

The Effects Of Temperature, Dust, And Cement-Coal Particles On PV Panel Performance: A Case Study In Iraq

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Abstract: In this study, experiments were conducted to assess the cooling performance of traditional photovoltaic (PV) panels using pulsed water spray cooling systems. The efficiency of the panels was also evaluated. The experiments took place over two months at the Al-Kitab University building in Kirkuk, Iraq, under typical weather conditions for the region. During the study, the average outdoor temperature was 39 °C, and the solar radiation measured 920 W/m². The experimental results revealed the following average temperatures for the PV panels: 57.5 °C with dust, 64.1 °C with cement and coal particles, and 36.5 °C when using the water-cooled system. The maximum temperatures of PV panels with varying amounts of dust (200 g, 300 g, 400 g, and 500 g) reached 57 °C, 57 °C, 60 °C, and 63.4 °C, respectively. The electrical performance of the PV panels affected by cement and coal particulates was measured at 71 °C and 58 °C, respectively. The impact of the spray water cooling system was significant, reducing the panel temperature to as low as 34 °C and increasing electrical efficiency from 12.2% to 16%. Based on the experimental data, the overall efficiency of a typical clean panel is estimated to be 12%. The utilization of the spray water system improved panel efficiency to 14.5% while keeping the panels clean and cool.

Keywords: Dust Accumulations; Cement; Coal; Power; Efficiency; and PV System.

1. Introduction

In recent decades, we have adopted various forms of clean energy, such as solar energy, which is environmentally friendly. Two main reasons for transitioning to sustainable, clean energy sources are the rising energy prices and the anticipated depletion of fossil fuels. Solar energy stands out as one of the most promising renewable energy resources. However, dust accumulation and high temperatures can significantly reduce the efficiency of solar panels. In the Middle East, Iraq is among the countries most affected by sand and dust storms. To evaluate the impact of cleaning on the efficiency of photovoltaic (PV) mono-crystalline modules, an experimental setup was established using nozzles to spray water on both sides of the panels. This nozzle assembly was designed to ensure that the water spray was evenly distributed. A total of 20 nozzles (10 on each side) were installed for this purpose. [1].

One effective way to prevent photovoltaic (PV) cells from overheating, which can damage the panel and reduce its output current, is to keep the cells cool. The operating temperature is a crucial factor influencing the energy generation potential of a PV module. Generally, higher temperatures have an inverse effect on both efficiency and output power. Two critical elements that contribute to enhancing efficiency are minimizing reflections (with a reflection coefficient of 0.260) and effectively dissipating thermal heat (measured at 0.218 nD°). These factors significantly improve the performance of commercial solar panels when immersed in water. [2]. This study is the first of its kind to assess the impact of various types of particulates, such as coal, cement, and dust, on the

performance of photovoltaic panels in Iraq. In the coming years, investments in PV panels along the Erbil-Kirkuk highway are expected to increase. This highway and the ongoing construction in the region generate a significant amount of dust, which adversely affects the performance of the photovoltaic panels.

This paper discusses the effects of dust formation, cell temperature, ambient temperature, and water-cooling systems on photovoltaic (PV) panels. Considering that Iraq predominantly has a desert environment, the impact of weather conditions is critically important for any related decision-making. The findings of this research will help determine whether regular cooling and cleaning of PV panels are necessary, and if so, what the optimal frequency and duration should be.

2. Literature Review

This paper provides a comprehensive overview of research studies related to solar technology, the accumulation of dust, and the influence of temperature on the performance of photovoltaic (PV) panels. It highlights experimental investigations of various types of cooled and cleaned PV systems based on different technologies used in solar systems.

