Experimental Performance of an Advanced Air-type Photovoltaic-Thermal(PVT/a) Collector

Jin-Hee Kim[1], Jong-Gwon Ahn[2], Sang-Myung[2] and Jun-Tae Kim[3]

[1] Green Energy Research Center, Kongju National University, Cheonan (South Korea)

[2] Graduate School, Kongju National University, Cheonan (South Korea)

[3] Department of Architectural Engineering, Kongju National University, Cheonan (South Korea)

Abstract

A photovoltaic-thermal (PVT) collector is a solar collector that combines a photovoltaic module with a solar thermal collector, which produces electricity and heat at the same time. Depending on the medium used for collecting thermal energy, there are two types of PVT collectors: air-type and water-type. The integration of PV modules with a thermal collector can cause a temperature rise of the PV module, which in turn decreases the efficiency of the PVT collector. In order to obtain better performance of air-type PVT (PVT/a) collectors, it is necessary to extract the heat, in the form of hot/warm air, from the PV module, which then decreases its temperature. This article presents the performance of a new design of a PVT/a collector that uses air as the heat recovery fluid. In this study, an advanced PVT/a collector were newly developed, and its electrical and thermal performance was analyzed from experimental results in outdoor conditions. The results indicated that the thermal and electrical efficiencies of the PVT/a collector were, on average, approximately 30 % and 7 %, respectively.

Keywords: Air-type PVT collector, advanced design, baffle absorber plate, Thermal efficiency, Electrical efficiency

1. Introduction

A photovoltaic-thermal (PVT) collector is a solar collector that combines a photovoltaic module with a solar thermal collector, which produces electricity and heat at the same time. Depending on the medium used for collecting thermal energy, there are two types of PVT collectors: air-type and water-type. The integration of PV modules with a thermal collector can cause a temperature rise of PV the module, which in turn decreases the efficiency of the PVT collector. Ooshaksaraei et al. (2017) investigated four types of air-based bifacial PVT collectors by experimental and analytical methods under steady-state conditions [1]. Tomar et al. (2017) studied analytical models for four PVT/a collectors with different layers. The electrical and thermal efficiency were compared under outdoor condition [2]. Jaaz et al. (2018) experimentally tested a compound parabolic concentrator (CPC) along with PVT/w where the cooling process of the CPC was conducted using water jet impingement technique [3]. Tomar et al. (2018) made five PVT/w collectors with different cell types, namely mono-crystalline (m-Si), polycrystalline (p-Si), amorphous silicon thin film (a-Si), cadmium telluride thin film (CdTe) and copper indium gallium selenide (CIGS) photovoltaic modules. In the paper, theoretically calculated results were experimentally validated in outdoor ambient environment [4]. In order to obtain better performance of air-type PVT (PVT/a) collectors, it is necessary to extract the heat, in the form of hot/warm air, from the PV module, which decreases its temperature. The thermal and electrical performance of a PVT/a collector depends on their design affected airflow and heat transfer. In this light, there is need for an advanced design of PVT/a collector to improve the uniformity of the air flow and the heat transfer. This article presents the performance of a new design of a PVT/a collector that uses air as the heat recovery fluid.

In this study an advanced PVT/a collector was newly designed and made, and their performance was analyzed

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through experimental results. The aim of this study is to characterize the thermal and electrical performance of a new collector design of a PVT/a collector under both steady-state conditions.

