Amorphous Silicon Based Photovoltaic Thermal for Building Integrated Applications

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Abstract: - Striveous attempts have been made to improve the efficiency of Building Integrated Photovoltaic Thermal (BIPVT). System design parameters, type of cells, type of coolant and operating conditions are approaches which influence the efficiency of BIPVT. A new design concept of water-based PVT collector for building-integrated applications has been designed and evaluated. The results of simulation study of amorphous silicon (a-Si) PV/T module type are based on the meteorological condition of Malaysia for one day in the middle of March; 2009. It indicates that at solar radiation between 700-900 W/m\(^2\), ambient temperature between 22-32°C and fluid flow rate of 0.02 kg/s, the thermal and electrical efficiency of the PV/T was able to reach 72% and 5%, respectively.

Key-Words: - Amorphous silicon, Photovoltaic thermal (PVT), electricity, Thermal efficiency, BIPVT, Absorber Collector.

1 Introduction
One of the major issues with PV/T systems is that in order to maintain a high electrical output from the PV device, the operation temperature of the PV/T system needs to be kept low [1]. For monocrystalline (c-Si) and polycrystalline (pc-Si) silicon solar cells, the efficiency decreases by about 0.45% for every degree rise in temperature, while for amorphous silicon (a-Si) cells, the effect is less, with a decrease of about 0.25% per degree rise in temperature depending on the module design [2]. As temperature is increased, there are two major effects in typical PV cell operation. First, the dark saturation current of the PV cell increases which leads to a decrease in open circuit voltage. Second, the band gap of the photovoltaic material decreases which leads to an increase in photocurrent. The first effect is more dominant than the second effect and thus there is a net decrease in the solar conversion efficiency with increasing temperature, therefore, the low temperature operation is necessary [3].

In comparison with the crystalline silicon cells, amorphous cells hold the promise of reducing the module costs through lower material and energy requirements of the manufacturing process. In addition integrally connected modules are produced directly without the costly individual cell handling and interconnections [4].

Amorphous silicon photovoltaic (PV) modules offer several advantages for building-integrated applications. The material can be deposited on glass or flexible substrates, which allows for products like roofing shingles and integrated PV/building glass. The material also has a uniform surface, which is ideal for many architectural applications. Amorphous silicon modules perform well in warm weather and have a small temperature coefficient for power. Depending on the building load, this may be beneficial when compared to crystalline systems [5]. The advent of the energy crisis in the early 1970s led to the concept of hybrid PV/T systems became much more favourable research area. Some
of the relevant researches have been presented in Table 1.

**Nomenclature**

- $A_C$: Surface area of the PV/T collector
- $C_P$: Specific heat of coolant
- $d_h$: Hydraulic diameter
- $F$: Fin efficiency factor
- $F_R$: Collector heat removal factor
- $G_T$: Solar radiation at NOCT
- $h_{ct}$: Heat transfer coefficient between cell and absorber
- $h_w$: Wind heat transfer coefficient
- $K_{abs}$: Absorption surface thermal conductivity
- $K_b$: Back insulation thermal conductivity
- $K_e$: Insulation conductivity
- $L_{abs}$: Thickness of the absorption surface
- $L_b$: Back insulation thickness
- $m$: Mass flow rate
- $N$: Number of glass covers
- $Q_U$: Useful energy gain
- $T_a$: Ambient temperature
- $T_C$: Average module temperature
- $T_i$: Inlet fluid temperature
- $T_O$: Outlet fluid temperature
- $T_{pm}$: Mean plate temperature
- $T_r$: Reference temperature
- $U_A$: Building overall heat loss coefficient
- $U_b$: Bottom loss coefficient
- $U_e$: Edge loss coefficient
- $U_L$: Overall loss coefficient
- $w$: Flat box spacing
- $\varepsilon_g$: Emittance of glass
- $\varepsilon_p$: Emittance of plate
- $\delta$: Stefan–Boltzmann constant
- $(\alpha_{al})_n$: Transmittance absorptance of PV/T

## Table 1. Studies on PV/T systems

<table>
<thead>
<tr>
<th>Author and year</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Huang, 2001 [9]</td>
<td>PV/T collector water-heating (Averaged daily thermal efficiency and overall efficiency of 38%, 60%).</td>
</tr>
<tr>
<td>Chow, 2003 [10]</td>
<td>PV/T collector model based on the control-volume finite-difference approach; the dynamic model was able to output explicitly the time-varying temperatures at the sub-component level, and the thermal and electrical energy data as well developed</td>
</tr>
<tr>
<td>Zondag et al., 2003[11]</td>
<td>Best overall efficiency obtained from design of channel below the PV with PV on sheet and tube design</td>
</tr>
<tr>
<td>Tiwari and Sodha, 2006 [12,13,14]</td>
<td>Thermal model of PV/T water/air heating system (Analytical expression of the solar cells operating temperature presented and found that the daily efficiency of PV/T with water is higher than with air).</td>
</tr>
<tr>
<td>Ji et al., 2007 [15] and He et al., 2006[16]</td>
<td>Flat-box photovoltaic/water-heating system (daily thermal efficiency was around 40% and its primary-energy saving could reach up to 65% with a PV cell covering factor 0.63)</td>
</tr>
<tr>
<td>Kalogirou et al., 2007 [17]</td>
<td>PV/T for producing water heating and electricity(a-Si and pc-Silicon)</td>
</tr>
<tr>
<td>Chow et al., 2007[18]</td>
<td>A centralized PV/T wall as a water pre-heating system, thermal and electrical efficiency was 38.9% and 8.56%.</td>
</tr>
</tbody>
</table>