This study examines the mechanisms of dust adhesion and separation, as well as the temperature changes resulting from the air-blowing procedure. Implementing an effective cooling method can significantly enhance the efficiency of photovoltaic (PV) systems. These systems require large amounts of water, which poses a significant challenge for large-scale PV power plants. We are investigating a new cooling and cleaning system for solar PV modules that also regulates cell operation using compressed air. This research utilizes PV arrays that provide a dry facility and conducts empirical tests to quantify the increase in power generation resulting from the cooling and cleaning effects [3]. The current study investigates a pulse spray water cooling system for photovoltaic panels, focusing on minimizing water consumption. Previous research on water spray cooling systems has shown potential benefits [4]. Research has shown that cooling photovoltaic (PV) panels from the front is significantly more effective than other methods. This cooling technique can lower the temperature of the PV panels by up to 12%, leading to an increase in electrical efficiency of approximately 14% [5]. At the South African facility, photovoltaic panels are cleaned using a standard cleaning machine, along with labor, soap, and water. To improve this process, the researcher proposed a cleaning method that reduces costs by determining the optimal number of cleaning events and the ideal number of modules to clean each year. This approach acknowledges that, although less frequent cleaning may lead to a decrease in power production, it can still be more cost-effective [6], showing the cost-effectiveness of the strategy before the field implementation of the strategy. In a separate indoor experimental study conducted in Iraq, researchers examined the cleaning effectiveness of various ratios of household detergents and water for cleaning a 50-watt PV module covered with dust [7]. The researchers discovered that the power output from manual washing with the respective cleaning mixtures increased by 7.4% following the cleaning operation. During the operation of photovoltaic (PV) modules, dust particles can have two effects: they can scatter light when they accumulate on the front surface of the module, and they can also come from airborne dust particles in the surrounding environment [8]. Most solar energy is lost as heat, resulting in low energy conversion efficiency of these panels. This increase in temperature of the PV cells reduces both voltage and electrical power output [9].

3. Factors Affecting PV Panel Efficiency

Environmental conditions can degrade the performance of photovoltaic systems, such as solar radiation, temperature, dust, and shading. This section discusses the impact of two significant factors on the surface of solar panels: high temperatures and dust accumulation.

3.1 The impact of temperature on the effectiveness of solar panels.

Ambient and operational temperatures significantly impact the surface temperature of solar cells, posing a challenge in generating solar electricity and reducing the efficiency of solar photovoltaic (PV) systems. Photovoltaic panels lose efficiency by approximately 0.5% for each degree the ambient temperature rises. The system proposed in this study consists of two main components: cooling units and solar panels. The performance of the system was evaluated under two different cooling conditions: natural cooling and cooling with a thermoelectric module. The results demonstrate that using a thermoelectric module in conjunction with a heater can enhance the power output and efficiency of solar panels by an average of 10.50%. Throughout the testing period, the average temperature of the solar panel was about 10.04 °C lower than the operating temperature without the cooling intervention. [10].

3.2 The effect of dust on the performance of PV panels

The phenomenon known as soiling occurs when dust accumulates on solar panels, which reduces the optical efficiency of concentrated solar power (CSP) systems. While data for solar photovoltaic (PV) systems is available on a wide geographic scale, to better understand soiling impacts, researchers aligned precipitation events reported at a nearby meteorological station (located 3.4 km away) with satellite-derived solar resource data. This systematic analysis examined the average annual operating performance of a large commercial facility with a capacity of 86.4 kW DC. The findings revealed that soiling losses were approximately 0.21% per day. Figure 1 illustrates how dust accumulates on a PV panel. [11]. In dry parts of the world, sand dust harms solar photovoltaic (PV) installations [12].

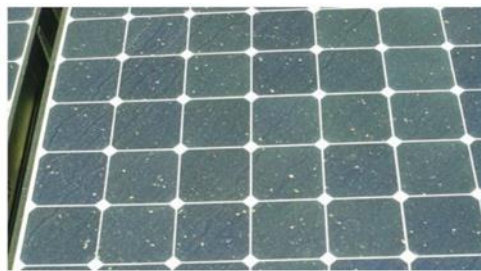


Figure 1: PV panel in UCSD with dust accumulation

Dust particles deposited on panel surfaces are approximately 30 mm in size on plain glass. The hydrophobic silica solution can reduce the adhesion strength of these particles. [13]. However, dust buildup and elevated panel temperatures significantly impair solar panel performance, rendering them a less potent alternative energy source [14].

