Thermal performance investigation of evacuated tube heat pipe solar collector integrated with parabolic Trough

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ABSTRACT

Conventional water heaters are used in rural in urban areas. Now a day's use of non conventional energy has been increased. Among them using solar energy for generation of hot water by using flat plate collector is very common. Using evacuated tube rather than flat plate collector increases the efficiency of system. A new system of evacuated tube along with parabolic trough is developed and studied experimentally. System has 4 set of evacuated tube from which two are with PTC and other two are without PTC to compare the efficiencies. Experiments are conducted by varying inclination angle and mass flow rate of water. Maximum efficiency is achieved at 30° inclination angle using PTC is 394.88%. Maximum temperature achieved is 84.2°C with PTC and 79°C without PTC. Enhancement in developed design with parabolic trough is relatively 10% more than system with only evacuated tube, as parabolic trough can reflect the solar rays on unused part of tube also. Experimental results shows that solar collector integrated PTC has much better collector efficiency.

Keywords: - *ETC integrated PTC, thermal performance evaluation, effect of variation in mass flow rate and inclination angle*

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1. INTRODUCTION

In high temperature application the performance of evacuated tube is better as compare to flat plate collector. Conventional solar water heater unable to support instant hot water generation due to various problems. Several experiments are conducted on performance evaluation, Optical design, construction and working of solar water heater. Types of collector used are flat plate collector, Heat Pipe, evacuated tube collector, parabolic trough collectors, compound parabolic trough collectors etc.

Fluid in glass evacuated tubes experimentally and numerically evaluated by natural circulation of heat transfer fluid. Such fluid in glass evacuated tube cannot withstand high pressures and hence it is suitable for application where water head is available (Morrison GL, Budihardjo I, Behnia M, 2005). Transient modeling for fluid in glass evacuated tube solar collector is developed (Budihardio *et al*, 2009). For high temperature and high pressure applications Metal in glass tube collector concept is developed (Azad E, 2009). When the heat pipe is maintained in a proper vacuum environment higher efficiency is achieved. But it is difficult to maintain a good vacuum environment due to non condensable gas generation during the operating time.

Excellent thermal performance can be achieved using Evacuated tube rather than flat plate collector even though both can absorb direct and diffused solar radiation. Efficiency of solar thermal collectors can be evaluated by two methods i.e steady state test method and quasi dynamic test method (M.A. Sahiba *et al*, 2015). Thermosyphon is the key element for evacuated tube system. For more efficient use of evacuated tube parabolic troughs are used integrated with the system (Zhen-Hua *et al*, 2013).

Stainless steel sheet of size 1.2 X 2.4 m is used for finding out the effective length of parabolic concentration collector. Thickness of the sheet is of 3 mm, fabricated under the basis of parabolic equations for reflecting the solar rays to collector (Manoon Pidhuwan, *et al*, 2004). To characterize the shape and size of parabola trough length, focal length, aperture width and rim angle are the important parameters [12].

Comparative study between FPC and ETSC for domestic solar water heater is done on same environmental condition. As a result of the same collector efficiencies were found 37.9 % and 50.3 % for FPC and for ETSC respectively (M.A. Sahiba *et al*, 2015). Filling the space between heat pipe & twin glass evacuated tube collector with heat transfer oil can increase production and efficiency to 0.933 Kg/(m^2h) and 65.2 % respectively (H. Jafari Mosleh *et al*, 2015).

The heat pipe made up of copper of 8.3 mm diameter is placed inside the ETSC to focal length .Heat pipe is partially filled with ethanol & parabolic collector is made of reflective sheets. Parallel sun rays incident on the reflector which reflects the same on ETSC (H. Jafari Mosleh *et al*, 2015). By using different nano fluids efficiency of the solar water heater can be increased. The performance evalution of tube solar collector using therminol B-12 as heat transfer fluid coupled with parabolic trough. Experimental set up consists of standard evacuated tube collector of length 1.00 mm & 47 mm diameter. The aperture area of parabolic trough is 1.2 X 0.6 m. The experimentation was conducted from 600h to900h in low thermal radiations and the beam radiation varies between 300 and 500W/m^2. Solar radiations are measured by using pyranometer. The maximum temperature achieved without parabolic trough is 40° C at 540 W/m^2 which is almost less by 28° C in comparison to the system with parabolic trough (P. Selvakumar *et al*, 2014).

2. EXPERIMENTAL SETUP

The experimental set up which is shown in figure 1 consists of an evacuated tube, parabolic trough, storage tank, inlet outlet valves, temperature sensors. Evacuated tube used is of 1800 mm and 58 mm diameter. Heat pipe is filled with ethanol glycol. The header has inlet and outlet along with safety valve. The parabolic trough is mounted on wooden structure. The material used for parabolic trough is reflective aluminum sheet with aperture area of 24.2 X 170 cm. As fluid is moving with thermosyphon phenomenon tank is kept on height.
For comparative study set up is made for two evacuated tubes with parabolic trough and two are without parabolic trough. Headers are separate for both the structure. The temperature sensors are placed at inlet and both the outlet to measure the temperature.
The set up is positioned in north-south facing. Schematic sketch of experimental set up is as shown in figure 2.

Fig. 1 Experimental Setup

Cold fluid is passing though the manifold through inlet valve. Temperature sensor places sense the cold fluid temperature. Evacuated tube collects the solar energy. This energy in the form of heat is passes to cold fluid in the manifold. Hot water is released through outlet valve with specified flow rate. Hot fluid temperature is sensed by sensor.
Similar process is being followed by both the system with PTC or Without PTC. Only difference in with PTC is sun rays are reflected to evacuated tube as PTC is made up of reflective sheet.

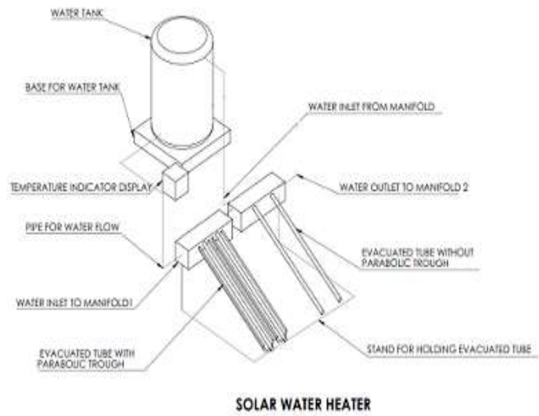

Fig. 2 Schematic sketch of set up

2.1 Parabolic Trough specifications.

Following specifications are calculated as per evacuated tube dimensions.

Table 1 Parabolic trough specifications

Aperture width	24.2 cm
Aperture length	170 cm
Rim angle	80°
Focal length	7.21 cm

Fig. 3 Specifications of parabolic trough

3. TEST METHODOLOGY

To evaluate performance of set up in terms of finding best operating flow rate and inclination angle for Pune region. Test is conducted on various inclination angles and at different flow rate of water. Inclination angle is changed with the increment of 10 degree. Flow rate of water for different inclination angle is varies with increment of 5 Littre per hour.

Observations are noted for specific angle and flow rate along with the readings of solar intensity in terms of W/m^2. Experiments are conducted in April 2016 between 10AM to 5PM.

4. PERFORMANCE CALCULATION

Thermal efficiency of system is defined as the ratio of heat energy absorbed by the evacuated tube to the heat energy absorbed by the evacuated tube integrated with parabolic trough (P. Selvakumar *et al*, 2014).

Energy incident on ETC collector

$$Q_{insident} = I \times A_c$$

Rate of Heat gained only by evacuated tube

$$Q_{ETC} = mC_{pw}(T_{in} - T_{out})$$

Rate of Heat gained only by evacuated tube

$$Q_{ETC\ integrated\ PTC} = mC_{pw}(T_{in} - T_{out})$$

Instantaneous efficiency of ETC

$$\eta_{inst} = Q_{ETC} \times I$$

Instantaneous efficiency of ETC

$$\eta_{inst} = Q_{ETC\ integrated\ PTC} \times I$$

4.1 Solar Intensity Vs time

As solar intensity plays an important role in system, it is important to find out value of solar intensity with respect to time. To understand the better stable time frames so accordingly experiments can be perform. Fig 4 shows variation of solar intensity with respect to time.

Due to summer solar intensity observed is quite close every day. Intensity is maximum during period of 12-1 PM. From 10 to 12 it’s increasing gradually. And from 1-5 PM it is decreasing.