2. Advanced Air-Type PVT(PVT/a) Collector Design and Experiment

2.1. Advanced Air-Type PVT (PVT/a) prototype

For this study, a prototype of an advanced air-type PVT (PVT/a) collector was developed, as shown in Fig.1. The PVT/a collector consists of a special PV module and absorber plates as a baffle for uniform of air flow; it has a 0.7m^2 PV area and an air layer of 80mm for collecting hot air. The glass to glass type (G/G) PV module was designed with 123W$_p$ mono-crystalline silicon PV for the advanced PVT/a prototype. PVT/a prototype were developed as shown in Fig.1. It has an absorber consisting of both photovoltaic (PV) cells and thermal absorbers in alternate rows. There are four thermal absorbers equally spaced in the PVT/a collector. They are located in the air cavity behind the glass PV glass assembly such that air can circulate above and below the thermal absorbers. The thermal absorber is made out of a thin metal sheet with highly selective blue coating. The PVT/a prototype have a gross are of 1.63m^2, and the PV modules' efficiency used for the collectors was 7.6% under standard test conditions (STC).

In outdoor experiment, the PVT/a prototype were tested. The back surface temperature of the glass-PV-glass assembly was measured with 5 surface thermocouples located in the middle of each PV row along the collector length; that is thermocouples referred to as Td1, Td2, Td3, Td4 and Td5 were arranged from the bottom to the top of PVT/a collector equidistantly. In addition, a distribution box was added at the second module outlet to promote flow uniformity across the cavity.

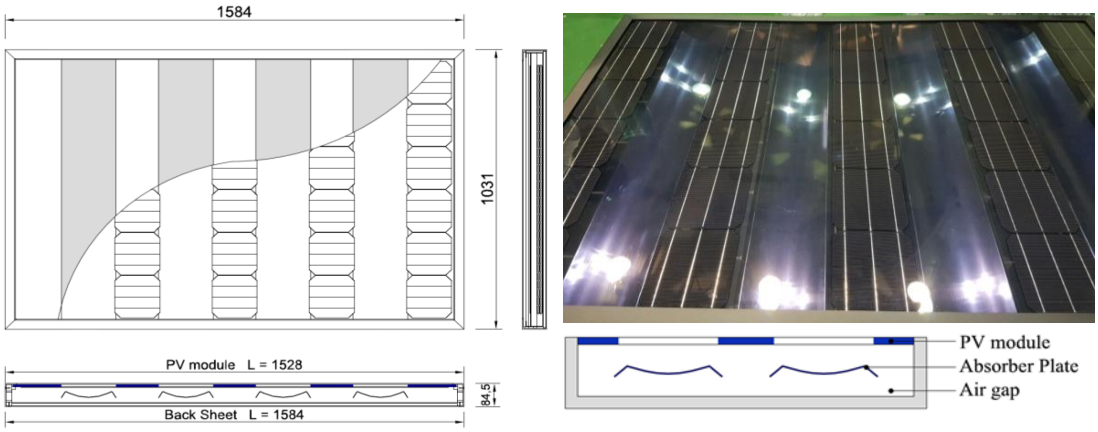

Fig. 1: Prototype design of the advanced PVT/a collector

The advanced PVT/a collector were also tested under outdoor conditions based on the ASHRAE 93-2013 [1] and ISO 9806 standards [2]. Several experimental devices were installed to measure the temperature of the PV laminate backside, the air layer, and the exhausted air, as well as the electrical power of the PVT/a collector. A T-type thermocouple was used to measure the temperature and an I-V curve tracer with Maximum Power Point Tracking (MPPT) was installed for measuring the electrical performance. For the measurement of the air flow rate, flow meters were installed inside the pipes of the inlet and outlet of the PVT/a collector. A data acquisition instrument was also connected to record all of the data related to the thermal and electrical performance of the PVT/a collector and the outdoor conditions.

The PVT/a Testing facility is an open-loop air circulation system. It includes the equipment required to circulate and control the amount of air entering and leaving the PVT/a collector as well as the sensors providing the information required for quantifying the amount of thermal energy that is being recovered. It is an open-loop system because the air heated by the collector is not recirculated in the loop, but rejected outdoors. However, ambient air is preheated in a chamber to temperature of 35 ^{o}C before being supplied to PVT/a collector. Some components for the thermal characterization are located in the air-loop chamber while some others are mounted directly on the multi-functional grid. The air-loop chamber sits separately with system and is connected to the

PVT/a collector on the multi-functional grid with two flexible ducts, one for the inlet and one for the outlet. To control the pressure inside the collector, the PVT/a testing facility uses two blowers to circulate air in the PVT/a collector. The blower located upstream of the collector, the inlet blower, operates in positive pressure and the blower located downstream of the collector operates in negative pressure (see Figure 2). For the experiment, air flowrate of 120kg/h was settled in a PVT testing facility. The experiment was carried out on September 2017. Fig. 2 shows the advanced PVT/a collector and the experiment setup.

