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Experimental Study of Temperature Influence on the Electrical Performance of Polycrystalline Photovoltaic Cell

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A thermal photovoltaic hybrid collector enables simultaneous electrical conversion of the solar radiation and recovery of heat absorbed by the cell. This energy cogeneration obviously yields the use of such systems which are very interesting in various fields. During the actual operation of the photovoltaic modules, the experimental characterization shows that the electrical efficiency decreases significantly with increasing temperature of the photovoltaic cells exposed to the sun. Our work focuses on an experimental study carried out in thermal transfer laboratory at the Faculty of Technology of the Tlemcen University, in order to analyze the effect of cell temperature, glazing on electrical performance, also the effect of the cooling of this cell.

Keywords: Thermal photovoltaic hybrid, electrical conversion, electrical efficiency, cell, cooling.

1. Introduction

The sun is everywhere; it is an environmentally friendly renewable source of energy. Today, solar energy is captured and then converted into two types of energy, thermal or electrical, using three different methods and technologies: passive solar energy, active solar energy and photovoltaic energy.

Between 12 and 18% of the incident solar energy can be converted by classical photovoltaic (PV) module, that is based on the crystalline silicon technology, Indeed, the PV module absorbs between 80 and 90% of the incident radiation, most of which is dissipated as heat. Consequently, the temperature inside the module increases. This temperature rise reduces significantly the electrical efficiency of the module. When the temperature rises by 1° C in a crystalline silicon solar cell, its conversion efficiency from solar to electrical energy decreases from 0.4 to 0.5% [1,2].

Various experimental and theoretical studies have been carried out for the development of PV/T hybrid collector. Most researches in this field attempt to evaluate the thermal and electrical performance and to analyze the economics of hybrid systems. So, some authors emphasize the development of analytical thermal models or then put an electrical analogy. Another research aimed at optimizing the performance of existing solar collectors by improving operating conditions (inclination, orientation of the collector, etc.) or by proposing innovative geometric configurations. Thus, they are based on the change in dimensions or properties of the constituent materials (thermal insulation, absorber, photovoltaic cells, etc.) or heat transfer fluids (air, water, etc.). These improvements are intended to increase the amount of absorbed solar energy and the heat transfer between fluid and the absorbent to reduce heat losses. Sandberg and Moshfegh [3,4] propose theoretical and experimental study of the thermal and dynamic phenomena within the air channel, allowing natural ventilation of the underside of the photovoltaic cell. Parametric studies have shown that the dimensions, position of the PV modules and the length of channel have a strong influence on the thermal and dynamic behavior of the system [3].

The mass flow effect on the performance of a PV/T single pass with the presence of fins, has been studied by Alfegi et al. [5, 6]. The experimental system contains photovoltaic cells placed at the top. The experiment was performed to examine the effect of mass flow. The results show that the efficiency of the PV module has increased from 49.135% to 62.823%, with a mass flow rate ranging from 0.0316 to 0.09 kg/s, a radiation of 600 W/m^2 and an inlet temperature of 35° C. The performance analysis of a dual-pass PV/T hybrid solar collector with fins has been well studied [7–9]. They proved that installing fins on the back of the collector improves heat transfer. The collector consists of three main components: glass cover at the top, photovoltaic panel and absorber at the bottom. The air passes through the upper part between the glazing and the PV panel and passes through the lower part between the panel and insulation. The fins were manufactured using aluminium to increase the ability to extract heat from PV module in order to increase collector efficiency.

Tiwari et al. [10] presented a theoretical and experimental study of a solar PV/T air collector with natural or forced ventilation. Solanki et al. [11] developed an experimental procedure for a PV/T collector, and compared it with a theoretical model that is based on energy conservation assessments. Joshi et al. [12] conducted a study to evaluate the thermal performance of a hybrid (PV/T) air collector. Two types of photovoltaic module (PV) were studied to compare these performances, where the first is a PV module placed between glass and tedlar and the second is placed between glass-glass.

Khelifa et al. [13] carried out a study based on an approach that combines the two numerical and experimental results and relates to the feasibility of water heating by hybrid solar collectors PV/T. Baloch et al. [18] investigated, experimentally and numerically, the influence of air flow in a converging passage, on cooling PV modules, for different angles.

