Applied Thermal Engineering 115 (2017) 178–187

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Research Paper

Evaluating the environmental parameters affecting the performance of photovoltaic thermal system using nanofluid

Y. Khanjari, A.B. Kasaeian *, F. Pourfayaz

Department of Renewable Energies, Faculty of New Sciences & Technologies, University of Tehran, Tehran, Iran

HIGHLIGHTS

- Using nanofluid in photovoltaic thermal system is studied theoretically.
- The examined factors consist of inlet fluid temperature and absorbed solar radiation.
- The efficiency, heat transfer coefficient and temperature in different sections are investigated.
- Al_2O_3-water nanofluid has better performance than pure water.

ARTICLE INFO

Article history:
Received 27 September 2016
Revised 19 November 2016
Accepted 20 December 2016
Available online 28 December 2016

Keywords:
PV/T
Al_2O_3-water nanofluid
CFD
Solar radiation

ABSTRACT

PV/T is a hybrid system which combines photovoltaic cells and solar collector. It can produce renewable electricity and heat, simultaneously. The aim of the present work is to study the effects of two environmental parameters on the performance of system. Also, the performance of pure water and Al_2O_3-water nanofluid are compared. The conduction and convection heat transfer are considered by CFD method. The mass, momentum, and energy equations are solved using the ANSYS Fluent. The second order upwind is selected as an interpolation scheme and the pressure-based solver is used for this laminar model. The pressure-velocity coupling method is the SIMPLE. Also, the gradients of the solution variables are determined by the least square cell based. The effects of solar radiation and fluid inlet temperature on the performance are modeled. Increasing the solar radiation reduces electrical efficiency; then, the thermal efficiency becomes fixed after a first rise. Nevertheless, the thermal efficiency remains fixed; the electrical efficiency decreases with increasing the fluid inlet temperature. The findings indicate that the heat transfer coefficient and the efficiency of Al_2O_3-water nanofluid are greater than pure water. The numerical model is validated by comparing the simulation results with the experimental data in the literature.

1. Introduction

Energy consumption has a significant effect on the human interactions with the surrounding environment. Whereas, the growth of the world energy demand in recent decades is very large. Solar energy is an available and sustainable choice to meet the energy demand in the future. Moreover, by substituting solar energy, the challenges including finitude of fossil fuels and the environmental pollution related to conventional resources are eliminated. A report of the International Energy Agency suggests that a quarter of the energy usage and supply may be derived from solar power by 2050 [1].

The solar energy can be applied in two different categories: solar thermal systems and photovoltaics. In a solar thermal system, solar energy converts to thermal energy, whereas in a photovoltaic case, electricity is directly produced from solar radiation. In a photovoltaic module, the electrical efficiency of the system decreases as the temperature of the module increases. In fact, a photovoltaic system uses a certain part of solar radiation for electricity production and the remainder is wasted in the form of heat. Therefore, with the circulation of a cold fluid through the system, the waste heat of photovoltaic module can be removed; consequently, higher electrical efficiency may be obtained. The combination of thermal and electrical sections constructs a new hybrid device called “photovoltaic thermal” energy system (PV/T). Using this combination, cogeneration of renewable power and heat is happened in a PV/T. Plus the greater energy performance of the system, the space occupied by a hybrid system is reduced.

* Corresponding author.
E-mail address: akasa@ut.ac.ir (A.B. Kasaeian).

http://dx.doi.org/10.1016/j.applthermaleng.2016.12.104
1359-4311/

Nomenclature

P	packing factor
A	area (m^2)
Cp	specific heat capacity (kJ/kg K)
G	solar radiation intensity (W/m^2)
h	convection heat transfer coefficient (W/m^2 K)
$\dot{m}$	mass flow rate (kg/s)
P	pressure (N/m^2)
PV	photovoltaic
U	fluid velocity (m/s)
T	temperature (K)
wt	weight fraction
Subscript	
f	base fluid
nf	nano fluid
p	nano particle
ref	reference
ave	average
cell	solar cell
i	counter
g	glass cover
atm	atmosphere
est	estimated
obs	observed
x	value (observed or estimated)
n	number of the values
MAPE	mean absolute percentage error
k	conductivity (W/m K)
g	gravity acceleration (N/kg)
d	diameter (m)
Re	Reynolds number
Pr	Prandtl number
Gr	Grashof number
Ra	Rayleigh number
Ri	Richardson number
Greek symbols	
β	temperature coefficient (K^{-1})
μ	viscosity (Pa s)
θ	tilt angle of setup
φ	volume fraction
η	efficiency
ρ	density (kg/m^3)
τ	transmitivity

