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Performance evaluation of a modified PV/T solar collector: A case study in design and analysis of experiment

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ABSTRACT

An experimental work on a modified photovoltaic/thermal (PV/T) solar collector was carried out in Istanbul, Turkey. In the proposed model the air enters into the collector through a slot at the middle of the glass cover. As the air flows over and below the PV panel in opposite directions, it gets the excess heat produced by panel and cools it. The measurements repeated by changing the position of PV module inside the collector and thermal and electrical performances of the solar collector were calculated for each configuration. The highest thermal performance was obtained when the distance between PV module and cover was 3 cm. As for electrical efficiency, the highest value was obtained when there was 5 cm gap between cover and the panel. It is also found that increasing the mass flow rate enhances the thermal performance of the system. The electrical efficiencies of the PV/T solar collector and PV module are compared using analysis of variance (ANOVA). The optimal configuration for PV/T collector is also suggested by the same method.

1. Introduction

The major problem related to the Solar PVs is their low efficiency. The performance of PV modules decreases as the temperature of the modules increases. By circulating a fluid, which will extract heat from the PV modules, module temperature is decreased and hence, performance of the PV modules increases. Photovoltaic Thermal/Hybrid collectors, combining a photovoltaic module and solar thermal collectors by producing heat and electricity simultaneously, has emerged as a promising technology to overcome this problem. In such systems, a fluid (usually air or water) removes the heat from the cell and reduces the module temperature.

The photovoltaic thermal systems were introduced first time by Kern and Russell in 1978. In that system the absorbed energy was removed by water or air. Two different one dimensional models for the prediction of electrical and thermal performances of flat plate photovoltaic thermal collectors were developed by Raghuraman (1981). The PV/T air collector was tested with single and double glass covers by Garg and Adhikari (1997).

A number of studies were performed to investigate the performance of various solar systems with different configurations. Othman et al. (2005) studied theoretically and experimentally the PV/T solar air collector with concentrating reflectors. A hybrid photovoltaic thermal solar air heater was studied by Othman et al. (2007). Their hybrid system consists of monocrystalline silicon cells pasted to an absorber plate with fins attached at the other side of the absorber surface. They found that the total efficiency of the system could be improved by the use of a double-pass collector system and fins. In another study the influence of reflectance from flat plate solar radiation concentrators made of aluminum sheet and aluminum foil on energy efficiency of PV/Thermal collector were investigated (Kostic et al., 2010). The results showed that total daily thermal and electrical energy generated by PV/Thermal collector with concentrators increase with the increase of solar radiation intensity concentration factor.

Shahsavar and Ameri (2010) designed a PV/T air collector and tested it under natural and forced convections with and without glass cover and compared the results with a theoretical model. A detailed thermal and electrical model was developed by Sarhaddi et al. (2010) to calculate the thermal and electrical parameters of a typical PV/T air collector. The authors reported that the thermal, electrical and overall energy efficiencies of PV/T air collector were

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Nomenclature

Latin symbols

A_p	area of absorber plate (m^2)
A_1	area of manometer container (m^2)
A_2	area of manometer tube (m^2)
CM	flow coefficient
c_p	air specific heat (J/kg K)
FF	fill factor
g	gravitational acceleration (m/s2)
h	manometer reading (m)
I	incident solar radiation (W/m^2)
I_{sc}	short-circuit current, (A)
k	thermal conductivity (W/m K)
$\dot{m}$	air mass flow rate (kg/s)
ΔP	pressure drop (Pa)
P	maximum operating power (W)
PV	photovoltaic
Q	air volume flow rate (m^3/s)
T_{air}	film air temperature between the outlet and inlet (°C)
T_{in}	inlet temperature (°C)
T_{out}	outlet temperature (°C)
ΔT	temperature difference between inlet and outlet air (°C)
V_{oc}	the open-circuit voltage (V)

