Performance evaluation of evacuated glass tube solar collector with latent heat storage material

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Abstract – Thermal energy storage strongly reduces energy consumption. Storage devices of thermal energy from phase change material (PCM) are essential in solar thermal and waste heat energy technologies that reduced the mismatch between the energy supply to demand and enhance their thermal performance. The storage of PCM thermal energy is more beneficial than sensible energy storage because of its high density of storage energy per unit volume/mass. The work carried out on experimental investigation of the performance of phase change material (PCM) storage for use with conventional solar water heating systems. Paraffin wax stored in small cylindrical polypropylene containers is used as the PCM. The containers are packed in a commercially available, cylindrical Thermal Energy storage tank. The PCM storage advantage is firstly demonstrated under controlled energy input experiments with the addition of an electrical heater on an insulated storage tank, with and without the PCM containers. It was found that the use of the suggested configuration can result in 11 to 12 ºC advantage in the stored hot water temperature over extended periods of time.

Index Terms – Evacuated glass tube solar collector, Thermal energy storage tank, Phase change material, Reflector, etc.

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1. INTRODUCTION

Industrial sectors and residential and commercial buildings consume much energy, particularly in space heating and domestic hot water (DHW) systems. The total energy usage of the residential sector accounts for 35.3% of total global energy consumption of this percentage, 73% is used for space and domestic water heating. In order to significantly reduce this consumption, the thermal energy present in phase change material (PCM) is used. This process reduces the mismatch between energy supply and demand and improves the energy efficiency of solar collector. Latent heat storage (LHS) is based on the heat absorption or release when a storage material undergoes a phase change from solid to liquid or liquid to solid. In this experiment utilize the Evacuated glass tube solar collector which is capable for producing temperature up to 70ºC.

An analysis of various Phase Change Materials and its application for flat plate Solar Water Thermal Storage System is aimed at analyzing the behavior of a four phase change materials as a part of thermal energy storage system. (Ganesh Patil, et al, 2015). In this paper the PCM storage advantage is firstly demonstrated under controlled energy input experiments with the aid of an electrical heater on an insulated storage tank, with and without the PCM containers. It was found that the use of the advice configuration can result in a 13–14 oC advantageous in the stored hot water temperature over extended periods of time. (Al-Hinti, et al, 2010).The new PCM-graphite compounds with optimized thermal properties were used, such as 80:20 weight percent ratio mixtures of paraffin and stearic acid (PS), stearic acid and myristic acid (SM), and paraffin and palmitic acid (PP). It can be concluded that PS gave the best results for increasing the thermal performance enhancement of the SDHW tank. (Muhsin Mazmana, et al, 2009).In this paper work is carried out to study the feasibility of storing solar energy using Phase Change Materials (PCMs) and utilizing this energy to heat water for domestic purposes during nighttime It is concluded that LHTES systems are a commercially viable option for solar heat energy storage with further research in this area. (Vikram, Kaushik, et al,). In this paper a detailed thermal model of a parabolic trough collector is presented. The thermal analysis of the collector receiver takes into consideration all modes of heat transfer; (Soteris A. Kalogirou, 2012). The storage of PCM latent energy is more beneficial than sensible energy storage because of its high density of storage energy per unit volume/mass. This review presents previous works on thermal energy storage as applied to DHW and heating systems. PCM has been used in different parts of heating networks and DHW systems, including solar collectors, storage tanks, packed beds, and duct networks. (M.K. Anuar Sharif, et al, 2015). In this work, a storage solar collector that consists of six 80-mm diameter copper pipes connected in series is integrated with a back container of paraffin wax as a PCM thermal storage media. (Abdul Jabbar, et al, 2013).

1.1 PCM's –latent heat storage materials

Phase change materials (PCM) are ''Latent'' heat storage materials. The thermal energy transfer occurs when a material changes from solid to liquid, or liquid to solid. This is called a change in state, or ''Phase.'' Initially, these solid–liquid PCMs perform like conventional storage materials; their temperature rises as they absorb heat. Unlike conventional (sensible) storage materials, PCM absorbs and release heat at a nearly constant temperature. They store 5–14 times more heat per unit volume than sensible storage materials such as water, masonry, or rock. A large number of PCMs are known to melt with a heat of fusion in any required range.

Table 1 Physical properties of paraffin's

Paraffin	Freezing point/ range (°C)	Heat of fusion (kJ/kg)	Group
6106	42-44	189	1
P116c	45-48	210	1
5838	48-50	189	1
6035	58-60	189	1
6403	62-64	189	1

Assumptions:

1) The solar radiation intensity along the axial and circumferential directions of the evacuated vacuum tube (collector unit) is uniform.
2) The wind speed is in the normal direction of the vacuum tube glass cover axis.
3) The working fluid in the tube is uniform and the flow is stable.
4) The temperature, pressure, and other state parameters in the same section are uniform.

