Energy Conversion and Management 148 (2017) 1265–1277

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Performance of a parabolic trough concentrating photovoltaic/thermal system: Effects of flow regime, design parameters, and using nanofluids

Farideh Yazdanifard [a], Ehsan Ebrahimnia-Bajestan [b,*], Mehran Ameri [a]

[a] Department of Mechanical Engineering, Shahid Bahonar University, Kerman, Iran
[b] Department of Mechanical Engineering, Quchan University of Advanced Technology, Quchan, Iran

ARTICLE INFO

Article history:
Received 11 January 2017
Received in revised form 26 May 2017
Accepted 26 June 2017

Keywords:
Concentrating photovoltaic/thermal (CPV/T) system
Nanofluid
Laminar regime
Turbulent regime
Energy
Exergy

ABSTRACT

The aim of this study is to simulate a parabolic trough concentrating photovoltaic/thermal (CPV/T) system and to investigate its performance from energy and exergy viewpoints in both laminar and turbulent flow regimes. After validating the proposed model with available experimental data from the literature, the effects of various parameters, including concentration ratio, pipe length, and diameter, on the performance of the system were examined in detail. Further, the effects of glazing the system and using nanofluids as the working fluid on the system efficiency were determined and discussed. The performance of the CPV/T system was also compared to that of a flat-plate photovoltaic/thermal (PV/T) system. The results showed that increasing the pipe length from 0.5 to 5 m decreases the total energy efficiency by about 9.33% in the laminar regime and 1.09% in the turbulent regime, while it increases the total exergy efficiency by about 33.65% and 10.37% in the laminar and turbulent regime, respectively. The increment of the pipe diameter has a negligible impact on the system performance, for a given flow rate. The results also indicated that applying nanofluids in the laminar flow is more effective compared to the case of the turbulent regime. Furthermore, the PV/T system can reach greater energy and exergy efficiency compared to the CPV/T system, whereas employing nanofluid in the CPV/T system is more efficient compared to the case of the PV/T system.

1. Introduction

Reduction of fossil fuel sources, as well as their greenhouse gas emissions, reflects the importance of using alternative energy resources, such as renewable energies, that are clean, affordable, and accessible [1]. It must be noted that renewable energy sources cannot meet all the energy demand owing to their instability and the complex process of integrating them with energy systems, but they can decrease some of the fossil fuel consumption.

The sun is the most important renewable energy source, with its endless supply of high-energy rays to the earth. Photovoltaic/thermal (PV/T) systems are a category of solar technologies that simultaneously generate electrical energy and heat. Increasing the PV cell temperature reduces the electrical efficiency, and therefore, solar cells in PV/T systems are cooled through flowing of heat transfer fluids (HTFs), and the harvested heat can be used. Various configurations of PV/T systems have been proposed in the literature [2].

On the other hand, concerns about the environmental hazards of photovoltaic technology have recently emerged. Manufacturing of PV panels requires the use of chemicals, and there is a possibility that toxic substances from manufacturing plants may leak into the environment in the event of non-compliance with safety rules, as was the case in a village in the central province of Henan [3]. Another concern involves the recycling of PV panels after the end of their life cycle. These risks may be reduced if the energy demand can be achieved by solar technologies using fewer photovoltaic cells.

One solution is using concentrating photovoltaic/thermal (CPV/T) systems that could yield a greater ratio of electricity to PV area. The focusing of sunlight by using concentrators leads to high-temperature thermal energy and expands its utilization for domestic hot water (DHW), heating and cooling spaces, and process heat of industries [4,5]. CPV/T systems work considerably better in the presence of higher beam radiation, and are therefore appropriate for tropical and subtropical zones.

