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Experimental validation of glazed hybrid micro-channel solar cell thermal tile

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Abstract

In this communication, an attempt has been made to evaluate the theoretical performance of a glazed hybrid micro-channel solar cell thermal (MCSCT) tile. Experiment has been performed in indoor condition and it has been observed that there is good agreement between theoretical and experimental values with correlation coefficient and root mean square percentage deviation in range of 0.995–0.998 and 3.21–4.50 respectively. Effect of design parameters on different combination (series and parallel) of glazed hybrid MCSCT tile for Srinagar climatic condition, India has also been evaluated. The theoretical results of glazed hybrid micro-channel photovoltaic thermal (MCPVT) module for 75 W_p have been compared with the result of single channel photovoltaic thermal (SCPVT) module. The average value of electrical and thermal efficiency of glazed hybrid MCPVT module are 14.7% and 10.8% respectively which is significantly higher than SCPVT module. The overall annual exergy efficiency based on second law of thermodynamics has also been evaluated at different mass flow rate for glazed hybrid MCPVT module for Srinagar climatic condition. It has been observed that maximum overall exergy efficiency is 20.28% at 0.000108 kg/s mass flow rate.

Keywords: Glazed solar cell; Photovoltaic module; Micro-channel; Electrical efficiency; Thermal modeling

1. Introduction

Classification of photovoltaic thermal system has been shown in Fig. 1a. Theoretical and experimental studies of (PVT) have been conducted as early as in mid 1970s. Wolf (1976), Florschuetz (1975, 1979), Kern and Russell (1978) and Hendrie (1979) on different occasions have presented the key concept and the data with the use of either water or air as the coolant. The research works that carried out mainly on flat-plate collectors have been presented by Raghuraman (1981), Cox and Raghuraman (1985), Braunstein and Kornfeld (1986) and Lalovic (1986). The works of O'leary and Clements (1980), Mbewe et al. (1985), Al-Baali (1985) and Hamdy et al. (1988) have included the performance analysis of concentrating PVT systems. Hayakashi et al. (1989) have also presented a system in which a roof has covered by 48 m^2 of PV-modules, which were connected to transparent tubes and filled with a black fluid. The electrical and thermal energy have been stored in batteries and two water tanks of 1 m^3 each respectively.

Bhargava et al. (1991) have investigated the effect of air mass flow rate, air channel depth, length and fraction of absorber plate area covered by solar cells (packing factor, PF) on single pass air collector. Nishikawa et al. (1993) have presented a system in which the PVT functions directly as the evaporator of a heat pump. The modeling of a channel type PVT collector for the cases of both air (100–300 kg/h) and water (40–120 kg/h) has been carried out by Prakash (1994). He has observed that decreasing the duct depth increases the thermal performance of air and water heater. Fujisawa and Tani (1997) have compared

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Nomenclature

A_c	area of solar cell ($m^{2)}$
b	width of the micro-channel (m)
C_f	specific heat of air (J/kg K)
d	depth of the micro-channel (m)
D_e	characteristic dimension or equivalent diameter of micro-channel (m)
dx	elemental length (m)
dt	elemental time (s)
f_c	coefficient of friction
h	heat transfer coefficient (W/m^2 K)
h_{bi}	heat transfer coefficient from back of tedlar to ambient (W/m^2 K)
h_{to}	heat transfer coefficient from top glass cover to ambient (W/m^2 K)
h_T	heat transfer coefficient from back of tedlar to flowing air (W/m^2 K)
$h_{b,in}$	heat transfer coefficient from back of insulation to ambient (W/m^2 K)
$I(t)$	incident solar intensity (W/m^2)
K	thermal conductivity (W/m K)
L	length (m)
$\dot{m}_f$	air mass flow rate in micro-channel (kg/s)
N	number of glazed micro-channel solar cell thermal (MCSCT) tile
Nu	Nusselt number
$\dot{Q}_u$	useful heat (W)
Re	Reynolds number
T	temperature (K)
U	overall heat transfer coefficient (W/m^2 K)
U_{tca}	an overall heat transfer coefficient from solar cell to ambient through glass cover (W/m^2 K)
U_{tcf}	an overall heat transfer coefficient from solar cell to flowing air through tedlar (W/m^2 K)
U_b	an overall back loss heat transfer coefficient from flowing air to ambient (W/m^2 K)
V	velocity of fluid (air) flowing inside of channel (m/s)
v	velocity of air (m/s)
β_0	temperature coefficient of efficiency (1/K)
η_o	efficiency at standard test condition ($I(t) = 1000$ W/m^2 and $T_a = 25$ °C)

Greek letters

α	absorptivity
β	packing factor
τ	transmittivity
η	efficiency
ρ	density (kg/m^3)

Subscripts

a	ambient
c	solar cell
eff	effective
f	fluid (air)
f_i	inlet fluid
f_o	outgoing fluid
in	insulation
T	tedlar

the annual performance of a flat-plate water collector, a PV module and a single glazed and unglazed PVT collector with mono-crystalline silicon solar cells. The evaluation of the measured data have shown that the single glazed PVT collector was the best, followed by flat-plate water collector, unglazed PVT and PV module in terms of overall energy gain. In terms of exergy analysis, the best performance was given by unglazed PVT, followed by PV module, single glazed PVT and flat-plate water collector.

Hegazy (2000) and Sopian et al. (2000) have studied the glazed photovoltaic thermal air system for a single and a double pass air heater for space heating and the drying. Kalogirou (2001) has investigated monthly performance of an unglazed hybrid PVT system under forced mode of operation for climatic condition of the Cyprus. He has found an increase of the mean annual efficiency of the PV solar system from 2.8% to 7.7% with thermal efficiency of 49%. A detailed sensitivity analysis has been conducted to determine the influence of the uncertainties in the measured parameters on the uncertainty level that can be assigned to coefficients of the efficiency curve for solar collectors (Braccio et al., 2002). Lee et al. (2001) and Chow (2003) have presented interesting modeling results on air cooled PV modules. Ji et al. (2003) have investigated a facade integrated 40 m^2 PVT collectors for use in residential buildings in Hong Kong, comparing thin film and crystalline silicon. For water heating, the annual thermal efficiencies have been found to be 48% for the thin film case and 43% for the crystalline silicon case. The movement of a photovoltaic module has been controlled by programmable logic-controller (PLC) unit to follow the Sun's radiation. They have found that the daily output power of the PV was increased by more than 20% in comparison with that of a fixed module. Vorobiev et al. (2005) have investigated the option to make a cell work at relatively high temperature (around 100–200 °C) and use the excessive heat in a hybrid system of some kind to increase the total efficiency of solar energy utilization.

Kalogirou and Tripanagnostopoulos (2005) have calculated the yield of a 4 m^2 PVT thermosyphon system for different climates. For their crystalline silicon PVT module, they found a useful thermal gain of 5.7 GJ for Nicosia, 5.0 GJ for Athens and 3.8 GJ for Madison, while the electrical performance ranged from 532 to 499 kWh. Design of