Study On Solar Absorber Integrated With Thermal Energy Storage For Process Heating

R. Senthil

Abstract: The main aim of this work is to construct thermal storage for the process heating application using combined sensible and latent heat concepts. Solid Aluminum storage with cylindrical phase change material (PCM) containers with paraffin wax fabricated. The heat storage was experimentally tested for process heating application using a concentrated solar collector. The incident solar energy is used to heat the transport medium and the transport medium passes through the solid storage. Aluminum stores energy as sensible heat and PCM stores energy as latent heat. The charging test conducted for two hours. The receiver with PCM storage serves for a longer duration of 30 minutes for the selected 15 kg Aluminum and 2 kg PCM. The thermal performance of heat storage is beneficial for process heating applications. The latent heat storage material showed improvement of productivity of hot water after the sunset.

Index Terms: Parabolic dish, Phase change material, Process heating, Sensible heating, Solar absorber, Thermal energy storage.

1 INTRODUCTION

Solar energy one of the promising renewable energy candidates for our thermal as well as electrical energy needs for its eco-friendliness. A large amount of energy being used for domestic and industrial purposes. There are many thermal energy storage materials available which mostly work based on sensible and latent heat principle. Thermal energy storage (TES) system consists of three parts, namely, the storage medium, the heat transfer mechanism and containment system. The present work focuses on the latent heat thermal energy storage system which can be used for various applications like water heating, cooking, steam generation, air dryer, space heating etc. Developed a physical model and analyzed in finite element analysis where a tube was surrounded by PCM storage in which fluid flows through the inner tube and exchanges heat with the PCM along its path. The enthalpy formulation during the charging process the conduction plays a major role and during the discharging process convection plays a major role. The effects of a temperature difference between the inlet of HTF and melting point of PCM, HTF inlet mass flow rate on charging and discharging were studied numerically using a physical model shell and tube storage [1]. Cardenas and Leon [2] reviewed high temperature latent thermal energy storage, phase change materials, design considerations and performance enhancement. Techniques to design to improve heat transfer in LHS units consists of fins arranged orthogonally to the axis of pipes of the HTF, for temperature below 400 °C aluminum fins can be applied. Mat et al. [3] analyzed the melting process in a heat exchanger with PCM RT82, HTF water and developed a two-dimensional numerical model. The model had 25.4 inner tube radius and 1.2 mm thickness. The middle tube and outer tube radii were 75 and 100 mm, respectively, with 2 mm thickness fins 42 mm long and 480 mm length, and 1 mm thick were welded to the inner tube, middle tubes.

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Heating both sides of PCM was found effective as HTF heats the PCM from both sides. They studied improve the heat transfer between the PCM and HTF by internal, external, and internal external fin enhancement techniques. They compared enhancement techniques the finned and internally finned tube. The effects of fin length on the enhancement techniques were also investigated and the results showed that was no significant difference among the PCM melting rate.Agyenim et al. [4, 5] numerically analyzed heat transfer enhancement technique by using internal and external fins for PCM melting in a triplex tube heat exchanger (TTHX). The inner tube radius is 25.4 mm, 1.2 mm thickness, rm is 75 mm and the outer tube radius is 100 mm, 2 mm thickness. The author concludes that the number of fins and fin length have strong effect on the melting rate time. There was a less time to melt the PCM with a greater number of fins. Increase in the mass flow rate increases the heat transfer rate and the molten volume fraction of the PCM. Increase in the inlet temperature of HTF rate increases the heat transfer rate and the molten volume fractions. Parabolic dish solar collector (PDSC) is most beneficial to produce the medium temperature working fluids. Few studies carried out to effectively utilize the heat storage at the focus of the solar receiver [7-10]. Demir and Dincer [11] investigated molten salt storage in solar tower plant to produce steam for the Rankine cycle. A part of the molten salt directly goes to hot storage tank after they are heated up by the solar tower. After the sunset, only the molten salt from the storage supplies energy to the cycle. Liu et al. [12] investigated on thermochemical energy storage technology stores and releases energy through endothermic and exothermic reversible reactions. A closed system with separated reactants and products store energy indefinitely in ideal case. The main thermochemical energy storage systems include redox system, metal hydride system, carbonate decomposition system, ammonia decomposition system, methane reforming system, and inorganic hydroxide system. Chen et al. [13] investigated the natural convection of phase change material in the melting process plays an important role in accelerating melting. Xia et al. [14] presented the effect of a PCM mixed with an insoluble liquid has higher energy converting efficiency during the whole melting process, where the massive micro vacuum formed during the freezing process is filled by the insoluble liquid, which increases utilization of the volume change. The effective heat capacity method is used, and the effects of porosity are considered when the PCM is in the solid state. The proposed model was observed with accuracy when describing the phase

