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THERMAL PERFORMANCE ANALYSIS OF SOLAR FLAT PLATE COLLECTOR INCORPORATED WITH LATENT THERMAL ENERGY STORAGE SYSTEM (PCM)

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Abstract—

Solar thermal technologies are encouraging, given the fact that solar energy is the cheapest and most commonly available of all renewable energy technologies. The recent promotion of solar energy for various applications has received significant attention from researchers, to improve the overall efficiency of various solar thermal systems. Thermal storage systems are essential to overcome the shortcoming of the discontinuous nature of solar energy. Latent heat storage by PCM are preferred over the other forms due to its higher energy storage density and a narrow operational temperature range. Among the family of solar collectors, Flat plate collector (FPC) is currently receiving considerable attention for its wide range of application. In this work experimental investigation has been carried out to investigate the thermal performance of solar flat plate collector with integration of latent thermal energy storage (PCM-60). The effect of mass flow rate of air on the instantaneous collector efficiency of solar collector with and without integration of thermal energy storage has been also investigated. The mass flow rate of air is varied from 0.01249 to 0.01527 kg/sec. The result shows that integration of TES with FPC enhances the collector efficiency by 13-20 % and at the same time it provides the air at required temperature when intensity of solar radiation is low. Thus by integrating TES with FPC hot air can be obtained even after sunshine hours. With increasing the mass flow rate of air collector efficiency also enhances.

Keywords—Flat plate collector, Thermal energy storage, Phase change material etc

INTRODUCTION

Flat plate collector based solar air heaters are usually applied in various processes of agricultural products, space heating and clothing etc. This system occupies an important place among solar thermal systems because of minimal use of materials. But due to the intermittent nature of solar energy, these solar air heaters could not put in to practice after sunshine hours. To remove the drawbacks associated with it, integration of the thermal energy storage with the solar air heat is the promising and effective solution for same. Energy storage system can decrease the difference between energy demand and energy supply. Energy storage is not only plays a vital role in improving the performance but also conserve the energy of wide range of solar thermal systems. The thermal energy storage can be used in areas where there is a large variation in solar energy or in regions where there is a elevated difference of temperature between day and night. The efforts are being made to integrate the thermal energy storage with flat plate solar collector to make use of solar energy for agricultural and industrial applications during off sunshine hours. Out of different thermal energy storage system, latent thermal energy storage system using phase change materials is gaining wide importance due to its numerous advantages.

Integration of latent thermal energy storage system not only provides the heated air at the required temperature but also it can be made active during the time at which intensity of solar radiation is low such that dependability on the cyclic nature of the solar energy can be eliminated. The performance of the thermal energy storage system depends on selection of phase change material, the geometrical configuration of the phase change material etc.The efforts are being made to integrate the thermal energy storage system with flat plate solar collector for air heating applications. The work carried out by various researches in this field has been reviewed in this section. The proficient alternative energy exploitation must consistently involve energy storage to be able to supply to fluctuation demand and at the same time to obtain a superior performance from solar energy source. Energy storage system also assumed greater significance in the situation dealing with intermittent supplies of input energy like solar energy. Phase change material (PCM) is one of the most favorite forms to store thermal energy. The results from previous studies indicated that PCMs can be adjusted to have a melting within the ranges which are most suitable for fruits and leaves drying applications.

Sharma et al. [1] reviewed the thermal energy storage systems with phase change materials. Mentioned the advantages related to phase change material and its applications. A different phase change material with thermal properties and applications has been presented. Numerous advantages related to PCM make its use in the thermal energy storage system.

Morrison, Abdel Khalik and Jurinak [2] evaluated the performance of air-based solar heating systems using phase change energy storage system. The main conclusion was that the PCM should be selected on the basis of melting point instead of its latent heat and he also found that air heating system utilizing sodium sulfate decahydrate as a thermal storage medium requires approximately one-fourth the storage volume of a pebble bed and one half the storage volume of a water tank.

