Performance Analysis of a Solar Parabolic Through Collector Using Different Reflective Material for Hot Water Generation

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ABSTRACT

A feasibility study and performance analysis of a solar parabolic trough collector is analyzed using Stainless steel ,Aluminium Foil and Glass Mirror as reflective materials for hot water generation. A parabolic trough is investigated usingdifferent reflective materials for concentration of radiation beam on absorber tube that is copper tube. The absorber pipe is a copper tube with appropriate black paint and a glazing (glass cover tube) is provided to minimize the losses and comparing the test results .Water is used as heat carrying fluid in absorber tube. The concentration ratio for PTC is 12.80 with aperture area 1.44 m^2 (with glazing). The maximum temperature of heating water obtained is 81.2^{0}C The average beam radiation during the collection period is 650 W/m2. The useful heat gain, the collector instantaneous efficiency, the thermal efficiency of the storage tank water and the efficiency of the system are found in each reflective material. The results obtained show that system is very effective for the heating of water using glass mirror as a reflective material. Moreover it is observed that system is highly efficient if a automated mechanism for tracking is employed.

Keywords: Parabolic Trough collector, solar hot water generation, hot water storage tank, thermal efficiency, system efficiency.

I INTRODUCTION

Renewable energy sources like wind energy, solar energy, geothermal energy, tidal energy etc. are the hope for the future energy need. These resources are pollution free which is a very big advantage. Solar energy has great potential to fulfill the energy needs. Utilization of a small part of this available energy makes a great help in fulfilling world energy needs. Solar energy is produced by the sun and transferred in the form of radiations. There is a need of devices which convert these radiations into useful form of energy. Currently, solar parabolic trough collector (PTC) is employed for a variety of applications such as power generation [1], industrial steam generation [2], and hot water production [3]. Solar thermal power plants based on PTC are presently the most successful solar technologies for electricity generation, as showed by the Solar Electric Generation Systems (SEGS) plant at KramerJunction in California, USA [4]. A feasibility study for the use of PTC in a hotel for hot water production was reported by Kalogirou and Lloyd[5]. It was shown that PTC could be more cost effective than the conventional flat plate collectors. Design and simulation analysis of a PTC hot water generation system has been done by ValanArasu and Sornakumar [6]. The simulation analysis shows good agreement with the test results reported by ValanArasu.A theoretical and experimental analysis of parabolic trough collector is done by ValanArasu and Sornakumar for hot water generation[7]. The most important advantage of PTC as compared with the other two types of collectors is its ability to function at high temperatures with high efficiency. For example, at a temperature of 100 °C, PTCs works at an efficiency of about 62%, CPCs at about 32% and the FPC at about 10%[8]. In recent days, PTC has been used many applications such as sea water desalination [9, 10], solar photocatalysis [11], solar detoxification of organic pollutants [12], *etc*.

The aim of this experimental work is to analyze the performance of a parabolic trough collector using different reflective material for hot water generation. For this reason, an experimental set up is designed and fabricated at NIT Kurukshetra, India. In the present work, a new parabolic trough collector system, which has been developed for hot water generation, is presented in fig. 1. The PTC system for hot water generation includes a PTC, a hot water storage tank (HWST), and a circulating pump of capacity25W. The parabola of the present collector with a rim angle of 90° is used. The solar receiver is made of a copper tube, a glass envelope and rubber cork seals at both ends of the glass envelope. The copper tube is coated with a heat resistant black paint and is surrounded by a concentric glass cover with an annular gap of 0.5 cm. The rubber corks are incorporated to achieve an air-tight enclosure. Water from the storage tank is pumped through the copper tube, where it is heated and then flows back into the storage tank. The PTC rotates around the horizontal north/south axis to track the Sun as it moves through the sky during the day. The axis of rotation is located at the focal axis. A manual tracking is employed by carefully observing the rotation of sun around the day in Kurukshetra. The specifications of the PTC system are detailed in table 1.

Table 1. Parabolic trough collector system specifications

Items	Value
Collector aperture	1.2 m
Collector length	1.2 m
Rim angle	90°
Focal distance	0.3 m
Receiver diameter	0.34 m
Glass envelope diameter	0.44 m
Concentration ratio	12.30
Water flow rate	0.09 kg/s.

