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Experimental Investigation on the Effect of Cooling Performance of Photovoltaic Panel using Nanofluid

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Abstract

Solar power, a promising green technology, is known to have a decrease in its efficiency as temperature increases. While solutions such as nanofluids offer the potential to cool the panels, their practical implementation has challenges. This study aims to analyze the cooling performance of a Titanium Dioxide (TiO_2) and Zinc Oxide (ZnO) based sunscreen on photovoltaic panels. The experimental set-up consists of polycrystalline solar panels, water, a DIY sunscreen kit including TiO_2 and ZnO, a heat fan, a spray bottle, an Arduino voltage sensor and a current sensor. Sunscreen and water were sprayed 10 to 30 times on the backside or frontside of the photovoltaic panel that is 55℃. Statistical analysis was done using SPSS. A temperature drop ranging from 3.5-11℃ was observed as the fluid was sprayed. Spraying on the back side rather than the front side, an increase in the rate of spraying, and utilizing sunscreen instead of water lead to larger temperature drops. Power and temperature showed significant correlations with a Pearson's R coefficient of -0.71 ($p<0.001$). Linear regression showed a R^2 value of 0.505 ($p<0.001$), with an equation of [Power] = - 0.338[Temp] + 44.561. Overall, TiO_2-ZnO-based sunscreen showed effectiveness on the cooling performance of photovoltaic panels. For further applications, verification of these results and an outdoor study would be needed.

Keywords: Nanofluid, Solar power, Photovoltaic panel

1. Introduction

The growing awareness of climate change and its potential impacts has indeed been a driving force behind a significant shift in global energy priorities. Green energy sources, such as solar power, hydropower, and wind power, have gained immense prominence as solutions. However, the efficiency of commercially available solar panels varies, and some widely used photovoltaic (PV) technologies have efficiencies in the range of 10-20% (Parthiban et al., 2022). Solar panels experience a decrease in efficiency as their temperature increases due to the photovoltaic conversion process generating heat, and therefore not being able to generate as much electrical energy. (Siecker et al., 2017).

Cooling of PV panels is a critical issue in the design and operation of concentrated photovoltaic technology (Bahaidarah et al., 2016). Various cooling methods are employed to cool solar cells, including passive cooling, active cooling, and cooling with phase change materials (PCMs). While passive cooling is cost-effective, it has a low heat transfer rate and offers limited enhancement in photovoltaic performance. Active cooling, though effective, requires an external power source, reducing the net output power of PV cells (Sharaf et al., 2022). Fluids are utilized to carry thermal energy from the collectors and ultimately cool PV panels. Using water as a cooling fluid is one of the simplest and most common methods in active and passive cooling. Water has a high heat capacity, low environmental impact and readily availability making it effective at absorbing and carrying away heat from the PV panels (Belyamin et al., 2022). PCM cooling is promising, but due to the low thermal conductivity of PCMs, it provides limited enhancement. To improve PCM cooling, additives such as nanoparticles or porous metals can be used. While nanoparticles offer better performance enhancement, they are expensive (Sharaf et al., 2022).

Nanofluids, which are nanometer-sized solid metal or metal oxide particles dispersed in single-phase fluids, offer superior thermo-physical properties due to the high thermal conductivity of nanoparticles. Metal or metal oxide nanoparticles, such as Aluminum Oxide (Al_2O_3), Zinc Oxide (ZnO), Titanium Oxide (TiO_2,) and others, have shown promising results in enhancing the cooling of solar panels, as demonstrated by various researchers. For instance, adding just a 5% volume fraction of ZnO_2 nanoparticles to ZnO_2–ethylene glycol-based nanofluids resulted in a 26.5% improvement in thermal conductivity. Similarly, studies using Al_2O_3/water and copper oxide/water-based nanofluids showed enhanced heat transfer coefficients with increasing nanoparticle concentrations (Benedict et al., 2020). In an experimental and numerical study, TiO_2, ZnO, and Al_2O_3 nanoparticles dispersed in water at a concentration of 0.2% increased PV efficiency by 6.54%, 6.46%, and 6.36%, respectively (Sardarabadi et al., 2016)

While nanofluids show potential for improving cooling efficiency, their practical implementation has challenges such as nanoparticle stability, cost-effectiveness, and health and safety (Gelis et al., 2022). In addition, there has not yet to be research that utilizes relatively simple real-life equipment, which could open numerous doors for various researchers to supplement the knowledge in the field currently. Therefore, this study aims to take the first step towards that direction by analyzing the effect of TiO_2-ZnO-based sunscreen on cooling PV panels.

