Energy Conversion and Management 155 (2018) 324–343

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Experimental investigation of cooling photovoltaic (PV) panels using (TiO_2) nanofluid in water -polyethylene glycol mixture and (Al_2O_3) nanofluid in water- cetyltrimethylammonium bromide mixture

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ARTICLE INFO

Keywords:
Nanofluid (Al_2O_3–water)
Nanofluid (TiO_2–water)
Concentration
Efficiency
Power

ABSTRACT

Cooling of photovoltaic (PV) panels was investigated experimentally outdoors using two nanofluids and water as a cooling medium for volume flow rate ranging from 500 to 5000 mL/min at concentrations (0.01 wt.%, 0.05 wt.%, and 0.1 wt.%) under different radiation intensity. Two types of nanofluids were used, namely Al_2O_3 in water -polyethylene glycol mixture at pH 5.7, and TiO_2 in water- cetyltrimethylammonium bromide mixture at pH 9.7, respectively. The cooling of PV panel required incorporating a heat exchanger of aluminium rectangular cross section at its back surface to accommodate different volume flow rate of the cooling medium aforementioned. The system was tested under climate conditions of Jerash-Jordan. Determination of flow characteristics; friction factor, f and product of friction factor Reynolds number, of TiO_2, Al_2O_3 nanofluids and water as a cooling medium were investigated. Also, a fRe comparison of the temperature between the cooled PV cell and without cooling for volume flow rate ranging from 500 to 5000 mL/min was presented. Results showed that the nanofluid cooled PV cell in both types caused higher decrease in the average PV cell temperature compared with the cooled cell with water and without cooling. In addition, Al_2O_3 nanofluid showed better performance than TiO_2 nanofluid. Furthermore, experimental results showed that higher concentration of nanofluid produces a better cooling effect of the PV cell for all the studied range of volume flow rate. Also, electrical analysis of power and efficiency showed that TiO_2 nanofluid gives better performance for the studied range of volume flow rate and concentrations compared with water cooling and without cooling.

1. Introduction

It is well known that global warming and climate change was caused by greenhouse gas emissions whereby a high percentage of emissions is due to burning fossil fuels. To reduce the environmental impacts of these gases, photovoltaic (PV) technology can be considered an ideal solution. However, one of the main problems which limit the extensive use of PV systems is the rising in temperature of PV panels. Overheating of a PV module decreases performance of output power by 0.4–0.5% per 1°C over its rated temperature (which in most cases is 25 degrees C). This is why the concept of "cooling of PV" has become so important [1,2]. An effective way of improving efficiency and reducing the rate of thermal degradation of a PV module is by reducing the operating temperature of its surface. This can be achieved by either by using conventional method of cooling by water and air with natural or forced convection or by what is called nanofluid which was introduced by **Choi and Estman** [3] in 1995.

Many researchers have proposed various techniques of water cooling to reduce PV surface temperature, and improve the performance of PV systems. Among them is the work done by **Krauter** [4] in which a thin film of water nozzles running over the surface panel was utilized. It was noticed that water decreased cell temperature up to 22°C and electrical yield by 10.3%. **Odeh and Behnia** [5] used water trickling method on the upper surface of the PV panel and obtained an increase of about 15% in system output at peak radiation conditions. **Hosseini et al.** [6] carried out an experimental study to compare the performance of a PV system combined with a cooling system with conventional PV. The results showed that combined system yielded higher power output and efficiency compared to the conventional one. **Royne and Dey** [7] used the technique of jet impingement cooling devices for arrays of densely packed PV cells. Their results showed that using this technique had only a weak effect on the electrical output of the photovoltaic system compared with the effect of changing the

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http://dx.doi.org/10.1016/j.enconman.2017.10.074
Received 25 July 2017; Received in revised form 24 October 2017; Accepted 25 October 2017
Available online 10 November 2017

Nomenclature

Symbols

A	cross section of heat exchanger channel
A_{pv}	photovoltaic cell area
$C_{p,nf}$	specific heat of nanofluid
$C_{p,np}$	specific heat of nanoparticles
$C_{p,bf}$	specific heat of base fluid
D_h	hydraulic diameter of heat exchanger channel
G_t	solar irradiation
H_{ch}	height of heat exchanger channel
I_{SC}	short circuit current
$I_{\max}$	maximum current
$k_{n,eff}$	effective thermal conductivity of nanofluid
k_{bf}	thermal conductivity of basefluid
k_{np}	thermal conductivity of nanoparicles
m_{np}	mass of nanoparticles
P	wetted perimeter
P	power
$P_{\max}$	maximum power
P_{in}	power input of the PV cell
P_{out}	power output of the PV cell
Re	Reynolds number
$\dot{Q}$	fluid flow rate
u_m	mean velocity of flow
V_{np}	volume of nanoparticles
V_T	total volume of mixture
W_{ch}	width of heat exchanger channel

