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Experimental study of integrated photovoltaic thermal management system with coupled phase change and water cooling

X.K. Yu, Y.B. Tao *

Key Laboratory of Thermo-fluid Science and Engineering, Ministry of Education, School of Energy and Power Engineering, Xi'an Jiaotong University, Xi'an, Shaanxi 710049, China

(*Corresponding Author: yubingtao@mail.xjtu.edu.cn)

ABSTRACT

In order to improve the thermal management performance of photovoltaic modules, extend the thermal management time and realize the full utilization of photovoltaic waste heat. In this study, an integrated PV thermal management system with coupled phase change and water cooling and heat dissipation was established. Using electric heating to simulate photovoltaic heat flow, the enhancement effects of phase change cooling and phase change air cooling in thermal management were studied and the existing problems were analyzed. The results show that phase change cooling can reduce the hot surface temperature, but the introduction of copper foam would shorten the thermal management time. Phase change and air cooling can improve thermal management time but is seriously affected by ambient temperature changes, and photovoltaic waste heat will be wasted. On this basis, the effect of phase change and water cooling system on PV thermal management is studied and the waste heat is fully utilized. The results show that the effective thermal management time reaches 3550 s when the water level of the water tank is 7 mm and the ambient temperature is 30 °C, which can satisfy the effective thermal management under 1 h high intensity light and the greater the water quantity, the longer the thermal management time.

Keywords: Photovoltaic thermal management, Phase change cooling, Air cooling, Water cooling

NONMENCLATURE

Abbreviations	
PCM	Phase change material
MF	*metal foam*
MFPCM	*metal foam*/paraffin

1. INTRODUCTION

The use of solar energy through photovoltaic technology is one of the most effective methods, however, limited by the efficiency of photovoltaic cells, most of the incident radiant energy is absorbed by photovoltaic panels and converted into thermal energy, resulting in higher temperatures and lower efficiency [1].

In recent years, the use of phase change materials (PCMs) for thermal regulation of photovoltaic modules has been widely concerned [2]. However, the thermal conductivity of phase change materials is low, and the melting speed in the heat storage process is limited by heat transfer, which affects the practical application. Existing studies have shown that the thermal conductivity of PCM can be effectively improved by filling phase change materials with metal foam [3-5]. Meng et al [6]. used numerical simulation to analyze the effect of metal foam (MF) porosity on the heat storage capacity of PCM. The results show that reducing the porosity can improve the heat transfer performance of PCM, but it will seriously affect the heat storage capacity of PCM, and seriously reduce the thermal management time.

At present, the research of PCMs in photovoltaic thermal management is mostly focused on enhancing the heat transfer performance of PCM, and there are few studies on the time of thermal management and waste heat utilization. In order to improve the thermal management time of photovoltaic modules and improve the utilization rate of energy, an integrated photovoltaic thermal management system with coupled phase change and water-cooling coupling heat dissipation was established in this study with using electric heating to simulate photovoltaic heat flow. The temperature control effects of phase change cooling and phase change-air natural convection coupled cooling in photovoltaic thermal management were studied and the

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existing problems were analyzed. On this basis, the enhancement effect of phase change-water coupled cooling system in photovoltaic thermal management and the feasibility of waste heat utilization are studied.

2. EXPERIMENTAL MATERIALS AND PARAMETERS

Paraffin, melting point 40-44 °C, latent heat of phase change 258 J/g, thermal conductivity 0.23W·m^{-1}·k^{-1}, purchased from China Hangzhou Luer Energy Technology Co., LTD. Copper foam, porosity 98%, pore density 20PPI, purchased from China Guangshengjia Electronic New Materials Co., LTD.