Storage tank capacity	15 litres
Tank material	Stainless steel
Tank insulation material	Glass wool
Insulation on pipes	Soflon
Water pump	25 W

A. Reflecting Materials:

In present PTC, Glass mirrors as a reflective material are used for concentrating solar radiation. A Stainless steel sheet of dimensions (4ft x 5ft) is used to form the parabolic shape in prototype. The stainless steel sheet is used to provide the mechanical strength to the parabolic trough. Stainless steel with dimensions (4ft x 5ft) is fixed in such a way it form a shape of present parabola. A piece of cotton cloth is then pasted on the sheet over which the mirror stripes which are 25 in number with dimensions (2in x 4ft) are pasted over the cloth. The mirror stripes are pasted in such a way that they do not affect the curve of the parabola. The mirror stripes are used because they have a very high reflectivity of 93%.Prototype parabolic trough collector with Glass mirror as a reflector is shown in fig.1.

B.Absorber Tube:

A copper tube with the glass cover tube on it joined by the glass to metal seals on both sides of the copper tube is used as an absorber tube. The glass cover tube is used so as to reduce the conductive, convective, and radiative losses from the copper tube. The copper tube with length 1.5m and with inside and outside diameter of 31.5mm and 32.5 mm is used

C.Insulation:

The SOFLON insulation is used on the pipes so as to minimize all the heat losses during the transport of working fluid from inlet to the outlet which is from the storage tank. Also glass wool is used for insulating the storage tank.

*Figure 1:*Experimental set up (Parabolic trough collector)

III MEASURING DEVICES INSTRUMENTS

Different measuring devices are used to evaluate the performance parameters of parabolic trough collector. Different parameters are measured in this experiment; in this includes:

- Ambient water Temperature
- Inlet and Outlet water Temperature
- Solar radiation intensity
- Water flow rate

RTD PT100 thermocouples are used to measure the temperatures at different points. The thermocouples are connected with a digital temperature indicator that gives the temperature with a resolution of 0.10^0C. The solar radiation intensity is measured during the day using a Pyranometer which is supplied by CM11 Kipp and Zonen, Holland. The flow rate was measured at the beginning of experimental work. The experimental data are recorded at intervals of 1hour during the daytime. The experiments were carried out during some selected clear sky days from 1 April 2012 to 1 June 2012.

IV.PERFNCEORMA PROCEDURE OF PTC FOR HOT WATER GENERATION SYSTEM

The following procedure was used to perform the experiments:

(1) The collector was exposed to the sun at least 30 min before the experiment.

(2) In each experiment, for 30 min duration, the water mass flow rate passing through the absorber was maintained constant.

(3) The collector was tracked with the sun manually by inspecting the reflecting rays falling on the absorber.

(4) After the preparation of the apparatus, the following readings were recorded:

- Mean water inlet temperature.
- Mean water outlet temperature.
- Total radiation falling on the collector surface.
- Mass of collected water.

V. PERFORMANCE ANALYSIS OF PARABOLIC TROUGH COLLECTOR

The performance of the new PTC hot water generation system is determined by obtaining values of collector instantaneous efficiency and the system efficiency for different combinations of incident radiation, ambient temperature and inlet water temperature(as shown in Fig.2). Absorber tube has a glass envelop around its periphery.. It is done to minimize the convective and radiative losses.

The thermal efficiency η, of a concentrating collector operating under steady-state conditions can be described by [5,6]:

$$\text{Efficiency } \eta = \frac{m_w c_{pw} (T_{out} - T_{in})}{I_b \times A_a \times t}$$

In the present work, the collector system is operated under closed loop mode. The rate of energy gained by the water in the storage tank for a time interval of 1 hour is given by:

$$Q_u = \dot{m} C_p (T_o - T_i)$$

The overall efficiency of the PTC hot water storage system is estimated by the following equation:

$$\text{Efficiency } \eta = \frac{m_w c_{pw} (T_{out} - T_{in})}{I_{av} \times A_a \times t}$$

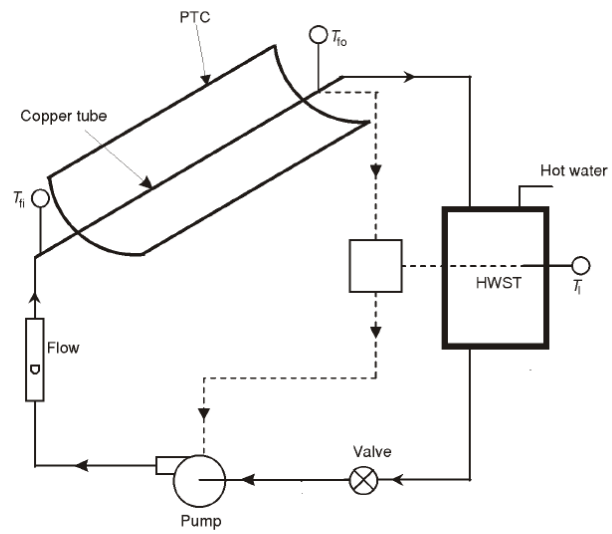

Figure 2 Line Diagram of Parabolic trough collector with storage tank

VI. EXPERIMENTAL RESULTS

Following readings has been taken on month May,2012,days is normal at the morning and noon. The variation of collector water outlet temperature, T_{fo}, and beam radiation I with time on one day,for stainless steel as reflecting material is shown in figure 3 . Similarly the variation of temperature of water with beam radiation for Aluminium foil and Glass Mirror are shown in figure 4 and 5.The collector water temperature increases progressively with time, which varies from 8.00 am to 04.00 pm, Indian Standard Time (IST), as the water is recirculated through a hot water storage tank of capacity 15 liters. The mass flow rate of water through the collector is 0.0 9kgps. The storage tank water temperature increases steadily from an initial temperature of 25 °C at 8.00 h and touches a maximum value of 81.2°C at 01.00 pm, as no energy is withdrawn from the storage tank during the collection period. At any instant, the collector water temperature is greater than the storage tank water temperature.

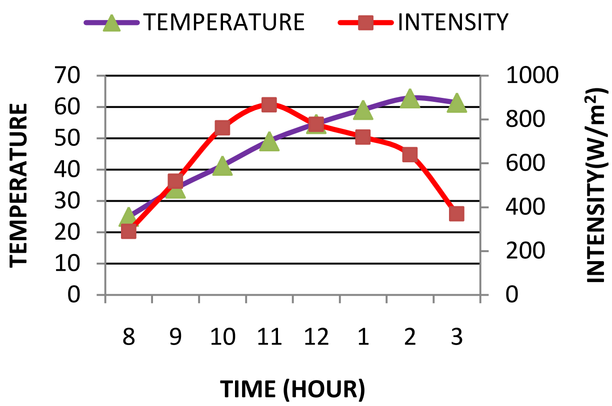

Figure3. Variation of collector water temperature, T_{fo} , and beam radiation I with time in Stainless Steel

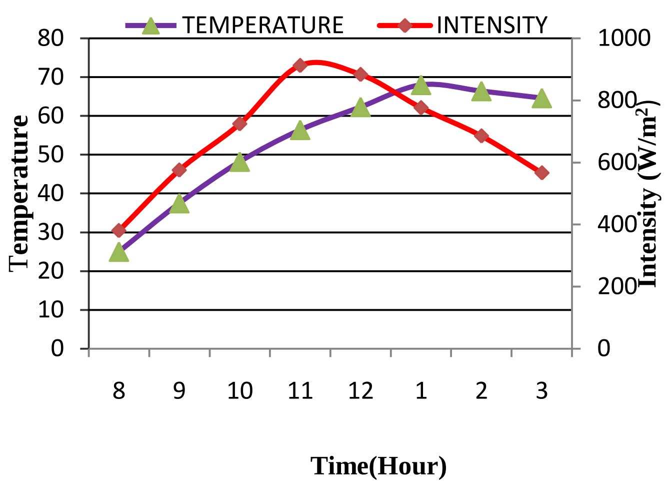

Figure4. Variation of collector water temperature, T_{fo} ,and beam radiation I with time in Aluminium Foil

The variation of beam radiation, I, and useful heat gain, Qu, with time is shown in fig.6. It is seen that a fairly smooth variation of beam radiation with the maximum occurs around noon. The useful heat gain first increases, reaches a peak value around noon and then decreases. This is due to the fact that the useful heat gain is strongly influenced by the incident beam radiation and therefore follows its variation.

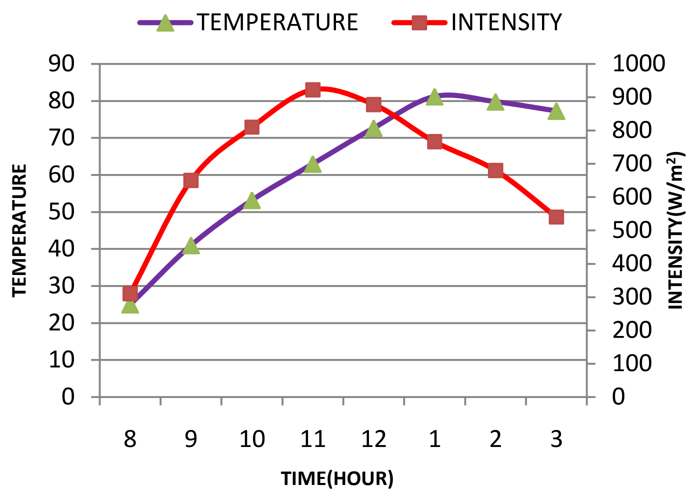

Figure5. Variation of collector water temperature, T_{fo} ,and beam radiation I with time in Glass Mirror

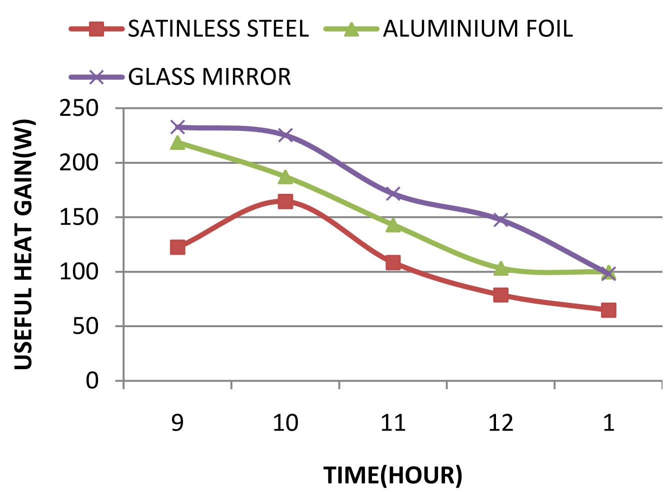

Figure6: Variation, Useful heat gain, Q_u, with Time

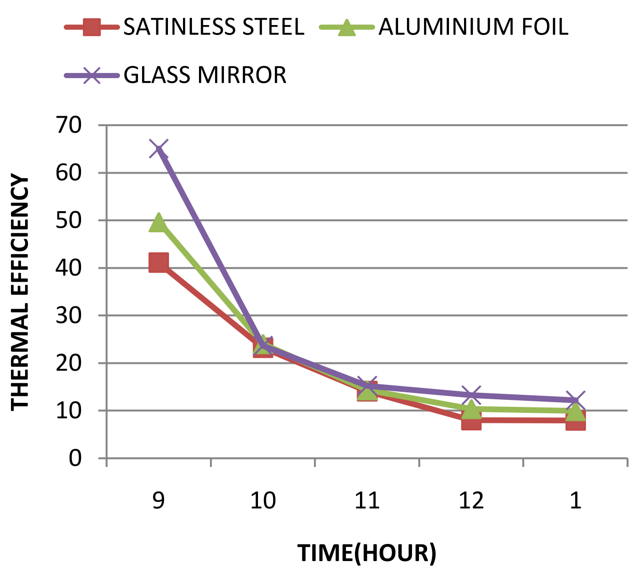

Figure7. Variation of System Efficiency (HOUR) with Time

The variation of hourly thermal efficiency of the PTC hot water storage system is plotted against time and intensity in fig. 7. The hourly system efficiency (thermal efficiency) decreases per hour as useful heat gain decreases continuously.

VII.CONCLUSION

In the present work, the performance of a new parabolic trough collector with hot water generation system is investigated through experiments over one full day in summer period. The system operates under closed loop mode by re circulating the water through a hot water storage tank. No hot water is withdrawn from the storage tank to the load during the collection period. The useful heat gain, the temperature gained by the storage tank water, variation of beam radiation with time and the efficiency of the system as a whole are evaluated on hourly basis. A maximum temperature of 81^{o}C is obtained in glass mirror this is because Glass mirror has high optical efficiency which is directly linked to thermal efficiency. Thermal and Overall system efficiency is better using glass mirror as reflective material In present work, the production of heating water using the sun flux is a viable undertaking for prototype parabolic trough collector so it can be used as a domestic water heating appliance. Feasibility of present parabolic trough can be analyzed in further practical application like air heating, domestic water heating, process heating etc.

Nomenclature		***Greek***	
A	collector aperturearea, [m^2]	ρ	specular reflectivity of the concentrator
W	collector width,[m]	τ	glass cover transmittivityfor solar radiation
d_{co}	diameterofabsorber tubewith glazing [m]	α	absorber tube emissivity/absorptivity
L	length ofcollector,[m]	$\eta inst$	instantataneous efficiency
C	concentration ratio, [–]	$\eta therm$	thermal efficiency per hour
C_p	specific heat capacity [J/kg K]	$\eta overall$	overall system efficiency
F_R	heat removalfactor, [–]	ηo	optical efficiency
I_b	beam or direct radiation,[W/m^2]	***Abbreviations***	
Qu	rate ofuseful heat received from the collector, [W]	*PTC*	Parabolic trough collector
Ta	ambient temperature, [K]	^{o}C	Temperature unit
T_{fi}	collector water inlet temperature, [K]	HWST	Hot water storage tank
T_{fo}	collector water outlet temperature, [K]		
T_l	storagetank watertemperature, [K]		
T_i	Initial storagetank watertemperature, [K]		
U_L	overallheat loss co-efficient, [W/m^{2}K]		
V	volume, [m^3]		
m	Mass flow rate[m^3/s]		

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