

Enhancing Photovoltaic Efficiency through Innovative Cooling Techniques Using Porous Marble

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Abstract

The efficiency of solar panels is a critical factor in enhancing the use of renewable energy, especially in regions with high solar irradiance. Elevated surface temperatures of solar panels lead to a noticeable decline in their electrical performance, as their efficiency decreases with rising temperatures. This research aims to improve the efficiency of photovoltaic panels through an innovative cooling technique that employs porous materials, specifically marble, which possesses effective thermal properties for heat absorption and dissipation. The core idea is to reduce the operating temperature of solar panels by utilizing porous marble, thereby enhancing their energy conversion efficiency. The experiment was conducted on the rooftop of the Faculty of Technological Engineering at Al-Balqa Applied University, an ideal location for studying this technology due to the region's high solar irradiance levels.

Three flow rates were assessed: 1 liter/min, 1.5 liters/min, and 2 liters/min. The first flow rate was applied on the first day, while the other rates were used on the second and third days, respectively, for comparative purposes. Three different sizes of marble were also utilized with porosities of 0.35, 0.4, and 0.48. The results highlight the critical role of porosity size in reducing temperature, indicating that a decrease in porosity size correlates with a reduction in temperature. This phenomenon can be attributed to homogeneous heat exchange and the time lag of heat transfer between the porous media and the flowing water, enhancing cooling efficiency, especially in the case of porosity 0.35, which demonstrated superior performance among all cases. The average rear surface temperature exhibited significant reductions of 35.7%, 34.8%, and 34%, with corresponding output power recorded at 9.4%, 7.8%, and 6.2%, respectively. Consequently, the case with a porosity of 0.35 showed the best performance for the photovoltaic module due to effective homogeneous heat transfer exchanges.

Keywords: PV cooling, Solar energy, porous media, Marble and Efficiency

1. Introduction

The overheating issue in photovoltaic (PV) panels is one of the key factors negatively impacting their efficiency. Therefore, numerous innovative solutions have been developed to address this problem and enhance the thermal and electrical performance of PV panels.

M. Elhady et al. (2018) proposed an innovative solution to the overheating problem in PV panels. Their results demonstrated that the proposed system significantly reduced the panels' temperature, leading to improved electrical efficiency and increased energy production. **Wu et al. (2018)** studied the heat transfer characteristics of a water-cooled PV/T system, where cooling channels were placed above the PV panels. Their findings showed that this design enhances heat transfer and improves the overall performance of

the solar system. **Idoko et al. (2018)** explored multi-concept cooling techniques to enhance PV module efficiency. Their study revealed that the use of innovative cooling methods significantly increases energy production and reduces operating temperatures. **Golzari et al. (2018)** carried out an experimental investigation on the effect of corona wind on the performance of an air-cooled PV/T system. Their results showed a notable improvement in overall system performance, where the corona wind effectively cooled the panels and enhanced energy output. **Castanheira et al. (2018)** implemented a demonstration project in Portugal for cooling existing PV power plants. The study indicated that the cooling system effectively reduced the PV panels' temperature, resulting in increased plant efficiency and higher energy production. **Jamali et**

al. (2018) conducted a study on enhanced power generation by cooling semi-transparent PV panels using a solar chimney. The results showed that this design reduced panel temperature and increased photovoltaic productivity. **Rajput & Yang (2018)** compared heat sink and water-based PV/T cooling systems for polycrystalline PV panels. The findings indicated improvements in both thermal and electrical performance with both systems, with a slight advantage for the water-cooling system.

Selimefendigila et al. (2018) presented an experimental analysis and dynamic modeling of a PV module equipped with porous fins. Their study demonstrated that using porous fins helped improve heat transfer and reduce the PV panels' temperature, leading to enhanced electrical efficiency.