Figure 1. Thermal energy storage with PCM enclosures in the aluminum receiver with lock nuts and the outer container without insulation

Change process of the pure PCM mixed with an insoluble liquid. The supercooling effect of PCM was decreased by increasing the quantity of material tested and it was established that an inorganic mixture based on bischofite is a promising PCM for low-temperature thermal storage [15]. Several researches work on PCM and its application are carried out recently [16-19]. Based on the summary of the literature review, the objectives have been formed and the methodology has been discussed in this chapter. The need of a thermal energy storage system for solar steam parabolic dish collector system is proposed. It is observed that due to fluctuation of solar radiation the steam energy produced is not completely utilized properly, the need of energy does not match with the supply of energy. Hence a lump sum amount of energy is being wasted daily; one of the ways to meet the demand is to store energy. The main objective of the study is to propose thermal energy storage for solar systems.

2 Materials and Methods

Much geometry has been adopted, analyzed and studied in TES systems for solar parabolic dish system having 16 meter-square aperture area with temperatures ranging from 60°C – 120°C. Those methods will be considered while designing the TES system and the best cost effective, efficient TES systems. The thermal energy storage experimental set up consists of a cylindrical solid aluminum and cylindrical PCM containers inside the receiver. There are lock nuts to close the PCM container. PCM was kept inside the receiver at the molten state for 90% of the volume to accommodate the thermal expansion during the phase change of PCM. The hot water from the solar heater could flow through the storage and the storage materials were charged to higher temperature through sensible and latent heat of storage materials. The surface temperature of the receiver can be allowed to reach the maximum of 100 °C for accounting the selective PCM properties. The heat transfer takes place from the exposed surface to the other end through conduction heat transfer in the solid and combined conduction and convection in the PCM. Properties of paraffin wax is given in Table 1.

TABLE 1.
Properties of Paraffin Wax

Properties	**Values**
Melting Point (°C)	60
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

The PCM melting takes place inside the receiver and retains the heat by its phase change. The receiver reaches uniform temperature due to PCM and then the heat transfer fluid (HTF) is passed through the heat transfer tubes, the heat is exchanged from the receiver to the working fluid (air or water). The objective of the PCM is not only to ensure uniform temperature but also to provide the stored heat during lean solar periods. (e.g. Cloud cover or late evening or early morning). Thus, in morning the solar energy is utilized as heat source and it is then self-sustained for integrated heat storage over aluminum cylinder, during night hours, we used as steam boiler to convert water into steam up to Paraffin wax gets solid. By insulating the entire setup, we can store the heat energy within the cylinder itself.

TABLE 2.
Properties of Aluminum (Receiver Material)

Material	Aluminum
Melting point, T_m	660 °C
Boiling point, T_b	2470 °C
Specific heat of Al, Cp	0.91 kJ/kg K
Specific heat of PCM, solid, Cp(s)	2.4 kJ/kg K
Thermal conductivity of Al (@ 20 °C), k	204 W/m-K
Density of liquid Al, (@ 660 °C), ρ_l	2370 kg/m^3
Density of solid Al, (@ 20°C), ρ_s	2700 kg/m^3

Then, the entire setup is to be insulated with glass wool except for the front face of the aluminum cylinder which is exposed to solar reflector. By inserting a thermocouple over the cylinder, we can identify the temperature lasting up to how many hours the heat can be stored.

3 Results and Discussion

The PCM integrated receiver is subjected to HTF flow rate of 25 kg/h at a temperature around 80 °C and the temperature trend of the receiver materials are given in Table 2. The solar radiation, average wind speed and ambient temperature are laid in the range of 430 – 560 W/m^2, 0 – 1 m/s and 28 – 38 °C respectively for the repeated experiments. The outdoor tests are conducted on Sunny days. The hot water coming out of the solar collector is used to heat the receiver materials. During the outdoor testing, water around 80 °C is used to heat the storage system. The aluminum temperature was found higher than PCM throughout the experiments. The PCM temperature was observed stable at its melting range. Energy stored in Al receiver with PCM is the sum of energy stored in Aluminum as sensible heat and energy stored in PCM

$= (m\,C_p \Delta T/t)_{Al} +$

$[\,m\,Cp_s\,(T_m - T_i) + m\,LH + m\,Cp_l\,(Tm - Tf))/\,t\,]_{PCM}$ (1)

Where, m is the mass of Al receiver (17 kg)

C_{pAl} is the specific heat of Aluminum (0.91 kJ/kg K)

ΔT is the difference in initial and final temperature of Al and PCM (°C) T is the time of operation (min)

LH is the latent heat (kJ/kg)

T_m is the melting point of Erythritol (°C)

T_i is the initial temperature of Al and PCM (°C)

T_f is final temperature of Al and PCM (°C)

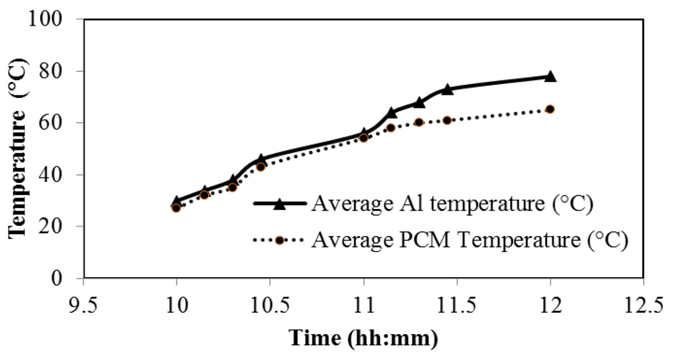

Figure 2. Receiver temperatures during the test duration (HTF temperature at 80 °C)

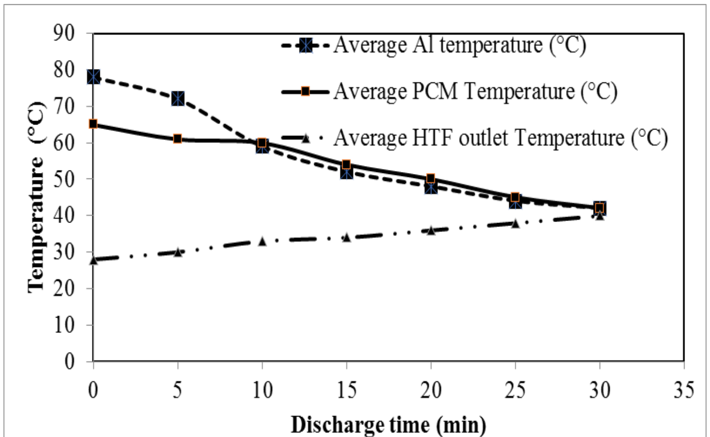

Figure 3. Discharge behavior of receiver for HTF at 25 kg/min

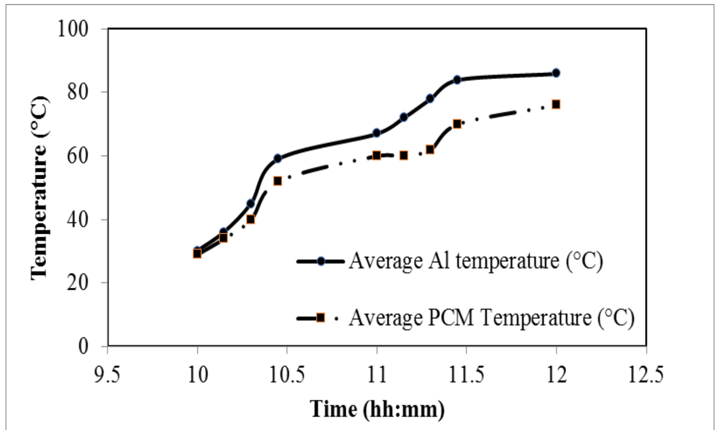

Figure 4. Receiver charging with HTF flow at 90 °C

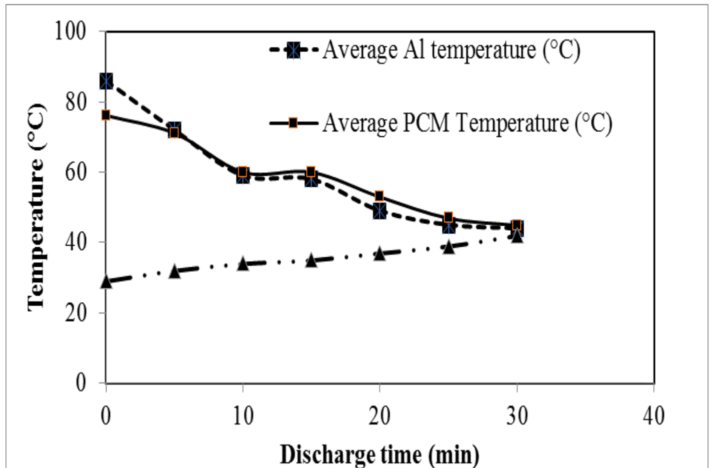

Figure 5. Discharge process with HTF at 25 kg/min

The average wind speed during the outdoor testing days was in the range of 0.2 – 1.2 m/s (Cup type anemometer, accuracy ±1%) . The solar beam radiation was observed using pyranometer (Kipp and Zonen, accuracy ±3%) in the range of 500 – 800 W/m^2 at the test site. The average ambient temperature was around 34.5 °C (RTD thermocouple, accuracy ±1%). The heat transfer flow rate was regulated by a feed water pump and valve arrangement. The discharging of thermal storage was conducted by passing HTF flow rate at 25 kg/h through the receiver. Heat of Aluminum and PCM was absorbed by the flowing HTF through the receiver. Figure 6 shows the energy stored in a sensible and latent form at two experimental trials with two fluid temperatures. The energy density is responsible for the heat storage variation in both receiver material and PCM.

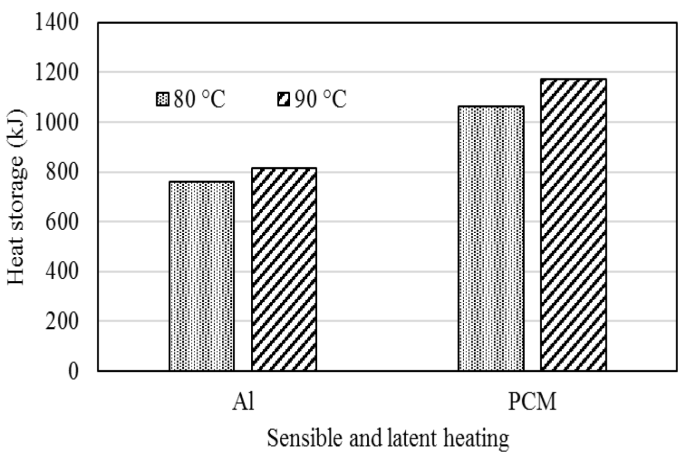

Figure 6. Energy stored in the receiver for HTF flow rate of 80 °C and 90 °C

The total energy stored in the form of sensible and latent heat for the HTF flow rate at 25 kg/hour with a temperature of 80 °C and 90 °C is 1837 kJ and 1934 kJ respectively. The increase in inlet temperature of HTF increases the total energy stored in two hours of operation. Selection of suitable PCM and sensible heat material are important to utilize the combined heat storage effect.

4. Conclusion

The outdoor testing of the fabricated thermal storage proved that the sensible and latent heat combined thermal storage is useful to store the intermittent solar thermal energy. The PCM in the storage was found helpful in storing more energy than the sensible heat of aluminum. Sensible heat materials provide a quick response to the application whereas, the latent heat materials possess more energy density. The increases inlet temperature of HTF to the storage increases the total energy stored at a given time. The storage system based on paraffin wax is useful for heating requirements up to 100 °C. Solid aluminum can store the sensible heat around 600 °C and a selective high-temperature PCM will match the applications above up to 500 °C.

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