3. PHOTOVOLTAIC THERMAL MANAGEMENT EXPERIMENT

Fig. 1 is the schematic diagram of the experimental device. The interior of the phase change component is a composite phase change material of metal foam/paraffin (MFPCM). The shell of the phase change component is 1 mm aluminum alloy, and the overall size is 30 mm*30 mm*9 mm. The heating surface at the top of the phase change module provides a constant heat flow boundary through the heating sheet to simulate the photovoltaic heat flux. The cooling surface of the bottom of the phase change component is in close contact with the fin. The fin extends into the water cistern to strengthen the heat dissipation, and at the same time, the water supply can be heated to improve the utilization rate of waste heat. The remaining surface is covered with 5 mm thermal insulation cotton. The inside size of the cistern is 33 mm*33 mm*12 mm. The data acquisition system consists of a data acquisition instrument and a type k thermocouple. The temperature measurement accuracy of type k thermocouple is 0.5 °C. The effects of phase change cooling, phase change-air natural convection coupled cooling and phase change-water coupled cooling on photovoltaic thermal management are tested according to the device.

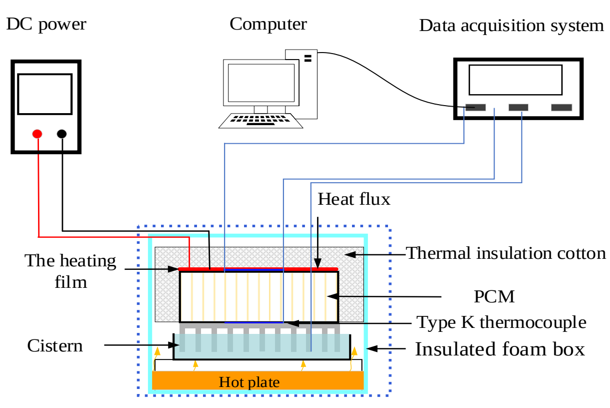

Fig. 1 Schematic diagram of experimental apparatus

4. RESULTS AND DISCUSSION

4.1 Effect of phase change cooling on thermal management

Fig. 2 shows the temperature change curves of pure paraffin and MFPCM as thermal management materials under the condition of ambient temperature 25 °C and heat flux of 1000 W/m^2. Fig. 2 shows that in the temperature control process, the average hot surface temperature of MFPCM is 46.0 °C, which is 1.9 °C lower than that of paraffin (47.9 °C). This is because the existence of MF skeleton improves the heat transfer performance, making the heat transfer inside the PCM more uniform. The melting and heat absorption rate of paraffin is accelerated, avoiding the accumulation of heat caused by slow melting of paraffin. At the same time, due to the improvement of heat transfer performance, the heat absorbed on heating surface can be quickly transferred to the cold surface and dissipated to the air, which greatly reduces the temperature difference between the hot and cold surfaces, as shown in Fig. 3. However, due to the addition of copper foam, the capacity of paraffin was reduced, and the thermal management time was relatively shortened. Compared with pure paraffin (1780s), the thermal management time was shortened by 8.4%, which was not conducive to thermal management.

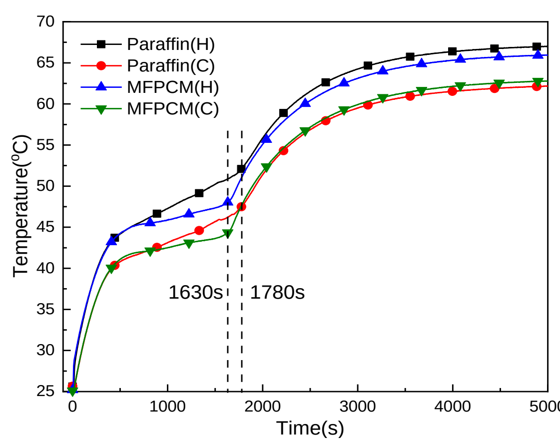

Fig. 2 Change curve of thermal management temperature for phase change cooling. H: Heating surface, C: Cooling surface

4.2 Effect of phase change and air cooling coupled heat dissipation on thermal management

Fig. 4 shows the influence of coupled heat dissipation of *phase change and air cooling* on the thermal management system at ambient temperature of 25 °C and heat flux of 1000 W/m^2, and the test results at different ambient temperatures are analyzed. The test results show that when the ambient temperature is 25

