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Study and modeling of energy performance of a hybrid photovoltaic/thermal solar collector: Configuration suitable for an indirect solar dryer

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ABSTRACT

In this paper, a configuration of photovoltaic-thermal hybrid solar collector embeddable in an indirect solar dryer system is studied. In the present structure of the solar photovoltaic/thermal air collector, the air goes through a double pass below and above the photovoltaic module. A system of electrical and thermal balance equations is developed and analyzed governing various electric and heat transfer parameters in the solar hybrid air collector. The numerical model planned for this study gives a good precision of results, which are close to the experimental ones (of previous literature), and makes it possible to have a good assessment of energy performance regarding the studied configuration (temperature, electric and thermal powers, electrical and thermal efficiencies, etc.). The numerical results show the energy effectiveness of this hybrid collector configuration and particularly its interesting use in an indirect solar dryer system that provides a more suitable air temperature for drying agricultural products. The values of the electrical, thermal and overall energy efficiencies reaches 10.5%, 70% and 90% respectively, with a mass flow rate of 0.0155 kg/s and weather data sample for the month of June in the Algiers site. The results presented in this study also reveal how important the effect of certain parameters and operating conditions on the performance of the hybrid collector.

1. Introduction

The sun is an inexhaustible source of energy. The solar energy in its first form (sunlight) can be converted into heat by thermal solar collectors or into electricity by photovoltaic solar cells. A new technology has been developed to combine both types of conversions; this technology is called the solar photovoltaic/thermal collector (PV/T). The hybrid photovoltaic/thermal collector generates electricity and thermal power simultaneously from solar photon through photo-electrical and photo-thermal interactions. It is a real thermal and electrical energy cogeneration system [1]. The generated heat is due to a part of the solar radiation absorbed by the solar cells but not converted into electricity. Obviously, this energy cogeneration can be widely used in energetic systems in various areas; building facades or rooftops and also in the agriculture, as in this study for the purpose of developing an efficient solar dryer.

During the effective operation of the PV panel, the experimental characterization indicates a significant loss of electrical efficiency while the temperature of the solar PV cell is increases due to exposure of sunlight. In lack of PV module cooling, the electric power loss reaches 20%. Solar PV cells temperature can be decreased by extracting heat with the use of natural or forced circulation of a fluid, like air. It prevents a sudden drop in the electrical efficiency of the photovoltaic module while ensuring the recovery of thermal energy.

Most research in this area have the objective of optimizing electrical efficiency of the PV modules and at the same time recovering a part of the dissipated heat in PV panel with the help of coolant.

Two configurations of Photovoltaic/Thermal air collector (PV/T with single-glass and PV/T with double-glass) have been studied and analyzed [2]. An experimental study of a hybrid PV/T air collector is presented consisting of a perforated metal siding placed on the back of the module [3].

A theoretical and experimental study of a PV/T solar air collector is presented, the PV/T collector consists of two photovoltaic

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Nomenclature

C	specific heat capacity (J/(kg K))
D_H	hydraulic diameter (m)
h_c	conductive heat transfer coefficient (W/(m^2 K))
h_r	radiative heat transfer coefficient (W/(m^2 K))
h_v	convective heat transfer coefficient (W/(m^2 K))
G	incident solar radiation (W/m^2)
k	thermal conductivity (W/m K)
M	mass (kg)
$\dot{m}$	mass flow rate (kg/s)
n	number of data
Nu	Nusselt number
P_m	power at maximum power point (W)
S	collector area (m^2)
t	time (s)

Greek symbols

ρ	density (kg/m^3)
μ	viscosity (kg/(m s))
β	fill factor
β_I	current temperature coefficient (mA/K)
β_V	voltage temperature coefficient (V/K)
ε	emissivity
τ	transmitivity
α	absorptivity
σ	Stefan–Boltzmann constant (W/(m^2 K^4))

Subscripts and abbreviations

a, amb	ambient
AM	air mass
af	above fluid
b	back
c	cell
eff	effective
ele, el	electrical
exp	experimental
f	fluid (air)
g	glazing, glass
gc	glass cover
gr	ground
i	insulation
in	inlet
lf	lower fluid
MPP	maximum power point
oc	open-circuit
of	outlet fluid
ov	overall
p	plate
PV/T	photovoltaic/thermal
RE	relative error
ref	reference conditions
s	series
sc	short-circuit
sim	simulation
t	Tedlar, time, top
th	thermal
u	useful
w, W	wind, width

modules connected in series. An air gap insulated with a layer of wood makes the convection of air possible below the PV modules [4]. The authors of another study compared the thermal performance between a glass-to-Tedlar solar PV/T collector and a glass-to-glass solar PV/T collector for a composite climate of New Delhi [5]. An improvement in electrical efficiency of photovoltaic module is shown by Touafek et al. due to the presence of a cooling system [6]. Also, they showed that the thermal performance of the hybrid collector could be improved by an addition of glass cover however, electrical performance decreases in this case. The glazed and unglazed PV/T collectors are the subject of a comparative study carried out by Agrawal and Tiwari [7], it is found that the glazed PV/T collector shows the best overall energy efficiency [8].

A comparative study is carried out of compound parabolic concentrated (CPC) and conventional flat hybrid double-pass PV/T systems [9]. The thermal and electrical performances of the systems (CPC and conventional flat hybrid PV/T) with and without fin are evaluated; it is found that the finned compound parabolic concentrated system gives the best performance. The thermal and electrical performances of four solar hybrid collectors are differentiated by the mechanical PV modules cooling mode: above, below, on both sides of the absorber and with double air circulation which have also been evaluated [10]. Another work has shown a comparative study between several configurations of hybrid solar collector: PV module without pipe, hybrid collector with pipe below the PV module, hybrid collector with pipe over PV module and hybrid collector with pipe below and above the PV module (two cases: two airflow and a single airflow). It is showed that the changes in the PV/T configurations have influenced the electrical and thermal performances of the PV/T collector [11].

A theoretical and experimental study on the double pass photovoltaic thermal collector suitable for solar drying applications has been made [12]. In another study, the performance of double pass PV/T air collector is analyzed and compared to single pass PV/T air collectors. It is showed that the double-pass configuration has better thermal performance than the single-pass (basic) configuration [13].

In this paper, the aim of the study is the assessment of thermal and electrical performance of a double pass hybrid solar collector. The proposed configuration of the hybrid solar collector is provided with an aluminum metal plate to promote heat transfer

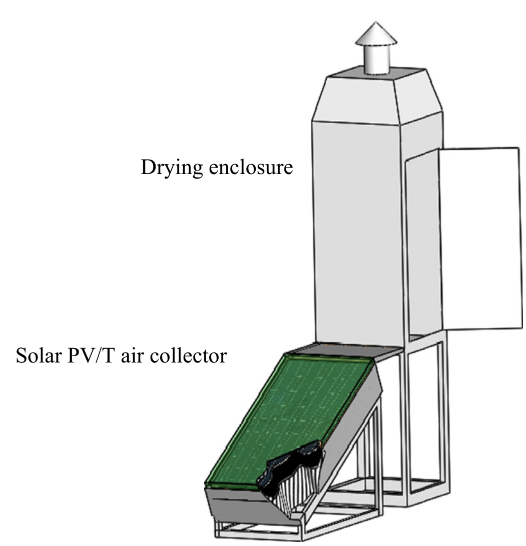

Fig. 1. Indirect solar dryer system provided with a solar photovoltaic/thermal air collector.

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