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Development and validation of a hybrid PV/Thermal air based collector model with impinging jets

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Abstract

In an air-based hybrid Photovoltaic/Thermal (PV/T) solar collector, a high heat transfer coefficient can be achieved between the absorber plate and the air by using impinging jets. A predictive model of a PV/T collector using impinging jets was developed, and a prototype was built and operated at an outdoor facility in order to validate and test the model capabilities. Overall, the model was found to produce relatively accurate results. Over 8 days of testing, the worst total daily energy model predictions were within 10% and 11% of the experimental value for the thermal and electrical outputs, respectively. The influence of time step and thermal mass on the accuracy of the model were examined.

Keywords: Hybrid; Photovoltaics; Model validation; PV/Thermal; Solar thermal collector

1. Introduction

In recent years, significant efforts have been made in combining photovoltaic and solar thermal technologies into the same panel (Hansen et al., 2007). When photovoltaic panels are exposed to the sun, they produce electricity. Due to their relatively low conversion efficiency, however, they also heat up, further reducing their conversion efficiency. If this thermal energy is collected, thereby cooling the PV cells, it should be possible to increase the PV efficiency. The combined electrical and thermal output of the system could be greater than a standalone PV or thermal panel of the same area. With added electrical generation capability, such a collector can then be used to meet some of a buildings thermal and electrical requirements, thereby reducing its dependence on external energy sources. Zondag et al. (2003) state three main advantages of PV/T collectors over stand alone PV panels or thermal collectors: their potential for greater energy output per area compared to separate thermal and PV production of the same total area, their architectural uniformity compared to separate PV and thermal systems, and a potential reduction in installation cost versus installing PV panels and thermal collectors separately. Sopian et al. (1996) found that increasing the packing factor, defined as the ratio of PV area to collector area, reduced the combined efficiency. Cox and Raghuraman (1985) found the opposite for a different collector design. Chow et al. (2009) found that the combined efficiency of an unglazed PV/T collector increased with packing factor. They also found that if that same collector was glazed, the combined efficiency of the collector decreases with packing factor. These varying results likely mean that the design of the collector dictates

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Nomenclature

A	area (m^2)
C	specific heat (J/kg K)
D	diameter of holes (m)
D_h	hydraulic diameter (m)
g	gravity (9.8 m/s^2)
h	heat transfer coefficient (W/m^2 K)
k	conductivity of air (W/m K)
L_c	characteristic length of collector (m)
L	length of collector (m)
m	Reynolds number exponent for impinging jet correlation
$\dot{m}$	mass flow rate (kg/s)
N	amount of discrete elements in x direction
Nu	Nusselt number (dim)
P	electrical power per collector area (W/m^2)
Pr	Prandtl number (dim)
Q	heat gain (W)
Ra	Raleigh number (dim)
Re	Reynold's number (dim)
S	incident solar radiation (W/m^2)
t	time (s)
T	temperature (K)
U	conductance (W/m^2)
v	coefficient for impinging jet correlation
V	wind velocity (m/s)
w	width of collector (m)
x	distance along flow direction (m)
X	distance between holes (m)
z	thickness
Z	distance between plates (m)
α	absorptivity (solar spectrum) (dim)
β	collector tilt angle (deg)
ε	emissivity (dim)
ϕ_1	coefficient for impinging jet correlation (dim)
ϕ_2	coefficient for impinging jet correlation (dim)
$\mu_{p,mp}$	PV max. power point temperature coefficient (1/K)
μ	dynamic viscosity (kg m/s)
η	PV efficiency (dim)
θ	angle (deg)
ρ	density (kg/m^3), reflectivity (dim)
σ	Stefan-Boltzmann constant (W/m^2 K^4)
τ	transmissivity (solar spectrum) (dim)
$(\tau\alpha)$	transmittance–absorptance product (dim)

Subscripts and Superscripts

a	ambient
B	back of collector
beam	beam radiation
c	convection
coll	collector
cond	conduction
D	based on hole diameter
D_h	based on hydraulic diameter
diffuse	sky diffuse radiation
ground	ground diffuse radiation
f_2	fluid between P_2 and P_1
f_1	fluid between back and P_1
g	glass cover
in	air entering discrete element
mp	maximum power point
n	normal
out	air leaving discrete element
P_2	plate on which impinging takes place
P_1	perforated plate
PV	PV cells
pref	reference power
r	radiation, refraction
side	side of collector
STC	standard test conditions
$''$	previous element

whether a PV/T collector is more or less efficient than a similar thermal collector.

One way to increase the efficiency of air based solar collectors is to enhance the heat transfer between the working fluid and the collector plate. This can be done through the use of impinging jets of air on the plate instead of the traditional parallel flow. In the parallel flow situation, shown in Fig. 1a, heat transfer from the absorber plate occurs through forced convection in parallel flow. In Fig. 1b, the heat transfer occurs through impinging jets. A simple impinging jet collector model was developed by Choudhury and Garg (1991) and Rask et al. (1977) who were the first to experimentally study such collectors. Both studies showed an increase in efficiency compared to a parallel plate collector; between 10% and 20% depending on the configuration, test conditions, and flow rate. Belusko et al. (2008) modeled and tested an unglazed impinging collector where the jet impingement was induced by negative pressure and the absorber plate was corrugated. They found a 21% increase in efficiency under typical conditions. These results clearly show that impinging jets provide higher efficiencies in air based solar collectors compared to typical parallel flow designs.

The present work describes one effort to develop a PV/T air heating collector which uses impinging jets. A model of the collector was developed, and validated by comparing results to a prototype of the system. It is intended that the model will be used to optimize the collector design and compare with other designs found in the literature.