Available online at www.sciencedirect.com

SCIENCE DIRECT®

Solar Energy 80 (2006) 751–759

SOLAR ENERGY

www.elsevier.com/locate/solener

Performance evaluation of solar PV/T system: An experimental validation

Arvind Tiwari *, M.S. Sodha

Centre for Energy Studies, Indian Institute of Technology Delhi, Hauz Khas, New Delhi 110016, India

Received 2 September 2004; received in revised form 30 May 2005; accepted 6 July 2005
Available online 22 August 2005

Communicated by: Associate Editor Jean Rosenfeld

Abstract

In this communication, an attempt has been made to develop a thermal model of an integrated photovoltaic and thermal solar (IPVTS) system developed by previous researchers. Based on energy balance of each component of IPVTS system, an analytical expression for the temperature of PV module and the water have been derived. Numerical computations have been carried out for climatic data and design parameters of an experimental IPVTS system. The simulations predict a daily thermal efficiency of around 58%, which is very close to the experimental value (61.3%) obtained by Huang et al.

Keywords: PV thermal; Solar energy; Water heater

1. Introduction

The energy payback time (EPBT) of a photovoltaic (PV) system lies between 10 and 15 years depending on insulation and the efficiency of the PV module. If the efficiency can be increased then the energy payback time can be reduced. In order to increase the efficiency of the PV module, the temperature of the PV module should be decreased (Zondag et al., 2003; Chow, 2003). Jones and Underwood (2001) have developed a non-steady-state thermal model for a photovoltaic system (BP 585) by considering the effect of heat capacity of the PV module. Infield et al. (2004) have suggested reducing the temperature of the PV module by flowing air between the PV module and the double glass wall for space heating. They have developed a steady-state model to evaluate an overall heat loss coefficient (U) and thermal gain factor (g). Similar studies were carried out by Tripanagnostopoulos et al. (2002), Zondag et al. (2002), Prakash (1994) and Chow (2003) by flowing air and water below the PV module to increase the electrical efficiency of the PV module. Such a system is referred as a photovoltaic–thermal (PV/T) or hybrid or combi-panel.

Zondag et al. (2002) have developed 1D, 2D, and 3D dynamical models of a combi-panel. They concluded that the simple 1D steady-state model for computing daily yield from combi-panel performs almost as well as more time consuming 2D and 3D dynamic models. Two types of combi-panel (PV/T hybrid) for water heating have been considered i.e. (i) tube-in-plate configuration, Zondag et al. (2002), Chow (2003), Huang et al.

* Corresponding author. Tel.: +91 11 26591255.
E-mail address: arvindtiwari02@yahoo.com (A. Tiwari).

0038-092X/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.solener.2005.07.006

Nomenclature

A	area
b	breadth
C	specific heat
$\mathrm{d}x$	elemental length
F_R	flow rate factor
h	heat transfer coefficient
h_{p1}	penalty factor due to tedlar through glass, solar cell and EVA
h_{p2}	penalty factor due to the interface between tedlar and the working fluid
$I(t)$	incident solar irradiation
K	thermal conductivity
L	length
M	mass
$\dot{m}$	rate of flow of water mass
n	number of observations
$\dot{Q}_u$	rate of useful energy transfer
t	time
T	temperature
U_b	an overall heat transfer coefficient from water to ambient
U_L	an overall heat transfer coefficient from solar cell to ambient through the back insulation
U_t	an overall heat transfer coefficient from solar cell to ambient through the glass cover
U_T	conductive heat transfer coefficient from solar cell to water through tedlar
U_{tT}	an overall heat transfer coefficient from glass to tedlar through solar cell
U_{tw}	an overall heat transfer coefficient from glass to water through solar cell and the tedlar
X	theoretical value
X_i	theoretical value of ith term
Y	experimental value
Y_i	experimental value of ith term

Subscripts

0	glass to ambient
a	ambient
bs	back surface of tedlar
c	solar cell
eff	effective
f	fluid
f_i	inlet fluid
f_{out}	outgoing fluid
G	glass
i	insulation
r	reference
w	water
T	tedlar
th	thermal

Greek letters

α	absorptivity
β	packing factor
η	efficiency
τ	transmissivity

(2001) and Kalogirou (2001) and (ii) parallel plate configuration, Prakash (1994) and Tiwari et al. (2005). Chow (2003) has developed a detailed dynamic model for photovoltaic–thermal collectors (tube-in-plate configuration) by considering the heat capacity of the glass, PV plate, absorber plate, tube bonding and insulation etc. Prakash (1994) has analyzed the transient behavior of a photovoltaic–thermal solar collector for co-generation of electricity and hot air/water for a parallel plate configuration. He concluded that the overall efficiency of the PV/T is significantly increased which can further reduce the energy payback time.

Huang et al. (2001) have conducted exhaustive experimental studies of an integrated PV/T system (IPVTS) of 45 l capacity under forced mode of operation. They have used both tube-in-plate and corrugated polycarbonate panel configurations and found that the latter gives a good thermal efficiency due to proper thermal contact between fluid and the PV module.

In this paper, a thermal model of an IPVTS system as proposed by Huang et al. (2001) has been developed and validated by their experimental results. The design parameters and climatic data of IPVTS system have been used for numerical computations (Fig. 4, Huang et al., 2001).

2. Experimental integrated photovoltaic–thermal system (IPVTS)

Fig. 1 shows a schematic diagram of an integrated photovoltaic–thermal system (IPVTS) set-up considered by Huang et al. (2001). It consists of a PV/T system ($0.516\ \mathrm{m}^2$) and an insulated cylindrical storage water heater of capacity 45 kg. The PV/T system comprises a PV module separated by a tedlar film from a channel through which the cooling water flows. The bottom of the channel is made of insulation material. The storage tank is connected to PV/T system through insulated pipes. A water pump (3 W, DC) with controller has been used to circulate the water. A cross-sectional view of the components of the integrated thermal system is shown in