



Review on Performance Analysis of Solar Panel Cooling Mechanism Using Nanofluid

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ABSTRACT

Harnessing solar energy through photovoltaic (PV) panels is a promising avenue for renewable energy. However, high operating temperatures can diminish PV panel efficiency. This study aimed to develop a cooling system to improve the electrical and thermal efficiency of PV panels. The research focused on using TiO₂, Al₂O₃, and ZnO nanoparticles added at 0.5 vol% to water as working fluids for active cooling. The system included a rectangular spiral and a tube behind the PV panel, with a solar simulator simulating varying solar radiation intensities for performance evaluation. Results showed that the nanofluid-based heat exchanger reduced panel temperature by 14°C, increasing electrical efficiency by up to 4.7% with the ZnO nanofluid. In the spiral configuration, the ZnO nanofluid reduced panel temperature from 60°C to 45°C, boosting I_{sc} from 2.16A to 2.9A and V_{oc} from 21.5V to 23V, resulting in a maximum power increase to 53W. This study highlights the potential of nanofluid-based cooling systems to enhance PV panel performance.

1. INTRODUCTION

The global energy crisis has spurred the development of renewable energy technologies, with solar energy emerging as a promising solution due to its abundance, cleanliness, and accessibility. Photovoltaic (PV) solar cells, which convert sunlight into electricity, have gained popularity for their eco-friendliness. Photovoltaic thermal (PV/T) systems, which combine PV and solar thermal collectors, are widely used in

developed countries for various applications, including residential and commercial buildings. In China, PV/T systems are utilized for hot water production and solar-assisted heat pumps, where the PV/T module serves as an evaporator. However, a major challenge faced by PV systems is the increase in panel temperature, which can significantly reduce their output power performance. For every 1°C increase in operating temperature, the output power of the PV module decreases by 0.4-0.5%. In building-integrated

photovoltaics/thermal (BIPV/T), the performance of PV modules deteriorates when the operating temperature exceeds 80°C during summer.

To improve the efficiency of PV modules and reduce thermal degradation, various cooling techniques have been employed. Forced convection using water is a popular cooling technique, and nanofluids, which are colloidal suspensions of nanoparticles in a base fluid, have shown promise due to their enhanced thermal conductivity. Nanoparticles smaller than 100 nm are dispersed into water, oil, or ethanol to create nanofluids.

One effective cooling technique involves forced convection of water using the spraying method on the top surface of the PV module. This method has been shown to improve overall PV performance, including current, power, and efficiency. Overall, implementing effective cooling techniques is crucial for enhancing the efficiency and longevity of PV systems.

Energy sources can be broadly classified into non-renewable and renewable categories. Non-renewable sources, such as fossil fuels, are finite and contribute to environmental pollution, leading to health issues. In contrast, renewable sources, like solar energy, are environmentally friendly and have no negative impact on the environment.

Solar photovoltaic (PV) systems harness solar radiation to generate electricity. However, only about 19-21% of solar radiation is directly converted into electricity, with the rest being either reflected or absorbed as heat. This heat raises the operational temperature of the PV cell, reducing its electrical efficiency.

To maintain optimal performance of solar cells, cooling techniques are essential to lower their temperature. For every 1°C increase in surface temperature, the efficiency of a solar cell can decrease by 0.3% to 0.5%. Studies have shown that monocrystalline panels are more efficient than polycrystalline ones. Previous research has focused on cooling methods for PV panels to improve their efficiency

2. RENEWABLE AND NON-RENEWABLE ENERGY

Solar energy is captured through photovoltaic cells, converting sunlight into electricity, or via solar thermal collectors, converting sunlight into heat for various applications. Wind energy is generated using wind turbines, which transform the kinetic energy of wind into mechanical power, subsequently converted into electricity. Hydropower is produced by harnessing the energy of flowing water, often achieved through rivers, waterfalls, or man-made dams. Biomass energy is derived from organic materials like wood, crop waste, and animal dung, either burned directly or

converted into biogas or biofuels. Geothermal energy, on the other hand, is sourced from the Earth's internal heat, utilized for electricity generation or heating and cooling purposes. These renewable energy sources play crucial roles in sustainable energy production, offering environmentally friendly alternatives to traditional fossil fuels.

Non-renewable energy sources are limited and take millions of years to form. They can't be replaced quickly. These sources, like coal, oil, and natural gas, create pollution when burned for energy. Nuclear energy is also non-renewable and comes from splitting atoms to make electricity. Tar sands and oil shale are other non-renewable sources that can be turned into oil, but getting the oil out is hard and harms the environment.

3. ENVIRONMENTAL EFFECT

Renewable energy sources, such as solar, wind, and hydropower, generally have lower environmental impacts compared to non-renewable sources. Solar and wind energy produce no greenhouse gas emissions during operation, but the manufacturing and disposal of components like solar panels and wind turbines can have environmental consequences. Hydropower,

while renewable, can disrupt ecosystems and alter water flow, affecting fish and wildlife. Biomass energy, derived from organic materials, can be sustainable but requires careful management to avoid deforestation and habitat destruction. Geothermal energy has minimal environmental impact but drilling and extraction processes can release greenhouse gases. Non-renewable sources like fossil fuels and nuclear energy have significant environmental impacts, including greenhouse gas emissions, air and water pollution, and habitat destruction.

Sustainability: Renewable energy sources are considered sustainable because they are naturally replenished and can be used indefinitely. They offer a way to reduce reliance on finite resources and mitigate climate change. However, their sustainability depends on responsible management and minimizing environmental impacts. Non-renewable sources, on the other hand, are not sustainable as they will eventually be depleted. Continued use of non-renewable sources can lead to energy insecurity and environmental degradation. Transitioning to renewable energy sources is crucial for long-term sustainability and reducing environmental impacts associated with energy production.

4. SOLAR PHOTOVOLTAIC SYSTEMS

A photovoltaic system, also called a PV system or solar power system, is an electric power system designed to supply usable solar power by means of photovoltaics. It consists of an arrangement of several components, including solar panels to absorb and convert sunlight into electricity, a solar inverter to convert the output from direct to alternating current, as well as mounting, cabling, and other electrical accessories to set up a working system. It may also use a solar tracking system to improve the system's overall performance and include an integrated battery.

PV systems convert light directly into electricity and are not to be confused with other solar technologies, such as concentrated solar power or solar thermal, used for heating and cooling. A solar array only encompasses the solar panels, the visible part of the PV system, and does not include all the other hardware, often summarized as the balance of system (BOS). PV systems range from small, rooftop-mounted or building-integrated systems with capacities ranging from a few to several tens of kilowatts to large, utility-scale power stations of hundreds of megawatts. Nowadays, most PV systems are grid-connected, while off-grid or stand-alone systems account for a small portion of the market.

Operating silently and without any moving parts or environmental emissions, PV systems have evolved from niche market applications into a mature technology used for mainstream electricity generation. A rooftop system recoups the invested energy for its manufacturing and installation within

0.7 to 2 years and produces about 95 percent of net clean renewable energy over a 30-year service lifetime.

5. COOLING TECHNIQUES FOR PV PANELS

Cooling techniques for photovoltaic (PV) panels are crucial to maintain their efficiency, particularly in regions with high temperatures. Passive cooling methods, such as natural ventilation and shading, can help reduce the temperature of PV panels without the need for additional equipment. Active cooling methods, on the other hand, involve the use of fans, blowers, or water to actively remove heat from the panels. Direct air cooling and water-based cooling, which involves spraying water over the panels, are common active cooling techniques. Phase change materials and heat pipes are more advanced methods that can effectively regulate the temperature of PV panels by absorbing and transferring heat. Additionally, thermal insulation and active tracking systems can further enhance the cooling efficiency of PV panels. Implementing a

combination of these cooling techniques can help maintain the optimal operating temperature of PV panels, ensuring maximum efficiency and longevity.

6. IMPACT OF TEMPERATURE ON PV PANEL EFFICIENCY

The impact of temperature on photovoltaic (PV) panel efficiency is a critical consideration in understanding the performance of solar energy systems. PV panels are semiconductor devices that convert sunlight into electricity, and their efficiency can be significantly affected by temperature changes. Generally, as the temperature of PV panels increases, their efficiency decreases. This phenomenon occurs due to several reasons:

Temperature-Dependent Voltage: The voltage output of a PV panel decreases with increasing temperature. This is primarily due to the temperature dependence of the semiconductor materials used in the panel's construction.

Reduced Open-Circuit Voltage: Higher temperatures lead to a reduction in the open-circuit voltage of PV panels. This decrease in voltage negatively impacts the overall power output of the panel.

Increased Resistance: Elevated temperatures increase the electrical resistance within the PV panel, leading to higher losses in power conversion and decreased efficiency.

Thermalization Losses: As temperature rises, the energy of photons absorbed by the PV panel is more likely to be dissipated as heat rather than converted into electrical energy, resulting in decreased efficiency.

Studies have shown that for every 1°C increase in temperature above standard test conditions (typically 25°C), the efficiency of PV panels can decrease by around 0.3% to 0.5%. Therefore, it is crucial to consider temperature effects when designing and installing solar PV systems. Implementing effective cooling techniques, as discussed previously, can help mitigate the impact of temperature on PV panel efficiency and maximize the overall performance of solar energy systems.

7. TYPES OF PV PANELS

Monocrystalline PV Panels: Made from a single crystal structure, typically silicon. Monocrystalline panels are known for their high efficiency rates, making them space-efficient and ideal for rooftops

with limited space. Monocrystalline panels perform better than polycrystalline and thin-film panels in low-light conditions. Monocrystalline panels tend to be more expensive due to their higher efficiency rates and manufacturing process.

Polycrystalline PV Panels: Made from multiple silicon crystals.

Lower efficiency: Polycrystalline panels are slightly less efficient than monocrystalline panels but are more cost-effective.

Suitable for large-scale installations: Polycrystalline panels are a cost-effective option for large-scale PV installations where space is not a constraint.

Thin-Film PV Panels: Made by depositing one or more thin layers of photovoltaic material onto a substrate.

Thin-film panels generally have lower efficiency rates compared to monocrystalline and polycrystalline panels. Thin-film panels are more flexible and lighter than crystalline panels, making them suitable for applications where weight and flexibility are important.

Thin-film panels are typically less expensive to produce than crystalline panels, but they require more space for installation.

In terms of suitability for different cooling techniques, all three types of panels can benefit from cooling to improve their efficiency. Monocrystalline panels, with their higher efficiency rates, may benefit more from cooling techniques that can help maintain their efficiency levels in high-temperature environments. Polycrystalline panels, while slightly less efficient, can also benefit from cooling to improve their overall performance. Thin-film panels, with their lower efficiency rates, may require more extensive cooling measures to offset their lower conversion efficiency. Overall, the choice of PV panel type and cooling technique depends on the specific requirements and constraints of the installation.

8. LITERATURE REVIEW

Hadipour et al. (2021), Using water spraying on the top of solar panels can make them work better. A study showed that spraying water in a specific way can cool the panels and improve their performance. Another study designed a system that sprays water in a pulsed way, which saves water compared to continuous spraying. This system reduced the panel temperature from 57.1 to 24.8 and 26.5 °C, making the panels work more efficiently.

Kordzadeh (2010) tried a different approach by putting a thin layer of water on top of the solar panels to make them work better. Also, the water used for cooling can be collected and used again, which helps save water.

Jakhar et al. (2017) found that by changing how water flows into the back of solar panels, the panels can work better and be more efficient. Their system increased the efficiency of the panels by 1.02-1.41%.

Nižetić et al. (2016) found that cooling solar panels on both sides at the same time works better. Their tests showed it could increase overall efficiency by 7.7%, electric power by 5.9%, and reduce temperature from 54°C to 24°C. They also discovered that using a passive method to control temperature with water and cotton wicks could reduce temperature by 12% and increase electric power by 14%. Additionally, combining traditional solar panels with cooling systems improved power output and efficiency compared to using just one method.

