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Improvement of Photovoltaic Panel Efficiency using Nanofluid

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Abstract

The performance of PV (photovoltaic) module is strongly dependent on its operating temperature. Most of the energy absorbed by the panel is converted to heat which is normally lost and provides no value. This work investigated experimentally the PV performance through using three separated PV panels. Three identical photovoltaic (PV) panels have been installed side by side to investigate the effect of cooling on the PV panels performance, one of them is used as a baseline ; the second is cooled using pure water; while the third is cooled using nanofluids. Aluminum Oxide (Al_2O_3) and Copper Oxide (CuO) nanoparticles were added to the pure water to form the nanofluid, each one with different concentration in order to find the optimum concentration of Al_2O_3 and CuO. Meteorological data was measured using a weather station. Also, the temperature of the cooling fluids together with the backside temperature of the PV Panels was recorded. It was found that an increase in the efficiency of the panel of 2% was obtained when 0.4 % Al_2O_3 by weight was mixed with the pure water. This increase in efficiency was 2.34% when 0.6 % CuO.

Keywords: *PV Cooling, Nanofluid, Solar Energy*

1. Introduction

Successful deployment of photovoltaic (PV) systems around the world for decades in a variety of applications; including power to telecommunication towers, remote weather stations, residential and grid-scale power plants, and community networks was achieved. Scalability of PV is probably the biggest advantage of PV technology in a wide range of applications. Moreover; it can be designed to meet the requirements of almost any power demands, and can work in conjunction with battery banks and diesel generators or any other power source to provide a continuous and stable power. Researchers have conducted studies on the efficiency of photovoltaic cells in the last decade, and amazing developments have been witnessed in this field.

Muharram, et al. (2013) [1] developed a cooling system based on water spraying of PV panels to determine how long it takes to cool down the PV panels to its normal operating temperature. It was found that the PV panels yielded the highest output energy if cooling of the panels starts when the temperature of the PV panels reaches a temperature of 45 C.

Balamuralikrishnan, et al. (2014)[2] found that it is possible to clean and cool the PV panel's front side using a cooling system in dusty and hot regions; which improves the efficiency of solar PV panels with active cooling to reduce heat loss. The hardware part of the experimental setup executes a cooling technology; which includes water as a coolant so that the efficiency is enhanced. This water not only cools the panel but also cleans it. Also, the hardware part has a solar tracker escorted by LDR (Light Dependent Resistor) circuit and DC motor for moving the solar panel to attain better insulation.

Baskar (2014) [3] proved that the efficiency of PV water pumping system was increased when the PV cell temperature cells were kept as low as possible. This is performed through automatically spraying water above the photovoltaic cells. Water is sprayed over the cells using a microcontroller unit and solenoid valve. Water reduces cell temperature of up to 35 degrees Celsius. The electrical yield can return an excess of 10.3%; even when energy is required to operate the pump.

Bahaidarah, et al. (2013) [4] reported that when using active water cooling on the rear side of the PV module, the module temperature decreased significantly to about 20% which led to an increment in the PV panel efficiency by 9%. A numerical model is developed using the Engineering Equation Solver software. The result of cooling the module through incorporating a heat exchanger (cooling panel) at its back surface, in the climate of Dhahran in Saudi Arabia, is also investigated experimentally. The results of the numerical model are found in good agreement with the experimental measurements.

Elnozahy, et al. (2014) [5] investigated experimentally the performance of a cooled PV module installed on the roof of a building in a hot dry area as compared with that of a module without cooling.. The results displayed a decrease of about 45.5% and 39% in module temperature at the front and back faces; respectively. Consequently, the cooled and surface cleaned module has an efficiency of 11.7% against 9% for the module without cooling and cleaning.

Karami and Rahimi (2013) [6] proposed that the nanofluid cooling performance is better than water and resulted in higher decrease in the average PV cell temperature. They achieved this experimentally through investigating the cooling performance of PV panel, which had channels fabricated in two different configurations as straight and helical shapes in the

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back side of the PV panel, via water-based nanofluids composing of small concentrations of Boehmite ($ALOOH \times H_2O$) for the PV cell. The results led to the highest electrical efficiency for PV cell; about 37.67% for the helical shape and 20.57% for the straight.

In this work cooling method of PV systems that uses nanoparticles was experimentally studied to show the effect of nanoparticles on the power produced by the PV systems; Al_2O_3 and CuO nanoparticles were used. Six concentrations of each type were tested to find the optimum concentration that causes a maximum increase in the PV performance

2. Results and Discussion

The experimental setup consists of three identical Mono-Crystalline PV panels, each one with an area of 0.184m^2. The maximum output, current and voltage is 1.11A, 18V; respectively, and each one with a maximum power output of 20W. The specification of these panels are given by Karadsi (2016) [7]. These panels were mounted side by side and facing true south with an inclination angle of 28 degrees. Two panels were constructed such that they may be cooled on the backside using water and two types of Nano fluid CuO and Al_2O_3), each one with different weight/mass concentration of nano particles, Six different concentrations of Al_2O_3 (0.1%,0.2% ,0.3%,0.4%, 0.5% and 0.6%) , while those of CuO are (0.2%, 0.3%, 0.4%, 0.5% 0.6% and 0.7 %). The third one represents the baseline panel, which was left without cooling. It is to be noted that the fluids after passing through the panels are cooled by using a chiller circuit.

The solar radiation was measured using a Pyranometer, while temperature sensors (K type thermocouples) were used to measure the, ambient temperature, backside of PV panels temperature, inlet and outlet water and Nano fluid. The open circuit voltage (Voc), short circuit current (Isc) and output power (Pout) was recorded every one minute for each panel separately using a locally manufactured data acquisition system All measured parameters were stored in a data logger system for further analysis.

2.1 Result of Al_2O_3

Figure 1 represents the cooling effect caused by the addition of different concentration of Al_2O_3 on the back side of the PV panel. As it can be seen, the maximum cooling effect was achieved at 0.4% concentration of Al_2O_3, with an efficiency of 12.06% when using Nano fluid, compared with 11.2% for the panel cooled by water only, and 10.04% for the baseline panel without cooling. Consequently and for the rest of the work deployed Al_2O_3 nano fluid cooling at concentration of 0.4% .

Figure 2. shows the effect of PV cooling using nanofluid (Al_2O_3). As indicated, the effect of cooling is more pronounced when nanofluid is used, followed by that of water. The maximum temperature drop was achieved at 2 p.m., with a maximum backside temperature of 46.9 ºC for the panel without cooling, followed by a value of 25.47 ºC when water is used; while it was 22.67 ºC when nanofluid is used. This is due to the fact that the thermal conductivity of nanofluid is higher than the thermal conductivity of pure water.

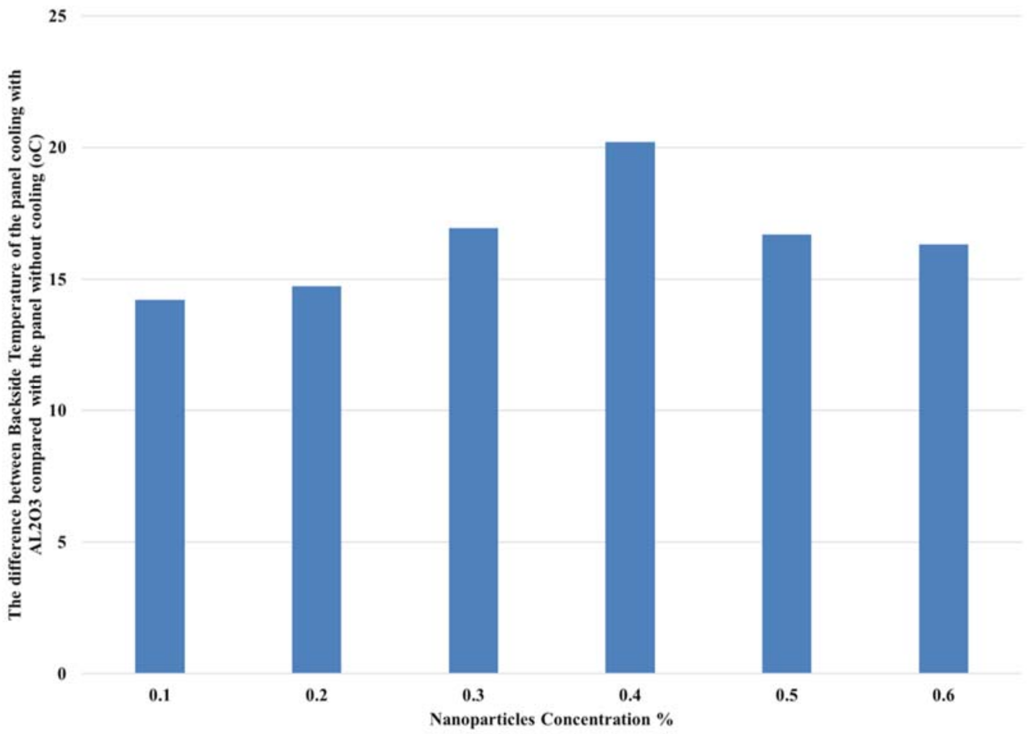

Figure 1: The difference between backside temperature of cooled panel using nanofluid compared with Panel without cooling vs. Nanoparticles Concentration for Al_2O_3

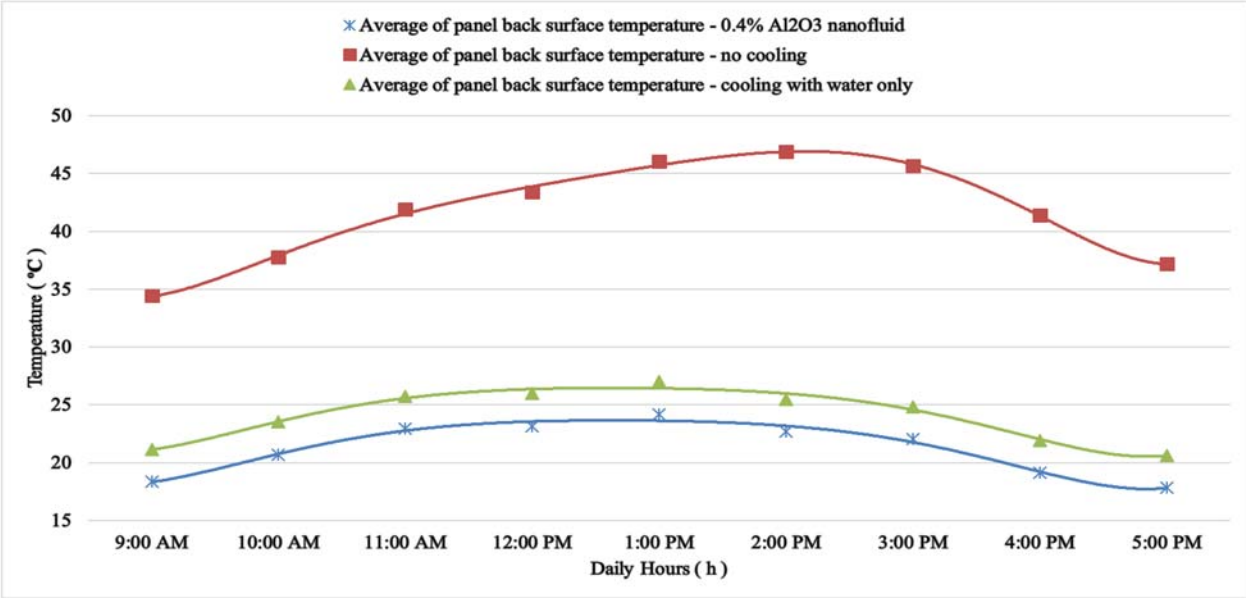

Figure 2: Comparison between the Temperatures of the Backside of the Three Panels

Figure 3 below shows the hourly Isc for the three panels. As shown in this figure, the Isc was almost of the same values during the day. Also, the Isc initially increases to a maximum value at noon; beyond which it starts to decrease. As shown, there is a slight increase in Isc for the panel cooled by nanofluid compared with other panels. This is due to the fact that when the cell temperature increases, the Voc decreases, while the Is increases slightly.

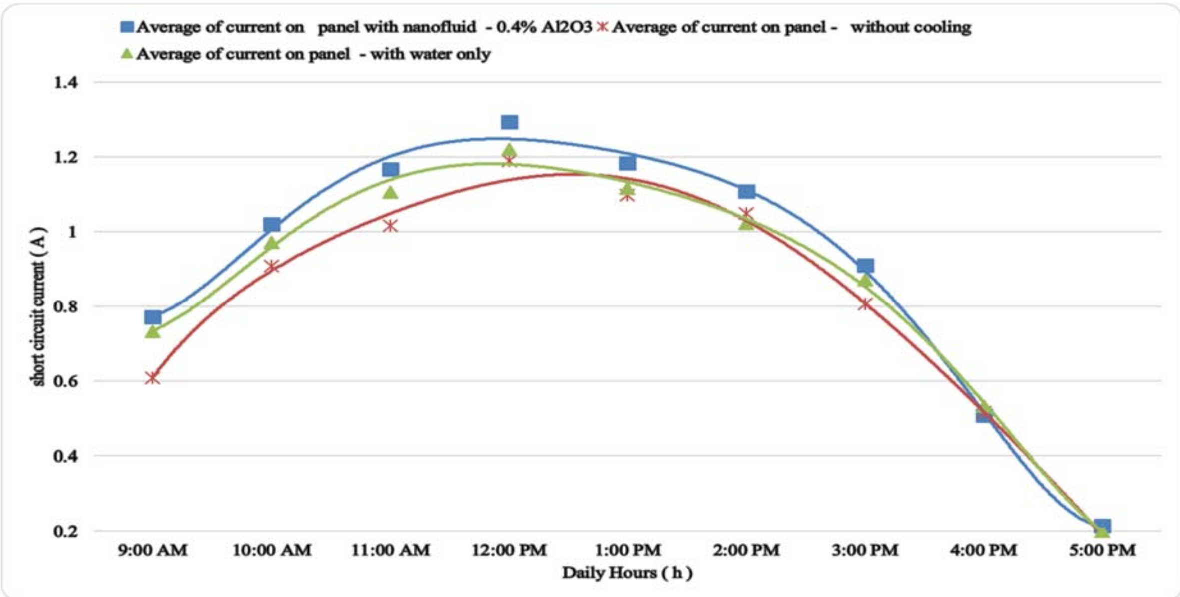

Figure 3: Comparison between the I_{sc} of the three panels

Figure 4 below shows the effect of cooling the PV panel using nanofluid (Al_2O_3). As indicated, the effect of cooling is more pronounced when nanofluid is used, followed by that of water. The maximum Voc increment was achieved at 12 p.m. with a maximum Voc of 20.19 V for the panel using nanofluid, followed by a value of 19.86 V when water is used; while it was 18.3 V recorded on the reference panel with no cooling on it. This is due to the fact that the thermal conductivity of nanofluid is higher than the thermal conductivity of pure water.

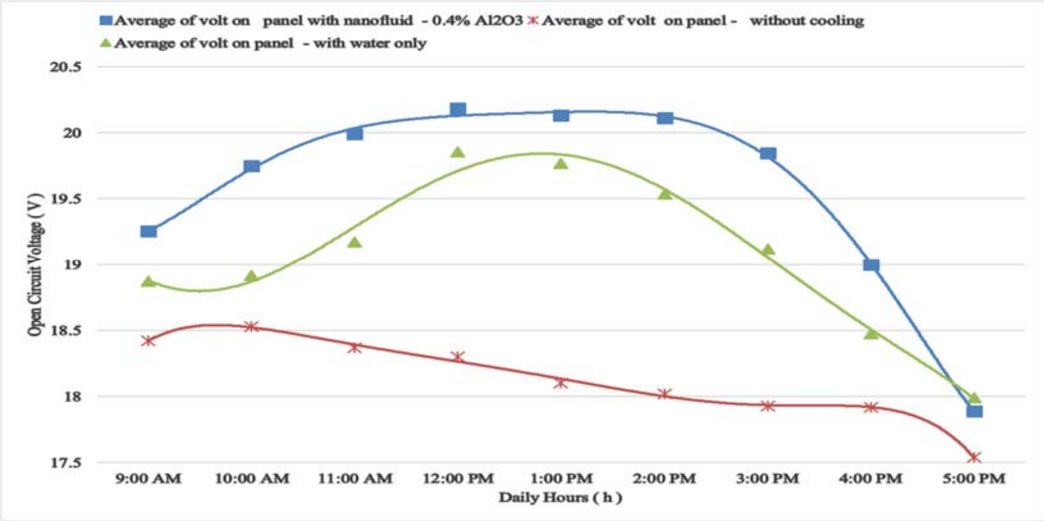

Figure 4: Comparison between the V_{oc} of the Three Panels

Figure 5 below shows the effect of cooling the PV panel using nanofluid (Al_2O_3) on the output power. As indicated, the effect of cooling is more pronounced when nanofluid is used, followed by that of water. A maximum output power of 19.79 W was obtained at 12 p.m. when the PV was cooled using Al_2O_3 nanofluid; while it was 18.36 W for the panel cooling with water only, 16.5 W was recorded for the reference panel with no cooling. This is due to the fact that the thermal conductivity of nanofluid is higher than the thermal conductivity of pure water. This high value of output power, which is almost same as the maximum power output of the panel as specified by the manufacturer is due to the fact that the weather station needs to be calibrated, which has not been performed in this study.

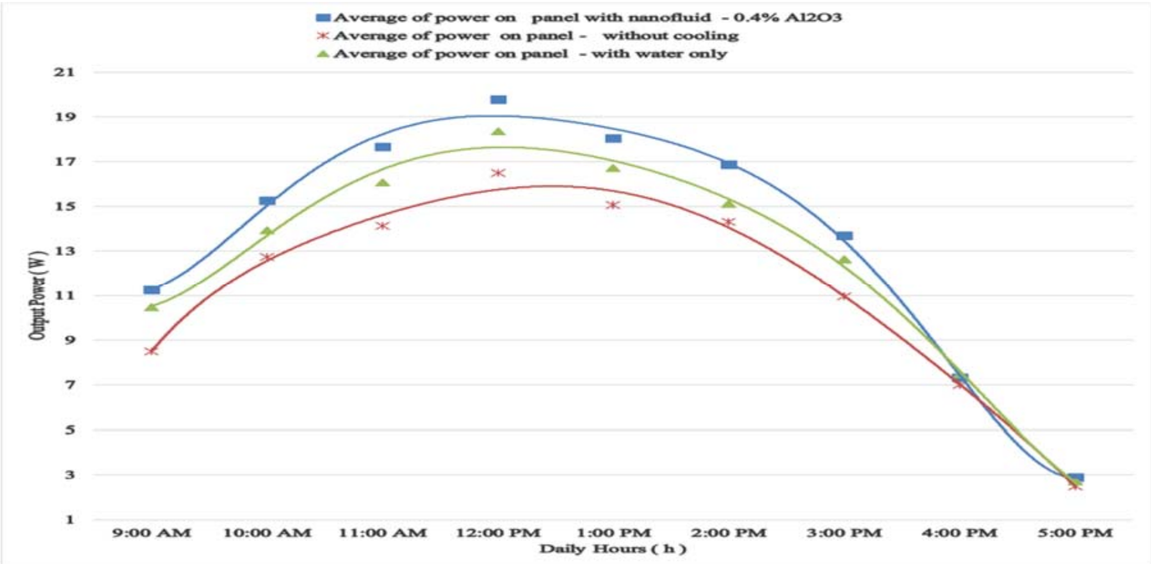

Figure 5: Comparison between the Output Power of the Three Panels

Figure 6 below shows that the maximum value of efficiency with cooling using Al_2O_3 nanofluid was 14.16 % obtained at 3 p.m.; followed by 13.08 % when cooling with water only. While it was 11.34 % for the panel without cooling. This is due to the fact that the thermal conductivity of nanofluid is higher than the thermal conductivity of pure water.

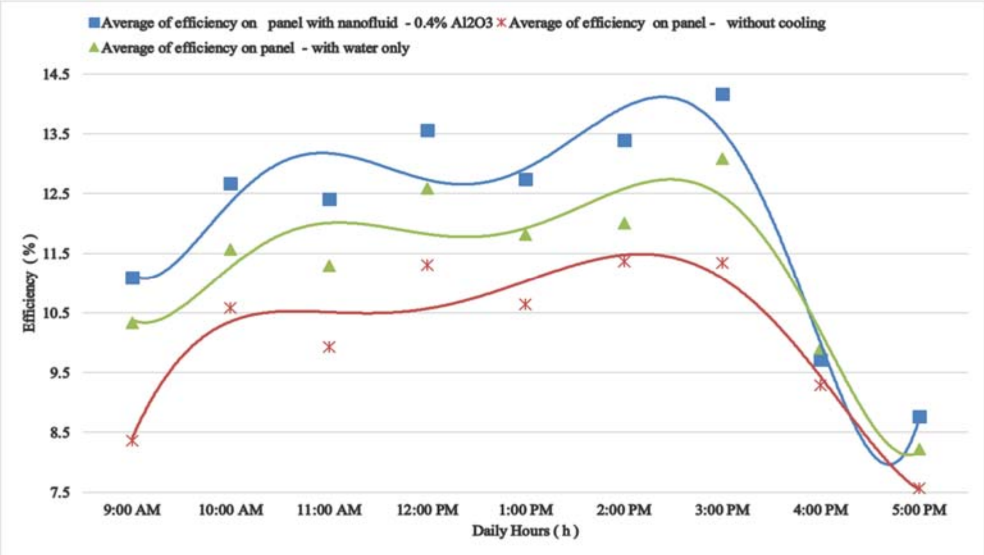

Figure 6: Comparison between the Efficiency of the Three Panels

2.2 Result of Copper Oxide (CuO)

Six different concentrations of CuO (0.2%, 0.3%, 0.4%, 0.5% 0.6% and 0.7 %) were used in this experiment. Experiment measurements were conducted simultaneously on the same three panels for comparison purposes.

The results showed that the addition of 0.6 % CuO resulted in a considerable increase in the efficiency of the PV panel; with an increase in the efficiency of 12.57 % for the panel cooled using nanofluid, 11.39 % for the panel cooled using water only, and 10.23 % for the base panel without cooling.

Figure 7 below shows the best concentration of CuO when added to water. As shown in the figure, the obvious difference in the temperature of the backside of the panel cooled using nanofluid and the panel without cooling; recorded when 0.6% CuO was added to water.

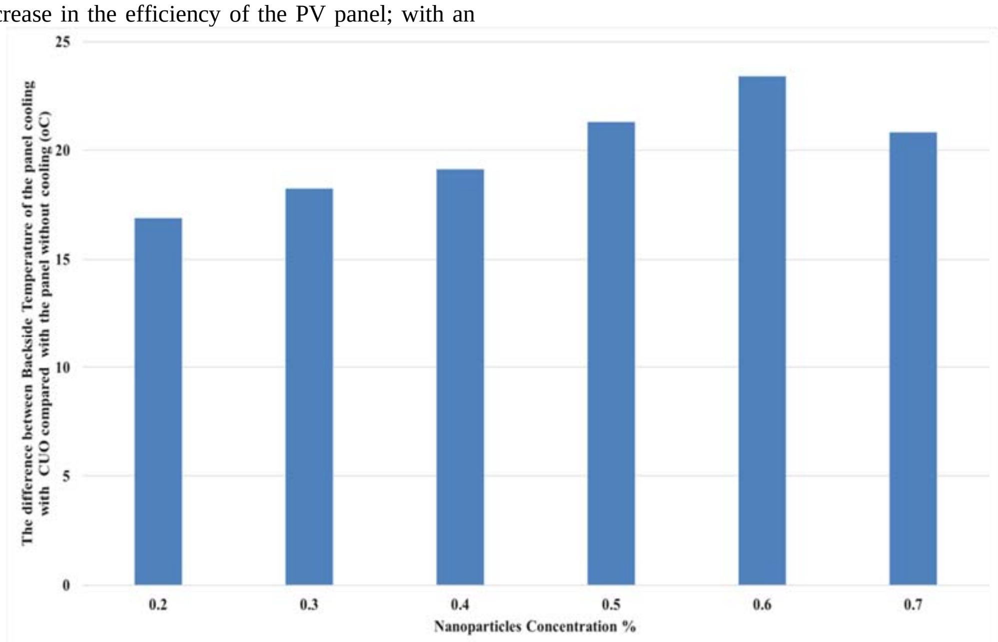

Figure 7: The Difference between Backside Temperature of Panel cooled using nanofluid compared with Panel without cooling vs. Nanoparticles Concentration for CuO

Figure 8 below shows the hourly solar radiation and ambient temperature during the day (27/9/2015). It is noticed that the hourly solar radiation increases from 555 w/m^2 at 9 p.m. to a maximum at noon, then decreases again to 134 w/m^2 at 5 p.m.

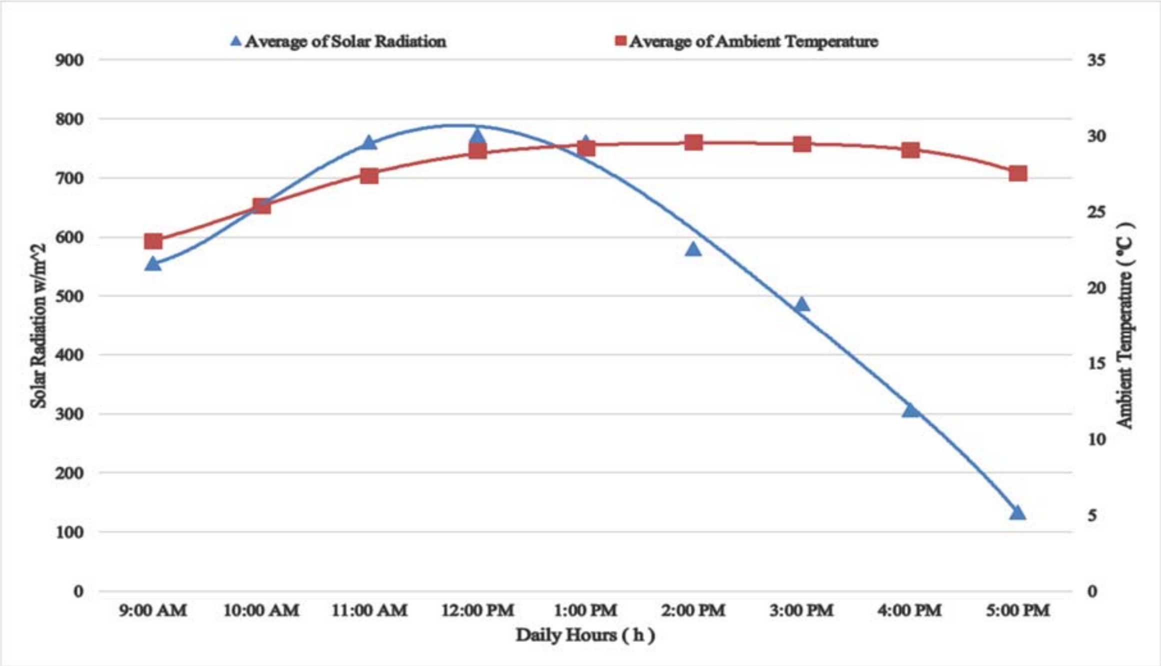

Figure 8: Hourly Solar Radiation with Ambient Temperature in the Test of 0.6 % Concentration of CuO

Figure 9 below shows the effect of cooling the PV panel using nanofluid (CuO). As indicated, the effect of cooling is more cleared when nanofluid is used, followed by that of water. The maximum temperature drop was achieved at 2 p.m., with a maximum backside temperature of 48.9ºC for the panel without cooling, followed by a value of 24.93 ºC when water is used; while it was 22.13 ºC when nanofluid is used. This is due to the fact that the thermal conductivity of nanofluid is higher than the thermal conductivity of pure water.

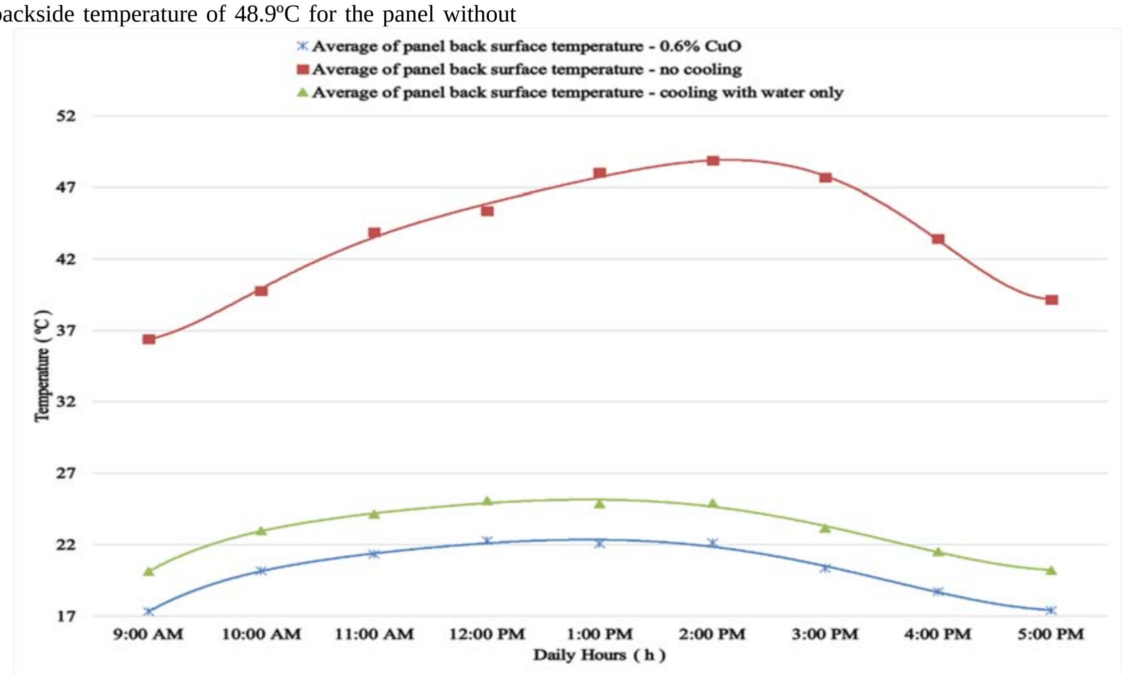

Figure 9: Comparison between the Temperatures of the Backside of the Three Panels

Figure 10 below shows the hourly I_{sc} for the three panels. As shown in this figure below, the I_{sc} is almost the same values during the day. Also, the I_{sc} initially increases to a maximum value at noon, beyond which it starts to decrease. As shown, there is a slight increase in I_{sc} for the panel cooled by nanofluid compared with other panels. . This is due to the fact that when the cell temperature increases, the V_{oc} decreases, while the I_s increases slightly.

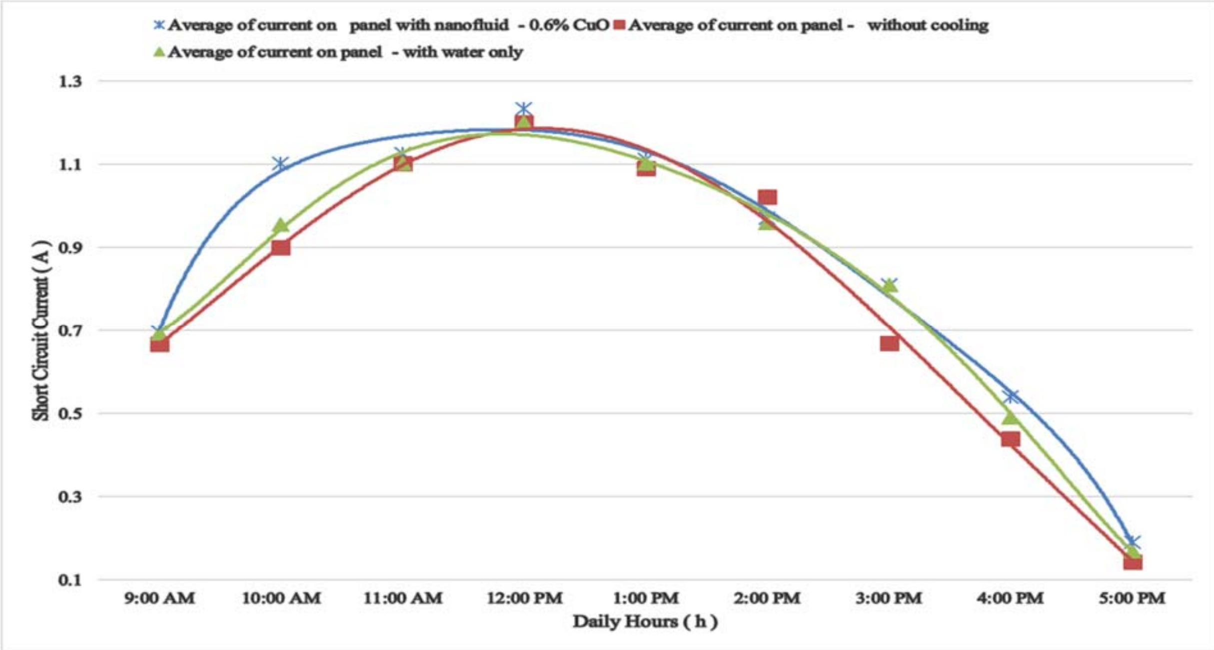

Figure 10: Comparison between the I_{sc} of the Three Panels

Figure 11 below shows the effect of cooling the PV panel using nanofluid (CuO) on the obtained Voc. As indicated, the effect of cooling is more noticeable when nanofluid is used, followed by that of water. The maximum Voc increment was achieved at 12 p.m. with a maximum open circuit voltage of 20.35 V for the panel using nanofluid, followed by a value of 19.63 V when water is used; while it was 17.64 V recorded on the reference panel with no cooling on it. This is due to the fact that the thermal conductivity of nanofluid is higher than the thermal conductivity of pure water.

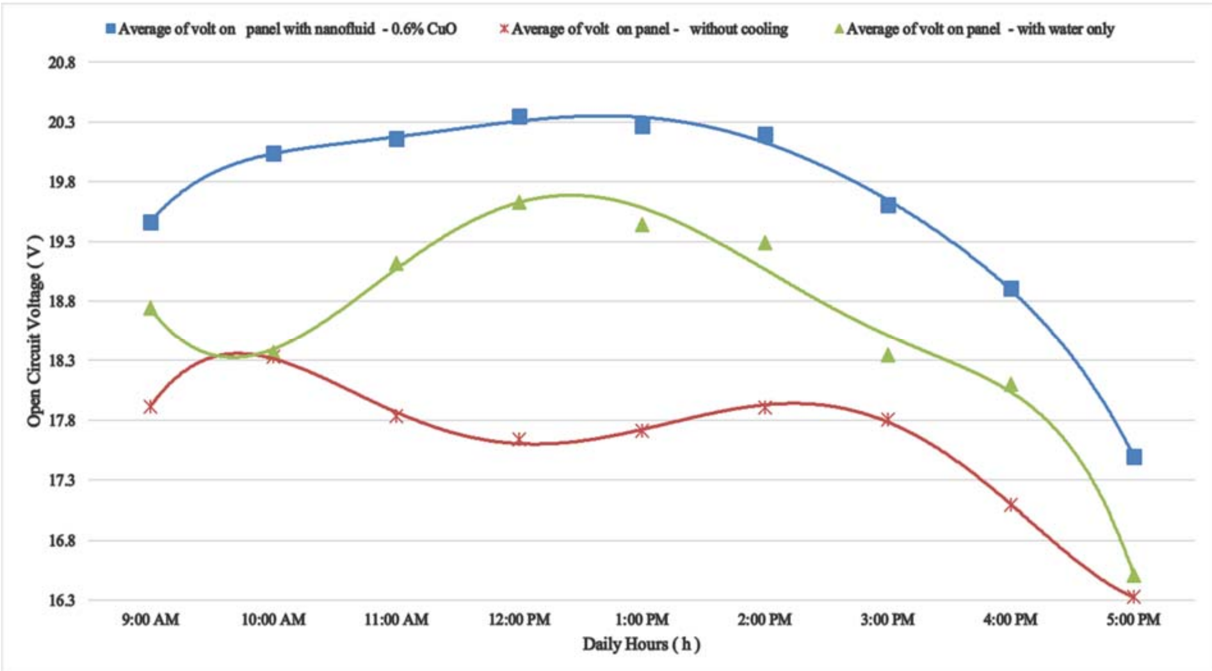

Figure 11: Comparison between the V_{oc} of the Three Panels

Figure 11 below shows the effect of cooling the PV panel using water nanofluid (CuO) on the obtained PV power. As indicated, the effect of cooling is more remarkable when nanofluid is used, followed by that of water.

A maximum output power of 19.02 W was obtained at 12 p.m. when the PV was cooled by CuO nanofluid, while it was 17.88 W for the panel cooling with water only, and 16.05 W was recorded for the reference panel with no cooling. This is due to the fact that the thermal conductivity of nanofluid is higher than the thermal conductivity of pure water. This high value of output power, which is almost same as the maximum power output of the panel as specified by the manufacturer is due to the fact that the weather station needs to be calibrated, which has not been performed in this study.

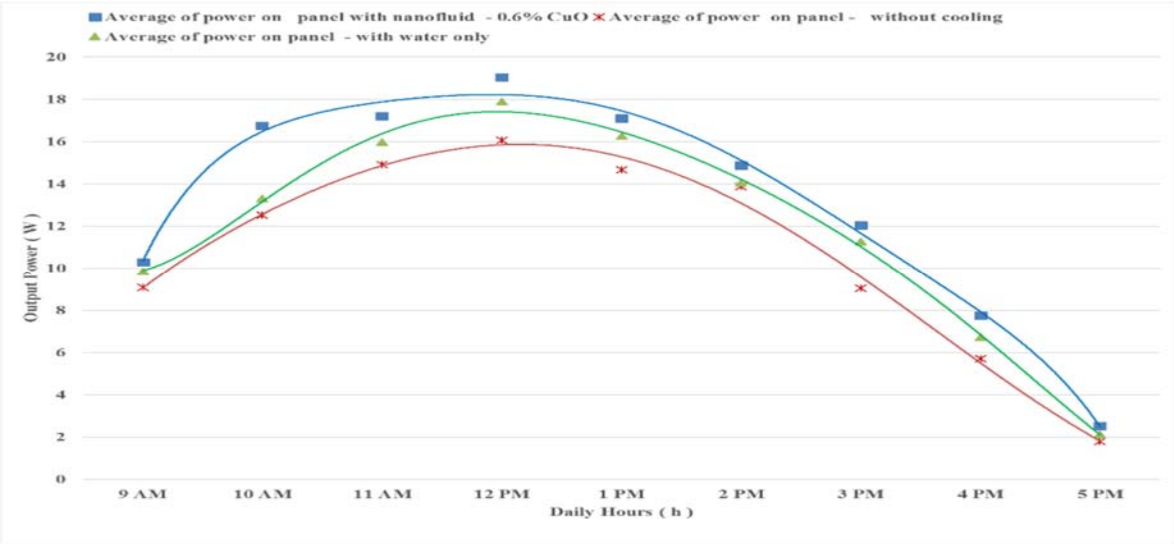

Figure 12: Comparison between the Output Power of the Three Panels

Figure 13 below shows that the maximum value of efficiency with cooling using CuO nanofluid was 13.92% obtained at 2 p.m., followed by 13.14 % when cooling with water only, while it was 12.99 % for the panel without cooling. This is due to the fact that the thermal conductivity of nanofluid is higher than the thermal conductivity of pure water.

3. Conclusion

This experimental work was conducted to investigate the effect of adding two types of nanoparticles; namely Al_2O_3 and CuO, on the amount of PV panel productivity using three side-by-side PV panels.

From this work, the following may be concluded:

1. In general, cooling increase the panel performance.
2. Nanofluid has more effect on improving the panel performance than pure water.
3. In general, CuO nanoparticles when used in cooling have a more pronounced effect on the panel performance than Al_2O_3.
4. The best performance of the panel was obtained when 0.6% of CuO and 0.4% of Al_2O_3 were used.

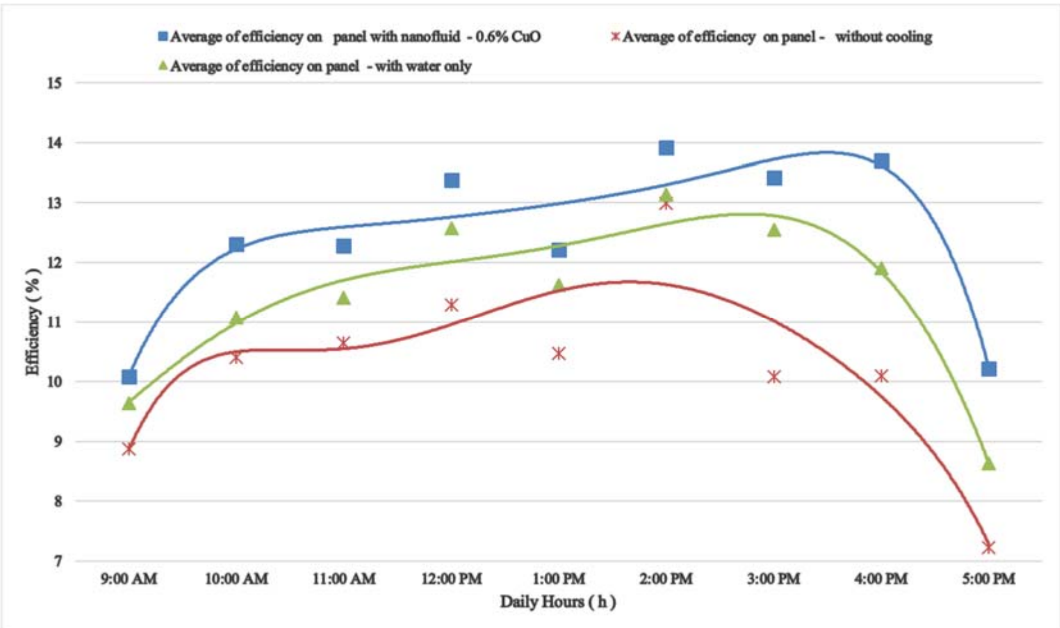

Figure 13: Comparison between the Efficiency of the Three Panels

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