Analysis of Dust Properties and Deposition Loss in Mono and Poly Crystalline Photovoltaic Modules in Southern Rajasthan

Manoj Lakhan[1], Ram Kumar Mathur[2]

[1]Department of Physics MLV Government College Bhilwara, India
Corresponding Author Email: *mlakhan1975[at]gmail.com*
Tel: +919460707379

[2]Department of Physics SPC Government College Ajmer, India

Abstract: ***Among all the renewable energy conversion technologies available on this earth, solar photovoltaic system is very important. The conversion of solar energy into electrical energy depends on the intensity of radiation coming from the sun, its spectrum, optical and electrical properties of the material used in making solar cells, geographical, atmospheric conditions of a particular place and compatibility with electronic devices etc. Except radiation and temperature in the atmosphere, dust makes radical change in the characteristics of solar panel properties. As dust accumulates on solar panels, their performance decreases and electrical power is reduced. The effect of dust on solar panels has been studied for the last several years, but at every site, the effect of dust on the properties of solar panels is unique and detrimental. Dust accumulation depends on the geographical and atmospheric conditions of the place, the origin of resources of dust at a particular place, wind speed, wind direction, chemical composition, humidity, temperature, rain and dust generation pattern etc. In this paper, chemical composition of dust, presence of various pollutants, its morphological study using SEM EDX technique has been done. Although the impact of dust deposition on the execution of sun powered panels has already been investigated by researchers but comparative study for two different and popular technologies; mono - crystalline and poly - crystalline in particularly Southern Rajasthan region which have not been addressed. Therefore in this work, dust mechanism and their effect on the performance has been analyzed and examined. To understand how dust impacts solar cell efficiency, we use scanning electron microscopy (SEM) and XRD techniques. The findings demonstrated that dust accumulation significantly affects solar cell efficiency. There was an average 14% drop in power output from poly - crystalline modules and an 18% drop from mono - crystalline ones. We also investigate that there is 3.45% decrease in efficiency for mono - crystalline module and 2.97% decrease in efficiency of poly - crystalline module. The results also show loss of power and efficiency is greater and higher in mono - crystalline module as compared to poly - crystalline solar module. This research illustrates how dust affects the output of photovoltaic modules that use sunlight for power generation. We compare mono - crystalline and poly - crystalline solar modules throughout several research locations, and we go over some solutions for cleaning the panels so they work better and can produce more electricity when the dust comes in performance domain***.

Keywords: Solar cell, dust impact, efficiency, performance, SEM

1. Introduction

The environmental and climatic effects such as dust, temperature, solar radiation, humidity, wind and solar insolation have their impact on execution of sun oriented cell module. The efficiency and power output of PV solar panel determined by dust factor. Quantity and pattern of dust settling pattern depends upon environmental changes, climatic changes and topographical conditions. Size of dust particles have very crucial role in deposition process and strength of covalent bonds with the outer layer of PV module. If size of dust partial is greater than wavelength of incoming radiation, then it promote scattering and reduce the radiation coming onto the surface panel and thereby degrade the performance and output power of solar PV module. Due to absorption of radiation and scattering of radiation by dust particles, transitivity of glass of the panel will decrease which further lead to degradation in the efficiency. Dust not only decreases the electromagnetic radiation on the solar panel but also changes the dependence on the angle of incidence of incoming radiation. The surface of module made up of glass sheet which is mechanically strong and flexible enough, is greatly influenced by dust accumulation, which in turn deteriorate the efficiency of panel. Dust accumulation became more challenging and problematic under high humidity condition. In humid atmospheric condition dust particles interacts with water which is present in moisture form and create mud. Alkaline metals (Na, K etc.) soluble in water and some not soluble substances ($CaCO_3$ etc.) after mixing remain with contact with the surface of panel because strong adhesive forces between surface and dust. Consequently this micro sheet of dust remain stick with the surface and modify the chemical and physical properties of the surface of including texture of the surface, optical properties, stress level and hydrophobicity of the glass. In these way optical and thermal properties gets alter and this change affects the PV module efficiency.

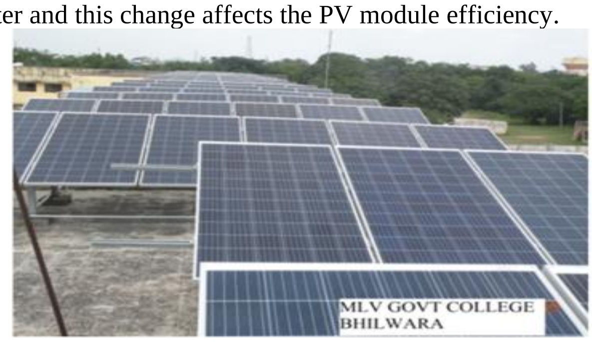


Figure 1: Dusty Solar panels at M. L. V. Govt. College Bhilwara

The purpose of this research at Bhilwara is to find out how dust affects the efficiency, output voltage, power, and short circuit current of solar panels in this particular location. The amount of radiation that may pass through a photovoltaic module depends on how much dust settles on its surface. The Bhilwara location is one of many places where dust gets accumalated. We used analytical instruments available at several institutions to measure the weight, size, form, and most significantly, elemental makeup of dust particles collected from various sites. Approximately 4gm/m^2 of dust settles onto solar module surfaces after 15 days of external exposure, and this quantity fluctuates between 16 and 18% after a year of full exposure without manual cleaning. Wind speed and wind direction affect the quantity of dust accumulation.

This experiment work was designed to investigate and quantify the impact of dust kept on the outer layer of two distinct kinds of photovoltaic module. That is mono - crystalline and poly - crystalline silicon. Two modules with different technical specification and manufacturing technique were utilized and saved in normal air for three months. At different intensity levels, we note different electrical parameters, Voc, Isc, Vmax, Imax and Pmax to find out various losses due to dust deposition. We take four samples of dust from Bhilwara, Banera, Hamirgarh and Chittorgarh for finding the overall dust deposition effect in Southern Rajasthan.

2. Literature Review

Azouzlate et al. (2000) [1] noticed that dust was the most significant parameter shown to directly affect PV modules. They demonstrated that dust accumulation on PV modules may alter electrical characteristics and significantly reduce module efficiency and output.

Dida et al. (2020) [2] discover that the efficiency of solar cells is much lower in natural environments compared to controlled laboratory settings. This is due to the fact that dust limits the transmittance of the glass, leading to a drop in the energy production. Experimenters in the Saharan city of Ouargla set out to determine how dust deposition affected the performance of crystalline PV modules operating in outdoor settings. Scientists have shown that the short circuit current generated by PV cells is directly related to the solar irradiation and inversely proportional to the density of dust deposits. After 4 weeks of outside exposure, the dusty module's power output was 5.71 percent lower than the clean module, and after 8 weeks of exposure, it increased to 8.41 percent lower.

Ali et al., (2017) [3] examined the effect of dust on the surfaces of two types of solar panels mono crystalline silicon and polycrystalline silicon. For three months during winter in Taxila, Pakistan, researchers utilized two modules of different technologies and left one by one module outside in the open ground. The final result of the experiment showed a dust density of 0.9867 mg/cm^2 on the surface of the PV module. According to these findings, the efficiency of PV modules declined dramatically as dust accumulation increased. As a whole, mono crystalline modules had a 20% drop in production and polycrystalline modules a 16% drop at 0.9867 mg/cm^2. As a result of dust buildup, the module efficiency dropped significantly and fluctuated. Compared to poly - crystalline, the efficiency decreases for mono - crystalline was larger. After 11 weeks of exposure to the environment, the percentage of decrease for mono was 3.55% and for poly it was 3.01%.

When exposed to sunlight, photovoltaic modules transform that energy into usable electricity by means of the creation of electron - hole pairs in the semiconductor layer. A PV module's efficiency is conditional on a number of variables, including geographical ones like longitude and latitude as well as environmental ones like temperature, wind, humidity, pollution, dust, and rain, as well as the specific kind of PV technology used. One of the most important environmental factors affecting the functioning of the modules is dust.

Hussain et al. (2017) [4] looked at the impact of air dust on the efficiency and power output of PV modules in great detail. They looked at the scanning electron micrograph of the dust samples to see what it looked like and how it was shaped. A comparison investigation was conducted with seven distinct dust samples at three different radiation levels (650, 750, and 850W/m^2) and varying weights of dust. The results showed that the output power of the solar PV system was drastically lowered owing to dust collection on its surface.

Kaldellis et al. (2017) [5] studied the impact of dust on the surface of the module and discovered that when the dust density climbed to 0.09 mg/cm^2, the efficiency of the PV module reduced by as much as 0.4%.

Rajput and Sudhakar (2013) [6] looked at how photovoltaic modules react when dust settles on their surfaces, leading to a drop in output voltage. When compared to a clean module, the results reveal a power reduction of up to 92% and an efficiency loss of up to 89%.

Adinoyi and Said (2013) [7] learnt how dust affects the performance of photovoltaic modules in Saudi Arabia. A 50% decrease in power was discovered and studied after six months of exposure to the natural climate.

Cabanillas and Munguia (2011) discovered that a crystalline silicon module's power consumption dropped by 6% and an amorphous silicon module's power consumption dropped by 13% when dust levels rose to 2.326 gm/cm^2 in 20 days. [8]
Kumar et al. (2000), [9] exposed the PV module's performance to dust. According to their findings, the efficiency dropped by 10%, 16%, and 20% when the dust density increased from 0.1gm to 0.2gm and 0.3gm, respectively.

Mohammed and Hasan (2010) discovered a 50% drop in PV efficiency, after looking into the effects of dust on solar panels. [10]

Sulaiman et al. (2011) investigated the effect of dust on PV modules in an indoor research. Module efficiencies were reduced by 18.1% and 16.5% when mud crust and talcum powder were used, respectively. [11] The study of performance loss of solar cells due to outside environment and bird droppings was done in western Rajasthan by Sisodia and Mathur. They studied the morphology of dust and bird dropping samples by SEM technique and told that much relative change solar cell performance occurs due to their chemical composition and particle size. They studied the bird behavior and observe that there is a considerable change in the transmission of solar cells due to bird dropping from October to March. Transmittance decreases by 13 to 15% on increasing the tilt angle from tilt angle 0 to 25°, and by 10% to 24% on increasing the tilt angle from 25° to 60°. [12]

A comparative experimental study of total three dust samples with specific weight and varying radiation levels has been performed by Tulsi Panwar and R. K Mathur. [13] Experimental data shows that power losses are directly related to dust density while inversely related to radiation density and it is also observed that dust collected from solar panels register maximum power loss which was also proven by SEM analysis. Sisodia and Mathur; in their another experimental study, showed that there is a significant loss in output energy yield of photovoltaic system with deposition of dust particles in Western Rajasthan. [14]In the context of physical properties, the XRD and SEM - EDS analysis of the collected dust samples is carried out and observe sediment characteristics of various dust samples in Western Rajasthan. With this consideration, the highest loss is observed in Bikaner dust sample.

Methodology and Experimental Setup

The Experiment and investigation is performed to find the effect of dust accumulation on two different kind of photovoltaic modules so we can prefer and install them at explicit area. After analyzing characters for both type of technology, we are able to know that which one is better at particular site. We compare parameters of mono - crystalline and poly crystalline modules. Two module of each type are used in outdoor experiment in laboratory to determine effect of dust on them. The panels also exposed to outdoor natural atmosphere to study natural airborne dust deposition on module and find that at what extent electrical efficiency and power are altered. Estimations were deducted for four kinds of dust samples tests which are taken from Bhilwara, Banera, Hamirgarh and Chittorgarh. We take different electrical output parameters Voc, Isc, Vmp, Imp and maximum power Pmax for both types of module technologies. The results show that dust accumulating strongly affects the execution of PV module. We also find that after three months the exposure of both types of PV modules, mono - crystalline module showed about 20% decrease in output power and polycrystalline showed 16% decrease in output power. Conclusively loss of power output and efficiency in mono crystalline is more compared to the polycrystalline.

The manufacturer's characteristic specifications are given in the table1 and 2.

Table 1: Manufacturer's characteristic specifications

Particulars	Mono - crystalline	Poly - crystalline
Module dimensions	640mmx320mm	640mmx320mm
Cell dimensions	160mmx80mm	160mmx80mm
No. of cells (in series)	12	12
Total cell area	0.2048m^2	0.2048m^2

Table 2: Appraised upsides of modules at STC

Electrical parameters	Symbols	Mono - crystalline	Poly - crystalline
Max power	Pmax [W]	50	40
Max current	Imax [A]	2.50	2.30
Max voltage	Vmax [V]	20	18
Short circuit current	Isc [I]	2.60	2.50
Open circuit voltage	Voc [V]	23.5	22.6
Fill factor	FF	0.7864	0.7686

Figure represents photograph of dust samples from different locations.

Figure 2: Dust samples

Dust deposition on the surface of PV module in outdoor condition is analyzed. The setup arrange at roof top of M. L. V. Government College Bhilwara to investigate natural atmosphere and climatic effect on performance of solar panels. We take both types of module for determine impact of dust. We take three months exposure of PV panel and note the weekly averaged solar Irradiance at 9 am, 12 pm and 3pm for 12 consecutive weeks in August, September and October.

Figure 3: Experimental set up at natural environment

Figure 4: Instruments for measuring Insolation, Temperature and Humidity

3. Result and Discussion

We have select days for measurement of electrical parameters and climatic factors taken as sunny and cloudless. We plot a graph between solar irradiance and no. of weeks. Over the period of study, the output power continuously reduced due to dust deposition. As well as dust density got higher values, the efficiencies and power of module decrease. The density of dust was 9.879gm/m^{2}after three month of exposure of panel without cleaning. Initial observations shows module efficiency of mono - crystalline and poly - crystalline at different time slots before starting experiment of dust effect.

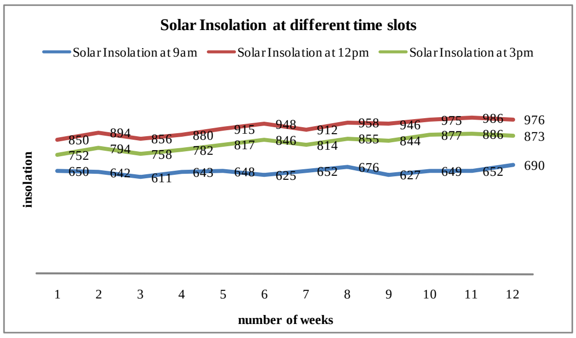


Figure 5: Solar Insolation at different time slots

The sites Bhilwara, Banera, Hamirgarh and Chittorgarh are representative of these environmental and climatic conditions or topography of study area.

Figure 6: Geographical locations of the sampling sites and some of the sampling sites with their atmospheric backgrounds

Adjoining table shows geo maps positions of to all the sampling sites.

Table 3: Local Meteorological Parameters over the Sampling sites.

Sample site	Latitude	Longitude	Weather	Wind speed
Bhilwara	25.33ºN	74.60ºE	clear	2.76m/s
Banera	25.50ºN	74.67ºE	clear	2.96 m/s
Chittorgarh	24.88ºN	74.63ºE	clear	2.14 m/s
Hamirgarh	25.18ºN	74.62ºE	clear	2.52 m/s

The solar conversion efficiency depends on power output of dusty panel. Dust contamination has negative impact on efficiency.

The variation of weekly averaged module efficiency of mono - crystalline and poly - crystalline module at 9 am, 12PM and 3pm are depicted by the following observation table.

Here are graphical representations of these observations as follows

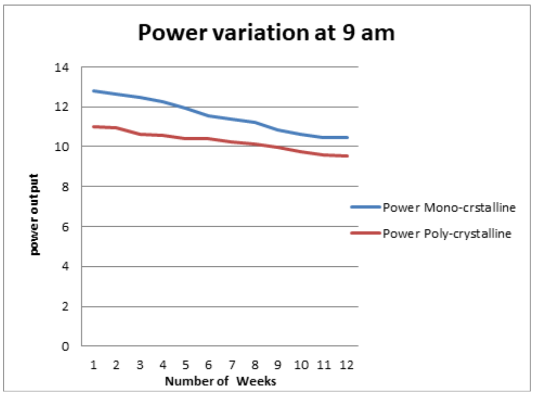


Figure 7: Variation of weekly average power of mono - crystalline and polycrystalline module

Here are graphical representations of these observations as follows

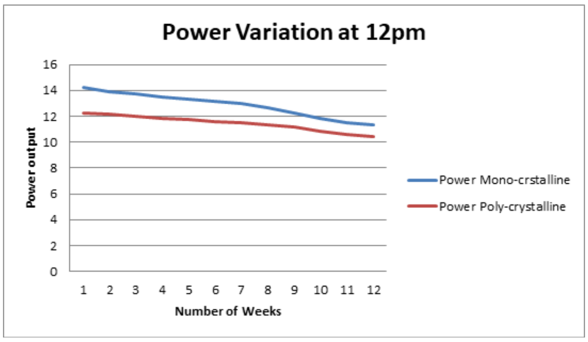


Figure 8: Variation of weekly average power of mono - crystalline and polycrystalline module

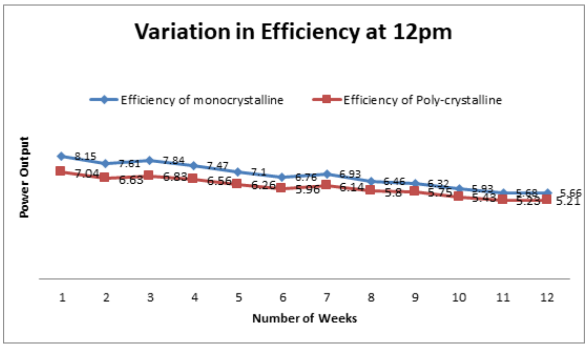


Figure 9: Variation of weekly average Efficiency of mono - crystalline and polycrystalline module

Here are graphical representations of these observations as follows

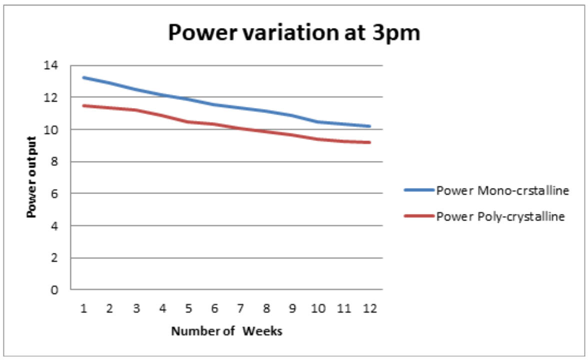


Figure 10: Variation of weekly average power of mono - crystalline and polycrystalline module

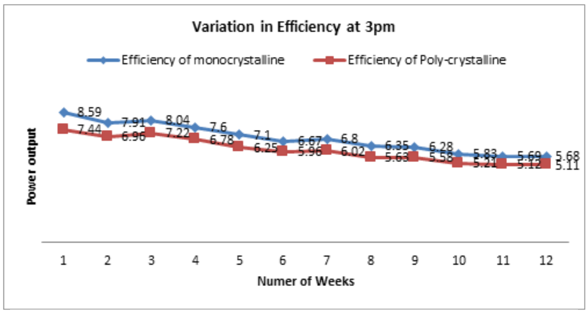


Figure 11: Variation of weekly Efficiency of mono - crystalline and polycrystalline module

We track down that following multi week observations in natural environment. There is 1.48% decrease in power output in mono crystalline module and 0.36% decrease in power output of poly - crystalline module at 9 am. As time laps the dust deposition increases, similar variation can be seen from data at 12pm and 3pm.

After 12 weeks of exposure in natural environment we find that at 9 am, the mono - crystalline module with dust shows 18.43% less power and poly crystalline shows 13.36% less power when we compared with clean module.

In the same way output power of modules 12 pm was 20.21% less for mono crystalline module and 14.92% less for poly crystalline module and at 3pm the output power reduction was 23.11% and 20.13% for mono - crystalline and poly - crystalline respectively.

It was found that mono - crystalline module have much power and higher reduction of power due to dust deposition.

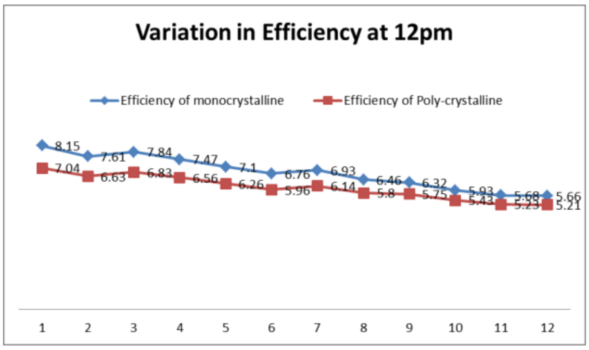


Figure 12: Variation of weekly average Power loss of mono - crystalline and polycrystalline module

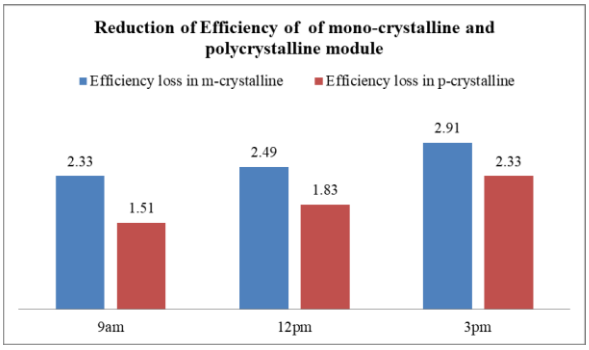


Figure 13: Reduction of Efficiency of mono - crystalline and polycrystalline module compared to clean module

At 9am, 12pm, and 5pm, we observe that the effectiveness of the module declines as the dust collection increases. We discover that after 12 weeks of exposure, the mono type of module reduces power by 20.18% and the poly crystalline module reduces power by 16.13% compared to clean mono - crystalline and poly - crystalline module. Decrease in percentage efficiency can be seen in graphs.

At different dust concentrations, the efficiency of mono and poly type silicon modules is shown in the above graph. After exposure of 12 weeks without cleaning, the percentage reduction in module efficiencies of mono and poly - crystalline was 2.23% and 1.51% at 9 am, 2.49% and 1.83% at 12pm and 2.91% and 2.33% at 3 pm respectively for 9.87gm/m^2 dust deposition.

After 12 weeks of exposure of modules of both types, we find that there is 2.54% reduction in efficiency in mono type and 1.89% reduction efficiency of poly crystalline module.

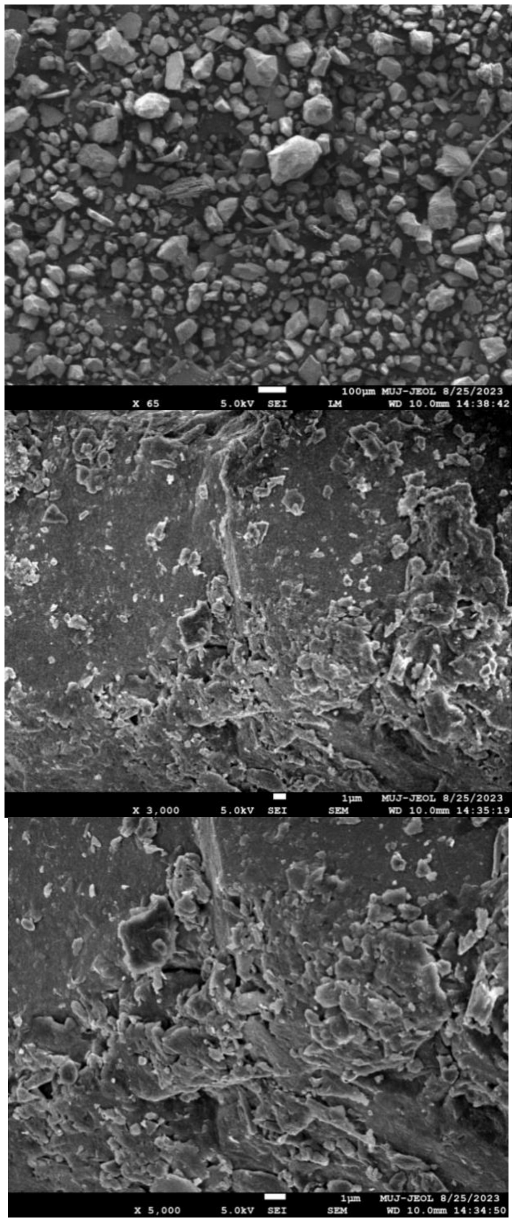
During the study the environmental and climatic conditions were quite stable and stationary and days were clean and sunny. Although rain cleans the panels but it cannot be reliable because of its unpredictable nature. It rains occasionally in Southern Rajasthan. So the main outcome of the study is that regular cleaning of panel is necessary and we cannot ignore it.

A study was conducted to examine the effects of dust collection on photovoltaic modules using mono crystalline and polycrystalline solar technologies. For 12 weeks in a row, data was captured while both kinds of modules were left in nature. After 12 weeks exposure the module get 9.87gm/m^2 dust deposition density and results additionally show that presentation and power both attenuates with increasing dust. When considering dust deposition of 9.87% gm. /m^2, it was discovered that mono - crystalline and poly - crystalline power outputs decreased by 20% and 16%, respectively.

The impact of dust also causes a noticeable decrease in the module's efficiency. The percentage reduction in efficiency was higher in mono - crystalline compared to poly - crystalline. They were 2.54% and 1.89% respectively. In order to keep the efficiency of PV modules at optimum condition, they must be cleaned regularly.

SEM and EDX Analysis of Dust Samples

Surface morphology and chemical analysis of different dust tests were completed using SEM - EDX. Images were taken for finding different shapes and sizes of dust particles. Total four dust tests were gathered for different locations and kept in plastic boxes. Samples were analyzed in Manipal University Jaipur in material science laboratory. We have taken SEM and EDAX APEX data of different dust samples. SEM images reveled that particles was find varying in size diameter ranging from 1.5 µm to 500 µm. From SEM images it was found that dust fall was dominated by spherical, irregular, long tubular and rhombic shapes of particles. Pictures are shown in following figures at various amplification levels.



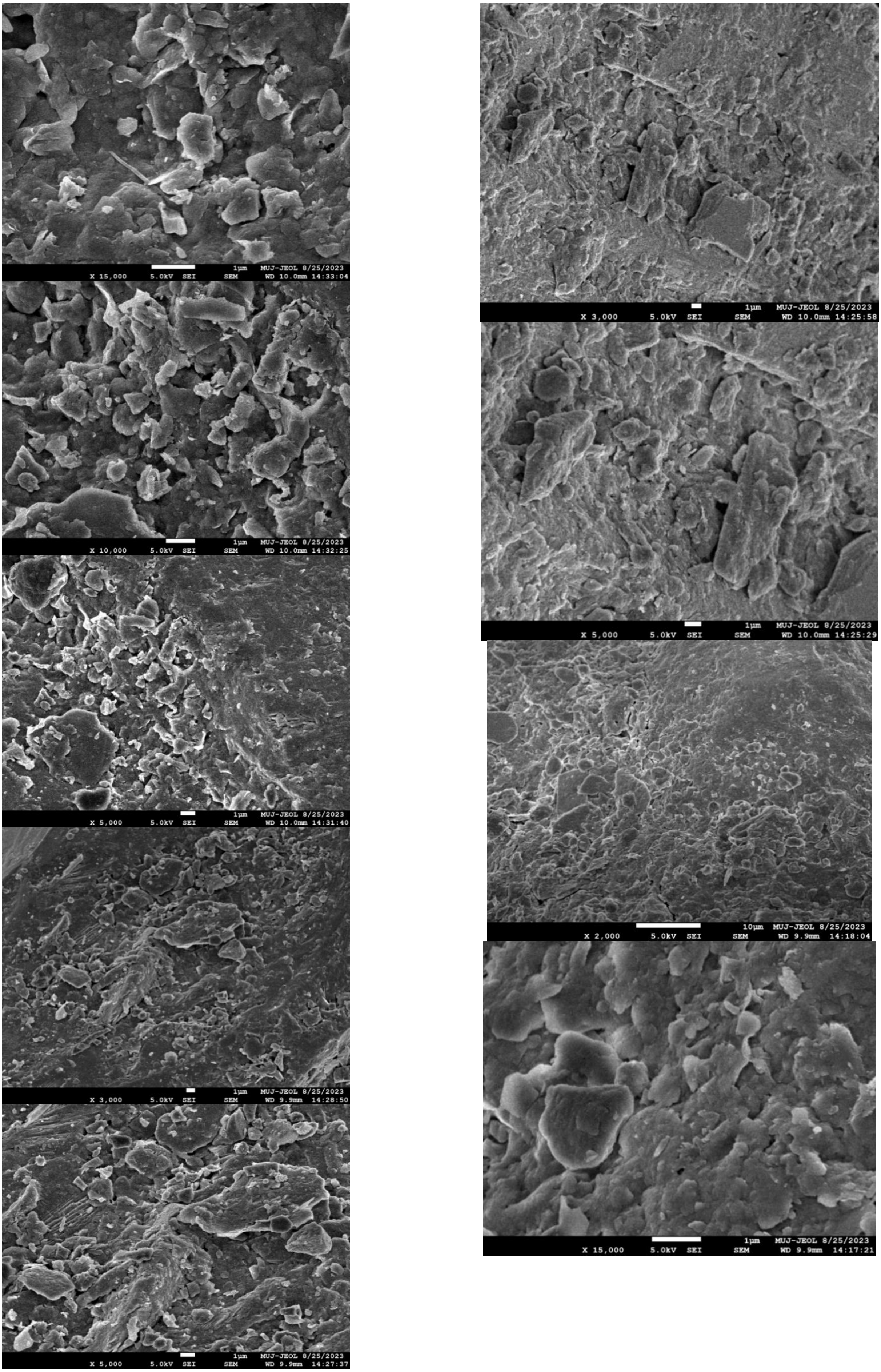


Figure 14: SEM Images of dust particles of Bhilwara

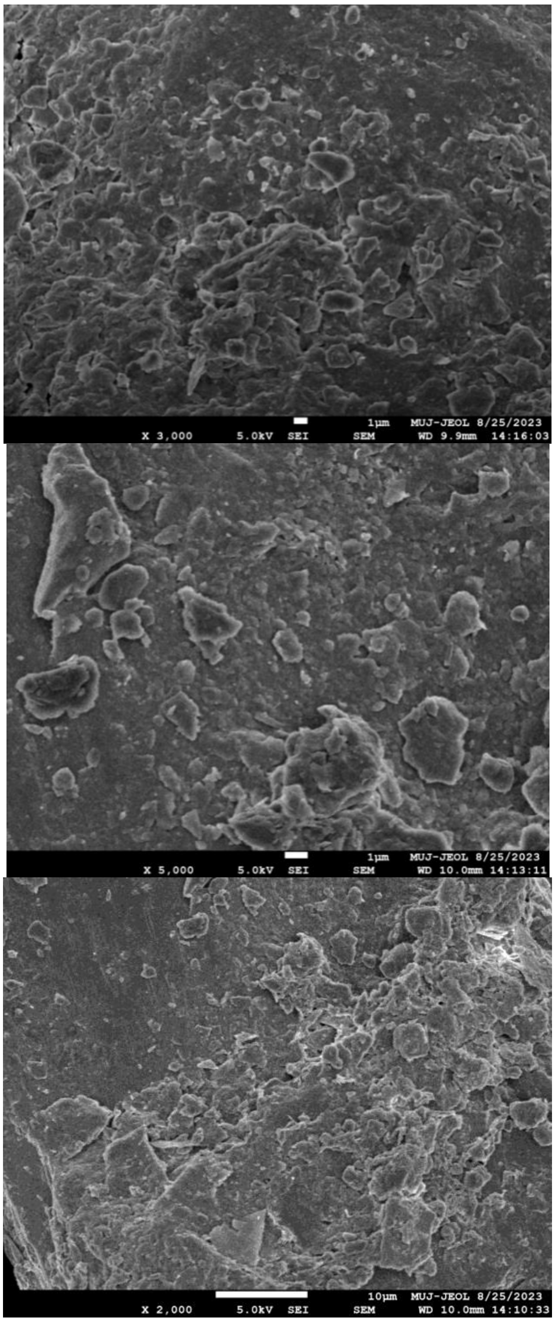
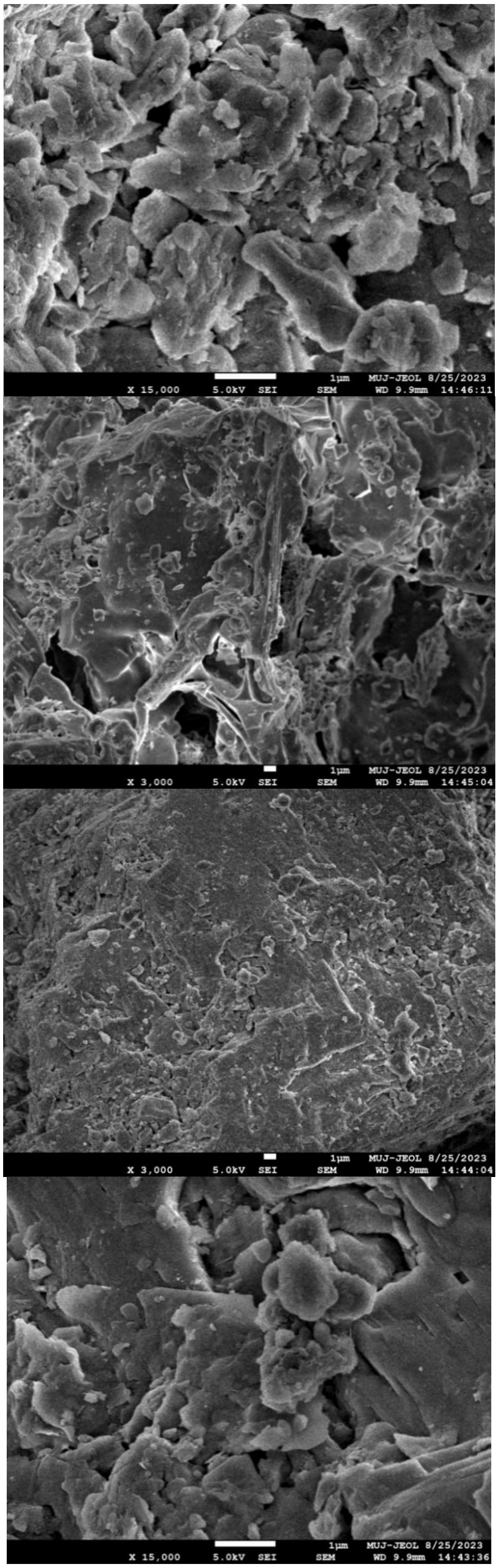


Figure 15: SEM Images of dust particles of Banera



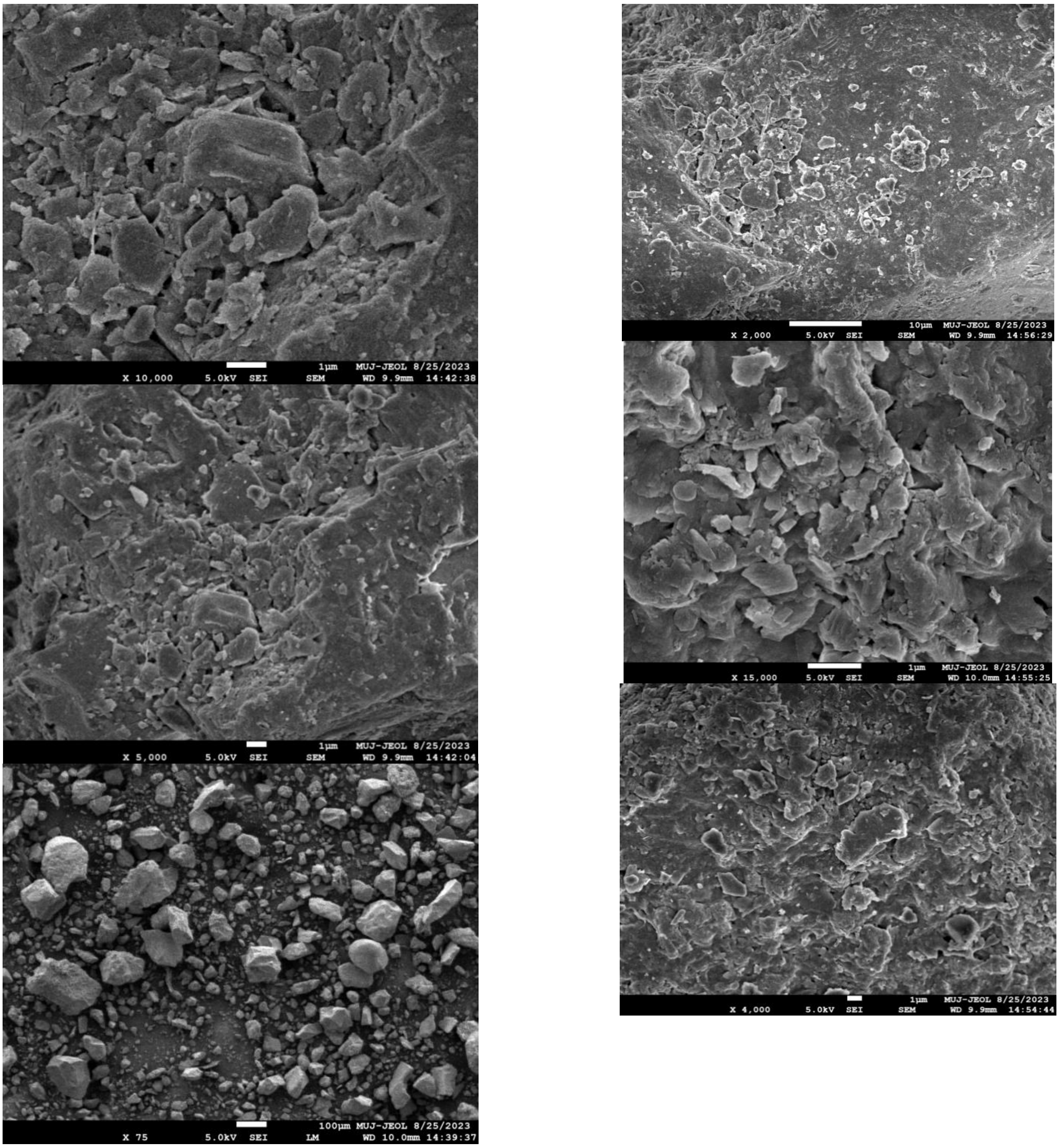
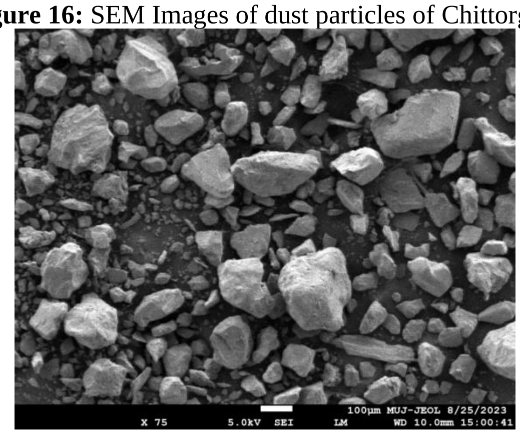


Figure 16: SEM Images of dust particles of Chittorgarh



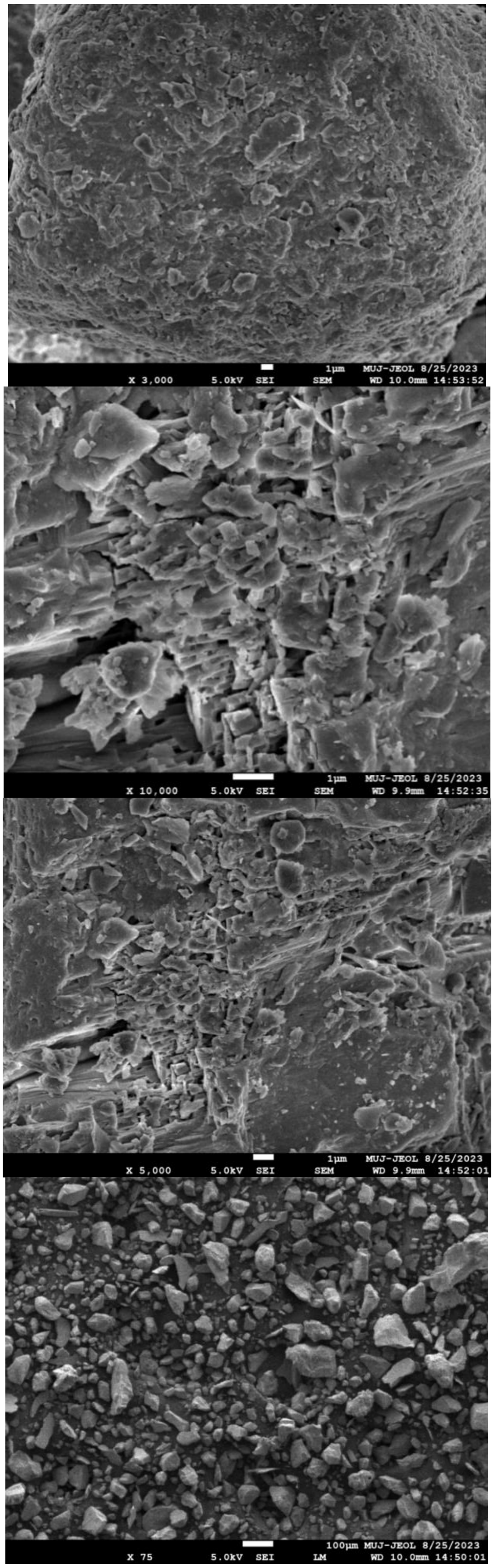


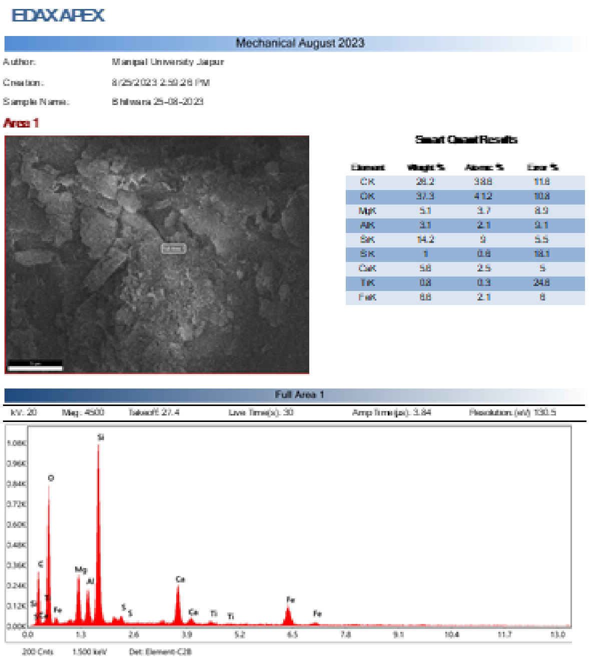
Figure 17: SEM Images of dust particles of Hamirgarh

The various shapes of dust particles might be due to their emission by different source, geological background and meteorological parameters of area concern. The rounded shape particles are considered as soot particles and fly ash. The presence of soot particles may be due to emission from vehicular traffic, thermal power plant in textile industries, exhaust from cement factories and different industrial activities in the area of research. Some rounded particles found with specific pattern having rough surface showing presence of pollen. The major part of dust is aluminum - silicate in terms of weight (72%) which is made of Si and Al oxides with varying amount of K, Mg, C and Fe. Some grapes like structure are because of carbon fractal originated from traffic activities there. We also find triangular structure and flatten structures which are rich in calcite and quartz. Angular structure type particles was found rich in quartz, C, N, O and Si The fine dust particles are significant in dust deposition near roadside area because they have dominant fraction of pollutants as heavy metals and poly aromatic hydrocarbons. We have analyzed the chemical, mineralogical and morphological characteristics of dust which deposit on PV panel during the period of August to October in southern Rajasthan. The research investigates that vehicular and industrial exhaust cause significant contribution impacting the performance of PV panel. Different types of shapes and irregularities in dust particles are found in SEM analysis. Various shapes like spherical, rectangular, plenary and angular shapes were investigated. Diameter of dust particles and size of particles are found in the range of 1.5 µm to 500 µm.

Ca, Al, Si, Fe, Ti, Mg, O, Na, K, N and C are the founding particles in dust of various concentrations. So we can say that dust is made - up of local rocks, industrial and vehicular emission etc. The samples were collected from Bhilwara, Banera, Hamirgarh and Chittorgarh which are situated in southern Rajasthan. Hamirgarh and Chittorgarh are located near textile industries area and are also residential zones.

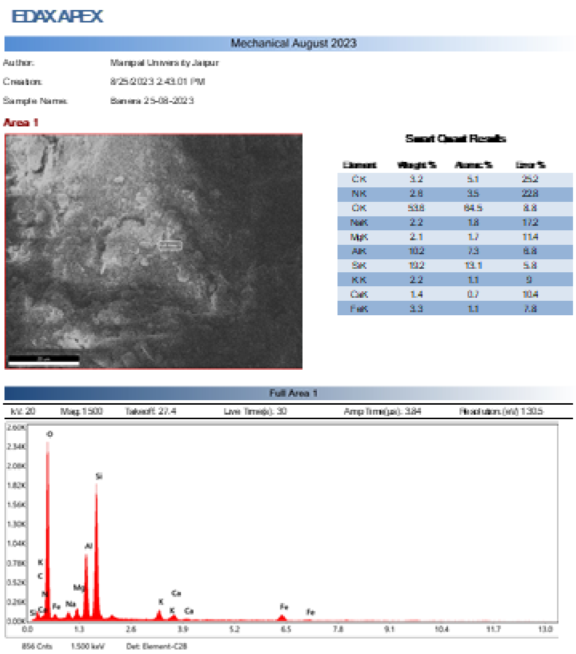
The area of study around Bhilwara has different industries such as textile and cement factories. The area of study has heavy traffic with major source of NO_2 and SO_2 in environment. Actually dust is consisting of salt material, organic matter from vegetation and pollutants from traffic and anthropogenic activities.

Following figures shows elemental composition of four dust samples as determined by SEM - EDX. It shows various elemental compositions in different samples of dust. Figures clearly show that carbon, silicon and oxygen have highest contributions relative to other elements in the dust.



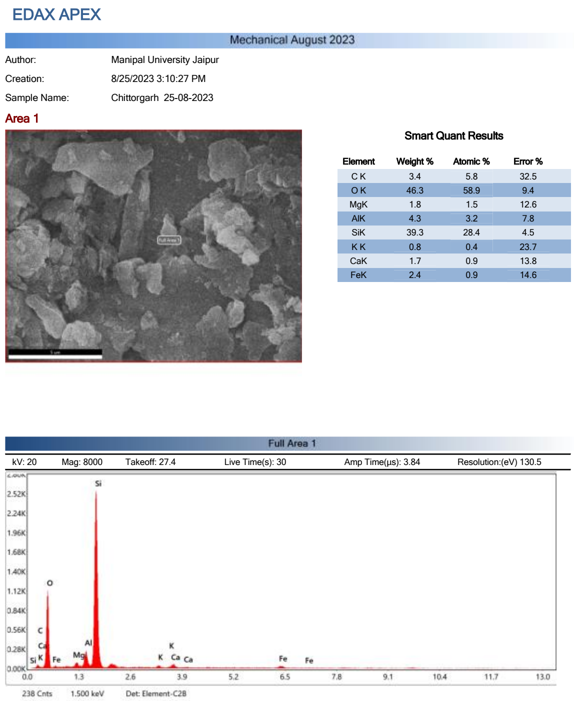
Element	Weight %	Atomic %	Error %
C K	26.2	38.8	11.8
O K	37.3	41.2	10.8
MgK	5.1	3.7	8.9
AlK	3.1	2.1	9.1
SiK	14.2	9	5.5
S K	1	0.6	18.1
CaK	5.6	2.5	5
TiK	0.8	0.3	24.8
FeK	6.6	2.1	6

Figure 18: EDX diffractogram of the dust sample Bhilwara



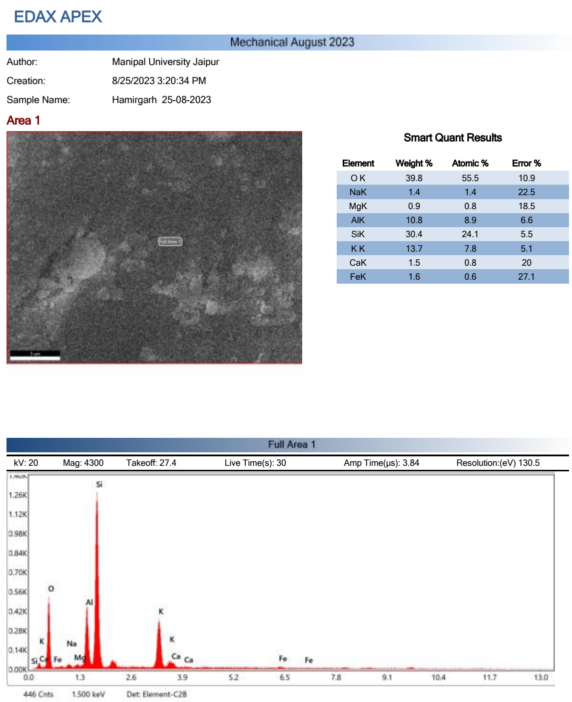
Element	Weight %	Atomic %	Error %
C K	3.2	5.1	25.2
N K	2.8	3.5	22.8
O K	53.8	64.5	8.8
NaK	2.2	1.8	17.2
MgK	2.1	1.7	11.4
AlK	10.2	7.3	8.8
SiK	10.2	13.1	5.8
K K	2.2	1.1	9
CaK	1.4	0.7	10.4
FeK	3.3	1.1	7.8

Figure 19: EDX diffractogram of the dust sample Banera



Element	Weight %	Atomic %	Error %
C K	3.4	5.8	32.5
O K	46.3	58.9	9.4
MgK	1.8	1.5	12.6
AlK	4.3	3.2	7.8
SiK	39.3	28.4	4.5
K K	0.8	0.4	23.7
CaK	1.7	0.9	13.8
FeK	2.4	0.9	14.6

Figure 20: EDX diffractogram of the dust sample Chittorgarh



Element	Weight %	Atomic %	Error %
O K	39.8	55.5	10.9
NaK	1.4	1.4	22.5
MgK	0.9	0.8	18.5
AlK	10.8	8.9	6.6
SiK	30.4	24.1	5.5
K K	13.7	7.8	5.1
CaK	1.5	0.8	20
FeK	1.6	0.6	27.1

Figure 21: EDX diffractogram and chemical composition of the dust sample Hamirgarh

Carbon 26.2%, silicon 14.2% and oxygen 37.3% Calcium 5.6%, Iron 6.6%, Aluminium 3.1%, Titanium 0.8% respectively are found in Bhilwara dust sample It is also found that urban dust particles are carbon rich as compared to rural soil. In addition copper and sulfur also present the samples.

Carbon 3.2%, Silicon 19.2% and Oxygen 53.6% Calcium 1.4%, Iron 3.3%, Aluminium 10.2%, Titanium Nitrogen 2.6%, Sodium 2.2% Potassium2.2% and magnesium 2.1% respectively are found in Banera dust sample It is also found that rural dust particles are oxygen rich as compared to urban soil. In addition Sodium and Potassium are also present in the samples.

Carbon 5.8%, Silicon 28.4% and Oxygen 58.9% Calcium 0.9%, Iron 0.9%, Aluminum 3.2%, and Magnesium 2.1% and Potassium 0.4% respectively are found in Chittorgarh dust sample It is also found that rural dust particles are oxygen rich as compared to urban soil. In addition, Potassium is also present in the samples.

Silicon 30.4% and Oxygen 39.8% Calcium 1.5%, Iron 1.6%, Aluminium 10.2%, Sodium 1.4% Potassium13.7% and magnesium 0.8% respectively are found in Hamirgarh dust sample It is also found that rural dust particles are oxygen and silicon rich as compared to urban soil. In addition Sodium and Potassium are also present in the samples in excess level.

Such contributions indicate that dust is a mixture of natural as well as anthropogenic emissions. Presence of S, K, Al, Mg and Na indicates contamination by industrial waste whereas contribution of Mg and sulfur indicates the influx of diesel combustion particularly from vehicles. Presence of oxides of aluminum, silicon, calcium iron and potassium indicates crustal origin from local rocks.

Experiments were conducted in Bhilwara that have longitude74.60º and Latitude 25.33º. It is textile city surrounded by various cloth factories and process houses. The residue tests have been done from Bhilwara, Banera, Chittorgarh and Hamirgarh during august month.

Thus in this study four dust tests were investigated for estimation of morphological parameters. As the SEM images we get, particles from Chittorgarh site have rounded layer structure, grape like structure and aggregate. As this site is situated near residential area of Chittorgarh, some signature of pollution were detected by spot EDX analysis of individual particles. Grapes like structure is nothing but the big aged carbon fractal consist of carbon monomers.

Due to vehicular exhaust and industrial activities, fresh fractals of carbon are released in atmosphere that reside in the atmosphere for a long time and settle down on the surface of panel due to gravity and other mechanisms. EDX analysis of particles reveals that the dust is rich in carbon and sulphur. The practice compositions were inferred based on spot EDX data.

The SEM analysis over Bhilwara founded with rough, broken or discontinuous layer on surface are termed as crust particles. At this site we also find some rounded off particles with specific shapes and pattern. These particles may be pollen.

Over Hamirgarh site, we found some flat triangular structures termed as triangular flat structure, some parallel layer structure and flattened rounded crust like particles. Based on ESX analysis the layer structure particles were inferred to be rich in calcite and quarts.

Over Banera site in general we found sharp edged particles termed as triangular particles which are signature of quarts, C, N, O and Si. Over Chittorgarh sampling site, which is representative of cementation area and mining zone, the partite are found to be smooth, angular with croconchoidal fractures Layered, angular and flattened particles were found to be dominant over all the sites. The information of particle shapes is valuable for modelers for designing the solar panels for optical simulation over the study areas.

We need morphological parameters also for simulation of dust particles optical properties. In SEM figures from various locations, we find that size of dust particles changes from I µm to 500 µm. From images we also analyze that some small and fine particles are attached to the big dust particles. The bright and small area is basically charged particles and due to having charge, these particles are bonded to big particles by electromagnetic forces.

Now there is a table & elemental composition of determined by EDX (energy dispersive spectroscopy). The table shows elemental composition of dust particles. The concentration of Na, K, Ca and O was found to be increased.

The EDX data showed that the elemental contents of the particles were now non - uniformly distributed. The high content of Si measured in flake like structure indicates primly presence of silicon. EDX figures shows X ray diffractogram of dust particles and revealed the presence of K, Na, Ca, S, Cl and Fe peaks. The dust particle's hallmark of CaSO4 (Gypsum) may be associated with the presence of S. Hematite, or iron oxide, is a possible companion mineral.
Metals and pollutants can have various effects on the performance and efficiency of solar cells. The impact depends on the specific type of solar cell technology and the nature of the metals or pollutants involved. Here are some general considerations:

- Metals can corrode when exposed to the elements, leading to a degradation of the solar cell's structure and materials. Corrosion can affect the electrical connections within the solar cell, reducing conductivity and overall efficiency
- Pollutants or metal particles settling on the surface of solar cells can create defects or barriers that hinder the absorption and transmission of sunlight. A decrease in power production and light absorption may occur as a consequence of this.
- Metals used in the structure of solar panels, such as frames or support structures, can cast shadows on the solar cells. Shadows reduce the effective area exposed to sunlight, leading to decreased power generation.
- Certain metals are used intentionally to dope semiconductors in solar cells to modify their electrical properties. Unintended metals or impurities can alter the semiconductor properties in an undesirable way, affecting the cell's efficiency.
- Pollutants in the atmosphere, like sulfur compounds, can lead to chemical reactions with materials in solar cells. These reactions may result in the formation of unwanted compounds that can degrade the cell's performance.

- Metals can have different coefficients of thermal expansion than the materials in solar cells, leading to stress and potential mechanical failure. High temperatures can also accelerate corrosion processes and impact the overall stability of the solar cell.
- Metallic contaminants can create unintended electrical pathways, leading to short circuits or leakage currents. This can decrease the overall electrical efficiency of the solar cell.
- To mitigate these effects, manufacturers often use protective coatings, encapsulation materials, and quality control measures to minimize the impact of metals and pollutants. Regular maintenance and cleaning are also essential to ensure optimal performance over the lifespan of solar panels. Additionally, ongoing research focuses on developing more resilient and durable materials for solar cell construction to enhance their resistance to environmental factors.

4. Conclusion and Future aspects

Deterioration in performance due to dust have great concern about green energy farms and carbon footprint. Solar energy from PV panel is one of the most important renewable energy sources and degradation of the panel's efficiency by dust deposition is serious problem. It is very challenging for mankind because in near future solar energy to going to main energy source because conventional energy sources are continuously depleting and efficiency of these sources demands uninterrupted energy supply. Solar energy, a key player in the shift towards sustainable power sources, relies on the efficient performance of solar panels. However, environmental factors, such as dust accumulation, pose challenges to the optimal functioning of these panels. This study explores and compares the effects of dust on mono crystalline and polycrystalline solar panels, delving into the unique characteristics of each technology and their responses to dust - induced performance.

Mono crystalline and polycrystalline solar panels are the two primary technologies harnessed for converting sunlight into electricity. We have studied their structures and efficiencies for assessing their susceptibility to dust.

Mono crystalline panels consist of single - crystal silicon, providing a smooth surface that facilitates a uniform electron flow. Recognized for their high efficiency, these panels are commonly utilized in solar installations. Polycrystalline panels are manufactured from multiple crystal structures, resulting in a lower production cost. Their textured surface, characterized by a blue - speckled appearance, sets them apart from mono crystalline panels.

The accumulation of dust on solar panels impedes sunlight absorption, affecting the panels' efficiency. This research work makes us able to understand the consequences of dust to devise strategies for maintaining optimal performance. Dust particles settle on the surface of solar panels, forming a layer that obstructs sunlight. This process hampers the panels' ability to convert sunlight into electricity. Reduced sunlight absorption leads to a decline in energy production. The extent of performance degradation varies between mono crystalline and polycrystalline panels due to their distinct surface properties.

In this study, we analyze various dust samples, their chemical compositions, their origin sources, their mechanisms of deposition and different elimination techniques for dust removing. We investigated the impact of dust particles and also highlighted previous research work over dust deposition The investigation show that dust deposition is very serious problem regarding power and efficiency and it is also necessary to mention that dust deposition depend upon many environment and climatic condition of site. We suggest some mitigation techniques depending on region where panel is to be installed. The panels should be cleaned at regular interval of time by a suitable elimination technique.

References

[1] Azouzoute Alone, Mohammad Garoum, Faovaz Jeffali, EL Ghali Bennouna (2020). Experimental study of dust effect on the transmission of a glass PV panel for a fix and tracking system" Materials Today proceeding April 2020.

[2] Mustapha Dida, Slimane Boughli, Djamel Bechki, Hamja Bouguettaia (2020) "Output power loss of crystalline silicon photovoltaic module due to dust deposition in Saharian environment" Renewable and sustainable energy reviews volume 124 May 2020, 109787

[3] Ali, H. M., Zafar, M. A., Bashir, M. A., Nasir, M. A., Ali, M., &Siddiqui, A. M. (2017). Effect of dust deposition on the performance of photovoltaic modules in Taxila, Pakistan. *Thermal Science*, *21* (2), 915 - 923.

[4] Hussain, A., Batra, A., &Pachauri, R. (2017). An experimental study on effect of dust on power loss in solar photovoltaic module. *Renewables: Wind, Water, and Solar*, *4* (1), 1 - 13.

[5] KaldellisJK, Fragos P, Kapsali M (2011) Systematic experimental study of the pollution deposition impact on the energy yield of photovoltaic installations. Renew Energy 36 (10): 2717–2724

[6] Rajput D. S. and Sudhkar K (2013) " Effect of dust on performance of solar PV panel"International Journal of Chem Tech Research 2013 5 (2) 1083 - 1086

[7] Mohammed J.; Adinoyi Syed A. M. (2013) "Effect of dust accumulation on the power output of solar photovoltaic module. "Renewable Energy; 2013; vol 60, issue c 633 - 636

[8] Cabanillas RE Mungia H (2011) "Dust accumulation effect of the efficiency of Si photovoltaic modules. "Journal of Renewable and Sustainable Energy", 3, 043114

[9] RajkumarSaini et al. (2000) " Effect of dust on the performance of solar panel – a review update from2015 - 2020 "Energy and Environment. pp1 - 53; 2000

[10] Mohammed A. O. Hasan A. (2012) "Effect of dust accumulation of performance of photovoltaic solar modules in Sahara environment. " Journal of basic and applied scientific research.2 (2012) pp 11030 - 110036

[11] Sulaiman SA, Hussain HH, Leh NSHN, Razali MS (2011) Effects of dust on the performance of PV panels. World Acad Sci Eng Technol 58 (2011): 588–593.

[12] Sisodia A K, Mathur R K (2019) Impact of bird dropping deposition on solar photovoltaic module performance: A systematic study in Western Rajasthan. Environmental Science and Pollution Research, 26, 3111931132. DOI10.1007/s11356 - 019 - 06100 - 2
[13] Panwar T, Mathur R K, ‘The sensitivity of Photovoltaic modules towards dust in Ajmer, Rajasthan. ’Vidhyabharti International Interdisciplinary Research Journal 12 (1) 162 - 171 (2021) ISSN - 2319 - 4979
[14] Sisodia A K Mathur R K, Performance analysis of photovoltaic module by dust deposition in western Rajasthan. Indian Journal of science and technology13 (08): 921 (2020) DOI: 10.17485/ijst/2020/v13i08/149928