Performance Comparative Study of Solar Water Heater with Evacuated Glass Tube and PCM Integrated Storage Tank

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Abstract

Immense emphasis has been given on the development of active solar energy systems which involve the integration of several subsystems such as solar energy collectors, heat-storage containers, heat exchangers, fluid transport and distribution systems, and control systems. This paper deals with thorough experimental investigation and comparative study of performance of Evacuated Glass Tube inside the flat plate collector and provision of Phase Change Material (PCM) inside the storage tank. This change in the pre-existing system enables the warmed fluid to carry the heat to a storage subsystem from which continuous hot water can be drawn for use at night and on cloudy days. A precise and detailed analysis of a solar flat plate collector is quite complicated because of the many factors involved. Efforts have been made to compare experimental value with formulated mathematical model which will describe the thermal performance of the collector in a computationally efficient manner.
Keywords: Energy Conservation, Evacuated GLass Tubes, PCM, Solar Water Heater, Thermal Storage

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I. INTRODUCTION

The escalating energy requirements alongside the reduction of the fossil energy reserves as well as environmental concerns have led to an increasing tendency toward renewable energy sources. Among these sources, solar energy has received considerable attention due to its ease of access and high potentiality in generating electricity and heat. The use of solar heating systems has increased due to the reasonable initial costs and relatively simple structure. The main component of these heating systems is the solar collector.

A solar collector is basically a heat exchanger which converts the solar radiation into heat. Among various types of solar collectors, flat plate collector, based on its simpler technology and lower costs, has globally become the mostly used one. One of the main applications of Flat plate solar collector is water heating. Domestic water heating which constitutes significant share of the residential energy consumption is an excellent application for utilizing solar energy.

However, due to the intermittent, unsteady environmental condition and time-dependant characteristics of solar radiation, the wide spread use of solar systems relies heavily on the enhancement of heat transfer using Evacuated Glass tubes and availability of feasible energy storage methods.

Evacuated tube solar collectors are based on single envelope vacuum tubes over copper tubes exposed to solar radiation improve heat transfer efficiency. Evacuated tube solar collectors minimise convective heat loss by placing the solar absorbing surface in a vacuum. Radiation heat loss is also minimised by using a low emissivity absorber surface. Solar thermal energy had been traditionally stored in the form of sensible heat by raising the temperature of either water or rocks for later use. But, due to their inefficient storage capacities, the usage of PCM is explored. The melting of PCM enables the absorption of larger amounts of heat which is available excessively in daytime. This stored heat can be later released to surrounding medium during night time.

This paper deals with comparative study of performance of simple solar water heater, heater with evacuated glass tube and storage tank provided with PCM layer interference.

II. LITERATURE REVIEW

Richard O'Hegarty et.al (2016) had categorised Solar Thermal Collectors into five core technology types, such as, Unglazed Collectors, Glazed Flat Plate Collectors, Massive Solar Thermal Collectors, Evacuated Tube Collectors and Concentrated Solar Collectors. The collectors are reviewed with reference to five core components (1) cover, (2) absorber, (3) heat transfer fluid network, (4) insulation, and (5) fixings and framing systems. In their research, they have concluded that a strong focus on providing black colour has been highlighted. State of the art colour coatings have been developed to improve the optical efficiency when colouring the cover. [1]

Prasad.P.Patil et.al (2018) had reviewed and discussed various flat plate collector and their parameters. The review finds that the maximum works were incorporated on the development of the geometrical parameters of collector to get the better thermal efficiency and heat transfer rate. The research gives promising results with innovative materials, concentration of radiation, different geometries, integrated solar thermal collector, heat pipe collector which can be the future collector, hybrid collector i.e. PV solar collector, heat transfer through nano particles and the use of twisted tape to get the swirls effect for increasing the heat transfer. [2]

M. Z. H. Khan et.al (2015) has explained flow of water through collectors by Thermosiphon Effect. A thermosiphon solar water heater relies on warm water rising, a phenomenon known as natural convection, to circulate water through the solar collector and to the storage water tank. The thermosiphon effect for solar water heating system has been employed with solar collectors as the principal heating component. These solar heating systems use either direct heating or indirect heating by the collector. In these cases, the thermosiphon induced flow is a result of the incident solar radiation, but it is also affected by the hot water removal pattern.[3]

Indra Budihardjo et.al (2006) outlines experimental investigations and numerical simulations undertaken to characterise the variation of circulation flow rate through single-ended evacuated tubes with the collector optical configuration, the solar input and the time of day. A non-dimensional correlation is developed from a conventional thermosiphon loop model taking into consideration the tube inclination angle and aspect ratio for an array of tubes over a flat diffuse reflector. The circulation flow rate can be correlated in terms of solar input, tank temperature, collector inclination and tube aspect ratio as expressed as

$$\mathrm{Re_d} = a_0 \left[\frac{\mathrm{Nu_d Gr_d}}{\mathrm{Pr}} \cos\theta \left(\frac{L}{d}\right)^n \right]^{a_1}$$

where Re = Reynolds Number
Nu = Nusselt Number
Gr = Grashof's Number. [4]

Anand M Markad and Dipak B Deshmukh (2017) state that the selection of the PCM for a given application requires careful consideration of the properties of various substances. One of the most important aspects is the conformable melting point and the high latent heat of fusion. The choice of the substance depends upon the temperature level of the application. Residential, commercial and industrial buildings often have hot water requirement at around 600°C and bathing, laundry and cleaning operations in domestic sector needs it at about 500°C. The right melting point enables that the phase changing comes off during every usage cycle. Thereby the latent heat could be fully utilized. The value of latent heat is very important, because the higher latent heat results in higher storable heat quantity. According these aspects we can choose several materials. We have to mind the chemical properties, the thermal expansion and the aspects of safety. PCMs in the range 50-1000c have been proposed for the water heating. [5]

Atul Sharma (2009) states that, the ideal PCM to be used for latent heat storage system must meet following requirements: high sensitive heat capacity and heat of fusion; stable composition; high density and heat conductivity; chemical inert; non-toxic and non-inflammable; reasonable and inexpensive. In the nature, the salt hydrates, paraffin and paraffin waxes, fatty acids and some other compounds have high latent heat of fusion in the temperature range from 30ºC to 80ºC that is interesting for solar applications. In his paper, a comparison has been made between different sized latent heat storage vessels and sensible heat storage in a water tank with different degree of stratification. The storage vessel consists of a number of closed cylindrical pipes filled with the phase change medium. These pipes were surrounded by heat transfer fluid. A cylindrical storage unit in the closed loop with a flat plate collector has been theoretically studied by Bansal and Buddhi for its charging and discharging mode. The calculations for the interface moving boundary and fluid temperature were made by using paraffin wax (P – 116) and stearic acid as PCMs. [6]

M.V.Kulkarni et.al (2014) concludes that, the use of PCM in solar water heater helps to reduce cooling rate of water, thus it enhance the maximum utilization of solar energy and hence improves efficiency of system. In this research with use of PCM efficiency of solar water heater increase from 31.25% to 44.63% and also heat storage capacity increase from 3260.4 kJ to 4656.5 kJ. Hence with using PCM material efficiency & heat capacity of solar water heater increases at reduced initial heating rate because PCM take heat to get heated. As PCM based solar water heater store maximum solar energy, it reduces the size of tank and hence can reduce cost of Solar Water Heater. [7]

Himangshu Bhowmik and Ruhul Amin (2017) mention that a reflector was introduced here to improve the performance of the solar collector. It was obtained from the observation that the heat transfer rate and the collector efficiency are strongly depending on solar radiation. In fact, the radiation emitted by the absorber plate of the collector cannot escape through the glass, and the reflector on the other hand used to concentrate the solar heat on the collector surface, thus maximize the collector efficiency. The collector efficiency is obtained here, without reflector as 51%, and with reflector as 61%. Thus, the overall efficiency of the flat plate solar collector is increased approximately 10% by using the reflector with the collector. [8]

Runsheng Tang et.al (2010) had conducted Comparative studies on thermal performance of water-in-glass evacuated tube solar water heaters with different collector tilt-angles and found that any tilt angle between 22° and 46° have same thermal performance. Their findings indicated that, to maximize the annual heat gain of solar water heaters, the collector should be inclined at an optimal tilt-angle according to the latitude location of the place of experiment. [9].

III. FACTORS INFLUENCING EXPERIMENTAL READINGS

The natural circulation flow rate through evacuated tubes depends on a number of factors, namely:

- Heat input per unit absorber area: Higher heat input results in higher density variation between the hot and cold streams in the tube, therefore higher driving pressure head.
- Tank temperature: The natural circulation through the collector is driven by the temperature difference between the hot and cold fluid. At higher temperature operation, the gradient of water density with temperature is higher, i.e. for a given temperature increment, the change in density is higher at high water temperatures. Also, water viscosity is smaller at high temperatures. Within the operating range of the collector the variation of water viscosity is as high as a factor of three.
- Collector inclination:
- Collector inclination determines the axial and radial components of gravitational acceleration. The axial component of the gravity drives the primary natural circulation and the radial component determines the secondary circulation around the tube circumference. In general, inclination closer to vertical would result in higher natural circulation flow rates.
- Tube length–diameter ratio:
- This parameter is included in the Nusselt number correlation using the functional dependence suggested by Lighthill (1953) in the analysis of heat transfer in single-ended thermosiphons.
- Circumferential heat flux distribution:
- Varying the distribution of heat input around the circumference of the absorber changes the flow structure in the tube, and in turn affects the circulation flow rate.

