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Modeling and detailed study of hybrid photovoltaic thermal (PV/T) solar collector

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ABSTRACT

A vast evolution to renewable energy resources such as solar energy is the best option for alleviating poverty in developing countries where the majority of people do not have access to modern forms of energy. Renewable energy resources, due to their inherent decentralized nature can largely contribute to resolve the energetic problems. Among these techniques and technologies for the exploitation of this solar energy, the Photovoltaic conversion is known to produce electricity; and thermal collectors that provide heating energies.

The two systems are independent and different, but there are not compatible, that can be completed using a hybrid design that allows using both techniques, thermal and electrical, in the process called (PV/T). The hybrid solar photovoltaic thermal (PV/T) offers an interesting option now because the absorbed solar radiation is converted into electric energy and heat (the conversion can be done simultaneously or separately).

In this paper, the mathematical model is presented; the studied system consists of a photovoltaic panel for the production of electricity, with a thermal system for water heating. It is constituted by a sheet and tube placed below the surface on which the solar cells are assembled to extract heat from the photovoltaic module, in order to cool the cells and to increasing their electric efficiency. This phenomenon is due to the unobserved part by cells. This model is based on the equations of the energy balances written for the various nodes of the system, and the coupled differential equations obtained are solved by using the finite difference method. The temperatures of the various layers of solar PV/T Collector and the coolant temperature are predicted. The objective of this work is to study theoretically and experimentally the hybrid (PV/T) Collector. The fluid flow and heat transfer in the module are studied using the ANSYS14 Software. The heat transfer phenomenon conjugate between the photovoltaic cells and the coolant is modeled using the FLUENT Software. The transfer of heat by the solar radiation is not modeled; however, the effects of radiation are taken into consideration when calculating the conditions for heat flux limit for the Collector layers. The geometric model and fluid domain for the CFD analysis is generated using ANSYS software Design Modeler, mesh geometry is carried out by ANSYS Meshing Software.

1. Introduction

Electricity and heat are the most important energy needs in the residential sector and the public and commercial services. Most of this energy is generated carriers from the center of conventional energy like coal and natural gas.

The combination of photovoltaic systems and solar thermal (PV/T, see figure) producing both electricity and heat simultaneously.

In doing so, PV/T allow high yields of energy per square meter and therefore more efficient use of the available space on the roof. Furthermore, the thermal sensor now actively cooled solar photovoltaic cells, results in an increase in electrical performance of the system. In addition, the PV/T systems provide a uniform appearance of the roof and require less installation costs, compared to the two individual systems installed. PV/T system has been studied extensively for the past three decades, yet very few commercial systems available on the market today (Zondag, 2008). However, there are still many uncertainties given the design of the PV/T

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Nomenclature

A	area	S	section of tube
C	specific heat	T	temperature
f	fluid	T_{Amb}	ambient temperature
FR	factor extraction of heat from the collector	T_{sky}	temperature of sky
G	global irradiance	T_v	temperature of glass
h_{cond}	exchange coefficient by conduction	T_{Cel}	temperature of cell
h_{conv}	exchange coefficient by convection	T_{Ted}	temperature of Tedlar
h_{rad}	exchange coefficient by radiation	T_p	temperature of plat absorber
$h_{condv\text{-}PV}$	exchange coefficient by conduction between glass and cell	T_{tub}	temperature of tube
$h_{condPV\text{-}Ted}$	exchange coefficient by conduction between cell and Tedlar	T_f	temperature of fluid
$h_{condTed\text{-}p}$	exchange coefficient by conduction between Tedlar and absorber plat	T_{iso}	temperature of insulation
l	length of tube	T_{out}	output temperature of the fluid
$\dot{m}$	mass flow rate	T_{in}	input temperature of the fluid
PV/T	photovoltaic thermal	U_L	loss ratio
Q_{in}	incident energy from the sun	λ	thermal conductivity
Q_{inab}	transmitted to the plate of the absorber	ε	emissivity
Q_{ele}	electric energy	$\tau\alpha$	absorptivity–transmitivity factor
		τ	transitivity
		α_{cel}	absorptivity coefficient of the solar cell
		η	efficiency

system. For example, what is the most optimal design, which has a better heat extraction means, other design features and what would be the annual yield of such a PV/T?