°C, the thermal management time is extended by 61% (2630s) compared with Fig. 2 MFPCM cooling. This is because the existence of the fin greatly improves the heat dissipation capacity of the phase change component, because the heat preferentially flows from high temperature to low temperature, making the heat quickly flow from the heating to the fin and heat exchange with the air, the speed of heat absorption of the paraffin is relatively slow. With the increase of ambient temperature, the cooling ability of phase change and air coupling heat dissipation weakens. When the ambient temperature increases to 35 °C, the thermal management time is only 1260s, because the heat dissipation capacity of fin decreases with the increase of ambient temperature, and heat is absorbed by paraffin.

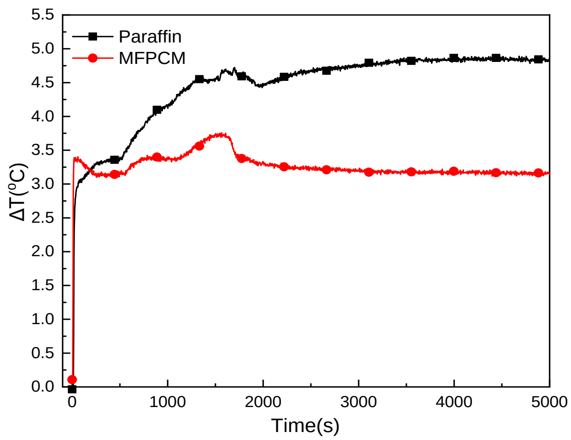

Fig. 3 The temperature difference between hot and cold surfaces

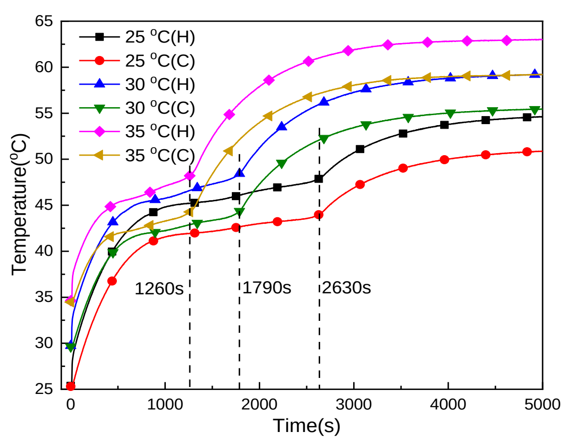

Fig. 4 Thermal management temperature curve of phase change air coupled cooling

4.3 Effect of phase change and water cooling coupling heat dissipation on thermal management

The core of photovoltaic thermal management is to reduce the temperature of photovoltaic modules and extend the time of thermal management, but with the strengthening of heat dissipation performance, photovoltaic waste heat is wasted. In this section, water cooling is introduced to improve the thermal management performance, and photovoltaic waste heat is used to heat water supply, so as to realize the reuse of photovoltaic waste heat. The coupled water cooling process is cooled by the natural convection of the tank, with no additional energy consumption. Fig. 5(a) experimental results show that at 1000W/m^2, when the water level of the water tank is 7 mm and the ambient temperature is 30 °C, the thermal management time of MFPCM is extended to 3550 s by 98.3% compared with Fig. 4(1790 s). This is because the heat absorbed by the phase change device after the introduction of water cooling can be quickly absorbed by water through the fin, making the paraffin melt slowly and maintaining the constant temperature of the photovoltaic device. Due to the ability of water cooling to strengthen heat dissipation, the final temperature of the hot surface is 52.8 °C when the heat exchange with the environment reaches stability, which is 6.4 °C lower than that of non-water cooling. Fig. 5(b) shows that the thermal management time is still shortened by the increase of ambient temperature, but it is still extended by 65.9% compared with 1260s in the same environment as Fig. 4. At the same time, due to the increase of ambient temperature, photovoltaic waste heat raises the water temperature to 48.3 °C, which is 2 °C higher than that in Fig. 5(a). Fig. 5(c) shows that the amount of water determines the length of thermal management time, and the greater the amount of water, the less heat used for melting paraffin, and the corresponding increase in thermal management time.

