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Effects of Thermal Resistance of Encapsulation Material on the Performance of a Single Pass PV/T Air System

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Abstract-- The power rating of PV panels provided by the manufacturers is not often realized in installed PV systems due different operating conditions compared to those specified by the manufacturers. In addition, the calculated outdoor performance based on the PV module temperature measured on its surface is not accurate since it does not take into account the effects of the encapsulation material used. In a hybrid photovoltaic/Thermal (PV/T) system, understanding the effects of the encapsulants on heat transfer is important in order to predict its overall performance accurately. Enhancement of heat transfer coefficients between the various components of the PV laminate and the heat removal fluid can be achieved through the use of encapsulants of appropriate thermal conductivity and thickness. In this study, a thermal model of a PV/T air solar collector taking into account the thermal resistance of the encapsulant material is presented. Energy balance equations for all the components of the system were formulated, coded in FOTRAN95 program and used to study the effects of the thermal resistance of the EVA adhesive used on its performance. The results indicate that both electrical and thermal performances increase for increasing thermal conductivity and decreasing thickness of the bottom EVA layer. However, the electrical efficiency increases while the thermal efficiency decreases with an increase in thermal conductivity of the top EVA layer.

Key words-- *PV panel, PV/T System, Encapsulation, Thermal Model, Thermal Efficiency, Electrical Efficiency*

I. INTRODUCTION

A sustainable energy system needs to build upon technologies whose operation does not cause any environmental problem. Hybrid Photovoltaic Thermal (PV/T) technology; the generation of electrical and thermal energy directly from sunlight is one of these technologies. The development of these systems is engineered by the poor electrical conversion efficiencies of commercially available PV modules which range from 5 to 20% [1]**.** This means over 80% of the incident solar radiation is not converted to electrical energy and is mostly generated in form of waste heat**.** The waste heat increases the operating temperature of the PV module leading to a reduction in its electrical conversion efficiency and may lead to degradation of the PV module due to thermal stress [2]**.** The PV module can be cooled through heat extraction with a proper natural or forced fluid circulation through a duct constructed behind the PV module [3]. The heat extracted can be used for low or intermediate temperature applications such as space heating, domestic hot water, agricultural crop drying etc. The system therefore generates both electrical and thermal energy at the same time thus achieving a higher energy conversion rate of the absorbed solar radiation**.** These systems are cost-effective solutions to rural electricity and thermal energy needs and have found practical application in Building Integrated Photovoltaics (BIPV) [4]**.**

Based on the heat transfer media, flat plate PV/T collectors can be classified into PV/T water collector, PV/T air collector or a combination of the two [5]. They can also be classified as either single pass or double pass depending on the passage of the fluid inside the duct [6].

Extensive investigations both experimental and theoretical have been carried out by many researchers since the mid 1970s on the design optimization of this hybrid collector in search of a more efficient and cost effective designs [7-10]. The optimization studies should also focus on the goal of improving the lifetimes of PV modules. The degradation mechanisms of PV modules due to prolonged exposure to sunlight call for the need for optimizing the manufacturing processes in order to extend their lifetimes. The multiple layers of a module are bonded or laminated together using a suitable encapsulant material. The encapsulant material must have high optical transmittance, good adhesion to different module materials and adequate mechanical compliance to accommodate stresses induced by the differences in thermal expansion coefficients for glass cover and PV cells [11].

Over the years, the dominant encapsulant material in the PV industry has been EVA (Ethylene Vinyl Acetate) polymer due to its competitive costs compared to other known polymers [12]. A significant amount of research has focused on the effect of degradation and discoloration of cured EVA films on the efficiency of laminated PV modules [13]. The published works have shown that when EVA films are used with the Cerium-doped glass cover, the performance loss associated with “browning” is not considered to be a significant problem [14].

Of greater concern; from the module lifetime perspective; is the fact that the solar cells also undergo degradation due to overheating caused by the portion of the incident solar radiation that is not converted to electricity. Proper heat dissipation from the solar cells ought to be addressed in order for PV module manufacturers to achieve the projected 30-year product lifetimes. The thermal resistance introduced by the EVA adhesive at the cell-glass and cell-tedlar interface has a significant influence on the heat transfer coefficients and hence on the PV cell temperature.

