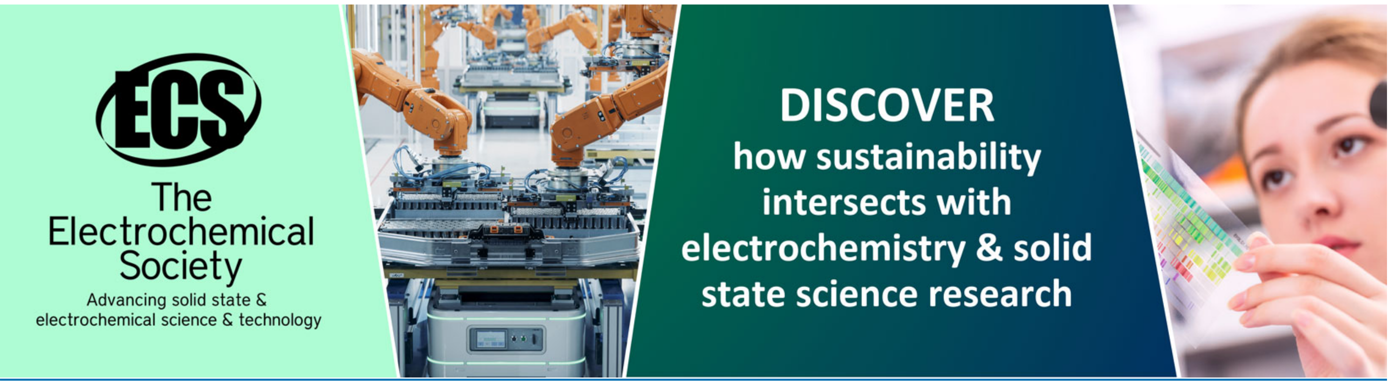
IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

Experiment study of a hybrid concentrated photovoltaic/thermal(CPV/T) system

To cite this article: Zhang Shunxiang *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **657** 012096



Experiment study of a hybrid concentrated photovoltaic/thermal(CPV/T) system

Shunxiang Zhang [1], Peng Li [1*], Qi Luo [2], Yuantao Chen [1]

[1]Wuhan University of Technology, School of Mechanical and Electronic Engineering, Wuhan 430070, China

[2]Wuhan University of Technology, School of Sciences, Wuhan 430070, China

[*]Corresponding author: lp1968@whut.edu.cn

Abstract. In order to improve the efficiency of solar energy utilization, a hybrid concentrated photovoltaic/thermal(CPV/T) system equipped with 750× Fresnel lens and roll-bond heat collector of water-bifurcated channel was proposed. The system produces both electricity and heat performance of the system was tested based on the outdoor measurement in a clear day. The experimental results show that the maximum generating power of the system can reach 3.656KW, with an average generating power of 3.31KW. The total generating energy of the system reached 25.21KWh from 9:00 am to 5:00 pm. The maximum and average electrical efficiency are 25.36% and 24.53%, respectively. The maximum and average thermal efficiency are 63.92% and 58.72%, respectively. The total efficiency can be more than 80%.

1. Introduction

Solar technology refers to transform solar energy into other forms of energy. There is not an effective cooling system, a lot of thermal energy will not be dissipated, which influences the photovoltaic conversion efficiency[1]. Therefore, a simple and efficient solar thermal collector is designed to lower the solar cells temperature and increase the system performance. At the same time, it can also provide and collect additional thermal energy. The hybrid device is called solar photovoltaic/thermal (PV/T) system.

Many kinds of research have conducted on such PV/T system in the past. Adnan[2] did in-depth analysis different types of PV/T systems. Nasrin et al.[3-4] made a comprehensive analysis of the PV/T system under different conditions. Gang[5] used water as the heat removal fluid, and the system efficiency can be improved effectively. For improving the further utilization of solar energy by PV/T, the concentrating photovoltaic/thermal (CPV/T) technology is proposed. Omar[6] have conducted CPV/T system about the types, performance and applications. Depending on the difference of system structure, CPV/T systems are divided into CPC type, dish type, and Fresnel type. Heng[7] carried out a comparative experiment to compare the performance of two systems. Ning et al.[8-9] have reported the research on the Fresnel CPV/T system both in theory and experiment, the results indicated the system performance was greatly improved.

This paper designs and realizations of a hybrid CPV/T system with the roll-bond collector, including solar tracking system, CPV/T module system, cooling and heat collection system, and electrical power generating system. Experimental tests are performed to evaluate the comprehensive utilization of the CPV/T system on a clear day.

2. Experimental setup

The CPV/T system is built in Xi Ning, Qing Hai Province, China, which consists of 32 CPV/T modules with an array of 8×4. After the sunlight is focused on the solar cells by the Fresnel lens, part of the solar energy is transformed into electric energy by solar cells, the other part is converted into "waste heat". The aim of the CPV/T module's photothermal part is to cool solar cells and collect thermal energy by cooling water. The modules are equipped on the solar tracking system, and connected by thermal insulation pipes, as shown in Figure. 1.

Figure. 1 CPV/T system

Each CPV/T module equips with 108 Fresnel lenses which area are 66.6×66.6mm^2 and 108 GaInP/GaAs/Ge triple-junction solar cells which area are 2.4×2.4mm^2, both they have an array of 12×9 and one Fresnel lens faces to a solar cell. The total solar cells adhere to the top of the flow channel of the roll-bond heat collector, and the insulation board is installed on the back side of the roll-bond heat collector that weaken heat loss. The electrical performance parameter of the CPV/T module listed in Table. 1, which are got through experimental tests under steady-state conditions (DNI =1000W/m^2, T_{cell} = 25ºC).

Table.1 Electrical performance parameter of CPV/T module

	Parameter	Value
1	Maximum power	145W
2	Maximum power voltage	26W
3	Maximum power current	5.6A
4	Open circuit voltage	28V
5	Short circuit current	6.5A

The roll-bond heat collector is easy to integrate with the CPV system and designed the CPV/T module has the advantages of compact structure, lightweight, easy processing, flexible installation, etc. For critical components of the CPV/T module, the roll-bond heat collector made of aluminium alloy structure. The desired pattern of flow channels is produced in the two bonded aluminium sheets by bonding them with air under high pressure. The roll-bond heat collector size of 830×630 mm^2.

A two-axis tracker is adopted to track the solar at altitude angle and azimuth. A light sensor is equipped to detect and feedback the solar position, so that the direct irradiation is always perpendicular to the Fresnel lens. The schematic diagram of this system showed in Figure. 2(a). The CPV/T modules are connected by thermal insulation pipes. Cooling water flows from the water tank to the main pipe, after flowing into the four branches for heat exchange with the solar cells, and hot water flows into the tank.

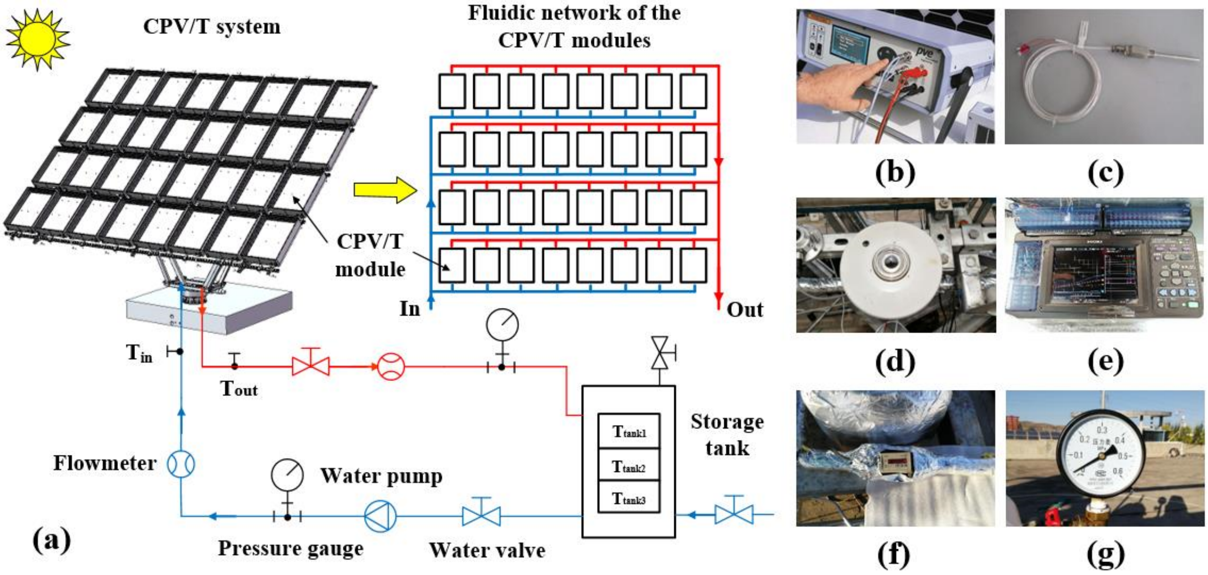


Figure. 2 The schematic diagram and experimental setup

The experimental tests include electrical output which measured by an I-V Curve Tracer (b, PVPM1000C40, accuracy is 5%), the temperature which measured by PT100 thermocouples (c, WZP-187-3PBO, accuracy is 0.1ºC), direct normal irradiance (DNI) which measured by an irradiation meter (d, TBS-2-B-I, accuracy is 2%). All the collected data are recorded in the data recorder (e, HIOKI8402-21, accuracy is 1.5ºC). The flowmeters (f) and pressure gauges (g) are installed in the tube.

3. Data analysis

The electrical energy of the CPV/T system is expressed as the following formula:

$$Q_e = nfA_cCD \tag{1}$$

Where n is the number of the solar cell; f is the tracking error factor of the tracker; A_c is the area of Fresnel lens; C and D are the concentration ratio and DNI, respectively.

Therefore, electrical efficiency can be calculated as:

$$\eta_e = P_e/Q_e \tag{2}$$

Where P_e is the electrical output of the system.

The heat collected by water Q_t and thermal efficiency η_t can be calculated by the following expressions:

$$Q_t = c_w\dot{m}(T_{out} - T_{in}) \tag{3}$$

$$\eta_t = Q_t/Q_e \tag{4}$$

Where c_w is the specific heat of water, $c_w = 4.2 \times 10^3 \mathrm{J/(kg \cdot K)}$; $\dot{m}$ is the mass flow rate; T_{out} and T_{in} are the outlet and inlet temperature, respectively.

For the CPV/T system, the actual energy that can be used is the heat collected and electrical output. Therefore, the total efficiency is defined as:

$$\eta_s = \eta_e + \eta_t \tag{5}$$

4. Results and Discussion

To study the influences of water temperature and DNI on this system, many experimental measurements have been carried on, and typical daily data on a sunny day is selected for analysis and discussion. The ambient temperature gradually increases from 7°C to 15°C, and the water temperature increases from 14.5°C to 30°C showed in Figure. 3.

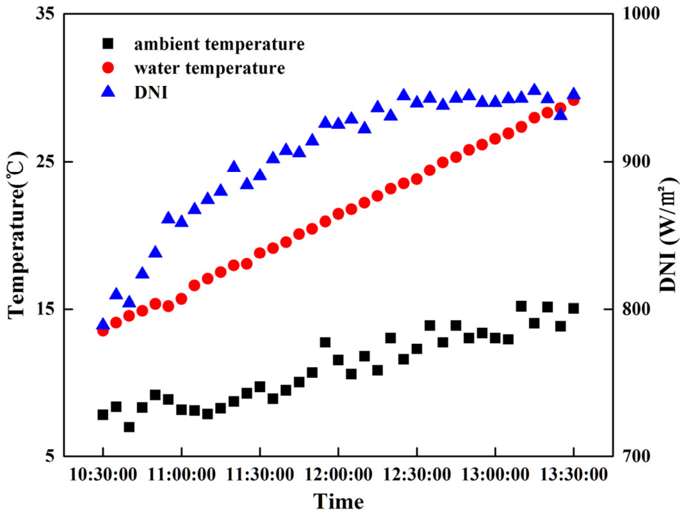


Figure. 3 The change of ambient temperature and water temperature over time

4.1. The influence of DNI on the electrical efficiency

From the Equations. (1-2), the electrical efficiency is directly affected by DNI. Figure. 4 shows trends of DNI and electrical efficiency from 10:30 am to 1:30 pm. It can be seen that the DNI increases from 10:30 am to 12:00 am with a value of 17.19%, and then keeps a steady stage around 950W/m². The electrical efficiency decreases by 5.4% before 12:00 am, but overall, the electrical efficiency remains at 22.1%-24.2%.

4.2. The influence of water temperature of the tank on the electrical efficiency

From Figure. 5 we can know that as the water temperature rises, the electricity efficiency slowly reduced. This is because the rising water temperature of tank, will lead to the cooling water temperature increase, and the heat transfer effect is weakened. As a result, the temperature of solar cells cannot be cooled in time, which affects the photoelectric conversion efficiency and makes electrical efficiency decrease.

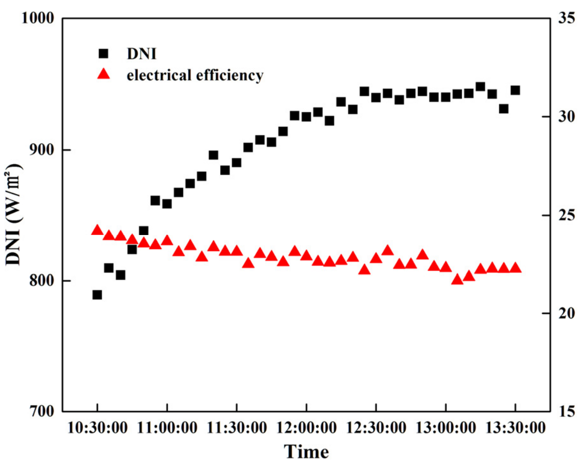


Figure. 4 The change of DNI and electrical efficiency over time

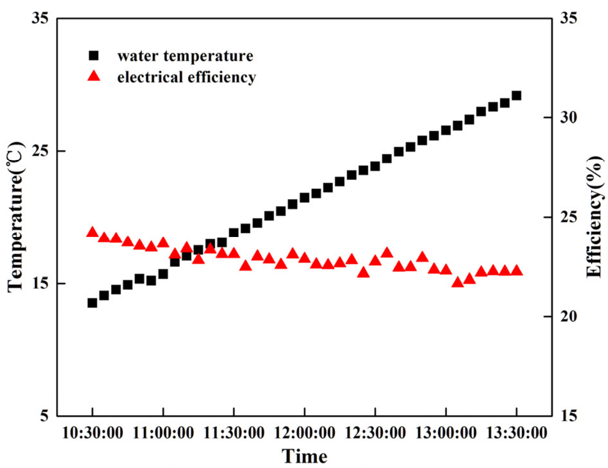


Figure. 5 The change of water temperature and electrical efficiency over time

4.3. The influence of DNI on the thermal efficiency

Figure. 6 depicts the changes in meteorological parameters and thermal efficiency, as well shows the thermal efficiency decreases during the rising stage of DNI. When the DNI remains stable after 12:00

am, the thermal efficiency continues to decrease, but the rate down obviously. At the start of the experiment, the thermal efficiency up to around 64%. Compared with 1:30 pm, the thermal efficiency is 55.33%, and reduces by 13.44%.

4.4. The influence of water temperature of the tank on the thermal efficiency

From the Equations. (3-4), the thermal efficiency is mainly affected by the temperature difference between inlet and outlet. Figure. 7 illustrates that as the water temperature continues to rise, the thermal efficiency shows a downward trend. This is because the decreasing temperature difference between cooling water and solar cells leads to a reduction in heat transfer.

