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Experimental investigation of solar thermal performance in PV/T system using SiO_2 nanofluid

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Abstract. The usage of clean energy sources, like solar energy, has been becoming more and more important because of the scarcity of fuel reserves and the need to reduce emissions of carbon to prevent global warming. In this context, a nanofluid-based PV/T (photovoltaic thermal) system has been developed to boost solar energy utilization for a variety of residential and industrial applications. The PV/T system pumps the SiO_2-nanofluid through the lowest part of the panel, decreasing the temperature of solar panel and increasing the overall amount of electricity produced. Furthermore, the heat generated through the panel can be used to raise the SiO_2 nanofluid's temperature. This temperature may be utilized later to heat the building's interior or provide hot water. To evaluate the performance of the PV/T system and the existing PV system under identical weather conditions, comparative measurements were made. The results showed that the PV/T system improves the PV system in terms of power generation efficiency because it utilizes the nanofluid (SiO_2) as the working fluid. Additionally, the working (SiO_2) nanofluid can be utilized for heating and supply of hot water because the PV/T system raised its temperature at the outlet to about 2-2.5%. SiO_2 nanofluid-based PV/T systems may, on average, significantly increase solar power utilization, more than two times that of traditional PV systems. The PV/T system is simple to install in buildings and needs minimal maintenance or repair. As a result, this technology may help to lower carbon emissions and encourage the use of renewable energy in various applications.

Keywords: PV/T system; SiO_2 nanofluid; solar energy

1. Introduction

The deployment of renewable energy sources has become increasingly recognized in recent years because of the demand for sustainable energy production. Solar energy, which is abundant, clean,

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and sustainable, has recently gained favor among the numerous renewable energy sources Al-Nabhani *et al.* (2022) and is frequently used to provide both electricity and heat Mahmood *et al.* (2021). Two prominent solar energy-using technologies are photovoltaic (PV) and solar thermal systems Kelebekler *et al.* (2020) and Al-Nabhani *et al.* (2022). Solar thermal collectors harness the heat from sunlight for heating residential and commercial spaces, whereas PV systems turn solar radiation into electrical power. The PV/T system, a unique technology that can simultaneously create electricity and heat, has been introduced as an effective way to maximize the efficiency of solar energy conversion. PV/T systems have several advantages over standard solar systems, including more affordable prices and improved overall thermal efficiency. To maintain the temperature constant while providing heat for diverse uses, these systems use collectors that take heat from the PV cells Usman *et al.* (2022). This prevents overheating. The PV/T system's efficiency is much higher than that of its parts because it makes use of the thermal component of the system. To increase the effectiveness of PV/T systems Al-Waeli *et al.* (2019) by absorbing the heat from the thermal collector and protecting the output voltage and performance of the PV cell over time, researchers investigated the application of working fluids in the collector, such as water, air, or nanofluids or their combination. Studies have considered nanofluids as working fluids to improve PV/T systems' performance substantially. Nanofluids can speed up heat transfer and hence improve the overall effectiveness of the system due to their unique thermal properties.

The addition of nanofluids, like CNT/Al_2O_3 Sathyamurthy *et al.* (2021) and hybrid nanofluid consisting of H_2O and Fe_3O_4/SiO_2 nanoparticles Khan *et al.* (2022) has shown encouraging outcomes in improving the electrical performance of PV/T systems and lowering the temperature of the panel. Additionally, it has been demonstrated that the efficiency of solar thermal collectors can be greatly increased by using nanofluids Gupta *et al.* (2021). Another experimental investigation Murtadha *et al.* (2022) on the impacts of cooling with aluminum-oxide (Al_2O_3) nanofluids and the water looked at the impact of various nanofluid concentrations (1-3 wt.%) and flow rates (0.8-1.6 L/min) on the temperature of the solar panel's surface, its efficiency, and its output power. According to the study's findings, a 3 wt.% nanofluid concentration resulted in the greatest drop in photovoltaic surface temperature-a decrease of 23.14% as compared to uncooled panels. A turbulent flow rate of 1.6 L/min also produced the strongest photovoltaic performance, increasing efficiency from 15% in laminar flow to 20.2% in turbulent flow. The energy output of solar systems increased with any reduction in photovoltaic surface temperatures, with nanofluid cooling at a 3 wt.% concentration producing the most gain. Furthermore, the highest temperature rise in the cooling fluid was caused by the turbulent flow of the nanofluid at a concentration of 3 wt.%. The use of nanofluid cooling for photovoltaic panels is discussed in detail in this paper, which also emphasizes how crucial it is to select the right nanofluid concentration and flow rate for the best cooling performance. Cooling is crucial in areas with high temperatures and radiation conditions because it may significantly improve the efficiency and lifespan of solar panels. CuO_2 nanofluids with a volume percentage of 5% had the maximum capacity for heat transmission, according to earlier studies Alrobaian *et al.* (2020). A photovoltaic/thermal (PV/T) system prototype model is examined in this research.

