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MEASURING DIRT ON PHOTOVOLTAIC MODULES
PART II

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Abstract

The accumulation of surface dirt on photovoltaic (PV) modules installed at MIT Lincoln Laboratory test sites can cause degraded electrical performance until it is removed either by washing or by rain. Modules with only RTV as a solar-cell encapsulant are more prone to dirt retention than modules covered with glass. Two techniques for measuring and quantifying surface dirt and its effects on module output are described.

One technique, using a standard portable glossmeter, measures the scattering of specular light by surface-dirt particles. This measured value can then be correlated with the peak power performance before and after cleaning. A second technique is also described which enables an investigator, in the field, to take dirt samples or replicas of the accumulated surface dirt from the PV module. Photomicrographs of urban, suburban, and rural dirt particles are shown.

Measurements of module peak power before and after cleaning indicate that dirt particles in urban environments are more degrading to PV performance than dirt particles found in rural areas. The significance of the measurements is not obvious, however, after examination of the photomicrographs of the dirt particles. It was found that the optical transmission of the particles has a greater effect on peak power performance than the quantity of these particles.

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Fig. 1. Glossmeter with 20-deg. specular angle.

P267-832

Fig. 2. Compact glossmeter on PV module.

1.0 INTRODUCTION

One of the most persistent degradation factors which affects the electrical output of photovoltaic (PV) modules is the accumulation of dirt on the transparent surfaces of the PV modules. At the present time, little can be done to minimize the presence of dirt and pollutants in urban and industrial environments. However, quantifying the degradation introduced by these particles and identifying the soil types provide information which can be used to develop corrective cleaning and encapsulating techniques.

In this second report on the subject¹, additional quantitative measurements of optical scattering by dirt particles, as indicated by a glossmeter, are presented for various MIT Lincoln Laboratory test sites. To better understand the types of soil that cause PV module performance to degrade, a dirt replication-transfer technique has been developed. By using this technique, dirt samples can be prepared for microscopic viewing. Finally, in order to determine the differences between urban and agricultural soiling, a computer image analysis was performed. It was found that both chemical and visual differences were minimal.

2.0 THE GLOSSMETER

The glossmeter, as shown in Fig. 1, is a simple, hand-held, optical instrument which measures specular light reflections from a shiny or glossy surface. The presence of dirt particles on the surface of a PV module causes impinging light to scatter and decreases the glossy specular reflection. Recently, a new, more compact, portable glossmeter with a digital readout has become available. It is shown positioned on a PV module in Fig. 2. In this later model, the battery unit is contained within, and calibration techniques are simpler than those of the model previously described.¹

2.1 Glossmeter Measurement Procedure

The normal procedure used in making glossmeter measurements involves collecting ten surface readings on the PV module over the encapsulated silicon (Si) cells and computing the average. This procedure is used for two reasons: first, because the cells are in the dirt-affected solar transmitting zone and, secondly, because they provide a reasonably uniform light-reflecting background.

In order to determine the relationship between loss in peak power and the glossmeter readings, the percent peak power (PP) loss is computed after "flashing" a module in the (as removed) dirty condition and again after cleaning. Flashing is performed in a large-area pulsed solar simulator (LAPSS) at MIT Lincoln Laboratory. These measurements are normally conducted on PV modules periodically removed from various MIT Lincoln Laboratory field sites.

The percent PP loss is calculated from the following formula:

$$\%PP_{\text{loss}} = \frac{PP_{\text{clean}} - PP_{\text{dirty}}}{PP_{\text{clean}}} \times 100.$$

Two years of results from the 25-kW PV solar array at MIT Lincoln Laboratory's Mead, Nebraska, experiment are shown in Table I.

After one year of service at the Nebraska test site, the front surfaces of the modules with RTV encapsulant become impregnated with dirt. Glossmeter readings, taken on 40 modules, indicate an average maximum value of 4 to 5g in the as removed, dirty condition (column 3). This corresponds to a %PP loss of about 9 percent (column 5), as shown in Table I. In addition, after one year in the field it is quite difficult to remove dirt from the modules with a cold-water-and-detergent wash alone. The glossmeter readings (column 4) reflect this fact, since after field washing and 12 months exposure the readings are down by 28 percent from those taken prior to exposure.