The use of Fresnel lenses [6], parabolic [7], compound parabolic [8], and hyperboloid [9] concentrators for focusing radiation on the

* Corresponding author.
E-mail addresses: fyazdanifard@yahoo.com (F. Yazdanifard), e.ebrahimnia@qiet.ac.ir, ehsan.ebrahimnia@gmail.com (E. Ebrahimnia-Bajestan), ameri_mm@uk.ac.ir (M. Ameri).

http://dx.doi.org/10.1016/j.enconman.2017.06.075
0196-8904/

Nomenclature

A	area (m^2)
CR	concentration ratio
c_b	thermal conductance of bond ($W\ m^{-1}\ K^{-1}$)
C_p	specific heat capacity ($J\ kg^{-1}\ K^{-1}$)
D	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 ($W\ m^{-2}$)
I_B	beam radiation intensity ($W\ m^{-2}$)
k	thermal conductivity ($W\ m^{-1}\ K^{-1}$)
L	length (m)
$\dot{m}$	mass flow rate ($kg\ s^{-1}$)
Nu	Nusselt number
pa	packing factor
P	pressure (Pa)
P_{pump}	pump power (W)
Pr	Prandtl number
ΔP	pressure head loss (Pa)
Ra	Rayleigh number
Re	Reynolds number
T	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
γ_t	intercept factor
δ	thickness (m)
ε	emission coefficient
$\dot{\varepsilon}$	exergy efficiency
θ	collector slope
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	volume fraction

Subscripts

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

PV/T system has been studied. Among them, parabolic concentrators are the most well-known owing to their ease of installation and low price. Parabolic concentrators concentrate sunlight onto receivers positioned at the focal point or the focal line of the parabola.

A substantial amount of effort has been done to determine the effective parameters in CPV/T systems. Li et al. [10] carried out experimental and numerical studies on the parabolic trough CPV/T system with various PV cells and concentration ratios. Their results revealed that GaAs cells exhibit the best performance under focused radiation. Ji et al. [11] concluded that increasing the concentrator reflectance of a parabolic trough CPV/T system improves the performance of the system. Chaabane et al. [12] compared two linear parabolic trough CPV and CPV/T systems. Their results showed that, in addition to its thermal output, the CPV/T system has higher electrical efficiency compared to the CPV system. Coventry [13] reported thermal and electrical efficiency values of 57% and 11%, respectively, for a parabolic trough CPV/T system with a concentration ratio of 37.

Karathanassis et al. [7] experimentally studied a parabolic trough CPV/T system with three receiver configurations, incorporating different PV cells and cooling section designs. Their results showed that wide PV cells achieve higher electrical efficiency, and heat sinks with microchannels of stepwise-varying width are promising owing to the significantly lower pump power requirement. Widyolar et al. [14] designed and tested a new CPV/T configuration that includes a parabolic trough reflector for focusing sunlight towards a compound parabolic concentrator formed of GaAs solar cells. Their experimental system achieved 37% thermal efficiency and 8% electrical efficiency.

Ju et al. [15] comprehensively reviewed a CPV/T system using spectral beam splitting (SBS) technologies. They found that employing SBS technologies in CPV/T systems can increase the outlet temperature without reducing the electrical output. Otanicar et al. [16] theoretically compared two thermally coupled and thermally uncoupled (using SBS) configurations. Their research showed that both configurations are promising from an exergy viewpoint.

In recent years, the use of nanofluids (a colloidal suspension of nanoparticles into fluids) in solar energy systems has received considerable attention. Verma and Tiwari [17] reviewed nanofluid application in different types of solar technologies, especially solar collectors. However, relatively little information is available on using nanofluids in PV/T systems, especially in CPV/T systems. Sardarabadi et al. [18] experimentally studied a PV/T system with a silica/water nanofluid as its coolant and concluded that the nanofluid significantly enhances the energy and exergy efficiency of the PV/T system. Sardarabadi and Passandideh-Fard [19] employed ZnO, TiO_2, and Al_2O_3 water-based nanofluids in a sheet and tube PV/T system. Their results indicated that TiO_2/water results in higher electrical efficiency and ZnO/water leads to greater thermal efficiency.