2. Materials and Methods

An experimental study was conducted to compare the cooling performance between water and sunscreen. The schematic view of the experimental setup is shown in Fig. 1. A total of 50 ml of fluids were utilized in this experiment, consisting of distilled water and sunscreen created from a DIY sunscreen kit. The sunscreen was prepared using the following ingredients: olive liquid (1g), lavender floral water (25g), aloe vera water (20g), lipidure (2g), minicare pentiol (2g), TiO_2 (2g), ZnO (2g), and Albutin (0.5g). All the materials were weighed, mixed, and thoroughly stirred. A spray bottle was utilized to spray the fluids. A heat fan was utilized as a heat source, and Polycrystalline solar panels (5x11 cm) were used. A HiLetGo voltage sensor and an ACS712 current sensor were utilized to measure the power output. The temperature of the PV panel was measured using a K-type thermocouple connected to a MAX 6675 amplifier that was attached to the back side of the PV panel. The Arduino was connected to the laptop and was coded to collect data once every second for 10 minutes.

Experimental procedures were as follows; place the panel directly 30cm in front of the heat fan. Then turn on the heat fan and wait for the panel to heat up to 55 ℃. After the PV panel reaches 55 ℃, turn on the Arduino to measure the current output, voltage output, and temperature of the solar panel and record for 10 minutes. Spray the water 10, 20, 30 times in the front of the panel (WF_10, WF_20, WF_30) and in the back of the panel (WB_10, WB_20, WB_30). Do the same for the sunscreens (SF_10, SF_20, SF_30, SB_10, SB_20, SB_30). Spray within the first 45 seconds.

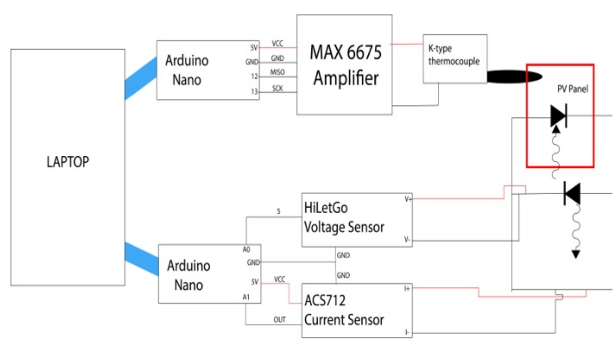

Figure 1. schematic view of the experimental setup.

Statistical analysis was conducted using SPSS (IBM Corporation, Armonk, NY, USA). Pearson's correlation coefficient was used to measure the strength of the linear relationship between the power output of the solar panel and the temperature in each group, along with the corresponding p-value. The coefficient determines the strength of this relationship, with values closer to 1 or -1 indicating a stronger association. A positive correlation implies an upward slope, meaning an increase in one variable corresponds to an increase in the other variable. Higher R-squared (R^2) values in this range indicate a better correlation. Linear regression provides a linear relationship between an independent variable (temperature in each group) and a dependent variable (power output of the solar panel) to predict

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the outcome of other events. The regression line equation is in the form Y = a + bX, where X is the explanatory variable (temperature) and Y is the dependent variable (power). Here, b represents the slope of the line, and a is the intercept. R-squared (R^2) is a goodness-of-fit measure for linear regression models, indicating the percentage of the variance in the dependent variable explained by the independent variables collectively. R-squared values range from 0 to 1, with higher values indicating a better fit of the regression line to the data. A t-test was conducted to compare the cooling effects (temperature) between water and sunscreen, as well as to compare the cooling effects (temperature and power) based on the amount of spraying between the front and back of the panel. When the t-test value exceeded the 95% confidence level student's t value, the compared groups were considered statistically different, rejecting the null hypothesis of no significant difference in mean values. Each p-value was compared to a significance threshold of 0.05 for all statistical tests. If the p-value was greater than 0.05, the measured characteristic was not deemed to be significantly different.

3. Results

When the fluid was sprayed at 55℃, the temperature dropped 3.5-11℃ and recovered back to 55℃ at the end of the 10 minutes, but the control group showed a continuous increase in temperature from 55 to 70℃ for 10 minutes. In particular, the SB_30 group showed the largest drop of 11 ℃, and the SF_10 group showed the smallest drop of 3.50 ℃. When considering the average temperature, the SB_30 group showed the lowest average temperature of 47.86 ℃, whereas the WF_10 group showed the highest average temperature of 53.59 ℃ (Fig. 2).