TABLE I
AGRICULTURAL EXPERIENCE - NEBRASKA
Total Number of Modules = 2240

1	2	3	4	5
Exposure Time (months)	Module Type (quantity)	Glossmeter Readings		%PP Loss
		Dirty	Clean	
		(g units)		
3	A (12)	33	53	3.8
	B (16)	28	51	---
7	A (12)	17	57	7.2
	B (21)	11	53	4.3
9	A (12)	17	52	5.0
	B (14)	12	49	6.6
12	A (12)	5	32	8.8
	B (28)	4	40	9.1
14	A (16)	4	44	14.6
	B (31)	4	49	12.1
26	A (14)	4	51	11.2
	B (32)	9	46	12.5

After one year of exposure, it is necessary to scrub the RTV silicone surface of the modules with pumice and warm water/detergent to restore completely the gloss readings of the modules. This cleaning technique was used on modules with 26 months of service and resulted in modules that are practically equal to new panels: The surface shine is intact and very little surface erosion has taken place due to either cleaning or weathering. Furthermore, cleaning in the laboratory is more effective than field cleaning. The Nebraska field cleaning in October 1979 yielded glossmeter readings of only 10, indicating that a tenacious and contaminating residual film was still left on the surface after cleaning.

In Fig. 3, a relationship between %PP loss and glossmeter readings from dirty modules is shown. An interesting phenomenon is the marked difference between urban dirt and agricultural dirt. One can surmise intuitively that the NYC dirt is more opaque than the Mead dirt since similar glossmeter readings produce different %PP losses. Some of the specular collimated light of the glossmeter appears to be transmitted through the agricultural particles onto the Si cell, whereas the urban dirt is filled with carbon particles which are light absorbing. In order to substantiate this conclusion, sample replicas of both types of surface dirt were collected.

Fig. 3. % PP loss vs. glossmeter readings.

3.0 TRANSFER DIRT REPLICAS

A technique, developed for use with the transmission electron microscope and involving cellulose acetate (CAc) films softened in acetone, can be used to remove dirt particles from a PV module's surface, as shown in Fig. 4. One-half-inch-diameter film discs are first punched from 5-mil-thick sheets of CAc. These discs are then bonded, using an anaerobic adhesive (bonds on contact), to an Al cylinder (1/2" OD x 3/8" ID x 1/4" long) for handling and microscope mounting. To sample a dirt surface, the CAc film is first softened on one side by vertically immersing a cylinder about one-eighth inch into acetone. It is important to prevent acetone from entering the cylinder and touching the back sides of the CAc film.

P185-327

Fig. 4. Dirt replication, PV module surface.

The film should be immersed in the solvent for ten seconds, removed, and the excess solvent then shaken off. Next, using an angular motion to prevent air entrapment (bubbles), the film should be pressed for ten seconds onto the dirty PV module surface being sampled. After 20 to 30 minutes of drying time (depending on ambient conditions), the replicas can be removed easily. The circular patterns, indicating where dirt has been removed, are seen in the bottom row of cells in Fig. 4. This procedure will not work when the module surface is damp or the ambient relative humidity is high. In these cases the CAC film becomes opaque or CAC will expand and produce a concave sampling surface that will not contact the dirt surface.

3.1 Particle Microscopy

The dirt replica cylinders are suitable for viewing on a metallurgical microscope at 100-200 X magnification. Adding a mirror backing to the non-sample end of the cylinder significantly enhances illumination. While polarized light produces fascinating colors, color microphotography is inconsistent and difficult to reproduce when compared with black and white.

3.2 Nebraska Dirt Replicas

In Fig. 5, the "unexposed sample" photograph displays the CAC film as is. In the adjacent photograph, the dirt accumulation after 16 months exposure and one mid-period washing is shown. The original magnification was 160 X. The glossmeter reading was nine g's just as the recent 11/79 Mead reading was also nine g's. The sampling process does indeed remove most of the dirt, as can be seen in the third view labelled, "same area re-sampled".

