IMPROVEMENT OF PV CELL PERFORMANCE BY USING DIFFERENT CLEANING METHODS

A THESIS

SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING TECHNIQUES OF POWER
AS PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR MASTER OF THERMAL TECHNOLOGIES DEGREE IN MECHANICAL ENGINEERING TECHNIQUES OF POWER
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2023/ / /

بسم الله الرحمن الرحيم

قَالُوا سُبْحَانَكَ لاَ عِلْمَ لَنَا إِلاَّ مَا عَلَّمْتَنَا إِنَّكَ أَنتَ الْعَلِيمُ الْحَكِيمُ

صدق الله العلي العظيم

سورة البقرة اية (32)

DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries, which have been duly acknowledged.

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Safa Faisal Saleh

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Supervisor Certification

We certify that this thesis entitled “IMPROVEMENT OF PV CELL PERFORMANCE BY USING DIFFERENT CLEANING METHODS) was prepared under our supervision at the Department of Mechanical Engineering Techniques of Power, College of Technical Engineering-Najaf, AL-Furat Al-Awsat Technical University, as partial fulfillment of the requirements for the degree of Master of Techniques in Thermal Engineering.

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LANGUAGE CERTIFICATION

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ABSTRACT

Photovoltaic (PV) modules are widely used for harnessing solar energy which ensure maximum output when their glass surface is clean. However, PV modules are open to dust, grime and other contaminations which get deposited on their surface causing reduction in transmittance and hence their efficiency reduces. The effect of presenting dust on the solar cell's surface plays a significant factor in reducing the efficiency of the cell, hence, its output power. So, several studies from various researchers were performed to develop cleaning methods for the cell's surface to improve its performance.

In the present study, four experimental systems of cleaning cases were conducted under Najaf, Iraq's climatic circumstances (32° 1' N / 44° 19' E) on a PV module consists of three PV panels, each of 135W and 20% maximum output power and efficiency, respectively. Each panel has dimensions of (0.62 x 0.95) m^2. The four cases of cleaning were the Natural (the standard case) which were performed upon the first PV panel, the Mechanical (by using nozzles of (0.5,1)mm) were performed on the second PV panel where the distilled water was feed in until 1LPM is all spread then the pump was shut off, the Nano-coating (by using (400, 700) nm Super-hydrophobic ZnO on the glass surface) were applied to the third PV panel, and the last method was a combination of the Mechanical and Nano-coating together which was applied to the same third PV panel after the completion of the third method on it.

The study was performed for all the systems of PVs instantaneously, meaning that the results of all the cases are being taken and registered at once and the device which were used to get all the results from the PV panels is called Solar Modul Analyzer which gives all the required outcomes of power, efficiency, current, voltage etc. Four days (1/7, 8/7,

17/7, and 25/7) in the month of July were taken into consideration for the study, starting each day from 8: A.M until 4:P.M and only the optimum results corresponding to 12:00 P.M were considered.

The results of the present study showed that using the combination method gave the most optimum results for the efficiency and power output of the PV panel among the other systems. A maximum overall PV efficiency and power output of around 14.29% and 81W, respectively, were achieved for the Combination case at the hour of 12:00 P.M. The Mechanical method gave a maximum PV efficiency and power output of about 13.81% and 79W, respectively. While the Nano-coating method has only given an efficiency and power output of about 12.1% and 69W, respectively. Lastly, the first method, which was the Natural case, has got the lowest results amongst the other cases, with an efficiency of 11.47% and power output of about 65W.

method had achieved a percentage of efficiency and output power of 3.4%, 10.80 %, respectively, more than the Natural case. 3.4%, 2.3%, respectively, more than the Mechanical case. 19.7%, 19.8%, respectively, more than the Coating case. 3.4% , 3.2% , respectively , more than the Mechanical case. 15.3% , 14.8% respectively , more than the Coating case The results showed that the nozzle with 1 mm diameter has better performance than the 0.5mm one. So, the whole results will be based and shown upon the 1mm diameter.

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Latin Symbols

Symbol	Definition	Unit
A	Absorption	Nanometers (nm)
E	Photon Energy	Joule (J)
FF	Fill Factor	--
h	$Planck\ constant$	$(6.63*10^{-34}JS)$
I	Absorption Intensity	(Absorption Unit)
K	Boltzmann constant	1.38×10^{-23} m2 kg s^{-2} K^{-1}
n	Refractive Index	--
PS	Poly styrene	--
q	Electronic charge	1.602×10^{-19} coulombs
R	Reflection	%
ZnO	Zinc Oxide	--

Greek Symbols

Symbol	Definition	Unit
η	Electrical Efficiency	%
η_{TR}	Electrical Efficiency at Temperature Reference	%
λ	Wavelength	Nanometers (nm)
ν	Frequency	Hertz (HZ)

Subscript

Symbol	Definition	Unit
I_{mp}	Maximum power current	Amper (A)
I_{SC}	Short Circuit Current	Amper (A)
V_{mp}	Maximum power voltage	Volt (V)
Iph	Photocurrent	Amper (A)
Is	Diode saturation Current	Amper (A)
V_{OC}	Open Circuit Voltage	Volt (V)
β_R	Temperature Coefficient	0.004-0.005/^{0}C
T_R	Refrence Temperature	(25) ^{0}C
T_C	Cell Temperature	^{0}C

Chapter One

INTRODUCTION

1.1 Background

Population and associated energy demands are increasing daily. Many fuels have been used as energy sources throughout history. People long relied on wood, coal, and fossil fuels for their energy needs. The carbon dioxide emissions from these fuels started altering Earth's climate and environment in the previous century. In recent years, people have sought an efficient, sustainable, and reusable energy source. Solar energy is the most popular alternative fuel. There are many different applications for solar energy, both directly and indirectly, such as the utilization of wind and geothermal power [1]. Heliostats, Fresnel collectors, and parabolic troughs are examples of concentrated thermal collectors that may create energy using sunlight. Water may be heated using solar collectors (Figures. 1.1, and 1.2) [1]. In addition, direct photovoltaic panels directly convert photons from the sun's energy into electrons within a semiconductor. The two most prevalent residential and commercial solar panel types are monocrystalline and polycrystalline.

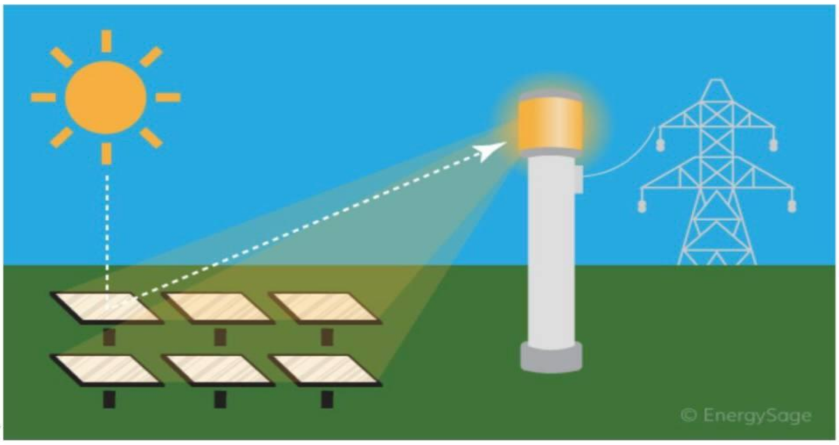

Figure 1.1: Heliostat solar collector [1]

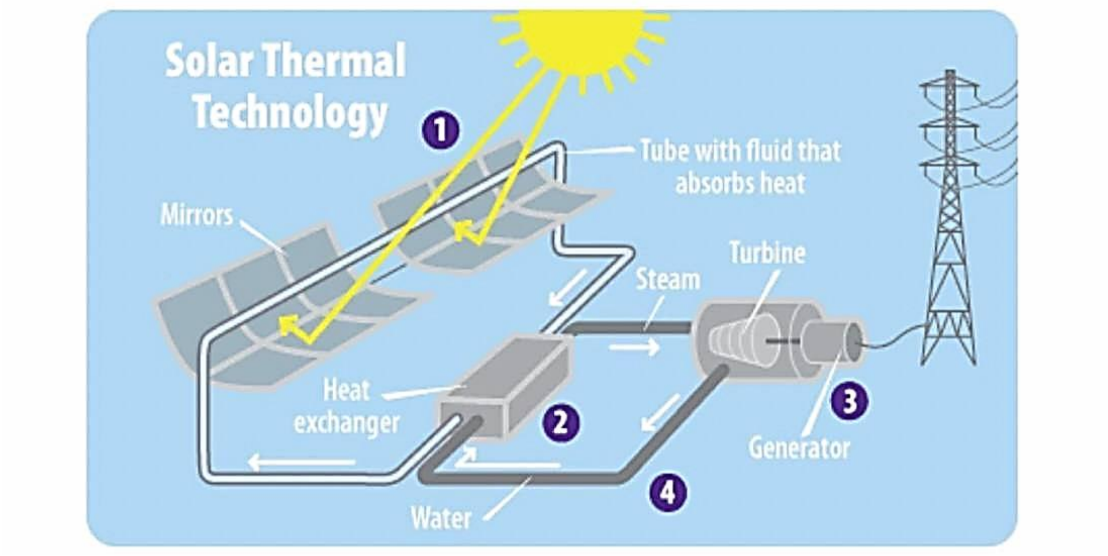

Figure 1.2: parabolic collector [1]

In order to transform solar energy into usable light, a photovoltaic panel uses the photovoltaic effect. Edmond Becquerel, a French scientist, discovered the photovoltaic effect in 1839 [1]. Photovoltaic panels may be found in a wide variety of forms and sizes; however, there is one thing that all of these panels have in common: the utilization of a semiconductor to convert light into energy. The solar panel has several layers, each performing a different function. The semiconductor layers' junction field between P-type and N-type semiconductors is most important. Photovoltaic panels are becoming widespread worldwide due to silicon semiconductors. In addition, photovoltaic cells may be utilized in both household and commercial settings since they are solid units that can be joined to other groups of cells and do not require moving parts. This makes them suitable for solar power systems [3] (see Figure 1.3).

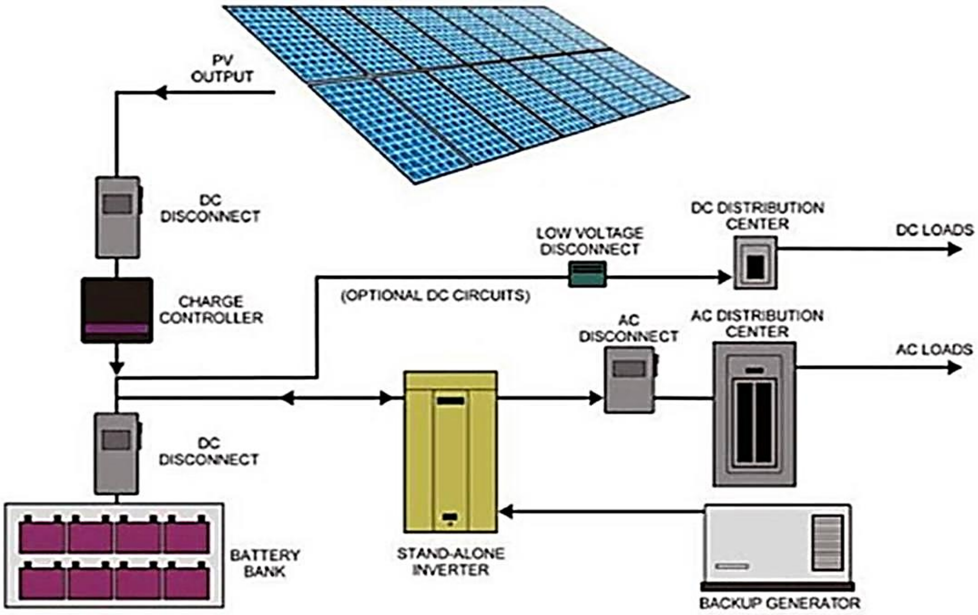

Figure 1.3: photovoltaic panel installation [3]

Industrial usage of solar panels began in the 1980s and has grown steadily since 1996. As the surface temperature of the panel is raised during operation, conversion efficiency also decreases [3]. Every 10^{o}C above 25^{o}C reduces performance by around 0.5% [4]. As a result, the panel surface overheated and lost a sizeable amount of energy. The panels' surface temperatures have been lowered to safe levels using various techniques.

1.2 Photovoltaic panel types

A photovoltaic cell is made up of two extremely thin layers of semiconductor material, most often silicon. Light triggers electrical changes in a semiconductor's molecules, and conductors may collect these electrons to provide direct current (DC). Due to the low power output of individual cells, it is common practise to connect many cells in series to produce a direct current (a "string"). Photovoltaic (PV) panels provide the required voltage and current when connected in parallel or series, and a glass cover placed over the cells results in a PV panel.

Different materials and technologies result in various sizes and shapes for photovoltaic panels. Even though there are three main types of photovoltaic panels utilized in homes and businesses, scholars have separated solar system evolution into three technical phases, as seen in Figure.1.4.

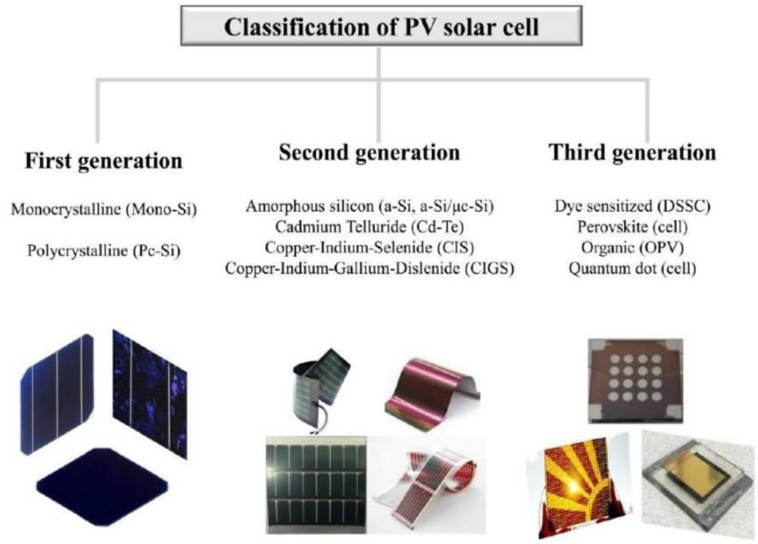

Figure 1.4: Generational categorization of photovoltaic panels [5]

1.3 Photovoltaic solar cell operating principles

Solar power may be harnessed and transformed into useful electricity using photovoltaics (PV). This effect is caused by the system's PV cells. The PV cell's semiconducting components are doped to produce a P-N structure by use of an internal electric field. Negative (n-type) silicon has a greater propensity to accept electrons, whereas positive (p-type) silicon is more likely to lose electrons and pick up holes. As sunlight hits a solar cell, it excites some of the semiconductor's electrons, turning them into electron-hole (negative-positive) pairs (Figure 1.5). The presence of an internal electric field causes this pair separation. Because of this, charges go from the negative to the positive electrode. The negative, load and positive electrodes are connected in a circuit via a single conducting wire. This generates an electric current that may be used to move the extra weight. The PV effect in a solar cell is as follows: [2]

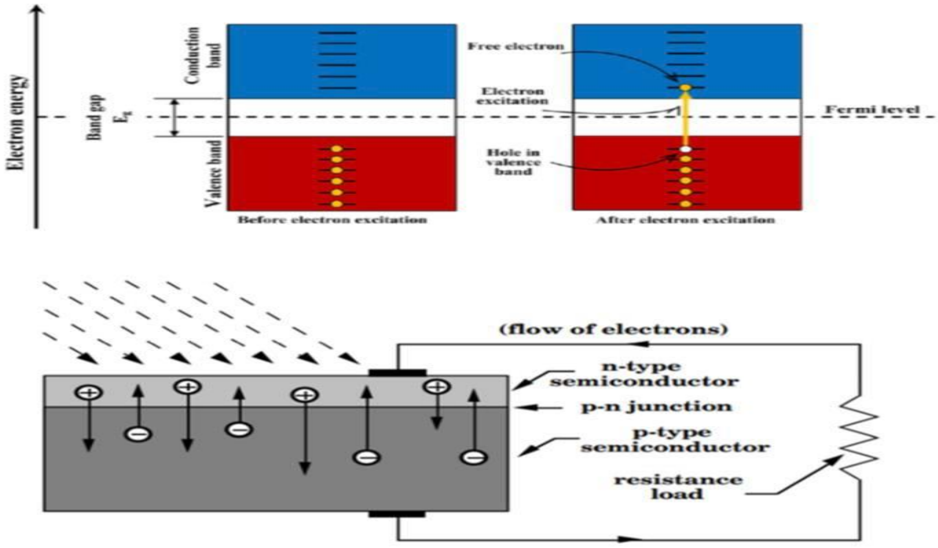

Figure 1.5: Solar cell operation [10]

1.4 Photovoltaic Cells Properties

In order to understand the photovoltaic cell behavior, we have to set a diagram representing only two cell outputs, as in fig. 1.6. The relation between the current that is pulled from the cell and the voltage that is provided by the cell is represented by the I.V carve, which is comprised of the voltage and the current. The power is a function of solar radiation, surface temperature, and manufacturing properties.

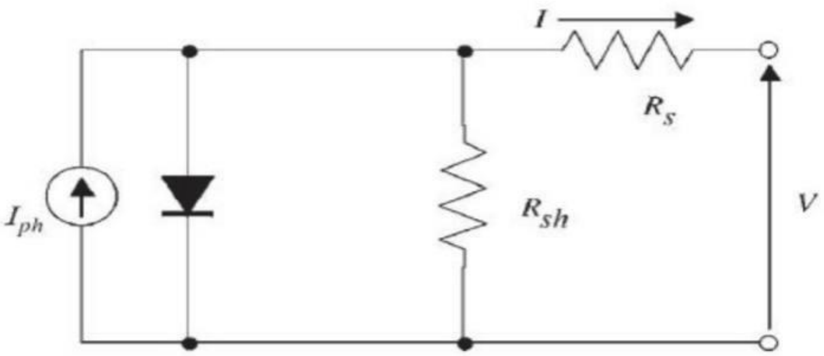

Figure 1.6: Photovoltaic cell electrical diagram[11]

As the current and the voltage is the most critical parameters for calculating the output power, two points have to be set in that diagram the maximum withdrawn current (Impp), and the maximum produced voltage (Vmpp). By pointing these values in the I.V diagram, the maximum of the values curves is where the maximum power can be calculated as shown in fig. 1.7, and the PV panel efficiency can be found [11].

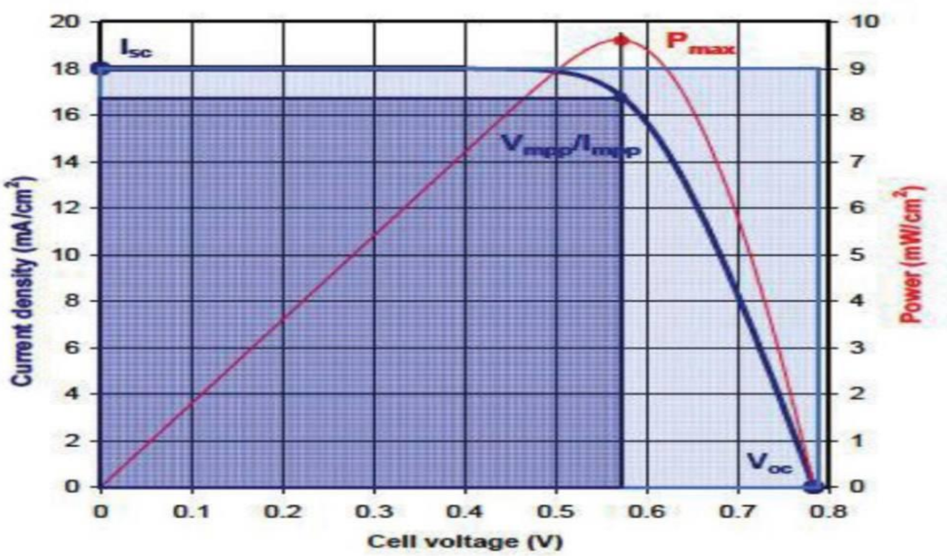

Figure 1.7: The I.V curve [11]

All the PV panel properties are given at the standard conditions, considered 1000 w/m^2 solar radiation and a 25°C ambient temperature. The efficiency of the panel at that condition is could the theoretical efficiency.

However, the panel can produce more or less power depending on the temperature and solar radiation. The maximum power produced by the same panel is called the actual maximum power and efficiency. The ratio between the actual and the theoretical efficiencies is called the Fill factor (FF), and as the fill factor is less than one, the better the performance and if the fill factor close to one that represents the maximum power produced is closed to the power produced at standard condition [12].

1.5 PV Panels Cleaning Methods

The performance of PV systems is hampered by dust buildup on solar photovoltaic (PV) modules, which reduces light transmission from the outer surfaces to the solar cells as shown in figure 1.8 below [13] and, consequently, photon absorption. Remedial actions are required to lessen such effects in areas like the Middle East where dust is common, and rainfall is infrequent. Currently, a variety of methods, including mechanical and active and passive electrical interventions, natural or nano-coating are used to address this sand soiling. Figure (1.9) below explains the different cleaning methods used for solar panels.