# 2 Analysis of PV/T

The analysis of the PV/T collector starts with the calculation of its characteristic parameters. This is achieved using the equations that refer to the flat plate collectors. The equations are modified and adjusted properly in order to include the added section of the photovoltaic [19].

## 2.1 Analysis of flat plate collector

Consider an energy balance on a simple flat plate collector:

$[\text{Useful energy collected}] = [\text{energy absorbed by plate}] - [\text{energy lost to surroundings}]$

$$Q_u = A_C F_R [\tau \alpha_e G_T - U_L (T_i - T_u)]$$  \hspace{1cm} (1)

To eliminate the need to determine plate temperature, a collector heat removal factor $(F_R)$, is introduced [20, 21]:

$$F_R = \frac{m C_P}{A_C U_L} \left[ 1 - e^{-\frac{A_L U_L F}{m C_P}} \right]$$  \hspace{1cm} (2)
Where the collector efficiency Factor is defined as:

\[
F' = \frac{1}{U_L} \left[ \frac{1}{U_L(D_h + (w-D_h)F)} + \frac{1}{wh_{\text{ca}}} + \frac{1}{2(D_h+b)} \right]^{-1}
\]

(3)

The fin efficiency factor \( F \) is given by:

\[
F = \frac{\tanh \left[ m \frac{w-D_h}{2} \right]}{m \frac{w-D_h}{2}}
\]

(4)

Then:

\[
m = \frac{U_L}{\sqrt{k_{\text{abs}} L_{\text{abs}} + K_{\text{pp}} L_{\text{pp}}}}
\]

(5)

The collector overall loss coefficient \( U_L \) is the sum of the top, bottom and edge loss coefficients:

\[
U_L = U_t + U_b + U_e
\]

(6)

The back loss coefficient is calculated by:

\[
U_b = \frac{K_b}{L_b}
\]

(7)

The edge loss coefficient, based on the collector area is:

\[
U_e = \frac{(UA)_{\text{edge}}}{A_C}
\]

(8)

And the top loss coefficient is:

\[
U_t = \frac{1}{N_c} \left[ \frac{T_m}{T_m - T_a} \right]^{\frac{1}{f}} + \frac{1}{h_w} \left[ \frac{T_m}{T_m - T_a} \right]^{\frac{1}{f}} + \frac{\sigma(T_m^2 + T_a^2) + N f}{N f + f - 1 + 0.133 \varepsilon_p N + f - 1 + 0.00591 N h_w \varepsilon_p - N} \right]
\]

(9)

Useful energy gain by the collector heats the collector fluid, therefore:

\[
Q = m C_p (T_o - T_i)
\]

(10)

Thus,

\[
\frac{Q_u}{A_c} = F_R \left[ \tau \alpha \frac{U_L(T_i - T_o)}{G} \right] = m \frac{C_p(T_o - T_i)}{A_c G}
\]

(11)

The collector efficiency defined as:

\[
\frac{Q_u}{A_c} = F_R \left[ \tau \alpha \frac{U_L(T_i - T_o)}{G} \right] = m \frac{C_p(T_o - T_i)}{A_c G}
\]

(12)

To evaluate collector performance, it is necessary to know the overall loss coefficient and the internal fluid heat transfer coefficient. According to and Beckman [20] “First an estimate of the mean plate temperature is made from which \( U_L \) is calculated. With approximate values of \( F_R \), \( F' \) and \( Q_u \) a new mean plate temperature is obtained and used to find a new value of the top loss coefficient. The new value of \( U_L \) is used to refine \( F_R \) and \( F' \), and the process is repeated. With a reasonable initial guess, a second iteration is seldom necessary”. The mean plate temperature can be calculated in bellow:

\[
T_{pm} = T_i + \frac{Q_u}{F_R U_L} \left( 1 - F_R \right)
\]

(13)

2.2 Theory of Photovoltaic modules

Electrical efficiency of the PV module, which is a function of average module temperature, \( \eta_e \), is given by:

\[
\eta_e = \eta_r (1 - \beta (T_C - T_r))
\]

(14)

In this study the above mention equation is used based on the suitable \( \eta_r, T_r, \beta \) and \( T_C \) for amorphous silicon cell. The above equation for calculation of temperature-dependent electrical efficiency of PV was used by Zondag et al. [11] and Tiwari and Sodha [14], based on Table 2.

