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Performance of nanofluid-based photovoltaic/thermal systems: A review

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ABSTRACT

Recently, applying nanofluids in PV/T systems for improving the performance of these systems has been fascinating many researchers. In this kind of research, nanofluids are employed in the PV/T systems as coolant or optical filter. To emphasis the capability of the nanofluids in PV/T systems, the present study aims first, to comprehensively review the features, structures, and the outcomes of PV/T system that applied nanofluids and investigated the effectiveness of nanofluids, and second, to comprehensively analyze the effective parameters on the performance of a nanofluid-based flat plate photovoltaic/thermal system in both laminar and turbulent regime. In this study, with respect to literature, a vast attempt has been done to study the effects of nanofluids parameters including volume fraction (0–4%), size (21 nm and 100 nm) and type of nanoparticles (TiO_2 and Al_2O_3), as well as type of base fluid (water and mixture of ethylene glycol-water). The accuracy of proposed mathematical model was demonstrated through the comparison of predicted results and the available data in the literature. It can be concluded from the results that, to improve the performance of the system, adding nanoparticles is more efficient in laminar regime compared to turbulent one. The results also indicated that using nanoparticles of larger diameter leads to greater total energy and exergy efficiency in the turbulent regime, while contrary behavior is observed in laminar flow. Moreover, it was observed that employing aluminum oxide in nanofluids improves the system performance more than titanium oxide, where water based nanofluids show higher energy and exergy efficiency compared to ethylene glycol-water based nanofluids.

1. Introduction

Nanofluid is defined as a dispersion of nanometer-sized solid particles (lower than 100 nm at least in one dimension) into fluids like water, ethylene glycol and oil. For the first time, Masuda [1] in 1993, introduced the concept of suspending nanoparticles into common heat transfer fluids and Choi [2] in 1995, applied the word “nanofluid” for this kind of colloidal suspensions. Afterward, performing many experimental and theoretical studies, it was found that generally, the nanofluids possess greater heat transfer characteristics compared to the common fluids [3,4]. For example, addition of 0.3% volume fraction of copper nanoparticles into ethylene glycol increased thermal conductivity by 40% [5], or suspending aluminum oxide nanoparticle in water with the volume fraction of 6.8% enhanced heat transfer coefficient of turbulent flow about 40% [6]. Besides, proposing the relations for thermophysical and heat transfer properties of nanofluids has been the subject of numerous studies that some of them are listed in Table 1.

Recently, due to the significant heat transfer characteristics of nanofluids, several work has been carried out on the application of this novel medium of heat transfer in the solar energy systems, especially solar collectors [7]. Javadi et al. [8] presented an overview of studies in the performance of the solar collectors and concluded that using nanofluid instead of conventional fluid improves heat transfer as well as thermal properties, efficiency, transmittance and extinction coefficient of solar collectors. There are some reports on other applications of nanofluids in solar energy systems such as thermal storage energy systems [9], solar cells [10] and solar distillers [11].

One of the inventive applications of nanofluids in solar energy equipment is in photovoltaic/thermal (PV/T) systems which incorporate photovoltaic module and heat extraction component in a single unit to produce heat and electricity, simultaneously.

A survey of literature data shows that various configurations of PV/T systems, which use air or water as coolant fluid have been investigated. Among them, Shahsavar and Ameri [35] conducted a theoretical and experimental study on a glazed and unglazed direct-coupled PV/T system cooled through the natural and forced air convective heat transfer. Their results indicated that glazing system

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Nomenclature

A	area (m^2)
A_c	collector area (m^2)
c_b	thermal conductance of bond (W m^{-1} K^{-1})
C_p	specific heat capacity (J kg^{-1} K^{-1})
D	diameter (m)
D_i	inner diameter (m)
D_o	outer diameter (m)
$\dot{E}_{pv}$	PV output power (W)
f	friction coefficient
g	gravitational acceleration (m s^{-2})
h_c	convection heat transfer coefficient (W m^{-2} K^{-1})
h_r	radiation heat transfer coefficient (W m^{-2} K^{-1})
h_l	head loss
I	solar radiation intensity (W m^{-2})
k	Thermal conductivity (W m^{-1} K^{-1})
K	Minor loss coefficient
L	length (m)
$\dot{m}$	Mass flow rate (kg s^{-1})
n	number of pipes
Nu	Nusselt number
pa	packing factor
P	pressure (Pa)
P_{pump}	pump power (W)
PV	photovoltaic
PV/T	photovoltaic/thermal
CPV/T	concentrating photovoltaic/thermal
Pr	Prandtl number
Ra	Rayleigh number
Re	Reynolds number
T	temperature (K)
T_{max}	Maximum cell temperature (K)
T_s	sky temperature (K)
T_{sun}	sun temperature, 6000 K
v_w	wind speed (m s^{-1})
w	width (m)
$\dot{X}$	exergy rate (W)

