Engineering Science and Technology, an International Journal xxx (2016) xxx–xxx

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

Engineering Science and Technology, an International Journal

journal homepage: www.elsevier.com/locate/jestch

Full Length Article

Experimental validation of a fully covered photovoltaic thermal compound parabolic concentrator system

Deepali Atheaya [a,*], Arvind Tiwari [b], G.N. Tiwari [a]

[a] Centre for Energy Studies, Indian Institute of Technology, Delhi, Hauz Khas, New Delhi 11 00 16, India
[b] Department of Electrical Engineering, College of Engineering, Qassim University, P.O. Box-6677, Buraydah 51452, Saudi Arabia

ARTICLE INFO

Article history:
Received 19 January 2016
Revised 28 June 2016
Accepted 28 June 2016
Available online xxxx

Keywords:
Photovoltaic thermal
Thermal modeling
Instantaneous thermal efficiency

ABSTRACT

The main advantage of PVT-CPC system is to generate both thermal and electrical energy at a low cost. Hence, an analytical expression of electrical and thermal efficiency of fully covered photovoltaic thermal compound parabolic concentrator (PVT-CPC) system has been derived as a function of climatic and design parameters. Further, an experiment has been performed for a typical day during the summer month namely 3rd and 4th May, 2016 at IIT, Delhi (India) for [case (A)] conventional CPC system and [case (B)] fully covered PVT-CPC system for thermal validation. The theoretical and experimental results for the outlet fluid temperature and electrical efficiency were verified with correlation coefficient (r) of 0.99. This indicates a close agreement between the theoretical and experimental results for thermal and electrical energy.

1. Introduction

Today there is an energy demand wor ldwide and researchers are trying to get a viable solution for the undergoing energy crisis. Solar energy has been utilized to get clean energy [1,2]. Photovoltaic thermal (PVT) technologies can be one of solutions to meet the energy shortage effectively [3]. PVT module is used to generate electrical and thermal energy for space heating, residential and industrial applications. Rabl [4] firstly designed a trough shaped cylindrical collector for concentrating solar intensity to obtain high temperatures. A photovoltaic thermal (PVT) collector was explored theoretically and tested by Gibart [5] by using a concentrated solar radiation. The results showed better thermal and electrical performance of the collector as compared to conventional flat thermal collector. Based on solar trough concentration, an experiment of a two phase photovoltaic thermal collector was conducted by Tan et al. [6]. The results indicated that as the temperature of solar cell attained 73 °C, the working medium output temperature was raised by 12.06 °C. An asymmetric compound parabolic photovoltaic concentrator (ACPPVC) was designed, fabricated and tested in the outside environment with and without concentrators by Mallick et al. [7]. It was observed that ACPPVC produced 1.62 times more power in comparison with conventional concentrator. A small concentrating photovoltaic and thermal system was analyzed by Kribus et al. [8]. This system concentrated solar energy about 500 times. Kong et al. [9] designed a similar concentrated photovoltaic thermal system to achieve a uniformly concentrated radiation. A thermal analysis of high concentration thermal system was also carried out by Chen et al. [10]. It was observed that for high concentration ratio and mass flow rate, the electrical efficiency increases with decrease in thermal efficiency. Xu et al. [11] studied experimentally a solar PV thermal system with permanent truncated parabolic concentrators. In their system, a refrigerant R134a flowed in the aluminum tubes below the PV cells to extract the solar radiation for evaporation of refrigerant. Further, the refrigerant was condensed to heat water in a condenser. A flux concentrating rate of fixed parabolic concentrator was reported as 1.6 times more power output as compared to PV cells without concentrator. Kunnemeyer et al. [12] investigated the performance of a V-trough photovoltaic thermal concentrator and reported that by concentrating solar intensity on the PV cells and cooling them, better electrical output can be achieved. A design of an air gap lens walled compound parabolic concentrator photovoltaic thermal (ALCPC-PVT) system was proposed and tested by Li et al. [13]. An improved overall system efficiency of 65.5% was reported by them. Mohsenzadeh and Hosseini [14] studied and tested a photovoltaic thermal system integrated with reflectors and vacuum tube solar

Abbreviations: CPC, compound parabolic concentrator; PVT, photovoltaic thermal.

* Corresponding author.
E-mail address: datheaya@gmail.com (D. Atheaya).

Peer review under responsibility of Karabuk University.

http://dx.doi.org/10.1016/j.jestch.2016.06.014
2215-0986/© 2016 The Authors. Publishing services by Elsevier B.V. on behalf of Karabuk University.

