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Photovoltaic thermal solar water collector designed with a jet collision system

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A photovoltaic thermal (PVT) solar collector with water jet collision of water was designed, fabricated and evaluated in this study. An indoor testing system with solar simulator was developed as the test rig. The different solar radiation levels were changed from 500 to 1000 W/m^2 in the indoor test. The mass flow rate of water changed from 0.033 to 0.16 kg/s at each solar radiation level. The thermal, PV and combined PVT efficiencies were subsequently determined. A high heat transfer coefficient was achieved between the PV panel and the water by using impinging jets of water. The maximum thermal, PV and PVT efficiencies of the PVT collector with jet collision were 72%, 11.35% and 81% at the solar radiation level of 1000 W/m^2, respectively. On the other hand, a mathematical model of PVT solar water collector with jet collision is developed. The results from the mathematical model are consistent with the experimental result with accuracy of 95.8% and 99.6% for PV efficiency and thermal efficiency, respectively.

1. Introduction

Conventional energies have been providing most of our energy needs over the past century. Although conventional (oil, coal and gas) energies are more convenient than alternative energy sources, it was not until recently when environmental pollution caused by these conventional sources has become a minor concern [1]. Global environmental concerns and rising energy demands, as well as the steady progress of renewable energy technologies, have opened up new opportunities for the resource utilisation of renewable energies [2]. The photovoltaic thermal (PVT) hybrid system combines photovoltaic (PV) panels with solar thermal systems to generate heat and electricity from integrated systems. Thus, the PV panel can be used as part of the thermal absorber [3]. In the PV panel, solar cells are installed on an absorber to collect solar thermal energy. When the temperature of photovatic panel is increased, the electrical efficiency of the photovatic panel is decreased. Cooling the solar cell to a relatively lower temperature increases the output energy or power of the solar system [4].

PVT solar collectors, also known as hybrid solar collectors, have become popular among researchers and scientists in the past decade due to the advantages of relatively higher efficiency and stability compared with specialised solar devices. Several numerical and experimental studies on the PVT solar collectors have been conducted. In general, most PVT solar collectors have PV panels made of polycrystalline, monocrystalline and amorphous solar cells with heat extraction units fitted together by using pipes and copper sheets or similar techniques. The application potential of PVT solar collectors varies depending on domestic and industry utilisation, such as for water pumping, hot water system, solar distillation of brackish and sea water, solar refrigeration, food dehydration and building-integrated photovoltaic (BIPV) systems [5–7]. Many researchers in the past few decades have focused on PVT collectors as way to increase PV efficiency. The building-integrated photovoltaic thermal (BIPVT) system is regarded the most attractive application of water-based and air-based PVT collectors, and thus, this system has been widely developed in recent years. The air-based PVT system in particular has become popular because of its low environmental impact and high reliability. The water-based PVT collector is generally made from PV panel, tubes for the absorber collector, insulated tank, and glass cover [8–10]. The TRNSYS program was used to analyse PVT systems with water heat extraction function for industrial applications. The system operated at two different (load supply) temperatures, then the industrial capabilities of the heat systems were determined. Results showed that the

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PV efficiency of polycrystalline solar cells was much higher than that of amorphous solar cells, but the solar thermal fractions yielded relatively lower values [8]. A modified Hottel–Whillier model was used to theoretically analyse the performance of PVT collector prototypes and the results were validated by using the experimental data from a PVT collector [10]. The effects of fin efficiency, lamination method, thermal conductivity between PV cells and their supporting structures on the PV and thermal efficiencies of the PVT were examined. The integration of the PVT into the building can lower system cost. The results showed that the PVT solar collector attained high efficiency and economically competitive costs, while the PVT systems with mono-crystalline silicon solar cells contributed to high exergy and energy efficiencies in buildings [11]. System performance was analysed by using computer simulation to examine the thermal and PV performance. The influences of different mass flow rates of water and packing factors of solar cells on the PV and thermal efficiencies were experimentally investigated. The results showed that the increased mass flow rate of working fluids effectively cooled the PV cells, but the increased flow rate of water in particular lowered thermal efficiency. The PVT collector needs to operate at an optimal water flow rate to meet the PV cooling requirement and subsequently increase PV and thermal performance [12]. The thermal and PV performance of the PVT collector wall system affixed at vertical facade was studied experimentally [13]. A comparison between experimental data and modelling was conducted, and the results showed that the PV and thermal efficiencies were 8.56% and 38.9% in the summer, respectively. A simulation model of the PVT and water heating system was developed [14]. The experimental results showed that onsite shading affected the PV performance of the system, and the results of the modelling were in good agreement with those of the experimental. Moreover, heat balance energy models were developed through computer simulation and subsequently used to calculate the performance of the water-based PVT solar collector system. The average PV and thermal efficiencies of the PVT system with collectors equipped with polycrystalline silicon cell and flat box-type thermal absorber were 9.39% and 37.5%, respectively [15]. A novel PVT collector was examined and developed experimentally and numerically, and computational fluid dynamics was used to validate the PVT model [16]. In addition, the influence of the mass flow rate of water on the PV performance of a PVT water collector was determined [17]. The results showed that the PV efficiency of solar cells increased to 5.3%, and the suitability of outlet hot water temperature was verified for domestic application. Many parameters notably affected the performance, such as water mass flow rate, array geometry and tube manifold flow direction, of the PVT solar collector on the basis of the experimental results [18,19]. Nonetheless, additional studies, particularly on the design of new PVT collectors, need to be conducted. One way to increase the thermal and PV efficiency of water-based PVT solar collectors is to enhance the heat transfer between the working fluid and the PV panel. This setup can be achieved by using impinging water jets on the PV panel. High heat transfer coefficients can be derived from impinged jet operations.

