



PV panel Water Cooling Using Different Jet Nozzle Diameter

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Abstract: Power conversion in PV cells is limited to 15-20% from the incident radiation. That conversion Suffers a severe drop with the rise of the PV cell temperature by 0.45~0.5% for each degree centigrade rise. The primary objective of this study is to reduce the cell temperature using front face cooling. A CFD model has been designed using COMSPL Multiphysics 5.3 to investigate the effect of water input temperature and the change of the water flow rate. A physical model was also utilized using two 330 PV panels for comparing the results at the same environmental conditions. The study shows that the PV cell efficiency could be increased by 22.8% using a 2 mm nozzle diameter and 4 L.P.M water flow rates.

Keywords: PV efficiency enhancement, photovoltaic cooling, PV power conversion, solar energy, water film cooling, efficiency enhancement.

1. Introduction

The power conversion in the photovoltaic cell is occurred under a phenomenon called the photovoltaic effect phenomena. The effect depends mainly on solar radiation and the material used to manufacture the cell itself. However, that phenomenon effected by the cell temperature, and the power conversion starts to drop as the temperature drops[1][2][3].Several studies attempt to reduces the cell temperature during the hot seasons. **Ahmed et al.** [4] study the effect of backside air cooling improved by air guides. Using ANSYS software to estimate the results, and the study refers that the optimum air guides should be used for a 2 m long PV panel are 18 and shifted by 70mm from the cell back surface. A passive way to cool the PV panels without consuming power was also studied. **JK Tonui** [5] study three different configurations for natural air circulation for improving the thermal gain from a PV panel using the PV/T system. The results show that all REF, TMS, and FIN configurations are effectively extracting the excess heat from the PV panel with a thermal efficiency of 16%, 18%, and 20%, respectively. Cooling with water has great potential due to water's high thermal conductivity and its advanced thermal performance. **M Mohamed Musthafa** [6] studied water cooling to improve the PV cell performance and reduce the cell temperature by 4 °C and enhance the efficiency of up to 12%. Other research by **K.A. Moharram** [4] and other colleagues using the same methodology improved time interval control. The cooling system was

designed to operate the water cooling after the cell reaches 45 °C and continue for 5 minutes. The results shows a cooling rates of 2 °C/min. and reduces the cell temperature by 10 °C. For reducing the cost of building a cooling system also using solving the lack of spaces. A study presented by **A. Abdulgafar** [7] for investigating the effect of water submerging. Immersing the photovoltaic panel with a certain depth for reducing its temperature and self-cleaning the PV panel front surface in order to improve its efficiency. The study was conducted an experiment of submerging the PV panel in distilled water with different depths. The experimental results show that the efficiency increased by 11% by submerging the PV panel with 6 cm depth. While, **M. Khaled** [8]

study the effect of reducing the PV cell temperature using phase change material (PCM). Using two PV panels in this experiment, the first one was conventional considered as a reference to compare the results with the PV panel that improved with petroleum jelly as pure PCM.

2. Mathematical model

2.1 Fluid Flow characteristics

The photovoltaic panel is assumed to be cooled by spraying water on the front face forming a laminar flow film, as shown in figure 1. The flow flowing on an incline tilted with 31.5°, and the only force acting on it and causing the fluid motion is the gravitational force. As the height and the fluid density are constant, the flow velocity depends only on the water flow rate. The fluid velocity and Reynolds number could be calculated using equations (1) which could be reduced to one dimensional equations (2) and (3).

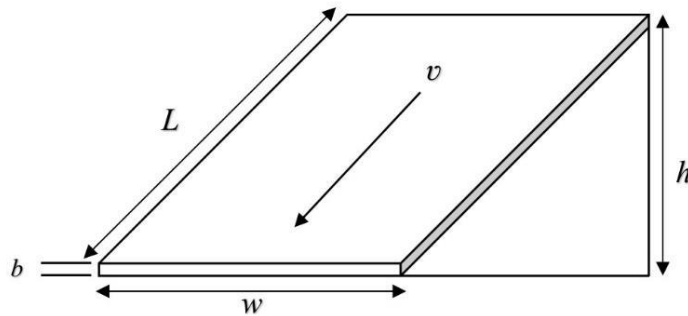


Figure 1. Fluid flow characteristics

$$\rho \left(\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + \omega \frac{\partial u}{\partial z} \right) = -\frac{\partial p}{\partial x} + \gamma \sin \theta + \mu \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} \right) \quad (1) [8]$$

$$V = \frac{b^2 \gamma h}{12 \mu L} \quad (2)[8]$$

$$Re = \frac{b V}{\nu} \quad (3)[8]$$

The main objective of modeling a water film on the PV panel's front face is to extract the excess heat and clean the panel's front side and allow more solar radiation to pass through the glass to the PV cell. The extracted heat could be calculated using the equation below.

