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Performance analysis of a novel LCPV/T system

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Performance analysis of a novel LCPV/T system

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Abstract. Low concentration photovoltaic/thermal technology (LCPV/T) can supply both heat and power. Meanwhile, it has the advantage of low cost and less land occupation, therefore, the LCPV/T technology is suitable for integrating with building. In this paper, the outdoor experiment of a LCPV/T system is carried in June 9th, 10th, 14th and 15th. And the system performance was measured. Furthermore, the variation of thermal and electric efficiencies was analyzed. (4) The maximum thermal efficiency of LCPV/T system is 61.55% (100L/h), the maximum electric efficiency is 19.41%.

1. Introduction

In 1979, Kern and Russell firstly proposed photovoltaic/thermal (PV/T) technology [1]. Subsequently, Bergene *et al* described the physical model of PVT system in detail [2]. PV/T technology has the advantages of less land occupation, low cost. Therefore, it is usually integrated with building [3]. At present, a lot of theoretical research and experimental demonstration on PV/T technology have been carried out.

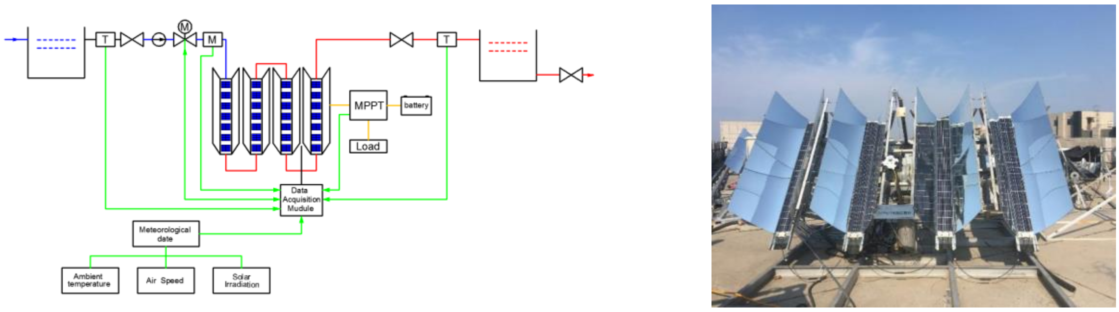
Carlo Renno *et al* proposed the theoretical model of a concentrating PV/T system, and the model was analyzed by Matlab software [4]. They also proposed a novel PV/T system, for domestic type, consisted of parabolic concentrator, triple-junction solar cell and active cooler, the performance of the novel system was optimized by mathematical method [5]. Brogren M et al designed an asymmetric water-cooled concentrating PV/T system, and this system was integrated with building for supplying heating [6]. The influence of concentrator on flat-plate PV/T system performance was analyzed by Kostic, the system electric and thermal efficiencies were also calculated [7]. Zhang *et al* proposed a novel spectral splitting concentrating photovoltaic/thermal system, in their study, the maximum temperature of solar cells in the SS-CPV/T system was about 12℃ lower than the maximum temperature of solar cells in the CPV/T system [8]. Widyolar, Bennett *et al* proposed a novel hybrid solar concentrated photovoltaic thermal (PV/T) collector, the modelled exergy efficiency with a thermal absorber operating at 500 ℃ is 37%. In experiment, the maximum outlet temperature reached was 365℃ with a thermal efficiency of around 37% [9].

Nowadays, numerous researchers designed novel concentrator to improve CPV/T system performance. In this paper, A LCPV/T system performance was measured. The concentrator used in this system was optimized and integrated with light compensation method [10]. The outdoor experiment of a LCPV/T system is carried in June 9th, 10th, 14th and 15th. Furthermore, the variation of thermal and electric efficiencies was analyzed.

2. Design and fabrication of LCPV/T system

2.1. Experiment setup of LCPV/T system

Figure 1(a) is the flowchart diagram of LCPV/T system. The water in the inlet tank passes through the pump, flow meter, electric control valve, and then goes into the LCPV/T collector and finally reaches the outlet tank. The electric energy generated by the module passes through the Maximum Power Point Tracking (MPPT) to the storage battery and load. The experiment setup is shown in figure 1(b), all data (meteorological data and experiment data) are obtained through weather station and data acquisition systems.



(a) (b)

Figure 1. (a) Flowchart diagram of LCPV/T system and (b) Experiment setup of LCPV/T system with biaxial tracking.

2.2. Design of the novel LCPV/T collector

The structure of the novel LCPV/T collector is shown in figure 2. It is composed of the novel compound parabolic concentrator (CPC), N type monocrystalline silicon battery, novel baffle heat exchange channel, heat insulation material and so on. The concentration ratio of the novel CPC is 4, and the height of the concentrator is 543.44 mm, and it is equipped with light compensation on both sides to improve the uniformity of light distribution. The photovoltaic (PV) cells are made up of 40 pieces of bifacial solar cells in series whose size is 78*78 mm. The upper surface of PV cells is adhered to the glass plate by EVA to reduce heat dissipation and wear. The under surface of PV cells is adhered to the TPT layer to absorb the heat produced by PV cells.

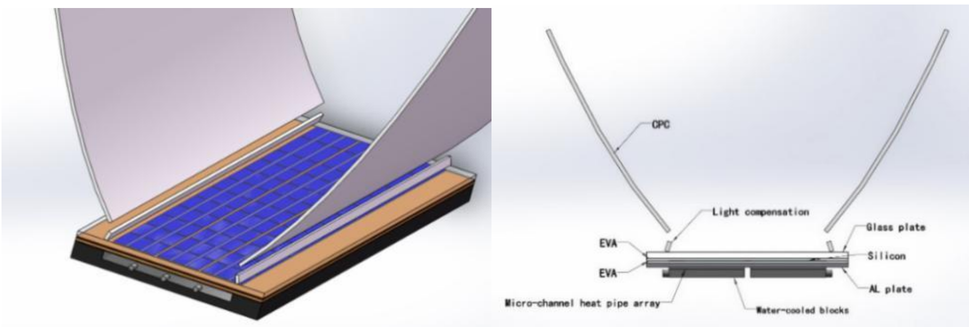


Figure 2. Cross-sectional view of the novel LCPV/T collector.

Flat-box channels are adhered to PV/T collector via silica gel. Meanwhile, in order to reduce heat loss, the collector is wrapped in insulation material.

Table 1 shows the dimension parameters of the PV/T collector [11].

Table 1. Dimension parameters of the novel LCPV/T collector [11].

Parameter name	Value	Unit
Size of the heat transfer channel	1600*162*9	mm^3
Thickness of up and down side of the channel	2	mm
Thickness of left and right side of the channel	3	mm
Thickness of the baffle in the channel	3	mm
Thickness of TPT	0.2	mm
Thickness of silica gel	0.6	mm
Coverage area of photovoltaic cells	1560*156	mm^2
Thickness of photovoltaic cells	0.2	mm
Absorptivity of photovoltaic cells	0.8	
Thickness of glass plate	3.2	Mm
Transmissivity of photovoltaic glass	0.947	
Concentration ratio of CPC	4	

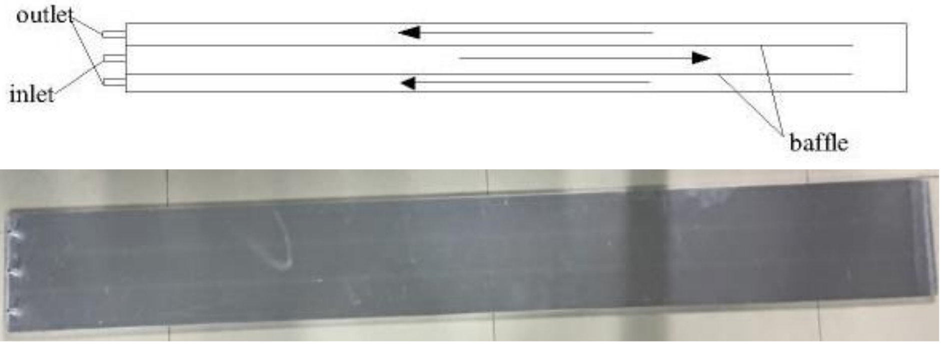


Figure 3. Horizontal section diagram of heat transfer flow channel.

Figure 3 illustrates the cross-sectional view of the novel LCPV/T collector. The refrigerant enters the channel from the middle entrance, reaches the other end and then turns back, flow out from both sides of the outlet finally. And the heat transfer process is more complete. Therefore, the temperature of the PV module is uniform in vertical aspect, the thermal stress in the flow direction is reduced. The channel is slightly longer than PV cells, thermal stress due to temperature difference between the inlet and outlet has less influence on the PV module.

3. Performance evaluation

The thermal efficiency of LCPV/T system:

$$\eta_{th} = \frac{Q}{CGA} = \frac{q_m c_p (t_{out} - t_{in})}{CGA} \tag{1}$$

Where C is the concentration of the LCPV/T collector; Q is the effective absorption of the LCPV/T collector; G is the solar radiation intensity; A is the effective area of PV module; q_m is the mass flow of water; c_p is the specific heat of water; t_{out} is the outlet temperature; t_{in} is the inlet temperature.

The electric efficiency of LCPV/T system:

$$\eta_{el} = \frac{E_c}{CGA} = \eta_0[1 - 0.004(t_c - 298.15)] \tag{2}$$

Where E_c is the output is power of PV module; t_c is the temperature of PV module; η_0 is the standard photovoltaic conversion efficiency (when T=298.15 K, solar radiation intensity G=1000 W/m^2), which is taken as 0.125.

The overall efficiency of LCPV/T system:

$$\eta_T = \eta_{th} + \eta_{el} \tag{3}$$

The overall exergy efficiency of LCPV/T system:

$$\eta_{exergy} = \eta_{el} + \eta_{th}[1 - \frac{298}{298 + (t_{out} - t_{in})}] \tag{4}$$

4. Analyze and discussion of experimental data

The experiment was conducted in June 9th, 10th, 14th and 15th at a roof of a building in Beijing, Changping. The irradiation, environment temperature and inlet/outlet temperature were obtained.

Figure 4 illustrated the variation on electric/thermal efficiency and electric exergy efficiency with solar radiation when the flow rate is 80 L/h. The inlet temperature was fluctuated slightly at 36℃ in the whole day. The outlet temperature increased with radiation until 2 p.m., and the maximum was 53℃. The radiation increased from 700 W/m^2 in the morning to 957 W/m^2 at noon, and then decreased. And the variation tendency of overall exergy efficiency was basically same as the one of electric efficiency, both of them were fluctuated around 18%, the thermal efficiency was fluctuated around 50% before 2 p.m.

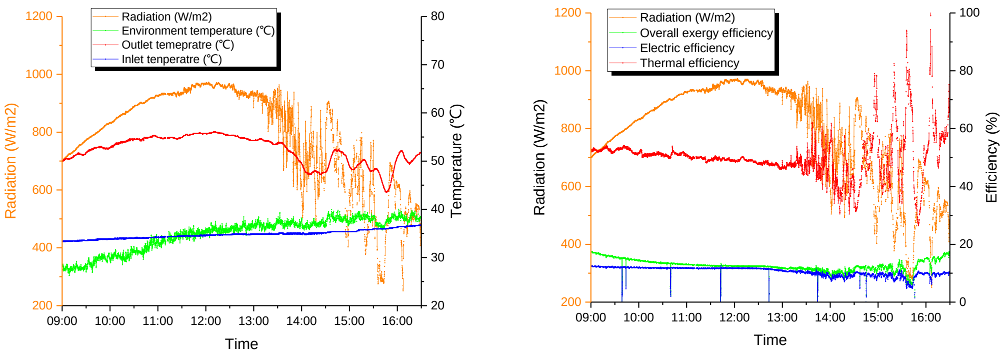


Figure 4. Experimental data in June 9th (80 L/h).

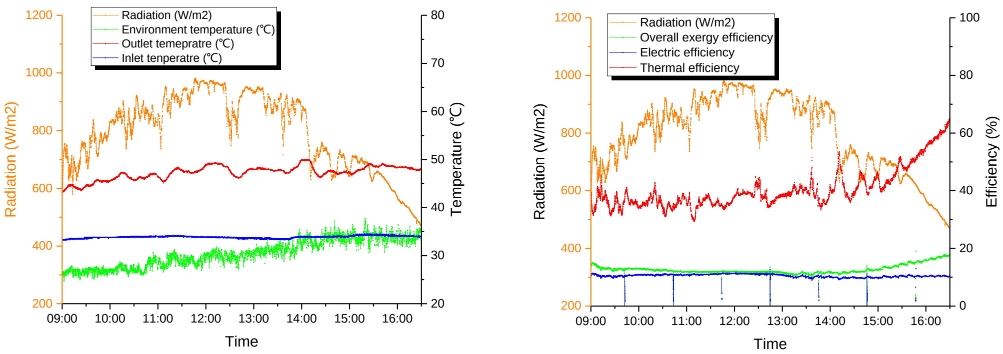


Figure 5. Experimental data in June 10th (90 L/h).

The experimental result in June 10th is illustrated in figure 5 when the flow rate is 90 L/h. Similar to the 80 L/h operating condition, the radiation reached the peak of 953 W/m^2. The inlet temperature was near 34℃, and the outlet temperature fluctuated between 47-51℃. The electric efficiency and overall exergy efficiency were fluctuated around 16%, the thermal efficiency basically maintained around

40% before 3 p.m.

The experimental result in June 14th is illustrated in figure 6 when the flow rate is 100 L/h. The peak value of radiation was 958 W/m^2, the inlet temperature was near 35℃ in the whole day, and the outlet temperature fluctuated between 46-50℃. The electric efficiency and overall exergy efficiency were fluctuated around 18%, the thermal efficiency basically maintained around 50% before 2 p.m.

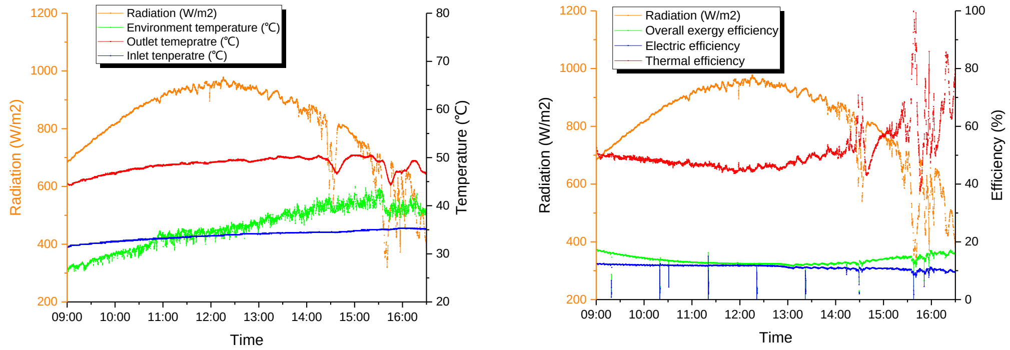


Figure 6. Experimental data in June 14th (100 L/h).

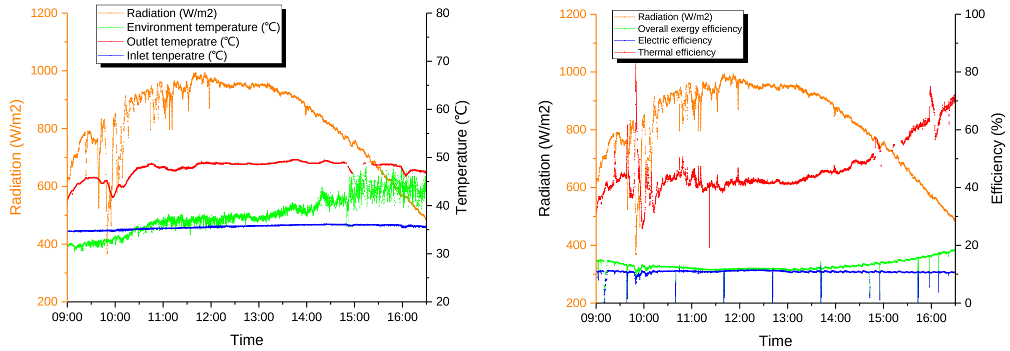


Figure 7. Experimental data in June 15th (110 L/h).

The experiment result under the operating flow rate of 110 L/h is illustrated in figure 7. The peak value of radiation was 962 W/m^2, the inlet temperature was near 35℃, and the outlet temperature fluctuated between 44-48℃. The electric efficiency and overall exergy efficiency were fluctuated around 18%, the thermal efficiency basically maintained around 45% before 2:30 p.m.

Compared experiment results under different flow rate, the inlet temperatures are basically same, and the outlet temperatures decrease with the flow rate increases. Those experiments were carried out under constant flow rate, and the outlet temperature shows that the water cooling device can effectively absorb the heat energy generated by the PV module to avoid efficiency loss caused by excessive module temperature. Furthermore, the three efficiencies are stable before 2:00 p.m., with a small fluctuation of radiation. It means that this system can operate stably under normal condition. However, with the instability of the radiation, the radiation fluctuation can exceed 10 W/m^2, the thermal efficiency begins to fluctuate violently, the electric efficiency and the efficiency also begin to fluctuate in a small range, but the value of the fluctuation is not very large. This system can guarantee the stable output of electric power in the unstable floating condition, but it is difficult to guarantee the stability of the thermal efficiency.

Comparing the efficiency of the four working conditions, it is found that the electric efficiency and exergy efficiency are stable at about 20%. However, the thermal efficiency varies with the difference of the radiation and the flow rate. The variations of the radiation under the 90 L/h and 110 L/h condition are basically the same, and the thermal efficiency under 110 L/h condition is about 5% more than that of the 90 L/h condition. In addition, in the June 15th data, it was clearly found that the thermal efficiency under 110 L/h condition increased with radiation decreasing, and the peak began to decline at 1 p.m. Meanwhile, the thermal efficiency fluctuated from near 40% to the final 70%, which was due to the decrease of the heat absorption of PV panel, while the temperature of PV panel is high still. The amount of heat absorption does not vary substantially, while the total solar energy absorption decreases, resulting in an increase in thermal efficiency.

5. Conclusion

- Under different flow rate, the inlet temperatures are basically same, and the outlet temperatures decrease with the flow rate increases.
- The water cooling device of LCPV/T system can effectively absorb the heat energy generated by the PV module.
- The electric efficiency of LCPV/T system and overall exergy efficiency were fluctuated around 18% under four different working condition.
- The maximum thermal efficiency of LCPV/T system is 59.64% (100 L/h), the maximum electric efficiency is 19.41%.

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