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Experimental investigation of jet array nanofluids impingement in photovoltaic/thermal collector

Husam Abdulrasool Hasan [a,*], Kamaruzzaman Sopian [a,*], Ahed Hameed Jaaz [a], Ali Najah Al-Shamani [a,b]

[a] Solar Energy Research Institute, Universiti Kebangsaan Malaysia (UKM), 43600 Bangi, Selangor, Malaysia
[b] Al-Musaib Technical College, Al-Furat Al-Awsat Technical University, 51009 Babylon, Iraq

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ABSTRACT

The effect of nanoparticles (SiC, TiO_2 and SiO_2) with water as its base fluid on the electrical and thermal performance of a photovoltaic thermal (PVT) collector equipped with jet impingement have been investigated. A PVT collector was tested indoor at set levels of solar irradiances and mass flow rates. The system consists of four parallel tubes and 36 nozzles that directly injects the fluid to the back of the PVT collector. The electrical performance of the PVT collector was determined based on the mean temperature of the PVT absorber plate. The SiC/water nanofluid system reported the highest electrical and thermal efficiency. The electrical, thermal, and combined photovoltaic thermal efficiencies were 12.75%, 85%, and 97.75%, respectively, at a solar irradiance of 1000 W/m^2 and flow rate of 0.167 kg/s and ambient temperature of about 30 °C. Moreover, the P_{max} of PVT with SiC nanofluid increased by 62.5% compared to the conventional PV module.

1. Introduction

A photovoltaic thermal collector (PVT) converts solar irradiance into electricity and thermal energy, while a conventional photovoltaic solar cell converts photons emitted by the sun into electricity. The PVT absorber plate convert the heat from the PV cells into thermal energy. The generation of electricity and heat by the PVT make the collector more efficient than the solar thermal collectors or conventional PV. Many experimental and numerical studies aspire to improve the electrical and thermal efficiency of the PVT (Tyagi et al., 2012; Ji et al., 2007; Shan et al., 2014; Ziapour et al., 2014). Working fluids are used to cool the PV solar cells, examples being water, air, and nanofluids (Daghigh et al., 2011; Chen et al., 2014; Xu and Kleinstreuer, 2014; Abu-Bakara et al., 2014; Sardarabadi et al., 2014). Despite the fact that PVT design is crucial towards its performance, studies on it remains scarce in literature. Ibrahim et al. (2011) indicated that the thermal efficiency of a sheet-and-tube collector is 2% lower than that of other collectors (such as free flow, channel, and dual-absorbers). Cerón et al. (2015) numerically analyzed the effect of liquid on the performance of tube-on-sheet flat-plate solar collectors, while Zhang et al. (2014) investigated the electrical and thermal performance of a novel design of solar photovoltaic/loop with a heat-pipe collector. They reported that the thermal and electrical efficiency system are 9.12% and 58%, respectively, while the overall exegetic efficiency of the system was 14.92%. Using nanofluids as a working fluid significantly improved the overall performance of photovoltaic/thermal without the need to alter the structural design (Xu and Kleinstreuer, 2014). Literature reported many works involving heat transfer using nanofluids as working fluids due to the nanoparticles' higher conductive heat transfer coefficient (Khanafer and Vafai, 2011), its transient local heat transfers and Brownian motion, and surface electrical charges (Koo and Kleinstreuter, 2005; Michaelides and Feng, 1994; Lee et al., 2006; Wu et al., 2009). The use of different types of nanofluids in solar collector systems for different applications were reviewed in Nagarajan et al. (2014). Suganthi et al. (2014) experimentally analyzed the effect of the ZnO/ethylene-glycol/water and ZnO/ethylene-glycol nanofluids as a working fluid for enhancing heat transfer. The results showed that the heat transfer coefficients increased with increasing thermal conductivity of the nanofluids. Bhattarai et al. (2012) experimentally and theoretically investigated the transient process of a PVT collector equipped with a sheet-and-tube water based system, while He et al. (2014) investigated the performance of a PVT system in a thermo-electric heating and cooling unit. They reported that the electrical and thermal efficiencies of the PVT system were 16.7% and 23.5%, respectively. Dehra (2009) studied a 2D thermal model for a PV unit to calculate the temperature distribution of a solar wall and

* Corresponding authors.
E-mail addresses: hussam2003hussam@yahoo.com (H.A. Hasan), ksopian@ukm.edu.my (K. Sopian).