Ghoneim and Klein [3] compared theoretically the performance of sensible heat storage and phase change storage for water and air based solar heating systems. Paraffin and Sodium sulphate were used as phase change materials and noted the analogous results as by Jurnik and Adbel Khalik [4].

Buddhi et al.[5] work is aimed for development of paraffin based PCMs that can be incorporated into solar dryer, the study is targeted on the determination of the suitable melting point of the PCM and the PCM selected will be in store in the solar dryer and tested to assess the effective of the PCM as the energy storage. The results from previous studies showed that paraffin based PCMs can be used to to have a melting within the ranges which are most suitable for leaves and fruits drying applications.

Design, development and performance evaluation of a natural convection solar air heater with phase change material energy storage studied out by Enibe [6] . Highest temperature rise of the heated air was about 15 K, while maximum efficiency was about 50%. The system is appropriate for use as a solar cabinet crop dryer for drying of medicinal plants, aromatic herbs and other crops, which do not require direct exposure to sunlight.

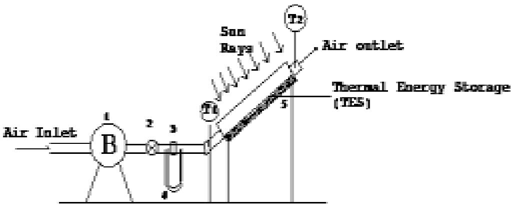
Zhou et al. [7] assessed the performance of a hybrid heating-system combined with thermal storage by phase-change material (SSPCM) plates numerically. A direct gain passive-solar house in Beijing is considered: it includes SSPCM linings of ceiling and the walls. The results revels the thermal-storage effect of SSPCM plates, which enhances the indoor thermal comfort level and saves about 47% of energy use and 12% of total energy utilization in winter.

M. M. Alkilani et al. [8] carried out a theoretical investigation of output air temperature due to thermal energy discharge process from a phase change material (PCM)

This work has been carried out to investigate the thermal performance of solar flat plate collector with integration of latent thermal energy storage (PCM-60). The effect of the variation in intensity of solar radiation on the collector efficiency with variable mass flow rate with and without integration of thermal energy storage is also evaluated.

DEVELOPMENT OF EXPERIMENTAL SET UP

Experimental system has been developed to investigate the effect of integration of latent thermal energy storage system with flat plate solar collector. The schematic diagram of the experimental system is as shown in the Fig.1.



1. Blower 2.Control Valve 3.4Orifice meter 5.Flat Plate Collector

Fig 1: Schematic of Experimental Set up

Experimental system consists of two flat plate collectors mounted side by side. One collector is for air heating purpose and other serves as the latent thermal energy storage. The flat plate collector developed for air heating purpose consist o the side wall and bottom insulated G.I. box covered with the glass. The absorber surface is coated with mat black to absorb the solar radiations. When solar radiations incident on the collector it get absorbed by absorber surface due to high absorptivity of the absorber surface. As the air flows over the absorber it gets heated and heated air can be obtained at outlet of first collector. The mass flow rate of air passing through collector has been controlled by supplying the pressurized air from blower through the flow control valve. The temperature sensors are mounted at inlet and outlet of the collector to measure the inlet out let air temperature. The second collector which serves as thermal energy storage consist of the aluminum pipes filled with the phase change material as paraffin wax and sealed on both the sides. These pipes are coated with black colour and placed in the collector. This collector serves as the heat exchanger. As solar radiation incident on the collector the energy get transferred to the phase change material during the day time and it get melted. As and when required when intensity of solar radiation is low, the air is to be passed through this second collector and heat exchange takes place between the PCM and air and thus air gets heated. This collector is also mounted with temperature sensors to measure the inlet and outlet temperature. The detail specifications of the solar collector and phase change material are as given below.

