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# Experimental study of using phase change material cooling in a solar tracking concentrated photovoltaic-thermal system

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## ABSTRACT

In this study, the effects of phase change material (PCM) cooling for a tracking-integrated concentrating photovoltaic-thermal (CPV-T) system are investigated experimentally. By designing a small scale CPV-T system with immersed encapsulated PCM spheres, the on-site experimental measurements were performed. The relationship of the electrical, thermal, and overall efficiencies with the solar irradiance is explored. The results are also compared to the existing CPV-T system with water cooling. Results show that compared with the CPV-T system with water cooling, the average increases of the electrical, thermal, and overall efficiencies for the CPV-T system with PCM cooling are more than 10%, 5%, and 15%, respectively. The comparison results demonstrate that using the PCM cooling is an effective way to improve the performance of a CPV-T system.

## 1. Introduction

Both concentrated photovoltaic (CPV) systems and solar tracking systems have been designed to enhance electrical power output per unit area of the PV panel and total energy efficiency of the system (Andreev et al., 2004; Kostic et al., 2010; Charalambous et al., 2011; Huang et al., 2011; Zhu et al., 2011; Su et al., 2014). Even a slight enhancement of the performance of solar PVs will dramatically reduce the unit energy cost of a solar PV system (Rahman and Khan, 2010; Numbi and Malinga, 2017). Results of Rahman and Khan (2010) showed that an average increase of 25% in the short-circuit current can be achieved by using mirror concentrators. However, the more solar light is converted into electricity, the more thermal energy will be generated in the solar PV cell. Moreover, due to the high intensity of the concentrated solar thermal radiation outside of the spectral range, the outer PV enclosure and inner solar cell temperatures increase substantially. The thermal energy accumulated will cause thermal stress on the material of the PV cells, which in turn would significantly decrease the electrical conversion efficiency (Garge and Adhikari, 1998; Looser et al., 2014; Skoplaki and Palyvos, 2009). Since the CPV collector with the concentrator is operated at relatively high temperature, the system electrical efficiency would decrease. Therefore, in order to release the thermal stress of PV panels and maintain the system energy efficiency, the thermal management of the electrical devices of CPV systems is crucially important.

A thermal management system based on cooling is often introduced to cool CPVs in order to ensure the electrical devices work safely and effectively under high solar irradiance. Different types of cooling systems have been designed to maintain the efficiency of PVs or CPVs. According to whether the cooling systems use electrical pumps or not, they can be grouped into two categories: active and passive cooling systems (Hasanuzzaman et al., 2016). The former uses pumps to circulate the cooling fluid such as the water cooling system (Zhu et al., 2011). In contrast, the later cooling system does not use pumps such as the air cooling based on natural convection.

In the active water cooling systems, extra energy will be consumed by the cooling fluid recirculation pumps. In order to reuse the thermal energy dispersed from CPV to the cooling fluid, the integrated concentrated photovoltaic-thermal (CPV-T) system is often designed to collect both concentrated solar light energy and thermal energy at the same time (Kramer and Helmers, 2013; Reddy et al., 2015). Han et al. (2011) simulated the forced convection in a bare CPV-T cell array by using commercial softwares. They showed that the direct-immersion cooling approach can maintain low and uniform cell temperature in the designed liquid immersion receiver. However, their results only presented the temperature distribution. The effects of the temperature distribution on the output power was not provided. In order to gain a better understanding of the electrical performance of active water cooling CPV-T systems, Su et al. (2014) designed a small scale concentrated solar tracking system and performed on-site experimental studies. They also performed numerical studies to simulate the mixed convection conjugate heat transfer of the CPV-T collector under high solar irradiance and high temperature difference.

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## Nomenclature

| | |
|---|---|
| $A$ | area of PV, $m^2$ |
| $c_E$ | energy cost per unit output energy |
| $c_p$ | thermal capacity of water, J/kg K |
| $d$ | water pipe diameter, m |
| $E_a$ | annual output energy |
| $I$ | solar irradiance $W/m^2$ |
| $M$ | investment money |
| $NPV$ | net present value |
| $\dot{q}$ | heat flux per unit area, $W/m^2$ |
| $\dot{Q}$ | heat flux, W |
| $P$ | output power per unit area, $W/m^2$ |
| $\dot{R}$ | change ratio of water, $s^{-1}$ |
| $r_{cost}$ | ratio of energy cost |
| $r_{in}$ | interests or inflation rate |
| $S$ | energy sale values |
| $t$ | time, s |
| $T$ | temperature, K |
| $U$ | velocity, m/s |
| $V$ | volume, $m^3/kg$ |
| $Y(t)$ | the 10-s reading of a particular variable |
| $\overline{Y}(t)$ | time average of $Y(t)$ |
| $\overline{Y}(I)$ | average value over an interval of irradiance |