Table (1.1) comparison of cleaning methods

method	**advantage**	**disadvantage**
Cleaning by water spry	Dust particles are effectively removed, and all PV panels section are covered. Water that has been cooled or heated could be used.	Water, pump, and controller are all required. Occasionally, a static system is used, and other times, a specific vehicle is used.
Self-cleaning	Use ultrasonic energy to reach the surface through the air; there is no need for water or human.	When there is much humidity, it is less effective. A unique power supply is required.
Natural removal dust	There are no costs or resources involved	It is a method that is linked to the weather

Self-cleaning and tracking	Useful in dry conditions to speed up the removal of dust particles from the PV surface	A motor, control circuit, and power source are required
Electrostatic removal dust	Without using moving parts, it is efficient and effective at removing dust particles.	High voltage converters and digital signal devices are all required and expensive.
Microcontroller based cleaning	A practical method to clean the PV panel fast	Need energy and electronic circuit and cost of parts

Figure 1.8: Cleaning of PV panels [13]

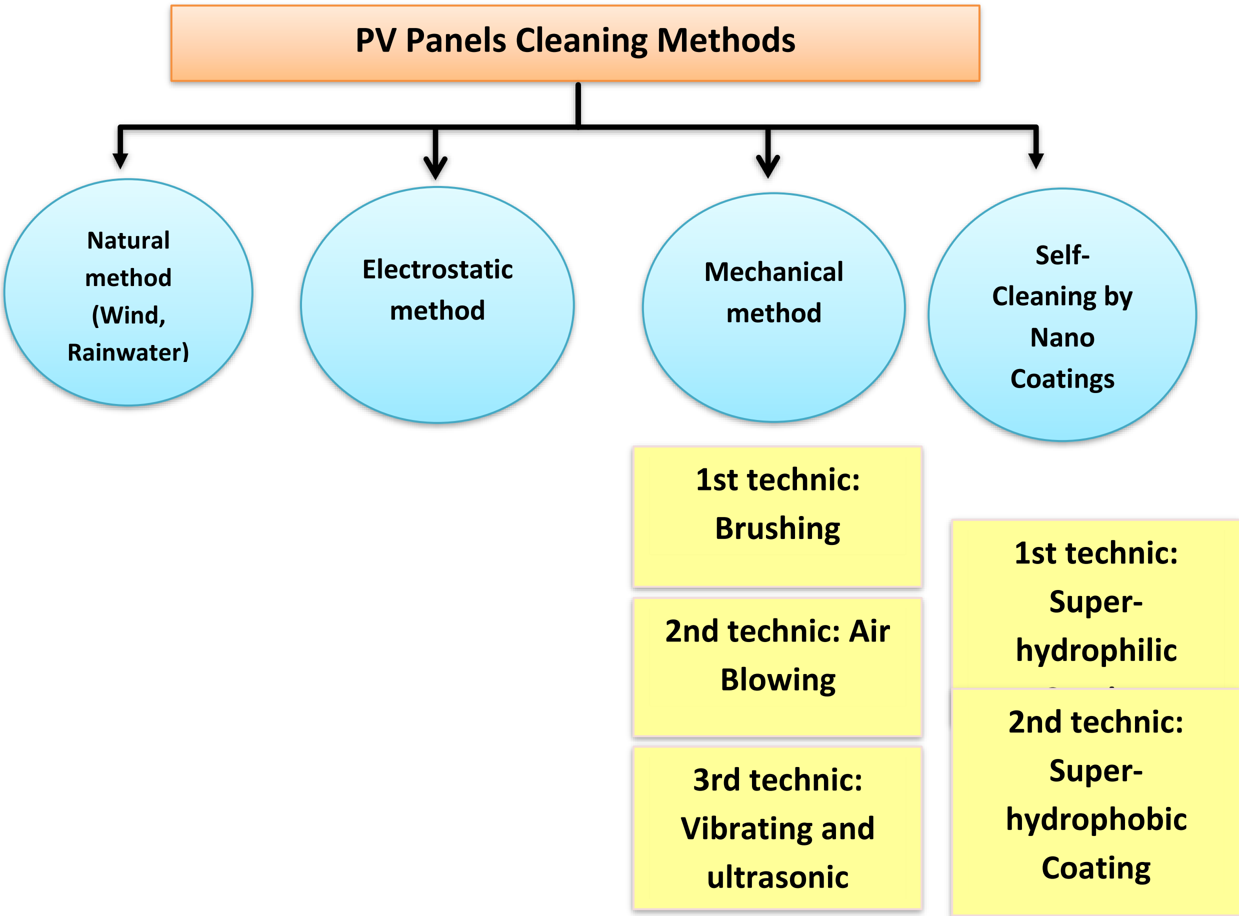

Figure 1.9: PV Panels Cleaning Methods

1.6 Nano materials

The most important characteristic of solar cells is that they produce clean energy using sunlight. However, their efficiency decreases due to the adhesion of moisture or raindrops and dust, so they need a greater number of cleaning times, and all the dust may not be removed, so it sticks to a layer that prevents sunlight from passing through. Coating these cells with a hydrophobic nano-material and easy to remove dust from them without sticky residues reducing the number of cleanings times and ensuring that dust does not remain on them. The thickness of coating must be very thin so that it allows the passage of light without affecting the efficiency of the cell itself, and it must also prevent the accumulation of water droplets and make it easy to slip and dust that is easier to remove with one wash without leaving particles on the surface. The most important thing about this coating is that it acts like a surface that does not like water droplets and makes them round. This is because of the high surface tension, meaning the surface does not get wet. It means that the drop should not leave any moisture on the glass of the solar cell, so the percentage of wetness is zero.

1.7 Problem Statement

Solar panel efficiency has been the topic of extensive scientific study and technological development in recent years.

There are a number of different aspects that can have an effect on the efficiency and power generation of a solar cell. Dust, water, sand, and moss are just some debris and particles that can collect on a solar photovoltaic panel's surface and prevent or divert light energy from reaching the solar cells. This is a serious problem because substances that absorb or scatter light operate as external resistances that lower the efficiency of solar photovoltaics.

This study aims to improve the performance of the PV panels that are being used in nations with hot weather and high dust density by developing different cleaning methods which are: Natural, Mechanical, Self-cleaning, and Mechanical/self-cleaning methods.

1.8 The Objective of the Study

This study aims to investigate various cleaning methods applied on three PV panels .

The study shall involve the following main steps to achieve the goal of this in visitation :

1- Cleaning the PV panels by using four type of cleaning (Natural,Mechanical,nano-coating and combined Meehanical and nano-coating .
2- Vising the Solar Module Analyzer to measure the electrical parameters (Isc , Voc , Z&I-V curve) .
3- Compare the efficiency of PV for the four cleaning methods.

Chapter Two

Literatures Review

2.1 Introduction

The efficiency of the solar cell was improved in a number of ways. Consequently, this chapter discusses several prior research focused on increasing solar cells' efficiency by adjusting and decreasing the cell's surface temperature and reducing incident light reflection.

2.2 The effect of dust on PV module performance

Dust collection is one of the main issues affecting PV modules' performance and lifespan [16]. The size and amount of dust impact how efficiently a PV module performs, the size of the dust has an inverse relationship with efficiency deterioration [17]. Darwish et al. (2013) [18] studied the impact of dust deposition on the daily energy loss of PV modules over a year. They found that the average amount of daily energy might be lost by 4.4% due to dust accumulation. They also suggested that when there is a prolonged drought, this loss may exceed 20%. A similar investigation was carried out by Said S. A. and Walwil H. (2014) [19] to assess the effect of dust fouling on a PV module's glass cover. They found that a 20% overall transmittance decrease and a 35% spectral transmittance reduction. Additionally, Kumar S. and Chaurasia P. (2014) [20] conducted a study to explore the influence of dust on the effectiveness of PV modules in India. They found that dust collection might reduce the effectiveness of PV modules by up to 40% in desert areas.

2.3 Methods for Improving Solar Cell Performance

There are various methods that are available to improve the performance of the PV panels and the cleaning methods are one of the best that have been intensively studied through many years and by various researchers in the literature. The following is a review for the different studies on the different cleaning methods:

2.3.1: Mechanical cleaning

M. Abdolzadeh and M. Ameri. (2009) [15] Conducted a study to examine the performance of a 225 W photovoltaic water pumping system with water spray over the photovoltaic cells. The experimental setup consists of two PV cells (45 x 2 W) with 13.5% power efficiency and one positive displacement surface water pump with a permanent magnet DC motor. It is found that spraying water over the photovoltaic cells strongly improves the system and subsystem efficiencies. It is shown that, spraying water over the cells increases the mean PV cell efficiency, subsystem efficiency and total efficiency 3.26%, 1.40% and 1.35%, respectively, at 16 m head. Maximum PV cell efficiency at standard condition is 13.5%. The photovoltaic water pumping system with water spray over the cells achieves 12.5% mean PV cell efficiency during the test day. In the case of system without water spray over the cells the mean flow rate at 16 m head was about 479 L/h during the test day, whereas it reached 644 L/h in the case of system with water spray over the cells.

S. Krauter (2004) [22] conducted experimental studies on the effect of front-face water cooling on power conversion efficiency and dust losses. Reflective losses might approach 30%, according to the testing data. The water spray cooling system might prevent overheated losses and increase the overall gain by up to 20%.

Dorobantu and Popescu (2013) [23] Implemented a solution to eliminate losses caused by the presence of deposits on the surface of the panels by installing a special device. It is designed to disperse a water film on the panel surface, thus achieving cooling and cleaning of the module. used a mono-crystalline panel of a maximum Power of 75W which is cooled by a continuous film of water that pours on the working surface of the panel. The photovoltaic panel was placed on a fixed frame, with a tilt angle of 35 degrees. During the measurements the average of radiation level was 780 W/m^2. Water flow measured was 33.3*10-6 m3/s. The results showed that due to the front water cooling of the panel, the electrical yield has return a plus of about 9.5%, which can cover the power needed to pump the water from the bottom of the panel to its top end.

S.Nizetic et al. (2015) [24] Presented an experimental investigation exploring the effect of spraying water on both sides of a PV panel simultaneously. An experimental configuration was assembled from a flat PV monocrystalline module of 50W nominal maximal power with an effective surface of 0.31 m^2. The panel was equipped with a system of nozzles mounted on the PV panel front and rear sides to ensure proper water spray distribution on both sides of the PV panel. The experimental result shows that it is possible to achieve a maximal total increase of 16.3% in electric power output and a total increase of 14.1% PV panel electrical efficiency by using the proposed cooling technique in circumstances of peak solar irradiation. Furthermore, it was also possible to decrease panel temperature from an average 54°C (non-cooled PV panel) to 24°C in the case of simultaneous front and backside PV panel cooling.

2.3.2: Self-Cleaning –Nanocoating

Using dip coating, spin coating, sol-gel, chemical vapour deposition, and spray coating, examine the impacts of nano-size particles including ZnO, TiO2, Silica, MgFe, CuO, and MnO2 on PV panel glass to remove dust and soil and prevent adhesion. The self-cleaning approach is the name given to this particular method. It is a method that requires less time and money to complete. Two distinct concepts form the basis of self-cleaning technology. Super-hydrophobic surfaces roll off water droplets and release pollutants when the water contact angle (WCA) reaches 1500. A super-hydrophilic surface formed a water film that detaches dust and transports it while maintaining a modest or zero water contact angle. A study on the self-cleaning properties of super-hydrophilic coatings found that they are 92% more effective than plain glass [25,26]. Figures (2.1) and (2.2) demonstrate the surfaces that are both extremely hydrophobic and hydrophilic, respectively.

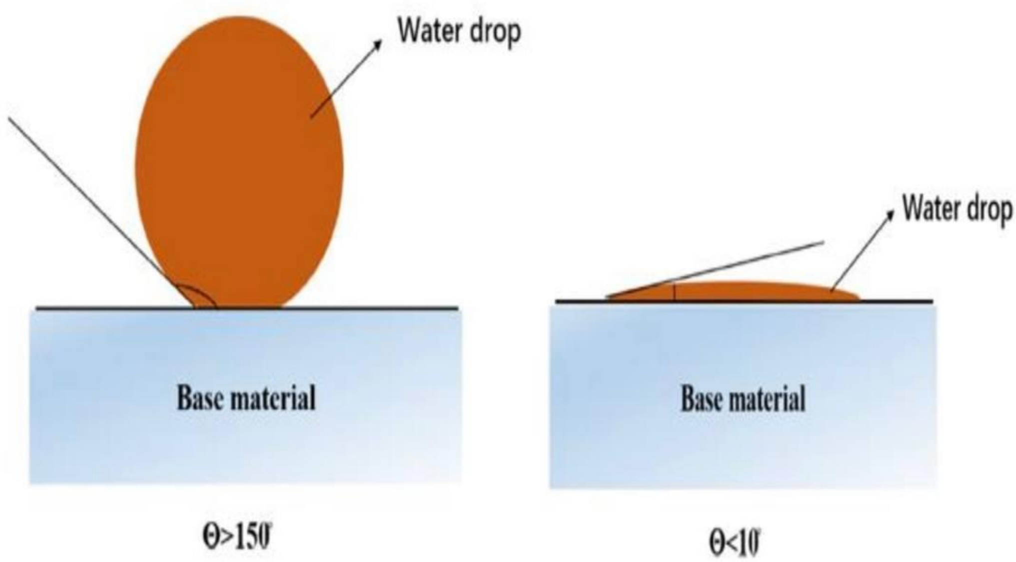

Figure 2.1: Super-hydrophobic, Super- hydrophilic surfaces [25]

Figure 2.2: Water droplets flowing down the superhydrophobic surface carrying dust particles [26].

C. S. Thompson et al. (2013) [27] Experimentally fabricated an optically transparent and anti-reflective, superhydrophobic self-cleaning coatings on glass substrates and used it on a PV panel surface. The 300 nm thick nanoflakes like interconnected network of coatings with 38% of porosity enabled the coating to acquire the competitive properties of super hydrophobicity with static water contact angle exceeded 160° and average transmittance level of 95%. Further, the prepared coating with average optical transmittance and self-cleaning superhydrophobic nature recovered the efficiency of the dust contaminated solar cell by more than 90% after being cleaned with water. These results suggested that the fabricated coating will be effectively used for self-cleaning solar panel cover glass applications. The uncoated glass substrate and aluminium oxide coated superhydrophobic glass substrate recovered the efficiency of saw dust contaminated solar panel by 67% and 91%, respectively, thereby enabling the fabricated superhydrophobic glass substrate to be effectively useful for self–cleaning cover glass applications.

Pedrazzi S. et.al. (2018) [28] Presented an experiment to study the influence of an anti-fouling nano-coating on the electrical energy produced by a string of photovoltaic modules. The coating effect was evaluated comparing the energy produced by two strings of the same PV power plant: one of them was cleaned and the other was cleaned and treated with the coating before the monitoring campaign. The PV plant was located in Modena, north of Italy. A first monitoring campaign of nine days after the treatment showed that the treatment increases the energy production on the PV arrays by about 1.82%. Results indicated that the increase is higher during sunny days with respect to cloudy days. A second monitoring campaign of the same length, but five months later, showed that the energy gain decreases from 1.82% to 0.69% due to the aging of the coating, which is guaranteed for one year by the manufacturer. A technical-economic analysis demonstrated that at the moment the yearly economic gain is 0.43 € per square meter of panel.

Thompson C.S et al. (2013) [29] Demonstrated a simple silica nanoparticle film that exhibits excellent self-cleaning and antifogging properties due to the superhydrophilicity of the coating. The coated surface was found to remove twice the amount of contaminant particles than bare glass under light wetting conditions. The coating was optimized for an average increase in transmittance of 5.4% over the wavelength range of 550–1100 nm on soda-lime glass substrates. This results in a 4.3% increase of the solar transmittance between 350 and 1100 nm.

Pan et al. (2019) [30] Conducted several tests to see how anti-dust coating and deposition technologies would fare on a solar cell's top glass surface. In order to make a comparison, they employed these four distinct glasses: "glass A (pure glass), glass B (silica gel), glass C (ethanol with SiO2), and glass D. (silica gel with SiO2)". Experimentation was carried out in an enclosed space for one hour with a tilt angle of 300. (time for exposure to dust).The results demonstrate that dust deposition was 51.4%, 38.6%, and 36.1% higher in samples B, C, and D than in naked glass sample A. As a result, following deposition, sample D has greater transmittance and reduced power losses.

Mishra and Bhatt (2019) [31]. Prepared and studied four coating solutions by varying compositions of Hexamethyldisilazane (HMDS) and polymethylmethacylate (PMMA) prepared by using tetraethylorthosilicate (TEOS) nanosilica sol. These solutions were coated on glass slides by spin coating methods and etched at high temperature. All the coatings were studied for its different properties like water repellence, anti-dust, transparency and contact angle measurements. Stability of coating was also studied with respect to temperature, external environment and pH. It was found that Super hydrophobic surface has high water contact angle of greater than 150^o which is a most important property of the surface with good water repellence and is mainly used to prevent a property of the substrate from the environmental factors like icing, dust, etc by coating. The results of the different coatings were observed and compared with each other. All the coatings show worthy results, out of which HT21 is finest in all aspects. Hence, they concluded that these kinds of coating can be suitable for solar panels to prevent various weathering effect.

Al-Badra et al. (2020) [32] Experimentally investigated the influence of using a nano-coating for PV panels together with an automated mechanical vibrator on the electrical performance of the panel. The function of the vibrator was to shake the panel twice daily, such that the dust on the panel can fall off by gravity. Three PV panels are examined where the first panel is with no coatings or vibration and is used as a reference for comparison, the second panel is coated with a nano-coating, while the third panel is coated with a nano-coating and shaken using a mechanical vibrator. It has been found that the accumulation of dust on the surface of solar panels is gradual and increases with time, especially in dry and desert regions, such as Egypt. The results showed that the average electrical efficiency of the PV panels with coating and mechanical vibrator has decreased by 12.94% during six weeks of operation, whereas the efficiency of the PV panel with coating dropped by 24.46%. However, the reference panel had a drop in efficiency of 33%. Dust mitigation using coatings is an effective technique in cleaning solar panels, and its performance can be improved if a vibration system is applied.

Zhao and Lu (2021) [35] Studied experimentally the self-cleaning performance of the super-hydrophilic coating on dust deposition of solar cells. Dust particles were first dryly deposited on the glass sample with and without a super-hydrophilic coating and then the water spraying was conducted to remove the deposited dust particles. It was found that when the water spraying was conducted, the dust deposition mass for bare and coated glass samples were both reduced obviously with the increased time of water spraying. The dust deposition mass on the coated glass sample was significantly lower compared with the bare glass sample. The self-cleaning efficiency of super-hydrophilic coating can reach more than 92%, compared with the bare glass cases. The results also showed that spectral transmittance for all the coated cases is significantly higher than that for all the bare cases. The maximum transmittance improvement can reach 26.5% when the deposition tilt angle was 30° and the spraying tilt angle was 60°.

Gwon et al. (2014) [36] Presented a facile method for producing superhydrophobic nanograss-coated (SNGC) glass surfaces that possess both reduced reflectivity and self-cleaning properties at the air/glass interface. The refractive index of a CaF2 nanograss (NG) layer on a glass substrate, deposited by glancing angle vapor deposition, was 1.04 at 500 nm, which was the second-lowest value ever reported so far. The fluorinated NG layer gave rise to a high-water contact angle (>150°) and very efficient cleaning out of dust with water drops. Using the dual functionalities of the SNGC glass, this study demonstrated super-hydrophobic nanograms-coated glass antireflective and super-hydrophobic photovoltaic cells with outstanding power conversion efficiency.

2.3.3 : Natural removal of dusts

Natural forces remove dust, including wind, gravity, and rainfall scouring. The following are some of the researches being presented on this method:

Gaier et al. (1990) [37] Conducted a study to apply a uniform dust layer on a PV surface to simulated Martian winds in an attempt to determine whether natural aeolian processes on Mars would sweep off the settled dust. Three different types of dust were used: an optical polishing powder, basaltic "trap rock", and iron (III) oxide crystals. The effects of wind velocity, angle of attack, height above the Martian surface, and surface coating material were investigated. It was found that arrays mounted with an angle of attack approaching 45° show the most efficient clearing. Although the angular dependence was not sharp, horizontally mounted arrays required significantly higher wind velocities to clear off the dust. It was shown that there seem to be two dust removal mechanisms at work. At low angles (22.5° and less) the dust particles were rolled off of the surface, and at high angles (45° and higher) the particles were aerodynamically lifted from the surface. The threshold value for the rolling mechanism appeared to be lower, but the aerodynamic lift mechanism appeared to be more effective.