Nougblega et al. [15] carried out an analysis of the thermal and electrical performance of two types of thermal solar hybrid photovoltaic collectors that can be integrated into building roofs. Othman and others [16] studied the performance of a PV/T solar collector constructed and tested in solar energy laboratory, Faculty of Science and Technology, Kebangsaan University Malaysia. Reteri and Korti [17] are studied the influence of temperature on the electrical behavior of the PV cell with and without forced convection cooling.

Our work deals with an experimental study on the cooling of a photovoltaic cell where air is the heat transfer fluid.

2. Experimental Setup

In order to evaluate the influence of temperature on the electrical performance of a photovoltaic cell, Fig. 1, an experimental system was proposed in the laboratory of heat transfer at the faculty of technology of Tlemcen University, Algeria. The main components of the experimental device are illustrated in Fig. 2. The schematic explication of the operation is shown in Fig. 3. The experimental system contains a tedlar plate under a polycrystalline photovoltaic cell and a supposed glass on this cell (width 155 cm, length 155 mm). An air duct leads a fan to the end to adjust the flow rate and its direction. A projector is used as a thermal radiative light source. Two multimeters are used to measure the voltage and current intensity generated by the cell. The study of the temperature variation during the experiments requires thermocouples placed in different positions to measure the cell temperature, tedlar and the air at the inlet and outlet. A potentiometer is used as an electrical load to measure the voltage in series.

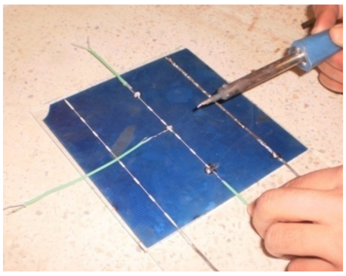

Figure 1 Welding of thermocouples on the polycrystalline photovoltaic cell

Figure 2 Experimental device

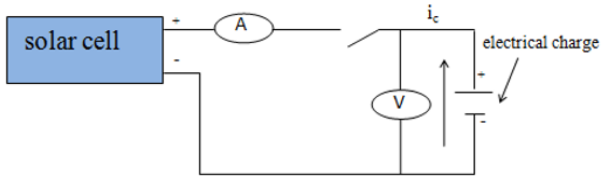

Figure 3 Performed electrical installation

3. Results and Discussion

To determine the radiation intensity generated by the projector as a function of the distance, we used the radiative transfer test bench available in the thermal transfer laboratory, see Fig. 4.

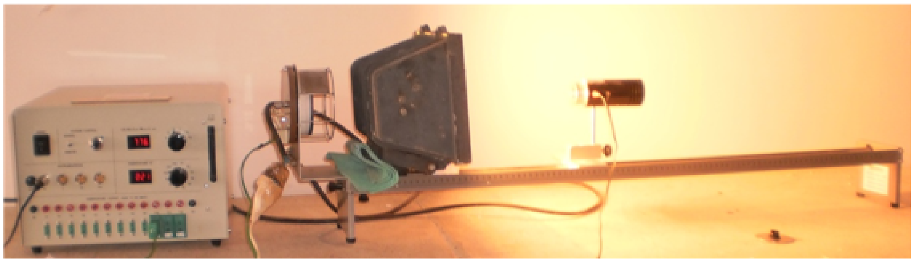

Figure 4 Radiate transfer unit

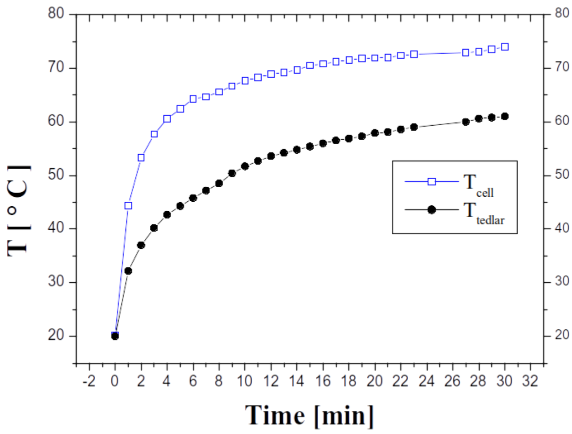

Figure 5 Evolution of radiation intensity as a function of distance

Figure 5 shows the radiation intensity variation of radiation of the projector as a function of the distance. We note that the intensity of the radiation is inversely proportional to the square of the distance (the law of inverse of square of Lambert).

In order to examine the operation of the photovoltaic solar cell, we have heated it for 30 min from 800 W/m^2 as radiation intensity, until the temperature of the cell starts to stabilize and then let it cool by natural convection by turning off the projector.