5. CONCLUSIONS

In order to make full use of solar energy resources, and improve the thermal management performance of photovoltaic modules, extend the thermal management time. In this study, an integrated PV thermal management system of coupled phase change and water cooling heat dissipation was established. The PV thermal management was carried out by connecting the PV module with the phase change cooling module, and the PV waste heat was reused by connecting the tank with the fin. The strengthening effects of phase change cooling and phase change air cooling in photovoltaic thermal management were studied and the existing problems were analyzed. On this basis, the strengthening effect of phase change and water cooling integrated system in photovoltaic thermal management and the feasibility of waste heat utilization are studied, and the following conclusions are drawn.

(1) Phase change cooling can reduce the hot surface temperature, but the introduction of copper foam will shorten the thermal management time.

(2) Phase change and air cooling can improve thermal management time but is seriously affected by temperature changes, and photovoltaic waste heat will be wasted.

(3) When the water level of the water tank is 7 mm and the ambient temperature is 30 ^{o}C, the effective thermal management time of phase change and water-cooling coupling heat dissipation reaches 3550s, which can meet the effective thermal management under 1h high intensity light.

(4) The greater the amount of water, the more heat is needed to raise the water temperature, and the longer the heat management time.

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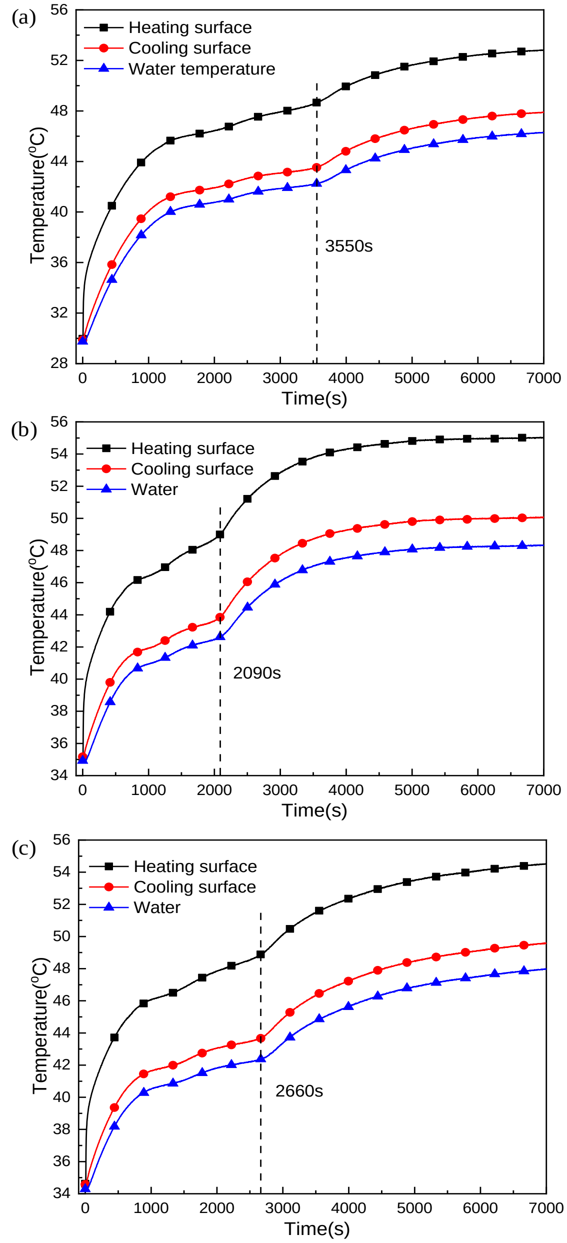

Fig. 5 Thermal management temperature curve of phase change and water coupled cooling (1000W/m^2). (a)The water level is 7 mm and the temperature is 30 ^{o}C. (b)The water level is 7 mm and the temperature is 35 ^{o}C. (c)The water level is 8 mm and the temperature is 35 ^{o}C

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