Masalha et al. (2023) conducted both theoretical and experimental studies on the performance of photovoltaic (PV) modules utilizing porous media cooling under controlled indoor conditions. Their findings highlighted the effectiveness of porous media in enhancing the thermal management of PV modules, leading to improved energy conversion efficiency. The study provided a foundational understanding of how cooling mechanisms could be optimized for better performance in solar energy applications. In another work by **Masalha et al. (2023)**, outdoor experimental and numerical simulations were performed to investigate the cooling of PV panels using porous media. This comprehensive study not only validated the cooling effects observed in indoor settings but also extended the research to real-world conditions. The results demonstrated significant reductions in operating temperatures, thereby increasing the overall efficiency of solar panels. **Masalha, Abdullah, and Rawashdeh (2019)** explored experimental and numerical investigations aimed at enhancing the efficiency of PV modules through the application of porous media. Their research focused on the thermal dynamics within the modules and highlighted how varying the characteristics of porous media can lead to significant improvements in thermal performance and energy output. In a related study, **Masalha et al. (2020)** examined the potential of nanofluids to improve the efficiency of PV modules. Their experimental investigations

revealed that integrating nanofluids as a cooling medium resulted in notable enhancements in thermal regulation and energy conversion rates, providing insights into advanced cooling techniques for solar technologies. **Masalha et al. (2021)** further investigated the use of a nano-fluid cooling system to improve the efficiency of PV modules. This experimental and numerical study underscored the importance of innovative cooling solutions in mitigating the temperature rise of solar panels, thus optimizing their performance and lifespan. **Elayyan et al. (2020)** presented a new design for a solar collector reflector, which aimed to maximize solar energy capture and efficiency. Although not directly related to PV cooling, their work contributes to the broader context of solar energy optimization, emphasizing the importance of design innovations in enhancing overall system performance. **Al-Jamea et al. (2022)** investigated water immersion and spraying techniques for cooling PV panels. This study explored alternative cooling strategies, contributing to a better understanding of how various cooling methods can be employed to maintain optimal temperatures and improve energy output in photovoltaic systems.

The modernity in this research is reflected through the use of a specific type of porous material, namely marble, as a means to cool solar cells. The utilization of marble, which has not been extensively studied in the field of solar system cooling, represents an innovative step that highlights the uniqueness of this work. The aspects of modernity are outlined as follows:

Selection of Marble as a Porous Material: Marble is distinguished as a natural material with unique thermal properties, such as a high ability to absorb and store heat. This choice transcends the use of synthetic or polymeric materials, which often lack thermal stability. Marble allows for effective cooling techniques that rely on its natural properties, contributing to a reduction in the temperature of solar panels and an increase in their efficiency.

Improvement of Thermal Performance: Porous materials such as marble are characterized by their ability to provide stable thermal equilibrium, which helps maintain the temperatures of solar panels within optimal levels. The effectiveness of

marble in distributing and absorbing heat makes it an ideal choice for reducing excess heat. This equilibrium contributes to increased efficiency in energy conversion, reflecting innovation in how natural materials are utilized to enhance the overall performance of solar cells.

Low Environmental Impact: Natural porous materials, such as marble, are considered environmentally friendly alternatives compared to industrial materials that may contain harmful chemical compounds. The use of marble offers a sustainable solution that can reduce negative environmental impacts, aligning with global trends toward improving energy efficiency and environmental sustainability.

Flexibility and Adaptability: Porous materials like marble demonstrate flexibility in various applications, allowing them to be used in multiple and diverse cooling systems. Marble can be incorporated into different design patterns of solar systems, making these materials adaptable to various environments, whether climatic or engineering. This flexibility enhances the significance of the research and expands the scope of its applications.

2. Research Methodology

The efficiency of solar panels is a critical factor in enhancing the use of renewable energy, especially in regions with high solar irradiance. Elevated surface temperatures of solar panels lead to a decline in their electrical performance, as their efficiency decreases with rising temperature. This research aims to improve the efficiency of photovoltaic panels through an innovative cooling technique that employs porous materials, specifically marble, which possesses favorable thermal properties for heat absorption and dissipation. The core idea is to reduce the operating temperature of solar panels by utilizing porous marble, thereby enhancing their energy conversion efficiency. The experiment will be conducted on the rooftop of the Faculty of Technological Engineering at Al-Balqa Applied University, an ideal location for studying this cooling technology due to the region's high levels of solar irradiance.

2.1 Site and Experimental Design

- **Site:** The rooftop of the Faculty of Technological Engineering at Al-Balqa Applied

University was selected as the experimental site due to its direct exposure to solar radiation throughout most of the year. This location provides optimal conditions for assessing the impact of the cooling technique on solar panel performance. Furthermore, the site offers adequate infrastructure for conducting experiments and installing the necessary equipment.