3.3 PV cooling methods

The performance of thermal complexes, specifically photovoltaic/thermal (PV/T) systems, is significantly influenced by various factors, one of which is the high surface temperature of solar cells. To address this issue, we employed nanofluid cooling, specifically a nano-liquid composed of Fe_3O_4 and water, in six different experimental setups. Of these, two setups utilized uncooled PV cells, while one used pure water for cooling. The results indicated that when compared to both water-cooled and uncooled PV solar cells, nanofluids effectively function as coolants and enhance the

overall performance of the PV cells. When nanofluids were applied at a volume fraction of 1%, we observed maximum electrical and thermal efficiencies of 19.5% and 55.45%, respectively. These findings stem from experimental investigations on the effects of water spraying on the efficiency and temperature of photovoltaic panels. As demonstrated in Figure 2, the water spraying mechanism applied to both the front and back surfaces of the photovoltaic panel successfully reduced the panel temperature and increased electrical output. The efficiency improved by approximately 30 °C, with reported increases of 16.3% in electrical output and 14.1% in overall efficiency [15-17]

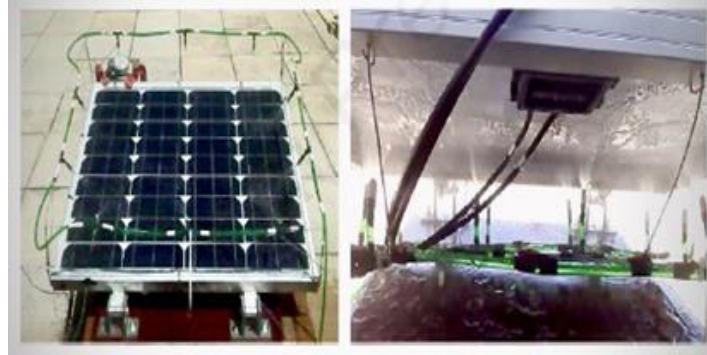


Figure 2: Cooling the front and back sides of PV panels by water spraying.

3.4 PV cleaning methods

In regions like the US and Europe, where dust deposition is relatively low, the air is gradually cleaned more effectively by natural elements such as snow, wind, and rain. In contrast, areas like North Africa and the Middle East face significant challenges with dust and sand, which can severely impact the efficiency of solar panels. In these locations, it becomes necessary to use artificial methods to clean the panels. Cleaning is performed using mechanical methods such as brushing, blowing, and wiping, all under electronic and electrical control. [18] and developed a self-cleaning mechanism for a single-axis solar tracking device. This technology involves spraying a stream of water onto the surface of lambda tips to remove dust particles.

4. The Methodology

For the practical analysis, this research utilized two identical solar panels. One panel was intentionally soiled with cement, coal, and dust, and the other panel remained clean, while the properties of both solar panels were already known. Thermocouples from three sensors were attached to the surface of each solar panel to measure their temperatures from 9:00 AM to 5:00 PM, with data recorded every hour. The recorded data included light output, the temperature of each panel, and measurements of current and voltage. Connections were established around the actual data, accompanied by images that demonstrate how each solar cell behaves in different scenarios.

4.1 Experimental setup

The experimental instrument was constructed and installed on the rooftop of Al-Kitab University in Kirkuk, Iraq, located at a latitude of 35.46° and a longitude of 32.9°. The parameters of the photovoltaic (PV) system, detailed in Figure 3, are connected to the steel structure and tilted at an optimal angle of 32.9° towards true south, which is ideal for the climate of Kirkuk [19]. The device is equipped with two test systems. The first system is designed for cleaning and cooling the panel surface using distilled water, which is delivered through nozzles mounted at the top of the panel. The second system measures the accumulation of dust and serves as the base system. As shown in Figure 4, the photovoltaic (PV) module is the core component of the system; it undergoes cleaning and

cooling once the system is activated. The experiment was conducted between 9:00 AM and 5:00 PM, on hourly basis