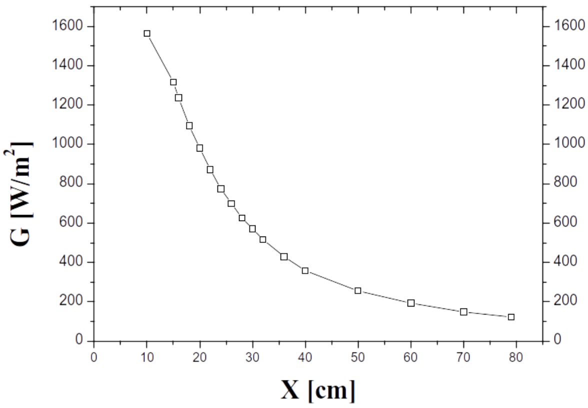

Figure 6 Evolution of cell and tedlar temperature during 30 min

Figure 6 shows the temperature evolution of the cell and tedlar as a function of time with a radiation of 800 W/m2. During 8 min, it is observed that the temperature of the cell T_{Cell} increases notably to a value of $T_{Cell} = 64.3°$ C as well as the tedlar where its temperature increases up to $T_{ted} = 47.2°$ C. The difference between the two temperatures reaches a maximum value of 33.6° C at $t = 13$ min. After $t = 25$ min, both temperatures stabilized at maximum $T_{Cell} = 73.5°$ C and $T_{ted} = 61°$ C due to thermal equilibrium between the radiative source and the cell. We have also noticed that the rate of heating of the cell is greater than the heating rate of tedlar, because the cell play the role of absorber and the thermal conductivity of cell and tedlar is very low.

At the end of the first step: $I = 800$ W/m2 and $T_{amb} = 19°$ C; $T_{Cell} = 73.5°$ C; $T_{ted} = 61°$ C; $I_c = 0.67$ mA and $U = 0.496$ V. Then we switched off the projector and used only the laboratory lighting as a radiative source to let the cell cool down. At the beginning of the second step: at $t = 0$ s $T_{cell} = 67.3°$ C, $I_c = 0.2$ mA, $U = 0.139$ V. Figure 7 shows the variation of the temperature of the cell and the electric power as a function of time. It can be seen that cell temperature begins to decrease until reaching a value equivalent to the ambient temperature. The decrease in temperature causes an increase in electrical power up to a maximum value $P = 0.1068 * 10^{-3}$ W at $T_{cell} = 24.5°$ C at $t = 19$ min and then begins to decrease with decreasing temperature. Our results show that $T_{cell} = 24.5°$ C is the optimum temperature of cell operation. Figure 8 shows the effect of the glazing on the variation of the temperatures of the cell and tedlar as a function of time with a radiation of 800 W/m^2. It is noted that the presence of glazing leads to a decrease in the temperature of the cell and an increase in temperature of tedlar this is due to the absorption of heat by the glazing and the absence of the convective transfer

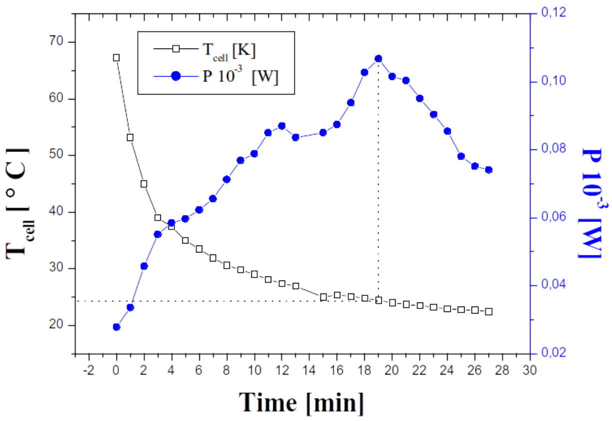

Figure 7 Evolution of cell temperature and electrical power during 28 min

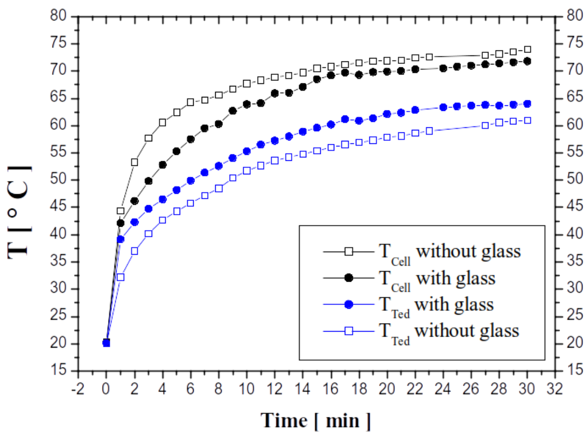

Figure 8 Evolution of cell and tedlar temperature with and without glazing during 30 min

from cell to the atmosphere. Therefore, conduction is the mode of heat transfer that dominates in the cell. It is also noted that the addition of the glazing minimize the gap between the cell and tedlar temperatures.

