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Performance Analysis of a PV/T Air system based on heat transfer perspective

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Abstract:

Hybrid photovoltaic/thermal (PV/T) systems produce both electricity and thermal energy resulting to an increase in the overall efficiency of the system and a reduction in the cost of solar electricity. A comprehensive parametric study has been carried out in this paper to investigate the mechanisms for increasing the wall heat flux and hence the overall performance of a PV/T air collector. The collector considered consists of a PV laminate, an air channel, a back plate and a back insulation material. In the study, a thermal model of a PV/T air solar collector under natural flow mode was developed, validated from experimental data and then used to generate modelling results on the effects of design and operating parameters on the amount of heat transferred to the air in the duct. The results indicate that increasing the air mass flow rate in the range 0 - 0.015 kg/s while keeping the thermal resistance of bottom EVA and tedlar layers very low result into a significant increase in the amount of heat transferred to air.

Key words: PV laminate, heat transfer, thermal resistance, PV/T collector, modeling, wall heat flux

INTRODUCTION

Energy is the key theme for future world development and its demand worldwide is increasing rapidly. Meeting this demand in a sustainable manner will not be possible without major changes in the energy supply systems. The impacts of climate change, caused by Green House Gas (GHG) emissions resulting from the use of conventional energy resources will not only burden economic development worldwide, but will also lead to various natural catastrophes [1]. Transition to renewable energy resources such as solar energy is the key way to mitigate the climate change and its associated effects.

Solar energy technology can broadly be classified into two namely - photovoltaics (PV) technology and solar thermal technology. In a typical PV system, only 5-20% of the incident solar energy is converted into electricity and the remainder becomes waste heat. The heat generated not only creates thermal stresses to the PV module but also increases its operating temperature resulting into a reduction in its electrical conversion efficiency [2].

Hybrid photovoltaic/thermal (PV/T) system addresses the temperature rise of the PV module through heat extraction with a proper natural or forced fluid circulation behind the PV module. The heat extracted can then be utilized for low temperature thermal energy needs. Hybrid photovoltaic/thermal (PV/T) system thus generates electrical and thermal energy simultaneously.

Over the last few decades, efforts have been devoted to improving the performance of PV/T systems while reducing their costs. The early work on the systems was carried out by Martin Wolf [3] who analyzed the possibility of combining the heat and electricity generation for residential use. He concluded that the system was technically feasible and cost effective. The studies that followed focused on the design aspects that will result into a higher efficiency [4-10]. The most recent works on these systems focus on finding the system design and operating factors which would result in increased electrical and thermal efficiencies [11-15]. The studies, however, have not considered the thermal resistance and temperature gradient across the thickness of the PV laminate. This assumption may be valid if the laminate used is an amorphous thin film but may not apply as well for other types of PV laminates. Mechanisms for increasing the heat transferred to the air in the duct also increase the electrical efficiency due to decrease in the PV temperature.

This paper analyses the effects of various parameters on the amount of heat transferred to the air in the duct for a single pass PV/T air system taking into account the thermal resistance of the components of the PV laminate. The system consists of a PV laminate, a back insulation and a rectangular air channel. The circulation of air in the duct is by natural convection.

THEORETICAL ANALYSIS

Figure 1 shows the PV/T Air system studied and the heat transfer mechanisms.

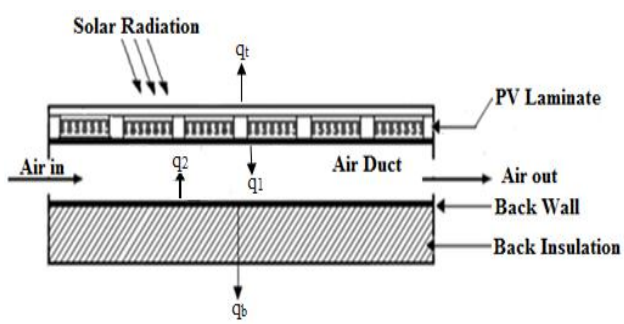

Fig. 1: Basic structure of a PV/T air system

The PV laminate is made up of the solar cells, the top glass cover and the tedlar joined together using EVA adhesive as shown in Fig. 2

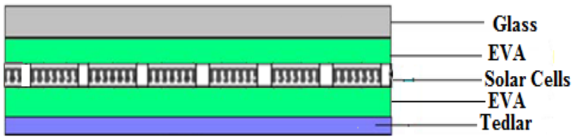

Fig. 2: Components of the PV laminate

THERMAL ANALYSIS

The heat transfers across the components of the PV laminate are shown in Fig. 3.