Thermal Energy Storage using PCM:

Thermal energy storage is implemented by use of phase change material. PCM material used is paraffin wax as shown in Fig. 2 and 3

The specifications of the TES are:

Overall dimensions of the collector used for thermal energy storage Length * Width * Height = 1m * 0.8m * 0.15 m

PCM storage type: Using pipes

Material of pipes used: Aluminium

Dimension of aluminium pipes:

Outer diameter (OD) = 51mm

Inner diameter (ID) = 45mm

Length of pipe (L) = 1m

Properties of Paraffin Wax (P60)

Melting temperature: 56^0 C to 64^{0}C ≈ 60^{0}C

Boiling temperature: 370^{0}C

Latent heat of storage (Fusion heat) = 210KJ/kg

Density: 900kg/m^3

Flat Plate Collector:

The Flat Plate collector is used for air heating purpose which further is supplied to the chamber using blower.

Specifications of the Flat Plate collector are:

Reflecting material used = Aluminum

Dimensions of collector:

Effective aperture area = 0.8m^2

Aperture width =0.8m

Physical parameters of solar air heating systems:

Overall Size of the collector

= Length * Width* Height

=1000m*800mm*150mm

Tilt angle 25^0 11’ (south facing)

Glass area 1 m^2

Collector glazing Window glass with 3 mm thickness

Absorber plate Width: 800 mm, length: 1000 mm

Bottom insulation 50 mm thickness of glass wool.

Solar radiation intensity is measured with the help of the solar radiation pyranometer.

Fig.2. Thermal energy
orage system with internal
CM filled aluminium tubes

Fig.3. Thermal energy storage system,
aluminium tubes colored with black
chrome paint

TEST METHODOLOGY

This work has been carried out with following test methodology under which developed collector is tested for given mass flow rate of air throughout the day under clear sky condition without and with insertion of thermal energy storage system. Experimental system has been tested for four different mass flow rates of air without and with insertion of thermal energy storage material. During testing day, after each half an hour the inlet and outlet temperature of the air, mass flow rate of air and intensity of solar radiation has been recorded. During testing of the collector with insertion of thermal energy storage the thermal energy storage system has been started after 4.00 pm when intensity of solar radiation is low. Thus instantaneous collector efficiency has been calculated for each half an hour. At the same time the temperature rise across the collector has also been recorded for each half an hour.

RESULTS AND DISCUSSION

The results are plotted to predict the performance of the developed experimental system. The variation in intensity of solar radiation with time is recorded for testing duration. During testing period it is assumed that the intensity of solar radiation remains uniform for each day of testing. From Fig.4 it is clear that the intensity of the solar radiation remained approximately same for the everyday of the experiment performance. The temperature varies in relation with the solar radiation intensity. The average solar radiation intensity considered for the energy calculations is 800W/m^2

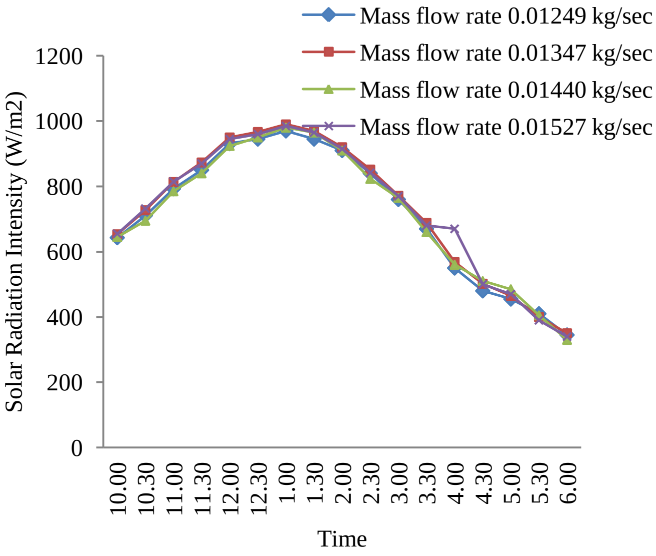


Fig.4 Variation of intensity of solar radiation with time during testing of FPC without TES

