SolarPACES 2024, 30th International Conference on Concentrating Solar Power, Thermal, and Chemical Energy Systems

Solar Collector Systems

https://doi.org/10.52825/solarpaces.v3i.2378

Published: 28 Nov. 2025

A Novel Indoor Approach of Artificial Soiling Deposition: Achieving Desired Soil Density and Uniformity

Ashraf Issalih[1,*], Peter King[1], and Mounia Karim[2]

[1]Cranfield University Cranfield, UK

[2]Derby University Derby, UK

*Correspondence: Ashraf Issalih, Ashraf.Issalih@cranfield.ac.uk

Abstract. This work introduces a new indoor method for the artificial soiling of solar reflectors, employing a closed-loop wind tunnel chamber to replicate controlled deposition methods in a laboratory setting. The experimental setup includes dispersing a constant dust amount and allows manipulation of deposition to examine the impact of airflow speeds (1, 3, and 4.5 m/s), dust concentration and various humidity levels. The results show significant improvements of artificial soiling deposition, leading to more uniform deposition on the mirror surfaces and allowing a repeatable test.

Keywords: Artificial Soiling, Chamber, Soil Density, Soiling Deposition

1. Introduction

Soiling has a direct impact on the efficiency of concentrated solar power (CSP) plants, leading to the decrease of mirror reflectance [1]. The performance of mirrors in CSP plants can be significantly affected by reflection losses, resulting in a decrease of up to 30% within one week [2]. Operations and maintenance (O&M) costs comprise approximately 14–17% of the overall levelized cost of electricity (LCOE) in a CSP plant, and must therefore be minimised [3], [4]. Using samples of CSP mirrors or PV cover glass and exposing them outdoors is a standard experimental method to evaluate soiling through the measurement of specular reflectance for CSP or the transmission for PV [5], [6].

Direct soiling monitoring is costly and time-consuming, and project planners need more comprehensive worldwide data when choosing a site. Furthermore, testing degradation takes years to accurately simulate outdoor degrading mechanisms without going over specific thresholds that might result in unreal side effects. Additionally, outdoor soiling studies are typically unpredictable and can lack control [7].

By contrast, in one instance outside soiling was repeated in the laboratory and generated results with good correlation (Average Pearson r = 0.65) to outdoor soiling data across various locations [8]. Indoor soiling platforms may accelerate the procedure to less than a few hours, resulting in lowering the duration of testing [9]. Despite these benefits, there is limited research done on indoor soiling [10]. Additionally, research following dust deposition and subsequent cleaning are still limited and this topic is still unclear [11]. Therefore, this research proposes a new indoor method capable of examining the impact of various wind speed mechanisms on soiling deposition on reflectors.

2. Methodology

A closed loop return wind tunnel chamber was constructed from transparent acrylic sheet, with dimensions of 28.5 x 36 x 80 cm, as displayed in Figure 1 and Figure 2. Inside the chamber, upstream and downstream guide vanes reduce turbulence inside the test section. This type of wind tunnel advantages includes greater flow quality control via corner turning vanes and screens [12]. The chamber is prepared with a pair of small fans that provide a controlled stream of air, capable of being changed to speeds between 1 and 4.5 (m/s). The closed-loop structure allows an ongoing flow of stable and homogenized air within the chamber, producing a constant and regulated environment for experiments [13].