<table>
<thead>
<tr>
<th>Authors</th>
<th>( \eta_r )</th>
<th>( T_r )</th>
<th>( \beta )</th>
<th>( T_C )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zondag et al. [11]</td>
<td>0.097</td>
<td>25°C</td>
<td>0.0045°C⁻¹</td>
<td>--</td>
</tr>
<tr>
<td>Tiwari and Sodha [14]</td>
<td>0.12</td>
<td>---</td>
<td>0.0045°C⁻¹</td>
<td>25°C</td>
</tr>
</tbody>
</table>

Table 2-Parameters for calculation of electrical efficiency
3 New design of absorber

Hybrid PV/T collectors produce electricity and heat. As temperature requirements increase, PV efficiencies rapidly fall off, by cooling the cells with a fluid stream; the electrical output can be improved. The advantage is to improve the global energy efficiency of PV/T modules by extracting the heat loose by using a heat removal fluid; therefore a simple and well designed absorber collector, in which water is heated and the PV module temperature can be reduced to keep electrical efficiency at the sufficient level, simultaneously has been proposed and designed (Fig. 1).

Fig. 1 Absorber Plate

This new design is of practical interest for water heating, as it can effectively contribute to cover thermal and electrical production based on simulation study and increment overall efficiency of PV in BIPVT.

In order to increase and improve thermal efficiency of the PV/T collector the amorphous silicon cell has been used. In recent years there have been an increasing number of applications requiring more efficient and lightweight thermal management such as BIPVT collector. The primary concerns in these thermal management applications are high thermal conductivity, low weight and low cost, therefore the absorber built of Aluminum.

4 Results and discussion

Figure 2 shows the hourly average variation of solar irradiation and ambient temperature for a typical day in the middle of March for Malaysia.

Fig. 2 Average hourly radiation and ambient temperature with time

Fig. 3 shows the variation of water temperature versus the time. The water temperature steadily increases with time and solar irradiation. As the solar irradiation decreases; the rate of increase in temperature of water also decreases. A maximum predicted water temperature of 56°C is obtained.

Fig. 3 variation of output water temperature with time

As seen from the figure 4, the cell efficiency declines as mean plate temperature raise.

Fig. 4 Cell efficiency as a function of mean plate temperature
The effect of mass flow rate on the photovoltaic, thermal, and combined photovoltaic thermal efficiencies are shown in Figure 5. The combined efficiency varies from 75.9 to 80.3% at mass flow rates of 0.01 to 0.04 kg/s.

It is observed that as the temperature rise decreases with increasing mass flow rate, the collector thermal efficiency increases due to the declining average temperature of the absorber plate. Thus, increasing the flow rate will increase the heat transfer coefficient between the channel walls and the water, resulting in a lower mean photovoltaic cell temperature; this will increase the electrical efficiency of the collector.

Thermal and overall efficiencies of PV module are shown in Fig. 6.

As seen from the figure, the thermal and overall efficiencies are always higher than the 67% and 71%, respectively. It is proven through mathematical model that this simple design having the highest thermal efficiency of 71.8 and overall efficiency of 76.73. This can be attributed to the higher thermal absorption of new absorber collector, the second reason is due to the fact that, amorphous silicon cell gain more heat compare to mono and poly crystalline silicon cell.

Fig. 7 indicates the cell efficiency as a function of the ratio \(\frac{(T_r-T_a)}{G_T}\).

Based on the regression analysis with confidence limits of 95%, three simple correlation equations can be written as follows:

\[
\eta_{thermal} = 0.719 - 2.795 \frac{T_r - T_a}{G_T}
\]

\[
\eta_{overall} = 0.767 - 2.737 \frac{T_r - T_a}{G_T}
\]

\[
\eta_{cell} = 0.048 - 0.007 \frac{T_r - T_a}{G_T}
\]

5 Conclusion
The temperature of photovoltaic modules increases when it absorbs solar radiation, causing a decrease in efficiency. This undesirable effect can be partially avoided by applying a heat recovery unit with fluid circulation with the photovoltaic module. System design parameters, type of cells, type of coolant and operating conditions are approaches which influence the efficiency of BIPVT. In order to compensate this problem a novel design of absorber Collector proposed. The results of simulation study of new absorber design of PV/T system indicated that the overall efficiency of this design can be much better than that of conventional absorber, the simultaneous use of...
new design of absorber and amorphous cell which absorb much more thermal energy compare to mono and poly crystalline silicon cell have a potential to increase thermal and electrical efficiency significantly and reduce the cost of BIPVT system.

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References: