Performance of double –pass solar collector with CPC and fins for heat transfer enhancement

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Abstract. 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 (air or water) with the photovoltaic module. Such unit is called photovoltaic / thermal collector (pv/t) or hybrid (pv/t). In this unit, photovoltaic cells were pasted directly on the flat plate absorber. An experimental study of a solar air heater with photovoltaic cell located at the absorber with fins and compound parabolic collector for heat transfer enhancement and increasing the number of reflection on the cells have been conducted. The performance of the photovoltaic, thermal, and combined pv/t collector over range of operating conditions and the results was discussed. Results at solar irradiance of 500 W/m² show that the combined pv/t efficiency is increasing from 37.28 % to 81.41 % at mass flow rates various from 0.029 to 0.436 kg/s..

1. Introduction
Solar energy is one of the most important source renewable energy that world needs, the major applications of the solar energy can be classified into two categories; thermal system and photovoltaic system. Normally these systems are used separately, now these systems can be combined to become hybrid photovoltaic thermal system (pv/t). A number of researches and development programs have been carried out to improve the applications of solar energy systems. Several design of photovoltaic thermal solar air collector has been proposed in the past. Among the first, Kern and Russel [6] are the first who give main concept of photovoltaic thermal collector using water or air as the working fluid. Hendrie and Raghuraman [5] have been made a comparative experimental study in (pv/t) collectors with liquid and air as the heat removal fluid (working fluid). Cox and Raghuraman [3] suggested air type photovoltaic thermal system by analysis the effect of various design variables on the performance of the system. Lalovic et al. [7] fabricated photovoltaic thermal collector using amorphous Silicon pv cell and its performance was tested. Garg et al. [4] presented the theoretical study of (pv/t) collector with reflectors; they found that the system is well suited for solar drying applications. Bharagava et al. [2] and Prakash [8] reported the effect of air mass flow rate, air channel depth, and packing factor. Sopian [9] have successfully demonstrated the improved performance of steady state double pass collector over the single pass collector due to efficient cooling of pv cells. Bergene and Lovvik [1] found that the thermal efficiency may increase only by a factor of 0.1 if flow rate increase from 0.001 to 0.075 kg/s. Sopian et al. [10] developed and tested a double pass photovoltaic collector suitable for solar drying applications and they comparison between theoretical and experimental results.
Tripanagnostopoulos et al. [11] built and tested various photovoltaic thermal collector models with both water and air as the working fluids. Zondag et al. [12] compared the efficiency of seven different design types photovoltaic thermal collectors.

2. Experimental Setup
The design of the double pass photovoltaic thermal collector with (CPC) and fins which considered in this paper is shown in Figure 1.

![Figure 1. Schematic diagram for double pass (pv/t) collector with (CPC) and fins.](image)

The system have three essential static components which are: a glazing on the top, back plate, absorber plate painted black and containing solar cells, CPC with concentration ratio of 1.86 is used as a reflector and located parallel to the air flow. 29 rectangular fins with density of 0.384 fin/cm, each fin 2.5 cm high and thickness of 0.1 cm attached along the length of the back of the absorber plate. 23 tungsten halogen lamps each rated at 500 W used to simulate solar radiation during the test. The intensity of the incoming solar radiation was measured by Eppley pyranometer. Ambient temperature and other temperatures at several positions of the system are measured by K-type thermocouple. The air is supplying to the collector at uniform rate from electrical blower, the air mass flow rate calculated from the air velocity which measured by HTA 4200 anemometer of the van type probe head. All these things connected direct to the data acquisition system to feeds them to the computer. The collector dimension is (0.755 * 1.22) m. the high of the upper channel is 16.5 cm and the lower channel is 12.5 cm. the total area covered by solar cells is 0.38 m². The sides and bottom of the collector are insulated with 5 cm of glass wool. In our configuration; inlet air enters through the upper channel formed by the glass cover and absorber plate and then through the lower channel formed by absorber plate with fins and the back plate. Air is circulated for one hour prior to the period in which data are taken. Data are sampled using the application program of the data acquisition system named DasyLab. Data include the solar radiation, temperatures, and mass flow rate.

3. Results and Observations
The performance parameters of combined photovoltaic thermal solar collector are obtained in terms of the solar cell efficiency and the thermal efficiency. The thermal efficiency of the double pass collector with CPC and fins is as follows:

\[
\eta_{th} = \frac{m \cdot c_p \int (T_\text{n} - T_\text{a}) \, dt}{A_{\text{tot}} \cdot CR \int T_{\text{in}} \, dt}
\]

The solar cell efficiency is as follows: \( \eta_{\text{pv}} = \frac{\eta_{\text{ref}}}{1 - 0.0045 \left( T_{\text{pv}} - T_{\text{ref}} \right)} \)

\( \eta_{\text{ref}} \) is the reference efficiency of the solar cell at \( T_{\text{ref}} = 25^\circ \text{C} \) which is in our study 10 %. The efficiency of the combined photovoltaic thermal collector is defined as the sum of thermal efficiency and electrical efficiency as:
The electrical efficiency is as follows:

\[
\eta_{\text{elect}} = \eta_{\text{thermal}} + \eta_{\text{electrical}}
\]

The electrical maximum power of the collector increases with the radiation intensity increase as can be seen in Figure 2. The air temperature rise decreases with increasing of mass flow rate as shown in Figure 3. Figure 4 shows the effect of radiation intensity on the temperature at various flow rates. In this Figure it can see that the temperature rise linearly to the solar radiation, so the collector which operate with high solar radiation levels experience high temperature rise. It can see also that at the same solar radiation the collector which operates at low mass flow rate will experience high temperature rise too. The effect of the mass flow on the efficiencies (photovoltaic, thermal, and combined pv/t) of the collector was shown in Figure 6. The experimental results show that, when the collector is operating at high mass flow rate; the efficiencies (photovoltaic, thermal, and combined pv/t) will increase. This is expected when the photovoltaic panel is cooled by the incoming air. As seen in figure 5 the photovoltaic efficiency is 9.72% to 9.78% at solar radiation of 500W/m² and inlet temperature of 25°C. The thermal efficiency is 27.55% to 71.68%. The combined pv/t efficiency is 37.28% to 81.41%. We can see that the combined pv/t efficiency is decrease at low flow rate because the mean photovoltaic temperature is high. Therefore, cooling of the photovoltaic cells by increasing the mass flow rate will increase the combined photovoltaic thermal efficiency.
Conclusions

Results show that the electricity production in a PV/T hybrid module decreases with increasing temperature of the air flow. This implies that the air temperature should be kept as low as possible. On the other hand, the system should deliver hot air for other purposes. A trade off between maximizing electricity production and producing hot air of useful temperatures is thus necessary. The simultaneous use of hybrid PV/T, CPC and fins have a potential to significantly increase in power production and reduce the cost of photovoltaic electricity.

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