Fig. 2: Outdoor experiment setup

3. Results and Discussion

3.1. Temperature characterization

On the basis of the experimental results, the temperature characterization of the advanced PVT/a collector is presented in figure 3, 4. In Fig. 3, it was found that the advanced PVT/a collector has a temperature gradient, as the temperature of the PV laminate backside is 50~64℃ at ambient of 29℃ and average irradiance of 870 Wm^{-2}. The temperatures at bottom and top part of PV backside are 50~53℃, 62~64℃, respectively.

Fig. 4 presents the inlet and outlet air temperature of PVT/a at the steady-state conditions. This graph show that the air temperature rise of the inlet and outlet of the PVT/a where a difference of 17 °C can be observed at the outdoor condition at ambient of 29 ℃ and irradiance levels of 870 Wm^{-2} with a flowrate of 120 kg/h.

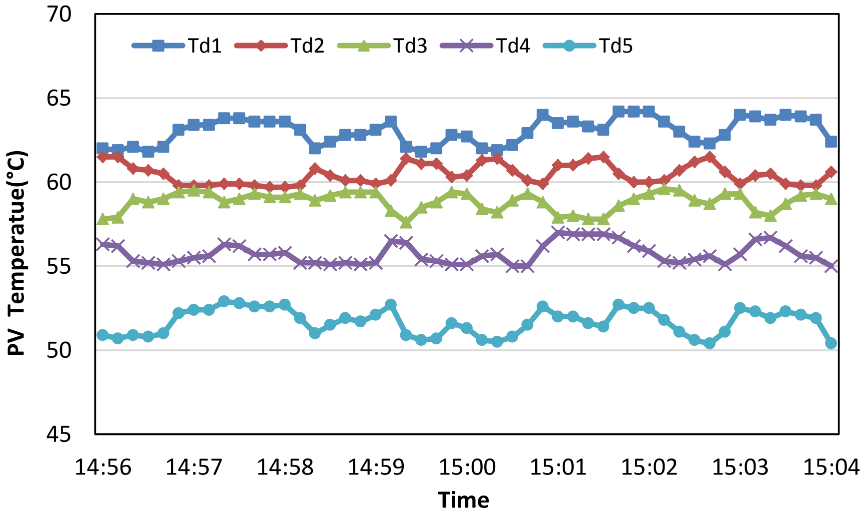

Fig. 3: PV backside (five points) temperatures of the PVT/a collector

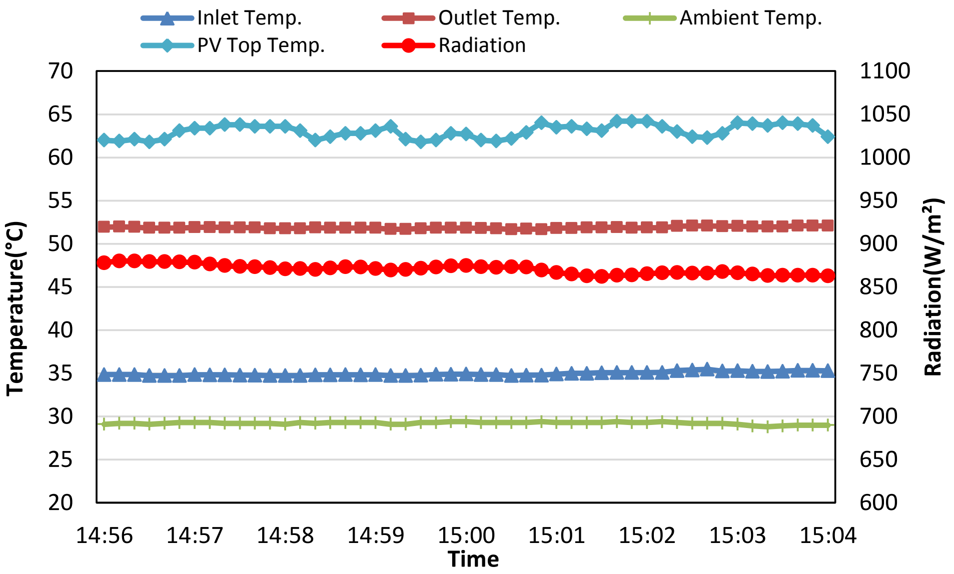

Fig. 4: The air temperature of inlet and outlet of PVT/a collector at the outdoor of steady-state condition

3.2. Thermal and Electrical performance

The thermal performance of PVT/a collector can be characterized by the air temperature difference of the PVT/a collector. On this basis, the thermal efficiency is determined as a function of the solar radiation (G), the mean fluid temperature (T_m) and the ambient temperature (T_a). The steady-state efficiency is calculated by the following equation [7]:

$$\eta_{th} = \frac{m\, C_p\, (T_0 - T_i)}{A_{pvt}\, G} \qquad \text{(eq. 1)}$$

η_{th} thermal efficiency [-]
A_{pvt} collector area [m^2]
T_o collector outlet air temperature [°C]
T_i collector inlet air temperature [°C]
$\dot{m}$ mass flow rate [$m^3\, h^{-1}$]