The purpose of the study is to compare the heating system of the PV/T system using water and silicon dioxide (SiO_2) nanofluids. In this study, the working fluid for an experimental evaluation of solar thermal performance in a PV/T system is SiO_2 nanofluid. This study's major objective is to contrast the performance of a PV/T system that uses pure water with a system that uses SiO_2 nanofluid as the working fluid. The study also aims at understanding more about the effects of many factors on the operation of the system, including current, voltage, power, temperature, fluid flow rate, solar radiations, light intensity, and ambient temperature and humidity.

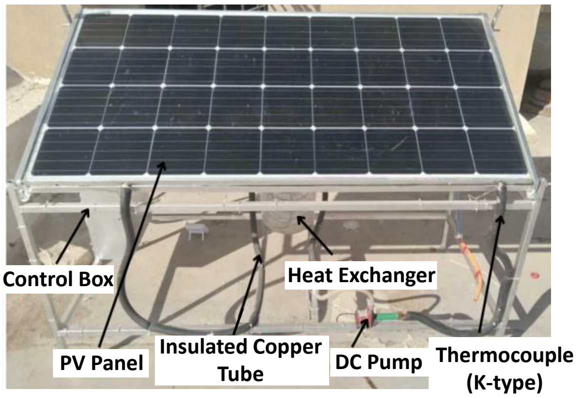

Fig. 1 Outdoor PV/T system assembly installed on the roof of the building used in the study

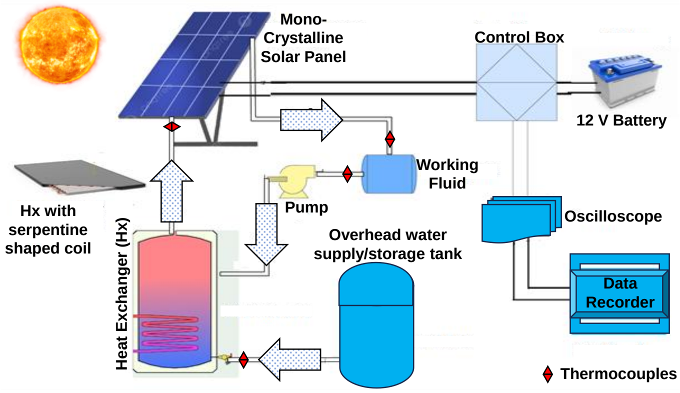

Fig. 2 A schematic diagram shows the details of the outdoor PV/T system assembly used in the study

2. Experimental setup and methodology

A widely used compound with a wide range of uses, including as a filler or strengthening agent in different materials, is silicon dioxide (SiO_2). The unique optical and thermal characteristics of SiO_2 particles in nano form make this material potentially helpful in solar thermal applications. To ensure achieving a good mixture of SiO_2 nano fluid solution, the base fluid (distilled water) and nano-powder (SiO_2) were mixed utilizing a magnetic stirrer at room temperature overnight. The final mixture contained 1 liter of H_2O and 4 grams of SiO_2 nanopowder at a concentration of 0.4 wt.%. The ability of the SiO_2 nanofluid to decrease light reflection and enhance light absorption is among the important characteristics that make it appropriate for solar thermal applications. This means that when exposed to sunshine, the SiO_2 nanofluid will absorb more solar energy and transform it into heat, which can be employed in a variety of solar thermal system applications. As shown in Fig. 1 and Fig. 2, a mono-crystalline flat plate solar collector of 165 watts was used in this study for absorbing solar radiation. The bottom and each side of the collector were appropriately insulated to minimize the heat losses due to heat conduction. To lower the surface temperature of the panel, a serpentine-shaped flow pipe constructed of copper and filled with working fluid was installed underneath the collector. The backup power source is a 50 MH 12V battery. To detect the temperature of the working fluid at the inlet and outflow as well as the temperature in the middle of the panel, three K-type (OMRON, 10 mm) thermocouple sensors were mounted to the plate. To move working fluid from the working fluid container to the entire pipe attached at the rear of the panel, a DC electric controllable mini submersible water pump (240 L/H) was installed in the system. The fluid flow was additionally controlled by a pressure controller. The flow of the working fluid was measured using a flow sensor (10 liters per minute, maximum). All the equipment installed in the framework were supplied with electricity and operated by a network of wires. The pipe used to transfer heat from the working fluid to the water in the working fluid container was connected to a heat exchanger. The PV/T system's results were recorded using a Hantek oscilloscope. Hantek Oscilloscope is connected to a laptop to digitally record the data. The cooling circuit was located on the back side of the panel, and a pump was used to maintain a steady flow of nanofluid through it. Heat exchangers were used to cool the hot nanofluid in the PV/T system's cooling circuit. The temperature of the nanofluid was measured using temperature sensors in the cooling circuit. The sensor set at the PV panel's center on the back side of the panel measured the surface temperature of the panel. The storage battery, charge controller, and the direct current load of the consumer complete the electrical circuit. Here, a 300-watt, 24-volt LFW lamp was employed. Charge controllers are necessary for connecting switches between the consumer's load, the battery, and the solar panel in a PV/T system for it to produce power continuously. A flow sensor is used to detect fluid flow. The sensors additionally measure the system output's current and voltage. The trials were carried out outside on the roof. The panel was immediately exposed to solar light from the sun. Using a digital temperature and humidity clock meter, the ambient temperature was monitored at various time intervals. With the aid of a Lux meter, solar radiations were also measured in the same way.

3. Results and discussion

The effectiveness of solar energy applications varies based on local environmental factors. When solar radiation strikes a module, the surface temperature rises, which determines how well the PV system works. The outcomes are discussed in this section. First, the performance of the PV/T system with distilled water as the working fluid was recorded. Next, the performance of the PV/T system with SiO_2 nanomaterial mixed with distilled water as the base fluid was recorded. Finally, the performance of the PV/T system without any working fluid was recorded. In this section, a comparison of all the tests was also covered.

According to a system comparison using distilled water and SiO_2 nanofluid as the working fluid, as shown in Fig. 3, the temperature of the distilled water at the intake is lower than that of the SiO_2 nanofluid. Because these fluids travel through a serpentine-shaped pipe at the back of the panel, which makes the fluid warmer than distilled water, this demonstrates that the SiO_2 nanofluid has a stronger capacity to withstand temperature changes than distilled water. This suggests that SiO_2 nanofluids can be utilized as cooling fluids in photovoltaic systems to lower the photovoltaic inlet temperature, which may result in higher thermal energy gain causing improved output power and thermal performance, which may lead to improved power generation and extended life span of the photovoltaic cells.

The working fluid's response is shown in Fig. 4, which is consistent with the results shown in Fig. 3. Higher temperatures in the center of the panel than with pure water are the result of the SiO_2 nanofluid's greater ability to absorb heat. Also supporting the idea that the SiO_2 nanofluid aids in absorbing more heat from the panel is a slightly higher temperature in the panel's center relative to

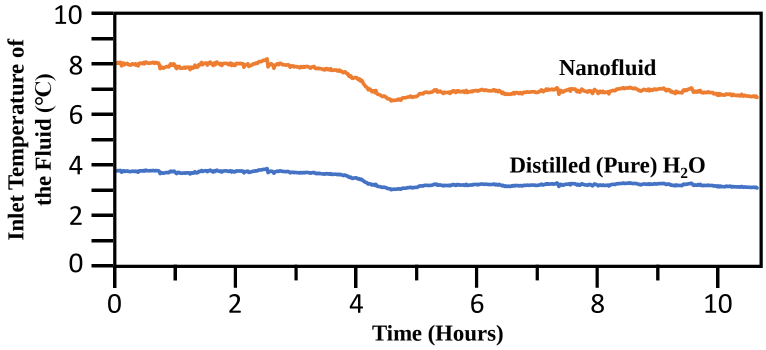

Fig. 3 Comparison of the Inlet Temperature of the PV/T System of SiO_2 nanofluid with Distilled Water as the working fluid

