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Dynamic performance analysis of photovoltaic–thermal solar collector with dual channels for different fluids

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ABSTRACT

The performance of the hybrid photovoltaic (PV) module depends on its operating conditions (especially temperature). Only a small percentage of incoming solar radiation is converted into electricity, and the rest is converted into heat. This overheats the PV module and reduces its performance. This work presents the performance of photovoltaic–thermal (PV/T) solar collector with dual channels for different fluids. The PV/T solar collector's electrical and thermal characteristics like temperatures of the solar cell and outlet fluids, electric power generation efficiency and thermal power efficiency are analyzed through comparison of four PV/T collectors with different fluids. It is found that water–water cooled PV/T collector is the most efficient in both electrical and thermal performance. Water–water cooled PV/T collector can provide the most amount hot water. The temperature of water in air–water case is the highest. Air–air cooled PV/T collector may provide the most amount hot air which its temperature is the highest. It is also found that an increase in mass flow rate of water and the height between the upper pipe and the lower pipe leads to better overall efficiency in water–water cooled PV/T collector.

1. Introduction

World's economy relies heavily on fossil fuels, such as oil, natural gas, coal and nuclear energy. World Energy Council (WEC) in its report stated that the fossil fuel would continue to be the dominant energy source, and the share of renewable energy would be around 20% of total energy by 2050 [1]. However, fossil fuels are not only depleting fast, but also are causing global warming due to greenhouse gas emission. Therefore stable and sustainable development of world economy needs renewable energy.

Solar energy has great potential and vast application prospects because of its non-polluting nature, abundance and inexhaustibility. Photovoltaic (PV) technology is the most common way of transforming energy in solar radiation into electric energy through PV panels. A key variable for the photovoltaic conversion process is the operating temperature of the solar module. This temperature affects the electrical performance of silicon-based PV devices [2]. In general, the solar cells using silicon technology convert about 25% of the capture sunlight into electricity at 300 K, and the efficiency will decrease gradually as the temperature rises [3]. This means that the majority of solar radiation energy is absorbed as heat, which gets accumulated in the PV module. As a result, the increased module temperature leads to decreased photovoltaic efficiency. In order to solve this problem, a fluid such as air and water is used for cooling the PV modules. This heat which is absorbed by the fluid can be utilized again [4]. The purpose of photothermal conversion is, collecting solar radiation energy, and converting solar radiation energy to thermal energy.

The photovoltaic system generates waste heat, which has negative influence on electrical performance of the PV module, whereas this waste heat can be the input for a photothermal system. Naturally, it is beneficial to combine these two systems into a hybrid photovoltaic–thermal (PV/T) system, which meets the requirements of both systems. The hybrid PV/T system can recover undesired thermal energy from the PV modules, and this recovered thermal energy can be utilized for other purposes. Usually three types of working fluids (air, water and refrigerant) are used in practical applications. The refrigerant–cooled PV/T system combines the PV modules and air conditioning system into an all-weather photothermal system. The systems using other working fluids (air and water) have advantages like minimal usage of material and low operating cost. But they have a poor thermal to electrical conversion efficiency. The PV/T collector with dual channels is composed of a PV cell and heat transfer pipes (shown in Fig. 1).

In recent years, the hybrid PV/T systems have been investigated by many researchers, as they have become crucial to utilizing solar energy. Wolf [5] and Florschuetz [6] did a theoretical and

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Nomenclature

c	specific heat capacity, kJ/kg K
D	equivalent diameter, m
F	packing factor
H	height, m
h	convective heat transfer coefficient, W/m^2 K
I	solar radiation intensity, W/m^2
K	total heat transfer coefficient, W/m^2 K
L	length, m
$\dot{m}$	mass flow rate, kg/s
r	height ratio between the upper pipe and the lower pipe
T	temperature, K
v	flow velocity, m/s
W	width, m
x	distance in flowing direction, m

Greek letters

α	absorption coefficient
σ	Stefan–Boltzmann constant
δ	thickness, m
μ	dynamic viscosity
η	photovoltaic efficiency
λ	thermal conductivity, W/m K
τ	transmission coefficient
γ	kinematic viscosity, m^2/s