2. OBJECTIVES AND METHODOLOGY:

Investigation carried out in the field of Evacuated tube solar collector system by different researchers. The following work has been observed after analyzing all the literature work. Performance analysis of Flat Plate collector system with Phase change material has done. It is observed that the main application of a evacuated tube solar collector is to generate hot water which is utilize for water heating, air heating, waste water treatment and other applications. Evacuated glass tube Collector system with Reflector not attempted by many researchers before. Also thermal analysis has not considered for the Thermal Energy Storage Tank with phase change material used for storing latent heat. The proposed work has main objective is performance improvement of Domestic Evacuated glass tube solar water heating system by adopting the phase change material as an energy storing material.

The main objectives are,

1. Performance Analysis of Domestic Evacuated glass tube solar water heating system by adopting the phase change material as an energy storing material.
2. To design and manufacturing of thermal energy storage tank at minimum heat loss.
3. To Analysis the thermal performance of solar collector by inserting the Reflector below the Evacuated glass tube collector.
4. To determine the variation in solar system efficiency for three different conditions.
5. To Analysis the Efficiency of Phase changes material.

2.1 Methodology

To achieve the above mentioned objectives, the following methodology is preferable for the proposed work:

1. To selection of input parameters by literature survey for the evacuated tube solar collector system can be made proposed study comprehensive and easy.
2. Study of EGTSC system with respect to the performance i.e. thermal efficiency, collector efficiency, quality, reliability, durability and most important the conservation of energy.
3. To design and fabricate the Prototype Evacuated Glass Tube Solar Collector system for transferring the heat to phase change material at maximum temperature.
4. Thermal analysis of the EGTSC & thermal energy storage tank in terms of useful heat gain, temperature of PCMs in the storage tank, instantaneous hourly and overall thermal efficiency.
5. Experimental validation, performance evaluation and selecting the best result for improved efficiency of the fabricated EGTSC system.

Table 2. Thermo-physical properties of the paraffin wax.

Sr. No.	Property name	Values
1	Melting point	58-60 °C
2	Latent heat of fusion	190 KJ/Kg K
3	Density (Solid Phase)	820 Kg/m^3
4	Density (Liquid Phase)	780 Kg/m^3
5	Specific Heat	2.4 KJ/Kg K
6	Thermal Conductivity	0.24 W/mk

3. EXPERIMENTAL SETUP:

Fig. 1 Actual Experimental setup

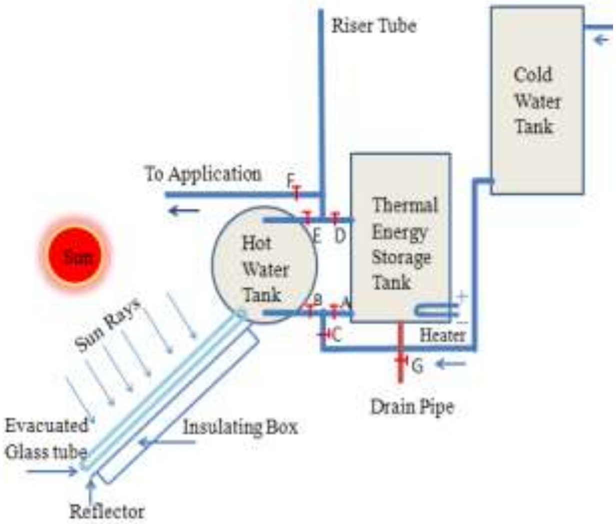

Fig. 2 Experimental setup

Experimental setup consist of Evacuated glass tube collector containing eleven number of tubes, completely insulated hot water tank, well Insulated thermal energy storage tank, cold water tank, reflector, Insulating box etc. Here TES tank utilize to increase the performance of the system with the help of paraffin wax used as a phase change material for storing large amount of latent heat during its fusion. Here TES tank & Hot water tank are connected in such way that, they are utilizing in both way separately or together. A schematic diagram of the experimental setup is shown in Fig. 1. The setup is essentially similar to conventional, commercially available, solar water heating systems with a few differences. It consists of eleven evacuated tubes with an area of 860 mm X 1700 mm, with a tilt angle of 30ºC. The collectors which have black painted reflector plates placed at back of the evacuated tubes. The galvanized steel storage tank is cylindrical in shape having a length of 750 mm, an inner diameter of 500 mm and a volume of 140 lit. It is insulated with 25-mm thick layer of glass wool insulation.

