 1%) and flow rate was measured using a flow meter (accuracy ± 1%) during the test periods. The measurement uncertainty was determined with a value well below 6%.

CONCLUSION

In melting process, heat transfer takes place initially conduction and then convection but during solidification process, initially by convection and then by conduction. Melting front varies radially outward from the outer tube of HTF tube. Melting in bottom is found ineffective due to buoyancy effects induced by density and temperature gradients. An increase in HTF inlet temperature by 5°C reduces the melting time by 6.2% and increases the efficiency by 3.9%. Mass flow rate increases the melting rate and energy stored, but it leads to pressure drop as well as power loss due to pumping. The effective melting is achieved while the HTF tube is eccentric and the solidification is improved with concentric HTF tube.

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