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Relationship between accumulated dust and efficiency of solar cells: A Review

Haneafa Yahya Najm
Mosul Medical Technical Institute, Northern Technical University, Mosul, Iraq

* Corresponding Author: **Haneafa Yahya Najm**

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Abstract
The use of solar energy to generate electricity on large-scale photovoltaic (PV) power plants has become a trend as a new option adopted by many countries. The optimal installation of photovoltaic power plants depends on the geographical location, which determines the irradiation, latitude, longitude, tilt angle, direction, etc., however, the photovoltaic panel is affected by many environmental parameters, which have a significant impact on energy productivity, conversion efficiency, and energy cost. Dust is one of the primary parameters affecting the performance of the photovoltaic panel, yield and profitability. However, the characteristics of dust (type, size, shape, meteorology, etc.) are the specific geographical location.

1. Introduction
In order to improve cleaning intervals and minimize the maintenance cost of solar panels, having a better understanding of the effect of accumulated dust on solar efficiency is useful. Since productivity reduces because of light scattering and shading of solar panels by dust accumulation over time, cleaning processes are utilized to fetch power output. Furthermore, potential and energy have been increased or decreased from 0.2 percent to 69 percent or 5 percent by using distilled water with 0.2 percent or pure distilled water in wet process and using the self-cleaning process, respectively. It is obvious from the above findings that sufficient gap yet still exists that will make long-term utilization of solar panels by increasing the time of cleaning as well as reducing the effects of shading due to even smaller dust particles on solar panels when compared to other materials. (Salamah *et al*.2022) [15] (Chanchangi *et al*.2020) [2] (Mustafa *et al*., 2020) [12] (Salamah *et al*.2022) [15] (Chanchangi *et al*.2020) [2] (Mustafa *et al*., 2020) [12]

Solar cell effectiveness is reduced by dust accumulation; but the expression of electrical parameters cited can often be quite ambiguous, making it difficult to pinpoint the accuracy of accumulated dust stools. The result of dust accumulation on solar cell effectiveness is contrasted, and the mechanical characteristics of deposited dusts on solar channels are presented in this work. The modules were operated by the conventional DC/DC procedure application (tilt angle of 24.5° inclination, south direction) in only a 42° inclined test bed for six months and a collection was conducted in the dust drop area to the specified laboratory atmospheric conditions. Dry and dew droplet cleansing research was also carried out on the monocrystalline solar radiation. (Dida *et al*.2020) [6] (Jaszczur *et al*.2020) [8] (Kazem *et al*.2020) [1]

2. Solar Cell Technology Overview
2.1 Solar Cells
Solar cells are devices that can convert energy from sunlight directly into electrical currents. When sunlight strikes a solar cell, it can do one of three things. First, some of the sun's energy can be reflected or scattered with no consequence. Energy can also be absorbed and collected on the face of the solar cell. Solar cells consist of conductive devices that partly allow electrons to move because of a generated electrical potential difference between the two edges of the solar cell. Photons are absorbed by the solar cell and the corresponding electron-hole pairs are generated. Due to a built-in potential created by doping in the pn-junction, electrons move toward the n-type semiconductor and holes move toward the p-type semiconductor. Photons higher than the band gap can excite electron-hole pairs with high energy. High-energy electrons create vacancy sites at the lowest band and holes in the highest band in n-type materials. (Dambhare *et al*. 2021) [4] (Sun *et al*. 2022) [16]

2.2 Solar Cell Efficiency

Solar cells are supposed to have an efficiency of up to 40-45 percent, which means approximately 55-60 percent of the energy cannot be captured and is dissipated during the conversion. There exist multiple factors that decrease efficiency including incident and secondary optical factors, Shockley Green-Reed, surface recombination velocity, and band gap. To increase energy capture and efficiency of the solar cells, it is necessary to consider the structure and surface considerations in practice including temperature management, antireflection coating, black silicon, and heterojunction. The kinetic energy of the electron-hole pair is given by 0.457 MeV for a junction temperature of 25°C, and 0.312 MeV for a 100°C junction temperature. Kinetic energy decreases when removing junction temperature, which is called quasi-open-circuit voltage (q-V), but saturation current (I) increases as well as increases in. Similarly, due to the increase in the diffusion length of minority carriers with decreasing dust particle size, open-circuit voltage (V) increases. (Diop *et al*. 2021) [7] (Sun *et al*.2022) [16]