- **Experimental Design:** The experiment is structured to compare the performance of solar panels equipped with a cooling system against those without cooling. Four conventional polycrystalline silicon solar panels, each with a rated capacity of 30 W, were installed. One panel serves as a control (no cooling), while the remaining three are fitted with a cooling system consisting of a channel filled with porous marble beneath the panels. Marble was chosen for its thermal properties, particularly its capacity to absorb, store, and dissipate heat efficiently, thereby reducing the temperature of the solar panels and increasing their energy conversion efficiency.

Three sizes of porous materials, namely 0.35, 0.4, and 0.5, were used in the study. Experiments were also conducted with three different flow rates of 1, 1.5, and 2 liters per minute to measure the effects of these variables on the cooling efficiency of solar panels. This experimental design aims to evaluate thermal performance and energy efficiency under various conditions, helping to determine the optimal size of cooling materials and the flow rate that achieves the best results in reducing temperatures and increasing energy production.

2.2 Materials and Equipment

- **Solar Panels:** The study uses four conventional polycrystalline silicon solar panels, each with a rated capacity of 30 W. The technical specifications of these panels are provided by the manufacturer and detailed in Table 1.

- **Porous Materials:** Porous marble was selected as the cooling material for its ability to absorb and dissipate heat. Marble was chosen based on its thermal durability, stability, and effectiveness in maintaining cooling performance under prolonged exposure to solar radiation.

- **Measurement Instruments:**

- **Thermal Sensors:** High-precision thermal sensors were installed at multiple locations on the surface of the panels, beneath them, and within the porous marble material to continuously monitor temperatures during the experimental period.
- **Solar Irradiance Meter:** A solar irradiance meter was employed to measure the amount of solar radiation incident on each panel, providing essential data for correlating external conditions with performance.
- **Electrical Performance Measurement Device:** A multi-function meter was used to measure the voltage and current output of the solar panels, enabling the calculation of electrical efficiency.
- **Half-Horsepower Centrifugal Pump:** This pump ensures a constant flow of water through the cooling system.
- **Flow Meter:** A flow meter was used to monitor and regulate the water flow rate within the cooling channels, helping to optimize cooling efficiency.

3. Experimental Procedures

- **System Installation:** The solar panels were installed on the rooftop, with the cooling channels positioned beneath the three panels equipped with the cooling system. The channels were filled with porous marble, ensuring maximum thermal contact between the panels and the marble to optimize heat transfer. Water circulates through the cooling channels via a centrifugal pump to maintain a steady flow and efficient cooling.
- **Performance Monitoring:** The performance of the solar panels was continuously monitored under varying climatic conditions between 9:00 AM and 4:00 PM. Temperature, voltage, and current measurements were recorded at regular intervals for both the cooled panels and the reference panel without cooling.
- **Data Collection:**
 - **Temperature Measurements:** The surface and internal temperatures of the solar panels were periodically recorded. Additionally, the temperature of the porous material beneath the panels was measured to assess the cooling system's effectiveness.

- **Electrical Output Measurements:** Voltage and current were recorded for all solar panels in both cooled and non-cooled conditions, providing accurate data on how the cooling system affects the overall efficiency of the panels.

Figure 1 illustrates a schematic representation of the solar cell integrated with a cooling channel filled with porous materials. This diagram delineates the operational synergy between the solar panel and the cooling system, emphasizing how the incorporation of porous materials facilitates effective thermal management. The cooling channel, utilizing materials such as marble, is crucial in dissipating excess heat from the solar panel, thereby mitigating temperature elevations and enhancing the conversion efficiency of solar energy into electrical energy. This representation provides an in-depth understanding of the system's mechanics, elucidating the cooling process and its resultant effects on solar cell performance.

