Performance characterization of single-path and double-path air-based bifacial photovoltaic thermal solar collector

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Abstract: This paper examines and compares bifacial photovoltaic thermal solar collectors based on the first law of thermodynamics. The mathematical model has been developed and solve for the performance evaluation of the system. Two Air base bifacial photovoltaic thermal (PVT) panels has also been designed base on Bifacial PV cells requirement. Two air base panel configurations considered were model one is a single path and model two is double path parallel flow. From the energy point of view or the first law, bifacial PVT with two parallel path air streams shows the best efficiency (45%-63%) compare to the single path models.

Keywords: Photovoltaic thermal, Bifacial Solar cell, Flat plate, Energy efficiency

1. Introduction
Solar energy is well-known as the most environmental friendly renewable energy. Hybrid Photovoltaic thermal (PVT) collectors are specially designed solar collectors that generate both electrical and thermal energy. Air based collectors are in use for drying, space heating and heat pump applications. The photovoltaic cells are paste on top of the absorber plates. Mono-facial photovoltaic cells absorb solar radiation reaches the front aperture and convert it to electrical energy (Fig.1).Bifacial PV cell has the privilege of solar abortion by rear surface as well as front surface as shown in Fig. 1.It leads to supplement electricity generation [1].

This paper examines the performance in term of electrical and thermal for bifacial photovoltaic thermal solar Panel for building integrated PV, space heating and other industrial process heat such as drying. Most of existing PVT designs are based on mono-facial PV cell requirement and are not appropriate for bifacial cells.

Fig.1 Mono-facial and bifacial photovoltaic solar cells
Bifacial solar cells demand supplement solar radiation for back surface and it strongly depends on ability of reflector to provide appropriate radiation[2],[3].

PVT panels have higher total efficiency compared to thermal and electrical one, individually. Bifacial cells increase electrical efficiency of flat plate PV and PVT panels with negligible cost increase[4].Most of existing PVT designs has an absorber plate and/or insulation material behind PV cells that blinds the rear aperture of bifacial cell [5-9].Flat plate Air base solar thermal collectors are classified as single-path and double-path solar panels. Double path panel has higher electrical and thermal efficiency compare to single path panel [10].

Park et al. [11] studied the thermal and electrical performance of semi-transparent PV module at building integrated application. There is no absorber plate attach to Semi-transparent PV cell. It reduces the temperature of the module that leads to higher electrical efficiency.

Output energy of a PVT panel is a function of few parameters such as flow rate, packing factor, number of glazing and etc. It has been observed in previous research that maximum energy obtained at 310°C [12]. Energy efficiency of Air-base PVT panel has been reported as Table 1:

<table>
<thead>
<tr>
<th>Reference</th>
<th>Panel Type</th>
<th>Energy efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>[13]</td>
<td>PVT-air</td>
<td>55%</td>
</tr>
<tr>
<td>[14]</td>
<td>PVT-air</td>
<td>55% - 66%</td>
</tr>
<tr>
<td>[15]</td>
<td>PV</td>
<td>7% - 12%</td>
</tr>
<tr>
<td>[16]</td>
<td>PVT-air</td>
<td>33% - 45%</td>
</tr>
<tr>
<td>[12]</td>
<td>PVT-air</td>
<td>45%</td>
</tr>
</tbody>
</table>

PVT: Photovoltaic thermal
PV: Photovoltaic

Table 1: Energy efficiency comparison of air based PVT panels PVT

Reflection and absorption by glazing reduces solar radiation reaching the PV cells. From energy balance view point, glazing is favorable as it reduces thermal loose.

2. Mathematical Modeling
Panel thermal efficiency and PV cell electrical efficiency depend on cell temperature, air flow rate, packing factor and etc. The energy balance model will determine the panel properties such as electrical energy output and temperature of outgoing air stream.

2.1. Panel design
Varieties of material could be used as reflector, including mirror type, semi-mirror type and diffuse type. Reflection properties of diffuse reflectors has been studied for bifacial photovoltaic cell [2]. White color has the highest reflection efficiency of 75% followed by yellow color with 61% reflection. In this research we focused on Air base design, non-tracking system and white color diffuse type reflection. Two Air base bifacial photovoltaic solar panels have been developed. As shown in Fig.2 and Fig.3.

Model one is a single path Air based PVT panel equipped by a reflector beneath the PV lamination. The only Air stream flows between lamination and reflector (Fig.2). Model two has a supplement glazing over PV lamination with separation that allows Air flow between glazing and lamination. There are two parallel air streams over and beneath lamination (Fig.3).

(a) Cross section view, (b) heat transfer coefficient of energy balance model
2.2. Energy Balance of Bifacial PVT Collectors

Energy balance modeling has been carried out to compare the performance of above-mentioned designs. PV cell bifacially assumed equal to one, which means both aperture of PV cell have same efficiency, \( \eta_{PV_{front}} = \eta_{PV_{rear}} \). Total electricity generation of Bifacial PV cell is sum of front and rear \( E_{I_{PV}} = E_{I_{PV_{front}}} + E_{I_{PV_{rear}}} \). Energy balance equations have been written for every model as follows.