$$\dot{m} c_p \Delta T Q = \quad (4)$$

2.2 PV Panel efficiency calculation

As it previously mentioned the PV conversion efficiency drops by 0.5% for each degree centigrade rise. And the cell conversion efficiency could be calculated using equation (5).

$$\eta_{act.} = \eta_{std} [1 - \beta (T_s - 25)] \quad (5) [9]$$

Where.

$\eta_{act.}$ is the actual cell conversion efficiency at the surface temperature

η_{std} is the cell efficiency under the standard conditions (1000 w/m² & 25 °C)

β is the conversion reduction due to the thermal drift which is 0.5 °C⁻¹

T_s is the PV panel surface temperature

2.2 CFD model

Solving high complexity problem requires highly advanced computational software. For simulating PV panel cooled by a water flow film, a CFD model has been developed using COMSOL Multiphysics 5.3 based on the Finite element calculations. Using different parameters to simulate different weather conditions. The CFD model is required to estimate the effect of two main parameters and the PV panel's thermal behavior. A water temperature used was varying from 20 °C to 45 °C to study the effect of changing the water temperature on the PV panel temperature and cooling rates. The water flow rate was also used with different values varying from 1 to 10 L.P.M. for the same purpose.

The model geometry and mesh were made using COMSOL Multiphysics 5.3. The geometry was identical to the PV panel dimensions, as in figure 2.

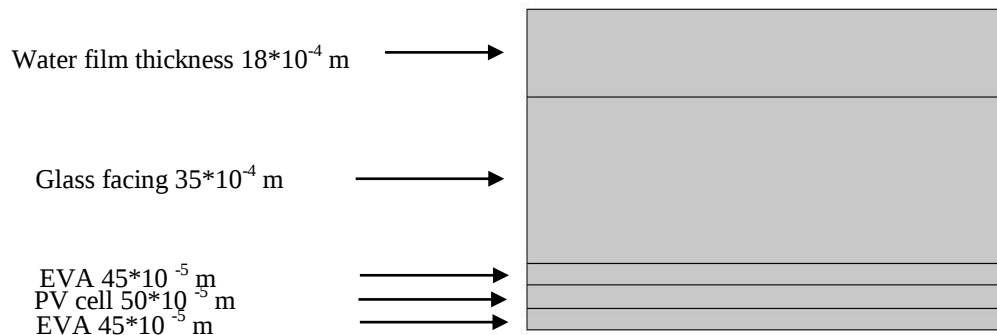


Figure 2: CFD Model Geometry Dimensions

The mesh was also made using the same pre-mentioned software. A mesh independency check was carried out as in figure 3 to choose the right mesh to use. A mesh of 444700 elements (422,465 domain elements and 22,235 boundary elements) were chosen, as shown in figure 4.

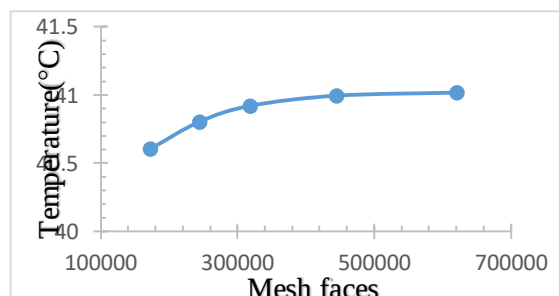


Figure 3. Mesh independency check

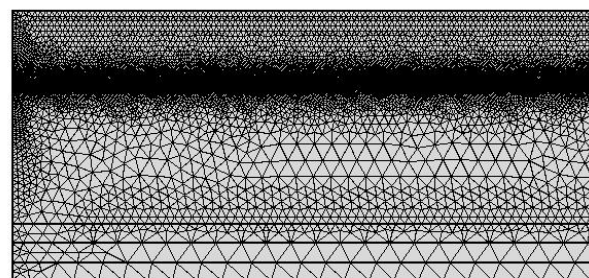


Figure 4. CFD Model Geometry mesh

3. Experimental setup

Experimentally study the effect of enhancing the PV panel electrical and thermal performance utilizing cooling, the front face cooling was suggested. Two 330 w break power PV panels were used to fabricate a physical model, the first PV panel was considered to be the reference and worked as a convectional panel. While the second PV panel was improved by the cooling system, as shown in figure 5.

The cooling system consisted of the water pump, water flow meter, control valve, distributing pipe, collecting tray, and the evaporation mesh, as shown in the schematic view in figure 6.



Figure 5. Experimental model

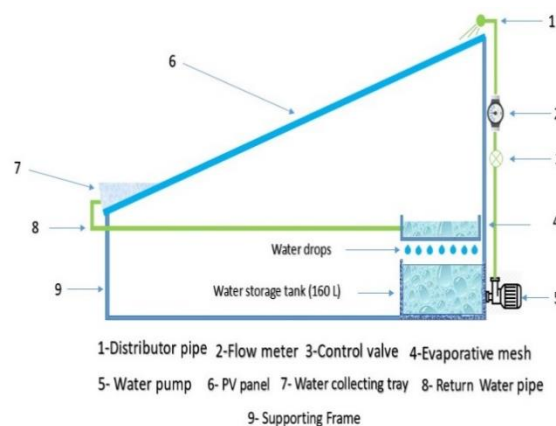


Figure 6. Experimental model schematic view

The water pump was selected to satisfy the required power with a specification of (20 W, 2000 LPH, and 2.5 m max head). Also, a flow meter ranging (2 -18) L.P.M. was selected to calculate the exact amount of water flow rate at the starting of the experiment.

For reducing the cooling water temperature and despite the collected heat, a galvanized iron tank of 160 L was used with an evaporative mesh above it with 280 holes. The holes were 2 mm diameter to form water droplets and incise the evaporation and reduce the water temperature as in figure 7.

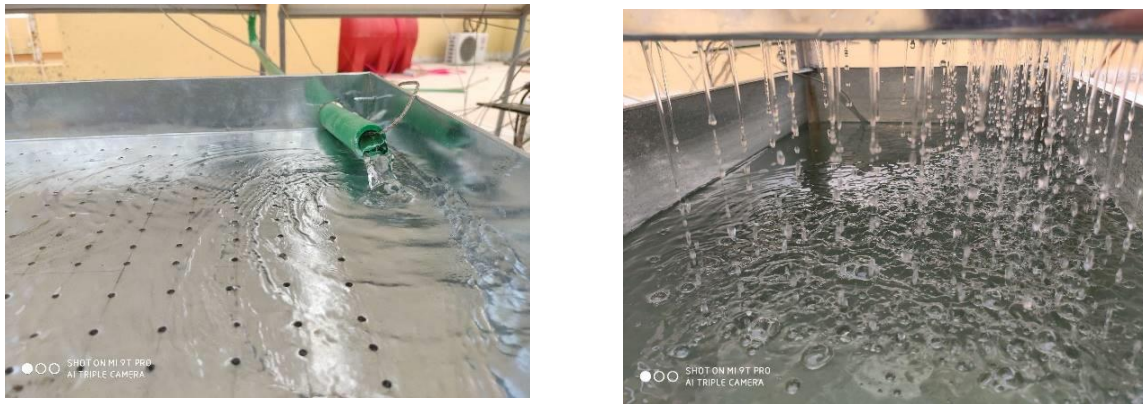


Figure 7. Over tank evaporative mesh

For distributing the cooling water evenly on the front face of the PV panel, a distributing pipe with four different nozzle diameters was selected. Each pipe contains 20 nozzle holes distributed evenly, each 5 cm with diameters at (2, 3, 4, and 5 mm), as shown in figure 8.

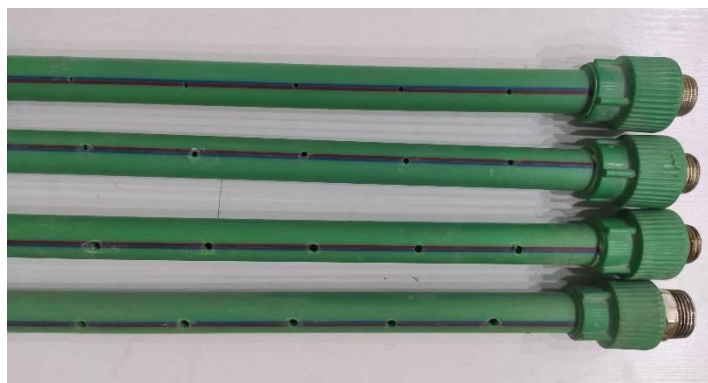


Figure 8. Water
distribution pipes

4. Results discussion

The numerical and experimental models' results were evaluated, presented, and discussed in this paper. The water flow velocity and the Reynolds number are depending on the water flow rates. As shown in figure 9, the Reynolds number does not exceed the laminar values. For the flow velocity was ranging from 0.5 to 4 m/s, as in figure 10.

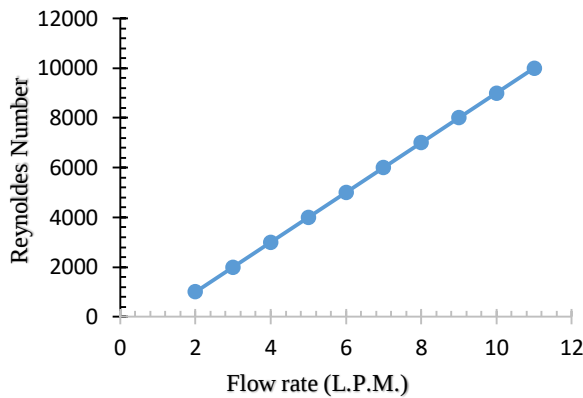


Figure 9. variation of the Reynolds number with the change of water flow rate

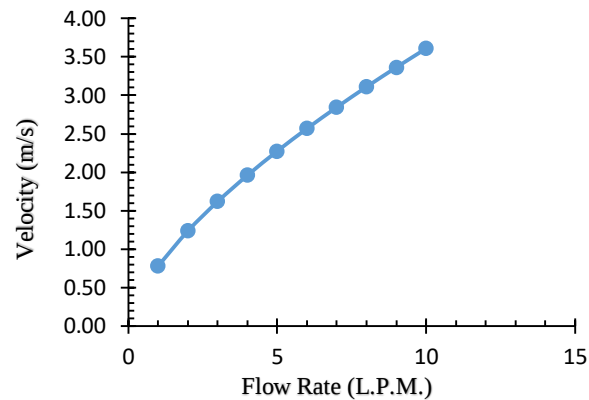


Figure 10. Variation of the average flow velocity with the change of water flow rate

The numerical results show that the variation of the water flow rate has effective values ranging from 4 to 8 L.P.M. as shown in figure 11, and the PV panel surface temperature will eventually reach a steady-state condition and the only variable that controls the surface temperature is the cooling water input water temperature as it is shown in figure 12.

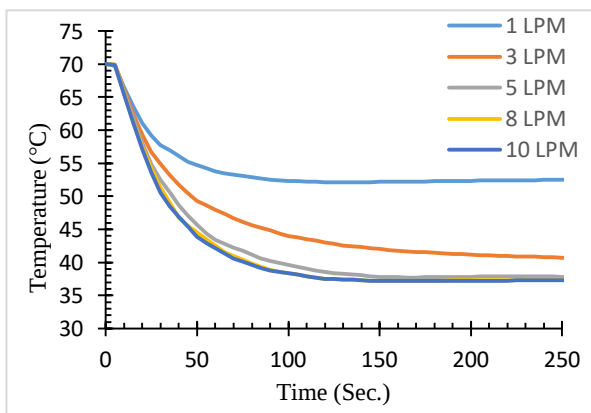


Figure 11. variation of PV surface temperature with the water flow rate

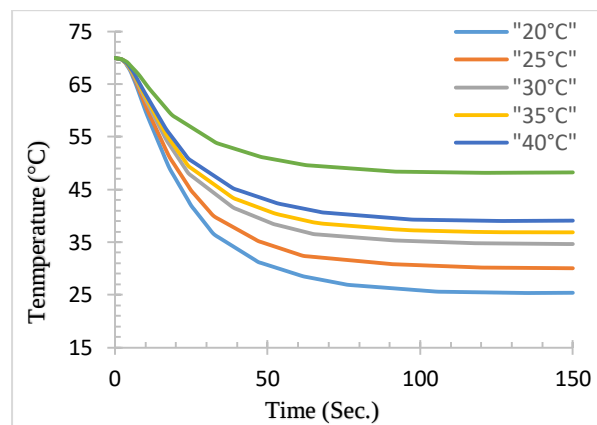


Figure 12. variation of PV surface temperature with the input water temperature

All the experiments were conducted using the pre-mentioned experimental model on the 5th to 25th of Jun 2020 on the building's roof-top in Najaf city - Iraq, located at (31.97 °N, 44.36° E).

The experimental results show a remarkable agreement with the numerical cooling time results and the steady-state temperature. The water cooling system reduced the PV panel temperature from 70.1 C to 39.5, 37.2, 36.5 and 35.2 when using 5, 4, 3, and 2mm nozzle diameter respectively. As shown in figure 13.