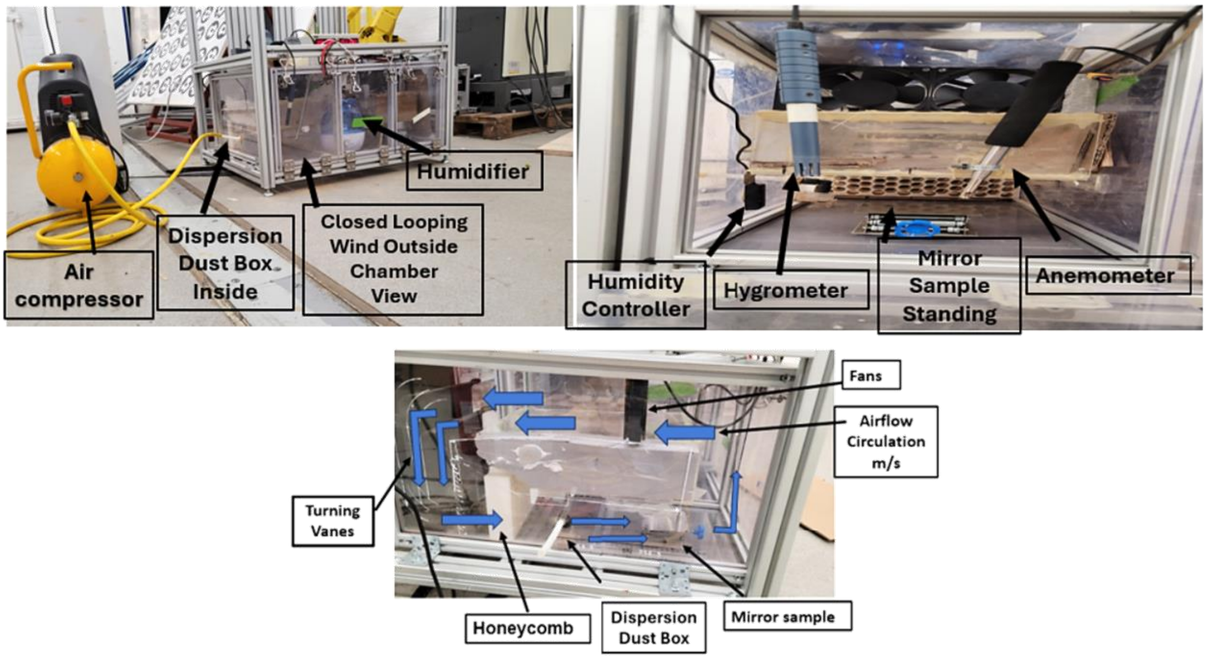

Figure 1. *Soiling experimental chamber*

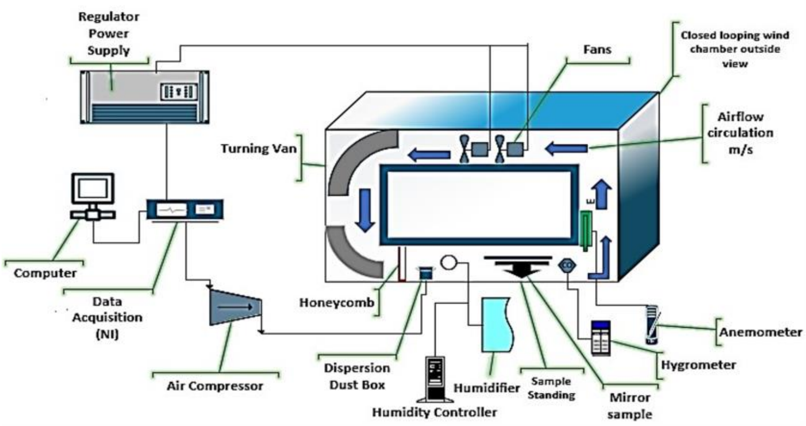

***Figure** 2. Soiling experimental chamber diagram*

In this study, natural dust composed mainly of quartz and silicates was used as an artificial soiling representative, with characterization of grain size distribution to ensure its relevance to real-world deposition conditions. Preparation began with a drying process to remove any moisture content in the sand, followed by sieving to < 63 µm according to the existing air flow ability to transport the sand particles, with consideration of the increased influence on deposition of small size particles. Mirror samples from AGC glass were prepared with dimensions of 10 cm × 10 cm and 1 mm thickness. The mirror sample was placed horizontally within the chamber.

At the beginning of the experiment, the fan was adjusted to provide the intended airflow speed (low, medium, high), and was allowed to settle for 1 minute and 30 seconds, to have a homogenous, stable flow air (this time was determined from previous experiments within the chamber). Using this period allowed for a consistent stabilisation airflow for each trial, reducing variability between runs. A humidifier was used to create a mist cloud over the mirror surface prior to soiling deposition. The dust, once emitted by an air compressor, was transported by the dry or wet airflow towards the mirror sample located in the test section.

Uniformity and repeatability assessment are crucial for evaluating the effectiveness of the soiling deposition technique. The mass of the mirror samples was measured both before and after each soiling cycle. At five specific locations on the samples, a Condor reflectometer was used to measure the mirror samples reflectance and microscope images were captured. This gives a further insight into the variability of the soiling process across the samples.

3. Results and Discussion

The result of the experiments revealed effectively controlled dust density and clear relationships between control parameters and the achieved density. The technique effectively achieved a homogeneous soil density, ensuring consistency throughout the mirror surfaces and minimal fluctuation in the distribution of dust

3.1 Mass deposition and reflectance

The mass deposition density and average specular reflectance values for different wind speeds are shown in Table 1.

