Energy Conversion and Management 78 (2014) 641–651

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Performance analysis of photovoltaic thermal (PVT) water collectors

Ahmad Fudholi [a,*], Kamaruzzaman Sopian [a], Mohammad H. Yazdi [a], Mohd Hafidz Ruslan [a], Adnan Ibrahim [b], Hussein A. Kazem [c]

[a] *Solar Energy Research Institute, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia*
[b] *Universiti Kuala Lumpur Institute of Product Design and Manufacturing (UniKL IPROM), 56100 Cheras, Kuala Lumpur, Malaysia*
[c] *Faculty of Engineering-Sohar University, PO Box 44, Sohar PCI 311, Oman*

ARTICLE INFO

Article history:
Received 21 June 2013
Accepted 11 November 2013
Available online 18 December 2013

Keywords:
Electrical performance
Thermal performance
Photovoltaic thermal (PVT)
PVT performance
Primary-energy saving efficiency

ABSTRACT

The electrical and thermal performances of photovoltaic thermal (PVT) water collectors were determined under 500–800 W/m^2 solar radiation levels. At each solar radiation level, mass flow rates ranging from 0.011 kg/s to 0.041 kg/s were introduced. The PVT collectors were tested with respect to PV efficiency, thermal efficiency, and a combination of both (PVT efficiency). The results show that the spiral flow absorber exhibited the highest performance at a solar radiation level of 800 W/m^2 and mass flow rate of 0.041 kg/s. This absorber produced a PVT efficiency of 68.4%, a PV efficiency of 13.8%, and a thermal efficiency of 54.6%. It also produced a primary-energy saving efficiency ranging from 79% to 91% at a mass flow rate of 0.011–0.041 kg/s.

1. Introduction

The idea of combining photovoltaic (PV) and solar thermal collector to provide electrical and heat energy is not new, yet it has received limited attention. Growing concern about energy sources and their usage has consequently increased interest in photovoltaic thermal (PVT) solar collectors. PVT solar collectors, which basically combine the functions of a flat plate solar collector and a photovoltaic panel, convert solar radiation directly into both electrical and thermal energies. Research on PVT started during the mid-1970s focused on PVT collectors, with the primary aim of increasing PV efficiency. Domestic application was regarded as the main market. Initially the focus was on air- and water-based glazed collectors. Given these problems, the cost of a complete PVT system is incredibly high and therefore unaffordable for industrial and residential owners. One of the most attractive applications of air- or water-based PVT collectors is the building-integrated photovoltaic thermal (BIPVT) system, which has undergone rapid development in recent years. However air-based PVT systems have undergone more developed. The PVT system has potential in generating both type of energies because of its higher reliability and lower environment impact. Generally, a water-based PVT system consists of a PV module, an absorber collector in the form of tubes, a transparent glass cover, and an insulated container. Over the next few years, BIPVT publications are expected to increase, and PVT products are expected to undergo rapid growth [1–3].

Several studies on PVT solar collectors have been conducted. Fig. 1 shows PVT water collector with glass cover. The purpose of the transparent cover, firstly to reduce the conduction losses from the absorber collector through the restraint of the stagnant air layer between the absorber collector and the glass and secondly to reduce the radiation losses from the collectors. As shown in Fig. 3, produced a hybrid PVT systems consist of PV modules made from polycrystalline and amorphous solar cells with heat extraction unit mounted together using the copper sheet and pipes concept. The application aspects in the industry of PVT systems with water heat extraction has been studied thoroughly and analyzed with TRNSYS program. The study includes the industrial process heat system that operated at two different (load supply) temperatures. The result shows that the electrical production using polycrystalline solar cell is more than when using amorphous solar cells but in term of solar thermal fraction gives slightly lower results [3].

Theoretically analyses were based on a modified Hottel–Whillier model, and the results were validated using experimental data from a prototype PVT collector [4]. The effects of design parameters, such as fin efficiency, thermal conductivity between the PV cells and their supporting structure, and lamination method, on both the electrical and thermal efficiencies of the PVT were also determined. Furthermore, PVT can be prepared using of lower cost materials, such as precoated color steel, without significantly decreasing the efficiency. Integration of PVT into rather than onto

* Corresponding author.
E-mail address: a.fudholi@gmail.com (A. Fudholi).

