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Using high-frequency ultrasound waves and nanofluid for increasing the efficiency and cooling performance of a PV module

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A R T I C L E I N F O

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A B S T R A C T

In this paper, the potential of using high frequency ultrasound for improving cooling performance of a PV module has been investigated experimentally. Atomized CuO nanofluid (0.01–0.8 (w/v)) as well as atomized pure water have been used as coolant fluids. The various parameters such as module surface temperature, maximum power increase and cooling efficiency of PV module using atomized nanofluid have been compared with those of pure water. It has been observed that atomizing the working fluid by ultrasound energy significantly enhance the cooling performance of the studied PV module. Results depict that cooling by atomized nanofluid was more efficient than cooling by atomized pure water. In addition, increasing the nanofluid concentration has positive effect on the cooling efficiency and maximum generated power of PV module. Results show that by atomizing 0.8 (w/v) nanofluid, module average surface temperature decreased up to 57.25% and increase in maximum power reached to 51.1% than the layout with no cooling system.

1. Introduction

In recent years, due to environmental concern more research focus on diversify away from non-renewable energy sources and develop renewable energy technologies [1,2]. Solar energy is a clean and inexhaustible renewable energy resource with zero waste generation and no carbon dioxide emissions [3]. Photovoltaic (PV) technology is one of the common methods of direct converting the solar radiation into electricity [4,5]. Only around 15–20% of the incident solar radiation that absorb by the PV module can be converted into electricity and the rest is dissipated as heat [6]. When the ambient temperature during the exposing PV cell in the front of sunlight is high, the surface temperature of PV module increased, which results in decreasing the electrical efficiency [7,8]. Therefore, it is necessary to find efficient cooling methods to achieve higher heat dissipation rates from PV modules. Many innovative active and passive techniques had been used to enhance the cooling performance of PV modules. In active cooling techniques, use of an external driving force is required for the cooling process such as using water spraying [9] and hybrid jet impingement [10], which both methods need a driver to flow the water. Active cooling techniques have high efficiency and result in high generated power and accessible thermal energy. Passive cooling methods divided into three main groups including air passive cooling, water passive cooling and conductive cooling. A special type of passive conductive cooling in PV modules is using a phase change material (PCM), which it had been considered by many authors [11–16]. Sargunanathan et al. [17] performed a comprehensive review of the effective cooling methods of PV modules. Several of these important effective techniques for PV cooling are illustrated in Table 1. Recently, using nanofluids owing to the significant heat transfer characteristics for the cooling performance enhancement of PV modules has been gains more attention [30–36]. Karami et al. [24] used the water-based nanofluid containing nanoparticles of Boehmite to enhance the cooling performance of a PV module. Their results show that using nanofluid as working fluid results in higher decrease in the average PV module temperature and have positive effect on cooling performance. In another work conducted by Karami et al. [26], the cooling performance of water-based Boehmite nanofluid in a hybrid photovoltaic (PV) module was evaluated. Cooling performances of water and three different concentrations of nanofluid were compared. Their results show significant enhancement in the electrical efficiency about 27% for 0.01 wt% concentration of the nanofluid. In addition, the influence of using nanofluid in a water-cooled PVT system numerically was elucidated by Khanjari et al. [35] and higher electrical efficiency and cooling performance were reported for using nanofluid rather than pure water. Sardarabadi et al. [30] used silica/water nanofluid as a coolant to enhance the performance of a PV/T and reported that the thermal efficiency was increased by adding silica nanoparticles to the working fluid. Hussien

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Nomenclature

I	average intensity on absorber plate (W/m^2)
I_{PV}	photovoltaic arrays current (A)
P_{max}	maximum power of photovoltaic arrays (W)
$P_{nanofluid}$	power of photovoltaic arrays by cooling with nanofluid (W)
P_{PV}	photovoltaic arrays power (W)
P_{Udiss}	dissipated power of ultrasound (W)
$P_{withoutcooling}$	reference power (W)
Q	vapor flow rate (m^3/h)
$T_{nanofluid}$	temperature of photovoltaic arrays by using nanofluid as working fluid (°C)
$T_{pure\ water}$	temperature of photovoltaic arrays by using water as working fluid (°C)
V_{PV}	photovoltaic arrays voltage (v)