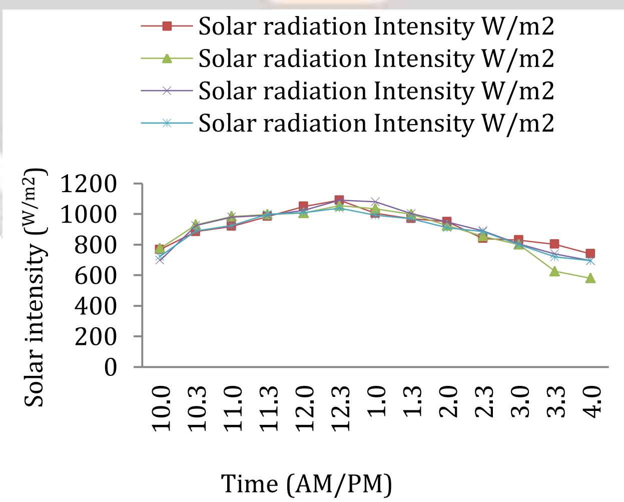

Fig. 4 Variation of solar intensity with respect to time.

4.2 Variation in outlet temperature with respect to change in inclination angle

In order to understand effect of inclination angle on collector performance between ETC and ETC integrated PTC study is carried out. As result of the same maximum temperature is achieved at 30° inclination angle. Observations are noted for outlet temperature along with respective inclination angle.

Fig. 5 & 6 indicates the outlet temperature observed during experimentation. Maximum temperature achieved with ETC is 71° C and with ETC integrated PTC is 76° C.

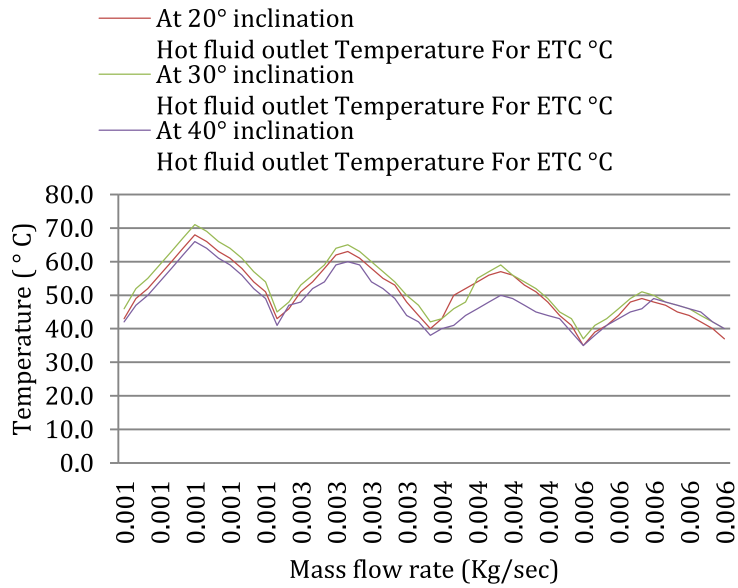

Fig. 5 Hot fluid outlet temperature variation at specified inclination angle with respect to mass flow rate for ETC

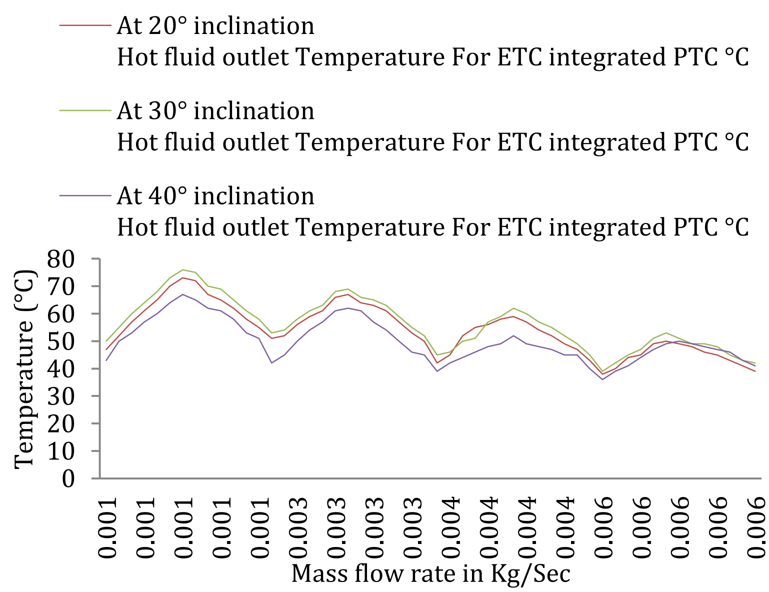

Fig. 6 Hot fluid outlet temperature variation at specified inclination angle with respect to mass flow rate for ETC integrated PTC

4.3 Effect of inclination angle on instantaneous collector efficiency

It is useful to compare the instantaneous collector efficiency with change in inclination angle in order to evaluate the suitable inclination angle. Fig. 7 & 8 show that maximum collector efficiency achieved at 30°.
At 40° inclination angle lowest efficiency is observed.
At 20° angle intermediate efficiency is observed.
System of ETC integrated PTC provides better results than ETC.

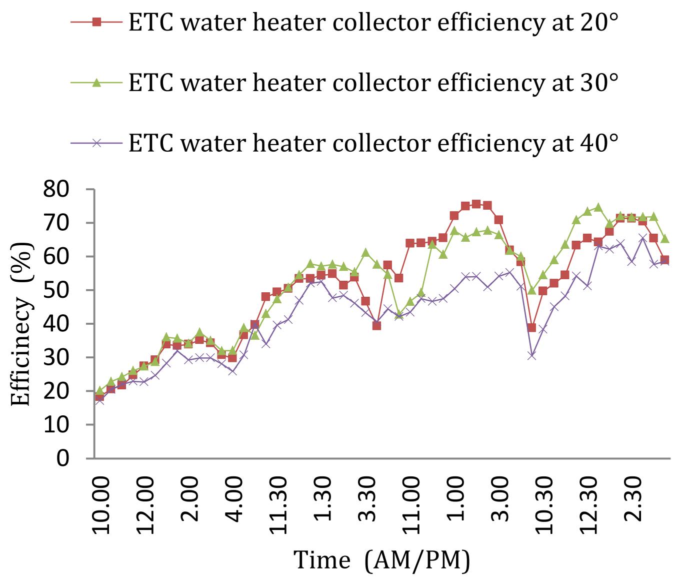

Fig. 7 Effect of inclination angle on instantaneous collector efficiency for ETC

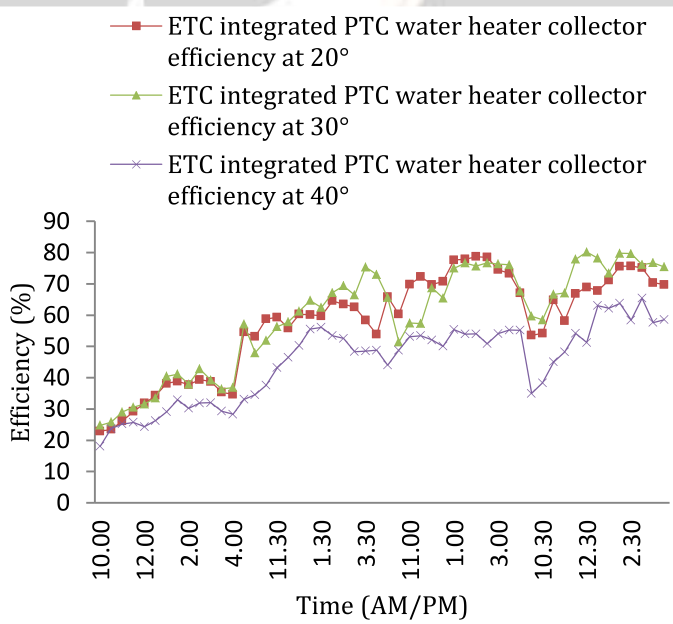

Fig. 8 Effect of inclination angle on instantaneous collector efficiency for ETC integrated PTC

4.4 Mass flow rate Vs instantaneous collector efficiency.

Mass flow rate also plays a significant role in the system. Hence variation observed with change in mass flow rate is also noted. Fig. 9 & 10 indicates that increase in mass flow rate increases the collector efficiency.

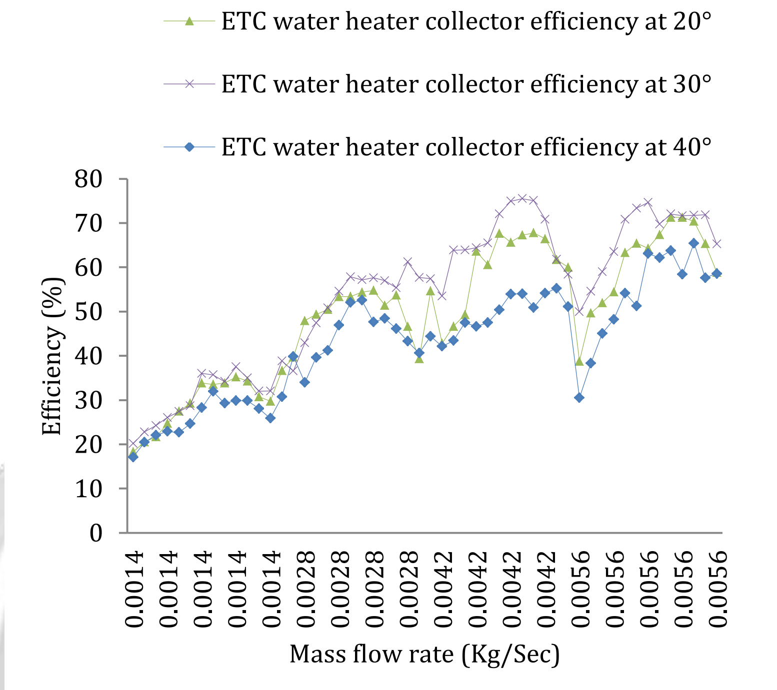

Fig. 9 Variation of instantaneous collector efficiency with respect to change in mass flow rate for ETC

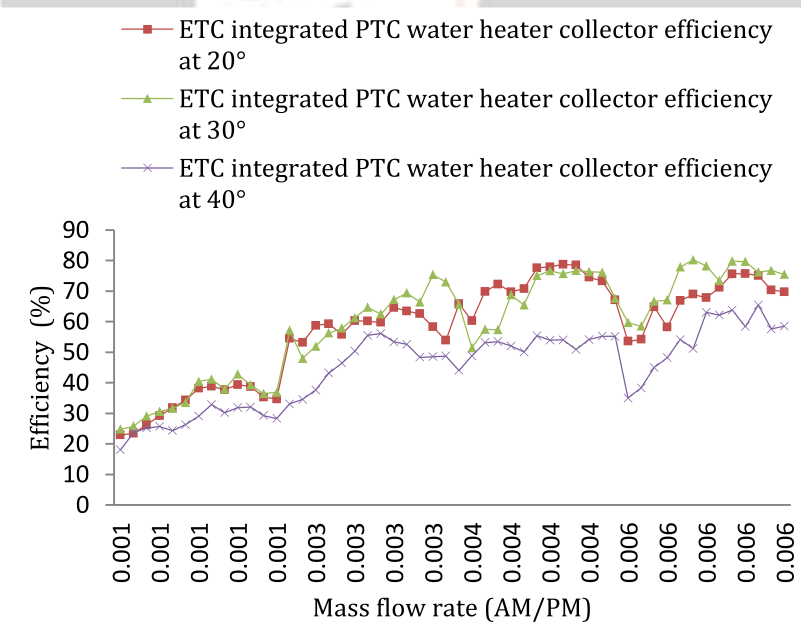

Fig. 10 Variation of instantaneous collector efficiency with respect to change in mass flow rate for ETC integrated PTC

4.5 Comparison of system with or without PTC

To investigate thermal performance of system mass flow rate and inclination angle kept variable. From fig. 9 & 10 it is observed that as mass flow rate increases causes an significant increase in collector efficiency. Better inclination angle evaluates that maximum solar radiations absorbed by the system either with parabolic trough or without parabolic trough. Hence from fig. 7 & 8 it is understand that 30° provides the better inclination angle for Pune region.

To evaluate the better system of with or without PTC, experiments are conducted on both systems simultaneously. Hence environmental conditions were also same. Fig. 11 shows comparison between collector efficiencies with or without PTC. The effect of mass flow rate on instantaneous collector efficiency with variation in the inclination angle has been evaluated. Optimum performance achieved at inclination angle 30°. This results in line with the similar findings in the literature.