0196-8904/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enconman.2013.11.017

Nomenclature

A_c	frontal area solar collector (m^2)
b	collector width (m)
C_b	conductance of the bond between the fin and square tube
C_p	specific heat of working fluid (J/kg °C)
D	diameter (m)
D_h	hydraulic diameter (m)
F	fin efficiency factor
F'	collector efficiency factor
F_R	heat removal efficiency factor
G_T	solar radiation at NOCT (W/m^2)
h_{fi}	heat transfer coefficient of fluid (W/m^2 °C)
k	thermal conductivity (W/m °C)
L	tube length (m)
l	thickness (m)
$\dot{m}$	mass flow rate (kg/s)
N	number of glass cover
n	number of tube
p	collector perimeter (m)
Q_u	actual useful heat gain (W)
S	solar radiation (W/m^2)
T	temperature (°C)
U_L	overall heat transfer coefficient (W/m^2 °C)
U_t	top loss coefficient (W/m^2 °C)
v	wind velocity (m/s)
W	tube spacing (m)
α	absorptance
θ	collector tilt
ε	emittance
τ	transmittance
η	efficiency
σ	Stefan's Boltzmann constant (W/m^2°C^4)

Subscripts

a	ambient
abs	absorber thickness
c	cell
fi	inlet fluid
g	glass
i	inlet
o	outlet
p	plate
pm	mean plate
PV	photovoltaic
PVT	photovoltaic thermal
r	reference
t	tube
w	wind

a building can also lower the system cost. In one study on a water-based PVT system, a numerical model of wall-mounted PVT water collector systems was developed by modifying the Hottel–Whillier model, which was originally used for the thermal analysis of flat-plate solar thermal collectors. Recently, performance analysis was conducted to analyze the exergy of PVT. The performance and life cycle cost of PVT systems with PV technology different from that of a similar PVT system were evaluated. The results show that the use of PVT systems is generally advantageous over that of similar PVT systems both from the efficiency and economic point of view. Mono-crystalline silicon PVT systems have higher energy and exergy efficiencies and are suitable for applications that have higher energy and exergy demands or have limited space for mounting, such as in multistory buildings [5].

A computer simulation was performed to analyze the system performance. The combined effects of solar cell packing factor and water mass flow rate on the electrical and thermal efficiencies were investigated. The simulation results showed that the increase in working fluid mass flow rate is beneficial for PV cooling. However, the advantage brought by the increased flow rate diminishes when the critical flow rate is exceeded, thereby decreasing thermal efficiency. System operation at the optimum mass flow rate can not only improve the thermal performance of the system but also meet the PV cooling requirement to achieve higher electrical performance [6]. A centralized PV and hot-water collector wall system

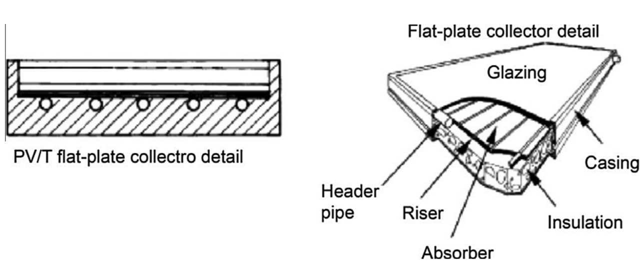

Fig. 1. PVT water collector with glass cover [3].

mounted at vertical facades was experimentally studied [7]. The results showed that the thermal efficiency was 38.9% at reduced (zero) temperature and electrical efficiency was 8.56% during late summer. A dynamic simulation model of a PVT and water heating system was developed. This modeling approach was validated by comparison with experimental data [8]. The results showed that the electrical performance is affected by on-site shading. Moreover, the output from the model showed high agreement with the experimental observations.

A computer simulation of a water-based PVT solar collector system using energy models was developed. Higher economical advantages relative to that of a conventional PV system were obtained. The annual average thermal and cell conversion efficiencies of a specific PVT system, which was mounted on a vertical wall of a fully air-conditioned building with collectors equipped with a flat-box-type thermal absorber and polycrystalline silicon cell, were 37.5% and 9.39%, respectively, compared with the normal building façade [9]. A computational fluid dynamic (CFD) model for a novel PVT collector was developed and experimentally validated [10]. The results indicated that PV cell efficiency can be increased to 5.3% and the outlet water temperature of the collector is suitable for domestic hot-water use. The effect of flow distribution on the PV performance of a PVT water collector was also investigated [11]. The results showed that parameters such as the manifold-to-riser pipe ratio, array geometry, manifold flow direction, and mass flow rate affect the flow distribution, which, in turn, affects PV conversion.

Innovative applications of PVT collector were performed recently [12–18]. PVT applications are cost-effective solar energy applications. However, additional studies must still be conducted, particularly on the design of new thermal absorber collectors. Alternative designs of PVT solar collectors are presented in this paper. A prototype of this new absorber was constructed. To date, studies on water-based PVT collectors have been few. Therefore, further experimental and analytical research should be performed to improve the electrical and thermal performance of water-based PVT solar collectors using new absorber collector designs.