2.3.4 : Self-cleaning and tracking solar photovoltaic panels

Bandam and Ashish (2016) [39] Studied enhancing the performance of the PV panels by implementing two algorithms, one for cleaning and one for tracking of the solar panel. Different cases were studied, CPWT (Cleaned panel with Tracking), CPWOT (Cleaned panel without Tracking) DPWT (Dusty panel with Tracking), DPWOT (Dusty panel without tracking). Results showed that the tracking was best suited then the fixed one, only when the dust on the panel is cleaned. When the tracking system was implemented without cleaning the panel, the efficiency was less than of the panel which is fixed and cleaned. Moreover, the efficiency of the panel was decreased by 50% even though it was tracking without cleaning. The power of the PV panel was as follows: 7.48W, 6.39W, 3.99W, and 2.819W for the cases, CPWT, CPWOT, DPWT, and DPWOT, respectively, as seen that the CPWT was the best case. The PV efficiency was calculated to be 7.13%, 6.08%, 3.80%, and 2.653% for the cases, CPWT, CPWOT, DPWT, and DPWOT, respectively. Finally, this system can extend to dual axis tracking and by that, more efficiency could be achieved.

2.3.5: Microcontroller based automatic cleaning of solar panels.

Halbavi et al. (2015) [43] Created an automatic cleaning system that detects dust on the solar panel and also automatically cleans the module in order to remove the dust on a regular basis. The DC gear motor is managed by an 8051 microprocessor in this automated system. A sensor (LDR) makes up this system. While a device with sliding brushes has been devised for cleaning PV modules. When compared to a PV module that has gathered dust, the proposed automatic-cleaning technique offers roughly 30% more energy output.

Zhen et al. (2016) [44] Created a robot that cleans solar panels to address the issue of dusting, and a type of automatic control system that the robot uses is also suggested and researched. The drive units, sensor units, information processing units, controller, and other parts of the control system were all designed in accordance with the function of the necessity. Results showed that the use of a control system can aid in the swift completion of tasks such as cleaning different kinds of solar panels. The application of the control system can assist in realizing the automation and industrialisation of the solar panel cleaning process. The control system can promise to work continuously at high temperatures and can be employed for earthquake proof and seismic resistance.

2.4: Summary of Previously Studies

After looking over the majority of the research that has been done before on how temperature and reflection losses affect the performance of solar cells, the most successful, cost-efficient, and time-effective passive method was nano-coating thin film. Nano-coatings can reduce the solar cell's surface temperature or restrict sunlight reflection to boost efficiency and power production. This study's problem is picking a Nanomaterial (Titanium Dioxide doped with Polymer-Polyvinyl Alcohol) and making it into a temperature-regulating and reflection-preventing covering. The optimum concentration of titanium dioxide and polymer will also be important in this investigation since the varied nano-coating concentrations used to affect the coating's ability to decrease temperature and reflect light.

No	Author	Inverstigation Scope	Type of Study	Fielding
.1	Zhenehal (2016)	Created automatic cleaning system	Experimental	The device with sliding brushes has been devised for cleaning PV modles
.2	Call ebal (2008)	Prevented dust from stelling on the surface	Experimental	The Solar cell Performance inercased to go %
.3	Gaofaetal (2011)	The soler pancl will imparten charge	Experimental	This approach limitation of the PV system because of raim
.4	Gaievetal(1990)	Used natural vemoral dust	Experimental	Tilt augle Manipulayion saler cell PV pancl
.5	S.Kreuter	Wofer spray cianing system	Experimental	Reflective losses Might approach 30 %
.6	S.Nizetic at.al(2015)	Exploring the effect spray water	Experimental	Achive maximal total incvease 39 %
.7	Thompson at.al(2013)	The preperd Self cleaining	Experimental	The efficiency mor than 90 %
.8	Pedrazzi et.al(2018)	Used nartuval remoral olust	Experiment	Relective losses 15 %
.9	Banf am et.al (2016)	Mectanical removal dust	Experiment	Used tracting with cleaning
.10	Hal bavia at.al(2015)	Automtarc cleaning system	Experiment	This approach limition of PV
.11	Zhao et.al(2021)	Self-Cleaning performenee	Experiment	Solar cell performans lucrased to 10%
.12	Gwon(2014)	Super hydrophic zno	Experiment	Tracing system
.13	S.kreuter	Natural remove alust	Experiment	increaseefficeny
.14	Drob antu at.al(2013)	Self cleaning Methode	Experiment	Increased efficiency to 20%

Chapter Three
Experimental Work

3.1 Introduction

The present chapter is concerned with showing the experimental setup for the whole systems and cases that have been used regarding the cleaning of the PV panels using for methods. We will explain depositing the nanocomposite onto the solar cell's front side (glass) and the technology used to manufacture super-hydrophobic nano-zinc oxide (ZnO) nanoparticles. We have employed solar cells made of polycrystalline silicon. This research was conducted on the rooftop of a building in Najaf, Iraq, at (32.022°) N and (44.26°) E**,** where the hot seasons cause the efficiency of solar panels to diminish.

Using nanocomposite as a covering layer aimed to reduce dust buildup on the solar cell's windscreen, which blocks sunlight and degrades the cell's efficiency. Solar cell efficiency and output were therefore enhanced by the Nano coating's UV-blocking and anti-reflective properties. UV-Visible spectroscopy, reflected meters, film thickness measuring tools, and solar module analyzers study how the coating affects solar cell performance.

3.2 Working Principle

The main idea of the work is to clean the PV panel surface and hence increasing the output power as well as increasing the efficiency of the panel by reducing the dust on the surface. To implement that, we have brought three PV panels into the work, one of the panels has a natural kind of cleaning, the second PV will take a mechanical cleaning method corresponding to inserting nozzles on the top surface of the PV to spray water onto the surface, the third PV has the method of Self-cleaning which is called the Nano-coating technology in which we apply a thickness of

Nano-coating material called ZnO upon the surface, the last method of cleaning was the combination of the mechanical and self-clearing methods together, which we have applied it on the third PV after we complete taking the results from it. Water is used as the operating fluid. The system includes everything you need to spray water on the PV's front face, lowering the water's temperature in the process. The main component is the photovoltaic panel, supporting frame, water pump, nozzle water distributer, water tank.

3.3 The photovoltaic panel

The poly-crystalline solar panel, the type of panel employed in this investigation, is the heart of any photovoltaic system. The PV panel was installed in Najaf city / Iraq at a latitude [32.022°] N and longitude [44.26°] toward the south with an incline angle of 17°. And the panel specifications were as in table (4.1).

Table (3.1): The Properties of Polycrystalline Silicon Solar Cells .

No.	Item	Description
1	Type	Polycrystalline HL36P100
2	Size (mm)	62mm*92mm
3	Maximum power (Pmax)	135 W
4	The voltage at P max (Vmp)	20.5V
5	Current at Pmax (Imp)	6.7A
6	Open circuit voltage (VOC)	22.5V
7	Short circuit current (ISC)	7.28A
8	Standard test conditions	1000 W/m^2 , 25 ºC

3.4 The Steel frame

All the system pares are installed together on a steel structure made of 3mm thickness steel. Welded and painted with anti-corrosion paint for long life using. The frame was made to be with an angle of 17° as shown in figure (4.1) below.

Figure 3.1: Cleaning system supporting frame

3.5 The Water pump

The water pump is the central part that circulates the water through the cooling system. Also, it is the only part that consuming power in the entire system. It is well known that the primary purpose is to improve power production to provide more power. For that particular reason, the water pump should be selected carefully for providing the needed flow rate and with the exact pressure (head) yet consuming the minimum possible amount of power. Our water pump is a 12V Micro Diaphragm Pump with maximum flow rate of 4 LPM, and maximum pressure of 0.6MPa.

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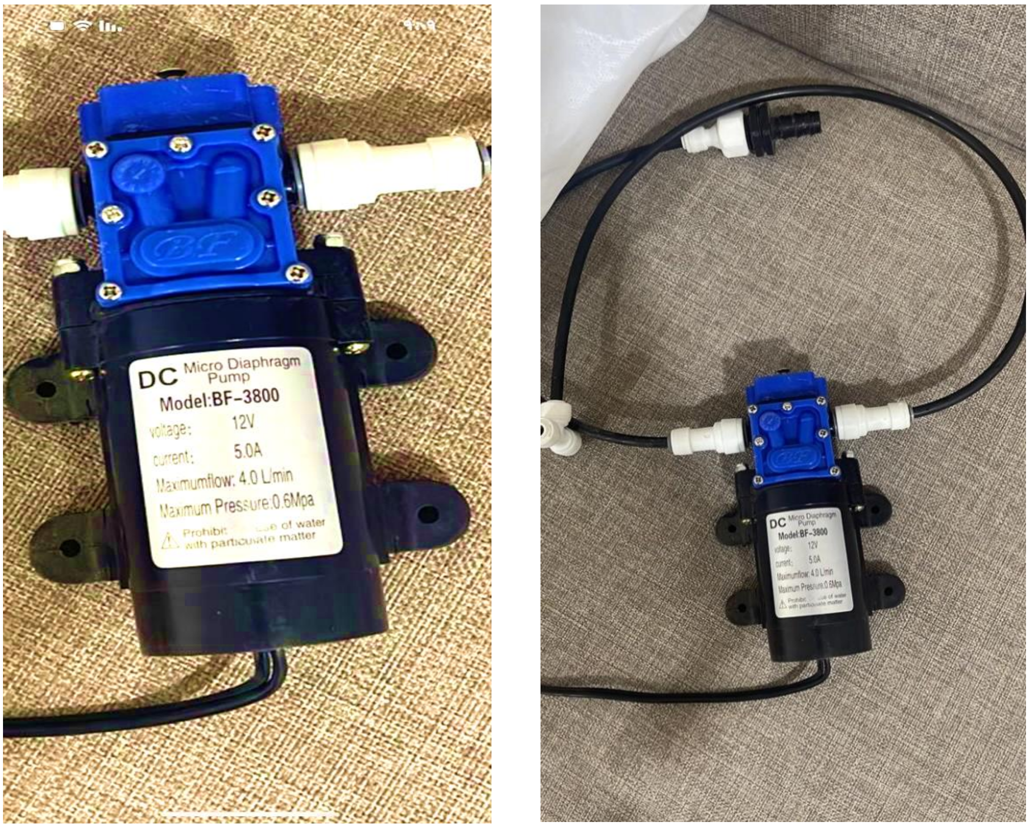


Figure 3.2: Water pump used to supply water to the nozzles.

3.6 The Water Nozzles

The water nozzles are used to spray water onto the surface of the PV panel. The nozzles that have been used were mounted on the top surface of the PV, three nozzles have been used along the width of the PV with equal distances. Two nozzle diameters (0.5, 1) mm were used to investigate the impact of each one the performance of the PV. The nozzles change the state of the liquid water into a spray state or vapor state which makes the water less consumed and also make the water being impacted on a large area. The nozzles were made from plastic, and the water being used is a distilled one.

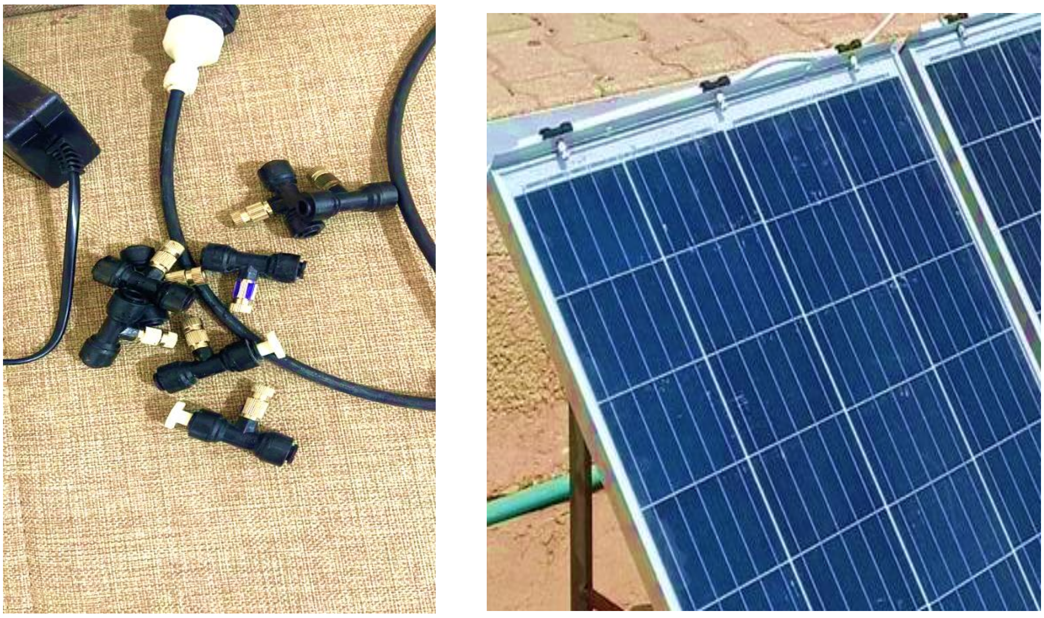


Figure 3.3: Water nozzles used to spray water on the PV.

3.7 Zinc Oxide (ZnO):

Zinc oxide (ZnO), a crucial metal oxide, is multifunctional due to its unique chemical and physical characteristics. It has high chemical stability, high electrochemical coupling coefficient, wide range of radiation absorption, non-toxicity, hardness, piezoelectric activity, and inexpensive cost. It appears as a white powder and is insoluble in water. [1]. Figure (4.4) depicts zinc oxide in (a) white powder and (b) mineral form (Zincite). The essential physical parameters of ZnO are listed in table (4.2).

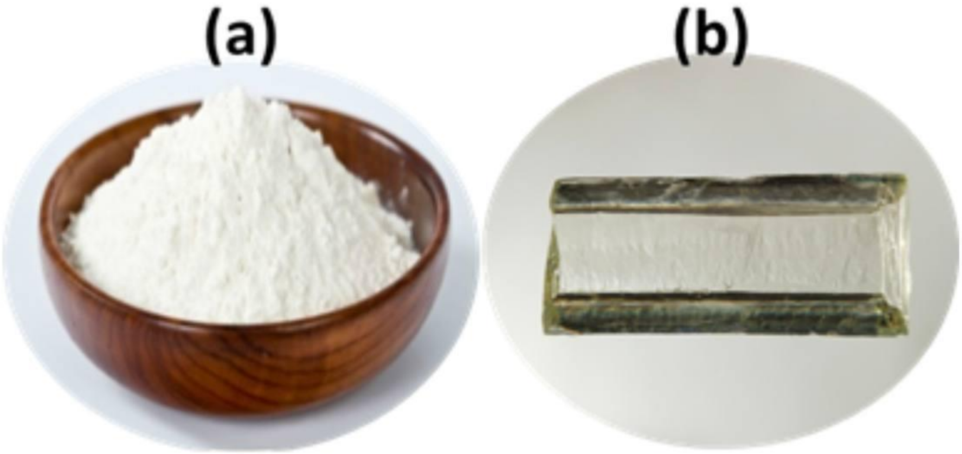


Figure 3.4: (a)Zinc oxide in the form of a white powder (b) Zincite in the form of a mineral

Table (3.2): Basic physical properties of ZnO [1].

Properties	Value
Chemical Formula	Zno
Molar mass	81.38g/mol
Density	5.606g/cm3
Appearance	White
Refractive Index (nD)	2.0041
Band Gap	3.3eV
Melting Point	1975 ºC
Flash Point	1436 ºC
Solubility in Water	0.0004 %(17.8 ºC)

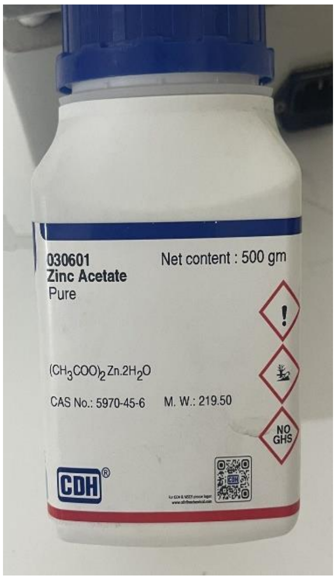
Table (3.3): Applications of zinc oxide in numerous industries [11][12]

Fields	Examples
Rubber	fillers, as an activator
Pharmaceutical and Cosmetic	dental pastes and component of creams as an absorber of UV radiation
Textile	absorber of UV radiation
Electronics	sensors, UV lasers and solar cell
Optical	light-emitting diodes, optically pumped lasers
Piezoelectric	bulk acoustic wave, filters, microelectro-mechanical systems (MEMS)
Nanoparticles	nanowire and nanorods devices, field effect transistor, photo diodes

3.8 The method of sol gel for the preparation of nano-zinc oxide:

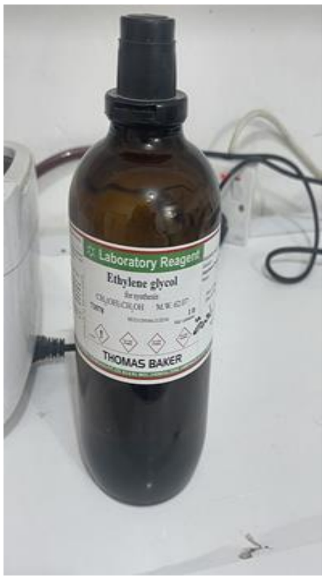
The sol-gel approach was employed to create nano zinc oxide by precipitating zinc salt (acetate zinc dihydrate) with sodium hydroxide and using ethylene glycol as a substance that improves dispersion and prevents precipitate accumulation. Dissolving 15 g of zinc in 250 ml of distilled water produced zinc acetate. A sodium hydroxide solution was made by dissolving 4 g in 250 ml distilled water. The solution was agitated for an hour at room temperature with 30 min in the presence of ethylene glycol. The base was added to the zinc salt solution drop by drop, with a flow rate of 10 ml per minute, through a burette with continuous stirring at room temperature to form a white cloudy suspension of zinc oxide, and the addition continued until the acidity function rose to 10 for the reaction to take place. The stirring was continued for 24 hours at room temperature until the crystal growth of the zinc oxide nanoparticles was terminated. The suspended solution was filtered through Whatman 1 filter paper and rinsed with distilled water to remove any excess base. This was done by measuring the acidity function of the filtrate until it was reduced to a value equal to 7. The white precipitate of nano-zinc oxide was dried at 100 for 6 hours in a drying oven and kept for characterization and later experiments.

Manufacture of hydrophobic zinc oxide: Hydrophobic zinc oxide was synthesized by coating it with oleic acid through mixing, stirring, and then washing it with ethanol. 1 gm of zinc oxide nanoparticles was weighed and added to 100 ml of ethanol with continuous stirring for one hour at room temperature to ensure its dispersion in ethanol. 1 gm. of oleic acid was dissolved in ethanol alcohol with a volume of 100 ml. It was added to the alcoholic solution of suspended zinc oxide by slow addition, and it lasted an hour with continuous stirring. The collected suspension was filtered with a Whatman 1 Win filter paper and washed with ethanol (5 times) to remove the oleic acid that did not cross over on the oxide surface. The residue was dried at 80°C for one hour, and the resulting material was a white hydrophobic powder. The powder is kept in a closed container to use in the process of spraying on the surface of the solar cell. The procedure depicted in the images below as shown in figure (3.5).



$(CH_3COO)_2Zn2H_2O$

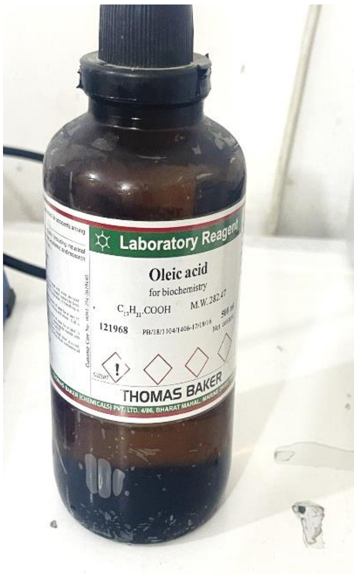
Distilled Water



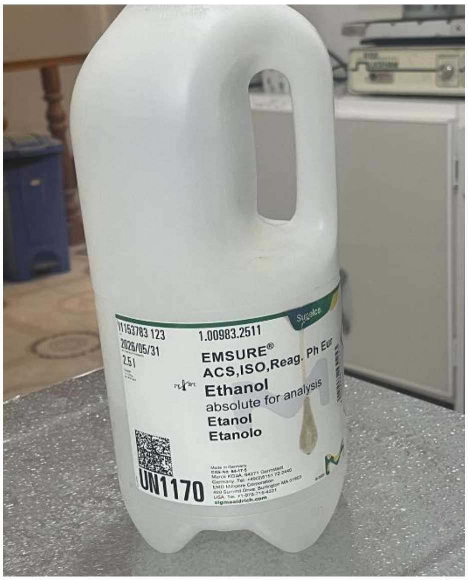
Ethylene Glycol

Electric Oven

Addition of NaOH

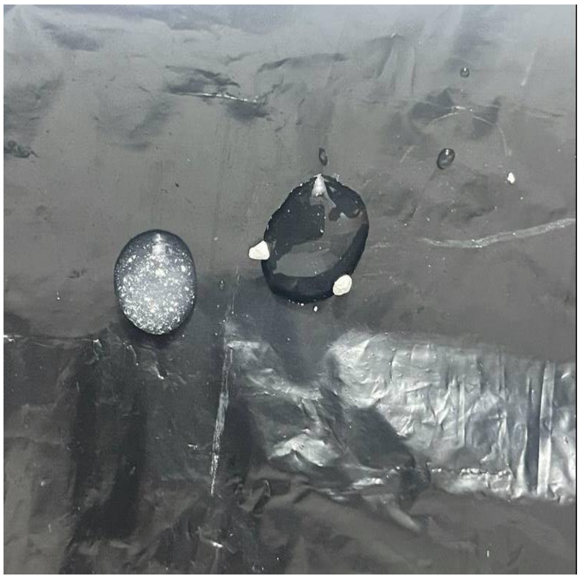


Oleic Acid



Ethanol

Blending Process



Addition of Olic acid

Figure 3.5: super hydrophobic ZnO prepared procedure

3.9 Coating procedures

The process through which dust accumulates on photovoltaic (PV) module glass is known as soiling. Dust particles are carried through the air in the form of aerosols, pollens, sand grains, and bird faeces, among other things [53]

If PV panels are not consistently cleaned, these particles will build on the glass and become difficult to remove. Numerous experiments have been done to see if a commercially available hydrophobic coating substance (nanotol) is effective in preventing soiling on PV modules. The following steps, seen in figure (4.6), make up the deposition procedure for this hydrophobic coating.