Analysis of EGTSC without Reflector

In the analysis of evacuated glass tube solar collector, find out overall efficiency of the collector based on input and output parameter.
Efficiency = Output/ Input * 100.
Input = Intensity of solar radiation * Aperture Area.
Output = Heat gain by the water = m* Cp* dT.
Specifications:
m = mass of water in hot water tank = 100 liter.
C_p = specific heat of water= 4187 Kj/Kg K.
D= External diameter of Evacuated Glass tube = 58 mm= 0.058 m.
L= length of Evacuated Glass tube = 1700 mm= 1.7 m.
N= Number of tube= 11 No.
A= area of Receiver Tubes = Tube diameter * Length of tube* No. of Tube.
= D*L*N
= 0.058*1.7*11= 1.09 m^2
I_T = Intensity of Solar Radiation at 8:00 am = 234 W/ m^2
By using the efficiency equation determine the efficiency at each hour.

$$n_h = \frac{m * c_p * (T_o - T_i)}{A * I_T}$$

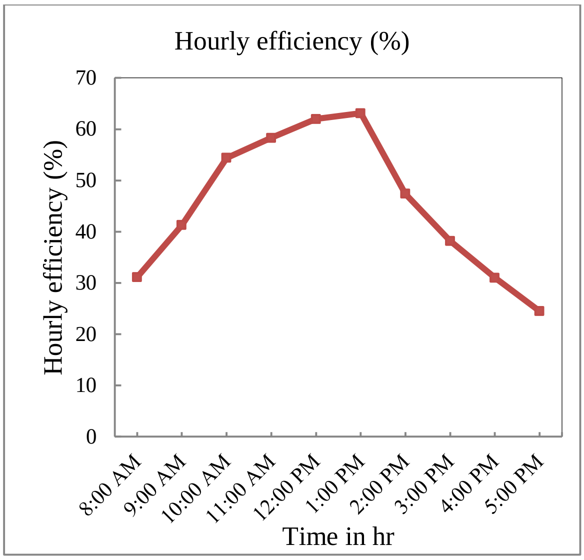

Fig. 3 Variation in efficiency without reflector

Above figure 3 show the variation in hourly efficiency, and at last the overall efficiency of the collector obtain near to 45.69 %, similarly maximum hourly efficiency 65.58 % obtain when the total intensity of radiation 1025 (W/m^2) available at 1 pm.

Analysis of EGTSC with Reflector.

In this analysis modify the evacuated glass tube solar collector by introducing reflector at back of evacuated glass tubes, to reduce heat loss due to space between two tubes. Here collector area increased that will be given by,

A= area of Reflector = width of reflector * Length of reflector.
= b*L
= 0.860*1.7= 1.436 m^2
I_T = Intensity of Solar Radiation at @ 8:00 am = 226 W/ m^2

$$n_h = \frac{m * c_p * (T_o - T_i)}{A * I_T}$$

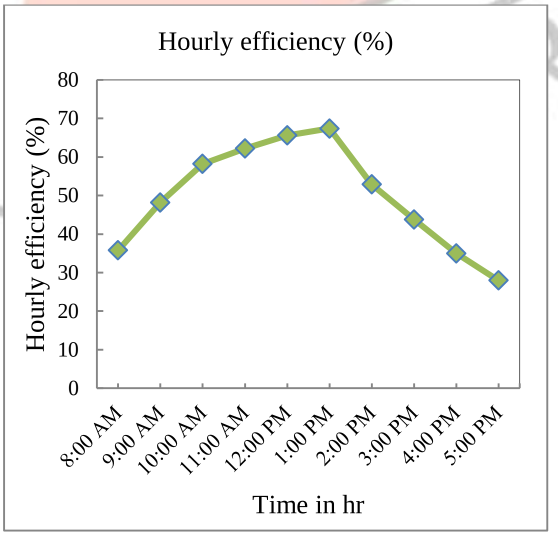

Fig. 4 Variation in efficiency with reflector

From figure 4, the overall efficiency of the collector obtain near to 48.70 %, similarly maximum hourly efficiency 65.47 % obtain when the total intensity of radiation 1002 (W/m^2) available at 1 pm.

Analysis of EGTSC with Reflector and TES tank.

In this analysis total mass of water is given by,

m = mass of water = mass of water in HWT + mass of water in TES Tank
= 100 + 80 = 180 liter.

Cp = specific heat of water= 4187 Kj/Kg K

A= area of Reflector = width of reflector * Length of reflector
= 0.860*1.7= 1.436 m^2
I_T = Intensity of Solar Radiation at @ 8:00 am = 236 W/ m^2