2.2.1 The photovoltaic efficiency

Bifacial solar cell has two apertures that contribute in electrical energy generation. Total electricity generation of Bifacial PV cell is sum of front and rear electrical energy.

\[
E_{I_{PV}} = E_{I_{PV_{front}}} + E_{I_{PV_{rear}}} \quad (22)
\]

Here we assume the efficiency of rear aperture equal to front aperture that doubles the total efficiency.

The efficiency of photovoltaic cell depends on its temperature [18] as:

\[
\eta_{PV_{front}} = \eta_{PV_{rear}} = \eta_{ref} \left[ 1 - \Phi_{ref} \left( T_{cell} - T_{ref} \right) \right] \quad (23)
\]

While \( \eta_{ref} = 10\% \), \( \Phi_{ref} = \frac{1}{T_{PV} - T_{ref}} \) and \( T_{ref} = 25^\circ C \).

2.2.2. Thermal efficiency

Thermal efficiency of panel could be defined as the ratio of thermal energy transferred to working fluid(s) over total solar radiation reaches collector surface.

\[
\eta_{th} = \frac{mC_p(T_o - T_i)}{S \times A} \quad (24)
\]

2.2.3 Combined Photovoltaic Thermal Efficiency

The total efficiency of PVT panel is a function of electrical and thermal efficacy. Electrical energy is more valuable than thermal energy, which should be taken into account at total efficiency calculation [19].

\[
\eta_{Total} = \eta_{th} + \frac{\eta_{el}}{\eta_{PowerPlant}} \quad (25)
\]

Where \( \eta_{PowerPlant} = 0.38 \) is the efficiency of conventional power plant [20].

3. Results and Discussions

Mathematical methods have been used to simulate the two panel models at steady state condition.

3.1. Temperature Profiles of Bifacial PVT

The two models have been simulated. Fig.4 represents the temperature of working fluid along the panel under 800 watts, 0.5 packing factor and 300kg/hr Air flow. Panel length is one meter and is divided to 100 points.
Fig 4: Air flow along panel length for (a) single path (b) double path parallel stream

It should be noted that there is only one Air stream beneath bifacial Laminate in model one, that carries 100% of flow rate. There are two air channel streams in second design, one over and the other beneath the panel. Both channels have same geometries and the flow rate has been evenly divided in two, which means each channel carries 50% of flow rate, compare to model 1. The additional air channel above the PV panel at panel model two increases the heat transfer surface, which has a significant development compare to model one. Table 2 shows the comparison of model one and two, in terms of temperature, efficiency and flow rate at a 0.083 kg/s total flow rate, 800W/m² solar radiation and 0.5 packing factor.

Table 2. Efficiency and temperature increase at a single condition

<table>
<thead>
<tr>
<th>Model</th>
<th>Total flow rate</th>
<th>Flow rate at every Channel</th>
<th>ΔT</th>
<th>η_PVT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.083 kg/s</td>
<td>0.083 kg/s</td>
<td>1.7</td>
<td>39%</td>
</tr>
<tr>
<td>2</td>
<td>0.083 kg/s</td>
<td>0.028 kg/s</td>
<td>3.7</td>
<td>59%</td>
</tr>
</tbody>
</table>

Electrical efficiency of four designs represented in Fig.5. Electrical efficiency of every aperture of bifacial cell assumed 10% at reference temperature, which is 25°C.

Models two, three and four have slightly lower electrical efficiency which is effect of reflection at lamination and glazing, beside non-ideal reflection performance by reflector (70%). Existence of supplement glazing at model two, three and four is a privilege compare to model one in term of thermal efficiency, which is clearly illustrated in Fig.6. Total efficiency of four models has been calculated by equation 25, as shown in Fig.7.

Fig.5. Electrical efficiency at different packing factors

Fig.6. Thermal efficiency at different packing factors
Electrical efficiency does not much depend on Air mass flow rate compared to thermal efficiency at the range of 0.03 kg/s to 0.14 kg/s. Regarding Fig. 7, the double path panel has higher total efficiency compared to the single air path panel, which also has been concluded by earlier researchers [21]. The higher total efficiency of model two is because of higher heat transfer surface and higher heat extraction consequently.

4. Conclusions

Energy and Exergy models have been developed for four bifacial PVT panels. Model Two has the highest total energy efficiency (45%-63%) followed by model three (42%-55%), model four (38%-53%) and model one (25%-40%). Model two has slightly higher total energy efficiency compared to model three (3%-8%); but model three has upgraded to model four (returning flow) because of ease of fabrication, from manufacturing view point. All four models of bifacial PVT panels represent higher electrical energy and exergy compared to bifacial PV equipped with similar reflector; which is because of effective cooling mechanism. Model one is the best option, if electrical energy is the dominant desired energy. Model two is the best option, if thermal energy is dominant. Meanwhile, model one has the highest Exergy efficiency (7.13%-7.18%) compared to model two (6.95%-7.75%), model three (6.9%-6.99%) and model four (6.89%-6.92). Exergy efficiency of model two is not much lower than model one but its energy efficiency is considerably higher.

References:


