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The Effect of Jet Impingement on the Performance of a Photovoltaic Module

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Abstract – The cell temperature of a photovoltaic (PV) module increases with increasing irradiation rate, and this increment adversely affects the output power or the electrical efficiency of the PV module. Therefore, in the present study, a series of experiments are performed to investigate the effect of cooling phenomenon on the performance of a PV module. To cool the module, an air impinging jet apparatus is installed at the back side of it. Experiments are performed at various values of flowrate (Q = 100, 200 and 300 LPM, liter per minute) and heat load (q_L = 150, 300 and 450 W). A multiple jet configuration is designed with six nozzles, and the dimensionless nozzle-to-plate distance (H / D) is kept constant at 8. It is concluded that the average surface temperature of the PV module can be decreased up to nearly 61.5% and the output power of the PV module can be improved up to 13.2% through the impinging air jet.

Keywords – Impinging Air jet, Photovoltaic Cell, Performance, Solar Energy, Flowrate

I. Introduction

The usage of fossil-sourced fuels leads to increment of the hazardous waste, and thus, the life comfort decreases or the health of the organisms falls into danger. In this regard, renewable energy sources are encouraged to meet the energy demand. Solar energy is one of the most popular renewable energy sources, and photovoltaic (PV) panels are used to convert the solar energy to the electrical energy. However, when a photovoltaic cell is exposed to solar radiation it can only transform limited amount of incident radiation into electrical power. The rest of the absorbed energy causes temperature rise of the cell, which decreases the panel performance. Thus, lots of researchers have performed different methods to decrease the cell temperature for better performance.

Odeh and Behnia [1] used a water cooling system to decrease the cell temperature. They achieved approximately 15% improvement in module performance at maximum incident radiation. Shahsavar et al. [2] combined a heating ventilating and air conditioning (HVAC) system and a PV panel to utilize the potential of waste energy for enhancement of energy efficiency. They cooled the PV panel with the air flow of the HVACs, and also, they used the waste heat of the PV panel as a heat load for ventilation. The increment of the electrical efficiency of the PV module was achieved as 7.2%. Teo et al. [3] developed a hybrid photovoltaic/thermal (PV/T) system. They cooled the back side of the panel with air flow. They concluded that the efficiency of the panel was improved from 8-9% to 12-14% through active cooling. Rahimi et al. [4] fabricated a wind tunnel to decrease the temperature of a photovoltaic cell. Also, they used a turbine in the tunnel for generating electrical energy. Depending on both the cooling of the cell and energy generation, they obtained an improvement of 36% in total output power. Arcuri et al. [5] placed a flow duct instead of a cooling apparatus covering all over the backside of the PV panel. They compared the contribution of the water and air cooling. Ebrahimi et al. [6] cooled the PV cell by using natural vapor with different flowrate. They concluded that cell temperature decreased with increasing vapor mass flowrate, and the electrical efficiency was improved up to 22.9% for the highest mass flowrate. Salem et al. [7] experimentally compared the performance of the cooled and uncooled photovoltaic thermal systems. They used three modules; one of them is uncooled and the other ones are cooled. The back surfaces of the cooled ones were covered with a cooling plate including straight and helical channels, respectively. Water was used as the coolant, and they obtained the best overall efficiency for the module including cooling plate with helical channel. Amanlou et al. [8] cooled the PV module with air flow and they focused on the uniform distribution of the flow. To improve the uniformity, they designed a new nozzle with concave side walls and three inner deflectors. The electrical efficiency of the module was improved up to 36%. On the other hand, they achieved enhancement in the efficiency by 13.5% due to increasing coolant (air) flowrate. Vittorini and Cipollone [9] developed a mathematical model to investigate the effect of aluminum fins on the performance of a PV module. The fins were placed by different numbers and layouts. They underlined the importance of the fluid selection and heat spreader design. Fakouriyan et al. [10] used water cooling for increasing the performance of a PV panel. The water was heated through the cooling process of the panel was used in a solar water heater. They concluded that the electrical efficiency of the panel was improved up to 12.3%.

In the previous paragraphs, the negative effect of high cell temperature on the performance of a PV module is emphasized. Also, different cooling methods performed by the researchers are summarized. Consequently, decreasing of the cell temperature is very important for performance improvement. Therefore, the aim of the present study is to enhance the electrical efficiency of a monocrystalline solar module by an active cooling method. In this context, the impinging air jet technique is utilized, and the effect of flowrate of the jet flow on the output power is experimentally investigated under various heat loads.