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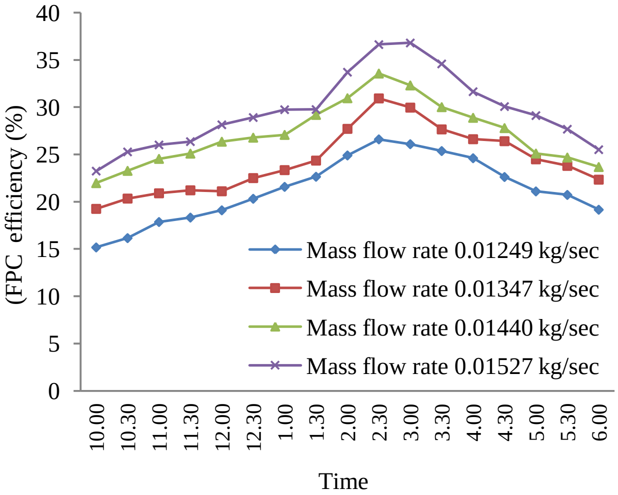

Fig.5 Variation of FPC efficiency with time during testing of FPC without TES

Fig.5 depicts variation in the thermal efficiency of the FPC for the four mass flow rates of the air throughout the day from 10am to 6pm. The maximum thermal efficiency obtained during experimentation is about 38% at around 2.00pm to 2.30pm for the maximum mass flow rate of 0.01527kg/sec.

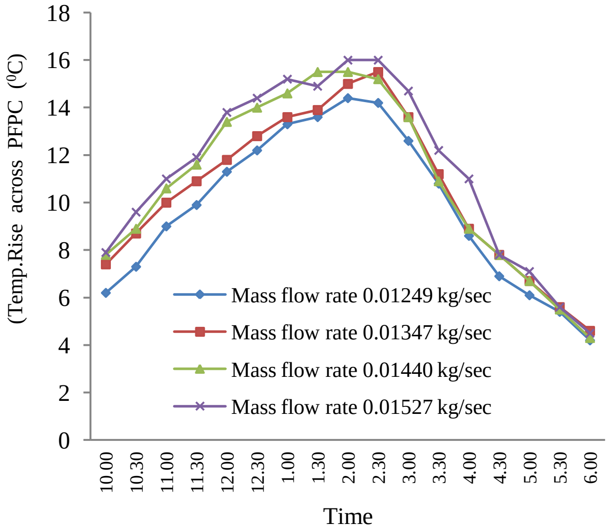

Fig.6 Variation of temperature rise across FPC with time during testing of FPC without TES

Fig. 6 shows the variation in the Temperature rise across the FPC for the four mass flow rates of the air throughout the day from 10am to 6pm. The maximum Temperature rise obtained during experimentation is about 14-16 ^{O}C at around 2.00pm to 2.30pm for the maximum mass flow rate of 0.01527kg/sec.

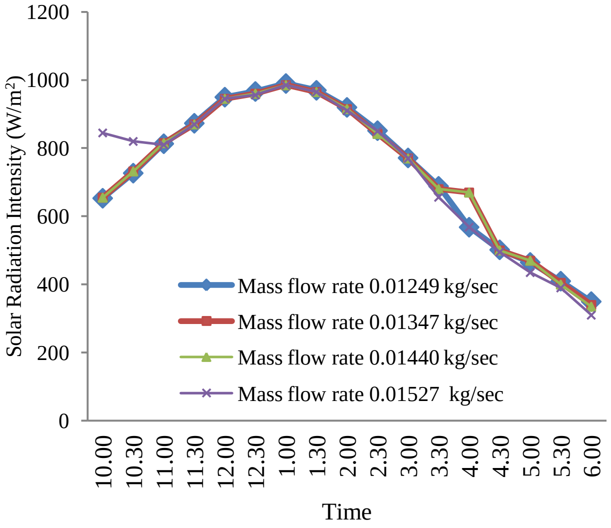

Fig.7 Variation of intensity of solar radiation with time during testing of FPC with TES

From fig. 7 it is clear that the intensity of the solar radiation remained approximately same for the everyday of the experiment performance. The temperature varies in relation with the solar radiation intensity. The average solar radiation intensity considered for the energy calculations is 800W/m^2.