Table 1. *The influence of different wind speeds on mass deposition and reflectance of mirrors*

Sampel	Wind Speed (m/s)	Mass Deposition Density (g/m²)	Average Reflectance (%)	Standard. Deviation
1	1	2.490	72	0.026
2	1	2.636	77	0.011
3	1	2.530	70	0.010
4	3	1.433	80	0.0119
5	3	1.334	79	0.012
6	3	1.124	78	0.0159
7	4.5	0.652	88.2	0.010
8	4.5	0.715	88	0.010
9	4.5	0.467	88.9	0.004

The results showed that the design of the experiment consistently achieved the desired soil density over several attempts. The large advantage of this artificial soiling method is that experiments can be repeated conducted under defined conditions. The study found a clear link between airborne dust levels and the amount of dust deposited on the mirror surfaces. Higher dust concentrations released in the air led to greater dust accumulation on the mirrors, while lower airborne dust resulted in reduced deposition, as demonstrated in Figure 3 and Figure 4.

Additionally, the results show that relative humidity enhance to increase the soiling rate on surface, as shown in Figure 5.

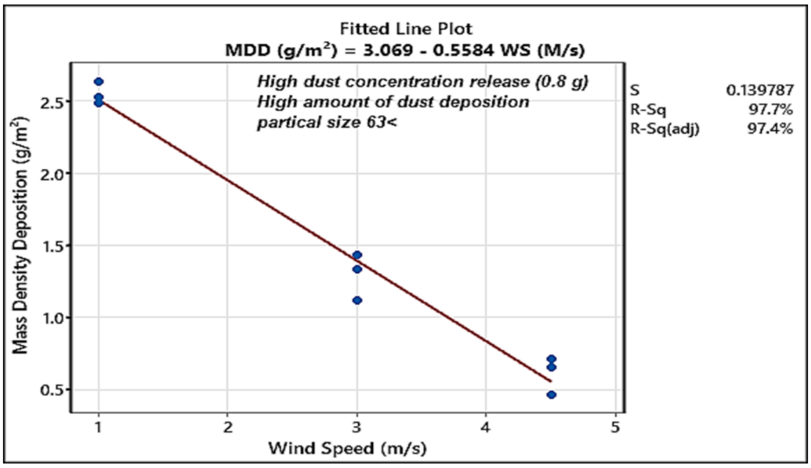

Figure 3. *Influence of different air speeds and high dust concentration on mass deposition*

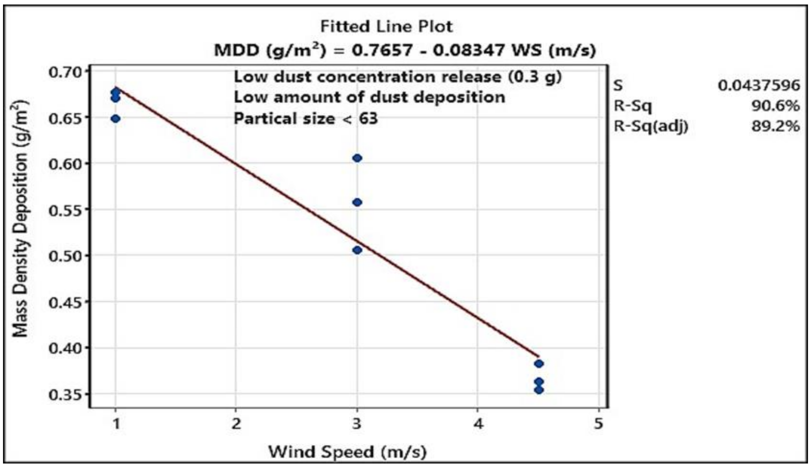

Figure 4. *Influence of different air speeds and low dust concentration on mass deposition*

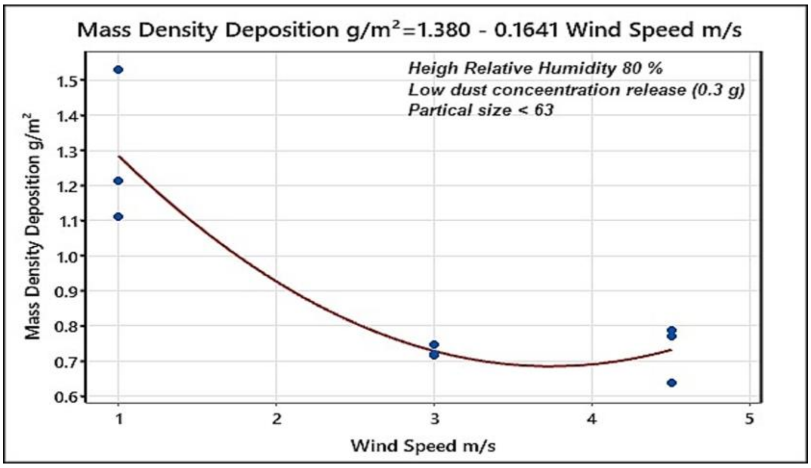

Figure 5. *Influence of different air speeds and relative humidity on mass deposition*