IV. EXPERIMENTAL SETUP

The main purpose of this work is to improve performance of conventional solar water heaters, by incorporating Evacuated glass tube collector and PCM integrated storage tank. The experimental set up consists of the following.

A. *Shell Type Insulated Storage Tank:*

A horizontal concentric cylindrical tank is made of GI sheet of 18 gauge thickness. Inner cylinder is of 15cm diameter while the outer cylinder is of 20cm diameter. The length of the cylindrical tank is 44 cm. The storage capacity of inner tank is 7.5 litres. In between the cylinder, Phase Change Material is placed. The tank is thermally insulated with 6 mm diameter asbestos fabric rope to minimize the heat loss to the atmosphere.

B. *Glazed Flat Plate Collector:*

Flat plate collector box is made from wood of 1.5cm thickness for a size of 44cm x 59cm x6cm. It consists of Reflector, Copper tube, Evacuated tube and Brass nipple. A flat plate collector is an insulated box containing an absorber plate and a network of flow tubes covered by a sheet of translucent glass or plastic. FPCs transfer heat to water or a working fluid as it passes through the network of flow tubes in thermal contact with the absorber plate. The translucent cover serves to reduce heat losses from convection.

C. *Evacuated Glass Tube:*

Evacuated Glass Tubes are prepared by taking copper tubes of diameter 12.5mm and 65mm length per piece and inserted inside glass tube of 25 mm diameter. Five copper tubes are vertically arranged and two copper tubes are horizontally arranged in collector. These tubes are joined by gas welding. The total circulation length of the copper tube is 15feet.

D. *PCM Layer:*

Industrial grade Paraffin 68 wax is used as PCM. Paraffin waxes are cheap and have high thermal energy storage density and low thermal conductivity. These waxes can store thermal energy for about 3 – 4 hrs with proper insulation.

E. Frames and Fittings:

Supporting frame is fabricated using mild steel L angle to support the heat exchanger, flat plat collector and storage tank. Frame is welded using arc welding method. Hot water hose of 8mm diameter is used for required length. This can withstand temperature of 150^{0}C. Threaded brass nipples connected to the copper coil using flare nut.

Fig 1: Experimental Setup

Fig. 2: Evacuated Glass Tube and Copper Tube Setup

Fig. 3: Paraffin Wax filled in Annulus as Phase Change Material

V. EXPERIMENTAL PROCEDURE

The experimental procedure consists of two methods namely, non-flow method and constant flow method. In Non Flow method, the storage tank is filled with 7 litres of water at room temperature and placed along with flat plate collector under the sun for 8 hours and reading is taken for every 30 minutes to observe the temperature variation. In Constant Flow method, the tank is connected to water source from which cold water constantly flow at a rate of 0.5 kg/hr and circulated through the flat plate collector and temperature variations are noted.

The main purpose of the project is to compare the heat transfer rate and temperature increase, in solar water heater with only evacuated tubes and with PCM integrated tank. PCM envelope surrounding the storage tank absorbs heat during day time and stores heat as latent heat. This enables the water heater to provide hot water even after sunset. The experiments were conducted in the bright day time in the months of March, April and May 2020. The data are recorded at an interval of 30 minutes from morning 10.00 AM to evening 06.30 P.M. Averaged Readings are tabulated and temperature increase is studied.

Table – 1
Observation for Solar Water Heater without PCM Tank

S. No	*Time*	*Cold Water In*	*Flat Plate Collector In*	*Copper Tube Temp*	*Flat Plate Collector Out*	*Hot Water Out*
		°C	*°C*	*°C*	*°C*	*°C*
1	*10.00 AM*	*32.1*	*33.4*	*49.0*	*45.5*	*43.2*
2	*11.00 AM*	*33.7*	*34.1*	*50.7*	*47.2*	*44.6*
3	*12.00 PM*	*33.8*	*34.9*	*51.8*	*48.3*	*46.2*
4	*01.00 PM*	*34.7*	*35.2*	*53.3*	*49.8*	*47.2*
5	*02.00 PM*	*35.6*	*36.1*	*53.8*	*50.3*	*47.6*
6	*03.00 PM*	*36.4*	*36.7*	*53.7*	*50.2*	*47.4*