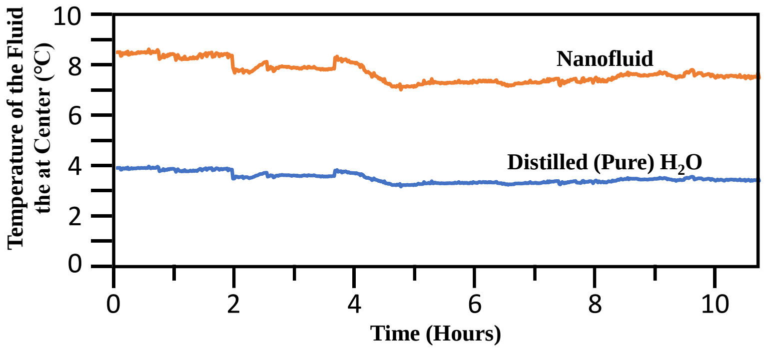

Fig. 4 Temperature comparison of the fluid at the center of the panel of SiO_2 v/s Distilled Water

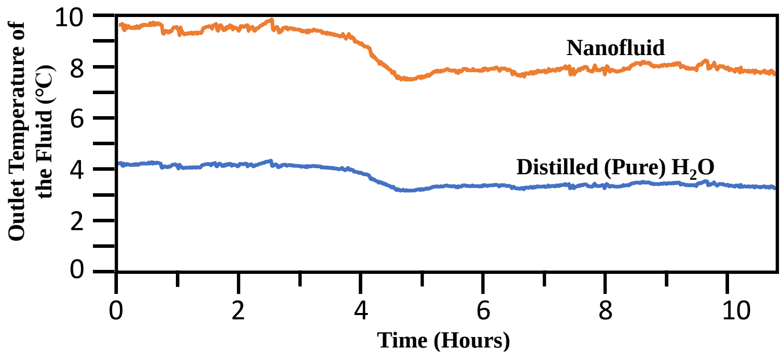

Fig. 5 Outlet temperature comparison of the fluid in the system of SiO_2 v/s Distilled Water

the fluid's inlet temperature (see Fig. 3 and Fig. 4). The maximum temperature is found in the center of the panel, and temperatures decrease toward the perimeter, giving the temperature profiles for the two working fluids an almost parabolic appearance. It is important to note that the SiO_2 nanofluid is more efficient at removing heat from the panel since its temperature in the center of the panel is greater than the temperature of distilled water at the same position. These findings add to the increasing amount of research demonstrating the advantages of employing SiO_2 nanofluids to cool photovoltaic cells.

Fig. 5 shows that the SiO_2 nanofluid has a higher fluid output temperature than pure water in addition to having a better capacity to absorb heat at the inlet and middle. This is because the panel's majority is covered by a fluid-distributed pipe in a serpentine design, which helps the panel to absorb the maximum heat. The higher exit temperature of the SiO_2 nanofluid is due to its greater capacity to absorb heat.

Figs. 3-5 highlighted the benefits of using SiO_2 nanofluids for PV/T system by showing how the temperature stepped systematically from lower to higher at the [**inlet**(Pure (~4)<Nanofluid (~8)]<[**middle**(Pure (~4)<Nanofluid (~8.5)]<[**outlet**(Pure (~4)<Nanofluid (~9.8)] respectively. The temperature of the nanofluid was always higher than that of the pure water at every location. The temperature gain (ΔT) at the outlet for nanofluid was at least 4-5 °C higher than that of pure water. This might be explained by the SiO_2 nanofluid's improved surface wettability and heat conductivity. However, in practical applications, it is crucial to consider the stability and rheological characteristics of nanofluids. An earlier study Dong *et al.* (2022) that looked at the stability of SiO_2 nanofluids in various storage environments discovered that even a modest amount of surfactant might dramatically increase the nanofluid's stability. Comparable results were drawn by Wanatasanappan et al. (2023) in their investigation into the rheological properties of Al_2O_3/H_2O-nanofluids. They researched that the viscosity of the nanofluid increased with increasing concentration and decreasing temperature. It is important to remember that using nanofluids in heat transfer applications comes with several challenges and limitations. The expensive nature of synthesis and the production of nanoparticles is one obstacle that may keep them away from being commonly employed in certain applications. Additionally, it's critical to carefully assess the potential health and environmental impact of nanoparticles before utilizing them for real-world uses. Overall, the application of SiO_2 nanofluids in heat transfer applications has shown an improvement in thermal properties when compared to standard working fluids. SiO_2 nanofluids are desirable alternatives for improving the effectiveness of heat transfer processes because of their distinctive thermal characteristics, such as increased thermal conductivity and heat transfer coefficient. To completely comprehend the effects of many elements on the thermal performance and stability of SiO_2 nanofluids, as well as to solve the difficulties and restrictions related to their application, more research is still expected.