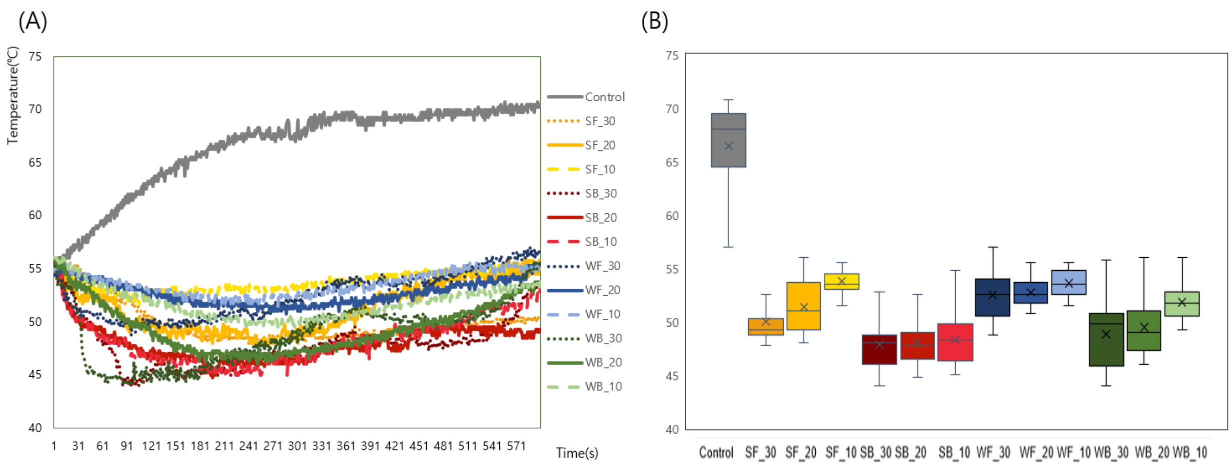

Figure 2. A line graph of the temperature by time (a) and box plots of temperature (b) of the solar panels according to experimental conditions.

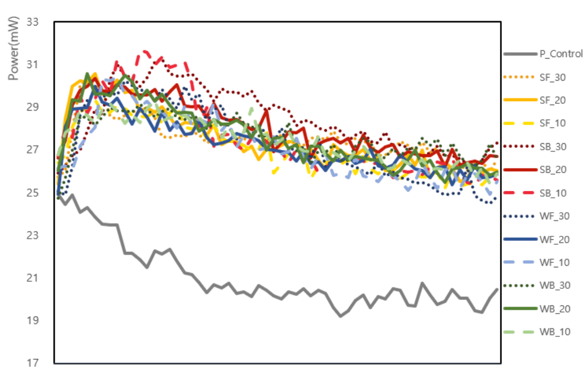

Figure 3. A line graph of the power output by time of the solar panels according to experimental conditions.

For the power output, an initial increase and then a decrease as time passes was observed, except for the control group where a continuous drop was shown. In 12 experimental groups, power output was increased after spraying at 55℃, and returned to 25 milliwatts (mW) at the end of the 10 minutes. In the control group, power output dropped by 6 mW. The WF_20 group showed the highest increase in power of 7.39 mW, while the SF_30 group showed the lowest increase in power of 6.56 mW. For the average power output, the SB_30 group had the highest average of 28.44 mW, and the WF_10 group showed the lowest average power of 27.11 mW (Fig. 3).

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Power and temperature showed significant correlation with a Pearson's R coefficient of -0.71 ($p<0.001$). Linear regression showed an R^2 value of the 0.505 ($p<0.001$), with the equation being [Power] = -0.338 x [Temp] + 44.561. When only taking the control into account, the R^2 value increased to 0.6998, which suggests a good fit of the linear line (Fig. 4) The equation of this line was [Power] = -0.3552 x [Temp] + 44.625.

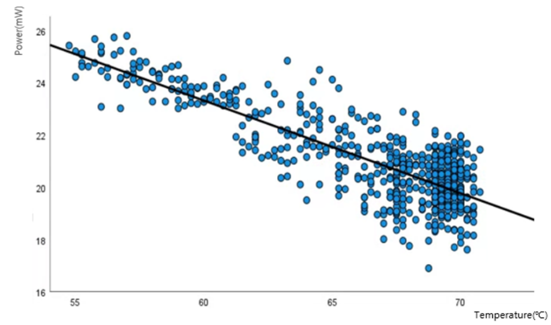

Figure 4. Scatter plots of Temperature vs Power.