Results indicate that Maximum collector efficiency is achieved at 30° inclination angle and at high flow rate i.e 0.05555 Kg/sec. **Current design with parabolic trough provides en enhancement upto 10% than system with only evacuated tube.**

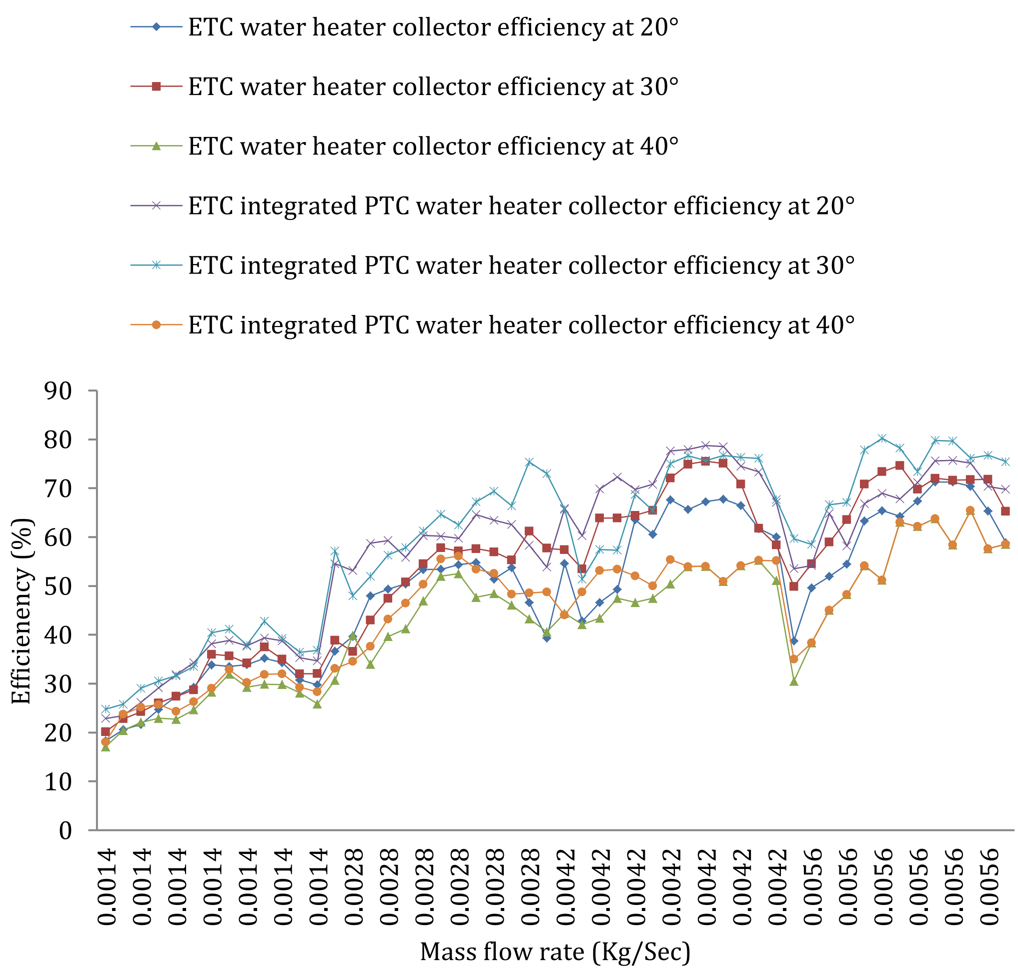

Fig. 11 Comparison between collector efficiency of systems with or without PTC

5. CONCLUSION

From the study investigation of performance evaluation for the system with and without PTC is evaluated. Set up of 4 evacuated tubes is divided into two systems. One is with parabolic trough having set of two evacuated tube, and another one having two evacuated tubes without parabolic trough. Effects of inclination angle and mass flow rate on both the systems are determined. Following are the results obtained from the experimentation.

1. System with parabolic trough is observed having maximum efficiency than System without parabolic trough.
2. Effect of inclination angle on efficiency is analyzed and it is observed that maximum efficiency is achieved at 30 ° inclination angle.
3. As the inclination angle is changed, the hot water output also changes. Experiments were conducted on 20°, 30° and 40 °. Among them 30° found optimum angle where maximum hot fluid output is observed.
4. As the mass flow rate of water increases efficiency of the system also increases. Maximum efficiency is observed at 0.0055 Kg/sec flow rate.
5. Instantaneous efficiency of ETC system and ETC integrated PTC system are compared and efficiency of system integrated with PTC found 10-11 % relatively higher than ETC.
6. Evaluation is done for solar intensity vs time on summer and it is observed that intensity of solar radiations are increased with increase in time up to 12-1 PM then again its drop down gradually. Maximum solar intensity observed was 1090 W/m^2

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