Greek symbols

η_{th}	thermal efficiency
η_{el}	electrical efficiency
ρ	density (kg/m^3)
θ	manometer tilt angle (degree)
τ	transmissivity
ω	uncertainty

about 17.18%, 10.01% and 45%, respectively, for a sample climatic, operating and design parameters. A PV/T solar air heater with a double pass configuration and vertical fins in the lower channel was investigated by Kumar and Rosen (2011). Their results showed that the extended fin area reduces the cell temperature considerably, from 82 to 66 °C. Siddiqui et al. (2012) and Amrizal et al. (2013) analyzed the thermal performance of PV modules with and without cooling by developing a three dimensional thermal model. At different climates, depending on their types the PV modules convert 6–20% of incident solar radiation into electricity. Most of the absorbed energy is converted to heat that increases the cell surface temperature and leads electrical conversion efficiency to drop (Amori and Abd-AlRahim, 2014).

Kim et al. (2014) designed an air-based PVT collector with a mono-crystalline PV module and analyzed its electrical and thermal performances. They found that the heated air from the PVT collector had, on average 5 °C higher temperatures than the outdoor air. A brief overview of the different solar flat plate PV/T technologies was presented by Michael et al. (2015). In their work, the applications, advantages, efficiencies, limitations and research opportunities related to PV/T technologies were discussed. The optimum values of channel depth, air mass flow rate and air distribution duct diameter optimization of photovoltaic thermal air collectors were investigated by Farshchimonfared et al. (2015). In that work, it was found that the optimum depth value increases as the collector L/W ratio and the collector area (A_c) increase. In order to calculate the thermal and electrical parameters of a PV/T collector a computer simulation program was developed by Ben cheikh el hocine et al. (2015). Their results showed that the thermal efficiency of PV/T collector is 16.24% in air heat extraction and the electrical efficiency is 11.12%, for a sample climatic, operating and design parameters.

In a study by Saeedi et al. (2015) the optimization of PV/T active solar still was carried out and the optimized value of mass flow rate, number of PV/T collectors and the objective function were obtained. Yazdanpanahi et al. (2015) performed an experimental investigation on exergy efficiency of a solar photovoltaic thermal water collector based on exergy losses. Hedayatizadeh et al. (2016) studied the exergy loss-based efficiency optimization of a double-pass v-corrugated plate solar air heater and carried out a detailed thermal modeling of the system.

The present study aims to minimize the cells operating temperature and maximize the collector thermal efficiency. A modified photovoltaic/thermal solar collector is proposed and tested experimentally. Its performance characteristics are analyzed using Analysis of Variance (ANOVA) method. In the proposed design, the PV panel is placed inside the collector instead of an absorber plate. Air enters to the system through a rectangular slot at the middle of the glass cover, passes over and below the panel and exits from another slot at the back side of the collector. The distance between the panel and the cover and also the air mass flow rate are varied during the experiments. To the best of our knowledge such an experimental study has not been presented in the literature for Turkey weather conditions. The following sections describe details of the proposed design and how the experiments were carried out.

2. Method and materials

A modified PV/T air collector was designed, manufactured and tested for increasing electrical efficiency of the PV module by reducing its surface temperature and at the same time, allowing the air to be heated by the sun's energy as it passes over the panel for using it in other applications. The modified PV/T collector was manufactured and tested.

The experimental studies were carried out in Istanbul, Turkey to investigate the thermal and electrical performances of the proposed PV/T solar collector with different configurations given as follows

i: PV module with no cooling (as the reference)
ii: PV/T collector with 3 cm distance between panel and glass cover
iii: PV/T collector with 5 cm distance between panel and glass cover
iv: PV/T collector with 7 cm distance between panel and glass cover

2.1. Experimental set-up

Investigated PV module and its characteristics are given in Fig. 1 and Table 1, respectively. In this design, the PV module was placed inside the air collector instead of an absorber plate. The frame of the collector was made of wood (2 cm thickness) and the interior sides of frame were painted in black. The distance between the PV module and glass cover was varied to find the best position for PV module inside the air collector for achieving the highest efficiency from the system. Specifications of photovoltaic panel (PV) are listed in Table 2.