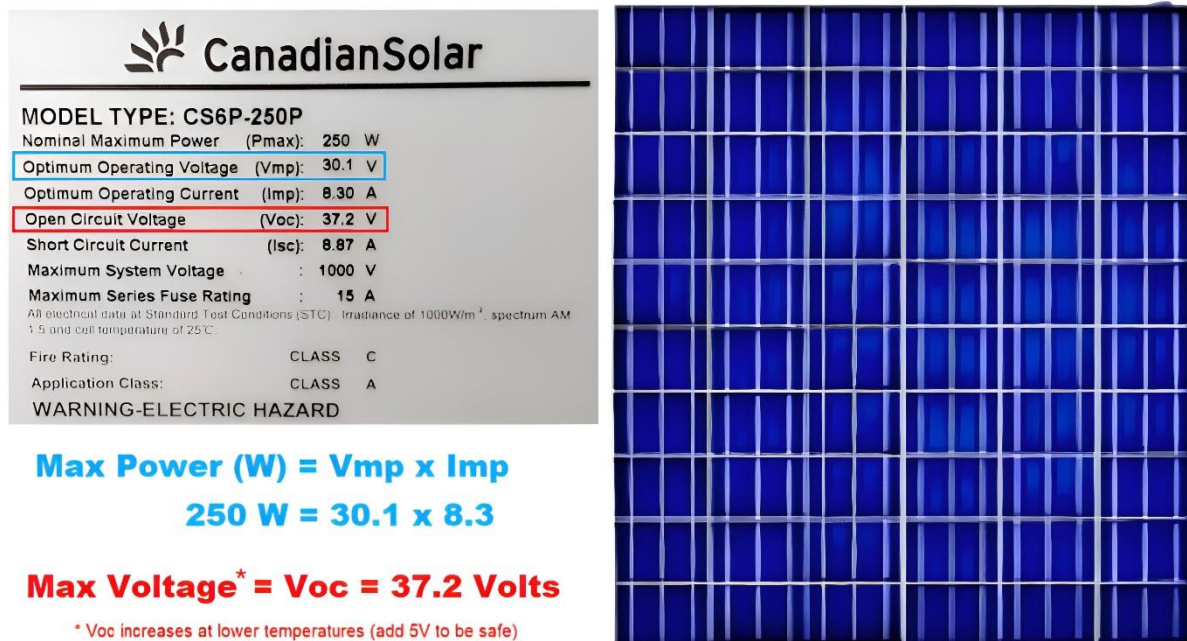


Figure 3: Polycrystalline solar cells datasheet.



Figure 4: The experimental setup.

The measurements were taken under the conditions shown in Figure 5. A UNI-T UT 203 ammeter was used to measure the voltage and current produced by the solar panel at different loads. This setup allowed us to find the threshold for connecting the solar panel, so we could set the maximum electrical energy output while adjusting for the optimal resistance. The solar panel's temperature was measured with a K-type thermocouple, which has an accuracy of ± 1 °C and an operating range of -50 to $+70$ °C. This was done to monitor any temperature increase caused by dust, coal, and cement buildup during the experiment[20]. During this period, solar radiation intensity was recorded using an SM 206 digital radiation meter, with an accuracy of ± 10 W/m². Additionally, the volumetric flow rate of water in the copper tube was measured with a rotameter.

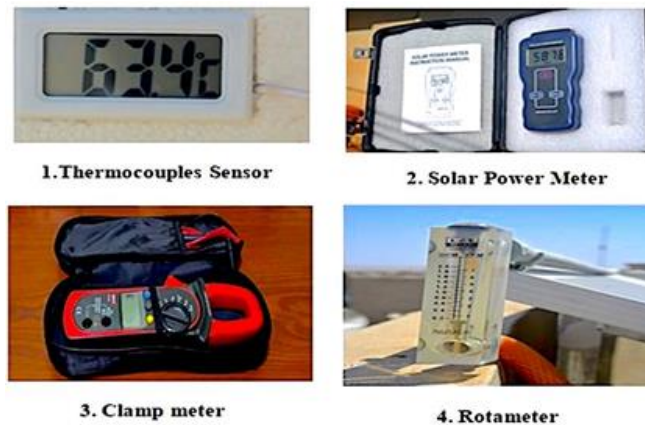


Figure 5: Measuring devices and sensors.

Four different weights of dust were applied to the surfaces of the solar panels, and measurements were taken daily and weekly. The weather conditions and environment affecting the solar panels resulted in the type of dust deposited on the panels being the same as that on the roof of the building where the experiments were conducted. To determine the accumulated weight of dust on the panels, an area of the building surface equal to that of the solar panel was used. The collected dust samples represented various periods of dust accumulation. The following hypothesis was considered: the amount of dust accumulated on the surface of the panel is homogeneous. The tilt of the solar panels was taken into account, and dust was collected from the tilted surfaces. The weights of the dust samples were transformed into thicker layers. Different weights—200, 300, 400, and 500 grams—were used to assess their impact on the performance of the photovoltaic (PV) panels.

