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Humidity impact on photovoltaic cells performance: A review

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Abstract: Photovoltaic cells today have spread widely around the world and have begun to be popularly accepted and their stations have increased dramatically. The electricity provided by solar cells has become a significant part of the world's generated electricity. Because they are located outdoors, they are exposed to all weather variables such as air temperature, solar radiation, wind, dust and pollutants, as well as relative humidity. In this study, many previous published studies were reviewed which focused on the effect of relative humidity with the rest of the weather variables on the performance of the solar cell. Inhalation of moisture into the cell causes its parts to eat yellowish and corrode metal connections, and result in reduced cell life and productivity. Studies have shown that cell work in high air temperature and high humidity conditions causes a significant reduction in cell efficiency. High relative humidity also has negative effects on solar radiation and reduces cell performance.

Keywords: photovoltaic, climatic variables, relative humidity, corrosion, colour change.

1. Introduction

Today, the world is totally affected by the oil market and its price volatility, which makes all humanity, whether economic security, well-being or sustainability, dependent on energy [1]-[3]. Energy interference in everything is the engine of transportation and the electricity generated by the rise of the well-being of society and its growth. On the other hand, the burning of fossil fuels has caused great damage to the environment due to pollution caused by oil production and arsenals in huge quantities [4], [5]. Millions of tons of contaminants from burning fossil fuels in power stations and transport mechanisms are being blown into the air so much that the earth cannot absorb them [6]. The accumulation of these pollutants, especially during the past two centuries, has caused the problems of life threatening the planet, including global warming and climate change [7].

Researchers around the world have agreed that renewable energies when it takes a large share from the fossil fuels' productive energy will help the planet regain some of its health [8]. Renewable energies are available in several forms, including solar, wind, geothermal, and bio-energy [9]-[13]. Biodiesel has been produced and used as an alternative or auxiliary to diesel fuel and studies have proven successful in reducing an important number of pollutants [14], [15]. The use of hydrogen as fuel for internal combustion engines or for fuel cells has proved successful and competitive for fossil fuels [16]-[19]. The use of solar energy with its various applications can rid the earth of the problems generated by the burning of oil, coal and natural gas [20].

Solar energy applications are used to heat water in heaters for domestic or industrial purposes [21], [22]. Heating the air by the sun to attain comfort conditions in homes and buildings is now available [23], [24]. Solar energy is used to heat water in solar ponds and to utilize the heat stored in these ponds in many applications [25]-[27]. Today, the distillation of potable water by the sun has become popular [28]-[31]. Houses can also be heated using a solar Trombe wall [32-35]. As for the production of electricity using solar radiation, there are several methods have become common and leading example of the solar chimney [36]-[38], concentrated power stations [39]-[41], and photovoltaic cells [42].

Today's solar cells are popular because of the high flexibility in their use as they can be used without connecting them to the grid or with connecting them. In both cases, these cells proved to be effective and their stations are spreading globally [43]-[45]. Photovoltaic cells are affected by weather conditions such as solar radiation intensity [46], temperature [47], shadows [48], [49], dust [50]-[53], and humidity [54]. The researchers treated each parameter separately and found acceptable solutions to neutralize or reduce its effects on cell productivity. For example, to reduce the effect of high solar radiation and the high temperature of the cell, which reduces the ability produced, the researchers found the solution using PVT systems [55]-[59]. These systems use fluids to cool the cell, including air, water, nanoparticles and nanofluids with phase change materials (PCM) [60]-[62]. Reducing the temperature of the cell and keeping it below 30°C allows it to operate at efficiency close to its nominal power [63]-[65]. Also, the researchers clarified the ideal conditions for the construction of PV plants or for the stabilization of individual cells and for neutralizing the effects of shadows on them [66], [67]. The researchers studied the types of dust and their physical and chemical properties [68]. The researchers also studied the best means of cleaning the cells and the necessary materials without affecting the cell's productivity or design age [69].

The moisture in the atmosphere also has a clear effect on the cell, which researchers have studied extensively. In Calabar-Nigeria, Ettah [70] studied the effect of relative humidity on the efficiency of PV cells and concluded that cell current increased when relative humidity drops below 69%. In the case of high relative humidity to higher than 75%, the voltage was increased. The study supported what the rest of the studies said, which is the low relative humidity causes an improvement in the performance of photovoltaic cells. In this paper, we will review several important studies on the effect of air humidity on the photovoltaic cell.

2. The humidity effect

Photovoltaic units are affected by water when it is in contact with the cellular components of the cell causing its efficiency to disintegrate, resulting in a decrease in their electrical productivity. Water also corrodes the metal joints and scratches the cell's viscosity [71]. Water is present in varying degrees in the air and relative humidity is defined as the ratio between actual water vapor pressure in the air and saturated water vapor pressure at the same temperature [72], [73]. The amount of humidity expresses the relative humidity of the air (RH) which varies depending on the water vapor saturation pressure which is directly affected by the temperature [74], [75]. In hot and humid climates, moisture penetrates into the PV cells through the cracks, causing a significant decrease in cell productivity [76]. The effects of moisture on the solar cell vary depending on the method of propagation during the solar panel, which is described as slow process [77]. The moisture permeates the polymer layer down to the cell, causing damage to interconnecting bonds. This damage caused many effects [78], [79], such as corrosion of weld joints [80]-[82]. Several studies and research works have been conducted to determine the effect of relative air humidity on solar cells. Relative humidity effect on PV panels cannot be studied without the other climatic variable.

2.1 Relative humidity and air temperature

High air temperature increases the amount of moisture the air can hold and defines the saturation limit. The work of solar cells at high temperatures above 25°C means a decrease in its performance. Bhattacharya [83] studied this effect in Rajasthan and linked it to other weather conditions such as atmospheric temperature, dust, and rain. The study showed that the relative humidity in the study area is in an average of 42% and the maximum value is about 70%. The study concluded that the most important and significant effect of relative humidity on solar cells is that they cause corrosion of the photovoltaic cell. Some weather conditions such as high air temperatures (above 40°C) and humidity of up to 60% for long periods help in decreasing the performance of the cell and reduce the its life. The combination of these two factors accelerates the corrosion process. These conditions also help the growth of fungi, especially when the relative humidity is high between 75% and 95%.

The efficiency of solar cells is as low as Prakash [84] clarified, and is influenced by many environmental factors such as temperature, dust, wind speed, and relative humidity. In this study, the solar cell was considered a glass panel and used physical glass properties as reference. The cell was cooled through a water cooling system without pressure to ration the amount of water used. The researchers concluded that the process of cooling and cleaning the solar panel in hot and dusty areas is essential to maintain the acceptable performance of these cells. The cooling of cells using water gave promising results, provided that the cooling process does not begin until after the temperature of the solar panel 40 degrees Celsius. The study did not address the important thing, which is the use of water causes corrosion in the long term.

Kattkar [85] analyzed the effect of relative humidity with the high temperature of the photovoltaic cell on cell efficiency in different climatic conditions. The cell was exposed to harsh weather conditions. The atmosphere was studied at ambient temperatures of 58°C and relative humidity of over 60%. The work of the cell in these harsh conditions resulted in a decrease in the efficiency of the solar cell by 32.42%. These results showed that the photovoltaic cell is affected highly by the environmental conditions in which it operates. Kazem [86] used three variable types of PV cells to study the effect of the relative humidity of the Sultanate's atmosphere on cell output. Oman is characterized by a very high humidity due to its geographical location overlooking the Arabian Sea. The results of the study agreed with many previous studies. In the case of low relative humidity in the atmosphere, the efficiency of the solar cell was improved. The monochromatic panels have higher efficiency than other crystalline and amorphous silicon cells in low relative humidity conditions.

Al-Hinai [87] analyzed the effect of several variables on the thin silicon layer and its reflection on the efficiency of solar cells. The study area (United Arab Emirates) was characterized by dry and cold weather in winter, and hot and humid in summer. The study concluded that there is a direct effect of relative humidity in the atmosphere on PV cell performance and that there is an inverse relationship between the relative humidity effects with the temperature.

Klampaftis [88] found that some of the silicon cell chips made of silicon (type n) clearly resist the effect of relative humidity in conditions of high temperatures up to 75°C and this resistance up to 100%. The researchers proposed three mechanisms that cause degradation: moisture diffusion through SiO2, and their interaction with hydrogen molecules at Si-SiO2 surface. The reaction of the water vapor with silica acid produced by the molecules of SiO2, causing a change in the film pressure and increasing the density of the material on the cell interface made up of Si-SiO2. Finally, during exposure to sunlight, the surface charge is deposited.

Rachmann [89] to study the effect of weather conditions on the presence of a cooling system on the production of PV cell. The researchers concluded that the relative humidity of the surrounding atmosphere resulted in increased dehumidification. The efficiency of the system is achieved at low temperatures with certain percentages of regenerated air.

2.2 Relative humidity and solar radiation

Gwandu [90] explained that the level of solar radiation is affected by the relative humidity of the atmosphere, as increasing the water vapor content in the air causes the increase of reflected refractive radiation. In such a case, the intensity of the solar radiation received by the photovoltaic cell is reduced, which is reflected in the productivity of the cell.

Darwish [91] proposed a relationship between humidity and radiation

$$\eta = \frac{I_{SC-\max}.V_{OC-\max}}{A_{C(\text{irradiance-level})}} \qquad (1)$$

Where AC is the area of the PV module, ISC is the short circuit current, and VOC is the open circuit voltage and η is the conversion efficiency. The study results revealed that wind speed can affect the solar radiation in an opposite way to relative humidity. If the solar cell is exposed to high humidity for a long time, this condition may lead to water penetrating the cell body resulting in a reduction in the solar cell outcomes.

Omobo [92] explained that relative humidity has a direct effect on the efficiency of converting sunlight to electricity because of a proportional relationship between solar radiation, current, and cell efficiency. The relative humidity negatively affects the intensity of solar radiation and the result is negative on the output of the cell.

Panjwani [93] studied the effect of relative humidity between (40 to 78%) on photovoltaic cells and found a varying loss between 15-30% of the produced energy. The researchers explained that the result is that a thin layer of water vapor inside the solar cell from the front of the sun, causing the loss of solar radiation energy as a result of absorption or reflection from the water layer.

Omubo [94] explained that solar cells produce better performance when they are constructed away from the seashore and in relatively less humid weather conditions. The researchers found that low relative humidity causes increased solar radiation, resulting in improved solar cell output.

In Algeria, Chegaar [95] studied the effect of the solar radiation intensity on three types of solar cells. Increased air mass increases the efficiency of monocrystalline and multi-crystalline solar cells. In the case of amorphous silicon cells, the results were reversed when studied in the same weather conditions. The study found a different result from previous studies as the authors concluded that the performance of photovoltaic cells increased with the relative humidity of all types of cells studied.

2.3 Relative humidity and wind

Mekhilef [96] measured the effect of the wind on relative humidity in the atmosphere and linked it to the deterioration in the productivity of photovoltaic cells. The wind affects the concentration of moisture in the atmosphere. As wind speeds increase, relative humidity decreases in the air, which means that the cell's productivity improves. But the increase in the speed of the wind caused the rise of dust and spread especially in the desert areas, resulting in the accumulation of this dust rising on the surfaces of the cells causing deterioration in the productivity of solar panels. The study concluded that the mutual effects of weather factors should be studied together to arrive at a more accurate analysis of their respective effects on the efficiency of solar cells.

2.4 Relative humidity with dust and pollutants

Skoczek [97] declared that pollution in hot and humid climate causes lamination on the edges of the solar cell, causing the deterioration of productivity and it increases the electrical risk of cells. The study concludes that moisture permeability into the solar cell results in chemical damage that negatively affects the metal bonding within the cell. The moisture penetration of the photovoltaic cell causes the salt to accumulate and contaminate inside it. Hydrofluoric acid resulted from the reaction of tin oxide and fluorine in the cell causes drilling and necrosis in the interconnections of the cell [98].

The researchers studied at length what the effect of moisture penetration into the body of the solar cell through the cracks and fractures in the glass and found that they cause serious damage such as corrosion and change the color of the cell and corrode its metal links.

Fig. 1, Natural cleaning cell (the higher one) and polluted cell (the lower one) [69]

2.5 Corrosion

The condensation of water in the air on the cell wall causes a viscous surface that facilitates the capture of dust and dirt particles. Laronde [99] and Peike [100] tested the degeneration of PV cells due to corrosion. The erosion of the network results in a reduction in the conductivity of the emitter, which is the main cause of the deterioration of the productivity of solar cells. The studies showed that the process of penetrating the hull of the solar cell by air humidity is accelerating with increasing temperature. Touati [101] tried to determine the effect of temperature, dust, and relative humidity factors on the performance of solar cells. The study was conducted in the State of Qatar where the high temperatures are accompanied by high relative humidity and atmosphere in general dusty. The researchers concluded that the accumulation of dust on the surface of the cell causes a decrease in its productivity higher than that resulting from high temperature or relative humidity. The researchers also found that high temperatures above 40°C significantly reduce the amount of electrical cell productivity.

In Miami, Florida, United States, Kemp [102] demonstrated that the water from moisture penetration into the cell caused erosion from the edges. Corrosion of the metal parts of the cell joints caused deterioration of cell efficiency. The results of the study correlated between the moisture inside the cell and the degradation rate. The researchers found that the best way to prevent the penetration of moisture inside the PV cells is by tightly sealed the cells by placing low-spreading charges have a high drying feature. In Wolgimuth [103] experiments, the solar cell was exposed to corrosion after approximately 1,000 hours of cell presence at temperatures below 85°C and relative humidity about 85%.

References [104] and [105] manifested that the penetration of moisture inside the photovoltaic cell causes the reflection of the solar radiation. This condition is called filtration, a situation in which the cells are separated from the windshield or polymer encapsulation due to the degradation of their adhesion.

2.6 PV panel colour change

Kimpi [106] explained that if moisture permeated the PV cell through cracks in it, it could cause cell failure. Perhaps the biggest phenomenon of the effect of moisture on the cell is the flaking of cells and this phenomenon caused the deterioration of the solar cell. One aspect of cell failure and deterioration of life span can be seen when watching a change in cell color. The penetration of moisture into the cell causes corrosion in the electrical connections in a way that contributes to the rapid degradation of crystallized silicon solar cells.

Ndiaye [107] has reviewed studies that have considered the causes of solar cell degradation. The study examined several reasons for the deterioration of cell productivity such as corrosion, color change, fragmentation and fracture. The results of the study showed that corrosion and color change are the most important factors that cause the deterioration of solar cell performance.

Changing the color of the cell to yellow or brown is actually a change in the nature of the cell. Any discoloration inside the cell causes adhesion between the glass and the cell, resulting in deterioration in the quality of the packaging. The change in the color of the cell results in a decrease in the light permeability of the cell, which causes a decrease in its efficiency [108]. Oriski [109] explained that meeting UV and water temperatures above 50°C cause cell color change in multiple areas, where the spread of these areas depends on the properties of the polymers used. The color change may be due to the type of polymer encased in the cell.

Kojima [110] studied the color change of the PV cell when exposed to artificial radiation. The results of the study concluded that the exposure of photovoltaic cells for more than 400 hours to light causes a poor yellowing of the cell and results in deterioration in its performance [111]. The cell envelope color change occurs when the UV condition exceeds 15 kW/m^2 and the wavelength between 280 nm and 385 nm [112]. Also, there is a linear relationship between the slow declines of cell performance with time when this cell is exposed to ultraviolet light [113].

Sometimes fractures or cracks in the glass of the cell result from the transfer and installation, and these cracks or fractures are difficult to achieve because observation with the naked eye is a complex matter [114]. However, these cells continue to function for a long time satisfactorily, but due to the leakage of moisture into them through these cracks increase the risk of electric shocks. Cell color and corrosion increase due to the penetration of moisture through these cracks and fractures. Fragments or cracks in the cell's glass can now be observed using various optical methods [115]. In recent years, solar cell producers have changed the thickness of cells and their envelope glass to reduce the cost of manufacturing and producing cells, but reducing cell thickness and glass makes them more fragile and more fragile during transport and installation [116].

Fig. 2, PV panel colour change [114]

3. Conclusions

The relative humidity of the atmosphere benefits solar cells on the one hand, it works to reduce solar radiation, but it also has many disadvantages. In this study, previous research works were studied to evaluate the effect of relative humidity in the atmosphere and its effects on photovoltaic cells related to the rest of the atmosphere variables such as air temperature, solar radiation intensity, wind, dust and pollution. The work of solar cells in harsh conditions such as high temperatures and relative humidity of over 70% caused a significant reduction in the efficiency of solar cells. Conversely, under low relative humidity and cool cell conditions, solar cells work more efficiently. Perhaps the most important risk of penetration of moisture into the cell is caused by corrosion of metal joints and necrosis in the polymers used in addition to the yellowing of its color. All of these risks result in a significant decrease in the performance of the solar cell in its operating life.

References

[1]. A. H. Al-Hamdani, A. F. Dawood, K. N. Abdullah, H. M. Hasan, M. Sarhan, H. Shareef, R. T. A. Hamdi, "Potential of Renewable Energy in Al-Fourat Al-Awsat: Al-Najaf City Case Study," IOP Conf. Series: Journal of Physics: Conf. Series 1032 (2018) 012014, doi :10.1088/1742-6596/1032/1/012014

[2]. M. A. Abdul-Hussain, R. T. A. Hamdi, "Connect the Wind Farms to the Electrical Grid and Indicate Their Effect on Improving the Characteristics of the Network," International Research Journal of Advanced Engineering and Science, III (1), pp. 45-48, 2018.

[3]. H. M. S. Al-Maamary, H. A. Kazem, M. T. Chaichan, "The Impact of the Oil Price Fluctuations on Common Renewable Energies in GCC Countries," Renewable and Sustainable Energy Reviews, LXX, pp. 989-1007, 2017.

[4]. M. T. Chaichan, H. A. Kazem, T. A. Abid, "Traffic and Outdoor Air Pollution Levels Near Highways in Baghdad, Iraq," Environment, Development and Sustainability, XX (2), pp. 589-603, 2018. DOI: 10.1007/s10668-016-9900-x.

[5]. H. M. S. Al-Maamary, H. A. Kazem, M. T. Chaichan, "Changing the Energy Profile of the GCC States: A Review," International Journal of Applied Engineering Research (IJAER), XI (3), pp. 1980-1988, 2016.

[6]. H. M. S. Al-Maamary, H. A. Kazem, M. T. Chaichan, "Renewable Energy and GCC States Energy Challenges in the 21st Century: A Review," International Journal of Computation and Applied Sciences IJOCAAS, II (1), pp. 11-18, 2017.

[7]. H. M. S. Al-Maamary, H. A. Kazem, M. T. Chaichan, "Climate Change: The Game Changer in the GCC Region," Renewable and Sustainable Energy Reviews, LXXVI, pp. 555-576, 2017.

[8]. M. T. Chaichan, H. A. Kazem, "Generating Electricity Using Photovoltaic Solar Plants in Iraq," Springer, ISBN: 978-3-319-75030-9. https://doi.org/10.1007/978-3-319-75031-6

[9]. H. Mazin H, H. A. Kazem, H. A. Fadhil, S. A. Aljunid, Q. M. Abdulmajeed, M. T. Chaichan, "Linear and Nonlinear Modeling for Solar Energy Prediction for Zone, Region and Global Areas," Chapter in Renewable Energy in the Service of Mankind, II, pp. 21-34, 2015.

[10]. H. A. Kazem and M. T. Chaichan, Design and analysis of standalone solar cells in the desert of Oman, Journal of Scientific and Engineering Research, vol. 3, No. 4, pp. 62-72, 2016.

[11]. H. A. Kazem and M. T. Chaichan, Wind Resource Assessment for nine locations in Oman, International Journal of Computation and Applied Sciences IJOCAAS, vol. 3, No. 1, pp. 185-191, 2017.

[12]. M. T. Chaichan & Ahmed S T, Evaluation of performance and emissions characteristics for compression ignition engine operated with disposal yellow grease, International Journal of Engineering and Science, vol.2, No. 2, pp. 111-122, 2013.

[13]. M. T. Chaichan, Performance and emission study of diesel engine using sunflowers oil-based biodiesel fuels, International Journal of Scientific and Engineering Research, vol. 6, No. 4, pp. 260-269, 2015.

[14]. M. T. Chaichan, Combustion and emission characteristics of E85 and diesel blend in conventional diesel engine operating in PPCI mode, Thermal science and Engineering progress, vol. 7, pp. 45-53 2018. https://doi.org/10.1016/j.tsep.2018.04.013

[15]. M. T. Chaichan, "Performance and Emissions Characteristics of CIE using Hydrogen, Biodiesel, and Massive EGR," International Journal of Hydrogen Energy, XLIII, pp. 5415-5435, 2018.

[16]. M. T. Chaichan, "EGR Effects on Hydrogen Engines Performance and Emissions," International Journal of Scientific and Engineering Research, VII (3), pp. 80-90, 2016.

[17]. M. T. Chaichan, "Safety Using of Hydrogen as Vehicle Fuel: A Review," International Journal of Computation and Applied Sciences IJOCAAS, IV (2), pp. 316-323, 2018.

[18]. M. T. Chaichan, D. S. M. Al-Zubaidi, "A Practical Study of Using Hydrogen in Dual – Fuel Compression Ignition Engine," International Journal of Mechanical Engineering (IIJME), II (11), pp. 1-10, 2014.

[19]. H. A. Kazem, M. T. Chaichan, "Experimental Analysis of the Performance Characteristics of PEM Fuel Cells," International Journal of Scientific & Engineering Research, VII (2), pp. 49-56, 2016.

[20]. H. A. Kazem, A. H. A. Al-Waeli, A. S. A. Al-Mamari, A. H. K. Al-Kabi, M. T. Chaichan, "A Photovoltaic Application in Car Parking Lights with Recycled Batteries: A Techno-Economic Study," Australian Journal of Basic and Applied Science, IX (36), pp. 43-49, 2015.

[21]. M. T. Chaichan, K. I. Abass& H. M. Salih, "Practical Investigation for Water Solar Thermal Storage System Enhancement Using Sensible and Latent Heats in Baghdad-Iraq Weathers," Journal of Al-Rafidain University Collage for Science, XXXIII, pp. 158-182, 2014.

[22]. H. A. Kazem, H. S. Aljibori, F. N. Hasoon and M. T. Chaichan, "Design and Testing of Solar Water Heaters with its Calculation of Energy," Int. J. of Mechanical Computational and Manufacturing Research, I (2), pp. 62-66, 2012.

[23]. M. T. Chaichan, A. J. Ali, K. I. Abass, "Experimental Study on Solar Air Heating," Al-Khawarizmi Eng. Journal, XIV (1), pp. 1-9, 2018.

[24]. M. T. Chaichan, K. I. Abass, D. S. M. Al-Zubidi, H. A. Kazem, "Practical Investigation of Effectiveness of Direct Solar-Powered Air Heater," International Journal of Advanced Engineering, Management and Science (IJAEMS), II (7), pp.1047-1053, 2016.

[25]. M. T. Chaichan, K. I. Abass, F. F. Hatem, "Experimental Study of Water Heating Salt Gradient Solar Pond Performance in Iraq," Industrial Applications of Energy Systems (IAES09), Sohar University, Oman, 2009.

[26]. M. T. Chaichan & K. I. Abass, "Productivity Amelioration of Solar Water Distillator Linked with Salt Gradient Pond," Tikrit Journal of Engineering Sciences, XIX (4), pp. 24-34, 2012.

[27]. M. T. Chaichan, H. A. Kazem & K. I. Abass, Improving Productivity of Solar Water Distillator Linked with Salt Gradient Pond in Iraqi Weather," World Congress on Engineering 2012, London, UK, 4-6 July, 2012

[28]. M. T. Chaichan, K. I. Abass, H. A. Kazem, "Design and Assessment of Solar Concentrator Distillating System Using Phase Change Materials (PCM) Suitable for Desertec Weathers," Desalination and water treatment, LVII (32), pp. 14897-14907, 2016. DOI: 10.1080/19443994.2015.1069221
[29]. M. T. Chaichan, "Enhancing Productivity of Concentrating Solar Distillating System Accompanied with PCM at Hot Climate," Wulevina, XXIII (5), pp. 1-18, 2016.
[30]. M. T. Chaichan, H. A. Kazem, K. I. Abass, A. A. Al-Waeli, "Homemade Solar Desalination System for Omani families," International Journal of Scientific & Engineering Research, VII (5), pp.1499-1504, 2016.
[31]. M. T. Chaichan, H. A. Kazem, "Single Slope Solar Distillator Productivity Improvement Using Phase Change Material and Al2O3 Nanoparticle," Solar Energy, CLXVI, pp. 370-381, 2018.
[32]. M. T. Chaichan, K. I. Abass, R. S. Jawad, A. M. J. Mahdy, "Thermal Performance Enhancement of Simple Trombe Wall," International Journal of Computation and Applied Sciences IJOCAAS, II (1), pp. 33-40, 2017
[33]. M. T. Chaichan, K. I. Abass, D. S. M. Al-Zubidi, "A Study of a Hybrid Solar Heat Storage Wall (Trombe Wall) Utilizing Paraffin Wax and Water," Journal of Research in Mechanical Engineering, II (11), pp. 1-7, 2016
[34]. M. T. Chaichan, A. H. Al-Hamdani, A. M. Kasem, "Enhancing a Trombe Wall Charging and Discharging Processes by Adding Nano-Al2O3 to Phase Change Materials," International Journal of Scientific & Engineering Research, VII (3), pp. 736-741, 2016
[35]. M. T. Chaichan, K. I. Abass, "Performance Amelioration of a Trombe Wall by Using Phase Change Material (PCM)," International Advanced Research Journal in Science, Engineering and Technology, II (4), pp. 1-6, 2015.
[36]. M. T. Chaichan & H. A. Kazem, "Thermal Storage Comparison for Variable Basement Kinds of a Solar Chimney Prototype in Baghdad - Iraq Weathers," International journal of Applied Science (IJAS), II (2), pp. 12-20, 2011.
[37]. S. T. Ahmed & M. T. Chaichan, "A Study of Free Convection in a Solar Chimney Sample," Engineering and Technology J, XXIX (14), pp. 2986-2997, 2011.
[38]. M. T. Chaichan, K. I. Abass& H. A. Kazem, "The Effect of Variable Designs of the Central Receiver to Improve the Solar Tower Efficiency," International J of Engineering and Science, I (7), pp. 56-61, 2012.
[39]. M. T. Chaichan & K. I. Abass, "Practical Investigation for Improving Concentrating Solar Power Stations Efficiency in Iraqi Weathers," Anbar J for Engineering Science, V (1), pp. 76-87, 2012.
[40]. M. T. Chaichan & K. I. Abass, "Practical Investigation for Measurement of Concentrating Solar Power Prototype for Several Target Cases at Iraqi Summertime Weathers," 1st Scientific Conference for Energy & Renewable Energies Applications, UOT, Baghdad, Iraq, 2011.
[41]. M. T. Chaichan, H. A. Kazem, A. A. Kazem, K. I. Abass, K. A. H. Al-Asadi, "The Effect of Environmental Conditions on Concentrated Solar System in Desertec Weathers," International Journal of Scientific and Engineering Research, VI (5), pp. 850-856, 2015.
[42]. H. A. Kazem, F. Hasson and M. T. Chaichan, "Design and Analysis of Stand-Alone Solar Photovoltaic for Desert in Oman," The 3rd Scientific International Conference, Technical College, Najaf, Iraq, 2013.
[43]. A. H. A. Al-Waeli, A. H.K. Al-Kabi, A. Al-Mamari, H. A. Kazem and M. T. Chaichan, "Evaluation of the Economic and Environmental Aspects of Using Photovoltaic Water Pumping System," Book ISBN: 978-981-10-1719-3, pp. 1-9, 2016.
[44]. M. T. Chaichan, H. A. Kazem, A. M. J. Mahdy& A. A. Al-Waeely, "Optimal Sizing of a Hybrid System of Renewable Energy for Lighting Street in Salalah-Oman Using Homer Software," International Journal of Scientific Engineering and Applied Science (IJSEAS), II (5), pp. 157-164, 2016.
[45]. M. T. Chaichan, H. A. Kazem, A. M. J. Mahdy& Al-Waeely A A, "Optimization of Hybrid Solar PV/ Diesel System for Powering Telecommunication Tower," IJESET, VIII (6), pp. 1-10, 2016.
[46]. M. T. Chaichan, H. A. Kazem, "Experimental Analysis of Solar Intensity on Photovoltaic in Hot and Humid Weather Conditions," International Journal of Scientific & Engineering Research, VII (3), pp. 91-96, 2016.
[47]. H. A. Kazem, M. T. Chaichan, "Effect of Environmental Variables on Photovoltaic Performance-Based on Experimental Studies," International Journal of Civil, Mechanical and Energy Science (IJCMES), II (4), pp. 1-8, 2016.
[48]. H. A. Kazem, M. T. Chaichan, A. H. A. Al-Waeli, K. Mani, "Effect of Shadows on the Performance of Solar Photovoltaic," Mediterranean Green Buildings & Renewable Energy, pp.379-385, 2017, DOI: 10.1007/978-3-319-30746-6_27

[49]. H. A. Kazem, M. T. Chaichan, "The Impact of Using Solar Colored Filters to Cover the PV Panel on Its Outcomes," Bulletin Journal, II (7), pp. 464-469, 2016. DOI: 10.21276/sb.2016.2.7.5.
[50]. R. T. A. Hamdi, S. H. Hafed, M. T. Chaichan, H. A. Kazem, "Dust Impact on the Photovoltaic Outcomes," International Journal of Computation and Applied Sciences, V (2), pp. 385-390, 2018.
[51]. M. T. Chaichan, H. A. Kazem, "Effect of Sand, Ash and Soil on Photovoltaic Performance: An Experimental Study," International Journal of Scientific Engineering and Science, I (2), pp. 27-32, 2017.
[52]. M. T. Chaichan, K. I. Abass, H. A. Kazem, "Dust and Pollution Deposition Impact on a Solar Chimney Performance," International Research Journal of Advanced Engineering and Science, III (1), pp. 127-132, 2018.
[53]. M. T. Chaichan, K. I. Abass, H. A. Kazem, "Energy Yield Loss Caused by Dust and Pollutants Deposition on Concentrated Solar Power Plants in Iraq Weathers," International Research Journal of Advanced Engineering and Science, III (1), pp. 160-169, 2018.
[54]. H. A. Kazem and M. T. Chaichan, "Effect of Humidity on Photovoltaic Performance Based on Experimental Study," International Journal of Applied Engineering Research (IJAER), X (23), pp. 43572-43577, 2015.
[55]. A. H. A. Al-Waeli, K. Sopian, H. A. Kazem and M. T. Chaichan, "Photovoltaic Solar Thermal (PV/T) Collectors Past, Present and Future: A Review," International Journal of Applied Engineering Research, XI (22), pp. 1075-10765, 2016.
[56]. A. H. A. Al-Waeli, K. Sopian, M. T. Chaichan and H. A. Kazem, H. A. Hasan, A. N. Al-Shamani, "An Experimental Investigation on Using of Nano-Sic-Water as Base-Fluid for Photovoltaic Thermal System," Energy Conservation and Management, CXLIV, pp. 547-558, 2017.
[57]. A. H. A. Al-Waeli, K. Sopian, H. A. Kazem and M. T. Chaichan, "PV/T (Photovoltaic/Thermal): Status and Future Prospects," Renewable and Sustainable Energy Review, LXXVII, pp. 109-130, 2017.
[58]. A. H. A. Al-Waeli, K. Sopian, H. A. Kazem and M. T. Chaichan, "Photovoltaic Thermal PV/T Systems: A Review," International Journal of Computation and Applied Sciences IJOCAAS, II (2), pp. 62-67, 2017.
[59]. A. H. A. Al-Waeli, M. T. Chaichan, H. A. Kazem, K. Sopian, "Comparative Study to Use Nano-(Al2O3, CuO, and SiC) with Water to Enhance Photovoltaic Thermal PV/T Collectors," Energy Conversion and Management, CXLVIII (15), pp. 963-973, 2017.
https://doi.org/10.1016/j.enconman.2017.06.072
[60]. A. H. A. Al-Waeli, Sopian K, M. T. Chaichan, H. A. Kazem, Ibrahim A, Mat S and Ruslan M H, Evaluation of the nanofluid and nano-PCM based photovoltaic thermal (PVT) system: An experimental study, Energy Conversion and Management, vol. 151, pp. 693–708, 2017.
[61]. A. H. A. Al-Waeli, M. T. Chaichan, K. Sopian, H. A. Kazem, "Energy Storage: CFD Modeling of Thermal Energy Storage for a Phase Change Materials (PCM) added to a PV/T Using Nanofluid as a Coolant," Journal of Scientific and Engineering Research, IV (12), pp. 193-202, 2017.
[62]. A. H. A. Al-Waeli, K. Sopian, H. A. Kazem, J. H. Yousif, M. T. Chaichan, A. Ibrahim, S. Mat and M. H. Ruslan, "Comparison of Prediction Methods of PV/T Nanofluid and Nano-PCM System Using a Measured Dataset and Artificial Neural Network," Solar Energy, CLXII, pp. 378-396, 2018.
[63]. A. H. A. Al-Waeli, M. T. Chaichan, K. Sopian and H. A. Kazem, "Comparison Study of Indoor/Outdoor Experiments of SiC Nanofluid as a Base-Fluid for a Photovoltaic Thermal PV/T System Enhancement," Energy, CLI, pp. 33-44, 2018
[64]. A. H. A. Al-Waeli, H. A. Kazem, K. Sopian and M. T. Chaichan, "Techno-Economical Assessment of Grid Connected PV/T Using Nanoparticles and Water as Base-Fluid Systems in Malaysia," International Journal of Sustainable Energy, XXXVII (6), pp. 558-578, 2018.
DOI: 10.1080/14786451.2017.1323900
[65]. A. H. A. Al-Waeli, M. T. Chaichan, H. A. Kazem, K. Sopian, A. Ibrahim, S. Mat, M. H. Ruslan, "Numerical Study on the Effect of Operating Nanofluids of Photovoltaic Thermal System (PVT) on The Convective Heat Transfer," Case Study in Thermal Engineering, XII, pp. 405-413, 2018.
https://doi.org/10.1016/j.csite.2018.05.011
[66]. H. Mazin, H. A. Kazem, H. A. Fadhil, S. Alawi, Q. Mazin and M. T. Chaichan, "Linear and Nonlinear Modeling for Solar Energy Prediction on the Zone, Region and Global," World Renewable Energy Council/Network (WREC XIII), London, UK, 3-8 August, 2014.
[67]. H. Mazin, H. A. Kazem, H. A. Fadhil, S. A. Aljunid, Q. M. Abdulmajeed, M. T. Chaichan, "Linear and Nonlinear Modeling for Solar Energy Prediction for Zone, Region and Global Areas," Chapter in Renewable Energy in the Service of Mankind, Vol. II, Springer, pp. 21-34, 2015.

[68]. H. A. Kazem and M. T. Chaichan, "Experimental Effect of Dust Physical Properties on Photovoltaic Module in Northern Oman," Solar Energy, CXXXIX, pp. 68–80, 2016. http://dx.doi.org/10.1016/j.solener.2016.09.019
[69]. M. T. Chaichan, B. A. Mohammed and H. A. Kazem, "Effect of Pollution and Cleaning on Photovoltaic Performance Based on Experimental Study," International Journal of Scientific and Engineering Research, VI (4), pp. 594-601, 2015.
[70]. E. B. Ettah, A. P. Udoimuk, J. N. Obiefuna and F. E. Opara, The Effect of Relative Humidity on the Efficiency of Solar Panels in Calabar, Nigeria," Universal Journal of Management and Social Sciences, II (3), pp. 8-11, 2012.
[71]. M. Koehl, M. Heck and S. Wiesmeier, "Modeling of Conditions for Accelerated Life Time Testing of Humidity Impact on PV-Modules Based on Monitoring of Climatic Data, Solar Energy Materials & Solar Cells XCIX, pp. 282–291, 2012.
[72]. H. K. Elminir, V. Benda and J. Tousek, "Effects of Solar Irradiation Conditions and other Factors on the Outdoor Performance of Photovoltaic Modules," Journal of Electrical Engineering, LII (5-6), pp. 125-133, 2001.
[73]. M. D. Kempe, "Modeling of Rates of Moisture Ingress into Photovoltaic Modules," Solar Energy Materials and Solar Cells, XC (16), pp. 2720–2738, 2006.
[74]. N. C. Park, W. W. Oh and D. H. Kim, "Effect of Temperature and Humidity on the Degradation Rate of Multicrystalline Silicon Photovoltaic Module," International Journal of Photo-energy, Article ID 925280, 9 pages, 2013.
[75]. A. H. A. Al-Waeli, K. Sopian, M. T. Chaichan, H. A. Kazem, A. Ibrahim, S. Mat and M. H. Ruslan, "Evaluation of the Nanofluid and Nano-PCM Based Photovoltaic Thermal (PVT) System: An Experimental Study," Energy Conversion and Management, CLI, pp. 693–708, 2017.
[76]. Rotronic Instrument Corp., The Rotronic Humidity Handbook, All you never wanted to know about Humidity and didn’t want to ask! 12/2005. www.rotronic-usa.com
[77]. A. H. Fanney, M. W. Davis, B. P. Dougherty, D. L. King, W. E. Boyson and J. A. Kratochvil, "Comparison of Photovoltaic Module Performance Measurements," Transactions of the ASME, LXXVIII, May, 2006.
[78]. Y. Charabi, B. H. M. Rhouma, A. Gastli, "GIS-Based Estimation of Roof-PV Capacity & Energy Production for the Seeb Region in Oman," IEEE International Energy Conference, Renewable Energy, LVII, pp. 635-644, 2013.
[79]. K. Morita, T. Inoue, H. Kato, I. Tsuda and Y. Hishikawa, "Degradation Factor Analysis of Crystalline-Si PV Modules Through Long-Term Field Exposure Test," in Proceedings of the 3rd World Conference on Photovoltaic Energy Conversion, pp. 1948–1951, May 2003.
[80]. N. G. Dhere and N. R. Raravikar, "Adhesion Shear Strength and Surface Analysis of a PV Module Deployed in Harsh Coastal Climate," Solar Energy Materials and Solar Cells, LXVII (1–4), pp. 363–367, 2001.
[81]. X. Han, Y. Wang, L. Zhu, H. Xiang and H. Zhang, "Mechanism Study of the Electrical Performance Change of Silicon Concentrator Solar Cells Immersed in De-Ionized Water," Energy Conversion and Management, LIII (1), pp. 1–10, 2012.
[82]. B. Bhattachary, S. Dey and B. Mustaphi, "Some Analytical Studies on the Performance of Grid Connected Solar Photovoltaic System with Different Parameters," proceeding to 3rd International Conference on Material Processing and Materials Science Characterization (ICMPC- 2014), VI, pp. 1942-1950, 2014.
[83]. J. K. prakash, N. Gopinath and V. Kirubakaran, "Optimization of Solar PV Panel Output: A Viable and Cost Effective Solution," International Journal of Advanced Technology & Engineering Research (IJATER) National Conference on "Renewable Energy Innovations for Rural Development" ISSN No: 2250-3536 20, New Delhi, 2014.
[84]. A. A. Katkar, N. shinde, G. C. Koli and S. P. Gaikwad, "Evaluation of Industrial Solar Cell W.R.T. Temperature," IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), I (1), pp. 27-38, 2011.
[85]. H. A. Kazem, M. T. Chaichan, I. M. Al-Shezawi, H. S. Al-Saidi, H. S. Al-Rubkhi, J. K. Al-Sinani and A. H. A. Al-Waeli, Effect of Humidity on the PV Performance in Oman, Asian Transactions on Engineering, Vol. 2, No. 4, pp. 29-32, 2012.
[86]. T. Al Hanai, R. B. Hashim, L. El Chaar L and L. A. Lamont, "Environmental Effects on a Grid Connected 900 W Photovoltaic Thin-Film Amorphous Silicon System," Renewable Energy, XXXVI, pp. 2615-2622, 2011.

[87]. E. Klampaftis, K. R. McIntosh and B. S. Richards, "Degradation of an Undiffused SI–SIO2 Interface due to Humidity," 22nd European Photovoltaic Solar Energy Conference, 3-7 September, Milan, Italy, 2007.
[88]. A. Rachman, K. Sopian, S. Mat and M. Yahya, "Feasibility Study and Performance Analysis of Solar Assisted Desiccant Cooling Technology in Hot and Humid Climate," American Journal of Environmental Sciences, VII (3), pp. 207-211, 2011.
[89]. B. A. L. Gwandu, D. J. Creasey, "Humidity: A Factor in the Appropriate Positioning of a Photovoltaic Power Station," Renewable Energy, VI (3), pp. 313-316, 1995.
[90]. Z. A. Darwish, H. A. Kazem, K. Sopian, M. A. Alghoul and M. T. Chaichan, "Impact of Some Environmental Variables with Dust on Solar Photovoltaic (PV) Performance: Review and Research Status," International Journal of Energy and Environment, VII (4), pp. 152-159, 2013.
[91]. V. B. Omubo-Pepple, C. Israel-Cookey and G. I. Alamunokuma, "Effects of Temperature, Solar Flux and Relative Humidity on the Efficient Conversion of Solar Energy to Electricity," European Journal of Scientific Research, XXXV, pp. 173-180, 2009.
[92]. M. K. Panjwani, G. B. Narejo, "Effect of Humidity on the Efficiency of Solar Cell (Photovoltaic)," International Journal of Engineering Research and General Science, II (4), pp. 499-503, 2014.
[93]. V. B. Omubo-Pepple, I Tamunobereton-ari and M. A. Briggs-Kamara, "Influence of Meteorological Parameters on the Efficiency of Photovoltaic Module in Some Cities in the Niger Delta of Nigeria," Journal of Asian Scientific Research, III (1), pp. 107-113, 2013.
[94]. M. Chegaar, P. Mialhe, "Effect of Atmospheric Parameters on the Silicon Solar Cells Performance," Journal of Electron Devices, VI, pp. 173-176, 2008.
[95]. S. Mekhilef, R. Saidur, M. Kamalisarvestani, "Effect of Dust, Humidity and Air Velocity on Efficiency of Photovoltaic Cells," Renewable and Sustainable Energy Reviews, XVI, pp. 2920- 2925, 2012.
[96]. G. Oreski, G. M. Wallner, "Evaluation of the Aging Behavior of Ethylene Copolymer Films for Solar Applications under Accelerated Weathering Conditions," Solar Energy, LXXXIII, pp. 1040-1047, 2009.
[97]. T. Kojima, T. Yanagisawa, "The Evaluation of Accelerated Test for Degradation a Stacked A-Si Solar Cell and EVA Films," Solar Energy Materials & Solar Cells, LXXXI (1), pp. 119-123, 2004.
[98]. R. Laronde, A. Charki and D. Bigaud, "Lifetime Estimation of a Photovoltaic Module Subjected to Corrosion Due to Damp Heat Testing," Journal of Solar Energy Engineering, CXXXV (2), Article ID 021010, 8 pages, 2013.
[99]. C. Peike, S. Hoffmann and P. Hulsmann, "Origin of Damp Heat Induced Cell Degradation," Solar Energy Materials and Solar Cells, CXVI, pp. 49–54, 2013.
[100]. F. Touati, A. Massoud, J. Abu Hamad and S. A. Saeed, "Effects of Environmental and Climatic Conditions on PV Efficiency in Qatar," International Conference on Renewable Energies and Power Quality (ICREPQ'13), Bilbao (Spain), 20th to 22th March, 2013.
[101]. M. D. Kemp, "Control of Moisture Ingress into Photovoltaic Modules,: In: 31st IEEE Photovoltaic Specialists Conference and Exhibition, Lake Buena Vista, Florida, 2005.
[102]. J. H. Wohlgemuth, S. Kurtz, "Reliability Testing Beyond Qualification as a Key Component in Photovoltaics' Progress Toward Grid Parity," proceeding in IEEE International Reliability Physics Symposium Monterey, California, April 10-14, 2011.
[103]. M. A. Munoz, M. C. Alonso-Garcia, V. Nieves and F. Chenlo, "Early Degradation of Silicon PV Modules and Guaranty Conditions," Solar Energy, LXXXV, pp. 2264-2274, 2011.
[104]. A. Skoczek, T. Sample, E. D. Dunlop, H. A. Ossenbrink, "Electrical Performance Results from Physical Stress Testing of Commercial PV Modules to the IEC61215 Test Sequence," Solar Energy Materials & Solar Cells, XCII, pp. 1593-1604, 2008.
[105]. M. D. Kempe, "Modeling of Rates of Moisture Ingress into Photovoltaic Modules," Solar Energy Materials and Solar Cells, XC (16), pp. 2720-2738, 2006.
[106]. A. Ndiaye, A. Charki, A. Kobi, C. M. F. Ke´be´, P. A. Ndiaye, V. Sambou, "Degradations of Silicon Photovoltaic Modules: A Literature Review," Solar Energy, XCVI, pp. 140-151, 2013.
[107]. D. Berman, D. Faiman, "EVA Browning and the Time-Dependence of I-V Curve Parameters on PV Modules with and Without Mirror Enhancement in a Desert Environment," Solar Energy Materials & Solar Cells, XLV (4), pp. 401-412, 2007.
[108]. J. H. Wohlgemuth, D. W. Cunningham, A. M. Nguyen, J. Miller, "Long Term Reliability of PV Modules," In: Proc. 20th European Photovoltaic Solar Energy Conference, pp. 1942-1946, 2005.
[109]. C. R. Osterwald, A. Anderberg, S. Rummel, L. Ottoson, "Degradation Analysis of Weathered Crystalline-Silicon PV Modules," In: 29th IEEE Photovoltaic Specialists Conference, New Orleans, Louisiana, 2002.

[110]. J. H. Wohlgemuth, D. W. Cunningham, A. M. Nguyen, G. Kelly, D. Amin, "Failure Modes of Crystalline Silicon Modules," In: Proceedings of PV module reliability workshop, 2010.
[111]. E. Rueland, A. Herguth, A. Trummer, S. Wansleben and P. Fath, "Optical l-Crack Detection in Combination with Stability Testing for inline Inspection of Wafers and Cells," In: Proceedings of 20th EUPVSEC, Barcelona, pp. 3242-3245, 2005.
[112]. W. Dallas, O. Polupan, S. Ostapenko, "Resonance Ultrasonic Vibrations for Crack Detection in Photovoltaic Silicon Wafers," Measurement Science and Technology, XVIII, pp. 852-858, 2007.
[113]. IEC: International Electro-technical Commission, Standard IEC61215: Crystalline Silicon Terrestrial Photovoltaic (PV) Modules, Design Qualification and Type Approval IEC Central Office, Geneva, Switzerland. 1987.
[114]. K. W. Jansen, A. E. Delahoy, "A Laboratory Technique for the Evaluation of Electrochemical Transparent Conductive Oxide Delamination From Glass Substrates," Thin Solid Films, CDXXIII, pp. 153-160, 2003.
[115]. G. Oreski, G. M. Wallner, "Aging Mechanisms of Polymeric Films for PV Encapsulation," Solar Energy, LXXIX, pp. 612-617, 2005.