In this paper, a new design of the PVT solar collector with a jet collision water base is presented. A prototype of this new PVT is designed, fabricated and evaluated. To date, studies on water-based PVT collectors are few. Therefore, experimental and theoretical study should be performed to help improve the thermal and PV performance, in particular, by using PVT solar water collectors designed with jet collision.

2. Experimental setup

The PVT solar water collector with jet collision was evaluated using a specially constructed solar simulator in the laboratory. The purpose of the solar simulator was to provide controlled indoor sunlight settings that can be manipulated for solar cell testing in laboratory conditions. The solar simulator was built using 45 tungsten halogen lamps (Brillanta) with 500 W in each lamp. The lamps were arranged in 8 columns. Solar radiation was controlled and changed at the laboratory by using a lamp regulator. In this study, the solar radiation levels ranged from 500 to 1000 W/m^2. The control parameters of the indoor tests included the following: PV mean output, input, and ambient temperatures; useful voltage and current; wind velocity at the collector surface; and jet water on the PV panel. The parameters were matched with the standards of the PVT absorber collector. The constructed layers of the PV panel are shown in Fig. 1. The PV panel was constructed from 36 pieces of polycrystalline silicon with dimensions of 1.56 m (length), 1.56 m (width) and 200 μm (thickness). Table 1 shows the characteristic of the polycrystalline silicon PV panel. The jet collision is applied directly to the backside of the PV panel to cool the PV solar cell, as shown in Fig. 2. A total of 36 nozzles were used to jet the water and cool the backside of the PV panel.

2.1. Experimental procedure

The PVT solar water collector with the jet collision system was evaluated in the laboratory with different solar irradiation levels and mass flow rates. The testing procedures of the ANSI/ASHRAE Standard 93 and ISO 9806-1:1994 was adopted to test the performance of the novel system design of the proposed PVT solar water collector. The experimental setup and the complete measurement system are shown in Figs. 3 and 4, respectively. Experimental tests were conducted in steady-state conditions to evaluate system performance. The thermal performance of the PVT collector with different parametric settings were evaluated by obtaining the instantaneous efficiency values of different combinations of mass flow rate, ambient temperature, inlet liquid temperature and outlet temperature. The PVT with the jet collision system was exposed to

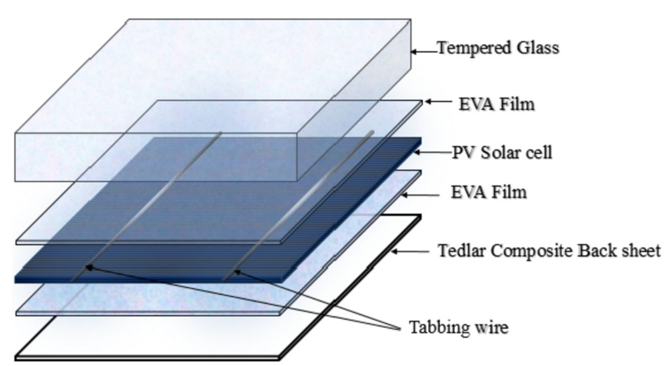

Fig. 1. Configuration of the PV panel.

Table 1
Typical electrical characteristics of polycrystalline silicon photovoltaic module.

Electrical performance under STC	Value
Maximum power (P_{max})	110 W
Current at P_{max} (I_{mp})	6.4 A
Voltage at P_{max} (V_{mp})	17.2 V
Short-circuit current (I_{sc})	6.9 A
Open-circuit voltage (V_{oc})	21.7 V
Dimensions	1490 × 675 mm
Glass thickness	4 mm
Cell number	36 PCS