Improving the Electrical Efficiency of a Photovoltaic/Thermal Panel by Using SiC/Water Nanofluid as Coolant

Mohammed Hasan Abbood  Haroun Shahad  Ali Abdul Kadhum Ali
University of Kerbala  University of Babylon  University of Kerbala
malmussawie@yahoo.com  hakshahad@yahoo.com  engali23@outlook.com

Abstract. For photovoltaic panels, high temperature has a major effect, reducing electrical efficiency and decreasing the panel’s life span. In this work, an aluminum pocket collector was manufactured and fixed to the rear side of a photovoltaic panel to form a photovoltaic/thermal system (PV/T). A SiC/water nanofluid was used as coolant fluid with two volumetric concentrations (0.1 and 0.5%). The experiments were conducted outdoors at Babylon University (32.46 °N, 44.42°E) in March. Different flow rates of SiC/Water nanofluid were tested (0.5, 1, 1.5 & 2 LPM). A comparison was made with another, identical, PV panel under the same conditions. SiC/water nanofluid had a noticeable effect on output power and results showed that the maximum enhancement in electrical efficiency was 33.27% with 0.5 % SiC/Water nanofluid and flow rate of 2 LPM, and the maximum overall efficiency was 92.43 %.

Keywords: PV; PV/T Solar system; SiC/water nanofluid; Power; Efficiency; Solar Energy

1. Introduction

Global warming is mainly caused by greenhouse emissions which are a result of burning fossil fuels. To minimize climate change, the world is turning to renewable energy. Use of a photovoltaic module is an important method by which to produce clean energy. The principle of its work is to absorb the incident radiation from the sun and convert it to electrical and thermal energy. Not all of the absorbed radiation waves are converted to electricity so, heat is generated inside the cells. According to a simple diode equation, which is the base of photovoltaic module, increasing the cell temperature will decrease the open circuit voltage, thus reduce the electrical efficiency.

Many cooling technologies are used to dissipate the generated heat inside PV modules. Hybrid PV modules, which are marked as PV/T, contain thermal units in contact with the rear side of PV in order to cool it and increase the electrical efficiency. Recently, nanofluid has come to play an important role as coolant in thermal units due to its high thermal conductivity, which improves the heat transfer process.

The application of nanofluid in a PV/T system was studied experimentally in 2016 by Al-Shamani et al. [1] They decided to use a new design of rectangular channel collector of stainless steel under a PV module. The dimensions of developed channels were 15 mm in height, 25 mm width and 1 mm thickness. Various different nanofluids were used (SiO$_2$, TiO$_2$, and SiC), with water as base...
fluid; the concentrations of the nanofluids were (0.5, 1 and 2) wt.%. The experiments were done outdoors, in tropical weather in Malaysia.

These scholars found the collector with SiC/water nanofluid had the best electrical efficiency at 13.52% and best overall efficiency at 81.73% at a flow rate of 0.17 kg/s and solar radiation of 1000 W/m².

In 2014, Karami and Rahimi [2] presented an experimental study to use Boehmite nanofluid as coolant on a hybrid PV system in Iran. They used an acrylic sheet to make micro channels of hydraulic diameter 783 μm attached to back of the PV panel, and used three concentrations of nanofluid (0.01, 0.1 and 0.3 wt.%). They found that the best enhancement in electrical efficiency was 27% for 0.01 wt.% and flow rate of 300 l/min.

Abdallah et al. [3] studied experimentally the use of Al2O3/water nanofluid and effects on the performance of a PVT system in Saudi Arabian weather. They used a plate and tube collector type attached to the back of the PV panel, and different concentrations (0.05, 0.075, 0.1, 0.2 & 0.3 V%), with different flow rates. The results showed that the best enhancement in electrical efficiency was 26.3%, which was obtained at 0.1 V% concentration and 1.2 l/min. However, Abu-Rahmeh [4] investigated experimentally the performance of PV modules using different cooling methods in Jordan. Abu-Rahmeh’s methods comprised the use of rectangular fins, cooling water and TiO2/water nanofluid of weight concentration 0.04%, under same conditions. The experiments were conducted in July, and it was observed that the PV electrical efficiency of TiO2/water nanofluid was the highest at 13.39%, while for water cooling the value was 12.99% and for the fins method it was 12.88%.

In 2018 Al-Shamani [5] presented mathematical and experimental evaluation for electrical and thermal efficiency of a PVT module. They used three kinds of nanofluid (CuO/water, SiO2/water, ZnO/water). The concentration of all nanofluids was 1%wt. They developed new collector of rectangular tubes in series. The results showed that SiO2/water nanofluid provides best enhancement in electrical and thermal efficiencies of 12.7% & 64.4%, respectively.

Hussein and colleagues [6] conducted an experimental study to improve the performance of PVT systems by using ZnO/H2O nanofluid at five concentrations (0.1, 0.2, 0.3, 0.4 and 0.5%) under Iraqi weather conditions. It was found that the decrease in cell temperatures was from 76 to 58 °C; this occurred at optimum flow rate of 2 l/min and concentration of 0.3 %, at which point the electrical efficiency reached 7.8%. Meanwhile, Kalita [7] developed a novel flat plate collector to improve the performance of a PVT system by using CuO/water nanofluid. Those experiments were carried out in Guwahati, India (26.14° N, 91.73° E). The developed collector contained transverse internal fins of dimensions 10 cm *0.5 cm *0.5 cm, with two inlet ports and one outlet port, and a constant flow rate of 60 l/hr. was used. The result showed that maximum electrical efficiency reached 7.8%.

Soltani et al [8] experimentally investigated different cooling methods for PV cells. They used SiO2/water nanofluid and Fe3O4/water nanofluid separately, under hot weather conditions in Iran, for five days. A sheet and tube collector was used under the PV cells. These researchers observed that the improvements in electrical efficiency were 3.35% and 3.13 % for SiO2/water and
Fe₃O₄/water nanofluids, respectively. Nasrin [9] investigated the cooling system of PVT both experimentally and numerically. The experiments were carried out under controlled environmental conditions in the University of Malaysia, with solar simulator range 200–1000 W/m². A novel serpentine collector without absorber plate was attached to the back of a PV module to dissipate heat. The flow rate was constant at 0.5 l/min. Different weight concentrations of multi wall carbon/water nanofluid were used (0 to 1%). It was observed that the maximum electrical efficiency was 11.96% with 1% wt., while the electrical efficiency when using water as coolant was 11.82%.

Karami and Rahini [10] conducted experimental studies using Boehmite nanofluid to cool PV modules using a collector with two configurations: helical and straight channels with a hydraulic diameter of 4.1 mm. They used different weight concentrations of nanofluid (0.01, 0.1 and 0.5 wt.%). The maximum temperature decrease seen in PV panels were 18.33 and 24.22 °C for the straight and helical channels respectively, this occurred at 0.1% concentration. The maximum improvements in electrical efficiency were 20.57% and 37.67% for straight and helical channels respectively.

The aim of this work is to investigate the performance of a photovoltaic panel when it is integrated with an aluminum cooling panel (pocket type) and using SiC/water nanofluid as coolant.

2. Methodology

2.1 Experimental Setup

The experimental rig was manufactured and installed outdoors at Babylon University, Iraq. It consists of three 100 W monocrystalline photovoltaic panels; their specifications are shown in Table 1. Two panels are equipped with pocket coolant panel and they are marked as photovoltaic/thermal panel or PV/T (for water cooled) and PV/TN (for nanofluid cooled). The third PV is stand-alone. The pocket coolant panel was manufactured from aluminum sheet with 3 mm thickness, as shown in Figures 1 and 2. It is fixed to the back side of the photovoltaic panel with insulation layer beneath.

The PV/TN solar system is cooled by SiC/Water nanofluid. The nanofluid is stored in the container to be pumped by use of a circulation pump, type Stream SXR40/6-3P. A helical coil heat exchanger with counter flow design is used, as shown in schematic Figure 3. The cooling fluid in the heat exchanger is pure water, which is stored in insulated tanks and can be controlled by throttling the valve and flow meter as shown in Figure 4.
Table (1) Specification of photovoltaic panel

| Module Model                  | ISTAR SOLAR IS100P, Italy |
|-------------------------------|---------------------------|
| Peak Power                    | 100 Watt                  |
| Nominal Voltage               | 12 Volt                   |
| Short Circuit Current         | 6.3 Amps                  |
| Nominal Temperature           | 45 ( +/-2) °C             |
| Dimensions (mm)               | 1205*675*35               |

The PV/T solar system was cooled by pure water under the same weather conditions shown in Figure 4.
Figure 4. Schematic of PV/T solar system

The rig was installed outdoor at University of Babylon, Iraq (32.46°N, 44.42°E). Different flow rates were tested in February and March, with two volumetric concentrations (0.1 & 0.5%) of SiC nanofluid. The PV/T, PV/TN and PV panels were directed to the south and the tilt angle was changed monthly. The test rig is shown in Figure 5.

Figure 5. The experimental setup
2.2 Preparation of Nanofluid

The nanofluid used in these experiments was SiC nanoparticles dispersed in deionized pure water. The SiC nanoparticles are a product of SkySpring Nanomaterials, Inc. USA, being of cubic shape 40 nm and purity +99%. The thermal properties of SiC nanoparticles are shown in Table 2. The preparation was done at the nanofluid unit, College of Engineering, University of Kufa in the following way:

1. Nanoparticles weighted with a sensitive weighing balance as shown in Figure 6a.
2. A magnetic stirrer (Jenway, England) was used to mix the nanoparticles with deionized water for fifteen minutes, as shown in Figure 6b.
3. A sonication process was sustained for twenty minutes using probe sonication equipment from MTI sonication Equipment, USA, as shown in Figure 6c.
4. Sonication bath for three hours as shown in Figure 6d.

Table 2. Thermal properties of SiC nanoparticles [11]

| Property                      | SiC Nanoparticles |
|-------------------------------|-------------------|
| Density (kg/m$^3$)            | 3220              |
| Thermal Conductivity (W/m K)  | 370-490           |
| Specific Heat (J/kg K)        | 0.737             |

(a) Weighing of SiC Particles  (b) Stirrrring Process
2.3 Thermophysical Properties of SiC/Water Nanofluid

The volumetric fraction and thermophysical properties of the SiC/water nanofluid can be calculated by using the following equations [6]:

\[
\phi\% = \frac{(m_i / \rho_s)}{(m_i / \rho_s) + (m_f / \rho_f)} \tag{1}
\]

\[
\rho_{nf} = (1 - \phi) \rho_f + \phi \rho_s \tag{2}
\]

\[
k_{nf} = \frac{k_f k_s + 2k_f k_s - 2(k_s - k_f)\phi}{k_f k_s + 2(k_s - k_f)\phi} \tag{3}
\]

\[
C_{p_{nf}} = \frac{(1 - \phi) C_{pf} + \phi \rho_s C_{ps}}{\rho_{nf}} \tag{4}
\]

\[
\mu_{nf} = (1 + 2.5\phi) \mu_f \tag{5}
\]
3. Measurement Instruments

The following instruments were used to measure the required variables of the experiments:

1. Thermometer type Lutron BTM-4208SD with 12 channels and SD card to record the temperature data of PV, PV/T and PV/TN backsides, inlet and outlet of cooling fluids.
2. Twenty-three calibrated thermocouples type k, used to measure the temperatures. Fifteen of them are distributed on the rear surface of the panels, four are fixed on the inlet and outlet of heat exchanger, and the remaining four are fixed on inlet and outlet of PV/TN and PV/T Solar Systems.
3. Anemometer AN200, used to measure wind velocity and ambient temperature.
4. Flow meter ZYIA floating type used to measure the flow rate of SiC/water nanofluid and pure water.
5. Solar radiation meter TES132, to measure the intensity of incident radiation.
6. Solar analyzer PROVA 200A, used to measure the electrical performance of photovoltaic panels such as maximum power.

4. Results and Discussion

The experimental tests were carried out outdoors, under the weather conditions of middle Iraq (at Babylon University), latitude of 32.46 °N and longitude of 44.42°E. Work took place from February to March, 2019. The measurements included solar radiation, temperature of PV back sheets and the electrical performance, as below.

4.1 Solar Irradiance and Air Temperature

Figures 7 and 8 show the variations in solar irradiance (SR) and ambient temperature (air temp.), with times, for selected days on February and March. They sky was clear. It is noted the maximum solar irradiance on 19 February was 1032 W/m² and air temperature 31.4 °C, while on 27 March the maximum solar irradiance was 1002 W/m² with a maximum air temperature of 34.7 °C. This is because Earth is closer to the sun in February, but the northern hemisphere is tilted away according to the solar inclination angle, which is larger than that in March. [12]
Figure 7. Variation in solar irradiance and air temperature with time

Figure 8. Variation of solar irradiance and air temperature with time

4.2 The Average Back Sheet Temperatures of PV, PV/T and PV/TN

Five thermocouples are fixed to the rear side of every PV, PV/T and PV/TN panel to measure the average temperature as shown in Figure 9.
Figure 9. Positions of thermocouple sensors

The results were collected on 19 February under clear sky conditions as shown in Figure 10 a. It is noted the maximum temperature of PV is 63.2 °C, while it is 41.6 °C for PV/T that is cooled by pure water and 40.9 °C for PV/TN which is cooled by SiC/Water nanofluid of 0.1 % concentration and flow rate of 0.5 LPM. Figure 10 b shows the temperatures of PV, PV/T and PV/Tn on 27 March. It is observed that the maximum temperature of PV is 60.2 °C, while it is 39.1 °C for PV/T cooled by pure water and 38 °C for PV/Tn cooled by SiC/Water nanofluid with 0.5 % volumetric concentration and flow rate of 2 LPM. This occurred because increasing the nanofluid concentration leads to enhancement of the thermal conductivity that raises that heat transfer rate.
Figure 10. Time variation of average temperatures of back sheets of PV Module, PV/T Solar System and PV/TN Solar System. (a) At 0.5 LPM flow rate and 0.1% SiC/water nanofluid concentration. (b) At 2 LPM flow rate and 0.5% SiC/Water nanofluid concentration

4.3 The Maximum Electrical Power

The maximum electrical power (Pm) of PV/TN cooled by nanofluid is better than that of PV/T cooled by pure water for all cases of flow, because the back-sheet temperature of PV/TN is lower than that of PV/T. The electrical power increases by increasing the rate of following fluid, due to the cooling effect that reduces the temperature of the back sheet. Figure 11a shows the electrical power of PV, PV/T and PV/TN on 19 February for 0.1% nanofluid concentration and 0.5 LPM of flow rate. It is noted the maximum electrical power of PV/TN is 71.6 W at 11:50 PM, while the maximum electrical power of PV/T is 69.8 W at 12:30 PM and the maximum electrical power of the PV panel is 61.3 W at 01:00 PM. The power drop for PV/TN after 12:30 PM is due to the rising of the nanofluid temperature compared with the pure water temperature of PV/T.

The maximum power on 27 March is 82.8 W at 12:00 PM for PV/Tn system with nanofluid concentration of 0.5% and 2 LPM., while the maximum electrical power of PV/T is 69.8 W at 12:30 PM and the maximum electrical power of PV panel is 61.3 W at 12:20 PM as shown in Figure 11b.
Figure 11. Time variation of electrical maximum power of PV module, PV/T solar system and PV/TN solar system. (a) At 0.5 LPM flow rate and 0.1% SiC/Water nanofluid concentration. (b) At 2 LPM flow rate and 0.5% SiC/water nanofluid concentration

4.4 Electrical Efficiency and Overall Efficiency

Figure 12 shows the electrical efficiencies of PV/TN, PV/T and PV. The electrical efficiency decreases by increasing the solar irradiance due to the temperature rising. According to silicon absorbance capability, most of the incident solar energy is converted to electrical energy, while the remaining is converted to heat energy inside the photovoltaic cells. Increasing the flow rates of nanofluid increases the electrical efficiency. Increasing the volumetric concentration of SiC/water nanofluid improve the electrical efficiency due to increased heat transfer rate. The maximum electrical efficiencies on 19 February are 9.72 %, 9.03 % and 7.17 % for PV/TN, PV/T and PV, respectively. Meanwhile the maximum electrical efficiencies on 27 March are 12.47 %, 10.4 % and 8.32 % for
PV/TN, PV/T and PV respectively. Figure 13 shows the average of electrical power on selected days (19 February and 27 March) for the PV/TN system, PV/T system and PV panel. It is noted that the average power of the PV/TN is better than that of PV/T and PV. The maximum enhancement in electrical power on 27 March is 23.93 %, with 2 LPM flow rate and 0.5% SiC/Water nanofluid concentration. The maximum enhancement of electrical power on 19 February is 19.21 % with 0.5 LPM flow rate and 0.1 % SiC/water.

![Graph showing electrical efficiency over time for PV/TN, PV/T, and PV systems on 19-2-2019.](a)
Figure 12. Time variation for electrical efficiency of PV module, PV/T and PV/TN system with SiC/water nanofluid. (a) At 0.5 LPM flow rate and 0.1% SiC/water nanofluid concentration. (b) At 2 LPM flow rate and 0.5% SiC/water nanofluid concentration.

Figure 13. The average electrical power for PV/TN, PV/T and PV on 19 February and 27 March.

Figure 14 shows the effect of flow rate on the overall efficiency for PV/T and PV/TN with 0.1% nanofluid concentration. It is noted that increasing the flow rate enhances the overall efficiency for both pure water and SiC/water nanofluid. The maximum overall efficiencies on 19 February were 66.69%, 62.23% and 8.32% for PV/TN, PV/T and PV respectively, while the maximum overall efficiencies on 27 March were 92.43%, 83.23% and 8.32% for PV/TN, PV/T and PV respectively. Figure 15 illustrates.
Figure 14. Overall efficiency for PV/T system compared with PV/TN system with 0.1% SiC/water nanofluid concentration for different flow rates.
5. Conclusions