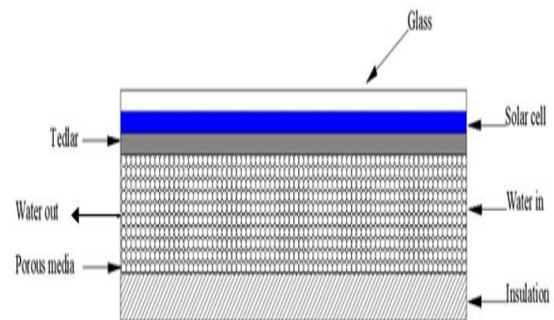


Figure 1: Photovoltaic system

Figure 2 depicts the configuration of the cooling channel affixed to the solar panel. This illustration showcases the secure attachment of the panel above the cooling channel, ensuring optimal thermal contact. The arrangement is engineered to maximize heat transfer efficiency between the solar panel and the cooling medium, thereby augmenting the overall cooling effectiveness. This figure underscores the critical role of engineering design in the enhancement of system performance.

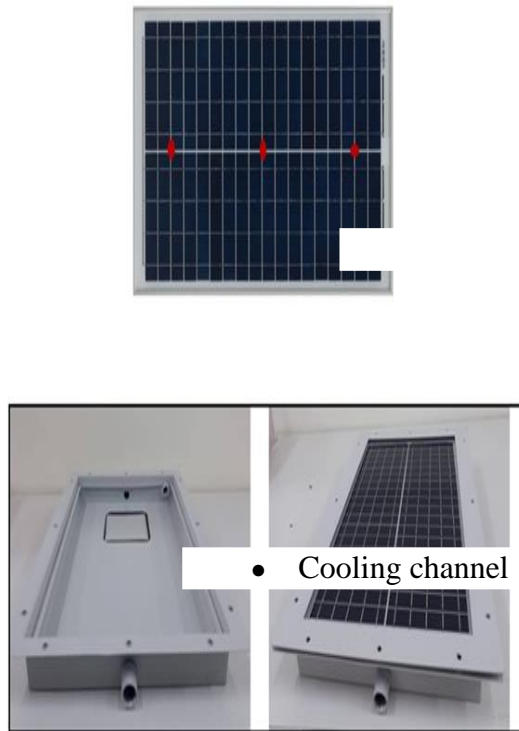
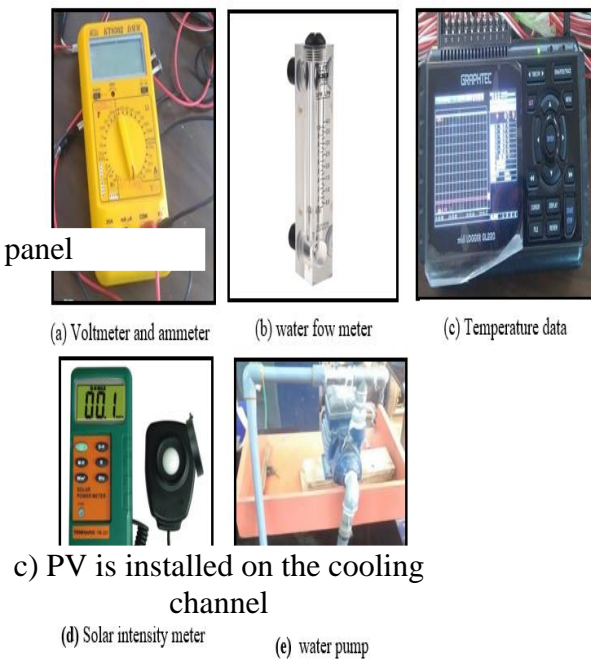


Figure 2: PV panel and cooling channel

Figure 3 presents the array of tools and instruments employed throughout the experiment, encompassing essential devices for precise measurements and data collection. Included are high-accuracy temperature sensors, a solar irradiance meter, and an electrical performance measuring device. This figure highlights the necessity of utilizing advanced measurement techniques to obtain reliable data pertinent to the system's performance and operational testing.

• PV panel



c) PV is installed on the cooling channel

(d) Solar intensity meter (e) water pump

Figure 3: Experimental instruments for PV cooling

Table 1 presents the specifications of the solar cell utilized in the study. This table delineates critical parameters, including the type of solar cell, rated capacity, efficiency, voltage output, and current output. Such specifications are essential for understanding the performance characteristics of the solar cell under various operational conditions and its suitability for integration with the cooling system. The detailed information provided in this table serves as a foundation for analyzing the effectiveness of the cooling techniques employed in enhancing the solar cell's overall efficiency.

Table 3.1: Photovoltaic panel specifications

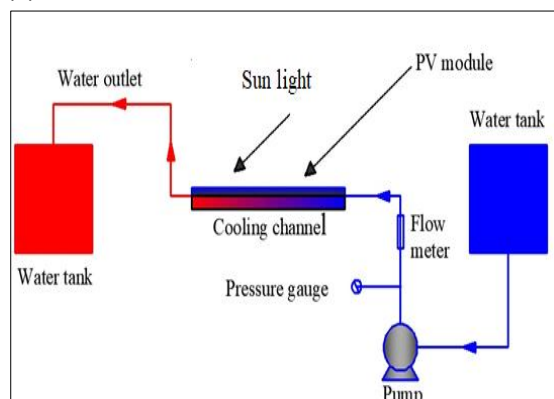
Solar PV module parameter	Value at AM 1.5 spectra STC
Maximum power, P_{max}	30 W
Open-circuit voltage, V_{oc}	22 V
Short-circuit current, I_{sc}	1.84 A
Voltage at P_{max}	18 V
Current at P_{max}	1.67 A
Operating temperature	-40°C to +85°C
Solar intensity, G	1000 W/m ²

Figure 4 offers a comprehensive overview of the complete experimental setup conducted on the rooftop of the College of Technology Engineering. This image details the configuration of the solar

panels and cooling channels, along with the instrumentation utilized in the study. The arrangement illustrates the meticulous placement of components to ensure rigorous data collection and the successful execution of the experiment, aligned with the established research objectives.



(a)



(b)

Figure 4: Experimental setup and schematic diagram for outdoor test

4. Results and dictations

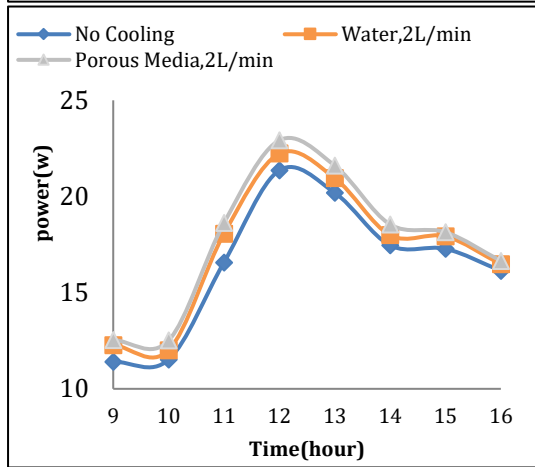
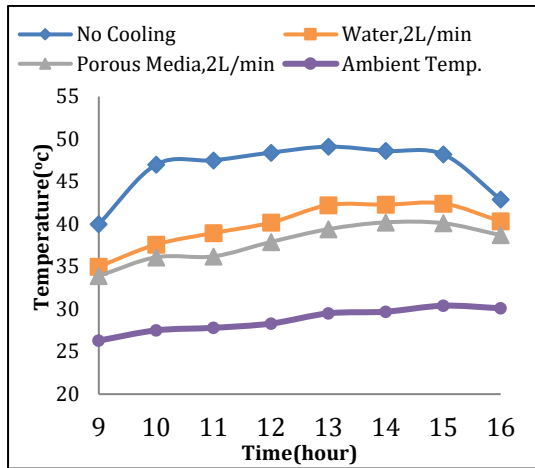
4.1 Experimental Comparison of Cooling Performance:

In this experiment, a comprehensive analysis was conducted to evaluate the cooling performance of porous marble with a porosity of 0.35 compared to water alone, as well as a scenario without any cooling system. The study utilized three distinct flow rates: 1 L/min, 1.5 L/min, and 2 L/min, with each experiment spanning a duration of 7 hours. Figures 4(a, b, c, and d) provide visual representations of the variations in surface temperatures of the solar cells under the different experimental conditions.

The results indicate a clear trend of gradual temperature increase across all cases examined. For the uncooled solar panel, the average temperature peaked at approximately 48.7 °C, reflecting the thermal stress experienced by the panel in the absence of any cooling intervention. In contrast, the panel cooled with water exhibited a significant reduction in the rear surface temperature, achieving a noteworthy value of 42 °C. This improvement underscores the effectiveness of water as a cooling medium, albeit with limitations.

