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Energy Procedia 75 (2015) 2157 – 2162
Energy Procedia

The 7th International Conference on Applied Energy – ICAE2015

# Thermal analysis of a solar concentrating system integrated with sensible and latent heat storage

Purnanand V. Bhale*, Manish K Rathod, Laxmikant Sahoo

*Mechanical Engineering Department, Sardar Vallabhbhai National Institute of Technology, Surat, India-395007*

**Abstract**

The scarcity and the up scaling cost of fossil fuels have forced everyone to look out for an alternative sources of energy. Most of the process heat requirements of industries fall in the temperature range of 125-350 $^{0}$C where solar concentrating collectors can meet most of the requirement. One of the most common problems that solar power generation systems face is the gap that exists between the availability of the solar resource and energy demand, causing the need for an effective method by which excess heat collected during periods of high solar irradiation can be stored and retrieved later for use at night or during periods of darkness.

The literature survey indicates that considerable amount of work in the area of thermal energy storage is concerned with either sensible heat storage system or latent heat storage systems only and not much reported on the combined sensible and latent heat storage systems. Moreover, very limited attempts are made in the high temperature actual solar concentrating systems of considerable size.

The purpose of this work is to investigate experimentally the thermal analysis of the concentrating solar system with sensible (without phase change material, PCM) and latent heat energy storage system. A 16 $m^2$ solar concentrating collector was used for this purpose. A heat exchanger was designed and fabricated to house the phase change material. A thermic fluid was pumped into the system via solar concentrator. The experimental results in the form of charging efficiency and overall efficiency with latent heat and without latent heat storage (only sensible) were presented. During the discharging experiments it was observed that the combined system performs much better than the mere sensible storage type system without phase change material for latent heat storage.


Peer-review under responsibility of Applied Energy Innovation Institute

* Corresponding author. Tel.: +91 261 220 1967; fax: 91-261-2228394.
*E-mail address: pvbhale@med.svnit.ac.in*

1876-6102 
Peer-review under responsibility of Applied Energy Innovation Institute
doi:10.1016/j.egypro.2015.07.357

*Keywords : Solar concentrating collector; latent heat storage; PCM; charging efficiency; overall efficiency*

## 1. Introduction

One of the most common problems that solar power generation systems face is the gap that exists between the availability of the solar resource and energy demand, causing the need for an effective method by which excess heat collected during periods of high solar irradiation can be stored and retrieved later for use at night or during periods of darkness. [1]. There are continues improvements in the receivers for better output. Thermal energy storage (TES) is of great importance to many fields of engineering since it offers numerous benefits for various the disparity between energy production or viability and consumption, thermal energy storage increases the effective use of equipment whose operation requires a heat supply. TES systems can help to reduce backup equipment required to secure power supply in hospitals, computer centers, and all those places where a reliable supply is vital TES systems can help to reduce backup equipment required to secure power supply in hospitals, computer centers, and all those places where a reliable supply is vital [2]. The literature survey [3-12] indicate that considerable amount of work in the area of thermal energy storage is related with either sensible heat storage system or latent heat storage systems only and not much work is reported on the combined sensible and latent heat storage systems. Moreover, very limited attempts are made in the latent heat storage system at higher temperature with actual solar concentrating systems of a considerable size. The purpose of this work is to investigate experimentally the thermal analysis of the concentrating solar system with sensible (without PCM, phase change material) and latent heat energy storage system (with PCM, phase change material). The experimental results in the form of charging efficiency and overall efficiency with latent heat and without latent heat storage (only sensible) were presented.

### 2.0 Experimental setup

The experimental set up consists of a concentrating solar collector, a receiver, a heat exchanger carrying stearic acid as PCM, a thermal storage tank & a heat transfer fluid (HTF) circulating pump. The concentrating solar collector has a reflecting surface of area 16 $m^2$, which concentrates the incoming solar radiation to the receiver, which is coated with black paint. The experimental set up is shown in figure 1. The term without PCM indicate only sensible liquid storage.

**Fig. 1 Experimental set up of the system**

The black paint on the receiver surface increases the absorptivity of the incident solar irradiance & reduces the reflectivity. The receiver transfers the solar radiation received from the collector to the HTF, which circulates through the tube. Experiments with & without PCM (sensible heat storage) were performed. Stearic acid was used as a PCM. The set- up comprised of a heat exchanger which transfers the heat from HTF to the Stearic acid. The pump circulates the 'Thermic 500' oil to the receiver & from the receiver to the storage tank via heat exchanger housing the PCM. Experimentations on a concentrating solar collector with and without PCM were conducted during the month of April in Surat city ($21.17^0$ N, $72.83^0$ E), India. The inlet & outlet temperature of HTF, the temperature of HTF in the storage tank & also the temperature of Stearic acid present inside the heat exchanger were measured. The shell and tube type heat exchanger was made of two concentric tubes of 1 m length. The inside tube, with an inner diameter of 0.033 m and outer diameter of 0.035 m, was made of brass. The outside tube, with an inner diameter of 0.128 m and outer diameter of 0.133 m, was made of stainless steel. In order to reduce the heat loss, the outside tube is thermally well insulated with good quality cerawool of 2 layers.

### 2.1 Performance parameters

#### 2.1.1 Energy collected ($E_c$)

The energy quantities are evaluated to measure the hourly collection and storage capacity of the present system. The energy collected (Ec) is the amount of energy gained by the collector during a time period of one hour. The formula for calculating $E_c$ is given in the equation below:

$$Ec = \frac{[Cp(To - Ti)_{j+1} + Cp(To - Ti)_{j})]}{2} X\, 3600$$

#### 2.1.2 Energy stored ($E_s$)

The energy stored (Es) is the amount of energy accumulated in the storage tank during a time interval of 1 hour. The equation used for calculating Es for sensible heat storage is given below:

$$Es = m\, Cp_{,HTF}\left(Tst_{,j+1} - Tst_{,j}\right)$$

The equation used for calculating Es with PCM are given below:

$$Es = m\, Cp_{,HTF}\left(Tst_{,j+1} - Tst_{,j}\right) + m_s\,(C_p)_{solid}\,(\Delta T)_{solid} + m_s\,(\Delta h)_{LHF} + m_s\,(C_p)_{liquid}\,(\Delta T)_{liquid}$$

Here, m=total thermic oil present in the storage tank only
$(C_p)_{solid}$= Specific heat of Stearic acid in solid state ; $(C_p)_{liquid}$= Specific heat of Stearic acid in liquid state
$(\Delta h)_{LHF}$= Latent heat of fusion of Stearic acid ; $m_s$= Mass of Stearic acid taken
$(\Delta T)_{solid}$= Change in temperature of Stearic acid in solid state ; $(\Delta T)_{liquid}$= Change in temperature of Stearic acid in liquid state

#### 2.1.3 Charging efficiency ($\eta_c$):

The charging efficiency ($\eta_c$) of the system is defined as the ratio of the energy stored (Es) in the tank and the energy collected (Ec) by the collector given by:

$$\eta_c = \frac{Energy\ stored\ in\ the\ tank\ (Es)}{Energy\ collected\ by\ the\ Scheffler\ collector\ (Ec)}$$

#### 2.1.4 Overall efficiency ($\eta_o$):

The overall efficiency ($\eta_o$) of the system is defined as the ratio of the energy stored (Es) in the storage tank and the hourly solar beam/direct radiation ($I_h$) falling on the given aperture area of the collector. The formula for calculating overall efficiency is given below:

$$\eta_o = \frac{Energy\ stored\ in\ tank\ (Es)}{Ao\ X\ Ih}$$

**3. Results & discussion**

The results obtained from the experimental investigation of the performance analysis of the concentrating solar system collector integrated with a HTF storage tank with & without PCM are discussed & presented in detail. The mass flow rate of HTF was maintained around at is 0.197 kg/s. The term without PCM was used to indicate only sensible storage.

**3.1 Variations of Tank temperature vs. Time with & without PCM**

Heat transfer fluid 'thermia B' was circulated with the hot fluid circulating pump. The experiments for PCM and without PCM were conducted throughout the day during the month of April. During the experimentation consistency was maintained by keeping the solar concentrator focussing time (10.32 am) and de-focussing time same (5.02 pm) same. The maximum temperature of HTF in the tank was recorded as $130^0$ C and time required to fall this temperature up to 65 $^0$C was recorded in both the cases. The HTF was circulated throughout the system till its temperature falls up to 65 $^0$C and the time required to achieve the same was recorded. During discharging experiments, the total time interval to reach 65 $^0$C for the same focussing and defocusing time was observed to be 150 minutes more for combined latent and sensible storage system over a simple sensible storage system. The figure 2 shows the variation of tank temperature with and without PCM with respect to time.

