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EVALUATING EFFECTIVENESS OF NON-WATER BASED CLEANING MECHANISMS FOR PV SYSTEMS

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ABSTRACT

PV systems in tropical regions are gifted with ample sunshine, but also vulnerabilities to high cell temperatures and dust settlement. Dust related degradation is progressive and if left unattended, can severely inhibit by more than 40% the efficiency and output of the system. Current mechanisms of cleaning PV systems adopt large quantities of clean water, making the system unsustainable. The current study thereby investigates the effectiveness of non-water based cleaning mechanisms based on traditional palm-leaf brooms. These brooms were found to be more than 90% effective in comparison to water based cleaning. The reason for this effective cleaning has been further scrutinized based on micro-structure studies and dust adhering properties.

INTRODUCTION

Harnessing solar energy directly as electricity is already seeing massive worldwide installation and commissioning of PV systems, from 5W panels for rural lighting to MW systems for industries and modern cities. However, massive adoption of new technologies brings forth problems hitherto invisible and unaddressed. Solar-rich tropical regions have awesome potential to harness solar energy, but constrained by consequent higher operating temperatures (for PV systems) and detrimental influences of dust. To examine the effect of dust on PV output (max) power loss, Molki (2010) deposited different densities of ground clay (up to 4g) on a 12 cm X 8 cm cell. Results showed that as dust deposition density increased, the rate of maximum output power loss decreased [3].

Tropical regions are also characterized by diverse terrains, vegetation, and city typologies influence the nature and severity of dust settlement. Atmospheric dust concentration decreases exponentially as a function of altitude except under dust storms. Thus, both orientation, such as tilt and height of the solar collectors make a significant difference in energy yield loss. Degradation is reduced if PV panels are installed at a high elevation to minimize dust deposition. Elevation of the solar collectors is often limited by the structural support needed against high-speed wind and the need of convenient cleaning and other maintenance requirements (Thornton, 1992). Clearing dust to ensure optimum PV performance not only involves effort, but also includes significant use of clean water and energy.

Automated cleaning processes, particularly those that do not require water, are most desirable for maintaining the high efficiency of solar plants in dusty environments. Large-scale cleaning operations with water followed by scrubbing require large amounts of water annually, the use of specially designed vehicles, and an experienced operations team. Such methods are expensive and difficult to implement when fresh water is in short supply. In many large-scale solar plants, cleaning must performed using desalinated seawater, leading to added energy load [4].

One recent work studying surfactants was published by Abd-Elhady et al., (2011) [5]. These studies were conducted in a laboratory environment using three types of surfactants: anionic cationic and zwitterionic. Surfactant is sprayed through a nozzle on dusty samples, and the results are analyzed using light microscopy images. The authors concluded that anionic, followed by zwitterionic, and then cationic were the most influential surfactants for removing deposited sand particles.

Another alternative approach for cleaning using electrostatic forces for dust removal without use of water is currently being studied. The fundamental principle of the electrodynamic screens (EDS) was introduced in 1970s at the University of Tokyo by Masuda et al., (1972). An EDS consists of a series of alternating electrodes embedded in a transparent dielectric film and applied to the surface of the solar collector.

However, these technologies bring in more complexity in manufacturing and operation, and would take a few years for widespread commercialization. Moreover, it adds to the PV system capital cost, but reduces operations cost. These processes are still under development for commercial applications. Therefore, until the time this technology breeds further there is a need to look at other easy and conventional cleaning methods conforming to sustainability. The current study evaluates the effectiveness of a few non-water based cleaning mechanisms for PV systems and also proposes suitable cleaning cycles. The study is based on experimental investigation on a PV system installed at the Indian Institute of Science, Bangalore (India). The investigation induces a detailed assessment on the nature of dust settlement (type and rate of dust deposition), its severity and influence on PV performance, and testing of various cleaning mechanism. Water-based cleaning has been adopted as a reference to measure the effectiveness of non-water based options. The study currently includes Poly-Si and CIS based PV systems maintained at different slopes to also understand the influence of slope on the severity of dust settlement. As against laboratory based investigation into dust related studies, the paper focuses on field based practical investigation into PV performance, also considering influence of other ambient parameters such as wind and temperature. The results of the study and preliminary findings have been reported in this paper.

EXPERIMENTAL

INSTRUMENTS

Reinhartd MWS 9-5 weather station was used to record the weather conditions during the measurements. Amprobe Solar-4000 module analyzer was used to record the IV characteristics. Center IR non-contact thermometer and Brainchild 8TC data logger module (K type thermocouple) was used to monitor the temperature of the experimental system. Morphological imaging of the samples were carried out at 5 kV with SE2 detector and subsequent (energy dispersive X-ray spectroscopy) EDS analysis also were carried out using Carl Zeiss Ultra55, field emission scanning electron microscope (FESEM).. Micro-indenter, Celestron Digital Handheld Microscope Model #44302 (power: 10 to 40x & 150x using a 19'' Monitor)

RESULTS AND DISCUSSIONS

Here to understand performance of the PV due to the interplay of dust with wind and temperature, CIS and poly Si type panels were used. Both these modules were commercially obtained. Measurements were carried out in natural sunlight ranging from 800~1050 W/m2. Observed parameters of these modules are as shown in table 1

Table 1: Measured parameters of the PV module that were used in the experiments.

Parameters	Poly crystalline	CIS
Nominal peak power (W)	37	150
Open circuit voltage (V)	21.8	108
Short circuit current (A)	2.4	2.2
Voltage at peak power (V)	17.2	81.5
Current at peak power (A)	2.2	1.85

Figure 2: Scanning electron micrographs of electrospun P3HT:PCBM blend.

Visible light image of dusty, broom cleaned and water cleaned poly crystalline and CIS is as shown in Fig 1. These images reveal the effectiveness of the cleaning mechanisms adopted.

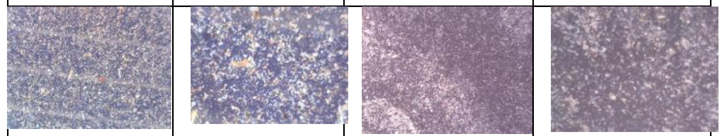
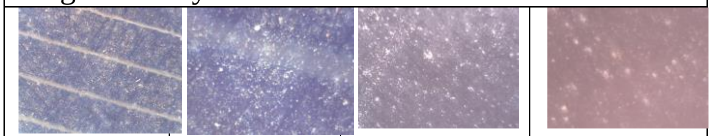
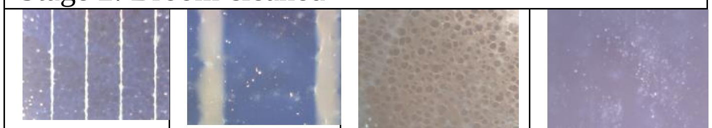
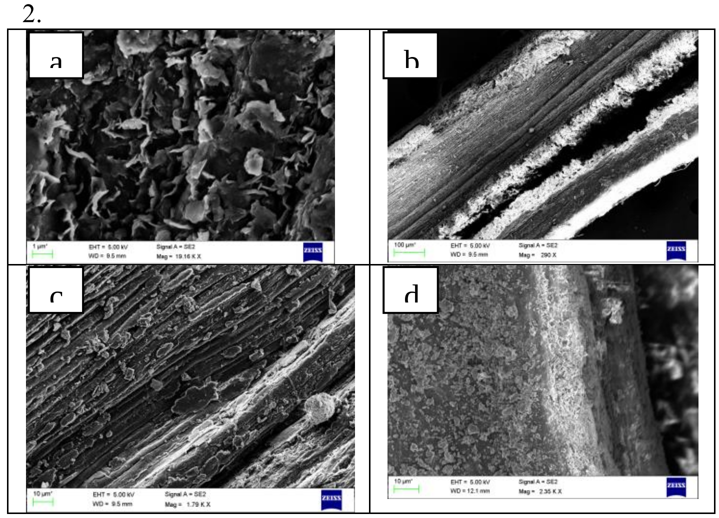
Poly crystalline		CIS	
50x	150x	50x	150x
			
Stage 1: Dusty			
			
Stage 2: Broom cleaned			
			
Stage 3: Water cleaned			

Fig 1. Optical images of the PV panel surface at various cleaning stages (Magnification of 50x and 150x using a 19'' monitor)

Samples of the broom, before and after cleaning the surface of the PV panels were collected and analyzed for topography Fig. 2.



Traditional Indian palm leaves were used as broom for cleaning the dust and bird droppings on the surface of the PV panels. These palm leaves observed under electron microscope suggest ridges and sharp-edged serrations. These projections are believed to help in dislodging dust effectively. The serrated edges also comprised a rough texture (Fig. 2 a) that improve the effectiveness in dislodging the dust from the PV glass surface. Surface topography of the broom samples, as observed through the SEM, after cleaning reveals the effectiveness of the microarchitecture, where heavy trapping of dust particles occurs due to the available surface area.

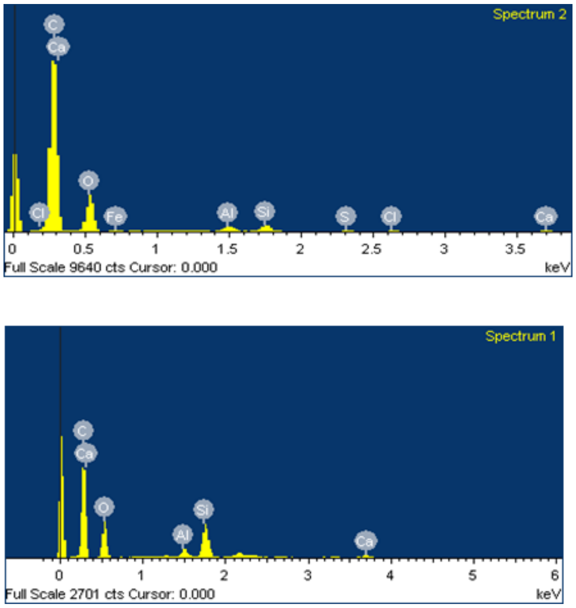


Fig 3. Elemental composition of the broom before and after cleaning the surface of the PV panels

Samples of the broom, before and after cleaning the surface of the PV panels were collected and analyzed for elemental composition by EDS measurements (see Table 2).

Table 2. Elemental composition of the collected dust samples from the surface of the PV panels

	Clean broom		Dusty broom	
Element	Weight%	Atomic%	Weight%	Atomic%
C	67.75	74.69	59.51	68.34
O	28.96	23.97	32.02	27.6
Al	0.75	0.37	1.21	0.62
Si	0.91	0.43	6.39	3.14
S	0.27	0.11		
Cl	0.33	0.12		
Ca	0.69	0.23	0.87	0.3
Fe	0.34	0.08		

These results indicate that Si is a major component in the dust picked up by the broom.

Fig. 4 illustrates the force required to dislodge the dust on the surface of the glass was measured by scratch test technique using a micro-indenter. Data indicates that drag force of the indenter on the clean PV glass is about ~ 5 Newton. A force upto ~ 44 newton was required for removal of dust from the surface of the glass panel. However, on dusty PV glass surface drag force increased proportional to the scratch distance. At about 20,000 mm the microscopic dust piles up, following which slippage of the indenter occurs.

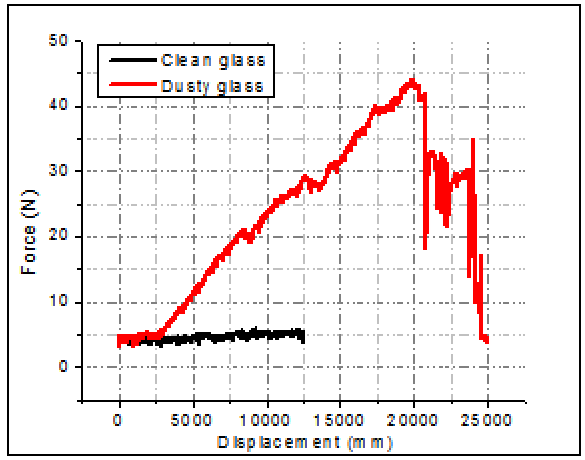


Fig 4. Micro-indentation force measurement on a clean vs dusty surface

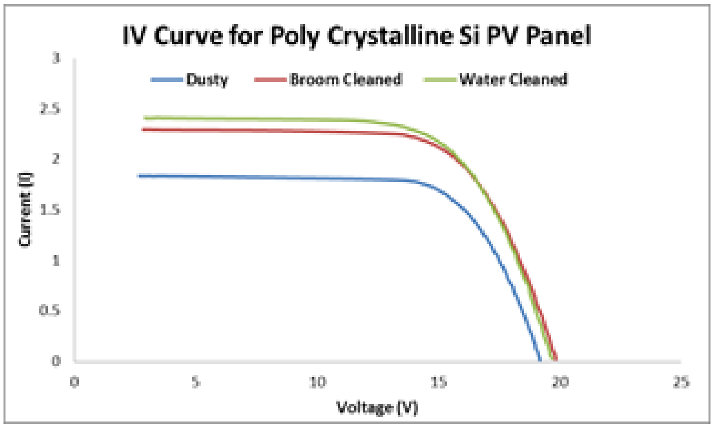
Both the panel types, Poly-Si and CIS were also tested outdoors for the IV response to assess the effectiveness of the cleaning mechanism adopted, viz., broom based followed by water. Figure 5 illustrates the change in IV characteristics (particularly I). While nearly a 2% efficiency degradation was observed between the dusty and broom-cleaned panel, the efficiency improvement by a water-cleaned panel was in the range of 0.2~0.4% over the broom cleaned surface as shown in Table 3. The dust deposition density was found to range between 0.68~1.11 mg/sq.cm and 0.54~0.66 mg/sq.cm for Poly-Si and CIS panels respectively. It is important to note the panels had collected dust (under natural outdoor conditions) for nearly four months. The broom was able to achieve more than 90% cleaning efficiency as compared to water-based cleaning (amounting to a time-averaged 0.5 L/m2/day).

However, following the broom cleaning, less than 50 ml/m^2 of water was required to completely clean the surface using a micro-fiber cloth. The effectiveness of using the broom more frequently needs to be assessed, which has the potential of completely alleviating the dependence of water for cleaning.

Table 3. Pmax and Efficiency of Poly-Si and CIS panels

Panel Type	Solar (w/m^2)	Condition	Pmax (W)	Eff. (%)	Jsc	Voc (V)
Poly-Si	1008	Dusty	25.5	7.03	5.110	19.2
	1004	Broom Cleaned	31.9	8.83	6.400	19.92
	1005	Water Cleaned	32.7	9.05	6.711	19.75
CIS	887	Dusty	94.4	8.67	1.195	99

	887	Broom Cleaned	111.3	10.22	1.386	100.87
	877	Water Cleaned	120.4	11.18	1.446	103.98



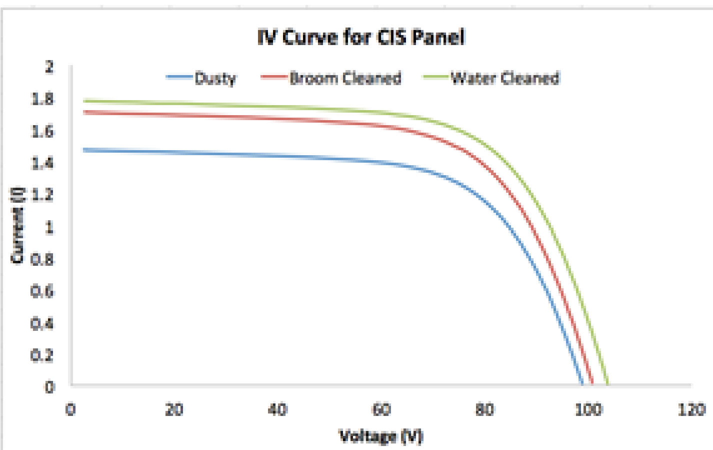


Fig 5. IV characteristics for Poly-Si and CIS panels at various stages of cleaning

CONCLUSION

The current study evaluates the effectiveness of non-water based cleaning mechanisms adopting traditional palm-leaf brooms. These brooms have been used for hundreds of years for various domestic applications. The brooms were found to be nearly 90% effectives as compared to water-based cleaning. The paper investigates the reasons for this effectiveness based on a study of its micro-structure and the physical properties such as available surface area. Further a micro-indenter based study revealed the nature of forces required to dislodge dust from the surface of the glass. The study could form basis for identification of appropriate non-water based environment-friendly mechanisms for maintaining clean PV systems for maximum output

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