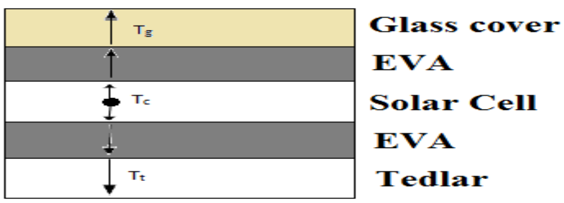

Fig. 3: Heat transfer across the layers of PV laminate

The heat generated by the solar cells is conducted upwards and lost to the ambient at the cover. The part conducted downwards to the tedlar will finally be transferred to the air in the duct. The amount of heat conducted upwards is given by:

$$q_{up} = R_{up} A_{pv} (T_c - T_g) \quad (1)$$

Where R_{up} is the upward thermal resistance and obtained as:

$$R_{up} = \frac{\left(L_{si}/2\right)}{k_{si}} + \frac{L_{eva\ t}}{k_{eva\ t}} + \frac{L_g}{k_g} \quad (2)$$

The amount of heat conducted downwards is given by

$$q_{down} = R_{down} A_{pv} (T_c - T_t) \quad (3)$$

Where R_{down} is calculated as:

$$R_{down} = \frac{\left(L_{si}/2\right)}{k_{si}} + \frac{L_{eva\ b}}{k_{eva\ b}} + \frac{L_t}{k_t} \quad (4)$$

The useful thermal energy, Q_u received by the air flowing along the duct is by two paths. One path is by convection from the tedlar back surface represented by the heat transfer coefficient h_{t-f} and the other is that radiated from the tedlar back surface to the rear surface of the duct and eventually transferred by convection to the air through the heat transfer coefficient h_{b-f}.

$$Q_u = q_1 + q_2 \quad (5)$$

Where q_1 and q_2 are the amount of heat convected to the fluid at the tedlar and rear surfaces respectively.

$$q_1 = A_c h_{t-f} (T_t - T_f) \quad (6)$$

$$q_2 = A_c h_{b-f} (T_b - T_f) \quad (7)$$

A_c is the collector area while T_t, T_b and T_f are the tedlar temperature, rear plate temperature and the mean air temperature in the duct respectively.

It is assumed that the rear surface of the duct is well-insulated, so that this surface is effectively adiabatic, and all the energy reaching it by radiation from the front surface is transmitted back into the fluid by convection. Hence $q_b = 0$ and h_{t-f} can be considered equal to h_{b-f} so that [14]

$$h_{t-f} = h_{b-f} = h_c \qquad (8)$$

For laminar flow in a duct between parallel plates, the convective heat transfer coefficient can be obtained as [15]

$$h_c = \frac{N_u k}{D_h} \qquad (9)$$

N_u is the nusselt number that gives the ratio of convective to conductive heat transfer across (normal to) the boundary, D_h is the hydraulic diameter which for non-circular ducts is calculated as [16]

$$D_h = \frac{4(W \times H)}{2(W+H)} \qquad (10)$$

RESULTS AND DISCUSSION

(i) Effects of Mass Flow rate

Fig. 4 and fig. 5 shows that the heat fluxes q_1 and q_2 and the convective heat transfer coefficient h_c all increase with mass flow rate but the outlet temperature decreases. This is due to the fact that the thin boundary fluid layer (viscous sub layer) which would otherwise increase the heat transfer resistance between the tedlar and the working fluid is broken at high values of mass flow rate.