Figure 9 shows the shape of the electrical efficiency and the cell temperature as a function of time. We find that the maximum value of the electrical efficiency is notable just after the power supply of the projector, then it decreases with the increase of the temperature. Our results show the influence of temperature on the electrical efficiency. The temperature of the photovoltaic cell will be lowered by extracting heat by the forced circulation of air through the channel.

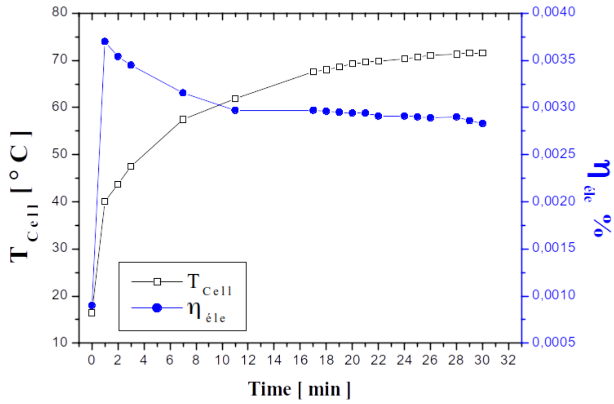

Figure 9 Evolution of cell temperature and electrical efficiency during 30 min

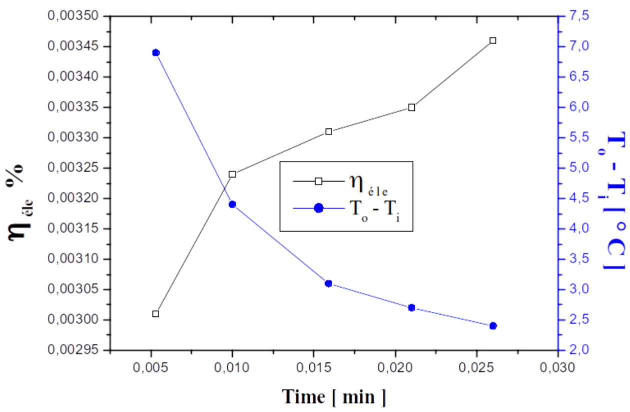

Figure 10 Evolution of electrical efficiency and air temperature difference between inlet and outlet as a function of mass flow

Figure 10 shows the cooling effect on the electrical efficiency. It is noted that the increase in the mass flow through the channel causes a decrease in the temperature difference ($T_{outlet} - T_{inlet}$) of air, where $\Delta_T = 7°$ C for 0.005 kg/s, $\Delta_T = 2.4°$ C for 0.026 kg/s due to the decrease in stay time within the channel. The increase of the flow rate from 0.005 to 0.025 kg/s allows an increase in the electrical efficiency with a gain of 0.0005% justified by intensification of convective exchange rate (the cooling rate).

4. Conclusions

During the photovoltaic conversion in the solar collector, heat is generated, thus increases the photovoltaic cell temperature and causes a drop in its efficiency. The aim of this work is to increase the electrical efficiency of the collector, i.e. its electrical efficiency by decreasing the temperature using forced air convection cooling.

Our experiments are done on the realized collector which contains a single cell (under the standard conditions).

- Primarily, we have validated the Lambert law of inverse of square; the radiation intensity is inversely proportional to the square of the distance.
- We concluded that temperature is a very important parameter in the photovoltaic solar cells behavior. The optimum temperature of operation is 24.5° C as well as PV panels, because the electrical performance of a solar cell is very sensitive to it. So a cooling of the PV panel was necessary in this case.
- The introduction of the glazing decreases the temperature of the cell and leads to an increase of tedlar temperature.
- The increase in mass flow rate has a positive influence on the cooling of the cell, which leads to an increase in the electrical efficiency. On the other hand, this increase gives unsatisfactory results for the temperature of the air at the outlet.

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