



3D study on the performance of cooling technique composed of heat spreader and microchannels for cooling the solar cells

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ABSTRACT

The performance of a new cooling technique composed of a heat spreader (HS) and microchannels for cooling the solar cells (photovoltaic panels) is carried out. 3D steady state physical model for the solar cell coupled with the heat spreader and the microchannels is developed and solved numerically. The model is used to investigate the effect of using the microchannels with the HS on the performance of the solar cell. Also, the effect of different configurations of the microchannels-HS cooling system on the solar cell performance is studied. These configurations are tested at different concentration ratios (CRs) of the incident solar radiation and different Reynolds number (Re) of the coolant water inside the microchannels. The results indicate that the cooling system with HS has the smallest value of the solar cell temperature and the maximum temperature difference of the cell. It also has the greatest cell efficiency and output electrical and net power of the cell compared to the cooling system without HS. When the microchannels and the solar cell have equal surface area and their area is smaller than HS area, the solar cell has the maximum net power output at high Reynolds number. At low CR ($CR = 5$), the cooling system with HS increases the cell efficiency and the net power compared to the system without HS by about 8%, and 13% respectively at Re equal 5 and 13% and 2% respectively at Re equal 65. Also, at high CR ($CR = 20$), using HS increases the cell efficiency and the net power by about 50% and 3.7% respectively at Re equal 5, and 53% and 2.8% respectively at Re equal 65. At high Re number, the most efficient cooling system configuration occurs when the microchannels and the solar cell have the same area and the HS area is greater than their surface area.

1. Introduction

Nowadays solar energy is one of the most vital sources of renewable energy which can be used by different technologies like solar heating, solar cooling, and solar power systems, and photovoltaics. The photovoltaic cell (PV) or the solar cell panel can produce electrical energy from the sunlight with the help of photovoltaic effect. Electricity can be generated from solar energy either by direct conversion to electricity using PV effect or by converting it into thermal energy and then to electricity. Although, the direct conversion efficiency of the PV system to electrical is superior to the conversion via thermal energy while the widespread of using the PV is still limited because of the need of large land area where its cost is expensive. Conventional PV systems are ideal for remote countryside areas and moreover, it is very expensive to extend an electric power line through those areas [1]. Also, due to the continuous increase in energy demands because of the large increase in population rate and the reduction of the fossil fuel, the concentrated

photovoltaics research field has many attractions nowadays. The solar cell may be harmfully damaged due to increasing its temperature because of the high densities of current and heat fluxes [2] and this represents a big problem in PV systems. PV cells only convert less than 20% of the incident solar energy to electricity due to its efficiency, while more than 50% of the incident solar energy is converted to heat yielding losses in PV efficiency and power and the rest is lost due to glass reflection, climate conditions, heat losses from solar cell, etc. Moreover, performance degradation is affected by the environmental conditions such as ultraviolet intensity and temperature [3]. Also, a thermal degradation may occur because of unnecessary heating of PV cells at higher working temperature. Also, PV module working time and reliability may be harmfully affected by higher module and ambient temperatures [4]. The PV cell efficiency and power output can be improved by decreasing the cell temperature with the help of cooling the solar cell modules with air or water. Moreover, it will be more economical if we reuse the heat energy produced from the module and

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Nomenclature		α	absorptivity
		τ	transmittivity
		<i>Subscripts</i>	
A_s	surface area (m^2)	c	cell
C	specific heat (J/kg K)	CD	conduction
G	solar radiation (W/m^2)	Ch	channel
h	heat transfer coefficient ($W/m^2 K$)	CV	convection
k	thermal conductivity ($W/m K$)	e	electrical
L	length (m)	f	friction
$\dot{m}$	mass flow rate (kg/s)	ref	reference
n	normal direction	G	glass
p	pressure (Pa)	HS	heat Spreader
P	power (W)	in	inlet
p_{out}	ambient pressure (Pa)	MC	microchannel
Q	heat rate (W)	out	outlet
$\dot{q}$	heat generation (W/m^3)	RD	radiation
$\dot{Q}$	total heat generated (W)	sky	sky
T	temperature (K)	th	thermal
T_∞	ambient temperature (K)	w	water
v	wind speed (m/s)	wd	wind
V	total velocity (m/s)		
W	width (m)		
<i>Greek symbols</i>		<i>Abbreviation</i>	
η	efficiency	EVA	ethyl vinyl acetate
ε	emissivity	HS	heat Spreader
β	temperature coefficient	MC	microchannel
σ	Stefan Boltzmann constant ($W/m^2 K^4$)	PV	photovoltaic
δ	layer thickness (m)	Re	Reynolds number
ρ	density (kg/m^3)	PCM	phase change material
ρ_f	reflectivity	TPT	(Tedlar/PET/Tedlar)
μ	dynamic viscosity (Pa s)		

extracted by the fluid which called photovoltaic thermal (PV/T) hybrid systems [5]. Some efforts from material researchers were done to enhance the stability and the efficiency of the solar cell especially for thin solar cell film [6]. Other techniques were used to raise the PV cells efficiency and power output such as use solar concentrator, use efficient cooling technique, correctly installed PV panels, avoid shaded area and do suitable maintenance, and sun tracking system whatever single or two axes tracking system [7]. The sun tracking system increases the solar energy incident on the PV panel but it increases the initial and running cost of the system.

Solar cells cooling techniques are classified into active and passive cooling techniques. Active techniques need an additional external power while passive techniques don't need this power. Some examples of active cooling systems are: water spraying on the front surface of the cells [8–10], cooling by jet impingement [11], and cooling by passing fluids (as air or water) through ducts or channels [12–18]. For passive cooling, some techniques like: PV cells immersion in dielectric medium [19], PV cells submersion in water [20,21], PV cells cooling by air flow due to bouncy force [22–24], using wind-driven ventilator [25], using nanoparticles [26,27], phase change materials (PCMs) [27–30], cooling PV cells by evaporation [31], and cooling by cotton wick [32]. Rosell et al. [33] found that using microchannels for cooling PVs has favor overall cooling technique exist because microchannels cooling have minimum thermal resistance. Rahimi et al. [34] investigated experimentally the effect of using microchannels with PV modules as PV/T system. In their study, they found that PV output power is increased up to 30% when microchannels are used. They used different ranges of Reynold number up to 70 and the used hydraulic diameter is 0.667 mm. Ramos-Alvarado et al. [35] theoretically investigated the pressure drop and temperature for different designs of microchannels cooling system. They suggested an optimum design and they recommended it for

cooling electronic systems, PV modules, and fuel cells. Reddy et al. [36] numerically studied microchannels system for cooling the concentrated photovoltaic modules. They found that the optimum dimensions of the microchannel for $120 \times 120 \text{ mm}^2$ PV module are 0.5 mm width and 8 aspect ratio. Moreover, their results recommended that straight flow channels because they have the lowest pressure drop. For $120 \times 120 \text{ mm}^2$ PV system with a flow rate 0.105 L/sec, the temperature rise, and pressure drop were 10 K and 8.5 kPa respectively. Radwan et al. [37] theoretically investigated the performance of low concentrated PV module with microchannels cooling system. They studied the effect of different operating conditions on the performance of the system. Their results indicated that using microchannels cooling system is significantly effective at a low concentration ratio of the incident solar radiation on the PV systems. Additionally, at high concentration ratio and Reynolds number 100, the electrical and thermal efficiencies are 18.5% and 62.5% respectively at reference efficiency of the cell material 20%. Radwan et al. [38] investigated theoretically four different flow of the coolant water configurations inside the microchannels of the cooling system of concentrated PVs at different operating conditions. The findings illustrated that at concentration ratio 20, single layer parallel flow design achieves the maximum output power and solar cell efficiency and minimum cell temperature compared to the other configurations. The heat sink or heat spreader represents a passive cooling technique of the PVs where they increase the heat transfer rate by using extended surfaces (Fins) in case of the heat sink and increasing surface area in case of the heat spreader. The advantages of the heat sink and the heat spreader in cooling are that they don't need any additional power or maintenance cost during system running. Kenji et al. [39] proposed a simple cooling technique concentrated PV with concentration ratio 50 by using a copper sheet of an aluminum plate. Their results showed that the proposed system has ten degrees lower in

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