- Initially, the glass is cleaned with distilled water and detergents .
- Then, use a concentrated nanotol Primer solution to clean the glass.
- The glass should then be cleansed with a diluted solution of Nanotol Primer to create the optimal surface for adhesion of the hydrophobic coating. A microfiber weeper is then used to dry the glass.
- The glass is sprayed with nanotol Sealant solution and left to sit for 10 minutes before being polished with a microfiber weeper.
- Keep the glass that has been treated clean for 48 hours before putting it outside.

3.10 Coating Process

The spraying method of hydrophobic nano zinc oxide was used using a local atomizer and with a pressure of up to 3 bar. The spray coat was prepared from the modified oxide by dissolving 0.5 g of the modified oxide in a solution of 500 ml chloroform containing 0.5 g of polystyrene as an adhesive. This mixture was stirred for 24 hours to ensure homogeneity and dispersion in the solution.

The sprayable solution, 100 ml of the last solution, is added to the spray container. The pressure and the shape of the drops are adjusted to be as small as possible and not leave large drops, after which the coating is uniform and homogeneously using the switches and taps of the spray device. The cleaning was done by Solar cells with water and ethanol by wiping and drying, then cleaned by paper and then by air at a pressure of 3 bar. The cells were sprayed manually and in four layers of different directions in length and width to ensure the homogeneity of the coating and to be transparent and not result in a hazy coating. Spraying with zinc oxide solution with chloroform was applied using a hand razor at a spraying speed of one meter, a pressure of 3 bar, and the distance of the atomizer from the surface was 5 cm. The process was repeated four times to obtain four layers of nano-axis zinc oxide without the appearance of haze on the surface to produce a transparent surface that allows light to pass through. The surface was subjected to heating using hot air at a temperature of 70 °C for 3 minutes to fix the coating on the solar cell.

Figure 3.6: (a, b, and c) Illustration of coating process

3.11 Measurement Devices

3.11.1 Solar Module Analyzer

The purpose of this experiment was to compare the solar cell's electrical parameters (ISC, VOC, η, and I-V Curve) before and after the application of the nanocomposite coating. PROVA instruments-INC Company provides a Solar Module Analyzer -Type- PROVA-210A. The device included software to save and download data to a PC (laptop) for further examination.

General requirements:

- AC Adaptor: AC 110 V or 220 V input, DC 12V / 3 A output.
- Dimension:257mm×155mm×57mm(L×W×H).
- Weight: 1160 g (battery included).

Figure 3.7: Solar Module Analyzer.

Figure (3.7) depicts the I-V Characteristics Measurement equipment used for indoor experiments at the Engineering Technical College of Najaf. Before and after nanocomposite coating, the solar module analyzer-module PROVA-210A measured the solar cell's electrical characteristics (ISC, VOC, η, I-V Curve). The software data describing the electrical characteristics were transferred to a personal computer. The whole testing period was one hour, using a 1000 W/m^2 halogen light source positioned perpendicular to the surface of the solar cell.

To determine how much power a solar cell can generate, measure the voltage and current output at various loads (from no load to the maximum load). The solar cell was tested with an ammeter, voltmeter, and variable resistance to determine its electrical characteristics, as shown in figure (4.10). Before and after applying the Nano coating, the solar cell was tested in a solar spectrum simulator. In closed circuits, the solar cell load is connected in series, whereas in open circuits, it is connected in parallel.

Notes: At zero time, measurements were taken to see how the Nano-coating affected the electrical properties of the solar cell. Without covering the solar cells, the I-V curves for various coatings with varying concentrations of Nanocomposites were determined. After an hour, nano coating effects on solar cell surface temperature and electrical characteristics were measured.

3.11.2 Coating Thickness Gauge

Nanocomposite Coating thickness was determined using the TT-260 as shown in figure (4.8). When the coating is contacted, a closed magnetic circuit is created between the probe and the magnetic metal substrate. This closed magnetic circuit's magnetic resistance fluctuates because the coating is non-magnetic. The fluctuation in magnetic resistance may be used to determine the thickness of the coating. Before Commencement, the equipment is calibrated to measure the thickness of the coating. By comparing readings collected before and after the coating process, we were able to calculate the coating's thickness. Many readings from various points on the solar cell's surface are collected to achieve a more precise thickness, and the average readings are obtained (1.156 μm). Appendix C has shown more details.

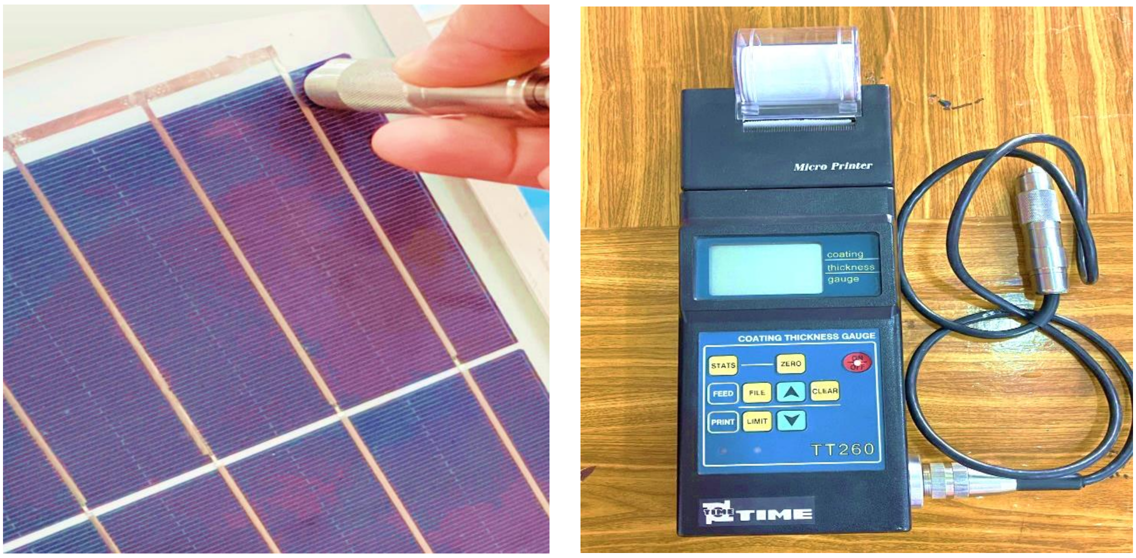


Figure 3.8: Coating Thickness Gauge.

3.11.3 Solar Power Meter

A solar power meter or (Pyrometer). A device that measures how much light gets to the solar cell. By altering the distance between the halogen light source and the solar cell, this thesis was able to keep the radiant flux at 1000 W/m^2. The Engineering Technical College of Najaf conducted experiments indoors with steady solar exposure. Figure (4.9) depicts a solar power meter (Pyrometer). Light intensity must be measured and recorded when it is completely dark (0 W/m2) as part of the calibration procedure before use. Different measurements were made to establish the correct distance between the surface of the solar cells and the halogen light source, which resulted in light intensity of 1000 W/m^2. The gadget includes a sensor lens, control buttons, and an LCD monitor. Table (4.4) and Appendix D detail its characteristics and calibration.

Figure 3.9: Solar Power Meter.

Table (3.4): Solar Power Meter specification.

Specifications	Details
Type	Tenmars TM-207
Reading range	0-2000 W /m2
Accuracy	± 10 W/m2
Reading time	0.25 second

3.11.4 Ultraviolet-Visible Spectrometer (UV-Vis)

To explore the effects of light absorption, transmission, and reflection on a solar cell. Shimadzu 1800 UV-Visible Spectrometer (UV-Vis) was used. Producing light with wavelengths that match the incoming solar energy is the object's main purpose. Radiation intensity was measured both incidentally and transmitted, with the difference between the two used to calculate the amount of radiation absorbed. The same apparatus may also measure reflectance of light using the reflection measuring option. With a lens, one may determine how much light is being transmitted or reflected by calculating the difference between the amount of light being emitted and received. A UV-Vis spectrometer is seen in figure (4.10). In this study, we employed this apparatus to compare the efficiency of polycrystalline silicon solar cells coated with Nanocomposite to those without the coating. The examination was hosted by the Kufa University Engineering College.

General requirements:

- Wavelength range: 190 – 1100 nm
- Wavelength accuracy: ±0.3 nm (190 to 1100 nm)
- Wavelength repeatability: ±0.1 nm
- Dimensions (W x H x D): 450 x 270 x 490 mm

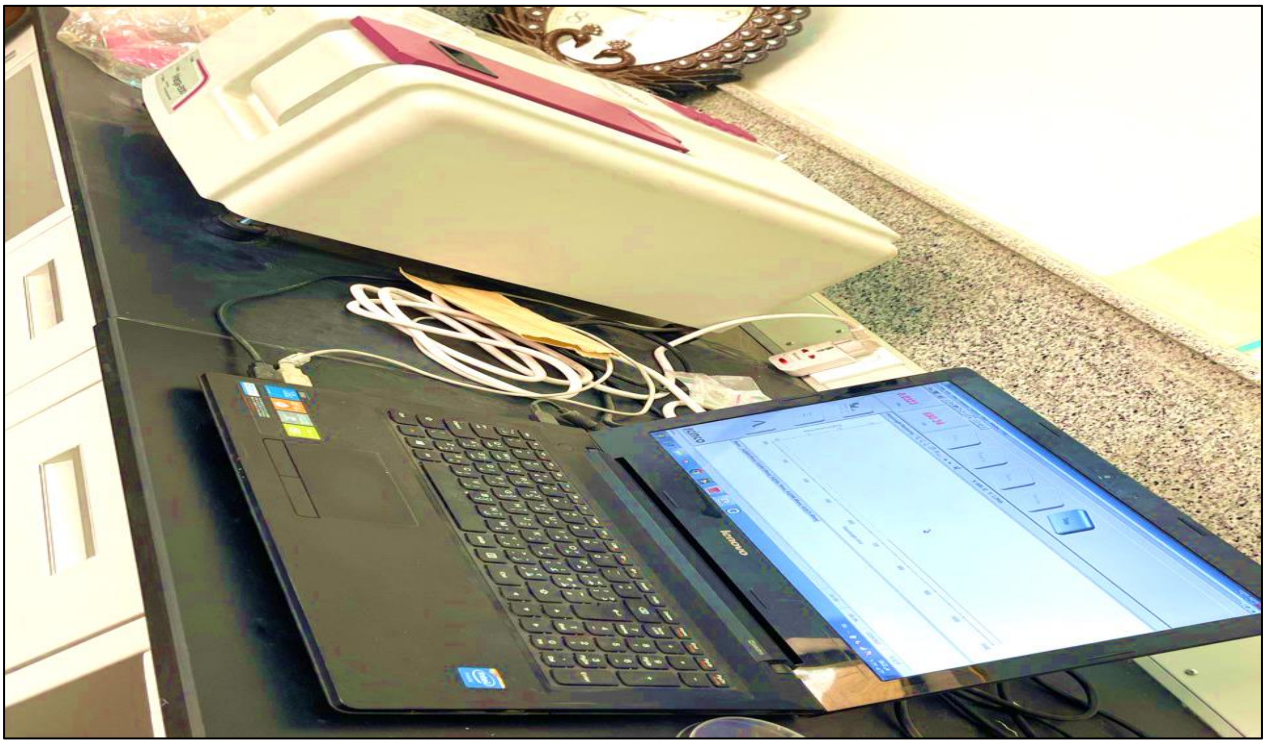


Figure 3.10: UV-Vis spectrometer.

3.11.5 Voltmeter

The maximum power produced by the photovoltaic panel is variable. It depends upon several parameters, such as the alignment angle, radiation intensity, the front glass visibility (dust and dirt), and the panel average temperature. Therefore, the exact instant produced power must be examined by testing the output voltage and current when subjected to an external variable load. A (CT- 9830) type voltmeter is connected in parallel to the load for testing the exact and instant voltage/ current for calculating the produced power with and without the cooling system operation, as shown in figure (4.11) below.

Figure 3.11: Voltmeter device.

3.12 Complete system diagram

The complete practical part of the system as well as the system's blueprints are shown in Figure 4.15 below. Where the three studied PV panels are seen in the diagram, water is pumped from the tank to the panel's nozzles where it is placed to clean the PV. The information and results are sent from the panels to the solar meter device and then to the laptop.

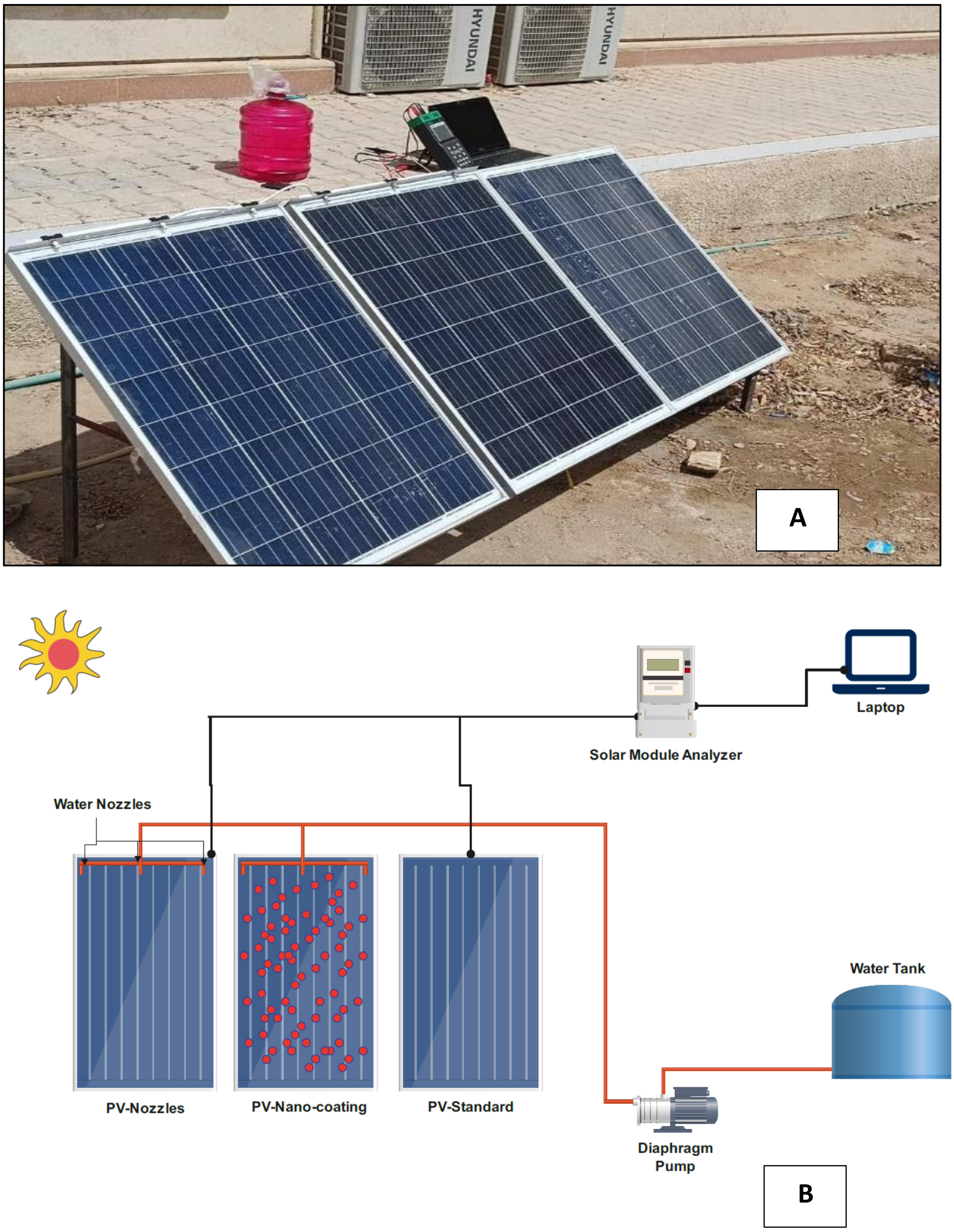


Figure 3.12: A: Experiment setup, B: Blueprint diagram

Chapter Four
Results and Discussion

4.1 Introduction

The performance and power output of polycrystalline silicon solar cells using coating by nanotechnology. Where nano zinc oxide was prepared and then modified to be super hydrophobic. Then, this nanocoat was spraying as superhydrophobic coat against dust and moisture. The major goals of this study were to evaluate the effect of superhydrophobic nano coat on solar cell performance in comparison without coat and coating in the presence of water cleaning. The expected result was to reduce reflection losses and indoor experiments were carried out at the Engineering Technical College of Najaf.

Taking the results and working were done for the month of July only and for four days in this month (1, 8, 17, and 25) every day was starting from 8:00 in the morning until 17:00 however only the optimum hour of 12:00 was considered in the results presentation.

4.2 Characterization of nano zinc oxide

4.2.1 X-ray Diffraction (XRD)

X-ray diffraction(XRD) is appropriate method to calculated the structure and crystalline size. Figure (5.1) show X-ray pattern for ZnO Through the XRD spectra examination for the most cases of the samples for ZnO film, three peaks were observed attributed to the diffraction from the surfaces (100), (002), and (101). These are actually corresponding to the positions $2\Theta = 32.90^{o}$, 34.25^{o}, and 36.05^{o}, respectively for pure ZnO film. The values are in good agreement with the standard values of the reported data (JCPDS), Card Number: 36-1451, having hexagonal wurtzite crystal structure, the prominent peaks presence demonstrations that the film has polycrystalline nature. The XRD diffractograms showed that the crystalline ZnO developed successfully in all samples, with no additional impurity peaks visible.