5. Results And Discussions

5.1 Effects of irradiation level

Figure 6 illustrates the capacity and efficiency of solar panels with and without water cooling. The maximum capacity reached 198 watts for panels using pulsed water spray cooling systems, while the uncooled panels produced a maximum of 175 watts. Additionally, the efficiency of the cooled panels improved to 13.7% after implementing the cooling system.

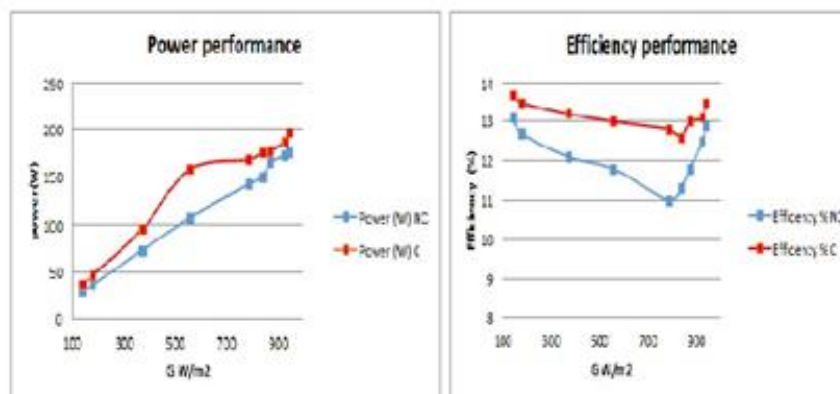


Figure 6: Power and efficiency performance.

5.2 The effect of ambient temperature on the power and efficiency of PV panels

The water cooling process reduces the temperature of the solar panels. An ongoing study has resulted in a 10% increase in electricity generation and a 17°C decrease in the temperature of photovoltaic

panels. This is a significant advancement, as solar panels are only able to convert about 20% of the solar energy they receive into electricity. Figure 7 illustrates how the cooling process affects the efficiency and power of the cells, demonstrating that both power and efficiency increase with cooling.

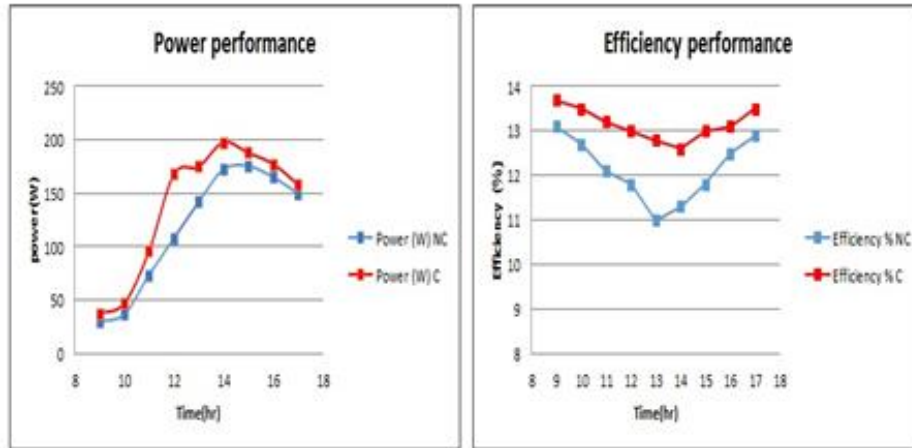


Figure 7: PV performance in the process of cooling.

From the cooling results, the power performance increased to 197.7 W at 2:00 pm.

5.3 Effects on the temperature of PV panels

Generally, the variations in solar panel energy production are primarily influenced by ambient air temperature and the amount of sunlight received. The intensity and duration of sunlight play significant roles in determining energy output, which can be adversely affected by high temperatures and other environmental factors. For instance, Figure 8 illustrates that the maximum panel temperature without cooling reached 68 °C. However, this temperature was reduced to 49 °C with the implementation of pulsed water spray cooling systems.