3.2 Microscopy

The technique effectively achieved a homogeneous soil density, ensuring great consistency across the mirror surfaces and minimum fluctuation in the distribution of soiling. Figure 6 and Figure 7 provide a visual representation of surface analysis.

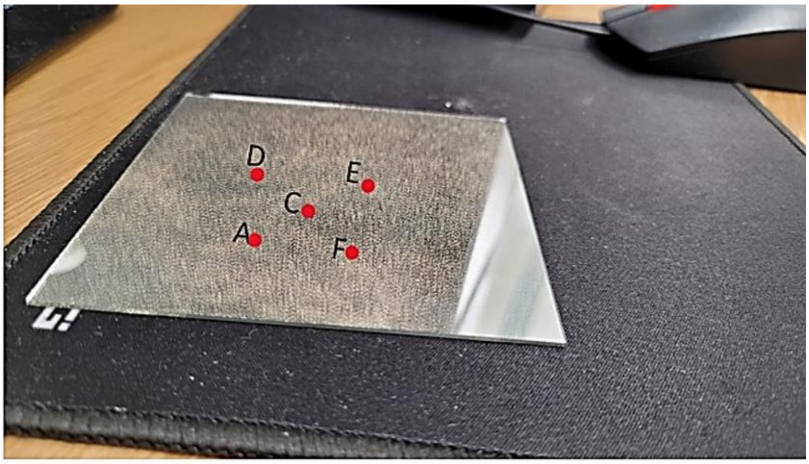

Figure 6. *Soil deposition uniformity test*

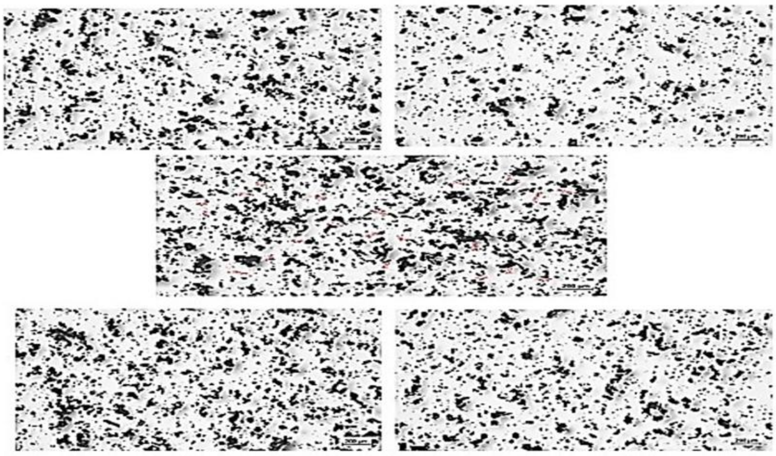

Figure 7. *Captured microscopy Images for five different points on mirror sample*

The experimental results demonstrate the repeatability of deposition density and provide a detailed uniformity analysis. These findings indicated that there is a correlation between these factors and the extreme density of the soil accumulated on the surface. Increasing the mass of dust released into the airflow leads to increased dust loading on mirror surfaces, while its reduction decreased the soiling accumulated. Higher airflow velocities aided the movement and dispersion of dust particles, resulting in more uniformity and less deposition on the mirror surfaces. In contrast, decreased velocities resulted in the concentrated collection of dust particles. Furthermore, a high level of relative humidity causes dust particles to clump together and accumulate on surfaces, whereas a lower relative humidity results in a lower-level dispersion of dust particles.

The key findings demonstrate that the method effectively controlled soil density, highlighted clear relationships between controlled artificial weather parameters (wind speed, relative humidity and particulate matter), and achieved density, confirmed repeatability of density control, and provided a detailed uniformity analysis. Particularly, the approach achieved a consistent dust density, in terms of correlation between wind speed and soiling density with R-squared values ranging from a minimum of 69% to a maximum of 97.7%. This indicates a good fit across different soiling amounts. Additionally, reflectance analysis of the mirrors demonstrated high uniformity across the test surfaces, with standard deviation very low variability (as shown in Table 1).

