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Microscopic measurement and analysis of the soiling behavior of surfaces with standardized and real dust – a parameter study

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Abstract

Desert areas are noteworthy for solar system installation due to high yearly global irradiance. These arid regions bear extreme conditions for surfaces, like glazing and mirrors, of solar thermal systems. Surfaces are targets for soiling because of wind and high dust loads. Soiling is causing a decrease in transmittance that limits the overall performance. At a certain level depending on surface properties, like functionality and their reliability, is surface material soiling-prone. For surface qualification is a reproducible soiling test needed. An in-house developed artificial soiling device achieves this purpose. Realistic dust deposition is used to test the functionality and properties of surfaces for application in arid regions. The parameter study points out the connection between properties of surfaces and the adhesion behavior of real dust. Soiled surfaces are analyzed by by spectroscopic (FT-IR) and gravimetric measurements.

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Keywords: dust particle interaction; atomic force microscopy; soiling test method; transmittance loss

1. Introduction

The actual efficiency of solar systems is influenced by various factors. Besides global irradiance and technical characteristics, the local environmental conditions are crucial for the reliability and resulting energy yield. Thus the deposition and adhesion of airborne particles on the glazing, like solar glass, or mirrors of solar thermal systems have to be considered as important aspects. Soiling, as the accumulation of dust and other inorganic and organic

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particles on surfaces is described, causes reversible optical losses and reduced transmittance of the glazing. Several empirical studies investigated this phenomenon by correlating the time of outdoor exposure or the amount of dust on glazing materials with the measured performance. All studies report a reduction in efficiency with increasing soiling rates. In some cases efficiency losses of 30% and more are found [1]. With exception of extreme events like a nearby construction sites or sand storms, accumulation of dust is steady process and can even increase this value further [2]. In this study parameters are researcher to understand this steady process better. Parameters, which are linked directly to the soiling of surfaces due to dust particle adherence, will be varied. The first parameter is the prevalent earth surface condition, influencing the dusts chemical and physical properties. The second parameter is the glazing material characteristic, especially the surface structure and functional coatings. The third parameter, influencing the negative effect of this phenomenon on performance, is the meteorological conditions. The conditions are represented by climate and weather, which are to some extent simulated by the accelerated ageing tests.

2. Artificial dust deposition

2.1. Adhesion of dust and variation of dust properties

To understand the adhesion of dust on surfaces suitable tests are required. Aim is a reproducible soiling test for deposition of a homogeneous dust layer. Hence a realistic dry soiling method is designed to simulate dust deposition and adhesion on surfaces. It is possible to qualify surfaces of small samples in a dusting device, Figure 1. The in-house developed artificial dusting device enables the investigations of dust adhesion on the macroscale.

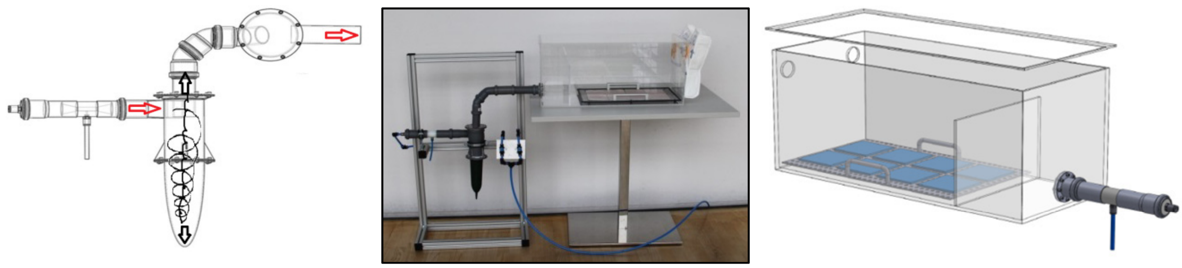

Fig. 1. Soiling test device, consisting of the dusting chamber (right) and a cyclone as add-on to soil with fine particles < 10 µm (left).