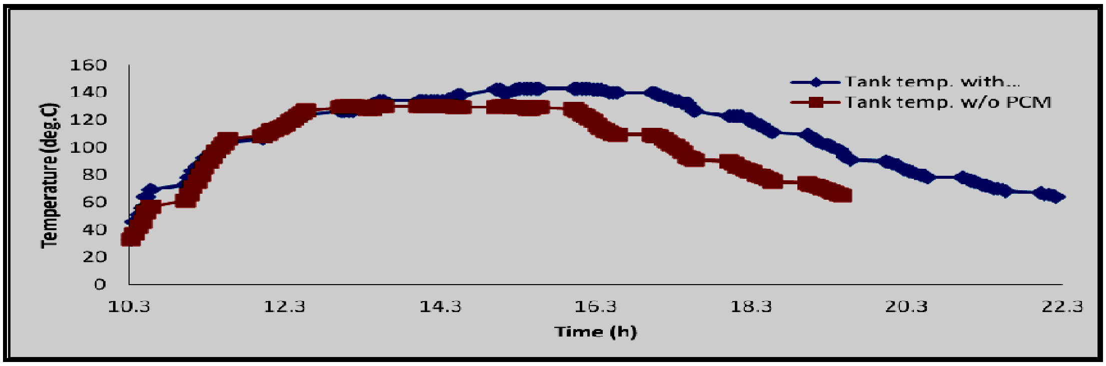


**Fig. 2 Comparison of tank temperature with and without PCM vs. Time**

From the figure 2, it is clear that the tank temperature increases with the increase of time up to 2 pm upto which the maximum solar radiation received and remains constant after this and then it started to decrease because of diminition of solar radiation intensity. The de-focussing of the concentrating collector was made at at 5.02 pm and the temperature of $65^0$ C of the storage tank was observed at 7.57 pm. Temperature was recorded after every 5 minutes of time interval.

**3.2 Variation of PCM temperature vs. Time**

Here the Stearic acid is used as the PCM. It is present inside the shell & tube heat exchanger. Temperature readings of 3 channels connected in series have been taken. There are 2 temperature readings, namely $T_1$, $T_2$ taken on each channel, so therefore there is a total of 6 temperature readings. $T_1$ is the middle layer temperature of PCM and $T_2$ is the inner layer temperature, which touches to the outer surface of the tube where thermic 500 oil is flowing.

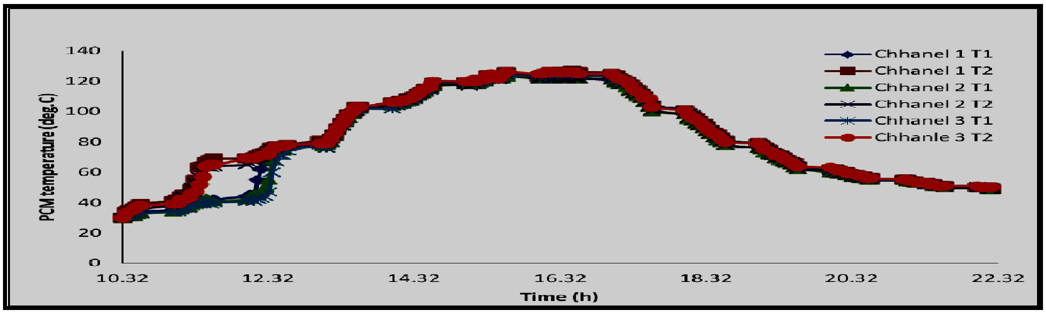


**Fig. 3 Variation of Stearic Acid (PCM) temperatures vs. Time**

While calculating efficiency average temperature of six readings was taken. The figure 3 shows the variation of Stearic acid (PCM) temperature inside the heat exchanger with respect to time.

### 3.3 Performance of the concentrating solar collector and storage system with & without PCM

The maximum value of charging efficiency and overall efficiency without PCM were of the order of 48.5 % & 27.47 % respectively obtained at peak temperature corresponds to 12.30 pm.