3.3 New York City Dirt Replicas

Under the microscope, the urban dirt does not appear to differ noticeably from the Nebraska sample. It is recalled from Section 2.1, that for the same glossmeter readings the %PP loss is three times larger in the urban environment (see Fig. 3).

Fig. 5. PV module dirt, Nebraska.

Typical urban dirt taken in the field from modules on the roof of New York University is shown in Fig. 6. Some soot is evident in the upper right-hand corner of the right photograph.

Fig. 6. PV module dirt samples, New York City.

In Fig. 7, the pronounced difference between a glass and RTV-covered module surface is demonstrated for modules in New York City. The worst glass surface showed only a 13 %PP loss, as contrasted to a heavily soiled

GLASS

SL # 416
 EXPOSURE = 13 MONTHS
 WASHING — 2 x
 PP LOSS = 13 %
 GLOSS
 DIRTY = 37
 CLEAN = 86

ARCO # 11198 III
 EXPOSURE = 7 MONTHS
 WASHING — 1 x
 PP LOSS = 2.7 %
 GLOSS
 DIRTY = 56
 CLEAN = 71

SL # 10809 III
 EXPOSURE = 1 MONTH
 WASHING — NO
 PP LOSS = —
 GLOSS
 DIRTY = 82
 CLEAN = —

RTV

SP # 4589 II
 EXPOSURE = 12 MONTHS
 WASHING — 2 x
 PP LOSS = 53 %
 GLOSS
 DIRTY = 4
 CLEAN = 48

ST # 12413 III
 EXPOSURE = 7 MONTHS
 WASHING — 1 x
 PP LOSS = 45 %
 GLOSS
 DIRTY = 3
 CLEAN = 40

ORIGINAL REPLICA MAGNIFICATION = 125 x

$\frac{1}{2}'' = 0.004''$

SAMPLES TAKEN JUNE 26, 1979
 NEW YORK UNIVERSITY ROOFTOP

MIT
 LINCOLN LABORATORY

Fig. 7. New York City PV solar modules: dirt replicas, gloss, and peak power loss.

RTV-covered module which had a 53 %PP loss for an equivalent exposure time. One glass module had less than 3 %PP loss. Glass module surfaces tend to wash well in rain and dirt particles do not adhere to them as is the case with silicone encapsulant.

3.4 MIT LL Dirt Replicas and Samples

The replicas in Fig. 8 show the type of dirt particles collected in the suburbs at MIT Lincoln Laboratory. For this RTV-covered module, the particles are similar to those collected in Nebraska and are typically 1 mil in size (25μ) after only 1-3/4 months of exposure. The glossmeter reading was only 36, showing that the module was not very dirty.

Fig. 8. PV module dirt sample, Lincoln Laboratory.

In Fig. 9, an in-situ microscope photograph is shown of an actual PV module surface, i.e., no replica. In the same area, a sample replica was taken and it is shown in the lower left-hand corner. In the upper right, the area where the dirt was removed is shown. The dirt removal capability of the replication process is clearly quite efficient.

Although this procedure provides an efficient means of sampling the dirt on PV module surfaces, it does little to shed light on the significant difference between agriculture and urban contamination.

Fig. 9. Dirt on PV modules, MIT LL roof.

4.0 IMAGE PARTICLE ANALYSIS

Replica dirt samples from Nebraska and New York City were sent to LeMont Scientific in State College, Pennsylvania, where an electron-beam particulate analysis was performed. LeMont's automated scanning electron microscopy permits direct measurement of the size, shape, and composition of individual particles collected on replicas using computer image analysis.² Particle size and shape are reported, as well as characteristic X rays from all elements. The data produced are voluminous.