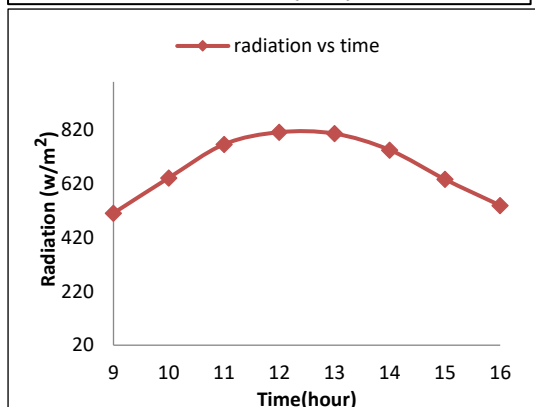
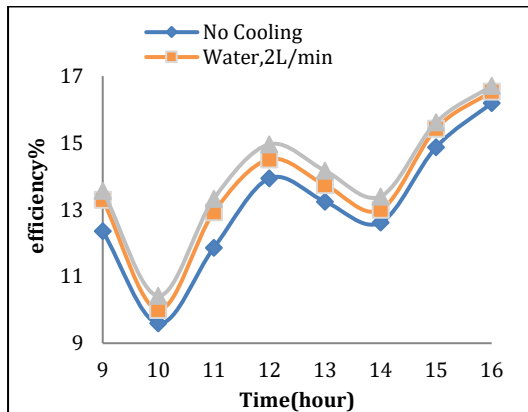
Notably, the incorporation of porous media with a porosity of 0.35 demonstrated a more substantial decrease in temperature, reaching an impressive 39.0 °C. This finding highlights the superior thermal management capabilities of the porous marble, which not only absorbs heat but also facilitates enhanced heat dissipation. The study further revealed that the lowest reduction in the solar cell surface temperature recorded was 19.5% at a flow rate of 2 L/min using the porous media with a porosity of 0.35.

The experimental data clearly illustrates that the implementation of porous marble significantly outperforms conventional water cooling in terms of temperature reduction. This is a crucial finding for the design of advanced cooling systems for solar panels, as maintaining lower temperatures can enhance their efficiency and longevity. The marked improvement in cooling efficiency with the use of porous media presents a promising avenue for future research and development in the field of solar energy technology. By leveraging the unique properties of natural materials such as marble, researchers can contribute to the optimization of solar panel performance, aligning with the growing demand for sustainable energy solutions.



a) PV temperature
Output power

b)



c) Efficiency

d) Solar radiation

Figure 5 Experimental results for temperature, power output, efficiency, and solar radiation at a volume flow rate of 2 L/min

4.2 Investigation of Cooling Performance under Varying Porosity:

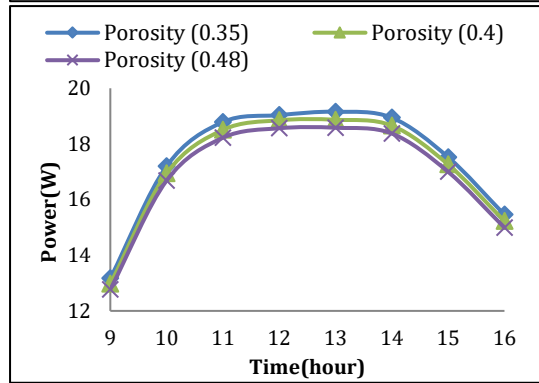
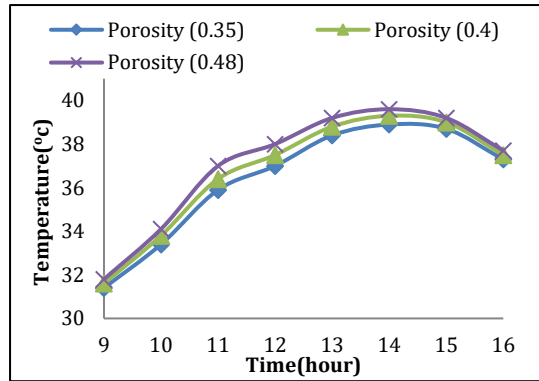
In the second experiment, three solar panels were outfitted with cooling channels beneath each panel, filled with varying sizes of porous media, alongside one panel without a cooling system. The aim was to identify the optimal porosity that delivers superior cooling performance, thereby registering the lowest possible temperature. The first cooling channel was filled with media having a porosity of 0.35, the second with a porosity of 0.4, and the third with a porosity of 0.48. All panels were tested under identical environmental conditions.