In order to obtain dust deposition parameters, deposited amount and transmittance loss, glass substrates are artificially soiled. The micro structured samples, the most common type of glazing structure for solar applications, are soiled in a horizontal position with two different types of dust. The soiling test device ensures a reproducible deposition of these dust types within the range of the natural or given particle sizes. Influences on the soiling phenomenon are researched by variation of dust types and their particle size distribution. Soiled samples are analyzed by gravimetric and optical measurements. The dust types are

A. Standardized test dust (fine), Arizona dust according to ISO 12103-1
B. Natural desert dust (fine), location Negev Desert

To change the particle size distribution a dust separator (cyclone) is interposed between the dust load zone and the dust in-let into the dusting chamber, which filters particles larger than 10 µm out of the dust-air-mixture. The amount of dust let into the dusting chamber, where the samples are located, is kept constant per dusting event. One exception is made, when the amount is raised to the 3.5 fold to investigate the influence of an increased initial dust load. After dust application are sample tilted to see what amount sticks to the surface, Table1.

Table 1. To identify the soiling load per dusting event is the influence on dust-surface interaction observed.

Test dust	Factor of dust amount (at the in-let)	Cyclone	Evaluation possible
A	1	No	Yes
A	1	Yes	Yes
B	1	No	Yes
B	1	Yes	Yes
A	3.5	No	No
A	3.5	Yes	Partly
B	3.5	No	No
B	3.5	Yes	Yes

Results

After increasing the amount of dust to 3.5 times a change in the attachment from dust layer to the surface is found. The deposited dust does not adhere any more on the surface while the samples are erected upright. Neither with nor without cyclone does the dust layer attach as expected. Most likely are the bonding forces between surface and dust layer at a certain dust load not strong enough or not yet stabilized. A difference exists between the behaviors of the dust types. The fine artificial Arizona standard dust slides down completely. Whereas the natural Negev desert dust shows remaining dust. The remaining dust which still adheres to the surface accounts only to 1.16 g/m². This is only 3% of the deposited dust before tilting. Using 3.5 times the dust amount as input for soiling tests is not senseful for reproducible testing. For the following test the normal amount has been used.

Figure 2 summarizes several graphs of 1x dusted glazing samples with the size of 100 mm x 100 mm. The reference (ref) sample visualizes the solar transmittance of the glass without dust. Compared are further the type I) artificial (Arizona) and II) real Negev (NGV) dust deposited with and without a cyclone to filter larger particle (> 10 µm) out of the dust-air mixture.

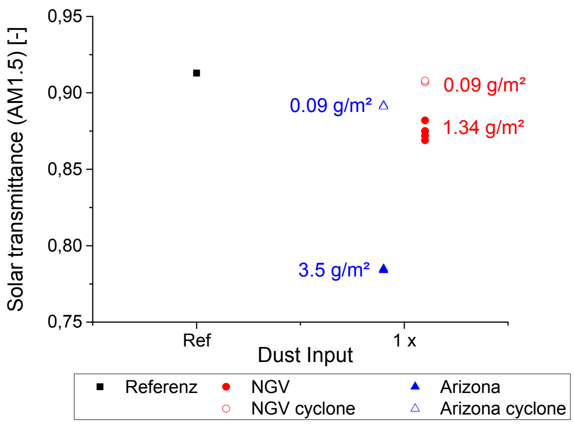

Fig. 2. Parameter study on the impact of dust particle sizes of different dust types on micro structured glass glazing.

The cyclone acts as kind of filter separating different particle sizes. Without cyclone the total amount deposited is 35 times higher for artificial dust and 15 times higher for the natural dust. The deposited Arizona dust reduces the solar transmittance by 13%, and with cyclone by over 2%. The deposited Negev dust reduces the solar transmittance by 5%, and with cyclone by less than 1%. Comparing the results in terms of the influence of the deposited particle sizes, it is to say that finer dust particles are worse for the transmittance.

In the following the influence of the two used dust types is compared. The deposition values of 3.5 g/m² standard dust and 1.34 g/m² natural dust, gained without the use of the cyclone, have a factor 3 in between them. Although the dust amount at the in-let is identical for these two tests, Table 2. The natural dust leads to ~ 1/3 of the dust sticking to the surface compared to the standard dust. The transmittance loss caused by the natural dust is also only ~ 1/3 compared to the transmittance loss caused by the Arizona dust. This gives a first indication that there is a linear “transmittance loss” to “dust amount”-correlation.