Nomenclature

A	area (m^2)
A_a	total aperture area (m^2)
A_r	total receiver area (m^2)
b	breadth of receiver (m)
c_f	specific heat of fluid (J/kg K)
b_o	breadth of aperture area (m)
dx	elemental length (m)
F'	flat plate collector efficiency factor
F_R	flow rate factor, dimensionless
h	heat transfer coefficient (W/m^2 K)
L_r	total length of the receiver area (m)
PF_1	first penalty factor due to glass cover
PF_2	second penalty factor due to absorber/receiver plate
PF_c	penalty factor due to glass cover for the portion covered by glazing
L_p	receiver plate thickness (m)
L_i	insulation thickness (m)
L_g	glass cover thickness (m)
I_t	total radiation (W/m^2)
I_d	diffuse radiation (W/m^2)
I_b	beam radiation (W/m^2)
$U_{t,ca}$	overall heat transfer coefficient from solar cell to ambient through glass cover (W/m^2 K)
$U_{t,cp}$	overall heat transfer coefficient from solar cell to plate (W/m^2 K)
$U_{t,pa}$	total (top and bottom) overall heat transfer coefficient from plate to ambient (W/m^2 K)
$\dot{m}_f$	mass flow rate of water in (kg/s)
U_{L1}	overall heat transfer coefficient from blackened surface to ambient
$(W/m^2K)\eta_o$	efficiency at standard test condition ($I_t = 1000\ W/m^2$, $T_o = 25\ °C$)
β_o	temperature coefficient of efficiency (K^{-1})

Greek letters

α	absorptivity
β_c	packing factor
ρ	reflectivity
τ	transmittivity
η_i	instantaneous thermal efficiency
$(\alpha\tau)_{eff}$	product of effective absorptivity and transmittivity
η	thermal efficiency

Subscript

a	ambient
c	solar cell
eff	effective
f	fluid
fi	inlet fluid
fo	outlet fluid
g	glass
m	module
p	plate

water heaters. The results indicated an increase in electrical and thermal energy output of the system. Recently, a study of photovoltaic thermal double pass and flat and compound parabolic concentrators system (PVT-CPC) was carried out by Elsafi and Gandhidasan [15] and the PVT-CPC system showed the best performance. Atheaya et al. [16] proposed a partially covered PVT-CPC system. It was found that partially covered PVT-CPC system has a superior thermal performance than fully covered PVT-CPC system. Further, fully covered PVT-CPC gives better electrical power. The main purpose of this work is to compare the performance of conventional compound parabolic concentrator system and fully covered photovoltaic thermal compound parabolic concentrator system by using the characteristic equation/curve to meet the electrical and thermal energy demand of users. Now, the prime objective of this present paper is experimental validation of the thermal model developed by Atheaya et al. [16].

2. Brief description of experimental set up

2.1. Conventional CPC system [case (A)]

An experimental set up of conventional CPC system was installed at the roof top of the building of IIT, Delhi (28°37′N 77°14′E). The sketch of the experimental arrangement for [case (A)] has been shown in Fig. 1. The conventional CPC system was mounted on a mild steel frame. The absorber plate was made up of copper and it had a selective coating of black chrome plating to enhance the absorptivity of plate. A glass plate was fixed at the top of it. A casing of aluminum material was fabricated and both the absorber plate and the glass were fitted inside the casing to reduce thermal losses. Water is allowed to flow below the absorber plate in the copper tubes and its inlet and outlet pipe arrangement has been shown in the Fig. 2. The capacity of water tank was 30 l and it was placed on a stand and connected to the inlet of the system. The water flowed from water tank to the pipe and then moved parallel into four smaller tubes and finally gets collected at the outlet. The reflectors of the CPC were made up of stainless steel polished material due to its high corrosion resistance, enhanced strength and high reflectivity. The reflectors were fitted with the whole aluminum casing with the help of three mild steel strips (32 mm × 5 mm) which were placed at three different places on both reflectors for support. A floating valve was placed inside the tank to maintain the water level at a particular height to ensure constant mass flow rate. The copper tube in plate was insulated from below by using glass wool to reduce bottom losses. Firstly, the experiment was performed at the conventional CPC system on 3rd May, 2016 in New Delhi.

2.2. Fully covered PVT-CPC system [case (B)]

The sketch of an experimental arrangement of fully covered PVT-CPC system has been illustrated in Fig. 3. In this case, a semi-transparent PV module (101 cm × 51 cm) was fixed to the top of glass as shown in Fig. 4. The PV module was sealed by placing plastic rectangular sheets and putty sealant The Figs. 5–7 shows the actual photograph of the top view, front view and side view of fully covered PVT-CPC system. The experiment was performed for fully covered PVT-CPC system on 4th May, 2016 in New Delhi.

3. Thermal modeling

The assumptions for writing the energy balance equations for cases (A) and (B) are as follows:

- Both the conventional CPC and fully covered PVT-CPC systems are considered in the quasi steady state.

Please cite this article in press as: D. Atheaya et al., Experimental validation of a fully covered photovoltaic thermal compound parabolic concentrator system, Eng. Sci. Tech., Int. J. (2016), http://dx.doi.org/10.1016/j.jestch.2016.06.014