Three flow rates were assessed: 1 L/min, 1.5 L/min, and 2 L/min. The flow rate of 1 L/min was applied on the first day, while 1.5 L/min and 2 L/min were utilized on the second and third days, respectively, for comparative purposes, as illustrated in Figure 5.

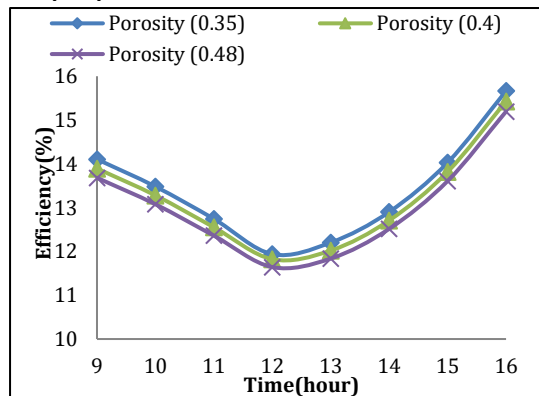
The results depicted in Figure 6 highlight the crucial role of porosity size in reducing temperature. It can be inferred that a decrease in porosity size correlates with a reduction in temperature. This phenomenon can be attributed to the homogeneous heat exchange and the time lag of heat transfer between the porous media and the flowing water, enhancing cooling efficiency, especially in the case of porosity 0.35, which demonstrated superior performance among all cases. The average rear surface temperature exhibited a notable decrease of 18.9% for case 0.35, while case 0.4 recorded a reduction of 18.1%, and case 0.48 exhibited a 17.2% decrease at a volumetric flow rate of 1 L/min.

Moreover, the output power was significantly enhanced, reaching 7.3%, 5.7%, and 4.1% for each case, respectively. At a flow rate of 2 L/min, the temperature reduction for each case was recorded at 24.4%, 22.5%, and 20.6%, respectively, while the corresponding output power was noted as 7.9%, 6.3%, and 4.7% for cases 0.35 to 0.48. Finally, at a flow rate of 3 L/min, the average rear

surface temperature decreased for each case by 35.7%, 34.8%, and 34%, with output power recorded at 9.4%, 7.8%, and 6.2%, respectively. Consequently, case 0.35 demonstrated the best performance of the photovoltaic module, attributable to the homogeneous heat transfer exchanges.



a) PV temperature
Output power



c) Efficiency

Figure 6: Experimental results for temperature, and power output, with different porosity sizes at a volume flow rate of 2 L/min

5. Conclusions

Impact of Porous Media on Solar Panel Cooling: The results demonstrated that the use of marble as a cooling medium in solar cells with a porosity

of 0.35 significantly reduced the backside temperature of the panels, reflecting the effectiveness of this type of material in enhancing solar panel performance. Achievement of Lower Temperatures: The lowest recorded surface temperature for the panels was 39.0 °C when utilizing porous media, compared to 42 °C for water-cooled panels and 48.7 °C for uncooled panels. This indicates that porous media not only effectively reduces temperatures but also contributes to increased energy conversion efficiency. Positive Impact of Different Flow Rates: The experiments confirmed that increasing the water flow rate has a positive effect on cooling performance, with higher flow rates (2 L/min) resulting in greater temperature reductions compared to lower rates. Additionally, the results showed that temperature reductions are inversely related to porosity size, emphasizing the importance of selecting the appropriate porosity size.

Improvement in Electrical Performance: Solar panels cooled using marble and optimized water flow exhibited notable increases in output power, surpassing 7.3% in the best-performing case. This highlights how effective cooling techniques can enhance the overall efficiency of solar energy systems. Environmental Sustainability: The use of marble and alternative porous materials is considered a sustainable choice compared to synthetic materials, as it helps reduce negative environmental impacts, aligning with global trends toward improving energy efficiency and environmental sustainability. Importance of Future Research: The findings indicate a need for further research to determine the optimal parameters for utilizing porous materials in cooling systems for solar panels, including exploring new types of materials and testing under various climatic conditions to achieve enhanced performance. These conclusions underscore the significance of employing natural materials to improve solar cell performance, contributing to innovation and sustainability in renewable energy technology.

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