In this paper, a steady state thermal model is developed to simulate the effects of the thermal resistance of EVA on the performance of a single-pass PV/T Air system. These effects will be analyzed based on the thermal conductivity and thickness of EVA which determine its thermal resistance.

II. PV/T AIR COLLECTOR DESIGN

The PVT/Air system studied consists of a PV laminate, a back absorber plate and back insulation. Air flows in the channel formed between the PV laminate by natural convection. The magnified view of the PV laminate is shown schematically in figure 1. The laminate consists of solar cells sandwiched between a glass top cover and a tedlar back bonded together using an adhesive EVA layer [15].

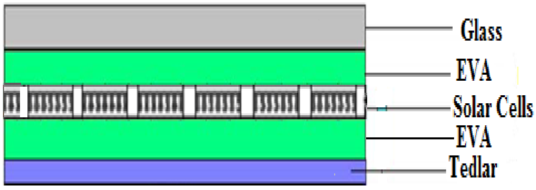

Figure 1: Structural Components of the PV laminate

III. THEORETICAL ANALYSIS

A small portion of the incident solar radiation absorbed by the cell is converted to electricity and the rest appears as waste heat raising the temperature of the cell to T_c. This heat is distributed among the various components of the PV laminate through conduction process. A fraction of this heat will eventually reach the fluid by convection process. The energy balance equations were constituted as follows:

A. Glass cover

On the glass cover, the absorbed solar radiation and that conducted from the PV cell and tedlar is balanced by that lost at the top. The energy balance for the cover is:

$$\alpha_g G + k_{c-g}(T_c - T_g) = U_t(T_g - T_a) \qquad (1)$$

Where $k_{c\text{-}g}$ is the heat transfer coefficient between the PV cells and the glass cover while U_t is the overall top loss coefficient.

$k_{c\text{-}g}$ is calculated as:

$$k_{c-g} = \left(\frac{L_e}{k_e} + \frac{L_g}{k_g}\right)^{-1}$$

U_t is determined using the equation:

$$U_t = \left(\frac{1}{h_w} + \frac{1}{h_{r,g-s}}\right)^{-1}$$

h_w and $h_{r,g\text{-}s}$ are convective heat transfer to the ambient and radiative heat loss coefficient to the sky.

B. PV Cell.

The energy absorbed by the PV cells which is not converted to electricity is balanced by the energy conducted from the cells to the cover and the tedlar.

$$\tau_g \alpha_c GP(1-\eta_{PV}) = k_{c-g}(T_c - T_g) + k_{c-t}(T_c - T_t) \qquad (2)$$

Where $k_{c\text{-}t}$ is the heat transfer coefficient between the PV cells and the tedlar calculated as:

$$k_{c-t} = \left(\frac{L_e}{k_e} + \frac{L_t}{k_t}\right)^{-1}$$

C. Tedlar

The energy absorbed by the tedlar through the spaces not occupied by the solar cells and that received from solar cells via conduction is balanced by the energy transferred to the back plate via radiation and that transferred to the fluid via convection.

$$\tau_g \alpha_t G(1-P) + k_{c-g}(T_c - T_t) = h_{r,t-b}(T_t - T_b) + h_{c,t-f}(T_t - T_f) \qquad (3)$$

D. Air in the duct

The heat absorbed by the air is equal to the heat energy gained from the tedlar and the back plate via convection

$$\dot{m}C_p(T_o - T_i) = h_{c,t-f}(T_t - T_f) + h_{c,b-f}(T_b - T_f) \qquad (4)$$

E. Back absorber plate

On the bottom plate, the heat gained from the back surface of tedlar via the radiation and is balanced by the heat lost to the ambient via the conduction and that transferred to the air via convection.

$$h_{r,t-b}(T_t - T_b) = U_b(T_b - T_a) + h_{c,b-f}(T_b - T_f) \qquad (5)$$

The heat transfer coefficients were calculated as:

$$h_{c-g} = \left[\frac{L_{si}/2}{K_{si}} + \frac{L_{eva},t}{k_{eva},t} + \frac{L_g}{k_g}\right]^{-1}$$

Where L_{si}, L_g and $L_{eva,t}$ are the thickness of silicon solar cell, glass cover and top EVA layer respectively while k_{si}, $k_{eva,t}$ and k_g are the thermal conductivities of these materials in the same order.