II. Materials and Method

The photograph of the experimental facility is seen in Fig. 1. The setup may be divided into three subsections: (1) photovoltaic module (2) flow line and (3) measuring instruments. The photovoltaic (PV) module is a monocrystalline type with the dimensions of 430 mm x 315 mm. Above the PV module, a halogen light source (max. 1000 W) is placed to form different heat loads. The distance between the bulb and the module surface is 250 mm. The module consists of six photovoltaic cells, each of which has the dimension of 157 mm x 145 mm. A thin aluminum plate was placed on the back surface of the module. Due to the symmetry and identical properties, one cell is chosen and the temperature measurements are performed over this cell. Before the placement of the aluminum plate, a channel with the height of 1 mm is graved on the aluminum surface to meet the required space for the cables of the thermocouples. The locations of thermocouples (K-type) on the back surface of the cell are shown in Fig. 2.

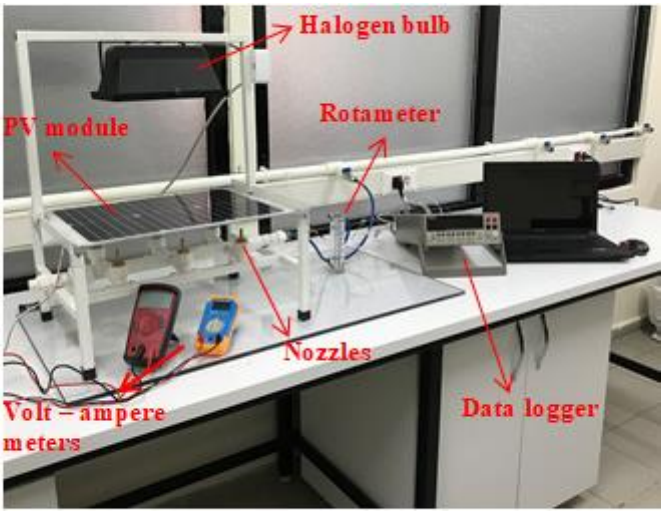


Fig. 1 The photograph of the experimental facility

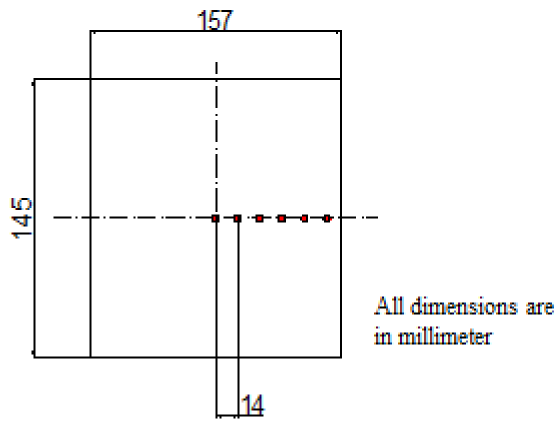


Fig. 2 Thermocouple locations on the back surface of the cell

The jet impinged on the surface of the aluminum plate. In this context, a manifold with six sorties are designed and assembled at the backside of the module. In every outlet, a circular nozzle with the diameter (D) of 5 mm is used, and thus, a multiple impinging jet configuration with six nozzles is obtained. The distance between the nozzle outlet and the aluminum surface (H) is 40 mm. Therefore, the dimensionless nozzle-to-plate distance is 8.

To provide a continuous flowrate and to study the effect of flowrate, a flowline has been established, and the air flow is supplied via a screw compressor. To control the flowrate, two devices are used. One of them is pressure regulator and the other one is rotameter. Also, to eliminate the adverse effects of any contaminant or moisture, the flow is passed through a filter and a dryer unit before the test section.

The flowrate is set to the desired value via a rotameter with the uncertainty of ±3%. The local temperature values over the PV cell are measured with K-type thermocouples (uncertainty in temperature measurement is ±0.1 °C). The output power of the module is calculated by multiplying the current and voltage values for every test condition.

In any experimental run, the experimental procedure can be shortly described as follows:

Before the investigation of the flowrate effect, the system is run without air cooling (flowrate, Q = 0). These tests present reference values. To imitate solar irradiation, the bulb in the system is set to 150, 300 and 450 W, respectively. These values are called as heat loads (q_L). In the cooling tests, the flowrate is set to 100, 200 and 300 LPM (liter per minute, L min^{-1}) for every heat load. Consequently, the screw compressor and dryer units are started. The pressure regulator and the rotameter are adjusted to obtain the desired flowrate value. The bulb is set to the desired heat load. Then, it is waited until to reach the steady condition. When the temperature readings reach the steady state (± 0.5 °C), they are collected via a data logger and computer. Also, the voltage and ampere values are read and noted via the relevant devices. Then, next experimental run is started.

