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An improved design of photovoltaic/thermal solar collector

F. Hussain [a,*], M.Y.H. Othman [b], B. Yatim [b], H. Ruslan [b], K. Sopian [b], Z. Anuar [a], S. Khairuddin [a]

[a] National Metrology Laboratory, SIRIM Berhad, 43900 Sepang, Selangor, Malaysia
[b] Universiti Kebangsaan Malaysia, 43600 Bangi, Malaysia

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Abstract

An improved photovoltaic/thermal (PV/T) solar collector combined with hexagonal honeycomb heat exchanger was studied. It is a combination of photovoltaic panel and solar thermal components in one integrated system. The honeycomb was installed horizontally into the channel located under the PV module. Air, as heat remover fluid is made to flow through the honeycomb. The system was tested with and without the honeycomb at irradiance of 828 W/m^2 and mass flow rate spanning from 0.02 kg/s to 0.13 kg/s. It was observed that the aluminum honeycomb is capable of enhancing the thermal efficiency of the system efficiently. At mass flow rate of 0.11 kg/s, the thermal efficiency of the system without honeycomb is 27% and with is 87%. The electrical efficiency of the PV module improved by 0.1% throughout the range of the mass flow rate. The improved design is suitable to be further investigated as solar drying system and space heating.

Keywords: Photovoltaic/thermal; Honeycomb heat exchanger; Thermal efficiency; Electrical efficiency

1. Introduction

One of the crucial factor that affect the popularity of photovoltaic module is that, it is relatively low in efficiency. Until today, commercially available photovoltaic module efficiency claim by manufacturers is between 6% and 16%. However, the claimed efficiency was at the temperature of 25 °C. In reality, especially for countries with hot weather, their ambient temperature during a sunny day will be more than 35 °C. The rising of the cell temperature will result in the drop of the module efficiency. A study had been carried out to investigate the influence of temperature on the performance of crystalline silicon type of solar cell (Ghani et al., 2015). Current and voltage data from a cell was collected at ten set temperatures (25, 30, 35, 40, 45, 50, 55, 60, 65, 70) °C using a precise measuring system while illuminated at a fixed value of irradiance 1000 W/m^2. One of major finding is that the reverse saturation current, I_o is the most temperature sensitive characterization parameter. Therefore, in order to minimize PV module losing its efficiency, a simultaneous cooling system using air or water as the heat transfer fluid can be implemented. The heat output from the system can be collected and stored as thermal energy. This advancing system is known as PV/T technology. A PV/T solar collector is a combination of photovoltaic panel (PV) and solar thermal components or system which is capable of producing both electrical energy and thermal energy simultaneously in one

* Corresponding author at: National Metrology Laboratory, SIRIM Berhad, Lot Pt 4803, Bandar Baru Salak Tinggi, 43900 Sepang, Selangor, Malaysia. Tel.: +60 3 87781735; fax: +60 3 87781661.
E-mail address: faridah_hussain@sirim.my (F. Hussain).

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integrated system. The photovoltaic panel could be from the selection of monocrystalline silicon, polycrystalline silicon, amorphous silicon, or thin-film solar cell. The solar thermal components are various designs of a solar thermal collector with heat exchanger (Chow, 2010).

For the last 42 years, there have been significant amounts of research and development work on PV/T technology (Chow, 2010). PV/T solar collector system can be classified as PV/T water system and PV/T air system. The PV/T/water systems are more efficient due to its high thermo-physical properties than the PV/T/air systems (Prakash, 1994). However PV/T/air systems are more extensively studied due to their low constructions and operational costs and cost effective solution for building integrated PV system.

Early research work for PV/T started in 1970s. The performance of a combination solar photovoltaic and solar heating system (PV/T) of a two story building, single family residence in Boston, USA had been analyzed (Wolf, 1976). The well known Hottel–Whillier model had been modified to analyze the photovoltaic/thermal flat plate collectors (Florschuetz, 1979). The modifications were based on the cell array efficiency and the decrease of cell efficiency with temperature. A combination consideration of flat-plate PV/T collector had been designed using computer simulation (Cox and Raghuraman, 1985). A PV/T system consists of flat solar air heater; solar cell and plain booster reflector was studied (Garg et al., 1991). The usage of booster has increased the thermal efficiency but decreases the electrical efficiency of the system. The model approach is suitable as solar dryer.

