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Solar Integrated Collector Storage Using Fresnel lens for Domestic Hot Water

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Abstract—The solar energy is an inexhaustible source of energy. However the time dependent and dilute nature of solar radiation requires a suitable concentration for the thermal applications. An effective solar collection system with efficient thermal energy storage is vital for the solar thermal domestic as well as industrial uses. The main aim of this work is to study the thermal performance of integrated collector solar thermal energy storage with paraffin as a thermal mass with a novel approach using Fresnel lens by direct heating of thermal mass through conduction heat transfer through fin to phase change material (PCM). This experimental work involved several aspects related to design of solar storage and orientation and precise the tracking of Fresnel lens, optimized mass flow rate of heat transfer fluid, different configuration of fins as well as heat transfer tubes (HTF) for the enhanced heat transfer in the entire system. The utilization of paraffin wax in the heat storage is investigated experimentally and the selected PCM worked well in the practical range of temperature around 60°C for domestic hot water (DHW) application.

Keywords—PCM, thermal energy storage, Fresnel lens, solar collector

I. INTRODUCTION

The solar energy is abundantly available in the most part of India. Its potential is around 4 -7 kWh/m^2 per day with 275 sunny days. Efforts of rational and effective energy management, as well as environmental considerations, increase the interest in utilizing renewable energy sources, especially solar energy. The solar energy is used or encouraged to be used in every country for its sustainability and carbon footprint. The need of the hour is the safer and healthier world. Most of the solar thermal applications involve flat plate and parabolic concentrating type of solar collectors with and without an energy storage system [1]. The energy storage can be integrated or discrete part with the solar collectors [2]. The separate and integrated energy storage (ICS) systems are having their own distinguished features. The integrated collector storage is better in the aspects of primary HTF transportation and its associated energy losses [3, 4]. The main objective of this work involved the introduction of Fresnel lens to concentrate solar rays as a point focus and the heat transfer into the sensible and or latent heat thermal materials in a thermal energy storage system. The most interesting physical parameters of a thermal storage is its high energy density, storage capacity and practically almost constant temperature operation. These two parameters determine the size and suitability of the storage to a specific application, respectively. There are two major types of thermal energy storage materials, namely sensible heat energy storage and latent heat storage [5]. The sensible heat storage has the advantage of being relatively cheap but the energy density is low and there is a gliding discharging temperature [14]. The thermo-cline as well as thermal stratification has been present in the sensible heat storage types and it requires optimization to improve the storage performance. Fresnel lens focuses 25% more than ordinary lenses. This study involved optimization of optical efficiency and thermal efficiency of thermal energy storage system using paraffin as a phase changing material (PCM) for energy storage in the temperature range of 50-65°C. The heat transfer rate of selected paraffin wax (ASTM D87) has been studied by the Differential Scanning Calorimetry (DSC) is shown in Fig.1.

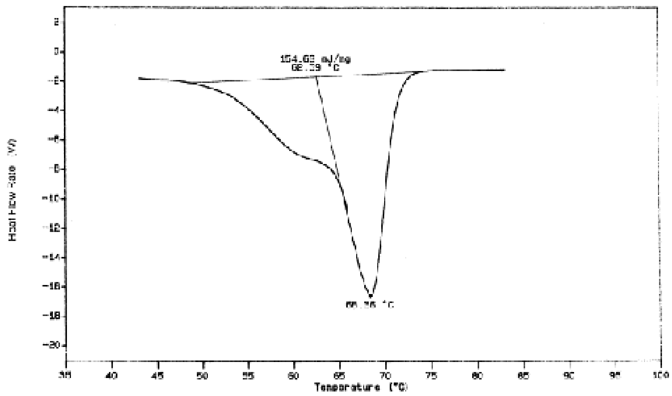

Fig.1 Melting characteristics of Praffin wax by DSC [15]

The stored heat energy is retrieved by supplying a heat transfer fluid to the Fresnel lens integrated thermal energy storage system. This is an innovative and effective solar thermal energy storage system using Fresnel lens [6-13]. In this work, the feasibility of Fresnel lens based solar ICS employing paraffin wax as selective PCM is tested experimentally for charging and discharging process successfully. The properties of paraffin wax are given in the table 1.