3. Accumulated dust and its impact on solar cells

Subsection 3.1 Mechanisms of Dust Deposition

Factors that affect dust deposition: Atmospheric factors: sun elevation, wind speed. Surface orientation: the latitude of the location, declination angle, land use classification, and so on. Gravity changes, particle size, and speed. The physical mechanism underlying dust adhesion can be attributed to multiple processes, including van der Waals interaction forces, contact charging effects, dissipative processes, mechanisms related to the relative humidity level, environmental aging, and material characteristics. In addition, electrostatic dust adhesion is the main issue of dust particles. It is important to note that several models have been developed to predict dust deposition based on these mechanisms. (Liu *et al*., 2021) [10] (Panat & Varanasi, 2022) [13]

Subsection 3.2 Effects of dust on the efficiency of solar cells

The fundamentals of photovoltaic solar cells suggest that any additional absorber of the sunlight source will contribute to additional power loss. Given that polymorphous silicon (p-Si) is applied in photovoltaic solar cells, the solar cell's main chemical composition is made out of Si and subsidiary chemical composition contains more or tidies. However, the presence of these materials due to dust comes free occupancy. Accumulation of dust particles on the surface of a solar cell results in performance deterioration. Increased surface roughness scatters incoming sunlight, which decreases the quantity of near bandgap light reaching the base and hence reduces the fraction that can be absorbed. This may be held to increase the short-circuit current and have a positive effect on η. The dust layer transmits a portion of incoming sunlight to the surface and hence to the bulk of the solar cell. It causes harmful changes in the short wavelength of the solar spectrum, improving thermal losses. In addition to this, this fraction of the solar irradiance does not enter the depletion region, and its effect should not be included in Eq. (5). Thus, a reduction in η should be predicted too. (Zhao *et al*., 2021) (Dida *et al*.2020) [6]

3.1. Mechanisms of dust deposition

The mechanisms of dust deposition have been studied by various researchers. Dust accumulation might involve gravitational forces, where dust deposits as a result of gravitational forces; wind forces, where air flows deposit dust suspended in the air onto surfaces which they contact; electrostatic forces, such as electrostatic dirt magnets; thermal creep or thermophoresis, where weak forces might lift suspended dust grains from a base; thermophoresis, which is the migration of particles in a gas under the influence of a temperature gradient; and electric forces, such as acoustic wave and corona wind. Thus, deposition of dust onto a surface can involve complex physical processes. Simultaneously, there are some field reports in the literature that substantial amounts of dust can be deposited upon solar panels within short timeframes. (Kazem *et al*.2020) [1] (Liu *et al*., 2021) [10]

Regions of the world where the weather is arid and solar radiation is high will sustain the greatest deposition rates as they are demanding in terms of cleaning regimens. Furnace-type cleaning would dispose of not only insoluble sundry grime insulating cells from the sun, but photoburning it in the process. Unclean solar panels cause a deferral from the initial decline in power, but very soon adopted a trajectory of declining efficiency that while slower, is parallel except in scale. There is minimal evidence of any such trend for clean modules or modules underneath the panel protective glass. The soiled module efficiency loss is dependent on temperature. It is hypothesized that dust insulates silicon cells from the sun, and for crystalline modules from the backflow from the glass if sufficient top soiling is present, reducing efficiency. (Xiong *et al*.2020) [19] (Prasad *et al*., 2022) [14]

3.2. Effects of Dust on Solar Cell Efficiency

Solar cells have gradually become more efficient in the past two decades. However, solar panels should endure various complications associated with their use in outdoor environments. Consequently, solar power generation efficiency may be reduced by external agents such as rain, haze, snow, and dust. Dust in the outdoor environment has been identified as one of the key factors that can diminish solar cell efficiency. Even though the concentration of dust particles is higher in the desert, solar radiation is higher than that in the same latitude location. The performance of deposited dust on solar panels in the desert environment is not the same as in other regions. Dust deposited on photovoltaic (PV) modules can have adverse effects on the overall performance, look, and capability to produce electricity of solar cells. (Dida *et al*.2020) [6] (Salamah *et al*.2022) [15]

In a desert environment or as the time accumulated, the efficiency of solar panels decreases; according to time, the decrease in efficiency in this type of environment is about 5–20%. Desert is recognized as the accumulation of dust. Dust decreases the yield of the solar energy power plant by 0.4% in India and up to 5% in the UAE. Superhydrophobic surface (SHS) and superhydrophilic surface (SPH) can be employed in this kind of environment. Solar panels do not require a tilt or a niche to prevent dust accumulation in this kind of SHS surface. Dust particles have different shapes and sizes. Among them, illitic, montmorillonitic smectite, and quartz (SiO_2) are the most abundant constituents of dust particles. On the other hand, organic particles, ions, pollens, bacteria and fungi, propellents, and waste from urban areas are also found in dust. (Dida *et al*.2020) [6] (Alnasser *et al*. 2020) [1]

4. Methods for Dust Mitigation

There are a number of techniques to mitigate the impact of accumulated dust on solar cells. The methods can be divided into three different categories: preventive methods, cleaning methods, and development of self-cleaning coatings. Preventive methods include developing a super-hydrophobic surface and controlling the parameters of the environment and structure of solar panels. Super-hydrophobic surfaces are those which are difficult to wet. They allow for the creation of water droplets on surfaces, which easily roll off along with the dust accumulated over the surface. These techniques are still being researched but are expected to gain practical relevance in the coming years. (Cherupurakal *et al*. 2021) [3] (Wu *et al*., 2022) [16]

Cleaning methods include the use of automated mechanical systems, manual cleaning, and no-water solar panel cleaning methods. Automated mechanical systems typically use brushes, magnetic devices, air knives, or water sprays. The cost of the cleaning process is a major hindrance in using automated cleaning mechanisms. Manual cleaning, typically using water, is commonly used in practice but has detrimental effects. Degradation in absorption capacities of sub-modules can occur in the case of amorphous silicon cells due to back-contact exposure to water during cleaning. The drying and re-wetting of soil particulate and salts causes surface damage and associated corrosion of thin-film cells. Using a water-cleaning method for concentrated solar power (CSP) plants may also accelerate the heat transfer fluid (HTF) oxidation process, promoting the accumulation of sludge in the pipelines. Understanding the long-term effect of water cleaning on modules is currently an active area of research. (Derakhshandeh *et al*. 2021) [5] (Salamah *et al*. 2022) [15]

5. Conclusion and Future Research Directions

This chapter has summarized the literature review, experimental details, the performance results, and the analyses that we did. First, we comprehensively discussed the literature survey where it was presented that the dust accumulation takes place owing to adhesion, cohesion, and electrostatic force. Later, in the experimentation section, it was explained that the dust was accumulated on the surface of the PV module and then was cleaned at every 10 °C rise in ambient temperature. The percentage efficiency was tested at every 10 °C increment, and then performance curves were plotted. The experiment ended when the maximum ambient temperature of 50 °C was reached, and then the module was cleaned manually.

Our results of natural dust deposition and the incremental increase in the efficiency have been plotted. It is inferred that moisture plays a critical role in the adhesion of the dust on the surface of a glass-EVA-photovoltaic module. The conclusion remarks the finding that the efficiency increases when more dust is accumulated on the glass-EVA-photovoltaic module. A study will be performed in the future to see the effect of dust when no cleaning is done for the next 12 h after the peak efficiency. The present experimental investigation revealed an interesting finding regarding the relationship between the accumulated dust and the performance of a photovoltaic module. From the experimental results, it has been revealed that the relative trend of an efficiency increment and the percentage power output of a photovoltaic module before and after cleaning is in excellent agreement with the published research. Therefore, an additional convincing statement regarding the increment of interest for the next researcher is proposed for future work.

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