In the experiments, the output power of the photovoltaic module is obtained as follows:

$$P_o = IV \qquad (1)$$

where, I and V represent ampere and voltage, respectively. The cell temperature (T_c) distribution is given for every test condition to show the effect of flowrate on the cell temperature. In this context, the thermocouples are placed on the back surface of a cell as it is shown in Fig. 2.

Another performance evaluation is performed based on the percentage change of the output power. In this regard, the enhancement ratio is defined as in the following form:

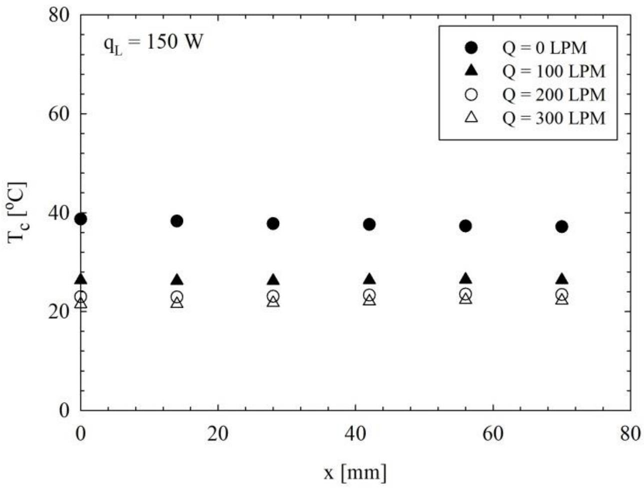
$$ER = \left[\frac{P_{o,\,cooled} - P_{o,\,uncooled}}{P_{o,\,uncooled}} \right] \times 100 \qquad (2)$$

where, P_o denotes output power in any experimental run, and the subscripts of cooled and uncooled represent the test conditions conducted with and without air jet.

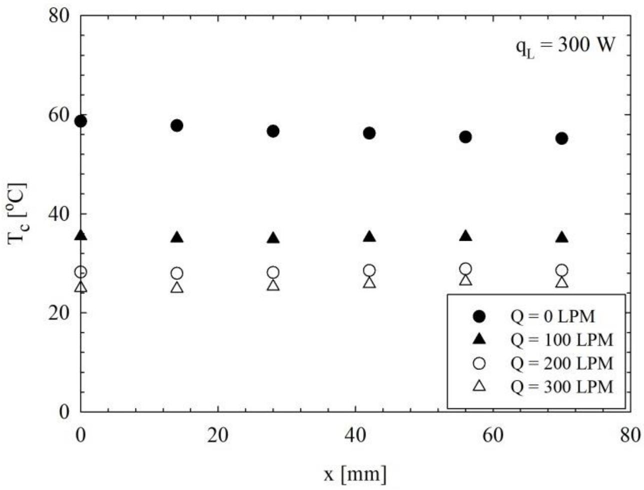
III. Results and discussion

In the present study, tests are performed for various values of flowrate (Q = 100, 200 and 300 LPM) and heat loads (q_L = 150, 300 and 450 W). The separation distance, in other words, the distance between the nozzle exit and the aluminium plate is 40 mm (or H / D = 8).

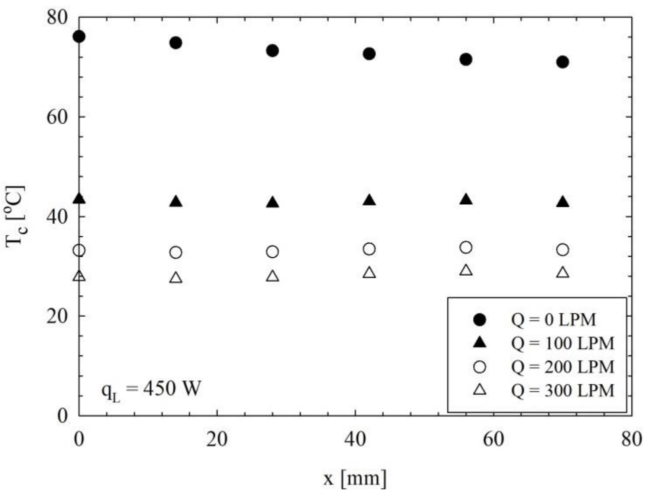
The distribution of the local cell temperature as a function of flowrate is presented for different heat loads in Figures 3a, b and c.