4.1 Composition

In Table II the chemical elements found above sodium (atomic number 11) are listed. Table II is interpreted as follows: in New York City, 93 percent of the particles found contained Si, totalling 49 percent of the elements measured. There was more Si in Nebraska; 99 percent of the particles examined had Si, which amounted to 77 percent of the elements found. With the exception of iron (Fe), all the other elements of urban vs. agricultural particles were surprisingly similar. The quantity of iron per

particle in the city was found to be six times greater than in Nebraska, yet the number of particles having Fe were equivalent.

TABLE II

URBAN VS. AGRICULTURAL PARTICLE IMAGE ANALYSIS

Elements Found	NY City (ST-3105)		Nebraska (ST-3903)	
	# Particles 905/3 Frames	Total Percent	# Particles 946/2 Frames	Total Percent
	Percentage of Particles Con- taining element		Percentage of Particles Con- taining element	
Mg	6.6	0.2	5.2	0.1
Al	35.5	6.2	62.9	7.3
Si	93.0	49.0	99.1	77.1
S	3.4	0.3	1.5	0.13
K	21.3	6.4	47.7	7.2
Ca	11.8	1.9	14.9	2.3
Ti	13.8	1.9	6.1	0.2
Cr	4.2	0.3	3.1	0.04
Mn	3.2	0.05	4.2	0.05
Fe	57.8	33.3	58.6	5.0
Ni	3.5	0.1	3.0	0.05
Cu	14.6	0.2	13.0	0.2
W	2.3	0.04	2.4	0.05
Zn	4.4	.1	3.0	0.05
Hg	2.6	.01	1.4	0.1
Pb	3.1	.05	0.4	0.01
Br	1.2	.01	0.11	0.00

Unfortunately, the element carbon has an atomic number of 6 and is beyond the limits of this X-ray spectroscopy. Soot and automobile by-products, e.g., rubber tire particles, would not be counted. It is these opaque particles which are the probable cause of the major difference in PV performance between the urban and rural solar modules.

4.2 Particle Size

In Table III, the particle-size measurements in both the city and agricultural areas are shown and do not appear to be strikingly different. The standard deviations are quite large, especially for the Nebraska site. It would also appear that Nebraska particles are slightly larger but the iron particles are not. The city iron samples are probably flyash from nearby industries.

5.0 CONCLUSION

Two field techniques for measuring dirt on the contaminated surfaces of solar photovoltaic modules have been presented. The first technique consists of using a commercially available portable glossmeter which, with laboratory measurements, can be correlated to the peak power (PP) performance of a PV module. This technique can also be used to quantify the efficiency of various field-washing techniques.

The second technique of replicating dirt permits the collection of contamination from the surface of PV modules so that it can be examined in the laboratory, either with photomicroscopy or even sophisticated image analysis.

These two measuring techniques enable an investigator to evaluate more accurately the effects on PV modules of field contamination and cleaning. To date, the most significant property of dirt particles which causes reduction in peak power is the opacity of the particles. The higher the carbon content in the particles, the less light is transmitted through them. This is evident in comparisons made with dirt particles from Nebraska and New York City.

TABLE III
PARTICLE SIZE STATISTICS

		NYC	Nebraska
Particle Area, μm^2	Avg.	7.85	14.8
(sigma)		± 27	± 43
Width to Length	Avg.	0.5	0.48
Length, μm		3.14	4.6
<u>Fe Rich</u>			
Particle Area, μm^2	Avg.	9.3	5.4
		± 40	± 9.8
Width to length	Avg.	0.55	0.61
Length, μm	Avg.	3.1	2.6
		± 3.7	± 2.4
<u>Si Rich</u>			
Particle area, μm^2	Avg.	6.97	14.5
		± 17.7	± 40
Width to length	Avg.	.47	.47
Length, μm	Avg.	3.25	4.7
		± 2.1	± 4.4

References

1. E. B. Murphy and S. E. Forman, "Measuring Dirt on Photovoltaic Modules," COO-4094-37, M.I.T. Lincoln Laboratory (21 March 1979).
2. R. J. Lee, et al., "Electron Beam Particulate Analysis," Industrial Research/Development (June 1979).

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