1. The electrical efficiency of a PV module is mainly affected by the module’s temperature. The higher the temperature of the PV module, the lower the electrical efficiency.
2. Increasing the volumetric concentration of SiC/water nanofluid enhances the electrical and thermal efficiency compared with pure water, due to the higher thermal conductivity of SiC/water nanofluid.
3. Increasing the flow rate of SiC/water nanofluid improves the electrical and thermal efficiencies.
4. The maximum enhancement in electrical power on 27 March is 23.93 % with 2 LPM flow rate and 0.5% SiC/water nanofluid concentration.
5. The maximum enhancement of electrical power on 19 February is 19.21 % with 0.5 LPM flow rate and 0.1% SiC/water nanofluid concentration.
6. The maximum electrical efficiencies on 19 February are 9.72 %, 9.03 % and 7.17 % for PV/Tn, PV/T and PV respectively, with 0.5 LPM flow rate and 0.1 % nanofluid concentration.
7. The maximum electrical efficiencies on 27 March are 12.47 %, 10.4 % and 8.32 % for PV/Tn, PV/T and PV respectively, with 2 LPM flow rate and 0.5 % nanofluid concentration.
8. The maximum overall efficiencies on 19 February are 66.69 %, 62.23 % and 8.32 % for PV/Tn, PV/T and PV respectively.
9. The maximum overall efficiency on 27 March are 92.43 %, 83.23 % and 8.32 % for PV/Tn, PV/T and PV respectively.
References

[1] A. N. Al-Shamani, K. Sopian, S. Mat, H. A. Hasan, A. M. Abed, and M. H. Ruslan, “Experimental studies of rectangular tube absorber photovoltaic thermal collector with various types of nanofluids under the tropical climate conditions,” *Energy Convers. Manag.*, vol. 124, pp. 528–542, 2016.

[2] N. Karami and M. Rahimi, “Heat transfer enhancement in a hybrid microchannel-photovoltaic cell using Boehmite nanofluid,” *Int. Commun. Heat Mass Transf.*, vol. 55, pp. 45–52, 2014.

[3] S. R. Abdallah, I. M. M. Elsemary, A. A. Altohamy, M. A. Abdelrahman, A. A. A. Attia, and O. E. Abdellatif, “Experimental investigation on the effect of using nano fluid (Al2O3-Water) on the performance of PV/T system,” *Therm. Sci. Eng. Prog.*, vol. 7, pp. 1–7, 2018.

[4] T. M. Abu-Rahmeh, “Efficiency of Photovoltaic Modules Using Different Cooling Methods: A Comparative Study,” *J. Power Energy Eng.*, vol. 05, no. 09, pp. 32–45, 2017.

[5] A. N. Al-Shamani, M. A. Alghoul, A. M. Elbreki, A. A. Ammar, A. M. Abed, and K. Sopian, “Mathematical and experimental evaluation of thermal and electrical efficiency of PV/T collector using different water based nano-fluids,” *Energy*, vol. 145, pp. 770–792, 2018.

[6] H. A. Hussein, A. H. Numan, and R. A. Abdulrahman, “Improving the Hybrid Photovoltaic/Thermal System Performance Using Water Cooling Technique and (Zn -H 2 O) Nanofluid,” *Int. J. Photoenergy*, vol. 2017, no. 3, pp. 1–14, 2017.
[7] D. D. P. Kalita, “Performance Improvement of a novel flat plate photovoltaic thermal (PV/T) system using copper oxide nanoparticle–water as coolant,” Int. Conf. Nano Energy Water, pp. 97–104, 2017.

[8] S. Soltani, A. Kasaeian, H. Sarrafha, and D. Wen, “An experimental investigation of a hybrid photovoltaic/thermoelectric system with nanofluid application,” Sol. Energy, vol. 155, pp. 1033–1043, 2017.

[9] R. Nasrin, N. A. Rahim, H. Fayaz, and M. Hasanuzzaman, “Water/MWCNT nanofluid based cooling system of PVT: Experimental and numerical research,” Renew. Energy, vol. 121, pp. 286–300, 2018.

[10] N. Karami and M. Rahimi, “Heat transfer enhancement in a PV cell using Boehmite nanofluid,” Energy Convers. Manag., vol. 86, pp. 275–285, 2014.

[11] A. H. A. Al-Waeli et al., “Comparison study of indoor/outdoor experiments of a photovoltaic thermal PV/T system containing SiC nanofluid as a coolant,” Energy, vol. 151, pp. 33–44, 2018.

[12] L. Wald and L. Wald, “Basics in solar radiation at Earth surface,” https://hal-mines-paristech.archives-ouvertes.fr/hal-01676634, 2018.