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Analytical characteristic equation for partially covered photovoltaic thermal (PVT) compound parabolic concentrator (CPC)

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Abstract

In this paper, an analytical expression for characteristic equation of a partially covered photovoltaic thermal compound parabolic concentrator (PVT-CPC) water collector system similar to Hottel–Whillier–Bliss (HWB) equation of flat plate collector has been derived. The derivation is based on basic energy balance equation for each component of partially covered PVT-CPC water collector system. The analytical result of proposed partially covered PVT-CPC water collectors [case (i)] has been compared with [case (ii)]: fully covered PVT-CPC water collectors; [case (iii)]: conventional CPC water collectors and [case (iv)]: partially covered PVT water collectors. It is observed that (a) an overall exergy efficiency of partially covered PVT-CPC water collector (25%PV) system is maximum and (b) an instantaneous thermal efficiency of conventional CPC water collector system [case (iii)] is maximum as compared to other cases.

Keywords: Photovoltaic thermal; Compound parabolic concentrator; Characteristic equation

1. Introduction

Designing and manufacturing of PVT-CPC systems is one of the solutions to face the energy crisis which is all around the world. In the literature many theoretical and experimental studies of PVT-CPC are available. The design of photovoltaic thermal (PVT) was firstly developed by Kern and Russell (1978). It was determined that when water or air is passed below the PV module heat transfer from the PV module takes place which reduces the temperature of PV module and leads to increase in the electrical efficiency. Hendrie (1979) analyzed a theoretical model of PVT systems. Further, Tiwari and Dubey (2010) reviewed the work in all aspect of PVT systems. Thermal modeling of hybrid PVT air collector integrated with compound parabolic concentrator (CPC) was done by Garg and Adhikari (1999). The thermal and electrical output of the system was better with CPC. Coventry (2005) studied the performance of concentrating PVT solar collector. The results have indicated thermal efficiency and electrical efficiency around 58% and 11%. A double pass photovoltaic thermal solar air collector with CPC and fins on the back side of the absorber area was studied by Othman et al. (2005). The efficiency of this system was found to be improved. Tchinda (2008) studied the solar air heater combined with compound parabolic concentrator. It was found that when mass flow rate of air increases then the outlet temperature of air reduces. Kandilli (2013) designed a concentrating PV combined system and found that the payback time of PV

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Nomenclature

A	area (m^2)
A_a	total aperture area (m^2) ($A_a = A_{am} + A_{ac}$)
A_{am}	aperture area over PV module (m^2)
A_{ac}	aperture area over glazed portion (m^2)
A_r	total receiver area (m^2)
A_{rm}	receiver area covered by PV module (m^2)
A_{rc}	receiver area covered by glass (m^2)
b	breadth of receiver (m)
b_o	breadth of aperture area (glass) (m)
c_f	specific heat of fluid (J/kg K)
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_{rm}	length of receiver covered by PV module (m)
L_{rc}	length of receiver covered by glass (m)
L_r	total length of the aperture 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
I_t	Total radiation (W/m^2)
I_b	beam radiation (W/m^2)
$\dot{m}_f$	mass flow rate of water in (kg/s)
$U_{t,ca}$	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)
U_{L1}	overall heat transfer coefficient from blackened surface to ambient (W/m^2 K)
η_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	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

system is reduced. A building integrated compound parabolic concentrator PVT systems was studied by Guiqiang et al. (2012). It was found that PVT-CPC collectors have lead to the reduction in the quantity of PV cells and an increase in the efficiency. An air filled asymmetric compound parabolic concentrator was developed by Mallick et al. (2007).The electrical efficiency of PV module was increased and it can be used for building façade integration. Nilsson et al. (2007) studied and optimized the thermal and electrical characteristics of PVT-CPC systems for higher latitudes such as Lund and Sweden.

An asymmetric compound parabolic photovoltaic thermal concentrator was designed and fabricated by Chaabane et al. (2013).The electrical and thermal performance of the system showed higher electrical and thermal output when compared to the asymmetric compound parabolic photovoltaic concentrator system.

In this paper, an attempt has been made to develop characteristic equation for a partially covered photovoltaic thermal compound parabolic concentrator (PVT-CPC) (Figs. 1a and 1b) similar to Hottel–Whillier–Bliss (HWB) equation of flat plate collector.

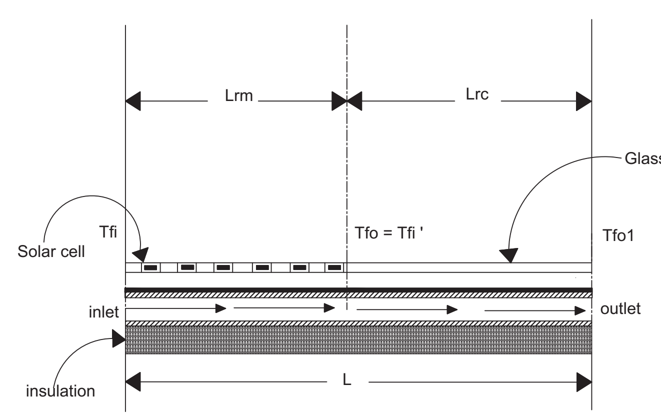

Fig. 1a. cross sectional side view of proposed partially covered PVT-CPC water collector system [case (i)] ($A_a > A_r$; $L_{rm} = 1$ m; $L_{rc} = 1$ m).