7	*04.00 PM*	*35.4*	*37.1*	*47.7*	*44.2*	*41.3*
8	*05.00 PM*	*35.2*	*37.3*	*47.1*	*43.6*	*40.7*
9	*06.00 PM*	*34.3*	*36.2*	*41.9*	*38.4*	*36.8*
10	*07.00 PM*	*33.6*	*34.7*	*39.8*	*36.3*	*34.8*

Table – 2
Observation for Solar Water Heater with PCM Tank

S. No	*Time*	*Cold Water In*	*Flat Plate Collector In*	*Copper Tube Temp*	*Flat Plate Collector Out*	*PCM Temp*	*Hot Water Out*
		°C	*°C*	*°C*	*°C*	*°C*	*°C*
1	*10.00 AM*	*33.2*	*36.3*	*49.0*	*45.5*	*39.3*	*38.5*
2	*11.00 AM*	*34.9*	*41.8*	*56.9*	*55.3*	*41.3*	*41.8*
3	*12.00 PM*	*34.5*	*51.6*	*57.6*	*56.1*	*43.5*	*44.3*
4	*01.00 PM*	*35.7*	*51.4*	*57.3*	*63.5*	*45.3*	*46.1*
5	*02.00 PM*	*37.4*	*51.6*	*57.8*	*65.1*	*47.9*	*47.4*
6	*03.00 PM*	*37.5*	*49.7*	*56.1*	*58.3*	*50.7*	*49.0*
7	*04.00 PM*	*37.2*	*44.1*	*51.6*	*53.9*	*52.6*	*50.3*
8	*05.00 PM*	*35.9*	*40.7*	*48.2*	*46.7*	*51.6*	*49.8*
9	*06.00 PM*	*35.2*	*36.9*	*44.2*	*41.4*	*50.7*	*49.2*
10	*07.00 PM*	*34.3*	*35.6*	*39.4*	*36.7*	*49.3*	*47.9*

VI. RESULTS AND CONCLUSION

It is evident from the table that, solar water heater equipped with evacuated glass tube but without PCM tank initially heats faster and provides hot water with higher temperature than that of solar water heater fitted with PCM tank. This phenomenon is observed because PCM wax observes heat energy initially and stores it as latent heat. Once steady state condition is obtained, that is PCM reaches melting stage, heat is transferred gradually to water in the inner tank.

After maximum exposure to sun radiation, i.e. around 01.00 PM, temperature of the hot water output reaches peak value. After 02.00 PM, when radiation effect reduces gradually, temperature of hot water output reduces drastically in Solar Water Heater without PCM Tank. However in the evening time, latent heat energy stored in PCM tank supplies heat energy to water and we continue to get hot water at steady temperature even after sun set.

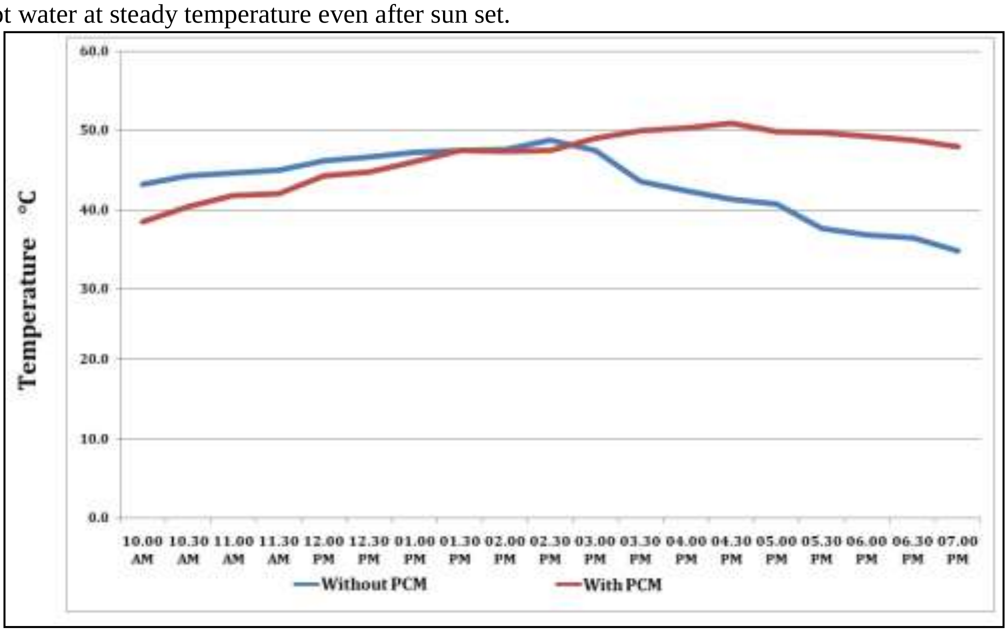

Fig. 4: Result Comparison

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