Experimental analysis of a novel Solar PV/T Collector

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Abstract. The output power of the solar photovoltaic panel decreases as the operating temperature increases. The use of photovoltaic/photothermal (PV/T) collectors not only effectively cools the operating temperature of the battery, increases photovoltaic power, but also produces hot water. Therefore, the PV/T collector improves the annual utilization efficiency of solar energy, and can meet the user's demand for different energies. This paper builds an experimental platform to compare the PV/T collector photovoltaic/photothermal performance and experimental comparison with traditional PV. The results show that the PV/T collector has a thermal efficiency of 31.5% and a photovoltaic efficiency of 17.82% at a flow rate of 0.023 Kg/s to achieve high efficiency in solar energy utilization.

1 Introduction

The operating temperature of solar photovoltaic cells plays an important role in photovoltaic performance. It is a function of solar radiation intensity, ambient temperature, material performance parameters, and local wind speed [1]. The Meneses-Rodrigues study found that, under normal conditions, the PV efficiency of PV cells decreases with increasing operating temperature [2]. Skoplasi studied the effect of operating temperature on PV cell performance and summarized the correlation between the two [3]. As the operating temperature of the photovoltaic cell increases, the electrical efficiency and output power of the PV module decrease. Obviously, the efficiency of photovoltaic modules in low temperature environments is higher than in high temperature environments.

In order to reduce the operating temperature of the PV cell and improve the performance of the photovoltaic module. Scholars have proposed solar photovoltaic/photothermal (PV/T) collectors that combine solar cells with solar collectors to increase the efficiency of solar energy utilization at different wavelengths while generating heat and electricity. Wolf proposes a combination of PV cells and water heaters to simulate the combined system performance to take full advantage of solar radiant energy [4]. PV/T collectors are better able to utilize solar radiant energy than PV modules that convert only part of the solar radiant energy into electrical energy. Raghuraman established a one-dimensional heat transfer model for PV/T collectors and flat-plate solar collectors, and proposed a method to improve the performance of the collectors by analyzing their performance [5]. Bhattarai et al. studied the effects of different structural features on the performance of

PV/T collectors [6]. He Wei et al. conducted a comparison of optoelectronic/photothermal efficiency experiments on single-function PV photovoltaic panels and solar collectors and dual-function PV/T collectors [7]. The results show that the photoelectric/photothermal comprehensive efficiency of the dual-function PV/T collector is significantly higher than that of the single-function solar water heater and photovoltaic panel. Ji Jie et al. designed a heat transfer model, applied PV/T collectors to the building and analyzed the system's annual performance [8]. Guo Chao proposed a multi-functional solar PV/T collector, which combines the functions of heated air and heated water and conducts experimental research on PV/T air collection and PV/T water collection respectively [9]. The results show that the PV/T system can efficiently use solar energy in both modes.

In this paper, the experimental bench is used to analyze the photoelectric/photothermal performance of solar PV/T collectors at different flow rates, and the comparative performance experiments of internal anhydrous PV/T and ordinary PV are carried out.

2 Experimental system and equipment

2.1 Dual function PV/T collector structure

The structure of the PV/T collector is shown in Figure 1. The collector includes: a glass cover, a solar cell, a heat absorbing plate, a copper branch pipe, a header, and an insulation layer. The heat absorbing plate is an aluminum plate having a height of 1.52 m and a width of 0.9 m. The front side is laminated with 72 monocrystalline silicon cells in series, and the back is 7

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laser-welded copper branches with an inner diameter of 8 mm. The total area of the solar cell is 1.76 m², and the portion of the surface of the heat absorbing plate that is not covered by the battery is a black absorbing coating. The branch pipe is connected to the system waterway through the collectors at both ends of the collector. The back and side insulation layers are glass fibers having a thickness of 0.03 m.

Fig. 1. Real picture of dual-function PV/T collector.

2.1 Experimental installation of photovoltaic/water thermal system

The experimental platform of the photovoltaic/water collector system is shown in Figure 3. The water system uses mechanical circulation. The collector is connected to the water tank vertically above the insulated water pipe, and the water in the water tank is 120L during the experiment. In the experimental test, the vertical water tank in the tank will produce significant temperature stratification, and three temperature measuring points are uniformly distributed along the height direction of the tank axis to determine the water temperature. In the collector, three temperature measuring points are evenly arranged along the water flow direction of the central branch pipe, and one temperature measuring point is arranged in the inlet and outlet of the collector water pipe to measure the water temperature of the collector. The temperature measurement points are all copper-constantan thermocouples (accuracy grade ± 0.5 °C). The system photovoltaic circuit is connected with a controller, a load and a battery. The controller has an inverter function and power tracking, and the photovoltaic energy output is measured by a power sensor (accuracy level 0.2).

Fig.2. Dual-function PV/T collector experimental system diagram.

The photovoltaic/photothermal performance test of solar PV/T collector is carried out in Hefei outdoor, the collector orientation is positive south direction, the inclination angle is 35°, and the solar irradiance is model TBQ-2 solar total radiation meter. It was measured that the system water flow was measured by a turbine flowmeter (accuracy level 0.5), and the experimental measurement data were recorded by a data acquisition instrument (HIOKI LR8402) with a recording time of 1 min.

3 Experimental results and analysis

3.1 Solar PV/T collector performance evaluation method

The solar PV/T collector can generate both electric and thermal energy, and its performance is evaluated by the efficiency of the converted electric and thermal energy.

The thermal efficiency of PV/T collector is defined as the ratio of the all-day heat gain of water in the tank to the solar radiation absorbed by the collector throughout the day, which is expressed as:

$$\eta_{th} = \frac{MC_p (T_{final} - T_{initial})}{HA_c} \quad (1)$$

PV/T collector PV efficiency can be defined as the ratio of solar radiation absorbed by the collector throughout the day to electricity generated by the collector throughout the day, which is expressed as:

$$\eta_{th} = \frac{\sum UI}{GA_{pv}} \quad (2)$$

Since electrical energy is a high-grade energy compared with thermal energy, a more equitable comprehensive efficiency is adopted to evaluate the efficiency of PV/T collector, expressed as:

$$\eta = \eta_{th} + \phi \frac{\eta_{pv}}{\eta_p} \quad (3)$$

Where $\phi = A_{pv}/A_v$; Where η_p is the conversion factor from thermal energy to electrical energy of the thermal power plant, and its value can be taken as 38%.

3.2 Performance analysis of dual-effect solar PV/T collector

The temperature change curve of the inlet and outlet of the water tank and the collector under the photovoltaic/water collection mode is shown in fig.3 ($Q_w=0.023$ kg/s). At the beginning of the experiment, the temperature of the water tank was 20.22 °C, which was close to the inlet and average ambient temperature of the collector. The temperature of the collector outlet and the heat absorption plate is higher than the temperature of the water tank because the water in the whole system begins to circulate 30 minutes before the test. At 12:00, the temperature difference between the inlet and outlet of the collector is the largest, and after

14:00, the temperature of the heat absorption plate drops slightly. At 16:00, the four curves were close to each other, and the outlet temperature of the collector was lower than the inlet temperature, due to the reduction of solar radiation and incidence Angle. At the end of the experiment, the water temperature in the water tank was 37.7 °C, and the water temperature in the all-day water tank was increased by 17.48 °C. The all-day water collection efficiency of the system was 31.5%.

Fig. 3. Temperature changes of the inlet and outlet temperature of the collector and the temperature of the water tank in photovoltaic/water collection mode.

The electric power in photovoltaic/water collection mode is shown in fig.4($Q_w=0.023\text{kg/s}$). According to the research results of Fudholi [10] et al, the temperature of PV/T solar battery is consistent with that of the heat sink because of the compact lamination of the heat sink and the small specific heat capacity and thickness of the solar cell. The all-day PV/T collector's electrical efficiency is higher than the contrast PV/T collector's electrical efficiency and the ordinary PV collector's electrical efficiency, and the contrast PV/T collector's electrical efficiency is the least. At 12:00, the difference between the three is the largest. The peak power of PV/T collector is 281.43W. By contrast, the peak power of PV/T collector is 253.84W and that of ordinary PV collector is 261.53W.

Fig.4. Change of PV/T collector and electric power in PV/ water collector mode and comparison experiment.

The temperature change curve of PV/T collector and comparison collector battery in PV/ water collector mode is show in Fig.5($Q_w=0.023\text{kg/s}$). The variation

trend of PV/T collector and contrast collector battery temperature and all-day irradiance were basically the same. The all-day comparison of PV/T collector battery temperature is higher than that of PV/T collector and ordinary PV. The temperature changes greatly around 12:00, and the three battery temperatures reach the maximum value at 13:00.

Fig. 5. PV/T collector and comparison of experimental battery temperature changes in PV/ water collector mode

Table 1 shows the all-day photoelectric photothermal efficiency test results of PV/T collector under different water flow in October 2019 and the comparison experiment. With the continuous decrease of water flow rate, the convection and heat transfer coefficient of water and heat absorption plate increases, which makes the PV/T water collection efficiency increase continuously, but the photoelectric efficiency decreases continuously. Compared with PV/T collector, there is no water flow and the battery temperature is high, so the photoelectric efficiency is the lowest.

Table 1 PV/T collector and photoelectric/photothermal efficiency of the comparison experiment under PV/ water heat collection mode.

Q_w (kg/s)	G (MJ)	η_{th} (%)	$\eta_{pv/t}$ (%)	$\eta_{pv/tc}$ (%)	η_{pv} (%)
0.023	22.20	31.50	17.82	15.98	16.48
0.033	18.73	27.79	18.09	16.32	16.82
0.056	20.20	23.22	18.61	16.96	17.39

4 Conclusion

Under the same environmental conditions, the PV/T collector photoelectric efficiency is higher than that of the comparative PV/T collector and ordinary PV. When the water flow rate is 0.023 kg/s, the photoelectric efficiency difference of the three is the largest. The photoelectric efficiency of the PV/T collector is 11.51% higher than that of the comparative PV/T collector, and 8.13% higher than that of the ordinary PV. This shows that increasing water heat collection is beneficial to increase PV photovoltaic efficiency.

PV/T collector photovoltaic/water collection mode, when the water flow is 0.023 kg/s, the solar energy utilization efficiency is 75.57%. This is higher than Ji Jie [11] and others in the L-shaped rib double-effect

collector experiment with a hot water collection efficiency of 63.8%. The dual-function PV/T collector has a higher solar energy utilization efficiency than a single collector solar collector, and at the same time can output electric energy and heat energy, extending the application range of the solar collector.

Nomenclature

A_c	Collector lighting area, m^2
A_{pv}	Total photovoltaic cell area, m^2
C_p	Specific heat capacity of water at constant pressure, $J/(kg \cdot K)$
G	Total solar radiation throughout the day, MJ/m^2
I	Photovoltaic cell output current, A
M	The total mass of water in the tank, kg
Q_w	Water flow, kg/s
$T_{initial}$	Initial temperature of tank, $^{\circ}C$
T_{final}	Tank end temperature, $^{\circ}C$
U	Photovoltaic cell output voltage, V
φ	Collector battery coverage, %
$\eta_{pv/t}$	PV/T collector photoelectric efficiency, %
$\eta_{pv/t c}$	Contrast PV/T collector photoelectric efficiency, %
η_{pv}	Ordinary PV photoelectric efficiency, %
η_{th}	PV/T collector efficiency of hot water collection, %

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