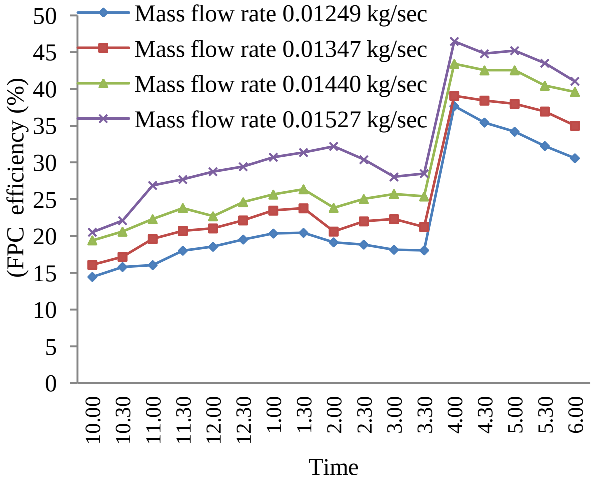

Fig.8 Variation of FPC efficiency with time during testing of FPC with TES

Fig.8 shows the variation in the thermal efficiency of the FPC with thermal energy storage for the four mass flow rates of the air throughout the day from 10am to 6pm. From the experimentation when we are activating (after 4.00pm) TES system will get the sudden rise of temperature as compared to ordinary days so will get the hike in the efficiency of collector.

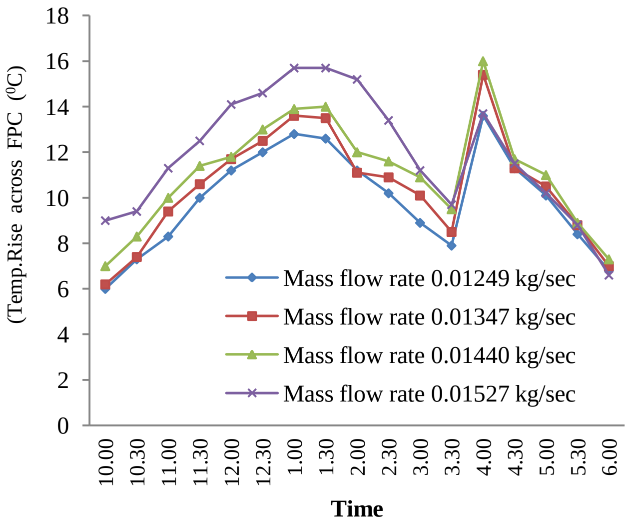

Fig.9 Variation of temperature rise across FPC with time during testing of FPC with TES

Fig.9 shows the variation in the Temperature rise across the FPC with thermal energy storage system for the four different mass flow rates of the air throughout the day from 10am to 6pm. From the experimentation when we are activating (after 4.00pm) TES system will get the sudden rise of temperature because of the latent heat of the PCM and it will effect on the hike in the temperature as compared to ordinary days.

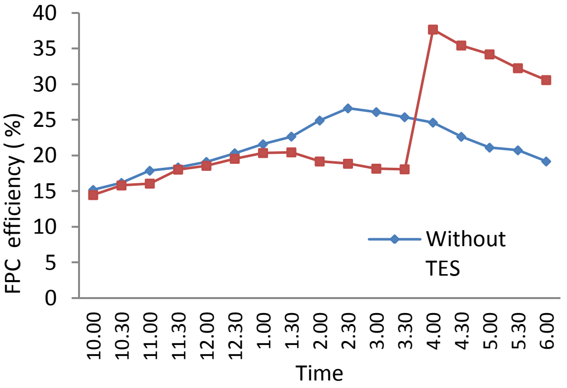

Fig.9 Variation of FPC efficiency with time during testing of FPC with TES and Without TES at mass flow rate 0.01249 kg/sec