Kahani et al. (2022) found that running a special fluid called TiO₂ nanofluid through a pipe in a wavy pattern under solar panels can make the panels work better. They discovered that using a small amount of nanofluid (0.5 wt%) can increase the panels' thermal efficiency to as high as 86.9%.

Based on reviews, significant attention has been given to PVT cooling systems using forced convection processes. The ability of the working fluid to cool the PV panel influences the increase in thermal and electrical efficiency values. Therefore, this study focuses on discussing the use of nanofluids in metal-oxide/water due to their superior cooling abilities compared to water alone. Nanofluids with higher thermal conductivity offer better heat transfer capabilities. The nanoparticles considered in this study are Aluminum oxide (Al₂O₃), Titanium oxide (TiO₂), and Zinc oxide (ZnO), which are dispersed in water as the base fluid at a concentration of 0.5 vol%.

9. EXPERIMENTAL SETUP OF PV/T SYSTEM

In this experiment, two types of solar panels, monocrystalline, and polycrystalline, are being utilized along with a novel cooling system using nanofluid. The panels are mounted on a structure with copper tubing underneath, through which nanofluid will circulate. The use of nanofluid aims to improve the cooling efficiency of the panels, thereby increasing their overall performance and efficiency.

The experiment involves two setup studies. The first setup includes the complete system with both types of panels and nanofluid circulation. This setup will allow for the study of the combined effects of panel type and nanofluid cooling on the overall performance of the system.

The second setup consists of only the pair of monocrystalline and polycrystalline panels without the nanofluid circulation. This setup serves as a control or baseline for comparison with the first setup. By comparing the performance of the panels with and without nanofluid cooling, the experiment aims to evaluate the effectiveness of the nanofluid cooling system in improving the efficiency of the solar panels.

Overall, the experiment aims to investigate the performance of monocrystalline and polycrystalline solar panels with and without nanofluid cooling. The findings from this study can provide valuable insights into the use of nanofluids for improving the efficiency of solar panel cooling systems, which can have significant implications for the development of more efficient and sustainable solar energy systems.

10. FUTURE DIRECTIONS AND CHALLENGES

Future directions in the development of solar panel cooling systems include optimizing the properties of nanofluids used for cooling, integrating smart technologies for real-time monitoring and control, developing advanced cooling techniques like phase-change materials and microfluidics, and exploring novel materials for solar panel construction. These advancements aim to enhance cooling efficiency, improve system reliability, and reduce costs, ultimately increasing the overall performance of solar energy systems. However, several challenges need to be addressed. Ensuring cost-effectiveness of cooling solutions, maintaining material compatibility between nanofluids and solar panels, minimizing environmental impact, and complying with regulatory standards are key challenges that require careful consideration. Overcoming these challenges will be essential in realizing the full potential of solar panel cooling systems and accelerating the adoption of solar energy as a sustainable power source.

CONCLUSION

Numerous methods have been developed to improve the efficiency of solar photovoltaic (PV) modules, with nanofluid-based forced convection emerging as a popular choice. Nanofluids, comprising nanoparticles dispersed in a base fluid like water, offer superior thermal conductivity and heat transfer properties compared to pure water. This study investigated the impact of different nanofluids on the thermal and electrical efficiency

of PV solar panels. Three types of nanofluids – aluminium oxide, titanium oxide, and zinc oxide – were tested, each dispersed in water at a concentration of 0.5 vol%. The nanofluid was circulated through a rectangular heat exchanger and a stainless-steel tube with a rectangular cross-section.

The results indicated that adding zinc oxide nanofluid, along with a rectangular spiral heat exchanger setup, achieved the lowest temperature of 45°C and the highest increase in electrical and thermal efficiency by 4.7% and 6%, respectively, at an irradiation intensity of 1000 W/m². This led to a notable increase in the panel's maximum power output, reaching 53 watts. The study emphasized the importance of nanoparticle concentration in the nanofluid, enhancing thermal conductivity through mechanisms like Brownian motion and particle thermophoresis. Brownian motion increases heat transfer paths, while thermophoresis directs molecules for more collisions, improving heat transfer.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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