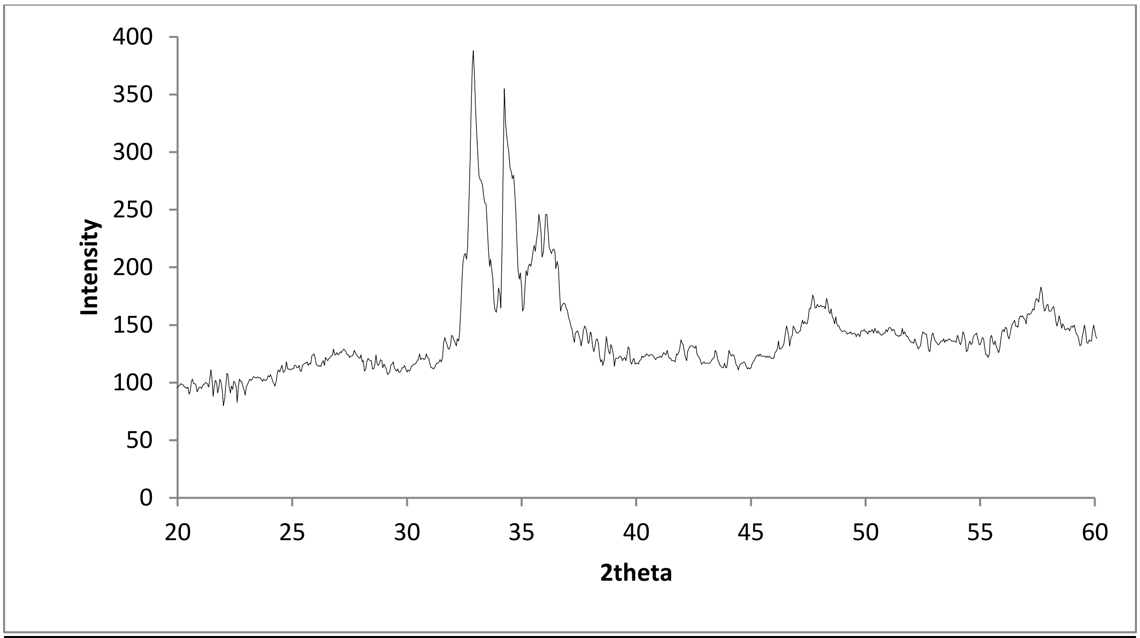


Figure 4.1: XRD for ZnO

4.2.2 Filed Emission Scanning Electron Microscope FESEM

The topography of the ZnO thin films deposited using spraying method. Figures (4.7- 4.9) present particles' morphology at a magnification of x200.0K and acceleration voltage of 15 kV for the prepared thin film. The image reveals that the formed nanoparticle's shape is approximately spherical and homogeneous in the range of (25.2 -83.22) nm

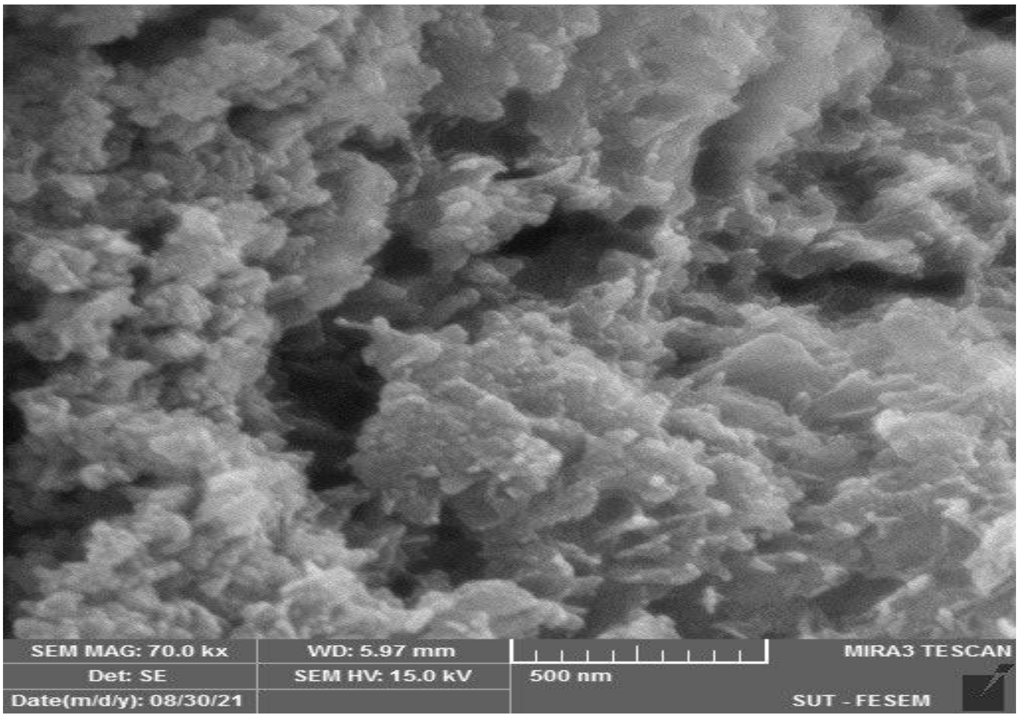


Figure 4.2: FE-SEM for ZnO thin film at 220 mJ

4.2.3 The amount of dust accumulated on a glass surface.

Glass surfaces were left and the weight of the dust on the glass surfaces was measured.

Table (4.1): Measuring the amount of dust.

No.	Months	Weight
1	17/3/2022	4.77 g/cm^2
2	17/4/2022	4.79 g/cm^2
3	17/5/2022	4.82 g/cm^2
4	17/6/2022	4.87 g/cm^2
5	17/7/2022	4.97 g/cm^2
6	17/8/2022	4.99 g/cm^2
7	17/9/2022	5.01 g/cm^2
8	17/10/2022	5.03 g/cm^2
9	17/11/2022	5.06 g/cm^2

4.2.4 Impact of Nanocomposite ZnO /PVA on Reflection Losses

Over 35% of incident light is reflected by the surface of silicon due to its high surface reflection coefficient. The PV panels' effectiveness is diminished due to this reflection. As a result, a solar cell with an anti-reflection coating may more effectively harvest energy from the sun. The anti-reflective coating increases the efficiency of solar cells by decreasing the number of photons reflected by the environment [38]. On the front side of the solar cell, a nano superhydrophobic coating that was made of ZnO and modified with oleic acid was applied in order to reduce the amount of power that was lost due to reflection. The best technique to assess the reduction in silicon solar cell reflection losses after applying the anti-reflection coating of superhydrophobic ZnO. The absorption was measured with a UV-Vis spectrophotometer with a reflection measuring option. The test was held at Kufa University's Engineering College and it is shown below in the figures 5.3 and 5.4.

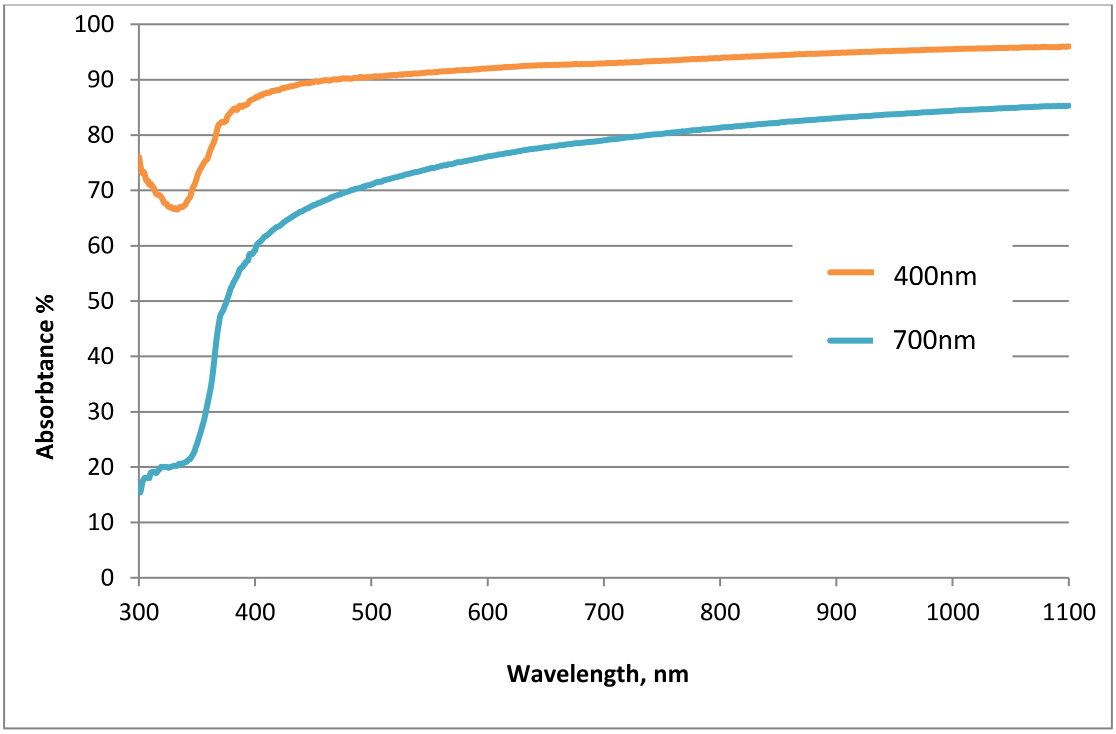


Fig: (4.3): UV-visible absorbance.

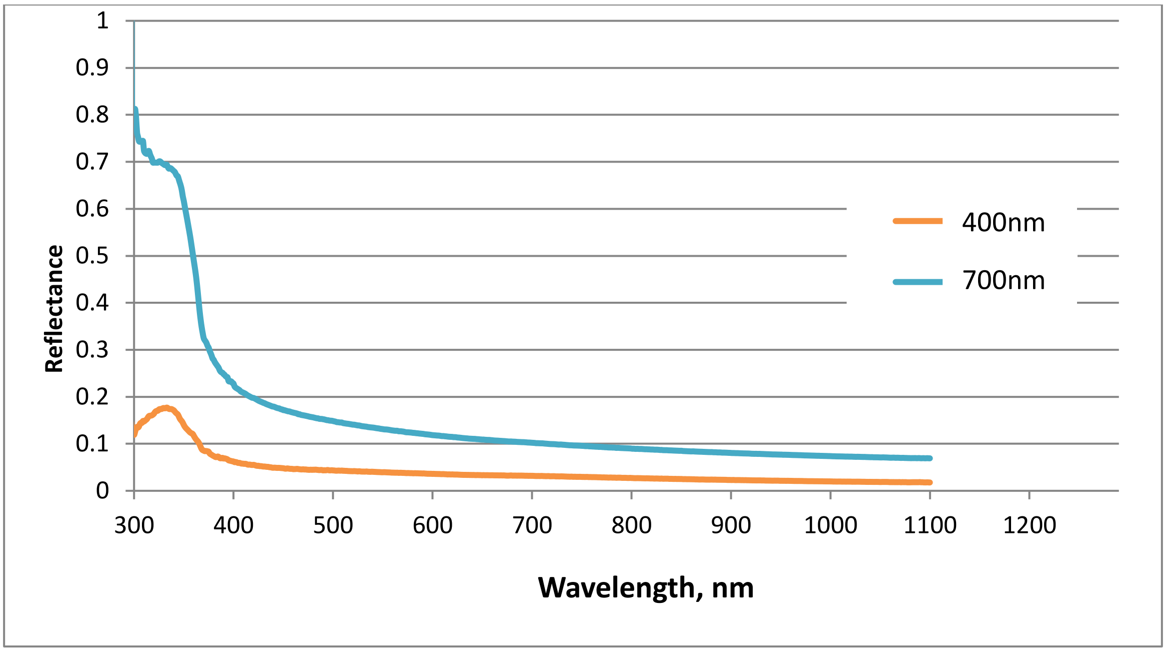


Fig: (4.4): UV-visible reflectance.

4.3. The effect of Ambient conditions

The solar radiation is the main parameter that controls the photovoltaic panels' production. Simultaneously, the rise of the fallen solar radiation increases the cell temperature and decreases its power conversion efficiency. The solar radiation varies along the daytime. This study recorded a maximum radiation value of 1040 W/m^2 at 12:00, and its value varies as shown in the figure. 5.5.

The ambient temperature and wind speed affect heat dissipation when the PV panel temperature rises owing to absorbed radiation and convection heat transfer with the surrounding air. As solar radiation, the ambient temperature varies from its minimum value in the early morning and its maximum at the day's peak. In this study, the ambient temperature and the wind speed changes throw the day (as shown in fig. 5.6 and 5.7), respectively.

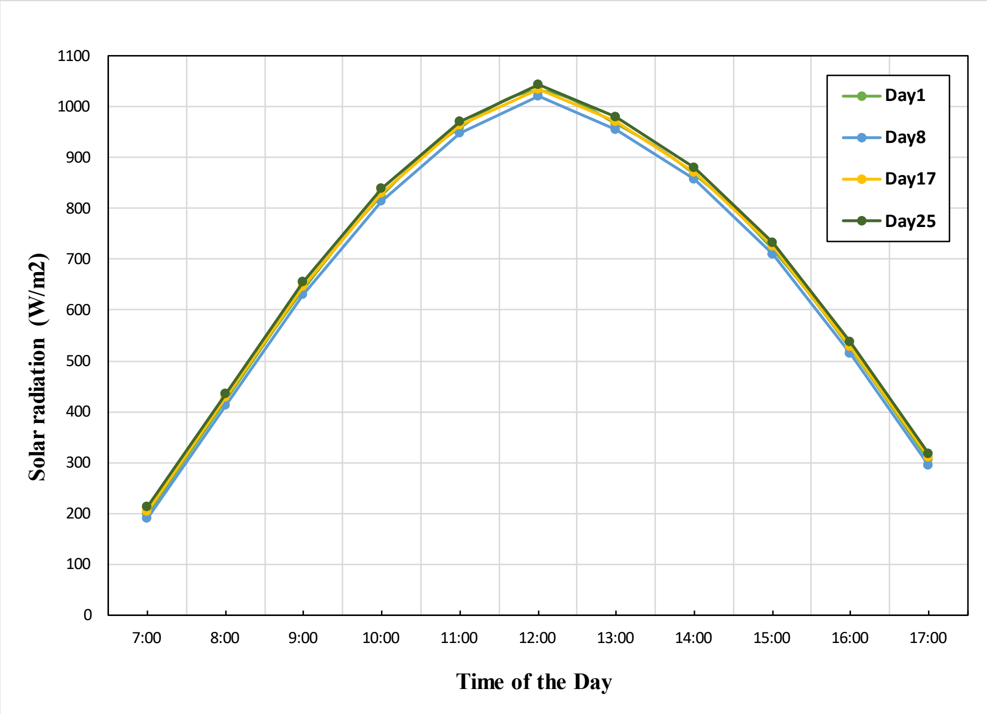


Figure 4.5: Hourly intensity of solar radiation

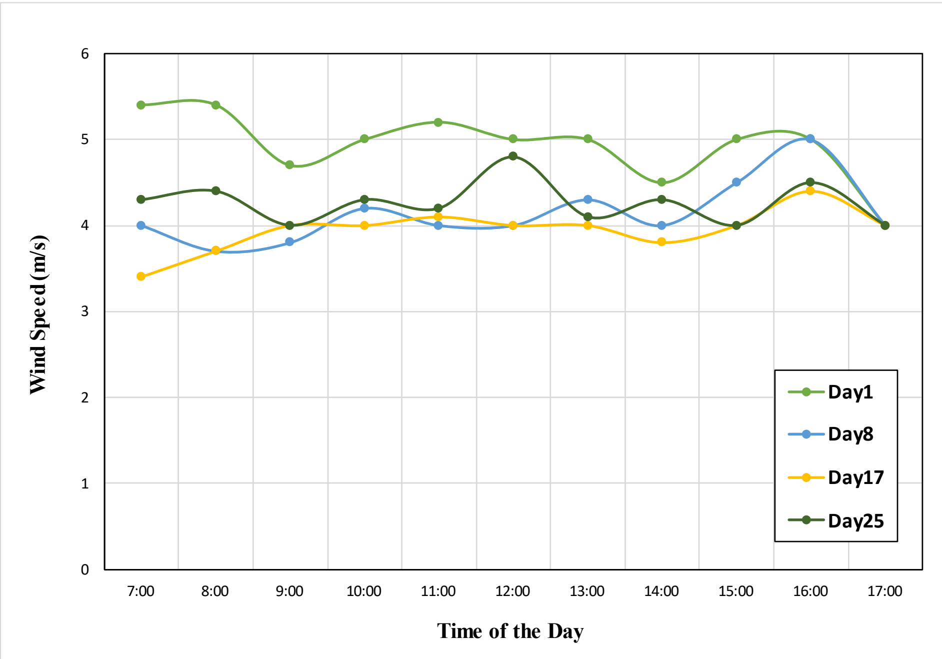


Figure 4.6: Hourly wind speed

4.4 Comparisons of the results for all cleaning cases

Comparisons of all the study's findings will be explained in this section, and the justification will take the shape of charts for the voltage, current, output power, and efficiency for each cleaning scenario and each day. In other words, the explanation will be split into four days, with each day containing all of the cleaning case outcomes. The integration of all these findings into a single form for four days and five cleaning cases will be shown by a chart that we will place at the end.

4.4.1 Comparison of the results for the 1st of July:

The findings as of July 1st are shown in figures (5.8 to 5.12). The voltage and current curves, as well as the power output, are all shown in one place in figure (5.8) for the first cleaning case, which is the standard case of cleaning. The figure makes it evident that the highest amount of electric power that can be generated by this typical solar panel is around 64 W. The highest voltage at this location will be roughly 14 V, and the maximum current will be 4.57 A, according to projections of this value onto the voltage and current curve in the same figure. The other figures that are (5.9-5.12), show the voltage-current-output power curves all in one figure for the Coating-only, Nozzle (0.5mm), Nozzle (1mm), and Coating-Nozzle (1mm) cases, respectively.

The voltage and power output of the solar panel are shown in figures (5.13-5.14) for all solar panel cleaning situations. The combined cleaning case with the 1 mm nozzles and coating, which has the highest power output of 80 W, is evident from the figure with a maximum voltage and current of 15 V and 5.3 A, respectively. This is because the coating layer inhibits the existence of dust deposits. In addition to cleaning with water using 1 mm nozzles, which lowers the panel temperature and raises voltage and productivity, this gives the PV a high capacity to absorb the maximum amount of solar radiation. The standard cooling case, on the other hand, featured the lowest voltage and a 64 W electrical output. The reason why the 1 mm Nozzle diameter was considered with the coating is that the 1 mm was of better performance in the cleaning than the 0.5 mm and that is shown below.

The maximum efficiency for all solar panel cleaning cases is shown in figure 5.15. The figure shows that the fourth cleaning scenario, which is the combination of nozzles and coating, had an efficiency value as high as 14.2% and that the regular cleaning scenario had an efficiency value as low as 11.4%.

Regarding the other cases we found that the maximum power and efficiency are as follows: The Coating-only case has got a maximum power and efficiency of 70W and 12%, respectively as shown in Fig. (5.9). While the Nozzle (0.5mm) and (1mm) achieved a maximum power and efficiency of 70W and 12%, 70W and 12%, respectively as shown in Fig. (5.10) & Fig. (5.11).