Table 2. Linear correlation of transmittance loss to adhering dust amount.

Dust	**Adhering amount [g/m²]**	**Factor**	**Transmittance loss [%]**	**Factor**
A	3.5	1	13	1
B	1.34	0.38	5	0,38

But it is remarkable that identical deposition amounts of natural and artificial dust lead to different solar transmittance values after using the cyclone. The transmittance is more reduced by the artificial Arizona dust, Table 3.

Table 3. Influence of particle sizes on the transmittance.

Dust	**Adhering amount [g/m²]**	**Transmittance loss [%]**
A	0.09	> 2
B	0.09	1

The dust deposition with natural dust onto these glazing samples is shown in Figure 3 and Figure 4. The deposition with cyclone (Fig. 3) and without (Fig. 4) clearly differences in particle sizes of up to 100 µm or up to 10 µm. This also shows the necessity for pre-treatment of dust in terms of separating the dust grain sizes from sand grain sizes in order to achieve a homogeneous coverage of the surface.

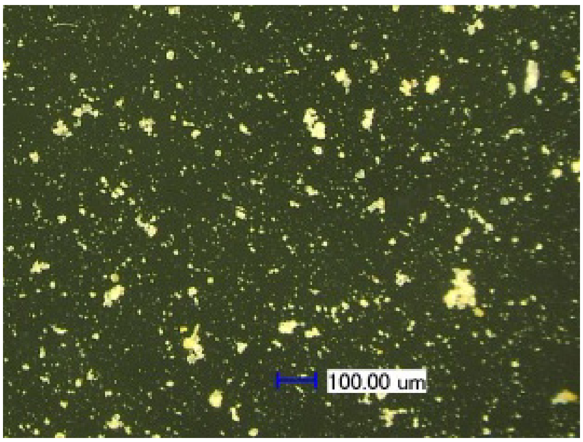

Fig. 3. Image of Negev dust deposited on solar glass glazing with the dusting device. Dust-soil particle size is up to 100 µm, dusted with soil < 1mm.

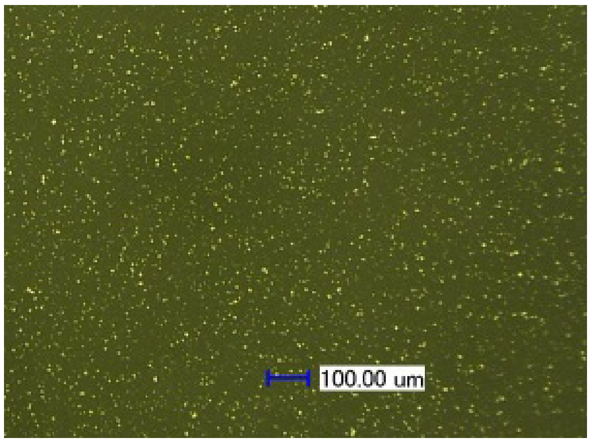

Fig. 4. Image of Negev dust deposited on solar glass glazing with the dusting device. Dust-soil particle size is up to 10 µm, by dusting device with cyclone as add-on.

2.2. Adhesion of dust by variation of dust type and glazing structure

Since the cyclone is well severing all particles larger than 10 µm, the following dusting tests are done without cyclone. Presented tests are done with soil, which is sieved to reduce the grains to a sufficient enough dust grain size. By artificial dry dusting is now the impact of the dust type and impact of glazing structure investigated. Changes in parameters are summarized in this study. The influence of the properties of three types of dust and two different structures of surfaces are investigated by gravimetric and optical measurements. The dust types are:

A. Standardized test dust (fine), Arizona dust according to ISO 12103-1
B. Natural dust (fine), from the desert location Negev Desert, Israel
C. Natural dust, from maritime location of Gran Canaria (GC) of the Canary Islands, Spain

Results

In Figure 5 is the adhering amount of these three different dust types on the two glazing structures of plain ("smooth") and micro structured ("structured") solar glass glazing shown. The amount of dust is applied in several dusting cycles. Each cycle uses the same amount of dust introduced into the dusting device. After each cycle the samples are removed, weighed, then tilted to 90° and tapped on the ground to remove the lose dust and then weighed again. After selected cycles the solar transmittance is measured, Figure 6.