C_p specific heat [$J\, kg^{-1}\, K^{-1}$]
G irradiance on the collector surface [$W\, m^{-2}$]

The thermal efficiency of the PVT collectors was conventionally calculated as a function of the ratio $\Delta T/G$, where $\Delta T = T_m - T_a$. Here, T_m and T_a are the PVT collector's mean fluid temperature and the ambient temperature, respectively, and G is the solar radiation at the collector surface. Hence, ΔT denotes the measurement of the temperature difference between the inlet fluid and ambient air relative to the solar radiation. The thermal efficiency, η_{th}, is expressed as

$$\eta_{th} = \eta_0 - \alpha_1 \frac{\Delta T}{G}$$

where η_o is the thermal efficiency at zero reduced temperature, and α_1 is the heat loss coefficient.

The thermal efficiency as a function of the ratio $\Delta T/G$ is shown in Fig. 5. As it can be observed, the thermal efficiency decreases with ratio $\Delta T/G$. This thermal performance dependency to ratio ΔT/G indicates that the prototype behaves like conventional solar thermal collector.

From the measurement results for the advanced PVT/a collector, it can be seen that the thermal performance can be expressed as in Fig. 5. The thermal efficiency of the PVT/a collector can be therefore be described by the relational expression, $\eta_{th} = 0.3709 - 5.5371(\Delta T/G)$. Thus, the collector thermal efficiency (η_0) at zero reduced temperature is 37%, which indicates relatively high performance. The heat loss coefficient (α_1), which can have an effect on reduction of thermal efficiency was 5.54 (℃ $m^2 W^{-1}$), which is can be observe low heat loss ratio. The average thermal efficiency of the PVT/a collector is about 30% under outdoor test conditions and with the given X axis coefficients ($\Delta T/G$).