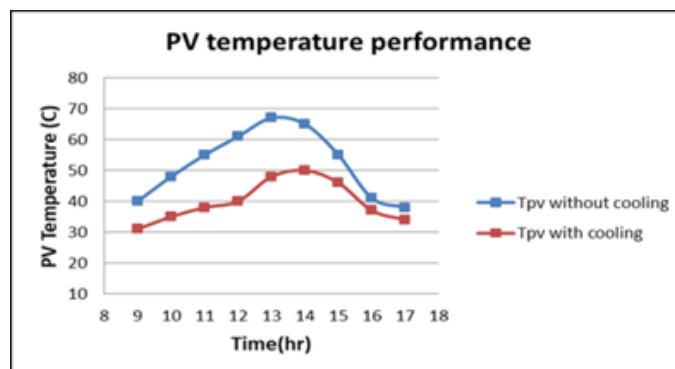


Figure 8: PV temperature with time.

5.4 Effects of dust on the performance of the PV panel

The photovoltaic (PV) panels have been operating for one week and have accumulated dust of varying weights on their surfaces. This dust accumulation has resulted in a cooling effect on the PV modules, which leads to reduced power output. After removing 200 grams of dust from the surface of the solar panel, the power output was measured at 187 watts, and the efficiency was calculated at 11.67% with a plate temperature of 57 °C when the solar radiation intensity was 977 W/m². From

this experience, we learned that dust accumulation causes an increase in temperature for the panels, which in turn reduces their efficiency and power output. As illustrated in Figure 9, the deposition of 500 grams of dust had a more significant impact on panel efficiency compared to other weights. The maximum energy values obtained during practical testing were lower than those recorded for a clean panel, measuring 169.36 W/m^2 for the clean panel and only 56.47 W/m^2 for the panel with dust accumulation. The data was plotted, and the results demonstrated that dust deposits on the surface of the photovoltaic panels resulted in a considerable loss of energy. Figure 9 shows the effect of dust accumulation at different weights.

5.5 The effect of coal, cement, and plaster on the performance of the panels

The maximum power output and the mass of coal dust deposition are presented graphically in Figure 9. The blue line represents the coal-contaminated panels, while the red line indicates the actual power outputs of the clean panels. The primary objective of this research is to investigate the impact of coal dust accumulation on the performance of solar PV panels. The experimental results revealed a gradual decrease in generated power due to the buildup of coal dust on the surface of the solar panels, reducing the output to 152.7 W . However, when a cooling and cleaning system was employed, the power output increased to 158.6 W .

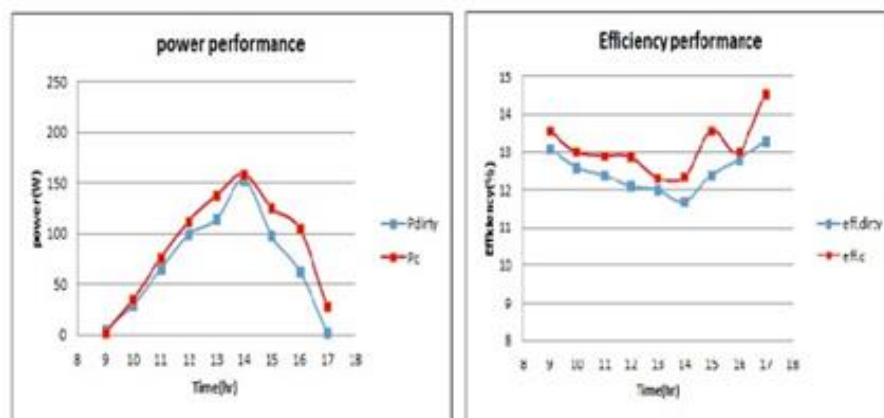


Figure 9: Coal deposition.

Figure 10 illustrates that the energy output of solar panels decreases more significantly when the temperature of the dirty panel, particularly one affected by cement, is higher. The graphs demonstrate the temperature differences between the sediment-laden solar panel string and the surrounding environment. Ultimately, the performance of the pulsed water spray cooling systems improved the average electricity efficiency by 14.5%.