(a)



(b)



(c)

Fig. 3 Distribution of the local cell temperature

In Figure 3, x denotes the distance from the center of the cell to the outer edge (see Fig. 2). When all the graphs in Fig. 3 are investigated simultaneously, it is seen that the cell temperature significantly increases with increasing heat load. In the present study, the maximum value of the heat load is chosen according to the allowable cell temperature. For q_L = 450 W, it is reached nearly 78 °C without impinging jet flow (uncooled condition). However, the cell temperatures obviously decrease with the application of impinging jet flow. The cell temperature decreases with increasing flowrate; while, the rate of decrease decelerates, too. This results indicate a probable optimum value for the flowrate in any given test condition. On the other hand, it should be noted that the effect of the flowrate becomes clear for higher heat loads. Another important result is related to uniformity of temperature distribution. Under the impinging jet conditions, the temperature distribution shows a quite uniform behavior.

As it is also stated by Arcuri et al. [5]; short circuit current increases and the open circuit voltage decreases due to the increment of the cell temperature. However, the percentage change of the voltage is more than the one of the current. Therefore the output power of the module decreases with increasing cell temperature. The obtained results confirm these statements. The detailed graph related to the output power is presented in Fig. 4.

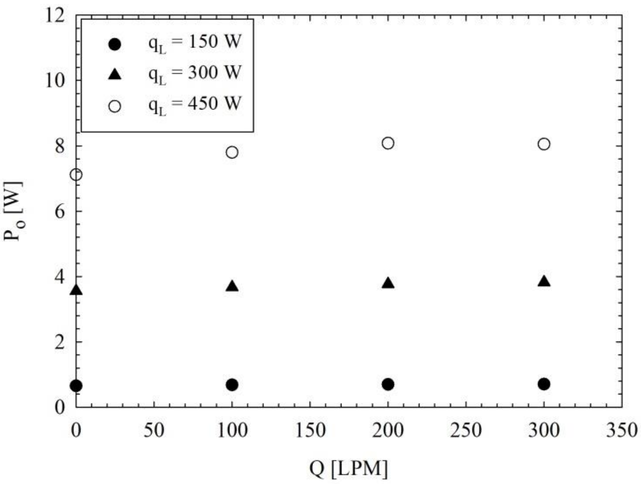


Fig. 4 Effects of both the flowrate and the heat load on the output power

The effects of both the flowrate and the heat load on the output power are seen in Fig. 4. With increasing heat load, the output power increases. Also, especially, in higher heat loads, an obvious enhancement is occurred in the power with increasing flowrate. In the case of q_L = 450 W, the enhancement ratio depending on the change from uncooled condition (Q = 0) to the condition of Q = 200 LPM is 13.2%.

In addition to the Fig. 4, the experimental database representing the values of current, voltage and output power is shown in Table 1. As it is seen in the relevant table, for example, in the case of q_L = 450 W, from Q = 300 LPM to Q = 0 LPM, the current increases, the voltage decreases and the power decreases. The variation in the voltage is more significant than the one in the current.

Table 1. Experimental database including current, voltage and output power

q_L (W)	Q (LPM)	I (Ampere)	V (Volt)	Po (W)
150	**0**	0.04	16.39	0.656
	100	0.04	17.17	0.687
	200	0.04	17.52	0.701
	300	0.04	17.62	0.705
300	**0**	0.20	17.79	3.558
	100	0.19	19.33	3.673
	200	0.19	19.84	3.770
	300	0.19	20.12	3.820
450	**0**	0.41	17.36	7.118
	100	0.40	19.50	7.800
	200	0.40	20.20	8.080
	300	0.39	20.65	8.054

IV. CONCLUSION

In the present study, the effect of flowrate on the performance of a PV module is experimentally investigated for different heat loads. In this regard, a PV module is cooled by impinging air jet with various flowrate, and the results obtained for cooled and uncooled conditions are compared. The results are summarized as follows:

- The cell temperature significantly increases with increasing heat load.
- The cell temperature decreases with increasing flowrate; while, the rate of decrease decelerates, too
- The average surface temperature of the PV module can be decreased up to nearly 61.5% and the output power of the PV module can be improved up to 13.2% through the impinging air jet.
- Under the impinging jet conditions, the temperature distribution shows a quite uniform behavior.
- With increasing heat load, the output power increases.

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