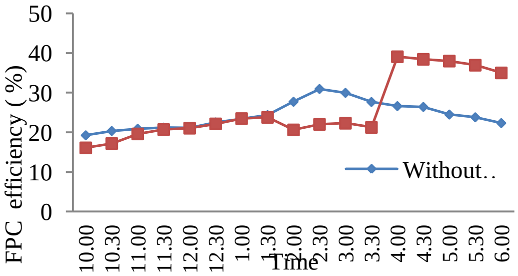

Fig.10 Variation of FPC efficiency with time during testing of FPC with TES and Without TES at mass flow rate 0.01347 kg/sec

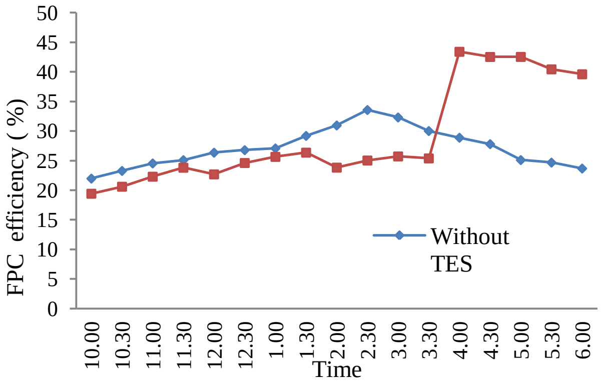

Fig.11 Variation of FPC efficiency with time during testing of FPC with TES and Without TES at mass flow rate 0.01440kg/sec

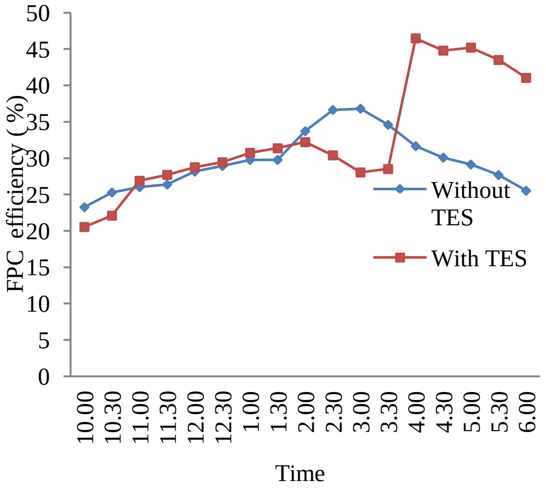

Fig.12 Variation of FPC efficiency with time during testing of FPC with TES and Without TES at mass flow rate 0.01527 kg/sec

Fig 12 shows the variation in the thermal efficiency of the FPC with and without thermal energy storage for the four different mass flow rates of the air throughout the day from 10am to 6pm. From the experimentation when we are activating (after 4.00pm) TES system will get the sudden rise of temperature as compared to ordinary days so will get the hike in the efficiency of collector.

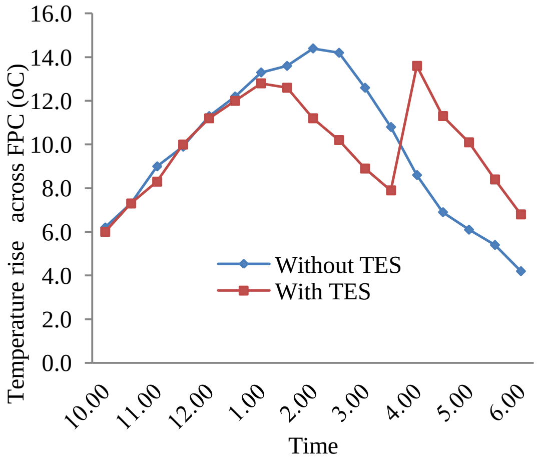

Fig.13 Variation of temperature rise across FPC with time during testing of FPC with TES and Without TES at mass flow rate 0.01249 kg/sec