The PV/T system with SiO_2 nanofluid has a higher voltage output than the system with pure water, as shown in Fig. 6. The improved thermal conductivity of the SiO_2 nanofluid, which enables greater heat dissipation and lowers the operating temperature of the panel, is what causes an increase in voltage. The result corresponds to an agreement with other results that show increased PV/T system performance when using nanofluids. The panel's efficiency increases, and its output voltage improves as the system's temperature decreases. SiO_2 nanofluid can thereby improve the system's overall effectiveness and efficiency when used in PV/T systems. The long-term stability and environmental effects of SiO_2 nanofluids in PV/T systems, however, require further study. The cost-effectiveness of employing SiO_2 nanofluids in practical applications must also be considered.

The PV/T system's current variation (in amperes) graph between SiO_2 nanofluid and distilled water is shown in Fig. 7. This graph demonstrates that utilizing SiO_2 nanofluid as a cooling system for the PV/T system generated higher current and voltage values than using pure water. Both the amount of solar radiation and the temperature of the photovoltaic surface have an impact on the current, but the cooling method also has an impact on the voltage. It is significant to note that identifying the right SiO_2 nanofluid concentration is necessary to obtain the best current values. The electrical performance of a PV/T system can be affected by various variables like nature of the fluid, sunlight intensity, and panel temperature. The PV/T system's voltage and current improvements are

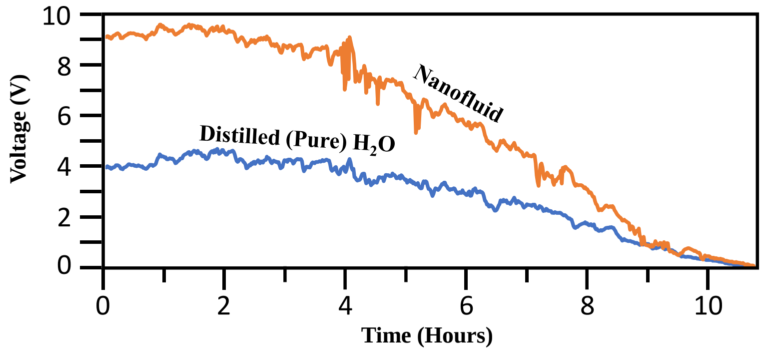

Fig. 6 Voltage variation of the PV/T system of SiO_2 v/s Distilled Water

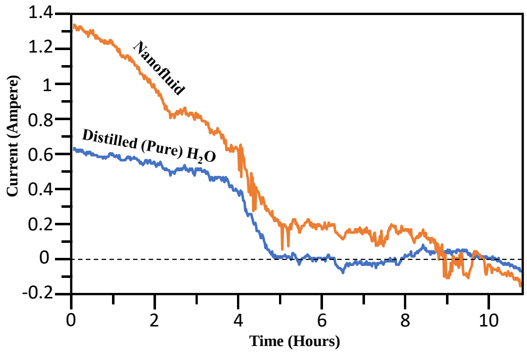

Fig. 7 The current variation of the PV/T system of SiO_2 v/s Distilled Water

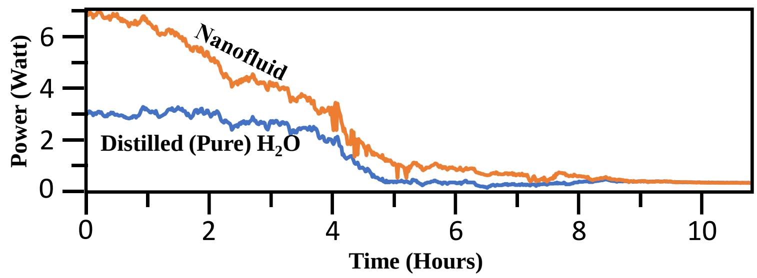

Fig. 8 Electrical Power Variation of the PV/T system of SiO_2 v/s Distilled Water.

shown in Figs. 6 and 7. As illustrated in Fig. 6, the SiO_2 nanofluid indicates a higher voltage than pure water. This is simply because of the cooling medium, which drops the surface temperature, is delivered into the flow pipe with a serpentine shape in the PV/T system. The improvement in voltage observed with the introduction of SiO_2 nanofluids suggests that they may be more effective compared to pure water at enhancing the PV/T systems power output. Due to internal charge carrier recombination, a reduced temperature coefficient of power, and rising module surface temperature, it can be shown in Fig. 7 that the current increases as the temperature rises. When the surface temperature rises in the afternoon, the current of the PV/T system using SiO_2 water is lower than that using pure water. This implies that SiO_2 water may be better able to maintain current output at greater temperatures than pure water.