Greek letters

α	absorption coefficient
β_r	reference temperature coefficient
δ	thickness (m)
ΔP	pressure head loss (Pa)
ε	emission coefficient
$\dot{\varepsilon}$	exergy efficiency
ρ	reflection coefficient, density (kg m^{-3})
η	efficiency
η_r	reference solar cell efficiency
κ	Boltzmann constant, 1.381×10^{-23} (J K^{-1})
μ	viscosity (Pa s)
σ	Stefan Boltzmann constant (W m^{-2} K^{-4})
τ	transmission coefficient
φ	collector slope, volume fraction

Subscripts

a	air layer
abs	thermal absorber
ad	adhesive
b	tube bonding
ele	electrical
bf	basefluid
g	glass cover
i	insulation
in	input
nf	nanofluid
np	nanoparticle
out	output
s	sky
t	tube
th	thermal
w	working fluid

leads to an increase in thermal efficiency and a decrease in electrical efficiency. Ameri et al. [36] performed tests on an air-based PV/T system with the action of natural and forced convection mechanism. They concluded that, installing glass cover, air flow rate increases in natural convection mode, while it decreases in forced convection. Gholampour et al. [37] investigated the performance of photovoltaic/thermal unglazed transpired solar collectors (PV/UTCs) both experimentally and theoretically. Their results showed that the amount of photovoltaic cooling in this system depends on the amount of air mass flow rate passed through the transpired plate. Kalogirou and Tripanagnostopoulos [38] experimentally and theoretically studied two thermosyphon PV/T systems, one with polycrystalline-silicon (pc-Si) and the other with amorphous silicon (a-Si) PV module. Their results pointed out that system with pc-Si solar cells gives higher electrical efficiency and lower thermal efficiency compared to a system with a-Si solar cells. Huang et al. [39] investigated the performance of a water-based PV/T system experimentally and introduced the concept of primary energy saving efficiency. They demonstrated that the primary energy saving efficiency of the PV/T system is greater than that of the single solar water heater or PV module. Sobhnamayan et al. [40] employed Genetic algorithm (GA) to find an optimum water inlet velocity and pipe diameter of a water-based PV/T system.

Although, there is a considerable amount of work reported in the literature on PV/T systems, investigating the ability of nanofluids in PV/T systems is in primary stages. Performing a review on solar energy applications of nanofluids, Mahian et al. [41] concluded that nanofluids have a reasonable capacity to employ in PV/T collectors.

To date, several review papers have separately investigated PV/T systems or applying nanofluids in solar energy technologies. Kasaeian et al. [42] considered using nanofluid in solar systems; Verma and Tiwari [43] and Al-Shamani et al. [44] studied nanofluids in solar collectors; Hasanuzzaman et al. [45] and Shukla et al. [46] investigated progresses in cooling PV technologies; Hussien et al. [47] reported cooling technologies based on using nanofluid in mini/microchannels, and Elbreki et al. [48] reviewed effective parameters in PV/T systems. To the best knowledge of the present authors, there is no review paper which especially investigates employing nanofluids in PV/T systems, and all mentioned papers just presented few reports in this field. On the other hand, reviewing the literature indicates that, relatively little information is available on the influence of effective nanofluid parameters on energy and exergy efficiency of PV/T systems.

Hence, the main contribution of the present review paper is of two-fold. In the first fold, a vast attempt has been done to provide a comprehensive and up-to-date review of configuration, effectiveness and advancement of nanofluid-based PV/T systems. In the second fold, the important parameters that affect the system operation have been examined in details, though proposing a mathematical model for a nanofluid-based PV/T system. Also, several correlations were proposed for thermophysical properties and heat transfer characteristics of some nanofluids, based on available data.