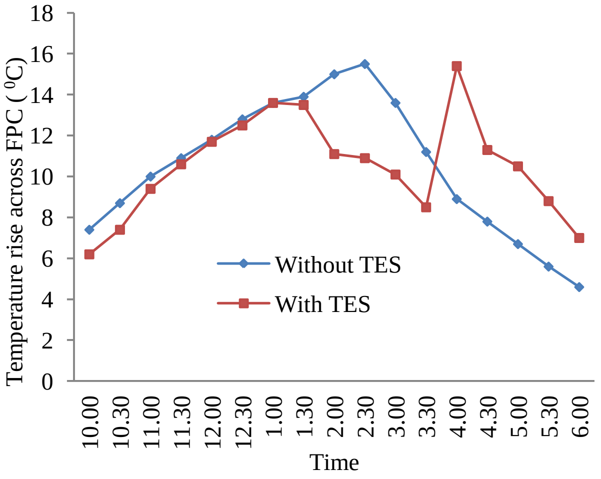

Fig.14 Variation of temperature rise across FPC with time during testing of FPC with TES and Without TES at mass flow rate 0.01347 kg/sec

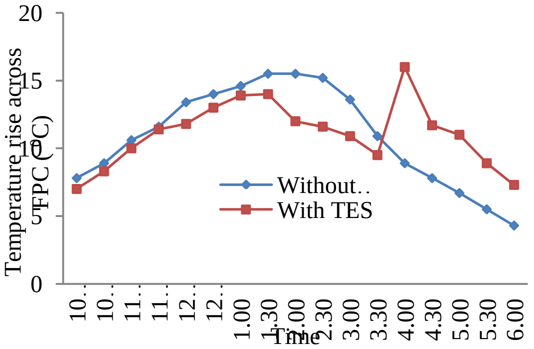

Fig.15 Variation of temperature rise across FPC with time during testing of FPC with TES and Without TES at mass flow rate 0.01440 kg/sec

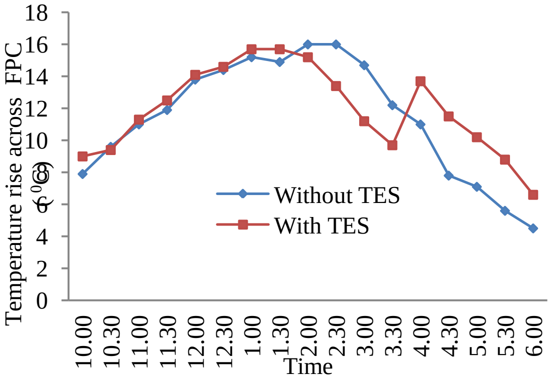

Fig.16 Variation of temperature rise across FPC with time during testing of FPC with TES and Without TES at mass flow rate 0.01527 kg/sec

Fig.13 to Fig.16 shows the variation in the temperature rise across of the FPC with and without thermal energy storage for the four different mass flow rates of the air throughout the day from 10am to 6pm. From the experimentation when we are activating (after 4.00pm) TES system will get the sudden rise of temperature because of the latent heat of the PCM and it will effect on the hike in the temperature as compared to system without TES.

V.CONCLUSION

In this study Flat plate solar collector for air heating purpose is tested with and without incorporation of thermal energy storage system with four different mass flow rate of air.

The following conclusions were drawn from this study.

- Integration of thermal energy storage with flat plate solar collector enhances the collector efficiency during off sunshine hours.
- Flat Plate collector efficiency range is 35-40%. Instantaneous collector increases with increase in mass flow rate of air.
- Temperature rise across flat plate collector range is 10-16 ^{0}C. As the mass flow rate of air increases temperature rise is also going to increased.
- It is observed that after sunshine hour at same mass flow rate of air 13-20 % Rise in Flat Plate collector efficiency with and thermal energy storage system as compared with without thermal energy storage.
- It is observed that after sunshine hour at same mass flow rate of air 8-11 ^{0}C temperature rise across flat plate collector with thermal energy storage system is obtained.
- Thus flat plate collector integrated with TES can provide the heated air at required temperature even after sunshine hours.

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