4. Conclusion

This study has developed and tested a novel technique for depositing a controlled layer of simulated dust indoors using a specialized apparatus, with the aim of achieving an ideal density and consistency across mirror surfaces. This establishes a direct correlation between the specific settings used and the uniform density achieved. This paper offers a dependable and repeatable method for recreating dust accumulation scenarios in a controlled environment. The developed approach addresses a significant challenge in existing methods by enabling precise control over soiling conditions. This control enhances the accuracy and reliability of CSP performance testing. The achievement of consistent and uniform soil deposition facilitates a more precise evaluation of the impact of dirt on solar energy systems, resulting in improved cleaning schedules and maintenance procedures.

Data availability statement

All data supporting the results of this study are all included within the paper. There is no included supplementary information; all details, methods, and results are available in the main text. This ensures that readers have full access to the information needed to understand, evaluate, and replicate our findings.

Author contributions

Ashraf Issalih conducted all the work with the participant authors. The authors were responsible for reviews and conceptualization. The participating authors provided the necessary support, ensuring the research successes. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

Funding

This study was partly funded as part of ongoing research by a Libyan Ministry of Education scholarship supporting the corresponding author's PhD study.

References

[1] A. A. Merrouni, A. Mezrhab, A. Ghennioui, and Z. Naimi, "Measurement, comparison and monitoring of solar mirror's specular reflectivity using two different reflectometers," Energy Procedia., vol.119, pp.433–445, Jul.2017.
[2] C. Kutscher, M. Mehos, C. Turchi, G. Glatzmaier, and T. Moss, Line-Focus Solar Power Plant Cost Reduction Plan. Washington, DC, USA: National Renewable Energy Laboratory, 2010.
[3] E. P. Roth and R. B. Pettit, The Effect of Soiling on Solar Mirrors and Techniques used to Maintain High Reflectivity. Albuquerque, NM, USA: Sandia National Lab (SNL-NM), 1980.
[4] F. Wolfertstetter et al., "Soiling in CSP: modeling and forecasting from weather inputs, German Aerospace Center (DLR), Plataforma Solar de Almería, Spain, 2018.
[5] International Renewable Energy Agency, Technology Brief: Concentrating Solar Power. Masdar City, Abu Dhabi, United Arab Emirates: IRENA, 2013.
[6] K. Ritter, A. McBride, and T. Chambers, "Soiling comparison of mirror film and glass concentrating solar power reflectors in southwest Louisiana," Sustainability, vol. 13, no. 10, May 2021, Art. no. 5727.

[7] M. Z. Khan et al. “Correlation between laboratory and outdoor soiling experiments with anti-soiling coatings,” Sol. Energy Mater. Sol. Cells, vol. 269, Jun. 2024, Art no. 112751

[8] N. Hussain et al. “Study of soiling on PV module performance under different environmental parameters using an indoor soiling station,” Sustainable Energy Technol. Assess., vol. 52, no. C, Aug. 2022, Art. no. 102260.

[9] P. Droege and L. Hedwig, “Editorial to the proceedings of the 9th International Renewable Energy Storage Conference (IRES 2015),” Energy Procedia, vol. 135, Oct. 2017, pp. 1–2.

[10] P. Borah, L. Micheli, and N. Sarmah, “Analysis of soiling loss in photovoltaic modules: a review of the impact of atmospheric parameters, soil properties, and mitigation approaches,” Sustainability, vol. 15, no. 24, Dec. 2023, Art. no. 16669

[11] R. Conceição, H. G. Silva, J. Mirão, and M. Collares-Pereira, “Organic soiling: the role of pollen in PV module performance degradation,” Energies, vol. 11, no. 2, Jan. 2018, Art no. 294.

[12] S. D. Kulkarni, M. A. Minor, M. W. Deaver, E. R. Pardyjak, and J. M. Hollerbach, “Design, sensing, and control of a scaled wind tunnel for atmospheric display,” IEEE/ASME Trans. Mechtron.vol.17, no.4, pp.635645, Aug.2012.

[13] T. Sarver, A. Al-Qaraghuli, and L. K. Kazmerski, “A comprehensive review of the impact of dust on the use of solar energy: history, investigations, results, literature, and mitigation approaches,” Renewable Sustainable Energy Rev. vol. 22, pp. 698–733, Jun. 2013.