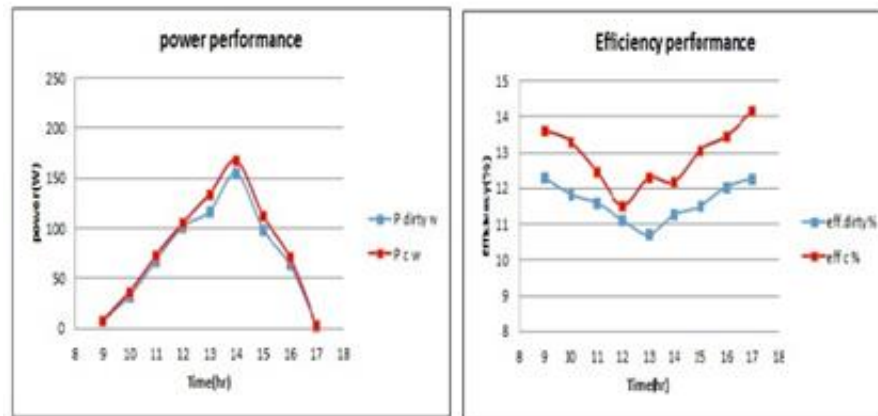


Figure 10: Shows curves for the difference in power and efficiency between a cement-deposited panel and a water-cleaned panel.

The impact of cooling technologies on the temperature of photovoltaic (PV) panels and their power output under varying solar radiation levels shows that water spray cooling is the most effective method at higher levels of solar radiation. The results indicate that the efficiency decreased to 10.7%, while the power output of the panel that had cement deposited on it was 155 W.

In Iraq, dust deposition on photovoltaic (PV) systems is more than double that in urban areas like Athens, where natural precipitation is more common. This highlights the significant impact of dust on solar energy systems in desert regions. Consequently, the accumulation of dust does not enhance the light-focusing effect on solar panels, ultimately diminishing their efficiency.

6. Conclusions

To improve the efficiency of photovoltaic panels, a study employed a pulsed spray cooling system tailored for the climatic conditions of Kirkuk, Iraq, through experimental research. Environmental factors such as temperature, humidity, wind, and dust deposition significantly impact the performance of solar panels. It was observed that the energy output and efficiency increased, reaching 197.7 watts with an efficiency of 14.5% when the panels were cleaned and cooled using the pulsed spray cooling system. This system was developed by directing water from a sprayer positioned on the front surface of the photovoltaic panel, resulting in a 14.5% boost in efficiency. Dust and other debris can accumulate on the panels, decreasing their efficiency and reducing the potential electrical energy they can generate. Water stands out as the most efficient, accessible, and cost-effective resource for removing dust, which enhances photovoltaic panel performance by cooling and cleaning the surface. Since its introduction, deep immersion spraying has demonstrated excellent cooling and cleaning abilities on solar photovoltaic cells. These findings emphasize the importance of regular cleaning and cooling techniques in maximizing the efficiency and energy output of photovoltaic modules.

Future studies could explore the long-term effects of different cooling and cleaning methods, as well as how dust characteristics influence solar module performance. Analyzing the relative costs of various cooling and cleaning options may provide valuable insights for practical implementation in solar energy systems. Furthermore, mathematical models describing the operational parameters of solar panels with direct water cooling and cleaning systems will be developed and integrated into dynamic simulations based on experimental data.

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Author's contributions

Author contributions **A.K and Y.K** writing original draft, methodology, investigation, and formal analysis. Main concept, **A.Y and A.A** data interpretation, and supervision. Writing review and editing, visualization, and data curation.

Conflicts of Interest

The authors declare no conflict of interest.

