Performance Evaluation Of Evacuated Glass Tube Solar Collector With Phase Change 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 performance evaluation of phase change material (PCM) storage with evacuated glass tube solar collector. 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 we can check the performance of evacuated glass tube solar collector with PCM or without PCM. It was found that the use of the suggested configuration can result in 8 to 10 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.**

I. 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 is work as per absorption or release when storage material change the phase 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 70°C.

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 11-12°C advantageous in the stored hot water temperature over extended periods of time (Muhsin Mazmana, et al, 2009). In this paper work is carried out to study the performance of storing solar energy using PCM and use this energy in night time. 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,). 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 system and DHW systems, including solar collectors, storage tanks. (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 material (PCM) is having a latent heat storage capacity .The thermal energy transfer when material change from solid to liquid or liquid to solid is called as change in phase. Solid-Liquid PCM's perform like storage material; their temperature increases as they absorb heat. PCM absorb and release the heat at a constant temperature. They store 8-13 times more heat per unit volume than sensible storage materials such as water.

Table 1 Physical properties of paraffin's

Paraffin	Freezing point/ range (ºC)	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.

II. 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 determine the variation in solar system efficiency for two different conditions.
4. 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 ºC
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

III. EXPERIMENTAL SETUP:

Fig. 3.1 Actual Experimental setup

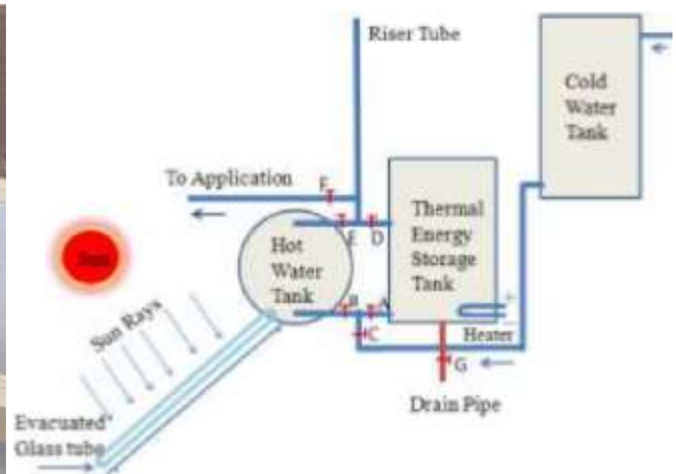


Fig. 3.2 General layout of EGTSC

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. 3.1. 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.

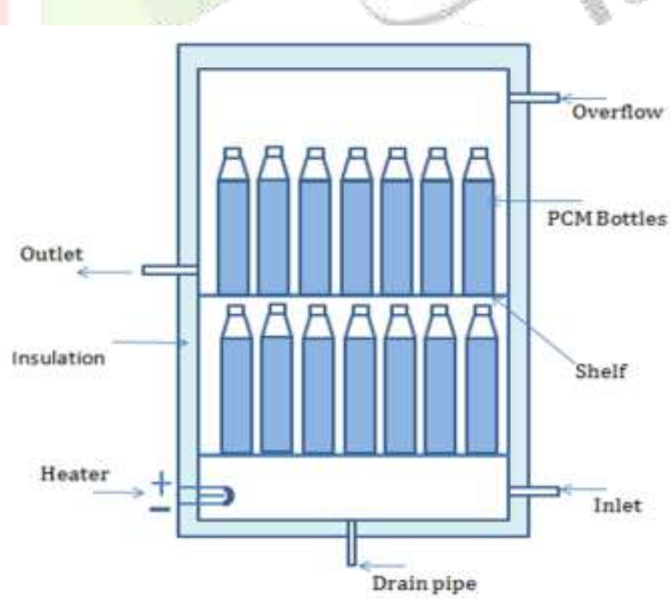


Fig. 3.3 Internal construction of Thermal Energy Storage Tank.

The proposed system has three main components: a) A Evacuated solar collector unit, b) A thermal energy storage tank and c) a well-insulated water storage tank. In this present study thermal analysis of solar collector and thermal energy storage unit was studied experimentally.

In this proposed system as illustrated in Figure 4.1, charging of phase change material in the TES tank is done during the day time when the solar radiation is available, during the charging period or day time, hot water flowing through natural circulation from hot water tank to thermal energy storage tank. The cold water passes through the solar collector it takes heat from the solar radiation and sent this heat to phase change material is called as charging of PCM. In which the PCM starts to be solidified and being fully solidified during complete transition, this PCM can be capable for release its heat, same PCM again used for charging. This process is continued until the ends of the PCM thermal life cycle. In the reveres circuit the water flow through thermal energy storage tank to hot water tank between these heat transfers take place, at the time of discharge during night time or in the absence of solar radiation.

3.1 TES Tank Specification:

Table 3

Sr. no.	name	material	Thermal conductivity (W/m-k)	Diameter (mm)	Thickness (mm)	Length (mm)
1	Inner Tank	Mild steel	55	500	1	750
2	Outer tank	Mild steel	55	550	1	750
3	Insulation	Glass wool	0.024		25	800

3.2 Thermal Analysis of TES Tank (Shell):

R_1=Conductive Resistance of outside tank.

R_2=Conductive Resistance through glass wool

R_3=Conductive Resistance of inside tank.

R_4=Convective Resistance of inside tank.

R_5=Convective Resistance of outside tank

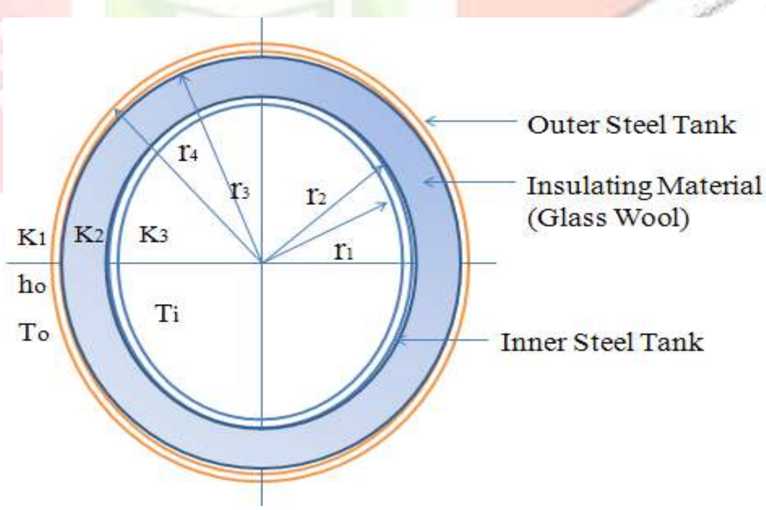


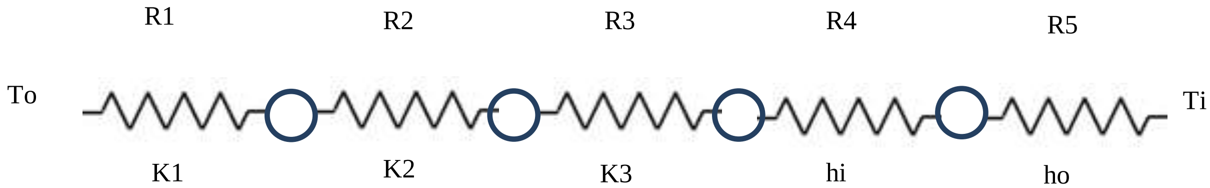
Fig. 3.4

R_1=Conductive Resistance of outside tank.

R_2=Conductive Resistance through glass wool

R_3=Conductive Resistance of inside tank.

R_4=Convective Resistance of inside tank.



$$Q_1 = \frac{T_i - T_o}{\frac{ln\left({r_4}/{r_3}\right)}{2\pi L K_1} + \frac{ln\left({r_3}/{r_2}\right)}{2\pi L K_2} + \frac{ln\left({r_2}/{r_1}\right)}{2\pi L K_3} + \frac{1}{h_i A_i} + \frac{1}{h_0 A_o}}$$

3.2 Thermal Analysis of TES Tank (Bottom Sheet)

R_1=Conductive Resistance of outside tank.

R_2=Conductive Resistance through glass wool

R_3=Conductive Resistance of inside tank.

R_4=Convective Resistance of inside tank.

R_5=Convective Resistance of outside tank.

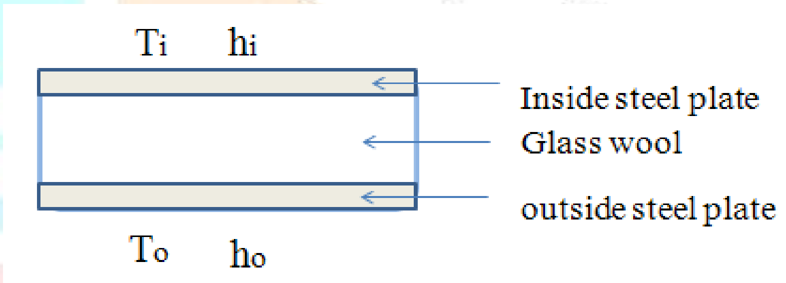
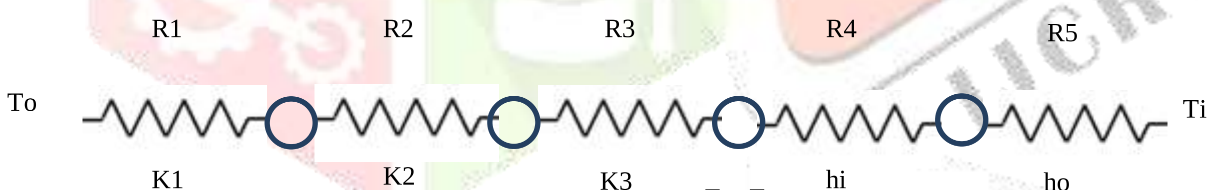


Fig 3.5



$$Q_2 = \frac{T_i - T_o}{\frac{X_1}{K_1 A} + \frac{X_2}{K_2 A} + \frac{X_3}{K_3 A} + \frac{1}{h_i A_i} + \frac{1}{h_0 A_o}}$$

$$Q = Q_1 + Q_2$$

IV. RESULTS AND DISCUSSION

4.1 Sample Experimental Reading: Without TES tank:

We take a reading after a complete one hour from 8:00 AM to 5:00PM without using TES tank. At that time we get overall efficiency (η_O) using following formulas is 45.69 %.

$\eta_{hourly} = \frac{Q_u}{AI_h} = \frac{m.c_p(T_o - T_i)}{AI_h}$ $\qquad$ $Q_u = m.c_p(T_o - T_i)$

$$\eta_{Overall} = \frac{Q_u}{AI_b} = \frac{m.c_p(T_o - T_i)}{AI_b}$$

4.2 Sample Experimental Reading: with TES Tank:

We take a reading after a complete one hour from 8:00 AM to 5:00PM with TES tank. At that time we get overall efficiency (η_O) 54.77168% using following formulas.

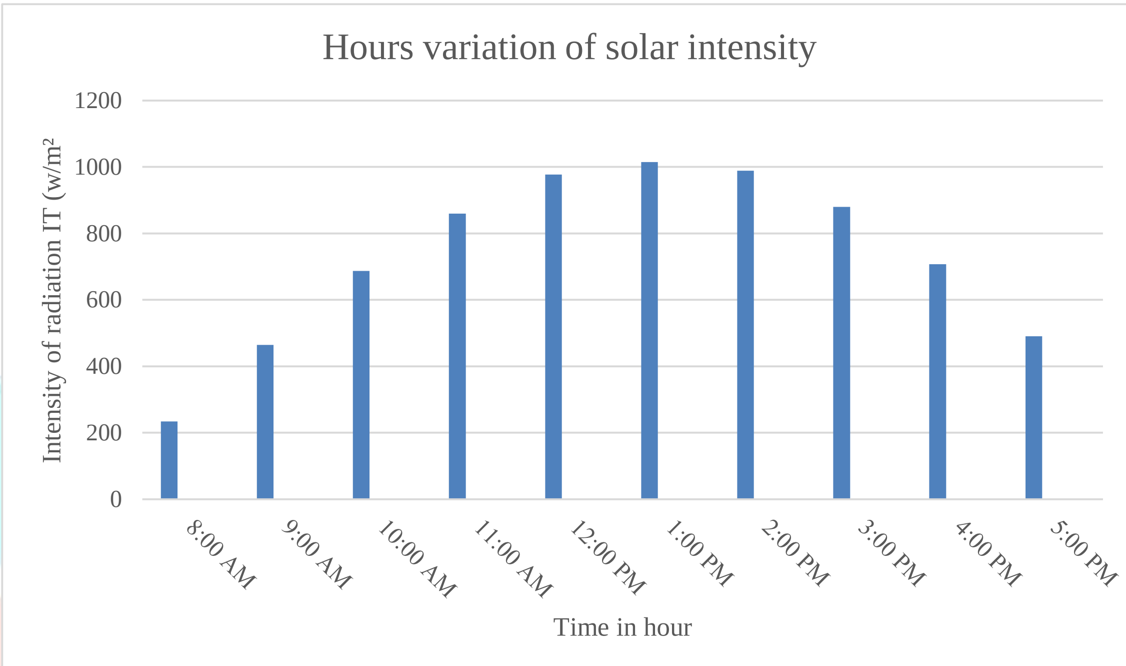


Fig. 4.1 Variation of solar intensity

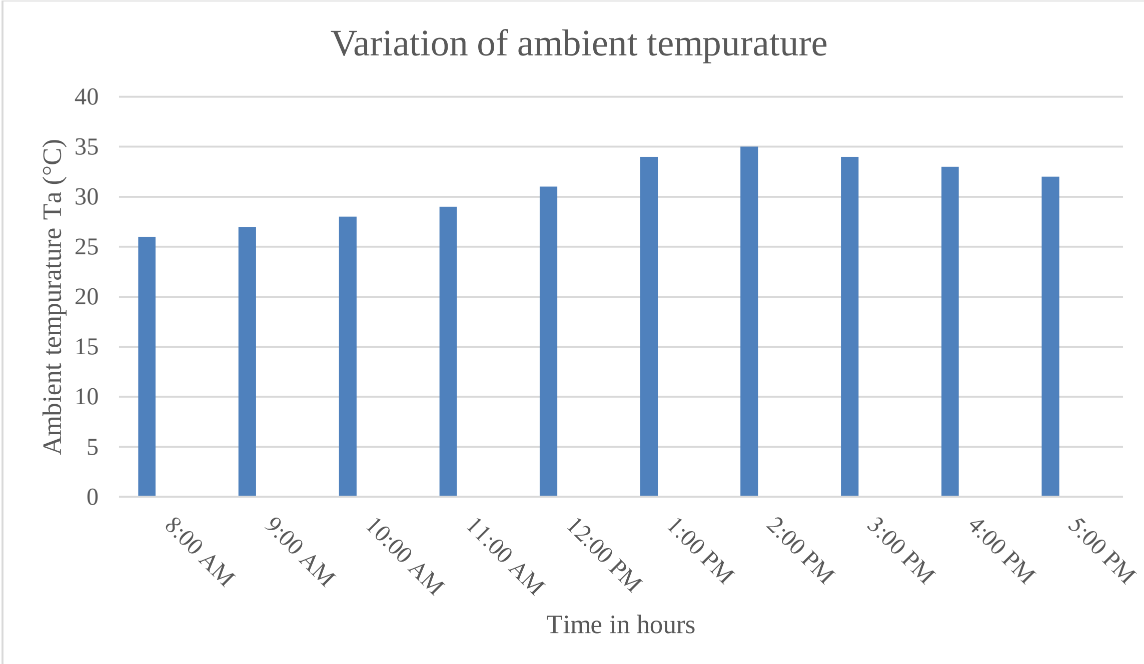


Fig. 4.2 Variation of ambient temperature

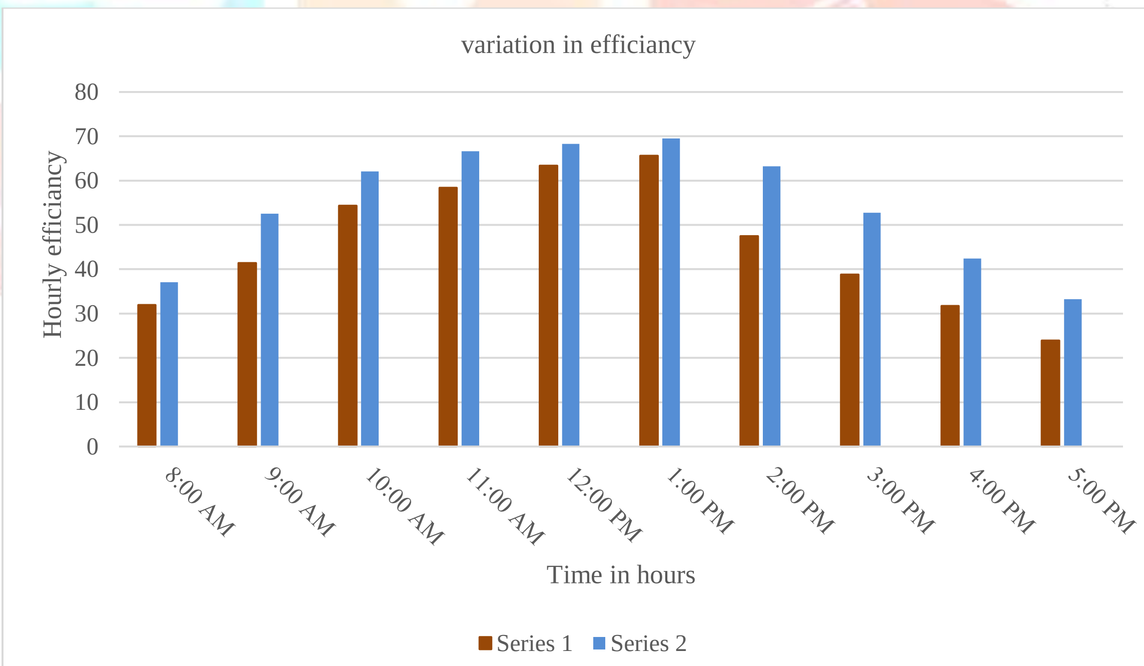


Fig. 4.3 Variation in efficiency

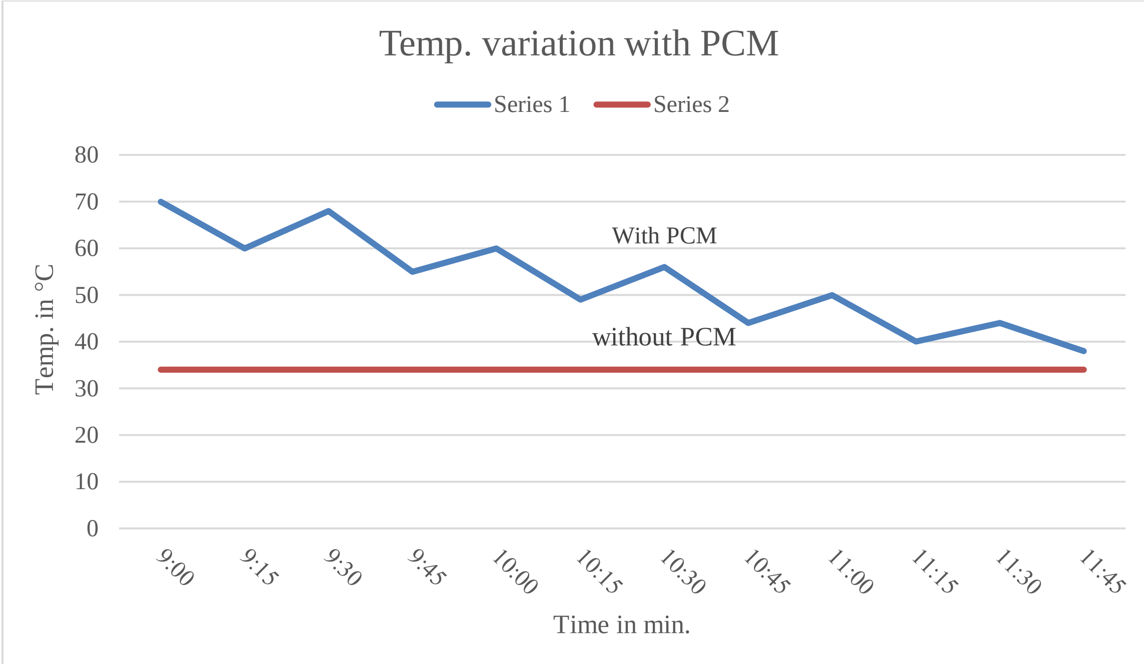


Fig. 4.4 Temperature variation with PCM

V. 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 energy consumption can be reduced by incorporating with PCM as capacity enhancing device.
(4) Output of system gives more satisfactory result with respect to time hot water can be made available for longer time.

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