Available online at www.sciencedirect.com
ScienceDirect
Solar Energy 107 (2014) 113–121
SOLAR ENERGY
www.elsevier.com/locate/solener

Outdoor test of a hybrid jet impingement/micro-channel cooling device for densely packed concentrated photovoltaic cells

J. Barrau [a,1], A. Perona [b,*], A. Dollet [b,2], J. Rosell [a,3]

[a] Applied Physics Section of the Environmental Science Department, University of Lleida, c/Pere Cabrera s/n, 25001 Lleida, Spain
[b] Laboratoire PROMES, CNRS, site Tecnosud, rambla de la thermodynamique, 66100 Perpignan, France

Received 28 January 2014; received in revised form 29 April 2014; accepted 25 May 2014
Available online 28 June 2014

Communicated by: Associate Editor Igor Tyukhov

Abstract

Densely packed concentrated photovoltaic (CPV) receivers require efficient active cooling in order to maintain the photovoltaic cells within their nominal operating temperature range. The cooling device must have low thermal resistance coefficients and also provide good cell temperature uniformity in order to maximize the efficiency and the reliability of the whole system. A hybrid jet impingement/microchannel cooling device designed for CPV receivers is experimentally tested under real sun in outdoor conditions. The measurements include the irradiation profile at the outlet of the secondary optics and the temperature distribution of the receiver. The experimental results show that the thermal resistance coefficient and the temperature uniformity provided by the cooling device met the requirements for CPV receivers. This work also emphasizes that the internal geometry of the cooling device must be tailored, at the design stage, to the irradiation profile provided by the optics, which is generally nonperfectly uniform in CPV systems based on densely packed receivers. The impact of the solar concentration ratio and flow rate on the electrical output of the receiver is also assessed.
© 2014 Elsevier Ltd. All rights reserved.

Keywords: Cooling device; Jet impingement; Micro-channel; Concentrated photovoltaic systems

1. Introduction

Concentrated photovoltaic systems (CPV) require extraction of high heat fluxes in order to prevent overheating which could be detrimental to cell efficiency and lifetime. In Fresnel lens-based CPV systems, the large distance between the individual small PV cells allows to use passive cooling devices. However, in systems based on parabolic troughs, passive cooling no longer suffice because all PV cells are located in a single densely packed receiver placed at the focal region. Furthermore, the cooling device must be compact in order to avoid undesirable shades on the optical system. So efficient active cooling is necessary for densely packed CPV receivers. The cooling performance of active cooling devices is mainly determined by two characteristics: thermal resistance which should be kept as low as possible and temperature uniformity.

Royne et al. (2005) showed that the thermal resistance coefficient of the cooling device in densely packed receivers must be lower than 10^{-4} K m^2/W for concentration levels higher than 150 suns. Jet impingement and microchannels cooling technologies permit to reach this high performance (Steinke and Kandlikar, 2006; Aldabbagh and Sezai, 2004).

* Corresponding author. Tel.: +33 468682269; fax: +33 468682213.
E-mail addresses: jerome.barrau@udl.cat (J. Barrau), arnaud.perona@promes.cnrs.fr (A. Perona), alain.dollet@promes.cnrs.fr (A. Dollet), rosell@macs.udl.cat (J. Rosell).
[1] Tel.: +34 973003703.
[2] Tel.: +33 468682212.
[3] Tel.: +34 973003568.

http://dx.doi.org/10.1016/j.solener.2014.05.040
0038-092X/© 2014 Elsevier Ltd. All rights reserved.

Nomenclature

A_c	area of the dummy/PV cell (m^2)
C_{pf}	specific heat of the refrigerant fluid (J/(kg °C))
C_s	solar concentration ratio at the CPV cell level (suns)
P_a	power absorbed by the dummy cell (W)
P_c	electrical output of the PV cells (W)
P_i	incident solar power (W)
P_f	power absorbed by the refrigerant fluid (W)
P_{Net}	net electrical power produced by the CPV (W)
P_0	term of the net PV output of the receiver that depends on the solar concentration (W)
PP	pumping power (W)
Q	flow rate (l/min)
q_c	electrical power density produced by the PV cells (W/m^2)
q_{direct}	direct radiation (W/m^2)
q''	heat flux that must be extracted by the heat sink (W/m^2)
R_a	average thermal resistance coefficient of the cooling device ($K\ m^2/W$)
R_i	thermal resistance coefficient at position i ($K\ m^2/W$)
R_{th}	thermal resistance coefficient ($K\ m^2/W$)
T_c	average temperature of the dummy cell (°C)
T_i	thermocouple i
T_{in}	inlet temperature of the cooling liquid (°C)
T_{out}	outlet temperature of the cooling liquid (°C)
$T_s(x)$	local temperature measured by the thermocouple at position x (°C)
X	equivalent solar concentration ratio at the heat sink level (suns)
x, y, z	coordinates (mm)

Greek symbols

α	relative temperature coefficient of the PV cells (%/K)
α_Q	flow rate coefficient of the CPV receiver ($W/(m^3/s)$)
ΔT_{max}	maximum difference between receiver temperatures measured in 2 different regions of the cooling device (°C)
η_c	PV cell efficiency (%)
ρ_f	refrigerant fluid density (kg/m^3)
σ_T	standard deviation (°C) of the cooling device temperature measured along the coolant flow direction

Subscripts

exp	experimental
theo	theoretical

The temperature distribution on the PV receivers under high concentration has also an impact on their efficiency and reliability (Royne et al., 2005). Large temperature non-uniformity may induce mechanical stress, due to the fact that thermal expansion depends on the local temperature of the receiver. Mechanical stress coupled with the large number of thermal cycles experienced by the CPV receiver causes thermal fatigue which affects the reliability of the whole system. A recent study (Chemisana and Rosell, 2013) analyzed the effect of temperature profiles on the cell's electrical parameters under low solar concentration with a Gaussian illumination distribution. Comparison between uniform, Gaussian and anti-Gaussian temperature profiles showed that cell performances are better for the Gaussian temperature distribution than for the uniform one. Output power is slightly higher for systems using heat sinks providing Gaussian temperature pattern. This opens the possibility to tailor the temperature distribution curve to maximize the cell open-circuit voltage, but this study should be extended to higher concentration ratios; moreover the slight increase in PV output must be balanced with the impact on reliability of the whole system. Nevertheless, the ability of the cooling scheme to provide a temperature pattern adapted to the illumination profile appears as an important factor.

In microchannel-based devices, the temperature of the cooled object always increases in the direction of the flow of the coolant. The only way to reduce the temperature gradient is to increase the flow rate which implies to strongly increase the pressure losses in the cooling circuit. As a consequence, a larger pumping power is required that reduces the net electricity production of the system.

Cooling devices based on jet impingement provide less uniform temperature distribution. Royne and Dey (2007) explored the viability of arrays of impinging jets as a cooling device for densely packed PV cells. Their proposed system included a complex return architecture that improves the performance of the cooling device. This study concluded that high heat transfer coefficients can be reached using such devices but also pointed out the difficulty for reducing the temperature non-uniformity inherent to jet impingement distributions.

Barrau et al. (2009) and Barrau (2008) developed a new cooling scheme that combines jet impingement and microchannel characteristics. The coolant enters the heat sink through a slot jet and impinges in the centre part of the device, then the fluid is separated in two opposite directions and flows through variable-width microchannel heat exchange zones. Experimental analysis (Barrau et al., 2010) showed that the hybrid cooling scheme reaches

Download English Version:

https://daneshyari.com/en/article/1549924

Download Persian Version:

https://daneshyari.com/article/1549924

Daneshyari.com