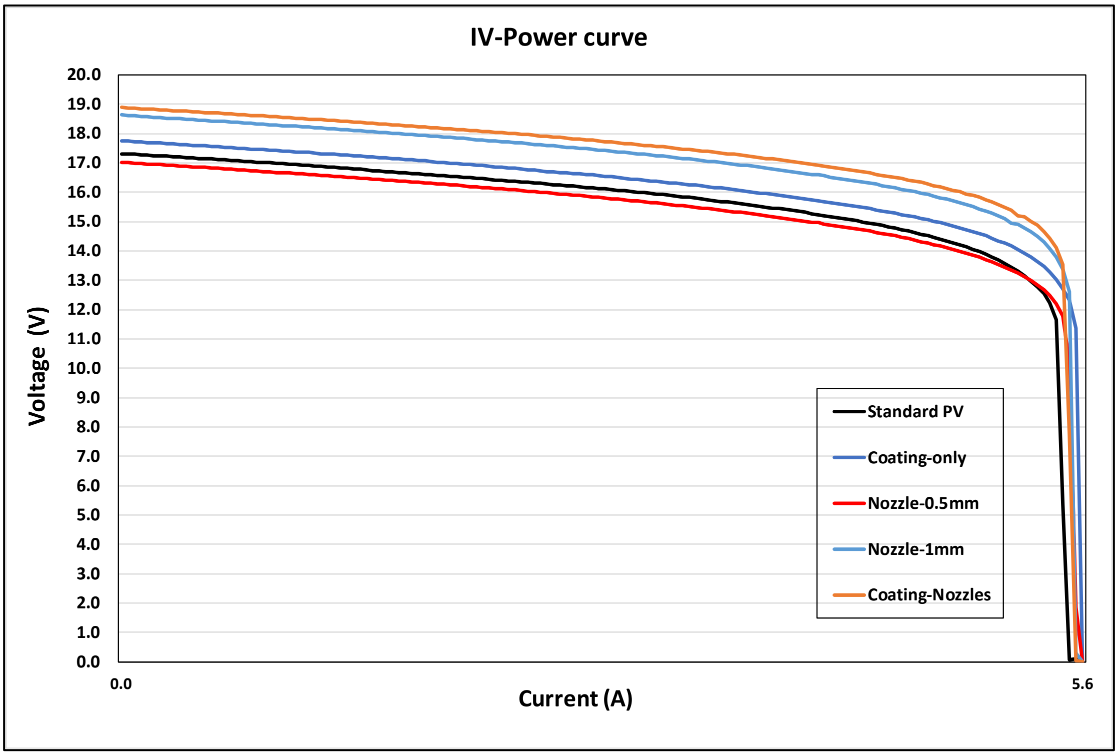


Figure 4.7: PV voltage for all cleaning cases-Day1

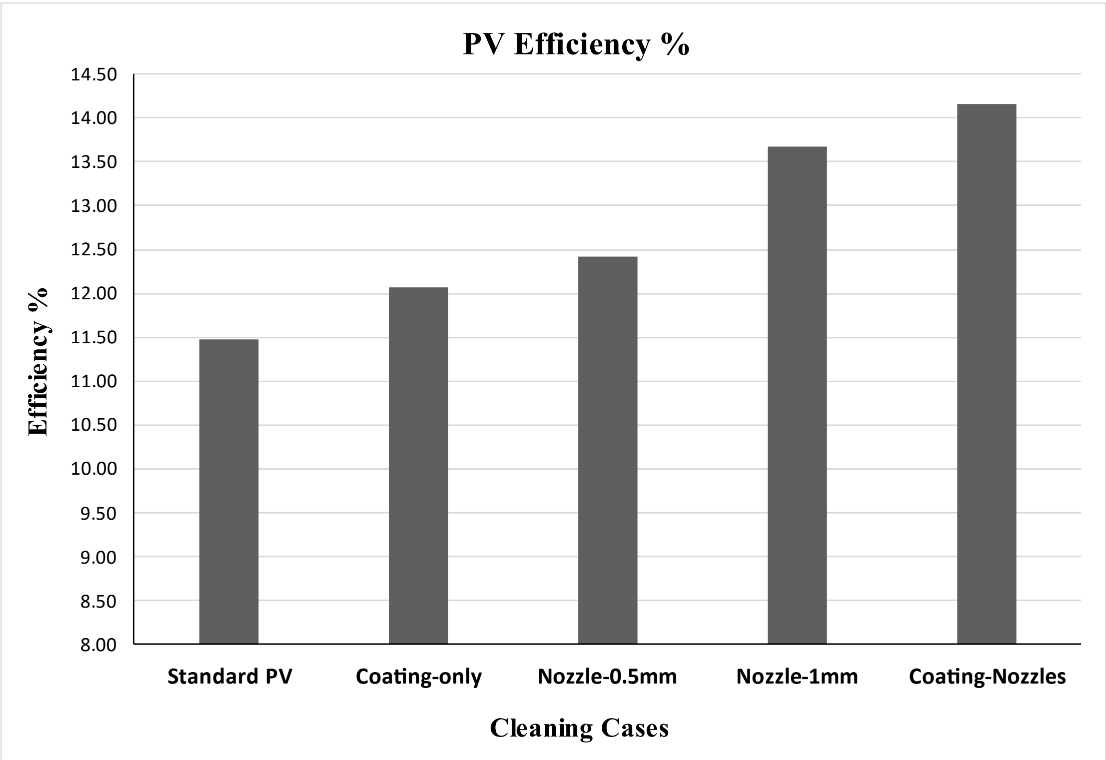


Figure 4.8: PV Efficiency for all cleaning cases-Day1

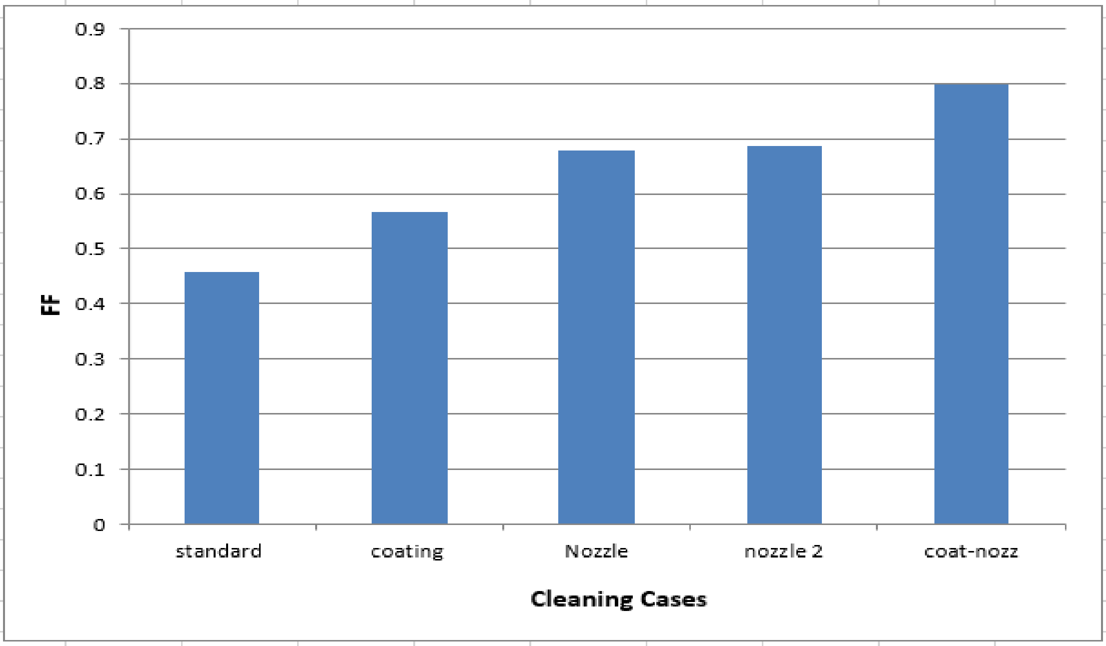


Figure 4.9 : Ful factor for all cleaning Day 1

4.4.2 Comparison of the results for the 8th of July:

The figures (5.16 to 5.20) present the results as of July 8th . Figure (5.16) depicts the voltage and current curves, as well as the power output, for the first cleaning instance, which is the standard case. The graph clearly shows that this conventional solar panel can create a maximum of about 62 W of electric power. Projections of this value onto the voltage and current curve in the same figure indicate that the highest voltage at this place will be approximately 13 V and the peak current will be 4.7 A. The voltage-current-output power curves for the Coating-only, Nozzle (0.5mm), Nozzle (1mm), and Coating-Nozzle (1mm) examples are shown in full in the other figures (5.17-5.20).

Figures 5.21 and 5.22 display the solar panel's voltage and power output for every solar panel cooling scenario. The image clearly shows the combined cooling case with the 1 mm nozzles and coating, which has the highest power output of 80 W with a maximum voltage and current of 15 V and 5.3 A, respectively. This is because the covering layer prevents dust deposits from forming. This gives the PV a high capacity to absorb the most solar energy in addition to cooling with water using 1 mm nozzles, which lowers the panel temperature and increases voltage and productivity. The lowest voltage and 62 W of electrical output were found in the conventional cooling case, though.

Figure 5.23 displays the greatest efficiency for all solar panel cleaning scenarios. According to the graph, the fourth cleaning scenario, which involves the use of coating and nozzles, had an efficiency value as high as 14.29% and the standard cleaning scenario as low as 11.01%.

The Coating-only case has got a maximum power and efficiency of 70W and 12%, respectively as shown in Fig. (5.17). While the Nozzle (0.5mm) and (1mm) achieved a maximum power and efficiency of 70W and 12%, 70W and 12%, respectively as shown in Fig. (5.18) &Fig. (5.19).

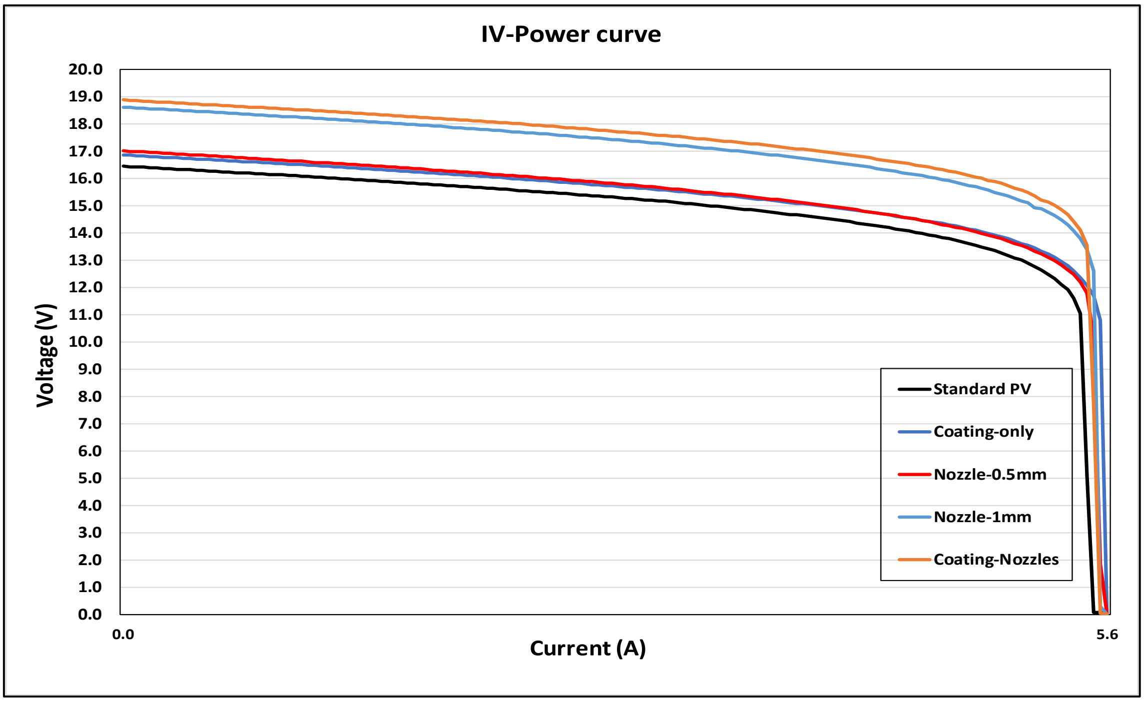


Figure 4.10: PV voltage for all cleaning cases-Day8

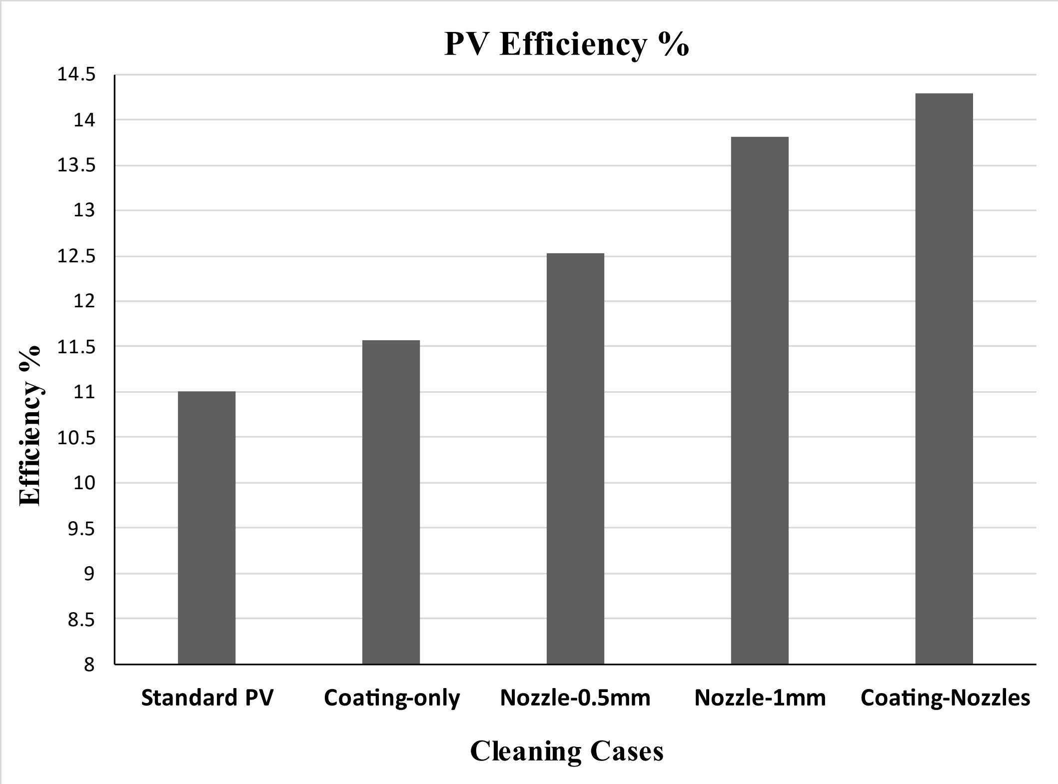


Figure 4.11: PV Efficiency for all cleaning cases-Day8

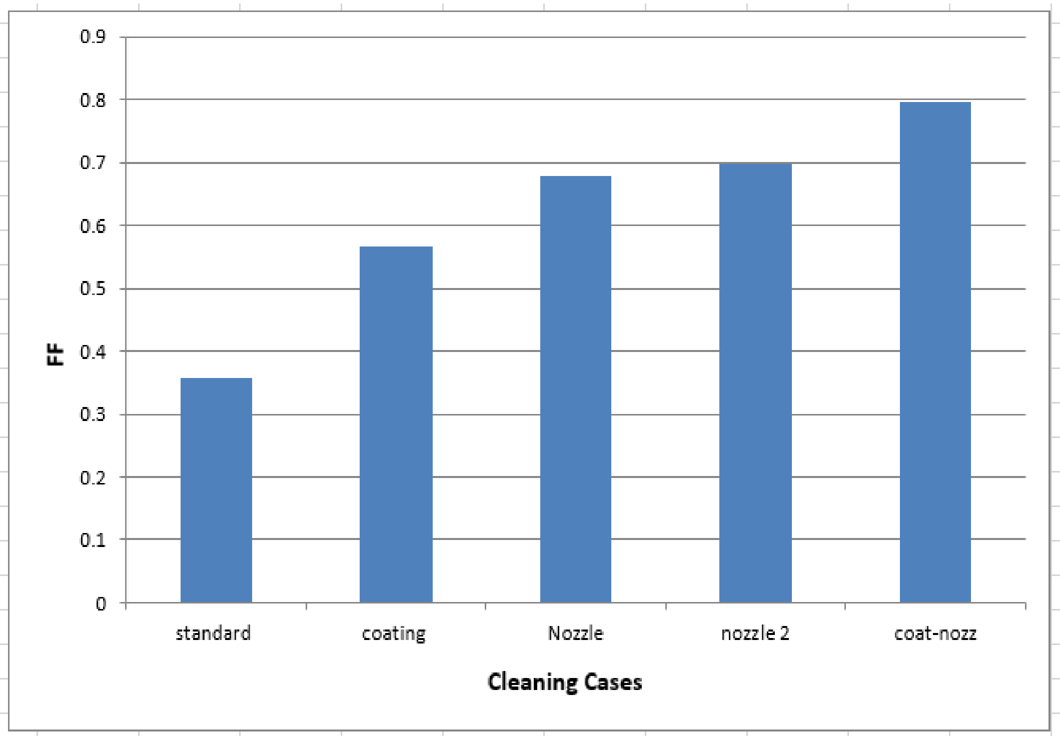


Figure 4.12 : Ful factor for all cleaning Day 2

4.4.3 Comparison of the results for the 17th of July:

Figures (5.24 to 5.28) depict the findings as of July 17th. Figure (5.24) depicts the voltage and current curves, as well as the power output, for the first cleaning instance, which is the standard case. The chart clearly shows that the maximum quantity of electric power that this average solar panel can create is roughly 58 W. According to projections of this number onto the voltage and current curves in the same figure, the highest voltage at this position will be around 12.4 V, and the maximum current will be 4.67 A. The additional figures (5.25-5.28) show the voltage-current-output power curves for the Coating-only, Nozzle (0.5mm), Nozzle (1mm), and Coating-Nozzle (1mm) cases all in one figure. Figures (5.29-5.30) illustrate the voltage and power output of the solar panel for all solar panel cooling scenarios. The graphic shows the combined cooling case with the 1 mm nozzles and coating, which has the highest power output of 80 W with a maximum voltage and current of 15 V and 5.3 A, respectively.

The conventional cooling case, on the other hand, had the lowest voltage and a maximum power output of 58 W. Figure 5.31 depicts the optimum efficiency for all solar panel cleaning instances. According to the graph, the fourth cleaning scenario, which is a mix of nozzles and coating, had an efficiency value of up to 14.08%, while the standard cleaning scenario had an efficiency value of just 10.30%.

The Coating-only case has got a maximum power and efficiency of 70W and 12%, respectively as shown in Fig. (5.25). While the Nozzle (0.5mm) and (1mm) achieved a maximum power and efficiency of 70W and 12%, 70W and 12%, respectively as shown in Fig. (5.26) &Fig. (5.27).

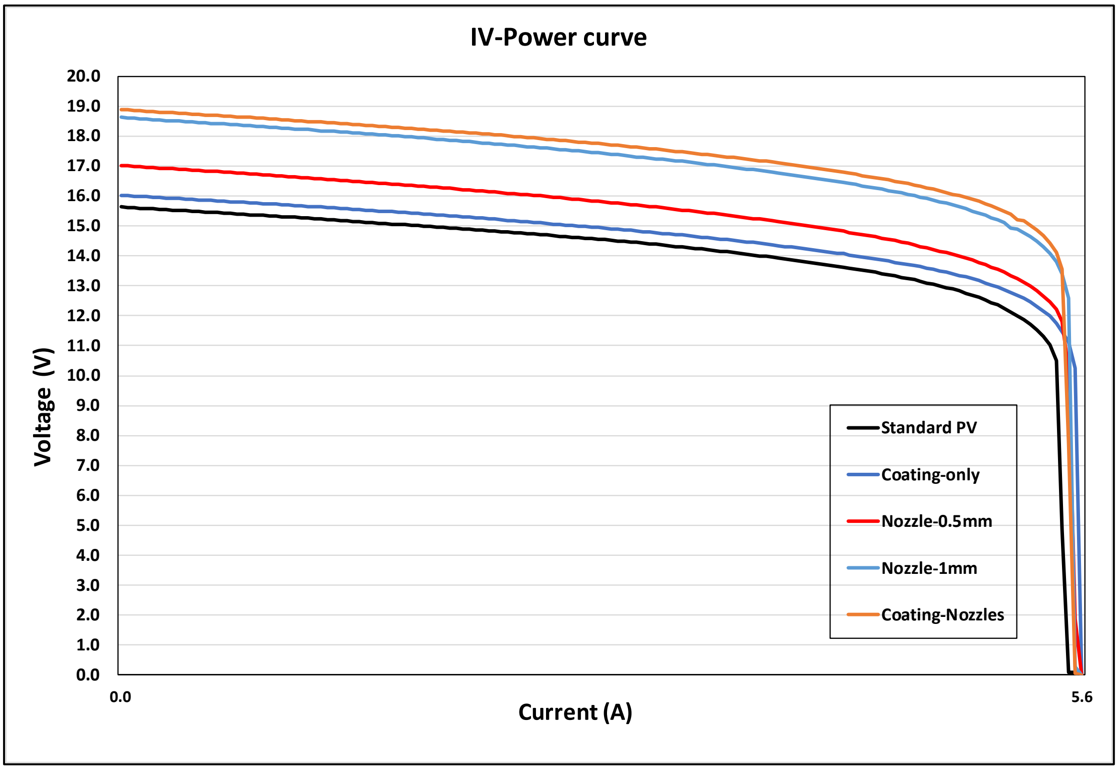


Figure 4.13: PV voltage for all cleaning cases-Day17

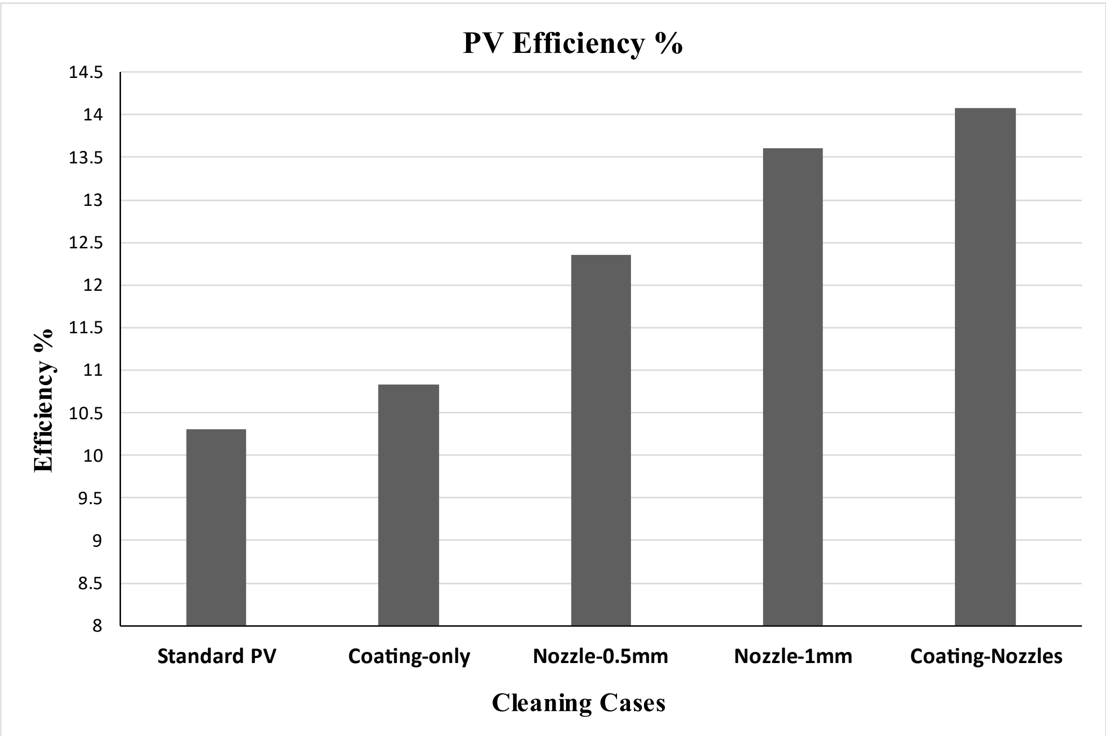


Figure 4.14: PV Efficiency for all cleaning cases-Day17

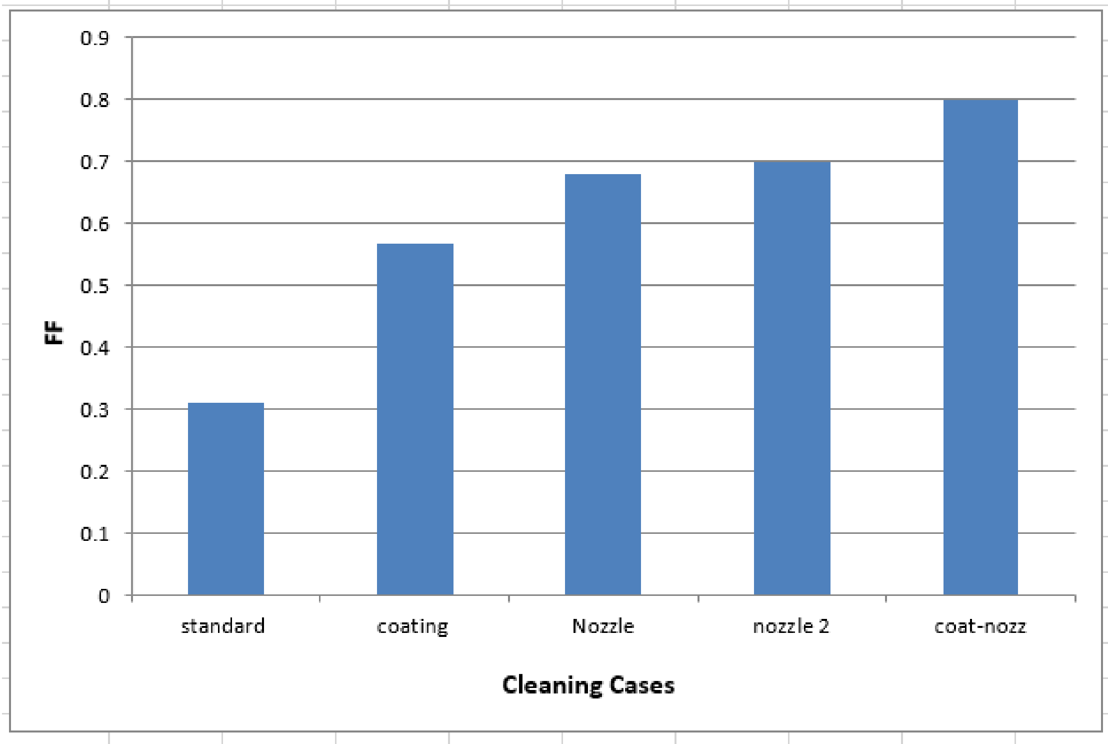


Figure 4.15 : Ful factor for all cleaning Day 3

4.4.4 Comparison of the results for the 25th of July:

In figures (5.32 to 5.36), the results as of July 25th are displayed. For the first cleaning scenario, which is the usual case, figure (5.32) displays the voltage and current curves as well as the power output in one location. The graph clearly shows that this common solar panel can produce up to 55.9 W of electricity as its maximum output. Projections of this value onto the voltage and current curve in the same figure give a maximum voltage at this position of around 11.75 V and a maximum current of approximately 4.75 A. The voltage-current-output power curves for the Coating-only, Nozzle (0.5mm), Nozzle (1mm), and Coating-Nozzle (1mm) examples are shown in full in the other figures (5.333-5.36). Figures 5.37 and 5.38 display the solar panel's voltage and power output for every solar panel cooling scenario. The image clearly shows the combined cooling case with the 1 mm nozzles and coating, which has the highest power output of 80 W with a maximum voltage and current of 15 V and 5.3 A, respectively.