$$n_h = \frac{m * c_p * (T_o - T_i)}{A * I_T}$$

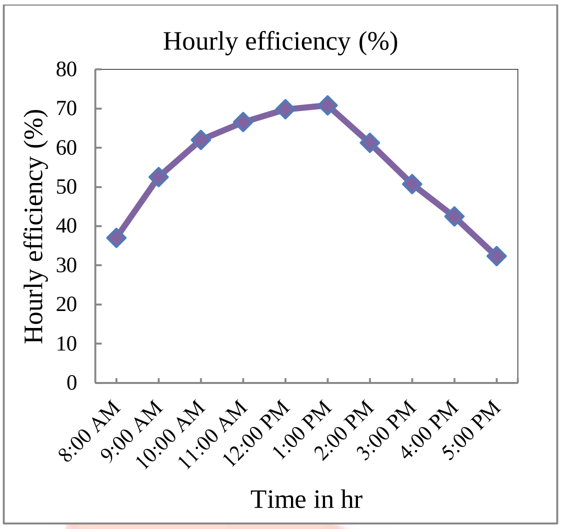

Fig. 5 Variation in efficiency with reflector & TES tank

From figure 5, the overall efficiency of the solar collector increased up to 9 to 10 % comparing with solar collector without PCMs, maximum hourly efficiency 69.49 % obtain at 1:00 pm, when the maximum Intensity of Solar radiation available.

4. Result and Discussion:

4.1 Variation in hourly efficiency:

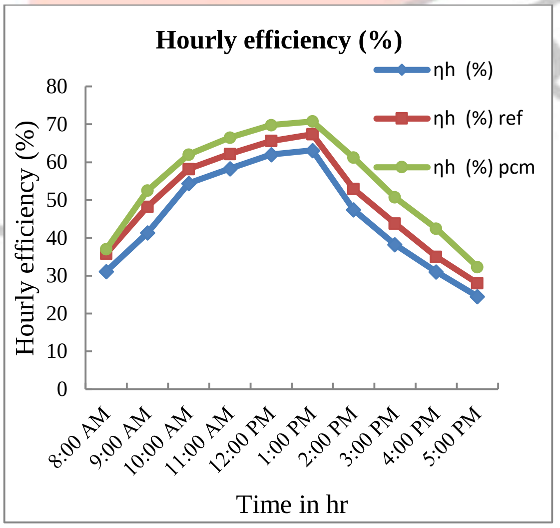

Fig. 6 Comparison in Variation of hourly efficiency for three different cases

Fig 6 show variation of hourly efficiency with time for three different conditions

1. n_h = represented the efficiency of collector without reflector
2. n_{href} = represented the efficiency of collector with reflector
3. n_{hpcm} = represented the efficiency of collector with reflector and TES tank.

From fig 6 conclude that maximum hourly efficiency obtain in a case number three, because of more amount of water and more temperature difference between inlet and outlet fluid.

4.2 Variation in Heat Gain:

Heat gain by water is directly proportional to hourly efficiency, due to increasing hourly efficiency heat gain by water also increase, also here heat gain by the PCM play the important role for storing latent heat. Heat gain by water is given by

$$Q_u = m * c_p * (T_o - T_i)$$

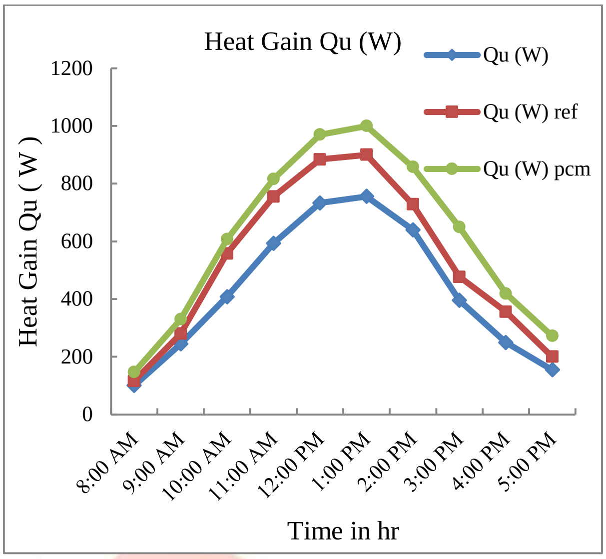

Fig. 4 Variation in Heat Gain

1. Q_u= represented the heat gain by water if collector without reflector
2. Q_{uref} = represented the heat gain by water if collector with reflector
3. Q_{upcm} = represented the heat gain by water if collector with reflector and TES tank.

5.CONCLUSION:

This paper reviews the application of PCM in domestic hot water and heating systems. These systems integrate PCM into Thermal Energy Storage tank. There have been several advantages for improving the thermal performance of the solar collector system. The following conclusions can be drawn as follow:

(1) Phase change material is viable option to increasing the efficiency of plant.
(2) The thermal performance of the PCM incorporation into storage tanks significantly enhanced in relation to energy capacity, operation time under a temperature range that is acceptable for application, and low DHW system.
(3) The average efficiency of the conventional solar collector is lower than that of the Evacuated Solar collector with reflector based on the boundary and climate conditions.
(4) The energy consumption can be reduced by incorporating with PCM as capacity enhancing device.
(5) Output of system gives more satisfactory result with respect to time hot water can be made available for longer time.

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