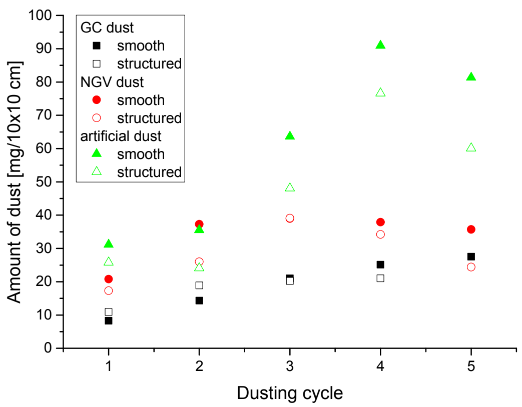

Fig. 5. Parameter study on the impact of dust type and glazing structure on the adhering amount of dust to the surface.

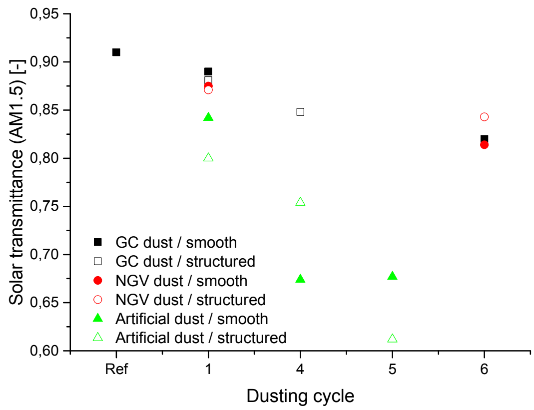

Fig. 6. Parameter study on the impact of dust type and glazing structure on the solar transmittance.

The data in Figure 5 shows that different dust types also adhere differently. The amount of dust on the surfaces increases with the number of dusting cycles, despite the tilting and tapping of the samples. Here only the tightly adhering dust is plotted. The artificial dust (green) adheres in larger amount compared to the natural dusts (red and black). After the first dusting cycle the coarser soil type from GC adheres with a total of ~10 mg, the finer Negev desert dust adheres with a total of ~20 mg and the artificial Arizona test dust with a total of ~30 mg. After four to five dusting cycles a saturation level is reached. The saturation level of dust strongly attaching to the surface line-up for the natural dust types at ~30 mg and for the artificial dust at ~90 mg. Test results, see Table 4, are valid under dry conditions and steady dust deposition. The solar transmittance, Figure 6, gives a good correlation to the deposited dust amounts. The solar transmittance values are further discussed in Table 5.

Table 4. Influence of dust types on adherence to surfaces.

Dusting cycle	Dust	Adhering amount [mg]
1	A	30
1	B	10
1	C	20
Saturation level		
4	A	90
4	B	30
5	C	30

The second influencing factor is the surface structure. The interaction of dust with surface structures is shown in Figure 7 by the example of Arizona dust. The dust is adhering to plain and micro structured glass and differences can be seen. On state of the art material, which is a structured surface, dust adheres less, but with larger standard deviation among samples.

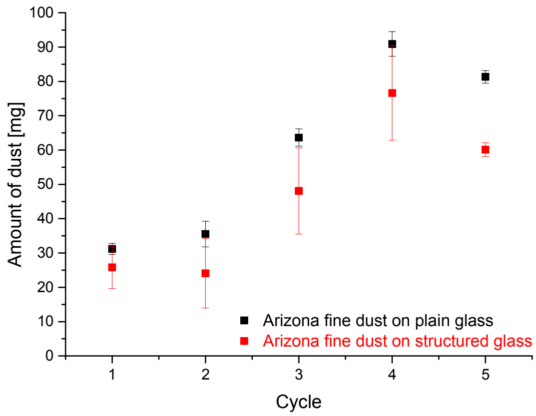

Fig. 7. Interaction of Arizona dust with different glazing structure.