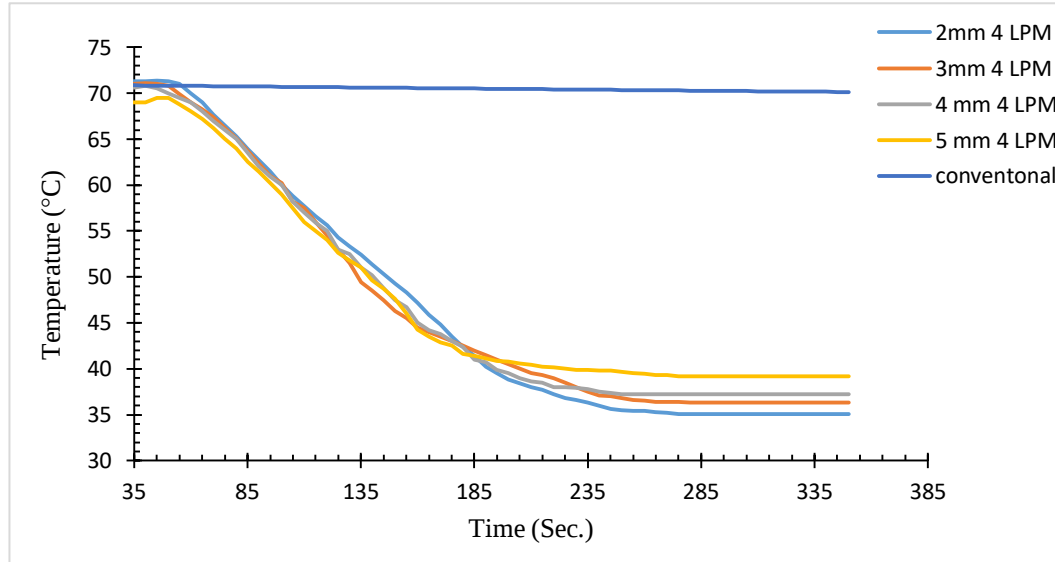


Figure 13. variation of the PV surface temperature with the change of the nozzle diameter

The PV cell's conversion efficiency mainly depends on the solar radiation, fabrication materials, and surface temperature. The PV panel conversion efficiency was significantly enhanced by 20.16% to 22.83%, as in table 1. The best conversion efficiency was when using 2 mm nozzle diameter and 4 L.P.M. water flow rate, as in figure 14.

Table 1: the different values of the conversion efficiency and the enhancement in the PV performance with and without water cooling			
	Conversion Efficiency	$\eta_{act.} / \eta_{theu.}$	Enhancing
2 mm	16.14%	94.94%	22.83%
3 mm	16.03%	94.29%	21.99%
4 mm	15.96%	93.88%	21.46%
5 mm	15.79%	92.88%	20.16%
without	13.14%	77.29%	0%

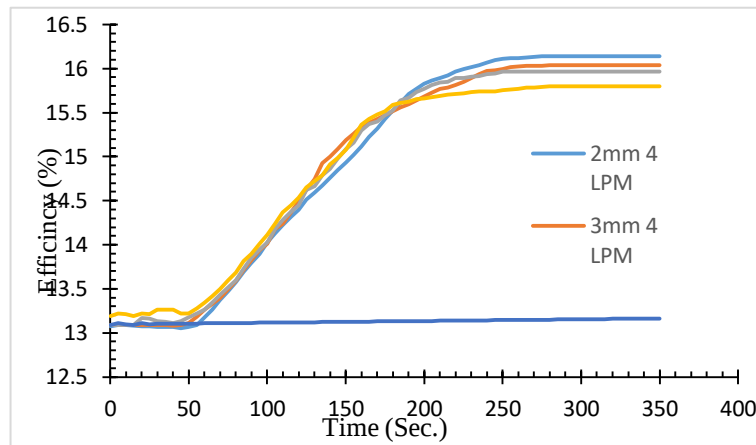


Figure 14. Variation of the conversion efficiency with the change of the nozzle diameter

5. Conclusion

Based on the results presented and discussions above. Several conclusions could be conducted and listed as following.

- 1- The water cooling system is highly efficient for reducing the PV panel temperature.
- 2- The PV panel surface could be reduced by 50.2% using a cooling water system.
- 3- The conversion efficiency increased by 22.83% using a 4 L.P.M. water flow rate and 2 mm jet nozzle.
- 4- The absorbed solar radiation increased by the cell due to the front face self-cleaning.

6. References

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