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Nomenclature

Ac	area of PVT collector (m^2)
b	width of PVT collector (m)
Cp	specific heat (J/kg °C)
H	nozzle-PV spacings (m)
F'	the efficiency factor of PVT collector
F_R	the heat removal of efficiency factor
G_T	overall solar radiation (W/m^2)
h_{fi}	the heat transfer coefficient (W/m^2 °C)
k	the thermal conductivity (W/m °C)
$\dot{m}$	mass flow rate of jet water (kg/S)
N	total number of glasses
Q_u	effective useful heat gain (W)
I	solar irradiance (W/m^2)
t	temperature (°C)
U_L	effective overall heat transfer coefficients (W/m^2 °C)
U_t	top losses coefficient (W/m^2 °C)
v	wind speed (m/S)
α	effective absorptance
θ	collector tilt angle
ε	effective emittance
τ	effective transmittance
η	efficiency

Subscripts

a	ambient
abs	effective absorber thickness
c	solar cell
g	glass
i	inlet of fluid
j	jet water
o	outlet of fluid
p	plate of absorber
pm	mean plate of absorber
PV	photovoltaic solar cell
PVT	photovoltaic thermal
r	reference value
w	wind

the ventilation for ducts used in a photovoltaic hybrid system by increasing the solar irradiation from 200 to 700 W/m^2. Xu and Kleinstreuer (2014) analyzed the performance of photovoltaic thermal co-generation system using a 2D model coupling thermal analysis and CFD simulations. Nanofluids was used for both the heating and cooling systems. The results showed that the efficiency increased to 70% for systems using nanofluids as its working fluids. Researchers are currently focusing on heat transfer enhancement using nanofluids. Limited thermophysical properties and the poor thermal conductivity of conventional fluids (pure water, ethylene-glycols) led the research community in a search for alternatives that could enhance heat transfer. Several researches reported that using nanofluids effectively improved thermal conductivity, and consequently, heat transfer performance. Nanofluids is regarded as a viable heat transfer fluid due to its better stability and an anomalous increase in thermal conductivity even at small volume fraction of suspended nanoparticles. Despite thermal conductivity being directly related to heat transfer capabilities of fluids, viscosity governs the ease of flow, pressure drop, and consequently pumping power during transport. The advantages of using nanofluids include (i) higher thermal conductivities compared to that predicted by currently available macroscopic models, (ii) excellent stability, and (iii) negligible penalty in pumping power due to pressure drop and pipe wall abrasion. Preparing nanofluids is an important step towards using nanoparticles to improve the thermal conductivity of conventional heat transfer fluids. Researchers have experimented with different types of nanoparticles, such as metallic particles (Cu, Al, Fe, Au, and Ag), non-metallic particles (Al_2O_3, CuO, Fe_3O_4, TiO_2, and SiC), and carbon nanotubes. The thermal conductivity of nanofluids varies with size, shape, and the material of the nanoparticles dispersed in the base fluids. For example, nanofluids containing metallic nanoparticles were found to have a higher thermal conductivity compared to nanofluids containing non-metallic (oxide) nanoparticles. The particle size is inversely correlated with the thermal conductivities of nanofluids. Furthermore, nanofluids containing spherical nanoparticles exhibit a smaller increase in thermal conductivity compared ro nanofluids containing cylindrical (nano-rod or tube) nanoparticles. Barrau et al. (2014) experimentally analyzed the effect of hybrid jet impingement/micro channel cooling device on the performance of densely packed concentrated photovoltaic (CPV) receivers. Jet impingement/micro channel cooling was used in order to keep the photovoltaic cells within their nominal operating temperature range. The experimental results showed that the thermal resistance coefficient and temperature uniformity provided by the cooling device met the requirements for the CPV receivers. Barrau et al. (2010) experimentally tested a new hybrid cooling scheme for high heat flux management and power devices. The benefits of micro-channel and jet impingement cooling technologies were analyzed in the context of improving the temperature uniformity of the cooled object. The experimental results showed a global decrease of the temperature of the heat sink in the direction of the fluid flow. Barrau et al. (2012) analyzed the performance of a new hybrid jet impingement/micro-channel cooling scheme for densely packed PV cells at high concentrations. The hybrid cooling scheme offers a minimum thermal resistance coefficient of 2.18×10^5 K m^2/W, with a pressure drop being lower in the micro-channel devices. The results showed that the net PV output of PV receiver was higher when cooled by the hybrid design compared to when cooled by the micro-channels. Rosell et al. (2011) numerically investigated a new hybrid jet impingement/micro-channel cooling scheme for utilization in a high heat-flux thermal management of electronic and power devices. The device was developed to improve the uniformity of the temperature of the cooled object. The results showed that pressure loss increased faster than the average heat exchange coefficient alongside the Reynolds number, while the average heat transfer coefficient and pressure loss increase alongside the dimensionless density of the channels. Royne and Dey (2007) experimentally analyzed the effect of a cooling device based on jet impingement for cooling densely packed photovoltaic cells at high concentrations. The device consists of an array of jets where the cooling fluid is drained around the sides normal to the surface. The results showed that the inherently non-uniform heat transfer distribution of jet arrays has little effect on the expected electrical performance of the PV array. This work investigates the effects of jet impingement using different types of nanofluids (nanoparticles), namely SiO_2, TiO_2, and SiC, with water as the base fluid, on the electrical, thermal, and combined PVT efficiencies. The PVT collector with an array of jet impingement was indoor tested under a solar simulator. The PVT collector was exposed to solar irradiance levels of 500–1000 W/m^2 and water mass flow rates of 0.05–0.17 kg/s. All of the nanoparticles were dispersed in pure water at a 1 wt.% concentration.