References

- [1] Sargunanathan S, Elango A, Mohideen ST. Performance enhancement of solar photovoltaic cells using effective cooling methods: A review. *Renew Sust Energ Rev.* 2016;64:382-93. <https://doi.org/10.1016/j.rser.2016.06.024>
 - [2] Hussain F, Othman MY, Yatim B, Ruslan H, Sopian K, Anuar Z, et al. Comparison study of air base photovoltaic/thermal (PV/T) collector with different design of heat exchanger. In: *World Renewable Energy Forum (WREF)*. 2012;1:189-94.
 - [3] Nižetić S, Čoko D, Yadav A, Grubišić-Čabo F. Water spray cooling technique applied on a photovoltaic panel: The performance response. *Energy Convers Manag.* 2015;108:287-96. <https://doi.org/10.1016/j.enconman.2015.10.079>
 - [4] Bahaidarah HMS. Experimental performance evaluation and modeling of jet impingement cooling for thermal management of photovoltaics. *Sol Energy.* 2016;135:605-17. <https://doi.org/10.1016/j.solener.2016.06.015>
 - [5] Li D, King M, Dooner M, Guo S, Wang J. Study on the cleaning and cooling of solar photovoltaic panels using compressed airflow. *Sol Energy.* 2021;221:433-44. <https://doi.org/10.1016/j.solener.2021.04.050>
 - [6] Tejwani R, Solanki CS. 360 sun tracking with automated cleaning system for solar PV modules. In: *35th IEEE Photovoltaic Specialists Conference*. 2010;2895-8. <https://doi.org/10.1109/PVSC.2010.5614475>
 - [7] Kumari N, Singh SK, Kumar S, Jadoun VK. Performance investigation of monocrystalline and polycrystalline PV modules under real conditions. *IEEE Access.* 2024;12:169869-78. <https://doi.org/10.1109/ACCESS.2024.3497318>
 - [8] Abass KI, Radhi A, Mahdy AMJ. Using water and surfactants in cleaning PV modules effect on its yield. *Int J Trend Res Dev.* 2020;7:2394-9333.
 - [9] Mejia F, Kleissl J, Bosch JL. The effect of dust on solar photovoltaic systems. *Energy Procedia.* 2014;49:2370-6. <https://doi.org/10.1016/j.egypro.2014.03.251>
 - [10] Hadipour A, Zargarabadi MR, Rashidi S. An efficient pulsed-spray water cooling system for photovoltaic panels: Experimental study and cost analysis. *Renew Energy.* 2020;164:867-75. <https://doi.org/10.1016/j.renene.2020.09.021>
 - [11] Saleh AH, Hussein AM, Danook SH. Efficiency enhancement of solar cell collector using Fe₃O₄/water nanofluid. *IOP Conf Ser Mater Sci Eng.* 2021;1105(1):012059. <https://doi.org/10.1088/1757-899X/1105/1/012059>
 - [12] Haeberlin H, Graf JD. Gradual reduction of PV generator yield due to pollution. *Power W.* 1998;1200-400.
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- [13] Khadim IJ, Mahdi EJ, Ubaid AH. Determining tilt angle for fixed solar panel to sites of Iraq's provinces by using the programs on NASA and Google Earth websites. *Eng Technol J.* 2014;32(3B):498-506.
- [14] Pan A, Lu H, Zhang LZ. Experimental investigation of dust deposition reduction on solar cell covering glass by different self-cleaning coatings. *Energy.* 2019;181:645-53. <https://doi.org/10.1016/j.energy.2019.05.223>
- [15] Salehi R, Jahanbakhshi A, Golzarian MR, Khojastehpour M. Evaluation of solar panel cooling systems using anodized heat sink equipped with thermoelectric module through the parameters of temperature, power and efficiency. *Energy Convers Manag X.* 2021;11:100102. <https://doi.org/10.1016/j.ecmx.2021.100102>
- [16] Abdolzadeh M, Ameri M. Improving the effectiveness of a photovoltaic water pumping system by spraying water over the front of photovoltaic cells. *Renew Energy.* 2008;34(1):91-6. <https://doi.org/10.1016/j.renene.2008.03.024>
- [17] Rashid MK, Mohammed HJ, Hameed HM, et al. The effect of titanium dioxide (TiO₂) nanoparticle concentration on the performance of polycrystalline silicon solar cells. *J Umm Al-Qura Univ Eng Archit.* 2025. <https://doi.org/10.1007/s43995-025-00207-z>
- [18] Zaihidee FM, Mekhilef S, Seyedmahmoudian M, Horan B. Dust as an unalterable deteriorative factor affecting PV panel's efficiency: Why and how. *Renew Sust Energ Rev.* 2016;65:1267-78. <https://doi.org/10.1016/j.rser.2016.06.068>
- [19] Dawood TA, Barwari RRI, Akroot A. Solar energy and factors affecting the efficiency and performance of panels in Erbil/Kurdistan. *Int J Heat Technol.* 2023;41(2):304-12. <https://doi.org/10.18280/ijht.410203>
- [20] Simiyu DSN. Optimal cleaning strategy of large-scale solar PV arrays considering non-uniform dust deposition [dissertation]. Pretoria: Univ. of Pretoria; 2020.
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