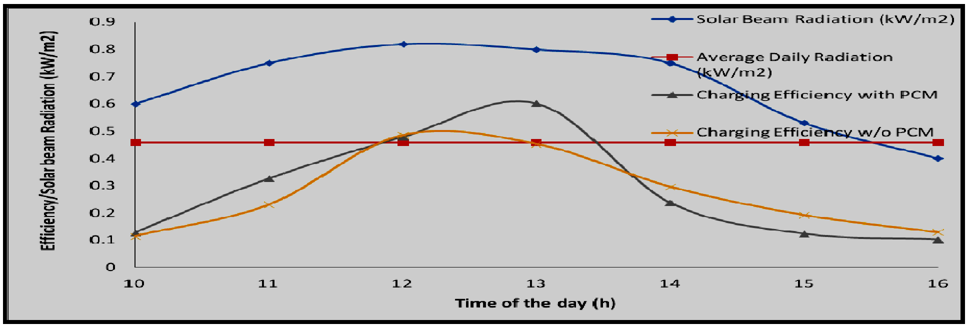


**Fig. 4 Comparison of Charging efficiency of the system with & without PCM**

The maximum value of the charging efficiency was 60.19% around 1 pm for the storage system PCM. The corresponding value was 48.5 % without PCM. The variation of the overall efficiency and charging efficiency with time for the reading showed in fig 4 and 5 for the system without and with PCM respectively. From the figure, it can be seen that the charging efficiency and overall efficiency increase with respect to time initially and reaches a maximum value at 1 pm and decreases after that because the solar radiation intensity diminishes as the day progresses.

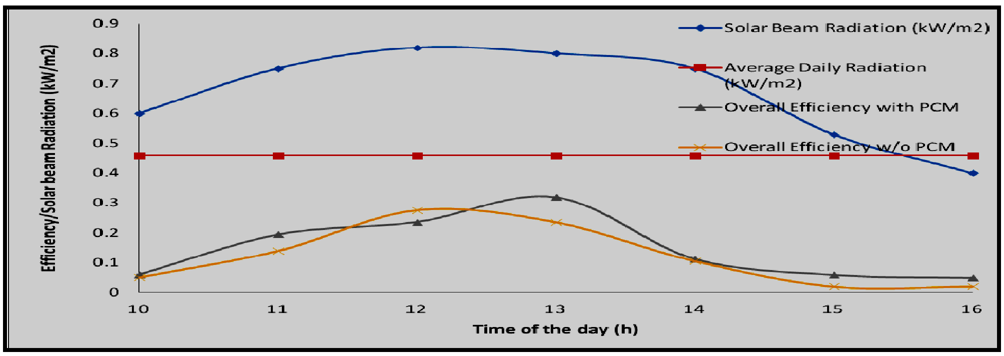


**Fig. 5 Comparison of Overall efficiency of the system with & without PCM**

The maximum value of overall efficiency was observed to be 31.88 % with PCM and the corresponding value of 27.47 % without PCM.

## 4. Conclusion

An experimental investigation of the performance evaluation of a concentrating solar collector, integrated with a thermal energy storage system with and without PCM was carried out. The performance study of the collector and the storage system with and without PCM has been conducted. The systems' charging efficiency, overall efficiency was studied as performance parameters. Variation in temperatures of the HTF and Stearic acid with time was recorded during the sunny day. It can be concluded that:

i. The overall and the charging efficiency of the setup increases during the morning, reaches a peak around noon and reduces afterwards.
ii. The maximum value of the charging efficiency was 48.5% around 12 noon for the system without PCM and was 60.19% around 1 pm in the afternoon for the PCM system.
iii. The maximum value of the overall efficiency was 27.47% around 12 noon for the entire system without PCM and was 31.88% around 1 pm in the afternoon.
iv. The maximum temperature of the tank reached in case when the system in not integrated with PCM is 130 $^0$C and During discharging experiments, the total time interval to reach 65 $^0$C for the same focussing and defocusing time was observed to be 150 minutes more for combined latent and sensible storage system over a simple sensible storage system. Considering the above facts, the system must be integrated with PCM so as to utilize the maximum of the available solar energy.

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