Many works have been carried out on the research and technological development of PV/T systems [2–6]. Also, some experimental tests for design development, theoretical methods for improving the thermal and electrical performance, and efforts for commercialization of PV/T were done in this area [7–9]. Many experimental and theoretical studies have been carried out regarding photovoltaic thermal collectors. The performance of nine different PV/T systems were considered and compared by Zondag et al. [10]. In Hong Kong, Chow et al. [11] examined two glazed and unglazed PV/T systems, with the construction design of sheet and tube. Their investigations were done based on both first and second law of thermodynamics. The results of energy analysis revealed that the glazed design was always appropriate, whereas the finding of their exergy analysis claimed that the use of unglazed design was more optimized. A thermal model was developed by Siddiqui et al. [12] to consider PV modules with and without cooling section. The effect of the environmental factors such as ambient temperature and absorbed solar radiation on the performance of PV panels were analyzed. Also, the effects of the inlet velocity, inlet temperature, and thermal contact resistance were studied.

A full-scale BIPV/T collector was investigated by Corbin and Zhai [13] to determine the effects of utilizing cooling system on both electrical and thermal efficiency. Computational fluid dynamics (CFD) method was used to simulate the represented system. Additionally, the variations of some factors including cell temperature, outlet temperature, and solar insolation were examined via implementing a parametric analysis. A simulation model was developed by Cerón et al. [14] in which different heat transfer mechanisms were simultaneously taken into account. In this study, the fluid flow pattern, the absorber temperature field and the distribution of heat flux were studied. The heat transfer results were validated against common experimental correlations available in the literature, and the Nusselt number for water fluid inside the tubes was derived. Perino et al. [15] installed experimental PV/T prototypes, and represented a simulation model for the mentioned PV/T systems in the TRNSYS, for both steady-state and transient conditions. The energetic and exergetic performance of PV/T system was evaluated. A reference efficiency of 72.8% and electrical efficiency of 10.5% were obtained using the mentioned PV/T system.

Spertino et al. [16] investigated a mono-crystalline PV module to examine the effect of using water-cooling on the performance. Also, a theoretical model considering both thermal and electrical was represented. Using a low weight plastic-laminated sandwich, instead of glass, was tested. The results indicated that working fluid must be utilized according to the location and the season of the year.

Tse et al. [17] evaluated the advantages of using water PV/T system in the office scale building. This system supported the electricity and hot water demand by a computer program. An economic analysis was also carried out to consider the time value of money. Study of a bi-fluid PV/T system was implemented by Jarimi et al. [18], and the two-dimensional steady-state model was performed using MATLAB. The tests were conducted in steady-state conditions under a solar simulator at the Solar Energy Research Lab UiTM Perlis, Malaysia. Three fluid modes of air, water, and combination of air-water were operated in the tests.

Many experimental and numerical investigations have been done in the literature to improve the performance of the conventional coolants such as water or air used in PV/T systems. Using nanofluids as a coolant in PV/T systems has not been completely developed. The heat transfer performance can be enhanced by improving the thermo-physical properties, and dispersing nanoparticles lead to the increase in thermal conductivity [19]. Thus, utilizing nanofluid, instead of conventional fluids such as water, can be an advantageous option. It shall be noted that many original types of research have been implemented on the influence of using nanofluid in solar systems [20–27]. However, a few number of theoretical studies focused on using nanofluids in PV/T systems, among which we can point to some relevant references such as [28,29]. Sardarabadi et al. [28] investigated the effect of using SiO_2 nanoparticles in a PV/T system experimentally. The electrical and thermal efficiencies were considered based on the first and second laws of thermodynamics. The results indicated that the thermal energy efficiency of using 1 wt% and 3 wt% nanofluids were increased by 7.6% and