Subscripts

max	maximum

Abbreviations

PV	photovoltaic

et al. [31] showed the improvement of the electrical and the thermal efficiency of a Hybrid Photovoltaic/Thermal system (PV/T) by using nanofluids. Similar works were performed by Sardarabadi et al. [32] and Al-Waeli et al. [36] to enhance the electrical and thermal efficiency of hybrid Photovoltaic/Thermal system (PV/T) with nanofluids as working fluids. In the mentioned studies, better electrical efficiencies were reported compared with that of pure deionized water. Simultaneous application of a nanofluid and a PCM as coolant mediums in a photovoltaic thermal system (PVT) were investigated by Sardarabadi et al. [37] and Al-Waeli [38] and increase in the thermal efficiency were seen compared with that of a conventional PV module.

Using the energy of ultrasound waves is a proper technique to enhance the rate of various heat transfer processes such as phase change [39], boiling [40,41], and convection [42,43]. In addition, previous literatures [44] showed increase in the cooling efficiency by application of ultrasound waves. Propagation of ultrasound into liquid medium generates tiny bubbles, as well as disintegrates larger bubbles into smaller ones [45]. Micro-streaming and cavitation are the major physical effects of the ultrasound propagation in a liquid, which they cause increase in turbulences, micro agitation and fluid motion [46–50].

High frequency ultrasound waves are very effective in cooling enhancement, as these waves take advantages of intensive momentum gradients and fluid currents compared to low frequency ones [50–53]. In the present study, a novel cooling method for a PV module is introduced to reach the highly effective cooling. Simultaneous application of nanofluid and ultrasound energy is investigated as an active cooling method for a PV module. Based on our previous experiences [54,55], the used and the dissipated powers of high frequency ultrasound waves are low. The main innovativeness in the present study is using of atomized CuO nanofluid by high frequency ultrasound. Therefore, in the present work, high frequency ultrasound waves are used to produce atomized fluid called cold vapor as cooling working fluid. The measured results for surface temperature, maximum power enhancement and electrical efficiency of PV module have been reported. The layout of using pure deionized water is selected as a reference for comparison with layout of using nanofluid.

Table 1
Summarized list of different applied cooling methods for enhancing PV module efficiency.

Ref.	Type of cooling method	Cooling system	Output
[18]	Passive cooling	Hybrid PV/TE system integrating heat sink	More effective structure attained through combining a heat sink with a TE module.
[19]	Passive cooling	Hybrid micro-channel solar cell/module	The average values of electrical and thermal efficiency of glazed hybrid MCPVT module are 14.7% and 10.8% respectively.
[10]	Active cooling	Jet impingement	1. The hybrid jet impingement/micro-channel cooling system show better performance rather than microchannel devices. 2. The hybrid heat sink provides a higher temperature uniformity of the PV receiver.
[20]	Passive cooling	Using nanofluid	The PVT/ZnO and PVT/TiO_2 systems show a better overall energy and exergy efficiencies compared to PVT/pure water and PVT/Al_2O_3 systems.
[21]	Passive cooling	Using PCM	PV-PCM panel show lower surface temperature and higher increase of energy generation efficiency compared to the conventional PV panel.
[22]	Passive cooling	Direct liquid-immersion cooling	The presence of a thin liquid layer leads to an increase in the silicon CPV solar cells efficiency by 8.5–15.2% from the reference value.
[23]	Active cooling	Water spraying	The proposed water spray cooling technique showed got a favorable effect on panel performance.
[24]	Passive cooling	Using nanofluid	The presence of nanoparticles showed a remarkable effect on decreasing the average temperature of the PV cell compared with that of pure water.
[25]	Passive cooling	Natural circulation of water in a flat-box absorber	The energy saving efficiency was found above that of the conventional system.
[26]	Passive cooling	Using hybrid microchannel with nanofluid	1. The results show that the helical channel works in a more efficient way compared with the straight one. 2. Nanofluid has the better performance for decreasing the average temperature of the PV cell compared with that of pure water.
[27]	Active cooling	Using ferrofluid and magnetic field	By applying alternating magnetic field on 3 wt% ferrofluid, the overall efficiency of the system improved about 45%.
[28]	Passive cooling	Using microchannel heat sink with nanofluid	The use of nanofluid show higher solar cell electrical efficiency.
[29]	Active cooling	Jet array nanofluids impingement	The PV module with jet impingement cooling system and SiC nanofluid show the highest electrical efficiency.