*Greek symbols*

| | |
|---|---|
| $\delta t$ | time steps |
| $\delta I$ | irradiance steps |
| $\rho$ | density, $kg/m^3$ |
| $\phi$ | fluid ratio of PCM |

*Subscripts*

| | |
|---|---|
| $a$ | annual values |
| $f$ | cooling fluid |
| *inlet* | inlet |
| *outlet* | outlet |
| *PCM* | phase change material cooling |
| *water* | water cooling |

*Superscripts*

| | |
|---|---|
| $-$ | averaged value |
| $\hat{}$ | predicted averaged value |

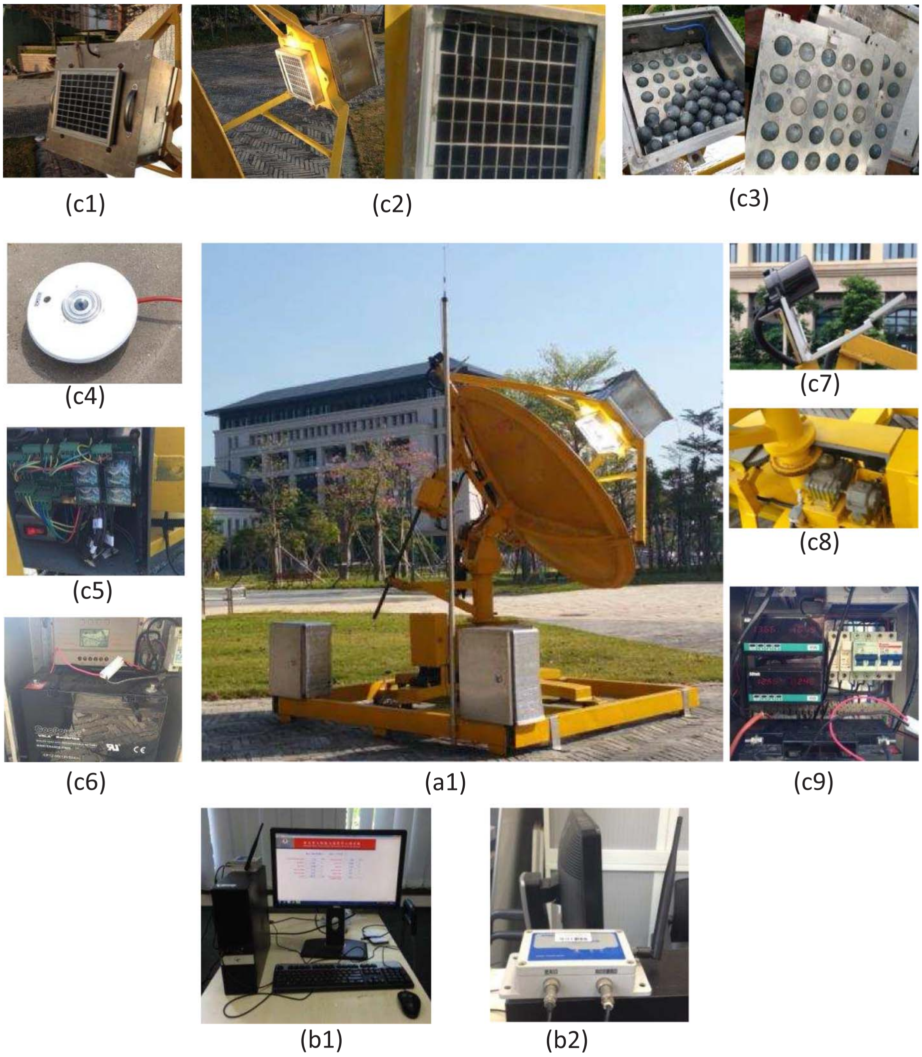

**Fig. 1.** The present CPV-T experiment system: (a) The outdoor system, (b1)-(b2) Indoor data collection system, and (c1)–(c9) Components of the outdoor system.