Subscripts

a	airflow
b	backplane
c	solar cell
e	environment
g	glass cover
w	water
ref	reference value at reference conditions

experimental study of PV/T in the mid 1970 s. Both PVT air-cooled (PVT/a) system and PVT water-cooled (PVT/w) system have received researcher's attention for further study. Hegazy [7] performed an extensive investigation of overall performance of a PV/T air collector. Four different designs were presented, testing the performance with air flow under or over the absorber and on both sides of absorber in a single pass or in a double pass fashion. Aste et al. [8] presented an experimental and theoretical research on performance of a hybrid PVT air collector, which used the waste heat recovered for heating the buildings. Tonui and Tripanagnostopoulos [9,10] investigated the use of thin flat metal sheet, suspended at the middle or finned back wall of an air channel in the PVT/a configuration. They achieved higher thermal output and lower temperature of the PV module. Shan et al. [11] evaluated PVT/a systems with five different configurations of heat transfer pipes and presented their electrical and thermal performance. Othman et al. [12] designed a prototype double-pass PVT/a collector with compound parabolic concentrator (CPC) and fins, and studied the performance of the system at a wide range of working conditions. The results indicated that the CPC increased the incoming radiation intensity to the solar cells, and fins improved heat transfer rate to the fluids. Shahsavar and Ameri [13] tested a direct-coupled PVT/a collector with a suspended thin aluminum sheet at the middle of air channel to enhance the heat exchange. The results showed that placing a glass cover on PVT/a led to a rise in thermal efficiency but a drop in electrical efficiency. Aiming to maximize the energy output of a PVT/a system, Bambrook and Sproul [14] concluded from experiment results that thermal and electrical efficiencies improved with the increased mass flow rate of air. Thermal efficiency achieved was in the range of 28–55% and the electrical efficiency varied between 10.6% and 12.2% at midday. Almost at the same time, Teo et al. [15] analyzed the influence of air mass flow rate on both electrical and thermal efficiency, and discovered that there existed an upper limit on both efficiencies, despite increase in air mass flow rate. Irshad et al. [16] presented a simulation model of a single room building integrated with PV Trombe wall. It was found that a decrease of air duct temperature enhances the efficiency of the PV Trombe wall.

Unlike air-cooling, which is limited by air velocity and forced convections, water cooling has better prospects due to higher specific heat capacity and better thermal conductivity. Coventry [17] presented measured results under typical operating conditions, and showed thermal efficiency around 58% and electrical efficiency around 11%. Ji et al. [18] constructed a flat-box aluminum-alloy PVT/w system, and the results showed that the higher PV cell covering factor and glazing transmissivity brought about a better performance of the system. For the purpose of domestic hot water, Kalogirou and Tripanagnostopoulos [19] presented TRNSYS simulation results of the PVT/w systems, which were performed at three locations of different latitudes. The results indicated that the PVT/w solar collectors have better chance of success especially when it is required in domestic applications. Pei

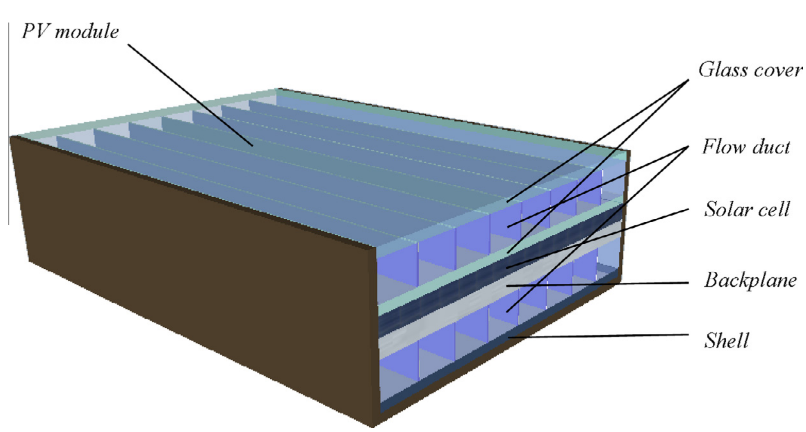

Fig. 1. The schematic diagram of the PV/T collector with dual channels.