Overall, the results show how temperature affects the output of voltage and current from the PV/T system, with the usage of SiO_2 nanofluids perhaps improving voltage output and SiO_2 water possibly improving current output at higher temperatures.

From Fig. 8, the SiO_2 nanofluid and pure water used in the PV/T system provide electrical power that varies depending on the amount of solar radiation and the surface temperature. At solar noon, when solar radiation intensity is at its highest, it has been observed that the SiO_2 nanofluid produces the most electrical output power. SiO_2 nanofluid is discovered to produce power that is, on average, more than that of pure water. After cooling with SiO_2 nanofluid at an optimal concentration, the experiment increased the power output of solar cells by 5% to 13% in comparison to the pure water system. These results support the results of an earlier work Murtadha *et al.* (2022), which showed that the use of SiO_2 nanofluid can significantly improve the electrical performance of a PV/T system. As discussed in the above sections and highlighted below by the distinct advantages of SiO_2 nanofluids and a rationale for their selection over other nanofluids, this research not only contributes to the scientific understanding of nanofluid applications but also aligns with broader considerations of efficiency, cost-effectiveness, and environmental impact in renewable energy systems.

The main advantages of Silicon dioxide (SiO_2) Nanofluids over other nanofluids are their elevated thermal conductivity compared to traditional working fluids and this property enhances heat transfer efficiency, making them promising candidates for applications in PV/T systems, they exhibit excellent stability and dispersion characteristics in a fluid medium and this is crucial for maintaining consistent and predictable performance over extended periods (a key consideration in practical applications). The economic viability and availability of SiO_2 support the commercial feasibility of SiO_2 nanofluids. SiO_2 is a cost-effective solution that is appealing for large-scale uses, such as those in energy sources that are renewable. SiO_2 is generally considered environmentally friendly. Choosing SiO_2 nanofluids aligns with a sustainable approach, minimizing potential negative impacts on the environment. SiO_2 nanofluids also exhibit properties beneficial for compatibility with solar panels, such as improved surface wettability, which can enhance heat absorption and transfer efficiency.

Rationale for Choosing SiO_2 Nanofluid in this Research are: SiO_2 nanofluids are a well-researched and promising solution for heat transfer applications, according to a thorough analysis of the literature currently being published. Previous studies have demonstrated their beneficial attributes which supports the decision to investigate them more. SiO_2 nanofluids have been widely used in various scientific studies, showcasing their versatility and applicability. Choosing SiO_2 allows for a comparison with established data and facilitates a deeper understanding within the existing scientific context. SiO_2 nanofluids align with the specific goals of this research, focusing on enhancing the thermal performance of a photovoltaic-thermal system. The chosen nanofluid's properties directly contribute to achieving the desired improvements in heat transfer efficiency. The advantages of SiO_2 nanofluids, such as cost-effectiveness and environmental friendliness, align with practical considerations for implementing such systems on a larger scale, enhancing the relevance and applicability of the research findings.

5. Conclusions

This study focused on the evaluation of a photovoltaic-thermal (PV/T) system using a 165W monocrystalline solar panel as the primary component and provided insight into the benefits of using SiO_2 nanofluids over distilled water in heat transfer applications for photovoltaic panels. The effectiveness of the technology was evaluated under two distinct working fluid and environmental scenarios. Thermocouples, flow sensors, current and voltage meters, lux meters to detect solar intensity, and other measuring devices were used. An oscilloscope was used to record the data, and the entire process was carried out outside in direct sunshine. The performance of the PV/T system was initially assessed using pure water as the working fluid and subsequently with SiO_2 nanofluid as a standard of comparison. The study concludes that PV/T systems with SiO_2 nanofluid added beat pure water systems in terms of thermal performance. Compared to pure water, the SiO_2 nanofluid method offers a higher fluid output temperature and a greater capacity for retaining heat at the panel's middle and input points of interest. Its improved surface wettability and heat conductivity, together with its serpentine pipe design, enable effective performance. However, there are a number of limitations to using nanofluids in heat exchange applications, including their cost, potential impact on the environment, stability, and rheological properties. SiO_2 nanofluids can be stabilized by surfactants, as evidenced by earlier studies, and their viscosity increases with concentration and decreases with temperature. To fully comprehend these fluids' effects on thermal efficiency, stability, manufacturing, toxicity, and environmental impact, more research is required.

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