A steady state model to analyze the performance of a single pass and double PV/T solar collector system suitable for solar drying had been developed (Sopian et al., 1996). The performance of four models of PV/T collector for single pass and double pass system had been evaluated (Hegazy, 2000). Heat balance equation had been identified and solved for each model. A double pass PV/T system with compound parabolic concentrator (CPC) and fins had been fabricated (Othman et al., 2005). Fins attached at the back of the PV absorber plate act as the heat exchanger. Performance of a solar collector with ∇-groove heat absorber had been studied (Karim and Hawlader, 2006). The efficiency of the system with ∇-groove is 12% more efficient than the plat plate collector. The thermal efficiency of double pass PV/T system with porous media at the lower channel had been studied (Sopian et al., 2000). A single pass PV/T system with aluminum ∇-grooved absorber plate was analyzed (Othman et al., 2009). The thickness of the aluminum is 0.7 mm, attached at the back of the PV module. A direct coupled outdoor PV/T system in Kerman, Iran was tested (Shahsavar and Ameri, 2010). The design of the system involves the use of a thin aluminum sheet placed in the middle of the air channel as the heat exchanger to cool the PV panels. Another PV/T solar collector with an active cooling system was fabricated to increase the electrical efficiency of a PV module (Teo et al., 2012). A parallel array of ducts with inlet/outlet manifolds was attached to the back of the PV module. Together with this work another work had been done to compare the performance of honeycomb heat exchanger with ∇-groove and stainless steel wool heat exchanger. Under similar set-up of working condition, each heat exchanger was tested one by one to monitor its performance (Hussain et al., 2012). Recently, a PV/T collector using impinging jets was developed (Brideau and Collins, 2014). The purpose is to increase the efficiency of air based solar collectors by enhancing the heat transfer between the working fluid and the collector plate. Result proved that the use of impinging jets enhance the heat transfer compare to the traditional parallel flow. Further research work on PV/T continues with designed, testing and analyzed a PV/T air collector system outdoor under real environmental condition (Kim et al., 2014).

This experiment studies a single pass air base photovoltaic/thermal (PV/T) solar collector combined with hexagonal honeycomb heat exchanger. A commercially available monocrystalline silicon PV module was used to produce the electrical energy. Fabrication process of honeycomb heat exchanger is simple. Locally purchased aluminum sheet had been made into 5 pieces of corrugated sheet. The five pieces of aluminum corrugated sheets as shown in Fig. 1 had been joined together to form a compact honeycomb with hexagonal geometry. The thickness of the aluminum sheet is 0.2 mm. The thickness of the compact honeycomb is 23 mm. The honeycomb was installed horizontally into the channel located at the back side of the PV module as shown in Fig. 2a. Figs. 2b and 2c show the photo of the compact honeycomb installed to the back of the PV module.

The schematic diagram of integrated components of the system is illustrated in Fig. 3. A blower, a heater and a ducting were used to maintain consistent air flow through the PV/T collector. Two units of variable voltage regulators had been used to control the speed of the blower and the temperature of the heater. Type T thermocouples had been used to measure temperature at various locations. The temperature of the heater was adjusted using variable voltage regulator to ensure that the inlet temperature is equal to the ambient temperature. The system was tested indoor with and without the honeycomb heat exchanger

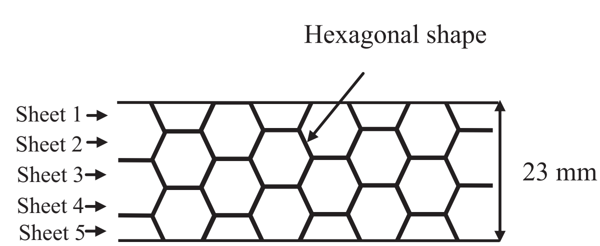

Fig. 1. Joined pieces of aluminum sheets.