The lowest voltage and 60 W of electrical output were found in the conventional cooling case, though. Figure 5.39 displays the greatest efficiency for all solar panel cleaning scenarios. According to the graph, the fourth cleaning scenario, which involves the use of coating and nozzles, had an efficiency value as high as 13.97% and the standard cleaning scenario as low as 9.7%.

The Coating-only case has got a maximum power and efficiency of 70W and 12%, respectively as shown in Fig. (5.33). While the Nozzle (0.5mm) and (1mm) achieved a maximum power and efficiency of 70W and 12%, 70W and 12%, respectively as shown in Fig.(5.34) & Fig. (5.35).

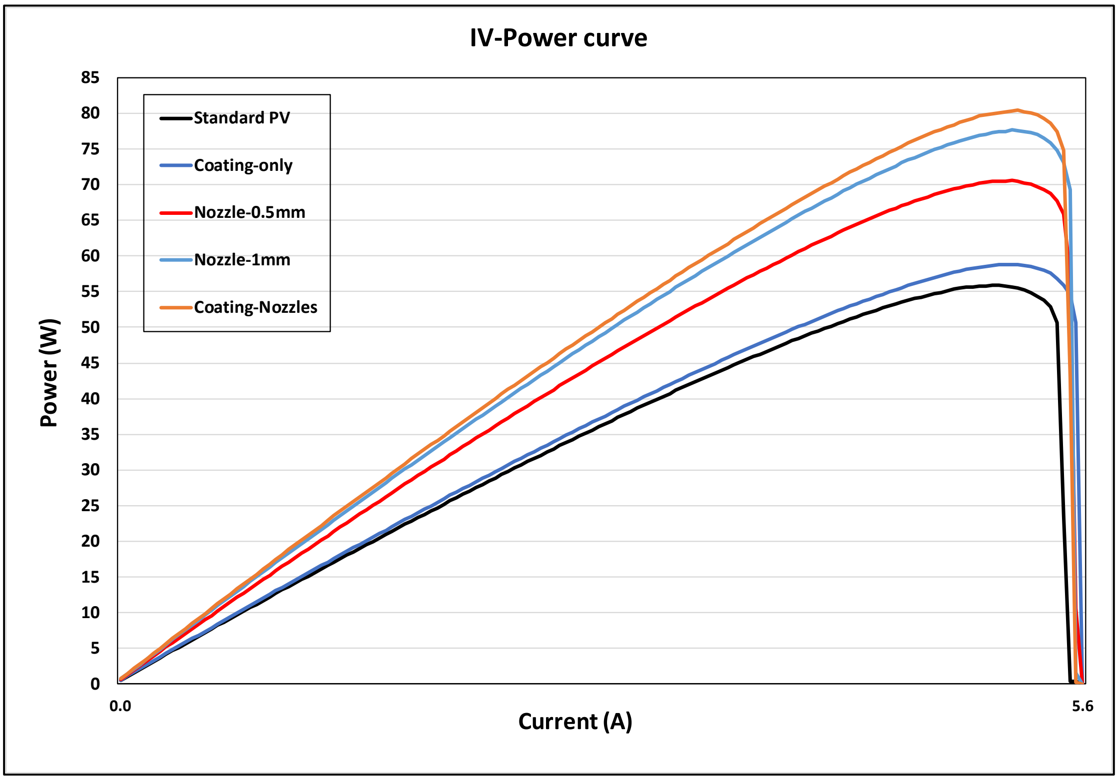


Figure 4.16: PV output power for all cleaning cases-Day25

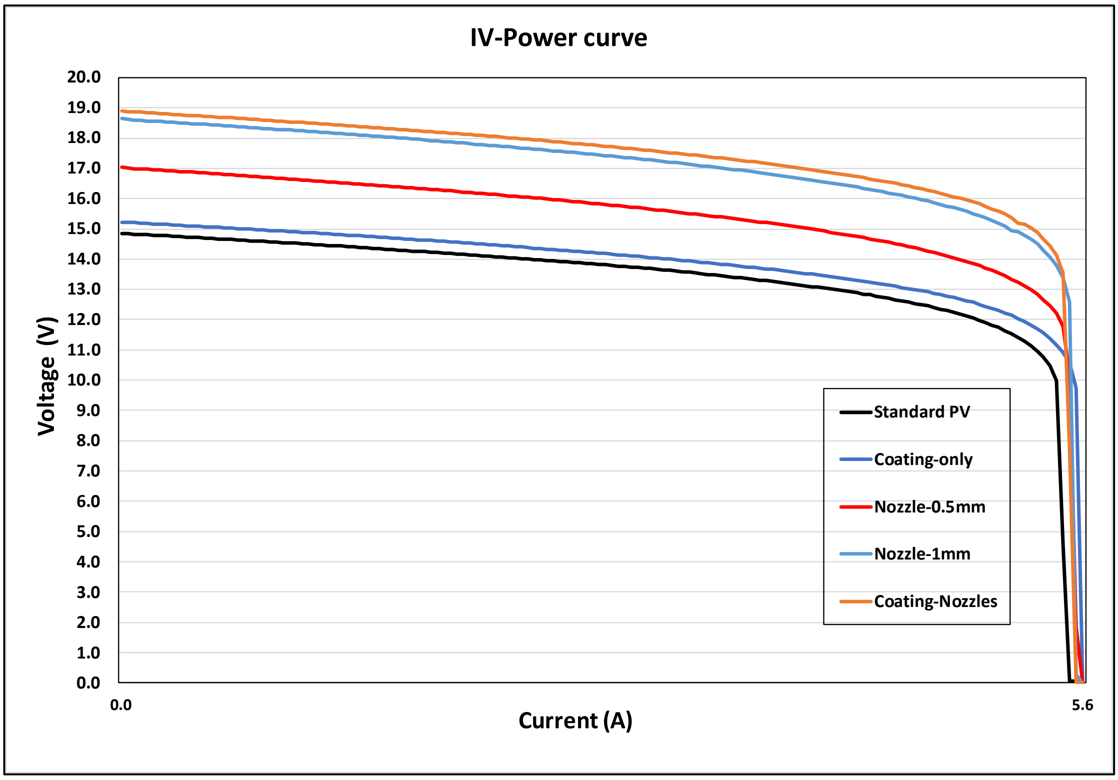


Figure 4.17: PV voltage for all cleaning cases-Day25

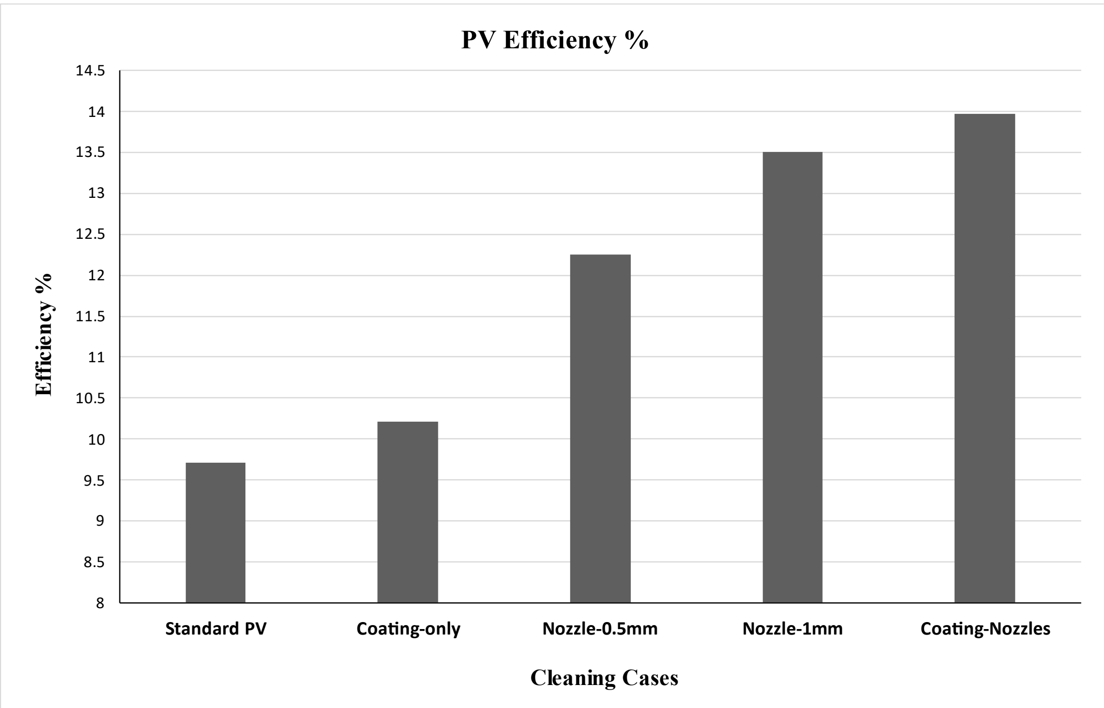


Figure 4.18: PV Efficiency for all cleaning cases-Day25

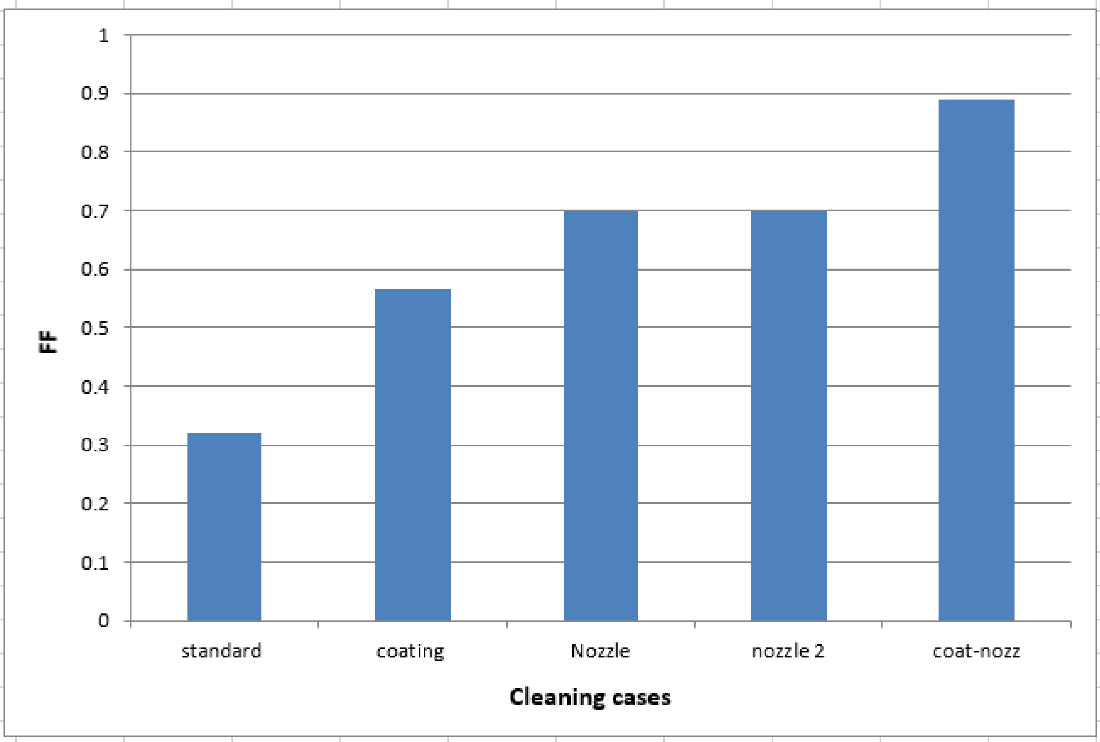


Figure 4.19 : Ful factor for all cleaning Day 4

4.5 Comparison of the results for all the studied cases:

The efficiency, produced power, and voltage final values for each solar panel cleaning case are shown in figures (5.40-5.42). It is obvious that panels that have a mixed cleaning process of water and coating always have the highest efficiency values. The same is true for the produced power and voltage. Additionally, it should be noted that while efficiency, power output, and voltage for the first and second cleaning scenarios decline over the course of the four study days, they remain nearly constant in the third and fourth cases. Below are the tables (5.2&5.3) which represent all the values for the power output and the PV efficiency for all the cases of cleaning.

Fig. (5.43) below shows the comparison of our present study of the Standard and Coating-Nozzle(1mm) cases with the results of the study conducted by the researcher Al-Badr [54] which shows a closer behavior to the researcher results.

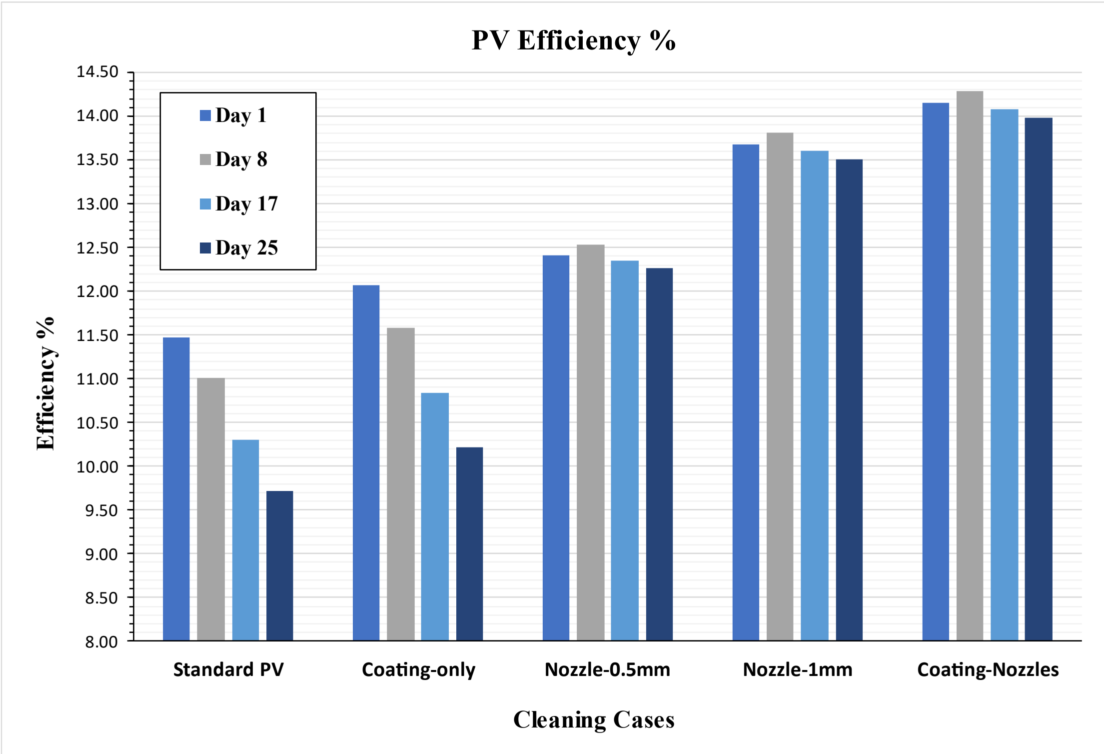


Figure 4.20: PV Efficiency for all days and cleaning cases

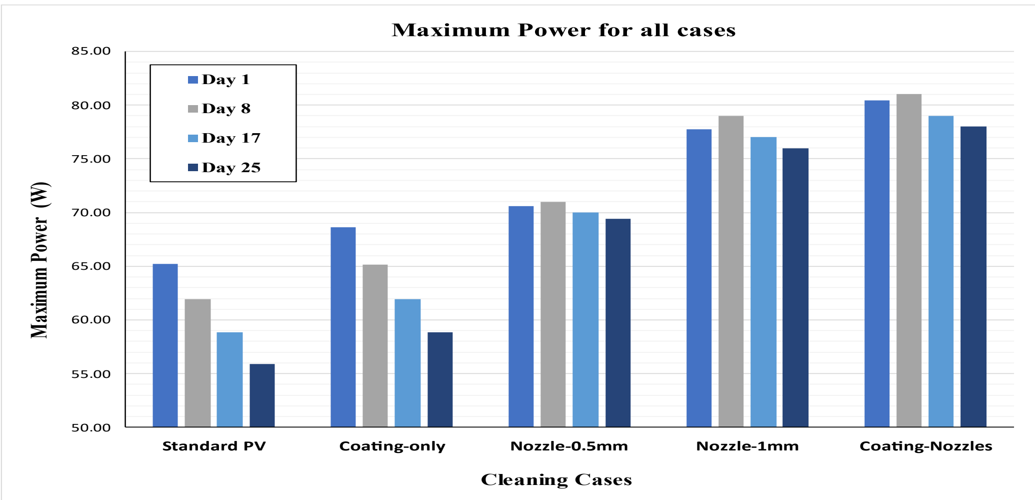


Figure 4.21: PV power output for all days and cleaning cases

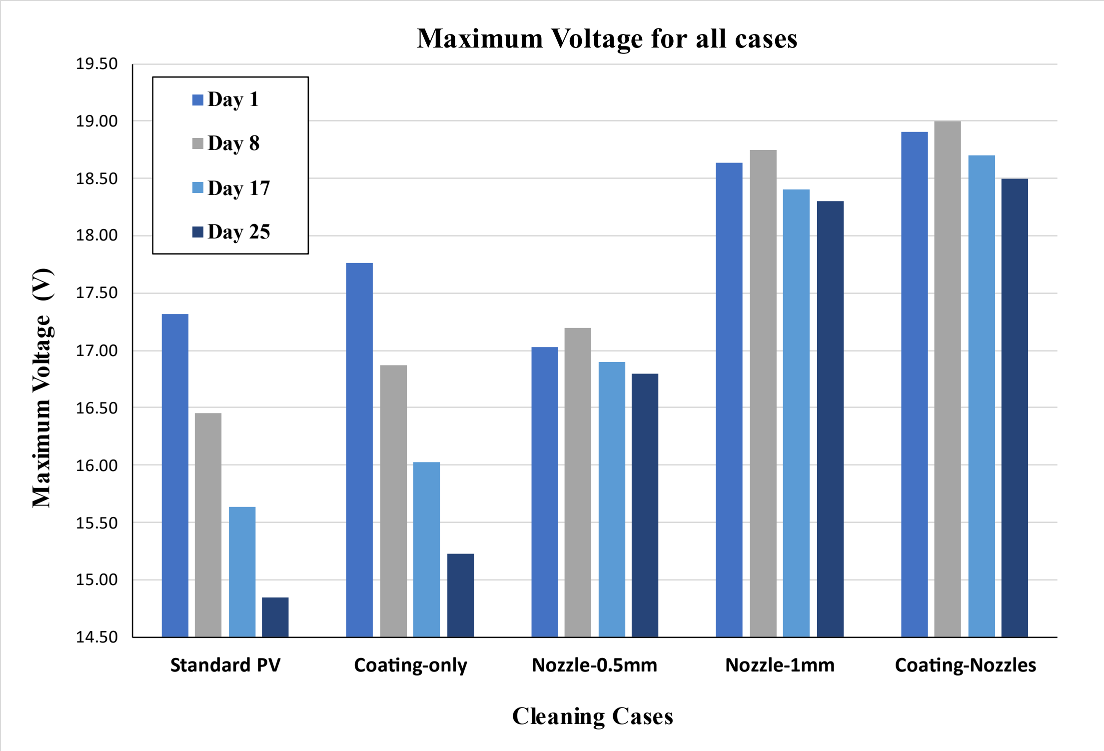


Figure 4.22: PV voltage for all days and cleaning cases

Table (4.2): Power output for all the cases of Day 1st of July

Days of study	Standard PV	Coating-only	Nozzle-0.5mm	Nozzle-1mm	Coating-Nozzles
Day 1	65.22	68.60	70.57	77.75	80.47
Day 8	61.96	65.17	71.00	79.00	81.00
Day 17	58.86	61.91	70.00	77.00	79.00
Day 25	55.92	58.82	69.40	76.00	78.00