$$h_{c-t} = \left[\frac{L_{si}/2}{K_{si}} + \frac{L_{eva},b}{k_{eva},b} + \frac{L_t}{k_t}\right]^{-1}$$

L_t and k_t are the thickness and thermal conductivity of tedlar respectively

IV. THEORETICAL SOLUTION PROCEDURE

The expressions for the temperatures of various nodes of the system were obtained from equations (1)-(5) and coded into FORTRAN95 simulation program then solved through iteration. The heat transfer coefficients were calculated using the standard heat transfer relations summarized in Duffie and Beckman [16]. In each iteration step, the calculated value of T_o is compared with the previous value and if they differ, the value of the air mass flow rate is adjusted. The process is repeated until the difference between the subsequent values of T_o is less or equal to 0.1 ^oC. The iteration loop is then iteration loop is exited and the final output values are generated.

V. RESULTS AND DISCUSSION

A. Effects of EVA Layer

The presence of EVA layer at the interface between the PV cells and tedlar or PV cells and glass introduces heat transfer resistance which affects the heat transfer coefficients $k_{c\text{-}g}$ and $k_{c\text{-}t}$ and hence performance of the PV/T system. The effects of the thermal conductivity of the bottom EVA layer on the heat transfer coefficients and the efficiencies is shown in figure 2 and figure 3. The results show that an increase in the thermal conductivity of bottom EVA layer leads to an increase in both the electrical and the thermal efficiencies. This is due to an increase in the amount of heat transferred from the solar cells to the tedlar and finally to the air flowing in the duct.

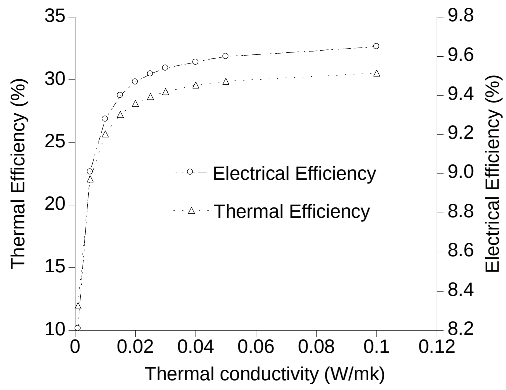

Figure 2: Effect of thermal conductivity of the bottom EVA layer

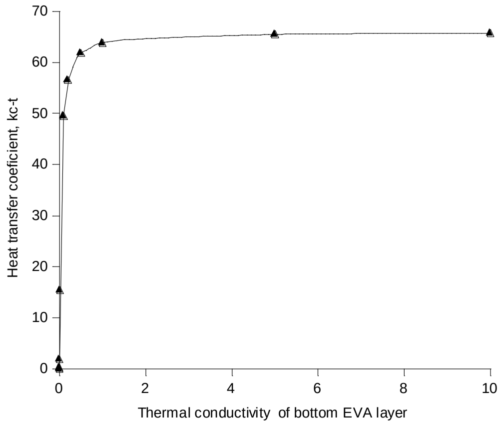

Figure 3: Effect of thermal conductivity of bottom EVA layer

On the other hand, an increase in the thermal conductivity of the top EVA layer results into an increase in k_{c-g} with a corresponding increase in electrical efficiency as seen in figure 4 and figure 5. The thermal efficiency, however, decreases due to an increase in the amount of heat transferred from the PV cells through the top EVA layer and lost to the ambient through the glass cover.