Greek letters

ρ	density
ρ_{nf}	density of nanofluid
ρ_{bf}	density of base fluid
ρ_{np}	density of nanoparticles
μ	dynamic viscosity
μ_{np}	viscosity of nanoparticles
ν	kinematic viscosity
ν_{np}	kinematic viscosity of nanofluid
ϕ	volume fraction of nanoparticles

average temperature of the cells. Hence it was concluded that liquid jet impingement would be a promising method for dissipating heat efficiently from densely packed cells. **Abdolzadeh and Ameri** [8] found out that spraying water over the front of PV cells improved the performance of a PV system, while **Nizetic et al.** [9] reported that better performance could be achieved by spraying water on the front and back surfaces of a PV panel. However, **Bahaidarah et al.** [10] used water cooling on the back surface and front surface to evaluate performance of PV module by using EES software. They found that the EES results for surface cooling; the cell temperature was 35°C whereas 37.8°C for non-cooling. In the contrast, for the back surface cooling; the cell temperature was 25.9°C with cooling whereas 42.8°C for non-cooling. A similar work by **Azadeh** [11] showed that the electrical power output and efficiency increased noticeably by cooling the PV cells with a thin film of water. **Rosa et al.** [12] **and Tina et al.** [13] carried out work to study the behaviour of PV panel submerged in water. Both observed an average increase in the electrical efficiency. **Furushima and Nawata** [14] used a cooling siphonage device for enhancing the performance of a PV power generation system. In the same context, many researchers [15–19] and [20–23] have investigated the effect of water and air based cooling, respectively, on the performance of hybrid photo voltaic thermal units of PV/T systems. From the analysis of the above mentioned articles, it is clear that cooling leads to an improvement in the performance of PV systems.

The thermal conductivity of nanofluids is much improved when compared with usual suspensions. The enhancement of the thermal conductivity of nanofluids over that of the base fluid is often a few times better than what would have been given by micrometer-sized suspensions. **Lee et al.** [24] presented conductivity measurements on fluids that contained Al_2O_3 and CuO nanoparticles in water and ethylene glycol. The results clearly indicated that the thermal conductivity enhancement of the Al_2O_3 and CuO nanofluids were high. They used volume fractions of only 1–5%. The enhancement was higher when ethylene glycol was the base fluid. An enhancement of 20% was observed at 4% volume fraction of CuO. The enhancement when water was the base fluid was lower but still substantial, with 12% enhancement at 3.5% CuO, and 10% enhancement with 4% Al_2O_3. **Wang et al.** [25] also measured the thermal conductivity of CuO–water and Al_2O_3–water nanofluid but their particle size was smaller (23 nm for CuO and 28 nm for Al_2O_3). They also measured the nanofluids with ethylene glycol and engine oil (Pennzoil10W-30) as the base fluids. The measurements showed a clear effect of the particle size and method of dispersion. The measurements showed a clear effect of the particle size and method of dispersion. **Xie et al.** [26] measured the thermal conductivity of aqueous Al_2O_3 nanofluids with even smaller particles (1.2–302 nm). They also observed the effect of particle size in addition to the effect of the base solution. **Murshed et al.** [27], who measured the thermal conductivity of aqueous solutions of spherical and cylindrically shaped TiO_2 nanoparticles, found that 15 nm-sized spherical particles show slightly less enhancement than 10 × 40 nm rods, which showed an enhancement of 33% for a volume fraction of 5%. However, the enhancement was far more than that predicted by the Hamilton-Crosser model. Same researchers [28] developed a combined model for the effective thermal conductivity. **Wang et al.** [29] proposed a fractal model predicts well the trend for variation of the effective thermal conductivity with dilute suspension of nanoparticles, and fits successfully with our experimental data for 50 nm CuO particles suspension in deionized water when/ < 0:5%. The calculated result also shows that the predictive calculation of effective thermal conductivity is complicated. Further work would be needed, especially for metallic nanoparticles inclusion. Similar results were obtained by other researchers [30–32].

Many researchers carried out different reviews on nanofluids characteristics, heat transfer and properties. **Zhou et al.** [33] presented a review on development of nanofluid preparation and characterization. **Lee et al.** [34] carried out a review of thermal conductivity data, mechanics and models for nanofluids while **Ghamdi et al.** [35] was related to of nanofluid stability properties and characterization in stationary conditions. On the same context **Fan and Wang** [36] presented a review of heat conduction in nanofluids while **Vajjha and Dass** [37] work was a review and analysis on influence of temperature and concentration of nanofluids on thermophysical properties, heat transfer and pumping power. Reviews of thermophysical characteristics of nanofluids and heat transfer were carried out by [38–40].

The influence of nanofluid on different solar thermal applications was investigated by many researchers. One of these applications is the solar collector whereby several papers were found in the literature. Among these is the work carried out by **Luo et al.** [41] in which they prepared nanofluids by dispersing and oscillating TiO_2, Al_2O_3, Ag, Cu, SiO2, graphite nanoparticles, and carbon nanotubes into Texatherm oil to study the performance of a DAC solar collector. Their results showed that the use of nanofluid in solar collector can improve the outlet temperature and efficiency. **Rahman et al.** [42] performed a numerical study for a triangular shape solar collector with nanofluids TiO_2, Al_2O_3