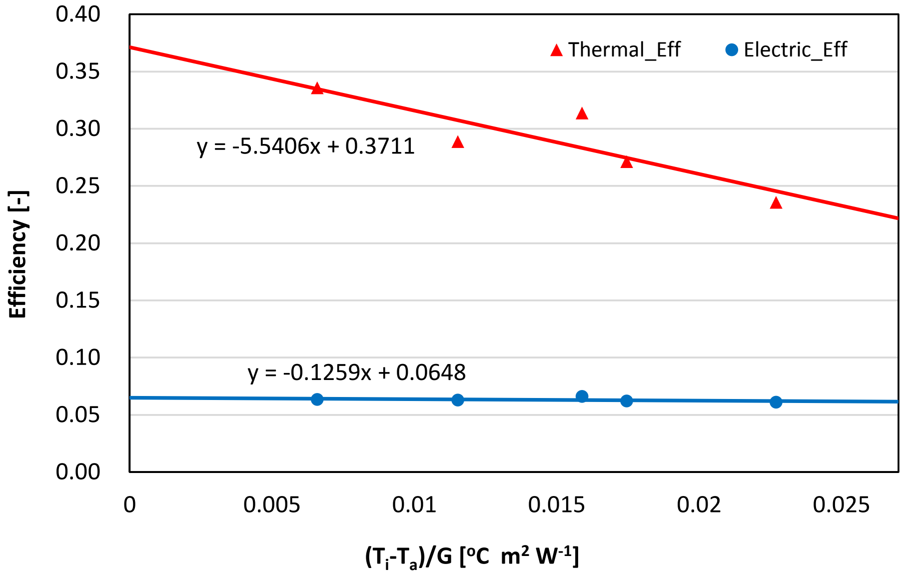

Fig. 5: Thermal and electrical efficiencies of the PVT/a collector

The electrical efficiency depends mainly on the incoming solar radiation and the PV module temperature. It is calculated with the following equation:

$$\eta_{el} = \frac{I_m V_m}{A_{pvt} G} \qquad \text{(eq. 2)}$$

where, I_m and V_m are the current and the voltage of the PV module operating under a maximum power.

The electrical efficiency of the PVT/a collector can be expressed with the following relational expression: η_{el} = 0.0648-0.1259(ΔT/G). The highest electrical efficiency of the PVT collector is 6.5% with the given X axis coefficients ($\Delta T/G$). As shown in Figure 5, the electrical efficiency is positive with regard to the X axis coefficients, as compared to the thermal efficiency. This occurs because, in spite of identical test conditions of the X axis coefficients, the electrical performance of the PVT/a collector was affected immediately by the PV temperature in addition to the X axis coefficients ($\Delta T/G$), i.e., ambient temperature, mean fluid temperature and solar radiation.

4. Conclusion

This paper presented the steady-state thermal and electrical performance of a new prototype of an advanced PVT/a collector. The design of this prototype is unique because its absorber consists of a combination of both photovoltaic cells and thermal absorbers in alternate rows. Experimental measurements were taken in outdoor conditions one PVT/a collector operated in open-loop.

Experimental results performed outdoors at the steady-state showed that at a flowrate of 120 kg/h and an irradiance level of 870 W/m², a temperature rise of 17℃.

The results show that at zero reduced temperature, the thermal and electrical efficiency levels of an advanced

PVT/a collector are 37% and 7%, respectively. Due to the unique design, the power generation is relatively low. Therefore, the advanced PVT/a collector had better thermal performance than the electrical performance.

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Nomenclature

A_{pvt}	Surface area of the collector	m^2
C_p	Specific heat of air at a constant pressure	$J\ kg^{-1}\ K^{-1}$
G	Solar radiation	$W\ m^{-2}$
$\dot{m}$	Mass flow rate	$kg\ h^{-1}$
T_a	Ambient air temperature	℃
T_o	Outlet air temperature of PVT	℃
T_i	Inlet air temperature of PVT	℃
η_{th}	Thermal efficiency	-
η_{el}	Electrical efficiency	-
I_m	Maximum current	A
V_m	Maximum voltage	V
P_{max}	Maximum power	W
FR(τα)	Thermal efficiency coefficient	-
FRUL	Heat loss coefficient	$^oC\ m^2\ W^{-1}$

5. References

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