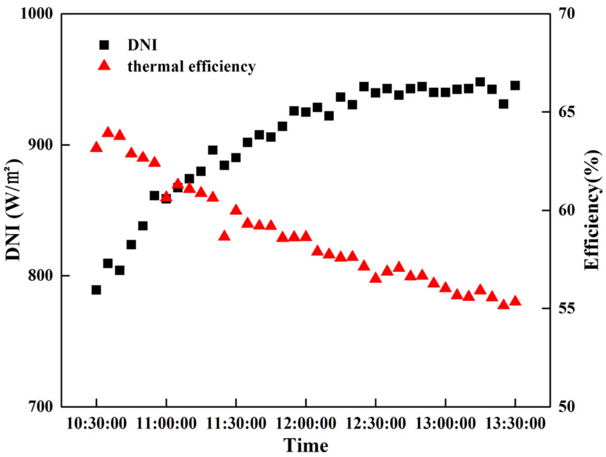


Figure. 6 Relationships between direct radiation and thermal efficiency

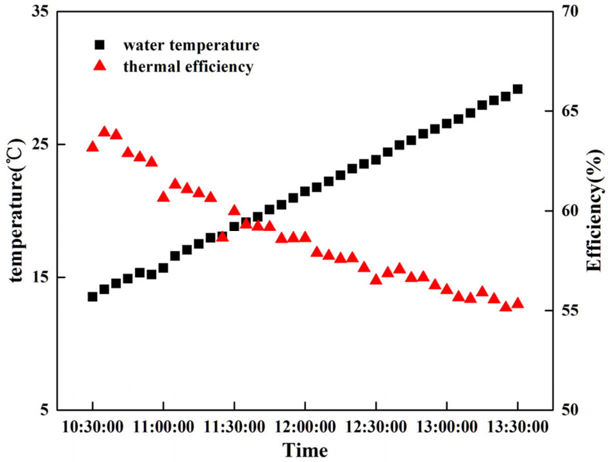


Figure. 7 Relationships between water temperature and thermal efficiency

4.5. The total system efficiency

The maximum generating power of the CPV/T system can reach 3.656W, with an average generating power of 3.31KW. The total generating energy reaches 25.21KWh from 9:00 am to 5:00 pm that day. The maximum and average electrical efficiency are 25.36% and 24.53%, respectively; the maximum and average thermal efficiency are 63.92% and 58.72%, respectively; the total efficiency can reach more than 80%.

5. Conclusions

A hybrid concentrated photovoltaic/thermal system is introduced and experimental research. It uses a Fresnel concentrator lens, high-efficiency solar cells, and adopts a High precision two-axis tracking system. The roll-bond heat collector with water-bifurcated channels can cool the solar cells well and collect heat effectively, which greatly improves the synthetic capability of the CPV/T system.

Experimental results show that the overall fluctuation range of electrical efficiency is small, ranging from 22.1% to 24.2%, with a decrease of 8.67%; the thermal efficiency is always in a state of decline, with a decrease of 13.44%. The maximum generating power of the system can reach 3.656KW, the maximum electrical efficiency up to 25.36%, the maximum thermal efficiency up to 63.92%, and the total efficiency is above 80%. It means the CPV/T system has high conversion efficiency and good development prospects.

Acknowledgments

This work was financially supported by Foshan Xianhu Laboratory of the Advanced Energy Science and Technology Guangdong Laboratory (XHD2020-001), the National Natural Science Foundation of China (grant numbers 51272198, 51772231), and Supported by the Excellent Dissertation Cultivation Funds of Wuhan University of Technology (2016-YS-035).

References

[1] Goswami D Y, Zhao Y. (2009) Proceedings of ISES World Congress 2007 (Vol. I-Vol. V). Springer, Berlin, Heidelberg.
[2] Ibrahim A, Othman M Y, Ruslan M H. (2011) Recent advances in flat plate photovoltaic/thermal (PV/T) solar collectors. Renewable and Sustainable Energy Reviews, 15(1):352-365.
[3] Calise F, Figureaj R D, Vanoli. (2019) Energy performance of a low-cost PhotoVoltaic/Thermal (PVT) collector with and without thermal insulation. IOP conference series. Earth and environmental science, 214:12116.
[4] Nasrin R, Hasanuzzaman M, Rahim N A. (2018) Effect of high irradiation and cooling on power, energy and performance of a PVT system. Renewable Energy, 116:552-569.
[5] Pei G, Fu H, Ji J. (2011) Annual analysis of heat pipe PV/T systems for domestic hot water and electricity production. Energy Conversion and Management, 56:8-21.
[6] Sharaf O Z, Orhan M F. (2015) Concentrated photovoltaic thermal (CPVT) solar collector systems: Part II-Implemented systems, performance assessment, and future directions. Renewable and Sustainable Energy Reviews, 50:1566-1633.
[7] Zhang H, Liang K, Chen H, Gao D, Guo X. (2019) Thermal and electrical performance of low-concentrating PV/T and flat-plate PV/T systems: A comparative study. Energy, 177:66-76.
[8] Xu N, Ji J, Sun W. (2016) Numerical simulation and experimental validation of a high concentration photovoltaic/thermal module based on point-focus Fresnel lens. Applied Energy, 168:269-281.
[9] Ben Y W, Maatallah T, Menezo C, Ben N S. (2018) Modeling and optimization of a solar system based on concentrating photovoltaic/thermal collector. Solar Energy, 170:301-313.