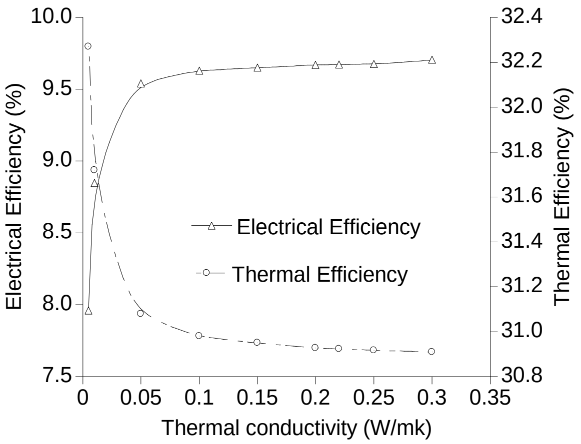

Figure 4: Effect of thermal conductivity of top EVA layer

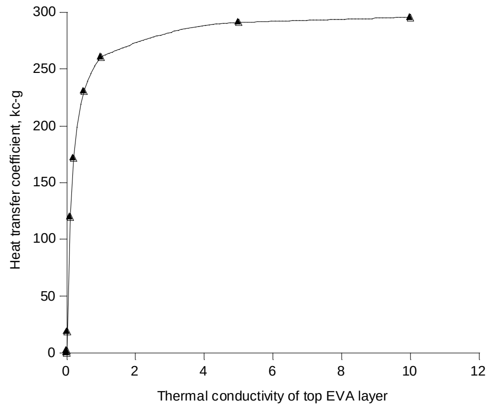

Figure 5: Effect of thermal conductivity of top EVA layer

Figure 6 and figure 7 show the effect of the thickness of the EVA at the PV cell-tedlar interface on the performance of the system. As seen from the results, an increase in the thickness of bottom EVA leads to a decrease in both the electrical and thermal efficiencies. This is due to a reduction in the amount of heat transferred from the PV cell to the air in the duct through the EVA layer. As a consequence, the PV Cell temperature increases as shown in figure 8 causing the observed reduction in the electrical efficiency.

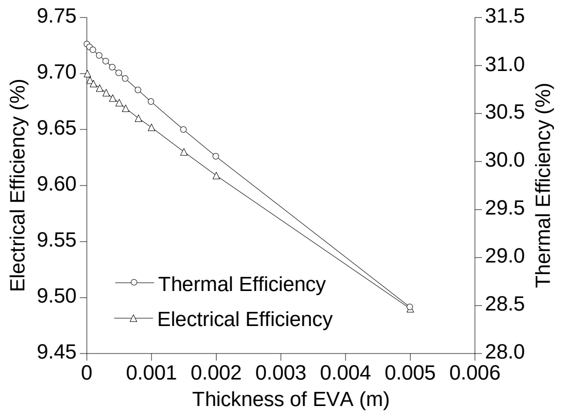

Figure 6: Effect of thickness of bottom layer of EVA on the efficiency

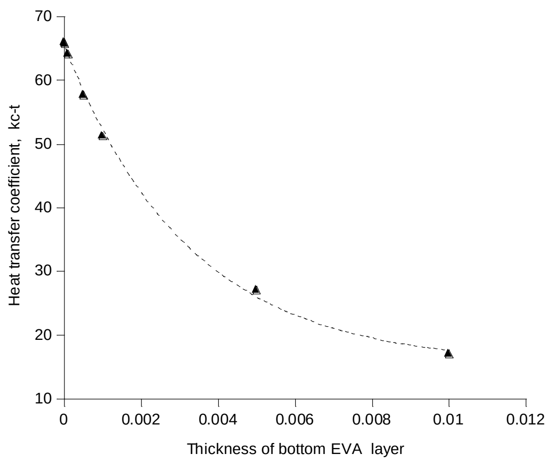

Figure 7: Effect of thickness of bottom EVA layer

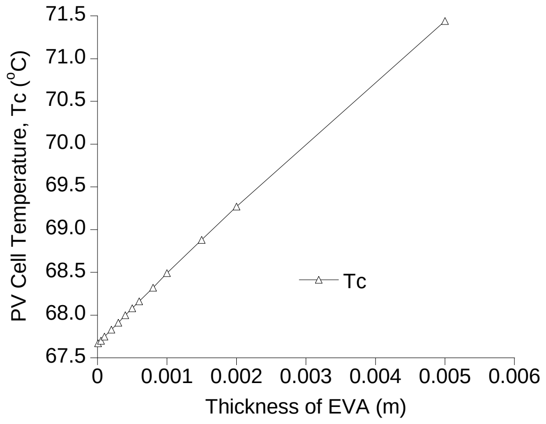

Figure 8: Effect of thickness of Bottom layer of EVA on PV Temperature

CONCLUSION

The developed simulation model for predicting the performance of a hybrid PV/T air system has been presented. It has been observed that the thermal, electrical and total PV/T efficiencies are dependent on the thermal resistance of the EVA encapsulant used. A reduction in the thermal resistance of the bottom EVA layer leads to an increase in both the electrical and the thermal efficiency.

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