***Table 1:* Properties of Paraffin Wax**

Properties of Paraffin wax , $C_{25} H_{52}$ (ASTM D87)	
Melting point	64 °C
Flash point	113°C
Boiling point	322°C
Density	Liquid :810 kg/m^3 at 70°C , Solid: 910 kg/m^3 at 20°C
Thermal conductivity	ks :0.25 W/m-K (Solid), kl: 0.228 W/m-K (Liquid)
Latent heat of melting	204 kJ/kg
Specific heat	Cp(s): 2 kJ/kg K (Solid) , Cp(l): 2.1 kJ/kg-K (Liquid)

II. METHODOLOGY

This project involved fabrication and testing of Fresnel lens based TES system for the effective utilization of solar energy during active solar times as well as off-sunshine hours for the domestic hot water needs with the help of its thermal energy storage. The Fresnel lens of size 0.20 m by 0.20 m is used to concentrate the incident solar rays to a point on the base copper plate and the attached copper fin transfer the heat to the storage medium. The heat transfer takes place through the fin by conduction and from the fin to PCM by conduction and convection phenomenon. The TES system consists of copper plate of diameter 0.11m and thickness 0.002 m, fin having dimensions of 0.25 m x 0.05 m x 0.003 m (length x width x thickness), stainless steel container of diameter 0.10 m, height 0.3 m and 0.003 m, heat transfer tube made up of copper having diameter 0.125 m of and the outer thermal insulation is made up of glass wool with wooden casing as outer layer. The stainless container was fit with annular steel sheet with an air gap of 2.0 mm in order to avoid heat losses to the surrounding. The thermal energy can be stored by using different kinds of thermal masses like water, oils and PCM materials. In this case, paraffin wax was used repeatedly for its life cycle. The different HTF tube configurations have been tested for its better rate of heat retrieval using single pass, multiple pass and coiled tubes as shown in Fig.2.

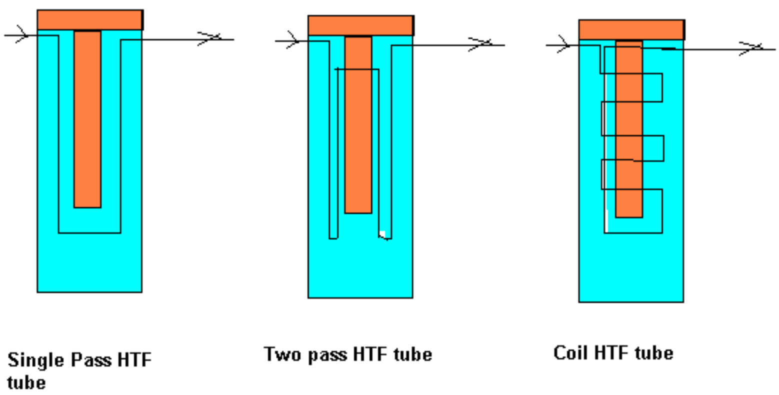

Fig.2 Different HTF tube configurations

This topic describes the methods for testing, producing and measuring temperature and flow rate of HTF through the Solar TES. The main objective of effective storage is tested repeatedly with the test parameters in a natural environment. The fabricated Fresnel lens solar collector is tested with its thermal energy storage for domestic hot water application with the help of pyranometer (Kipp & Zonnen) and thermocouples (0-500°C) which are fitted in the copper plate, fin and PCM side in order to measure the temperatures at various points. The Fresnel lens is tracking the sun with the help of stepper motor at the rate of turning the plate at an angle of 15° per hour of operation. The schematic diagram of the experimental set-up of solar thermal energy storage with water heater is shown in the Fig.3.

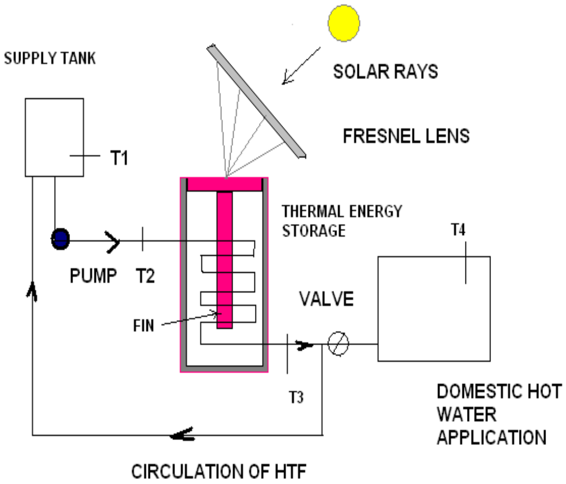

Fig.3 Solar Thermal Energy Storage using Fresnel lens

The heat transfer equations used to calculate the rate of heat transfer in the PCM as well as HTF are given below based on the sensible and latent heat aspects:

Heat stored in PCM, $Q_{pcm} = m_{pcm} \times Cp_s (T_m - T_i) + m_{pcm} \times LH \text{ of PCM} + m_{pcm} \times Cp_l \times (T_f - T_m)$

Heat transferred to HTF, $Q_{HTF} = m_{HTF} \times Cp_{HTF} \times (T_{wo} - T_{wi})$

Energy Balance equation, $Q_{pcm} = Q_{HTF} + Q_{losses}$

III. RESULTS AND DISCUSSION

The fixed flow rate of HTF (water) was supplied for heat retrieval from TES for the domestic hot water needs. The various results obtained were represented in the following graphs (Fig.4 -6) namely, time duration Vs solar intensity, ambient temperature, PCM Temperature, Fin temperature and water outlet temperature. The charging and discharging processes occurs at phase transition temperature range around 60 °C and the heat gained by the HTF is also showing a fairly constant temperature profile for the duration around 50 minutes of non-solar operation.

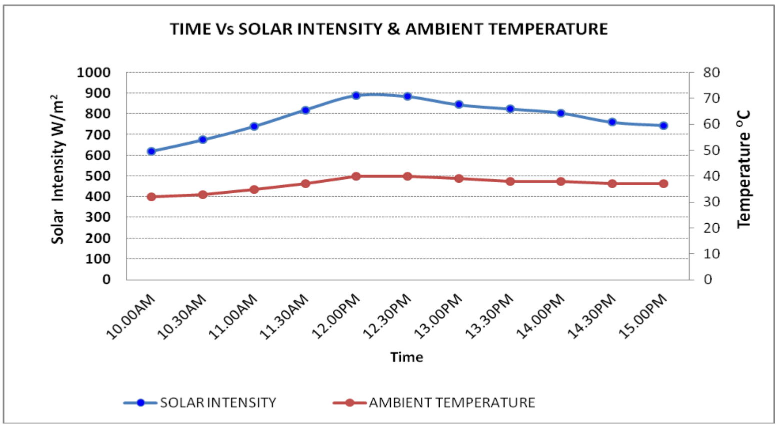

Fig.4. Time vs Solar intensity & Ambient temperature (April 2012, Monthly Average in Chennai, India)

From the Fig.4, It was shown that the effective concentration of solar beam radiation is from 11.00 am to 3.00 pm. The beam radiation has been concentrated to the copper plate surface of the TES. The complete charging of PCM in the container requires two to three hours of constant focus on the TES. The practical charging time is around 2 hours in case charging starts from 10.00 am. The charging time is reduced considerably if startimg time is 11.00 am. In case of continuous operation during peak solar hours and the excess energy stored in PCM. The heat retaining capacity completely depends on the effective thermal insulation of the storage container.

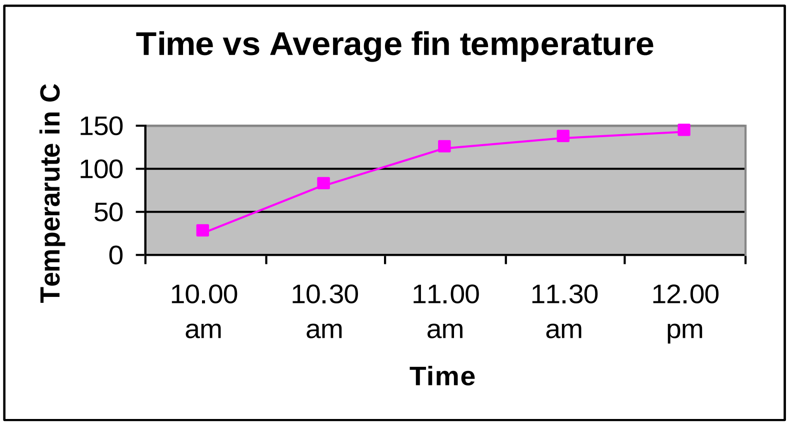

Fig.5. Solar hour vs average fin temperature

The fig.5 shows that the temperature history of fin at different time and the fin temperature reaches optimum due to beam radiation. The base plate temperature is 5-10% higher than the average fin surface temperature. The fin is made up of thin copper plate and the selective coating has been done on it to improve the heat transfer characteristics.

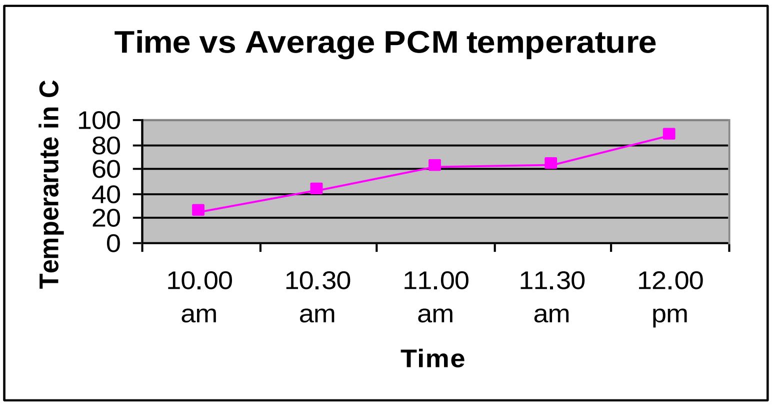

Fig.6. Solar hour vs average PCM temperature

The fig.6 shows that the temperature profile of PCM at different time and the PCM temperature reaches optimum in one hour. The PCM starts melting after one hour and it completely melts for an hour and then the sensible temperature increases. The reduced beam radiation and increased diffuse radiation affect the thermal performance of the system. The base PCM temperature is 10-20% lower than the top layer of PCM in the container. For the fixed mass flow rate of water during the discharge process had shown slight variation in thermal performance with respect to the number of HTF passes (Fig.7).

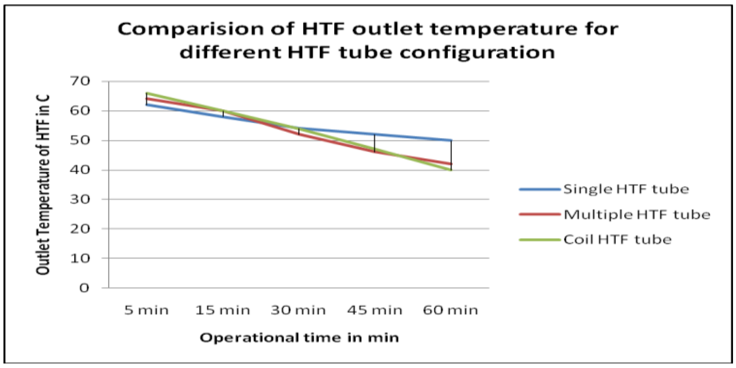

Fig.7 Operational time vs HTF outlet temperature for different HTF tube configuration

IV. CONCLUSION

The thermal behaviour of paraffin wax during charging and discharging processes was proved that it is one of the promising PCM candidates for the domestic applications in the practical temperature range between 50 °C and 70 °C. The direct charging of paraffin undergoes sensible heating as well as phase change process inside the TES container and it provides constant heat supply for around 1 hour of operation during non-solar duration. The multiple pass HTF tubes has shown involves 2-5% faster thermal response but the temperature drop is little steeper than single pass HTF tube. The temperature behaviour of PCM was not uniform inside the container due to the phase change from the axis of the container. The melting is faster than the discharge process and the retrieval efficiency has to be improved. The thermal performance enhancement techniques in the PCM as well as TES will be carried out in near future.

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