A comparison of cooling effects between water and sunscreen was conducted (Fig. 5). The average temperature of the sunscreen was significantly lower than that of water in all five groups (B_10, B_20, B_30, F_20, F_30) with a p-value < 0.001, except for the F_10 group (p=0.533). Moreover, the minimum temperature observed with the sunscreen tended to be lower than that with water across the five groups (B_10, B_20, B_30, F_20, F_30), except for the F_10 group. These findings suggest that the sunscreen exhibits superior cooling performance compared to water, particularly in the tested conditions.

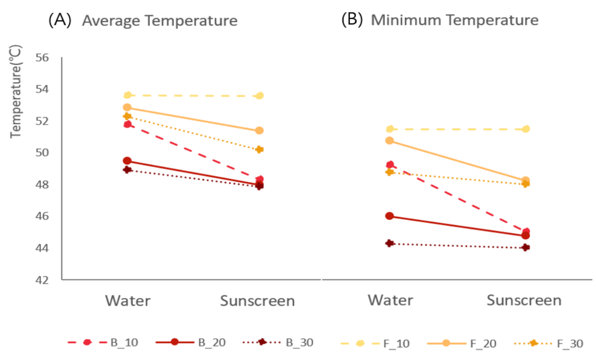

Figure 5. Comparison of the average temperature (a) and the minimum temperature (b) between the water and sunscreen groups.

Comparison of the cooling effects by amounts of spraying was done (Fig. 6). A larger number of spraying leads to a lower average temperature for all groups. In terms of power, more sprayings lead to higher average power output for all groups as well.

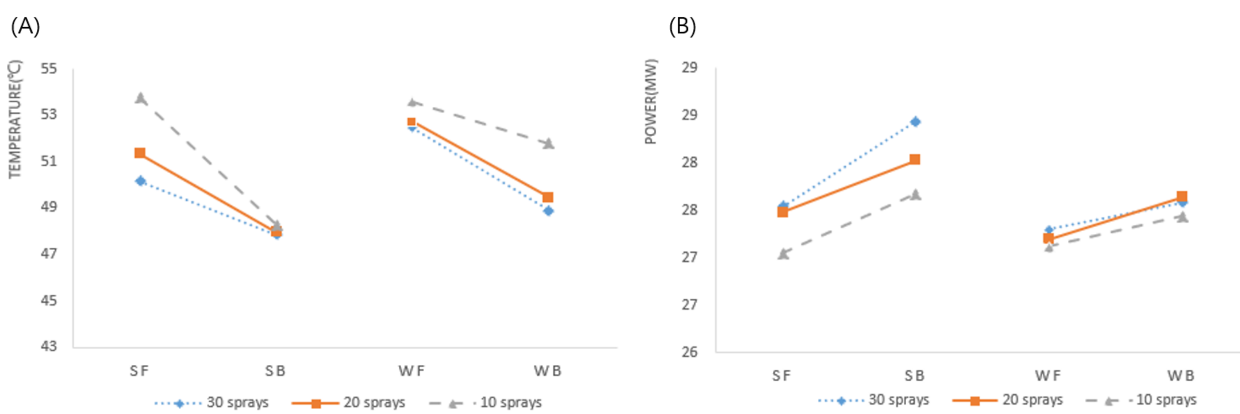

Figure 6. Comparisons of the average temperature (a) and the average power (b) according to 10, 20 and 30 times of spraying

In addition, for all amounts of spraying, the temperature when the fluids were sprayed in the front is higher than when the fluids were sprayed in the back, and the power is higher when the fluids were sprayed in the back.

4. Discussion

Higher temperatures can lead to a decrease in the voltage output of solar cells, thereby reducing overall efficiency. Nanofluids have emerged as a potential solution to mitigate the negative effects of elevated temperatures on solar

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panel performance. This study confirmed the effectiveness of a TiO_2-ZnO-based sunscreen in enhancing the cooling performance of photovoltaic panels. By applying the fluid through spraying, a notable temperature drop ranging from 3.5 to 11℃ was observed. This innovative approach shows promise in dissipating excess heat and maintaining the optimal operating temperature of solar panels, ultimately improving their overall efficiency.