These issues have not yet been experimentally verified in a complete energy system based on a hybrid photovoltaic thermal solar Collector, used for charge power or real application. Obtaining this information (thermal and electrical performance of the system, the values of annual electricity and heat generation, changes in temperatures at deferent layers of the Collector) is essential for developing or improving a PV/T energy system optimal and get an idea of the actual annual yields applications.

From a social point of view, the PV/T system results could provide low-cost electricity and decentralized renewable heat.

This study combines information available in the scientific literature, expert knowledge, good simulations and experimental data to obtain a comprehensive overview of research questions. An overview of the principles of PV/T system and its development thereafter, models, calculations and data for the numerical simulation are explained, the results of numerical simulations and experiment are summarized and compared with other configurations of PV/T that they already existed.

Most residential water heating systems is equipped with conventional water heaters that use fossil fuels or electricity to produce heat and therefore have a negative impact on the environment and provide energy-conversion efficiency, these parameters led us to say that solar energy are currently considered the most sustainable resource among different alternatives to renewable energy with the increasing environmental awareness. Hybrid solar photovoltaic/thermal (PV/T) that simultaneously produces/produced electricity and heat are currently considered the most effective devices for solar energy available to well-defined systems.

Several researches and development on this subject have been made in recent decades. Some studies and designs on PV/T Collector have been published; (Zondag, 2008; Chow, 2010; Hasan and Sumathy, 2010) made a review on research work of a PV-thermal Collector and system. His review includes the importance of photovoltaic hybrid system and its application for various sectors. It also includes characteristics equations, study of design parameters, and marketing. Ibrahim et al. (2011) and Tyagi et al. (2012) presented the recent advances of the photovoltaic/thermal (PV/T) solar Collectors.

Kern and Russel (1978) revealed the high value of coefficient of performance of a PV/T solar electricity and thermal energy.

Ito et al. (1997, 2005) performed experimental studies on PV/T continuous systems. Ji et al., 2008a, 2008b, 2009) have conducted experimental evaluations of PV/T systems and validate a mathematical model.

Some improvements in the systems of the evaporator PV/T based on the theoretical simulation have been reported (Xu et al., 2009; Zhao et al., 2011). Therefore, the electrical characteristics of photovoltaic devices have not been taken into account in earlier mathematical models of PV/T, when in fact the thermodynamics of the PV module can directly integrate with the exchange of energy from the PV output power (Tsai and Tsai, 2012). It is found that the accuracy of the solar Collector operating temperature estimated is the most important parameter in both the photovoltaic power generation and mutual exchange of energy. Tiwari and Sodha (2007) present parametric study of various configurations of hybrid PV/thermal air Collector: Experimental validation of theoretical model.

With the direct interaction of the two PV, power generation and the thermodynamics of the PV/T Collector.

Agrawal and Tiwari (2013) made a comparative analysis of different type of photovoltaic thermal (PVT) air collector namely: (i) unglazed hybrid PVT tiles, (ii) glazed hybrid PVT tiles and (iii) conventional hybrid PVT air collectors. It has been observed that overall annual thermal energy and exergy gain of unglazed hybrid PVT tiles air collector is higher by 27% and 29.3% respectively as compared to glazed hybrid PVT tiles air collector and by 61% and 59.8% respectively as compared to conventional hybrid PVT air collector. It has also been observed that overall annual exergy efficiency of unglazed and glazed hybrid PVT tiles air collector is higher by 9.6% and 53.8% respectively as compared to conventional hybrid PVT air collector. Based on a comparative study, it was concluded that the reduction of CO_2 emissions per year on the basis of overall heat energy gain of PV/T unglazed and glazed exceeds 62.3% and 27.7% compared to conventional hybrid PVT and on the basis of the overall exergy gain is 59.7% and 22.7%.

Matuska (2012) discuss the two configurations of unglazed PV/T (Low-tech, High-tech) and their ability to eliminate over heating of BIPV modules and found that the thermal generation unglazed Collectors BIPV/T up to 10 times higher than electricity.