Table (4.3): Electrical efficiency for all the cases of Day 1st of July

Days of study	Standard PV	Coating-only	Nozzle-0.5mm	Nozzle-1mm	Coating-Nozzles
Day 1	11.47	11.01	10.30	13.67	14.15
Day 8	11.01	11.58	12.53	13.81	14.29
Day 17	10.30	10.84	12.35	13.61	14.08
Day 25	9.71	10.22	12.26	13.50	13.98

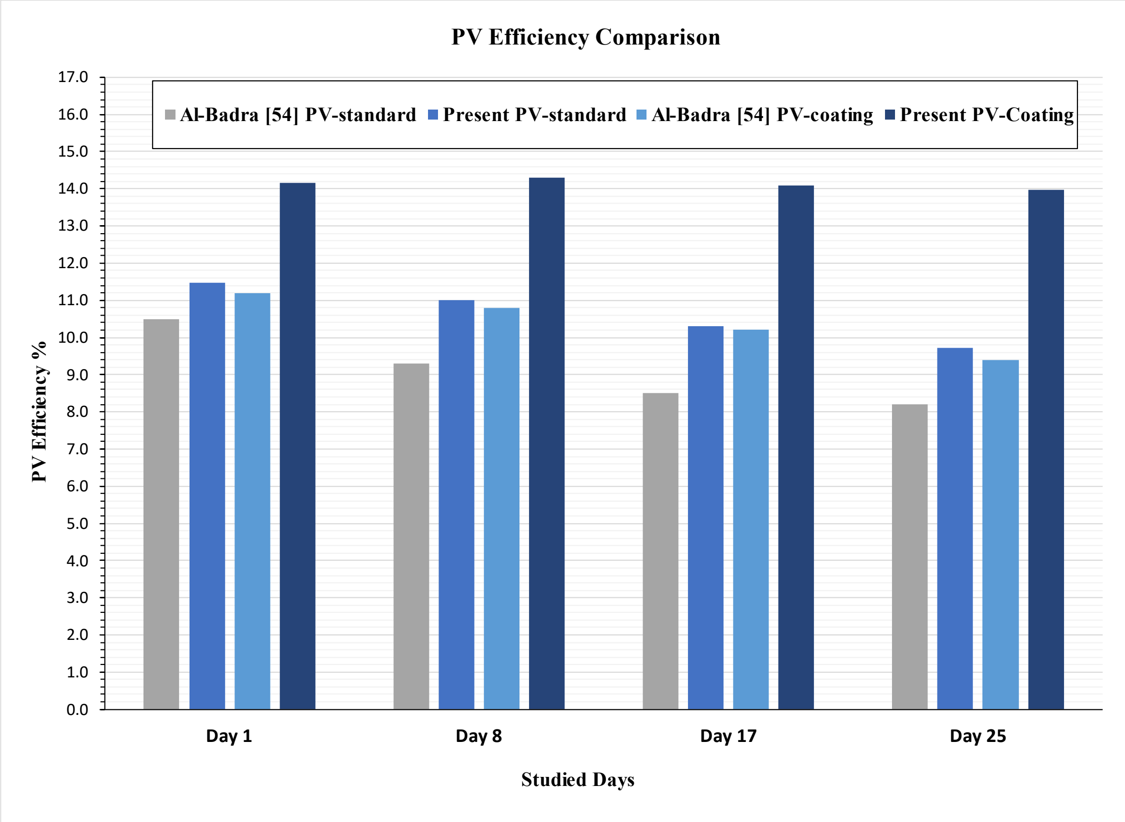


Fig: (4.23): PV efficiency comparison with other study

Chapter Five
Conclusions and Recommendations

5.1 Conclusions:

In the current study, four cleaning case experiments were carried out on a PV module by using of three PV panels, each with a maximum output power and efficiency of 135W and 20%, respectively, in the climatic conditions of Najaf, Iraq (32° 1' N/44° 19' E). Each panel is 0.62 × 0.95 meters in size. The first PV panel underwent natural cleaning (the standard procedure), the second PV panel underwent mechanical cleaning (using nozzles of (0.5,1) mm), the third PV panel underwent nano-coating (using (400, 700) nm Super-hydrophobic ZnO on the glass surface), and the fourth PV panel underwent all-out cleaning (using distilled water until 1LPM is spread). After the third approach was finished on the third PV panel, the last technique, a combination of mechanical and nanocoating was used on it. We can draw the following conclusions:

1. Using the combination method gave (coation and Mechanical cleaning) the most optimum results for the efficiency and power output of the PV panel among the other systems.
2. A maximum overall PV efficiency and power output of around 14.29% and 81W, respectively, were achieved for the Combination case at the hour of 12:00 P.M
3. The Mechanical method gave a maximum PV efficiency and power output of about 13.81% and 79W, respectively. While the Nano-coating method has only given an efficiency and power output of about 12.1% and 69W, respectively.
4. The results showed that the nozzle with 1 mm diameter has better performance than the 0.5mm one.

5.2 Recommendations

Polycrystalline silicon solar cells that have been improved with Nanocomposite materials were the focus of this research. It also utilized water alone to clean and water with paint; future studies could incorporate some suggestions to improve that work.

1. Conduct research on the influence that the thickness of the nanocoating thin film has on the performance of solar cells.
2. Researching the impact of different Nano-coating materials on solar cell performance.
3. Dip coating, spin coating, and electrical vapor deposition were all used to coat the solar cell.

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Appendices

Appendix −A

Solution model

Efficiency:

The solution for the PV efficiency is done as follows to calculate it.

Standard case - Day1:

$$\eta(\%) = \frac{P_{out}}{P_{in}} = \frac{V \times I}{G \times A} = \frac{65\ W}{1030\frac{W}{m^2} \times 0.552\ m^2} = \frac{65\ W}{568.56\ W} = 11.47\%$$

Standard case – Day25:

$$\eta(\%) = \frac{P_{out}}{P_{in}} = \frac{V \times I}{G \times A} = \frac{56\ W}{1043\frac{W}{m^2} \times 0.552\ m^2} = \frac{56\ W}{575.736\ W} = 9.7\%$$

Mechanical case - Day1:

$$\eta(\%) = \frac{P_{out}}{P_{in}} = \frac{V \times I}{G \times A} = \frac{77.7\ W}{1030\frac{W}{m^2} \times 0.552\ m^2} = \frac{77.7\ W}{568.56\ W} = 13.67\%$$

Mechanical case – Day25:

$$\eta(\%) = \frac{P_{out}}{P_{in}} = \frac{V \times I}{G \times A} = \frac{77.74\ W}{1043\frac{W}{m^2} \times 0.552\ m^2} = \frac{77.74\ W}{568.56\ W} = 13.5\%$$

Nano-coating case - Day1:

$$\eta(\%) = \frac{P_{out}}{P_{in}} = \frac{V \times I}{G \times A} = \frac{68.6\ W}{1030\frac{W}{m^2} \times 0.552\ m^2} = \frac{68.6\ W}{568.56\ W} = 12.07\%$$

Nano-coating case – Day25:

$$\eta(\%) = \frac{P_{out}}{P_{in}} = \frac{V \times I}{G \times A} = \frac{58.8\ W}{1043\frac{W}{m^2} \times 0.552\ m^2} = \frac{58.8\ W}{568.56\ W} = 10.22\%$$

Combination case - Day1:

$$\boldsymbol{\eta}(\%) = \frac{\boldsymbol{P_{out}}}{\boldsymbol{P_{in}}} = \frac{\boldsymbol{V \times I}}{\boldsymbol{G \times A}} = \frac{\mathbf{80.47\ W}}{\mathbf{1030}\frac{\boldsymbol{W}}{\boldsymbol{m^2}} \times \mathbf{0.552}\ \boldsymbol{m^2}} = \frac{\mathbf{80.47\ W}}{\mathbf{568.56\ W}} = \mathbf{14.15}\%$$

Combination case – Day25:

$$\boldsymbol{\eta}(\%) = \frac{\boldsymbol{P_{out}}}{\boldsymbol{P_{in}}} = \frac{\boldsymbol{V \times I}}{\boldsymbol{G \times A}} = \frac{\mathbf{78\ W}}{\mathbf{1043}\frac{\boldsymbol{W}}{\boldsymbol{m^2}} \times \mathbf{0.552}\ \boldsymbol{m^2}} = \frac{\mathbf{78\ W}}{\mathbf{568.56\ W}} = \mathbf{13.98}\%$$

Appendix –B

Solar meter calibration

Tenmars TM-207 was used to record the solar radiation every hour. As seen in fig. B.1, the Davis weather station at Najaf Technical College/al-Furat al Awsat Technical University in Najaf City, Iraq, was used to calibrate the solar radiation meter.

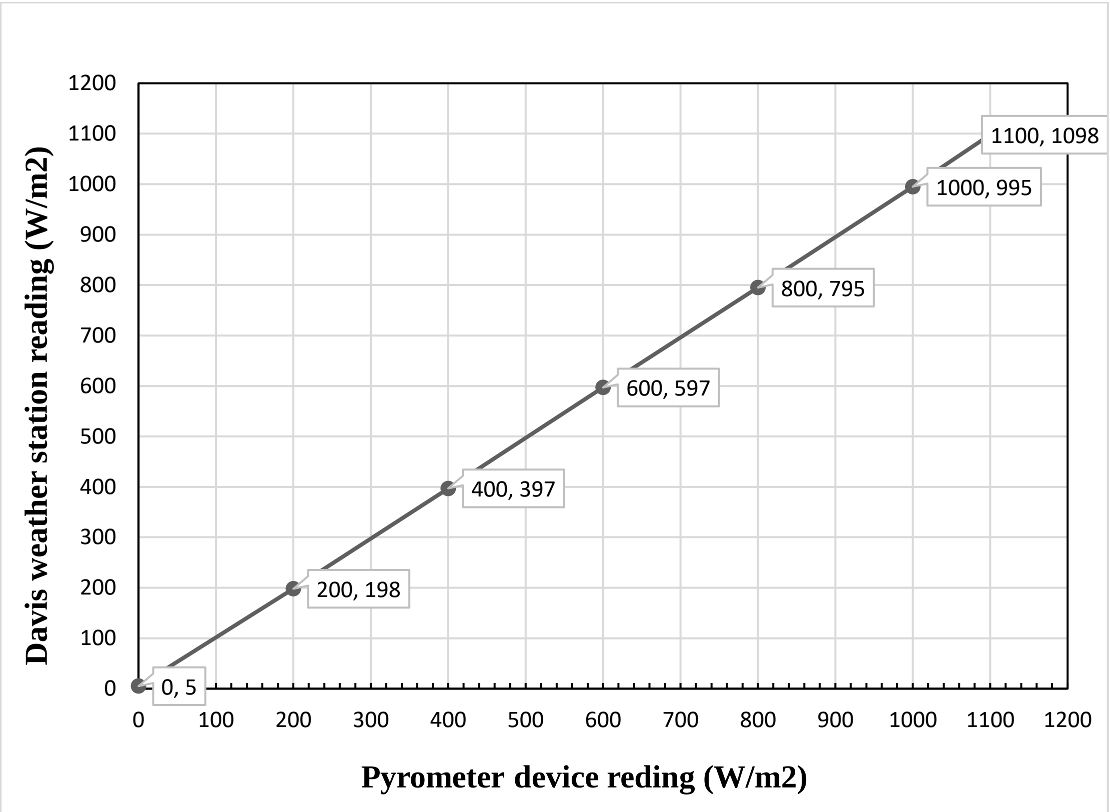

Figure B.1: Anemometer calibration with Davis weather station

Wind meter calibration

Every hour, an anemometer of type AM-4206M was used to record the wind speed. As depicted in fig. B.2, the anemometer was calibrated using data from the Davis weather station at the Najaf Technical College/al-Furat al Awsat Technical University in Najaf City, Iraq.

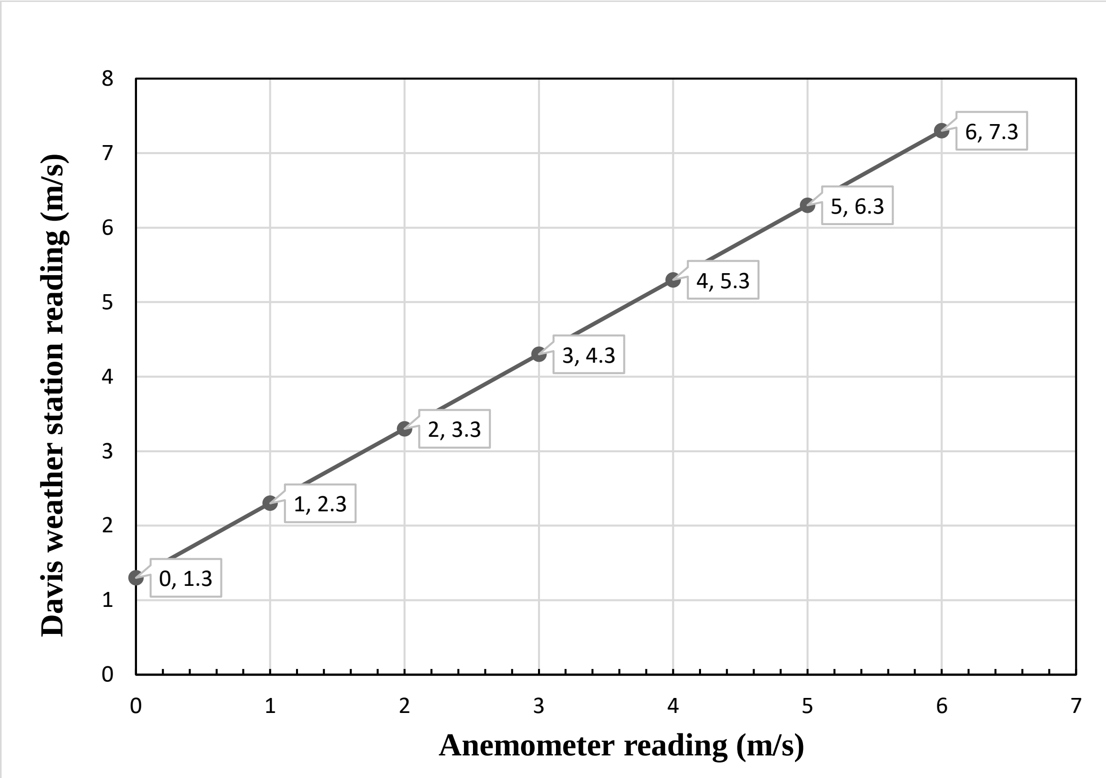

Figure B.2: Anemometer calibration with Davis weather station

الخلاصة

تُستخدم الخلايا الكهروضوئية (PV) على نطاق واسع لتسخير الطاقة الشمسية التي تضمن أقصى إنتاج عندما يكون سطحها الزجاجي نظيفًا. ومع ذلك، فإن الخلايا الكهروضوئية معرضة للغبار والأوساخ وغيرها من الملوثات التي تترسب على سطحها مما يؤدي إلى تقليل النفاذية وبالتالي تقل كفاءتها. يلعب تأثير تقديم الغبار على سطح الخلية الشمسية عاملاً هامًا في تقليل كفاءة الخلية، وبالتالي، قدرتها على الانتاج. لذلك، تم إجراء العديد من الدراسات من مختلف الباحثين لتطوير طرق تنظيف سطح الخلية لتحسين أدائها.

في هذه الدراسة، تم إجراء أربعة أنظمة تجريبية لحالات التنظيف على الخلية الشمسية في مدينة النجف، الظروف المناخية للعراق (32 ° 1 'N / 44 ° 19' E) على وحدة PV تتكون من ثلاثة ألواح كهروضوئية ، كل منها 135واط و 20٪ أقصى قدرة وكفاءة ، على التوالي. كل لوح بأبعاد (0.62×0.95) م^2. كانت حالات التنظيف الأربع هي كالتالي: الحالة الطبيعية (الحالة القياسية) والتي تم إجراؤها على اللوحة الكهروضوئية الأولى ، وتم تنفيذ الطريقة الميكانيكية (باستخدام نوزلات بحجم (0.5و1) مم) على اللوحة الكهروضوئية الثانية حيث تم تغذية الماء المقطر بسعة 1لتر/دقيقة ، تم تطبيق طلاء النانو باستخدام 400و700 نانومتر من ZnO المقاوم للماء الفائق على السطح الزجاجي (على اللوحة الكهروضوئية الثالثة ، وكانت الطريقة الأخيرة عبارة عن مزيج من الميكانيكية والنانو- معًا تم تطبيقه على نفس اللوحة الكهروضوئية الثالثة بعد الانتهاء من اخذ نتائج الطريقة الثالثة عليها.

أن نتائج جميع الحالات يتم أخذها وتسجيلها دفعة واحدة والجهاز الذي تم استخدامه للحصول على جميع النتائج من الألواح الكهروضوئية يسمى Solar Modul Analyzer الذي يعطي النتائج المطلوبة من الطاقة والكفاءة والتيار والجهد إلخ. تم أخذ أربعة أيام في الاعتبار (7/1 ، 7/8 ، 7/17 ، 7/25) في شهر يوليو للدراسة ، وتم اعتبار النتائج المثلى فقط للساعة 12:00 ظهرا.

أظهرت نتائج الدراسة الحالية أن استخدام طريقة الدمج أعطت أفضل النتائج من حيث كفاءة وإنتاج الطاقة للوحة الكهروضوئية بين الأنظمة الأخرى. تم تحقيق أقصى قدر من الكفاءة الكهروضوئية الإجمالية وإخراج الطاقة بحوالي 14.29٪ و 81 واط ، على التوالي ، لحالة الدمج في الساعة 12:00 مساءً. أعطت الطريقة الميكانيكية أقصى كفاءة للطاقة الكهروضوئية وناتج طاقة بحوالي 13.81٪ و 79 وات على التوالي. بينما أعطت طريقة طلاء النانو كفاءة وإنتاج

طاقة بحوالي 12.1٪ و 69 واط على التوالي. أخيرًا ، حصـــلت الطريقة الأولى ، وهي الحالة الطبيعية ، على أقل النتائج بين الحالات الأخرى ، بكفاءة بلغت 11.47٪ وناتج طاقة حوالي 65 واط.

تتميز طريقة الدمج بأقصـــى إنتاج للطاقة بالإضـــافة إلى الكفاءة ، ويرجع ذلك إلى مادة النانو النشـطة جدًا المسـتخدمة للطلاء والتي تجعل الغبار غير قادر على الالتصـاق على السـطح الكهروضوئي بالإضافة إلى قدرته الصفرية على الترطيب مما يعني المزيد يتم امتصاص الطاقة ، بالإضــافة إلى الاســتخدام الفعال للفوهات مما يؤدي إلى إجراءات التنظيف والتبريد. حققت هذه الطريقة نســبة كفاءة وطاقة خرج 70٪ ، 90٪ على التوالي ، أكثر من الحالة الطبيعية. 60٪ ، 50٪ ، على التوالي ، أكثر من الميكانيكية. 70٪ ، 90٪ ، على التوالي ، أكثر من الطلاء. بالنسبة لحالة التنظيف الميكانيكي، تم اســتخدام قطر كل من الفتحات 0.5 و1 مم. أظهرت النتائج أن الفوهة بقطر 1 مم لها أداء أفضــل من الفوهة 0.5 مم. لذلك ، ســوف تســتند النتائج بأكملها على قطر 1 مم.

تحسين أداء الخلايا الكهروضوئية باستخدام طرق التنظيف المختلفة

أطروحة

مقدم إلى قسم تقنيات الهندسة الميكانيكية القوى

كاستفاء جزئي لمتطلبات درجة الماجستير في التقنيات الحرارية في تقنيات الهندسة الميكانيكية للطاقة

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