Nanofluids, featuring nanoparticles with diameters between 1 and 100 nm, demonstrate unique properties for efficient heat extraction, particularly in solar systems. The integration of metal oxide-based nanoparticles—Aluminum oxide, Silicon oxide, Iron oxide, TiO_2, Copper oxide, ZnO, and Magnesium oxide—with base fluids was investigated to enhance PV/T system performance (Hossain et al., 2022; Mohammed et al., 2021). Utilizing nanofluids as cooling agents or spectral filters contributes to reducing PV temperatures and enhancing overall PV/T system efficiency. Recent studies explored combinations of various metal oxide nanoparticles with different fluids. In a study involving TiO_2, Al_2O_3, and ZnO fluid, it was observed that both TiO_2 and ZnO exhibit superior total energy efficiency and exergy efficiency compared to Al_2O_3 (Sardarabadi et al., 2017). Despite the advantages of nanofluids in enhancing heat transfer, persistent challenges include the high cost of production, potential health and environmental concerns, and the complexity of manufacturing and implementation. To address these challenges, this study utilized a do-it-yourself sunscreen kit containing TiO_2 and ZnO to mitigate potential toxicity and achieve cost savings. Aligned with previous studies, (Murtadha et al., 2023, Alktranee et al., 2022). our research demonstrated lower temperatures when cooling with nanofluids. More sprayings result in lower average temperatures for all groups. Additionally, increased sprayings lead to higher average power output across all groups. Murthada's work, (Murtadha et al., 2023), which investigated nanofluid flow rates (0.5–3L/min) in a PV/T system, showed that the power output increased and peaked at 2.5L/min, subsequently dropping at 3L/min. Since our research was conducted on a much smaller scale than that of Murthada's, the spraying could potentially fall under the portion of previous research when the values are continuously increasing.

Notably, regardless of spraying amounts, front spraying resulted in higher fluid temperatures but lower power, while back spraying exhibited the opposite effect. The results go against other study, with the solar panel showing a 118.03W increase when sprayed in the front but a 104W increase when sprayed in the back (Panda et al., 2023). Additionally, Nižetić's research indicated a greater power output increase with front spraying compared to the back, possibly attributed to particles blocking sunlight reaching the solar panel when sprayed on the front (Nižetić et al., 2016).

However, there are several limitations in this study. The largest is that the research was conducted indoors, therefore has a challenge in terms of expanding the research to real-life conditions. In addition, the sensor that was utilized for this research ended up having a lot of noise, which led to somewhat inaccurate results being displayed. These results, however, are still somewhat in line with previous researchers' outputs, but would be better if sensors were to have higher sensitivity. Commercial sunscreen spray kits containing nanomaterials were used. Due to safety concerns related to the hazardous nature of the materials and limitations of the laboratory environment, experimental-grade nanomaterials could not be used, potentially leading to differences in accuracy. Additionally, stirring and mixing using specialized equipment were not performed, resulting in uneven distribution. Furthermore, the amount sprayed from the household spray was not adjustable, which could introduce errors even if the spraying was performed by the same researcher using the same method. Only small pieces of polycrystalline solar panels (5x11 cm) were used in this study. It is important to note that voltage and temperature may vary when these panels are scaled up in size.

This study shows the promising role of TiO_2-ZnO-based sunscreen in enhancing the cooling performance of photovoltaic panels. This finding has the potential to be applied in outdoor settings and validated on a larger scale for real-life applications. In today's context, small solar-powered electronic devices such as outdoor lamps, phone chargers, speakers, fans, and similar products utilize solar panels to convert sunlight into electricity. This stored energy allows them to operate without the need for a traditional power source. Applying TiO_2-ZnO-based sunscreen to these devices can potentially improve their efficiency by enhancing their cooling performance, thereby increasing their effectiveness and lifespan. Further research could explore the long-term durability and stability of this sunscreen under various environmental conditions. Additionally, investigations into the scalability of this approach to larger photovoltaic systems and its potential application in real-world settings would be valuable.

5. Conclusion

This TiO_2-ZnO-based sunscreen showed effectiveness on the cooling performance of PV panel. Sunscreens have a better effect of cooling than when compared to water. Spraying on the back side rather than the front side leads to lower temperatures. The higher the spray rate, the larger the temperature drops, and therefore, higher power outputs. This study's advantage is that it has been conducted using homemade and consumer-grade materials that are relatively cheap, which opens a new doorway to research using solar panels and nanofluids. This reduction of cost in conducting research is valuable for expanding the application.

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