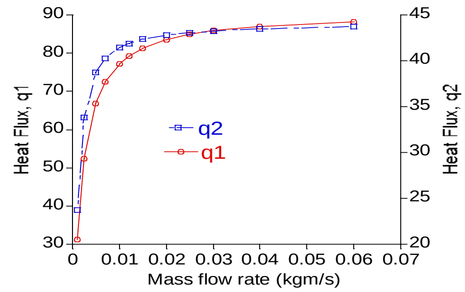

Fig. 4: Effect of mass flow rate on heat flux

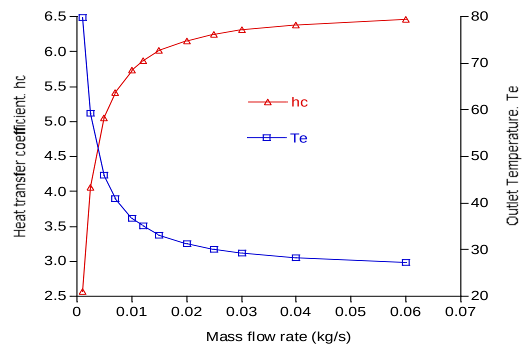

Fig. 5: Effect of mass flow rate on heat transfer coefficient and outlet temperature

(ii) Effects of Ambient Temperature

An increase in the ambient temperature (Fig. 6) leads to a corresponding increase in the air inlet temperature. As a consequence, the difference between the duct wall temperatures and the mean air temperature decreases. This leads to poor heat extraction from the PV module as reflected by the decrease in q_1. It is observed that q_2 is low at first due to low radiative heat exchange between tedlar and back plate. q_2 decreases after Ta=30 ^{o} C due to the narrowing back plate and average air temperature

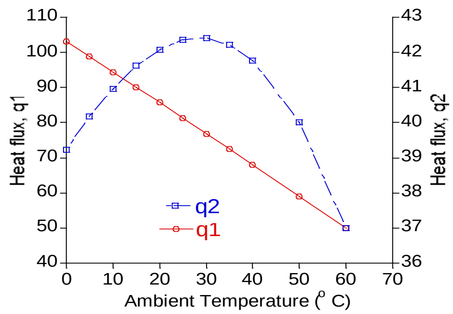

Fig. 6: Effects of Ambient Temperature

(iii)Effects of Thermal Conductivity of tedlar

It is observed from Fig. 7 that an increase in the thermal conductivity of tedlar leads to a corresponding increase in the amount of heat transferred to the air and a decrease in the PV cell temperature.

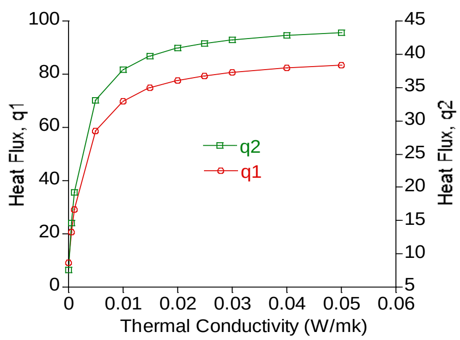

Fig. 7: Effect of thermal conductivity of tedlar

(iv)Effects of thickness of bottom EVA layer

The heat fluxes q_1 and q_2 as depicted in Fig. 8 both decreases with the thickness of bottom EVA layer. This is caused by the increase of thermal resistance as the EVA thickness increases.

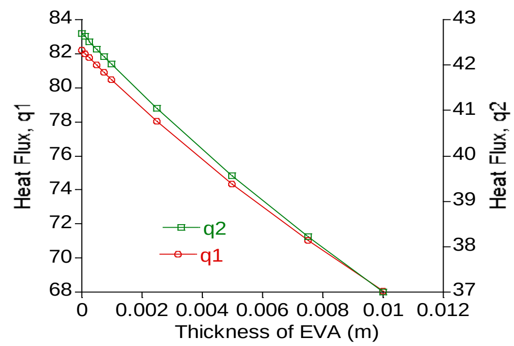

Fig. 8: Effect of thickness of bottom EVA layer

CONCLUSION

The mechanisms to increase the wall heat flux are greatly desirable if the overall efficiency of the PV/T system is to be increased. Increasing q_1 leads to higher overall efficiency. As noted from the results, increasing the mass flow rate from 0 - 0.015 kg/s while reducing the thermal resistance of the bottom EVA layer and the tedlar leads to a significant increase in q_1.

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