PERFORMANCE CHARACTERISTICS OF THE SOLAR PARABOLIC TROUGH COLLECTOR WITH HOT WATER GENERATION SYSTEM

by

Amirtham VALAN ARASU and Samuel Thambu SORNAKUMAR

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The performance of a new parabolic trough collector hot water generation system with a well mixed hot water storage tank is investigated in the present work. The storage tank water temperature is increased from 35 °C at 9.30 h to 73.84 °C at 16.00 h when no energy is withdrawn from the storage tank. The average beam radiation during the collection period is 699 W/m^2. The useful heat gain, the collector instantaneous efficiency, the energy gained by the storage tank water and the efficiency of the system as a whole are found to follow the variation of incident beam radiation as these parameters are strongly influenced by the incident beam radiation. The value of each of those parameters is observed to be maximum around noon, when the incident beam radiation is maximum.

Key words: *parabolic trough collector, solar hot water generation, solar storage system, hot water storage tank, performance characteristics of solar system*

Introduction

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]. Parabolic trough collector is preferred for steam generation because high temperatures can be obtained without any serious degradation of the collector's efficiency [4]. 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 Kramer Junction in California, USA [5]. A feasibility study for the use of PTC in a hotel for hot water production was reported by Kalogirou and Lloyd [3]. 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 Valan Arasu and Sornakumar [6]. The simulation analysis shows good agreement with the test results reported by Valan Arasu and Sornakumar [7]. The present work focuses on the performance study of a new PTC with hot water generation system.

Description of the parabolic trough collector with hot water generation system

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) of well-mixed type, and a circulating pump. The parabola of the present collector with a rim angle of 90° is very accurately constructed of fiberglass. A flexible solar reflector material from Clear Dome Solar, San Diego, Cal., USA (SOLARFLEX foil) with a reflectance of 0.974 [8] is used in the present work. 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. The tracking mechanism consists of a low speed 12 V D. C. motor and an embedded electronic control system. The input signals to the control system are obtained from light dependent resistors. The pump for maintaining the forced circulation is oper-

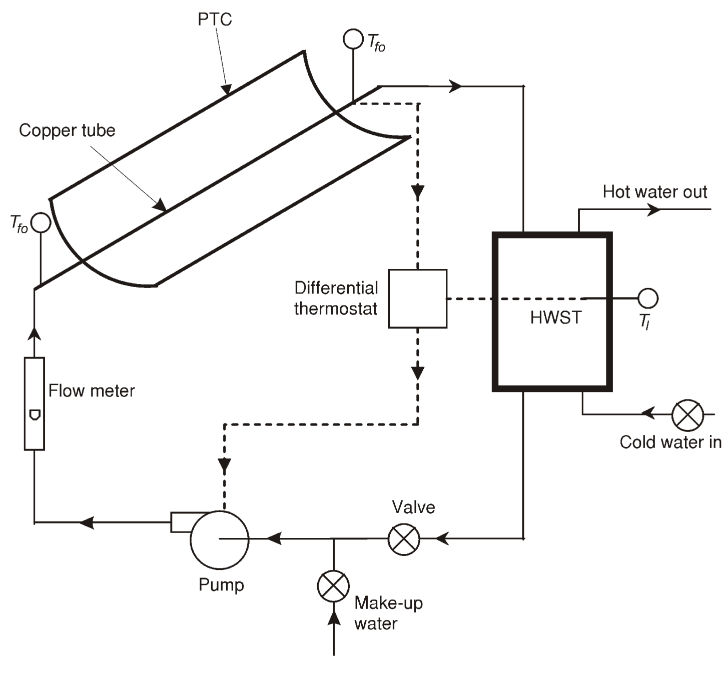

Figure 1. Parabolic trough collector with storage tank

ated by an on-off controller (differential thermostat), which senses the difference between the temperature of the water at the outlet of the collector (T_{fo}) and the storage tank water (T_l). The pump is switched on whenever this difference exceeds a certain value and off when it falls below a certain value. In the present work, the differential temperature controller value ($T_{fo} - T_l$) is set as 2 °C. It is assumed that the water in the storage tank is always well mixed and consequently is at a uniform temperature, T_l, which varies only with time. The specifications of the PTC system are detailed in tab. 1.

Table 1. Parabolic trough collector system specifications

Items	Value
Collector aperture	0.8 m
Collector length	1.25 m
Rim angle	90°
Focal distance	0.2 m
Receiver diameter	12.8 mm
Glass envelope diameter	22.6 mm
Concentration ratio	19.89
Water flow rate	0.7-1.0 l/min.
Storage tank capacity	35 litres
Tank material	Stainless steel
Tank insulation material	Glass wool
Insulation Thickness	5 cm
Water pump	367.65 W

Performance testing of the parabolic trough collector hot water generation system

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. The collector water outlet temperature (T_{fo}), ambient temperature (T_a) and storage tank water temperature (T_l) were recorded with the help of PT 100 – resistance temperature device (RTD) sensors. The solar beam radiation intensity was measured by a pyrheliometer and the mass flow rate of water by a rotameter. The wind speed was measured by a vane type anemometer. All parameters were measured as a function of time over a 30 minutes period and under steady-state or quasi-steady-state conditions. The time response of the parabolic trough solar collector has been determined in order to evaluate the transient behaviour of the collector, and to select the proper time intervals for the quasi-steady-state or steady-state condition. Whenever transient conditions exist, the equality defined by eq. (1) does not govern the thermal performance of the collector, since part of the solar energy absorbed is used for heating up the collector and its components or part of the energy lost results in cooling the collector. The time constant of the collector is determined according to ASHRAE standard 93 [9] as 67 s [7].

The thermal efficiency, η of a concentrating collector operating under steady-state conditions can be described by [10, 11]:

$$\eta = \frac{Q_u}{A \cdot I} = \frac{\dot{m} c_p (T_{fo} - T_{fi})}{A \cdot I} \tag{1}$$

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

$$Q_s = m_w c_p (T_{lt} - T_{li}) \tag{2}$$

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

$$\eta_s = \frac{Q_s}{A \cdot I_h} = \frac{m_w c_p (T_{lt} - T_{li})}{A \cdot I_h} \tag{3}$$

Results and discussions

The variation of collector water outlet temperature, T_{fo}, and storage tank water temperature, T_l, with time on one day, viz. April 30, 2005 is shown in fig. 2. The collector water temperature increases progressively with time, which varies from 9.30 to 16.00 h, Indian Standard Time (IST), as the water is recirculated through a hot water storage tank of capacity 35 litres. The mass flow rate of water through the collector is 1.0 lpm. The storage tank water temperature increases steadily from an initial temperature of 35 °C at 9.00 h and touches a maximum value of 73.84 °C at 16.00 h, 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.

The variation of beam radiation, I, and useful heat gain, Q_u, with time is shown in fig. 3. It is seen that a fairly smooth variation of beam radiation with the maximum (747 W/m^2) 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.

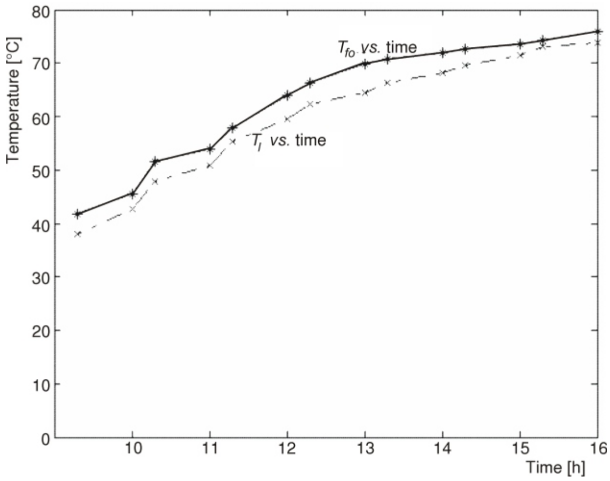

Figure 2. Variation of collector water temperature, T_{fo}, and storage tank water temperature, T_l, with time

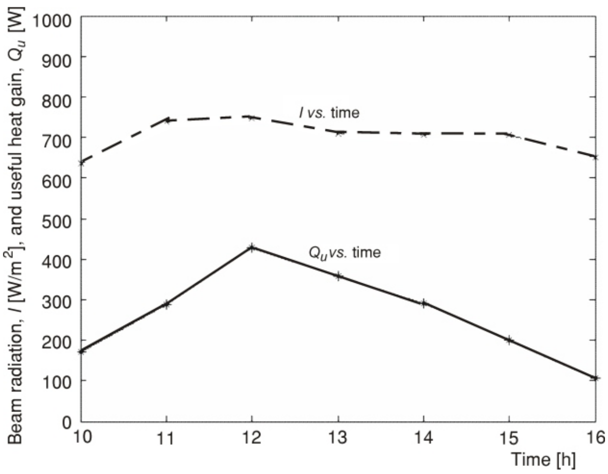

Figure 3. Variation of beam radiation, I, and useful heat gain, Q_u, with time

The collector instantaneous efficiency is computed using eq. (1). Plot showing the variation of the collector instantaneous efficiency with time is given in fig. 4. It will be noted that the general pattern of variation of efficiency over a day is the same as that of the useful heat gain because the value of efficiency depends on both the incident beam radiation and the useful heat gain.

The variation of hourly beam radiation and energy gained by the storage tank water per hour with time is presented in fig. 5. The hourly beam radiation increases till noon and then decreases. The energy gained per hour, Q_s, by the storage tank water starts increasing steadily and touches the peak around noon and then decreases. This effect is

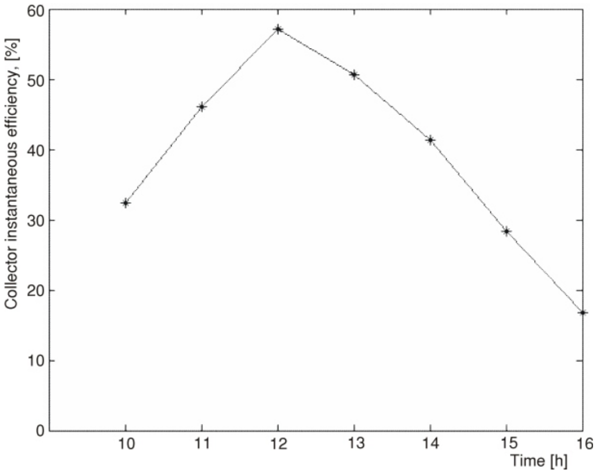

Figure 4. Variation of collector instantaneous efficiency with time

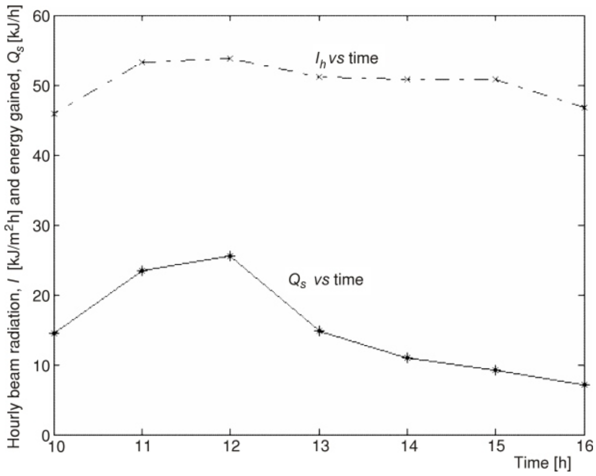

Figure 5. Variation of hourly beam radiation, I_h, and energy gained, Q_s, with time

due to the fact that the energy gained by the storage tank water is directly proportional to the useful heat gain across the collector with time. The variation of hourly efficiency of the PTC hot water storage system is plotted against time in fig. 6. The hourly efficiency increases till noon and then decreases.

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 recirculating the water through a

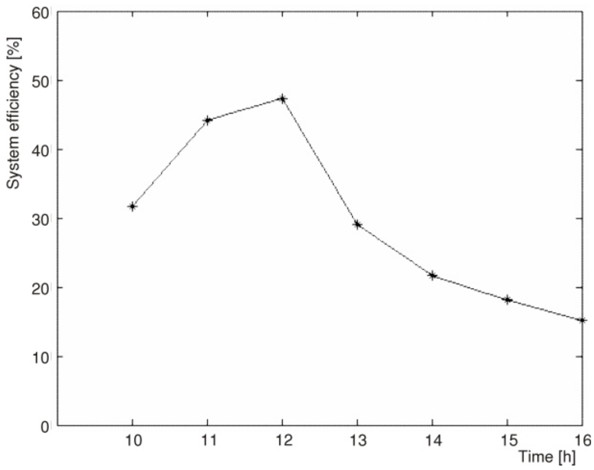

Figure 6. Variation of system efficiency with time

well mixed hot water storage tank. No hot water is withdrawn from the storage tank to the load during the collection period. The variation of collector water outlet temperature and the storage tank water temperature are measured between 9.30 and 16.00 h. The storage tank water temperature is increased from 35 °C at 9.30 h to 73.84 °C at 16.00 h. The average beam radiation during the collection period is 699 W/m^2. The useful heat gain, the collector instantaneous efficiency, the energy gained by the storage tank water, and the efficiency of the system as a whole are evaluated on hourly basis. All these parameters are strongly influenced by the incident beam radiation and found to follow its variation. The maximum value of each of those parameters is observed around noon, when the incident beam radiation is at its peak.

Nomenclature

A – collector aperture area, [m^2]
c_p – specific heat capacity of water, [$Jkg^{-1}K^{-1}$]
I – beam or direct radiation, [Wm^{-2}]
I_h – hourly beam or direct radiation, [$kJm^{-2}h^{-1}$]
$\dot{m}$ – mass flow rate of water through the collector, [kgs^{-1}]
m_w – mass of water in the storage tank, [kg]
Q_u – useful heat gain, [W]
Q_s – energy stored in the storage tank, [kJh^{-1}]
T_{fi} – collector water inlet temperature, [K]
T_{fo} – collector water outlet temperature, [K]
T_l – storage tank water temperature, [K]
T_{li} – initial storage tank water temperature, [K]
T_{lt} – storage tank water temperature after 1 hour time interval, [K]
η – thermal efficiency of the collector, [%]
η_s – hourly efficiency of the PTC hot water storage system, [%]

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Authors' address:

A. Valan Arasu, T. Sornakumar
Faculty of Mechanical Engineering
Thiagarajar College of Engineering
Madurai – 625 015, India

Corresponding author (A. Valan Arasu):
E-mail: a_valanarasu@yahoo.com

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