The reference glass glazing with a plain surface has a solar transmittance of 91 %. The one with structured surface has a solar transmittance of 91.3 %. The loss due to the adhering dust is displayed in Table 2. Both natural dust types stronger decrease the transmittance on smooth glass, whereas the Arizona dust decreases the transmittance more in combination with the structured surface. This fact has a lot to commend for testing tailored to specific location.

The saturation level of dust on the plain surface leads to transmittance loss in average of 9 % for Canary Island (GC) dust and to 11.4 % for the Negev (NGV) dust. The saturation level of dust on structured surfaces caused a lower transmittance loss. It accounts in average for Canary Island dust to 6.5 % and for the Negev dust to 8.1 %. Standard Arizona dust leads to major transmittance loss in average of 25.1 and 30.1 %. The measured transmittance values are visualized and plotted against the amount of dust in Figure 8.

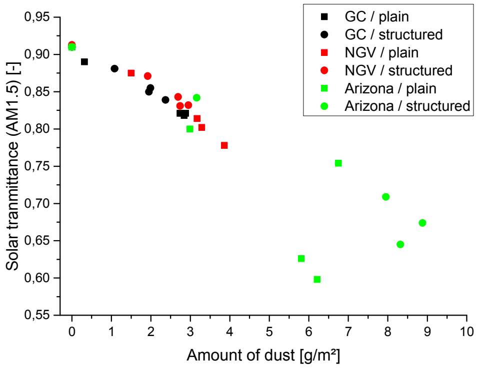

Fig. 8. Parameter study on the impact of dust type and glazing structure on the adhering amount of dust to the surface and effects.

Table 5. Transmittance loss caused by dust deposition.

	Solar transmittance loss (AM1.5) [%]	
Surface	**Plain**	**Structured**
Soiling		
NGV	11.4	8.1
GC	9.0	6.5
Arizona	25.1	30.1

Influences of the glazing structure and impact on the surface-dust interaction due to different dust types are found. Despite of that it is also shown that the solar transmittance decreases linearly at the beginning of the surface clogging caused by dust deposition. The linear drop is independent of the dust type. It is valid to a level of deposited dust for all dust types and surface structures. This level is to be defined. Still different types of dust lead to different agglomeration and saturation levels and hence are of different soiling potential in the negative meaning.

3. Findings and outlook

The application of the in-house designed dusting device with the dry soiling method, gives the option to qualify materials, and thus to enhance their functionality, stability and their surfaces to minimize soiling effects. This new characterization method is used in combination with weight and solar transmittance measurements. The characterization method of dry dusting samples is realistic for arid regions, as there is no dust-water-solution necessary for application of the dust any more. A wet application will always create disadvantages by comparing hydrophobic and hydrophilic material. The parameter study tests are performed with dry dust and dry surfaces. When higher relative humidity and condensation at night occurs stronger soiling effects and further decrease of the solar transmittance are expected, since wet surfaces show a larger adhesion potential for dust and the transmittance decreases linearly to the deposited amount of dust [3].

On macroscopic scale results of the wetting behavior and transmittance loss due to degradation tests and soiling represent a broad variation of parameters. The simulation of artificial dust deposition extends the understanding of transmittance loss due to soiling. This performed parameter study helps to understand the mechanism of soiling caused by real dust in comparison to standardized dust. First experiments with the soiling method revealed that, in up to 8 cycles, applied dust layer increases up to a certain saturation level. Differences exist between real dust and artificial dust. Real dust, from different locations, here dust from maritime (Canary Islands) and finer dust from arid (Negev desert) regions, level at 30-40 mg per 100 mm x 100 mm surface area, whereas the artificial dust levels at triple the amount. Nevertheless leads the dust from the arid regions with finer particles and smaller grain sizes to a maximal solar transmittance loss of 30 %. There are different soiling efficiencies found for different dust, depending on dust type and material. Influences of surface structures are also proven.

Prospectively further testing will be done to investigate the effects of anti-soiling coatings in solar applications. The dust deposition parameters can be used for economic feasibility studies and to evaluate geographic modelling of dust deposition risk maps. The purpose to research dust-surface interaction is to develop knowledge about dust and location combined with knowledge about surfaces. This may help to make decisions for best suitable site for solar energy system installation.

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