SolarPACES 2023, 29th International Conference on Concentrating Solar Power, Thermal, and Chemical Energy Systems

Measurement Systems, Devices, and Procedures

https://doi.org/10.52825/solarpaces.v2i.931

Published: 18 Oct. 2024

Contribution Effect of Operation Time on the Performance and Accuracy of the Condor Reflectometer

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Abstract. This paper evaluates the potential effect that operation lifetime could have on the accuracy and reproducibility of the Condor reflectometer. For this purpose, three Condors with different operation lifetimes have been used and compared in this study. In addition to the device's operation lifetimes, reproducibility and the repeatability of the measurements have also been evaluated. Silvered glass mirrors at different states have been used, e.g., clean, soiled and eroded in order to evaluate the effect of the surface properties on the difference reported using different devices. The obtained results have shown that the difference in specular reflectance reported by the three different Condors is more noticeable in case of soiled and eroded glass mirrors compared to clean sample. This could be linked to the surface roughness more than to the years of operation of the device itself.

Keywords: Device Accuracy, Operation Lifetime, Reproducibility

1. Introduction

The Condor reflectometer is an accurate optical portable device that has been developed and manufactured by Abengoa Solar in 2012 and is currently commercialized by Zeprem Solutions [1]. It allows the measurement of the specular reflectance at six different wavelengths λ= {435, 525, 650, 780, 940, 1050} nm, an incidence angle θ_i=12° and acceptance angle φ=290 mrad [2]. The device contains six different LEDs and six corresponding detectors, one LED for each specific wavelength (Figure1). The solar weighted specular reflectance is then calculated using the ASTM- G173 standard.

Each Condor is equipped with its own calibration mirror which is kept as a reference mirror. The specular reflectance of this reference mirror is initially pre-registered by the manufacturer in the device and no optical alignment is required by the operator.

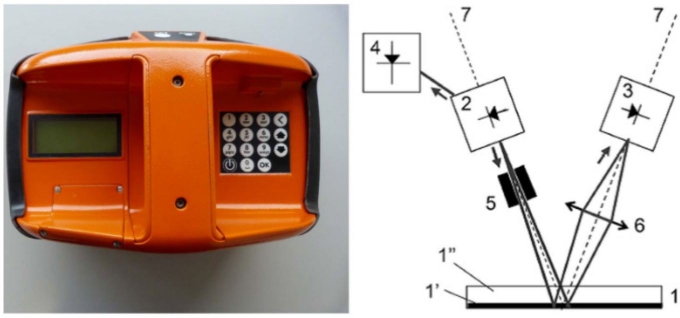

Figure 1. *Condor reflectometer, (1): Mirror; (1'): Reflecting surface; (1''): protective surface (2): LED emitter; (3): reflection detector; (4): Reference detector; (5): Diaphragm; (6): Lens; (7): Optic source*

Before measurement, the Condor needs to be calibrated using the reference mirror provided with the equipment [2]. During the calibration process, the device will automatically compare the six current measurements of the reference mirror to the ones pre-saved in the device by the manufacturer. So, in case of any degradation of the reference mirror or any optical misalignment of one of the LEDs or detectors inside the device, the measured values may be different to the pre-saved ones, which will lead to the calibration of the device to be erroneous. The operator may not notice the difference unless the variation is very high.

To evaluate the effect of long years of operation on the accuracy and reproducibility of the Condor device, three Condors with different operation lifetimes have been compared in this study. The main objective is to find out whether this optical device can still perform in the same way after long years of operation. The methodology that has been followed in this study is presented below.

2. Materials and Methods

Three different Condor devices have been used and tested in this study. One old device with wider design than the two other devices. This means that the location of the Leds in the first device might be different compared with the two others which look very similar in design. The operation lifetime of the devices varies from 0 to 8 years of use. Different tests have been performed in the Lab in order to evaluate the following:

- **Effect of Condor's operational lifetime:** Three different Condors have been used with different operation lifetimes,
- **Effect of operator:** To highlight the effect of the operator on the reproducibility of the results, three different operators have been chosen to conduct the experiment (Figure 2). The sample is measured in a row by the three operators, each time the operator will do a set of three measurements before leaving the device to the following operator. Three sets of measurements per each operator on every sample. The device is calibrated at the start of the experiments.
- **Effect of mirrors' conditions:** To evaluate the effect of the mirror's state and rough- ness on the potential variance of specular reflectance using the different Condors, it has been decided to use three different silvered glass mirrors; a clean mirror, a soiled and an eroded one (Figure 3),
- **Repeatability:** To ensure the repeatability of obtained results, three different measurements have been carried for each testing condition and each time three different values were taken as stated in the table 1 below.

Figure 2. *Three different operators for reproducibility tests*

To avoid differences in measurements due to a shift of the position of the Condor on the sample, especially for soiled and eroded mirrors, adjustments have been made in order to ensure that all measurements will be performed on the same spot. Any change in this spot may lead to a variation in the specular reflectance measured by the different Condors.

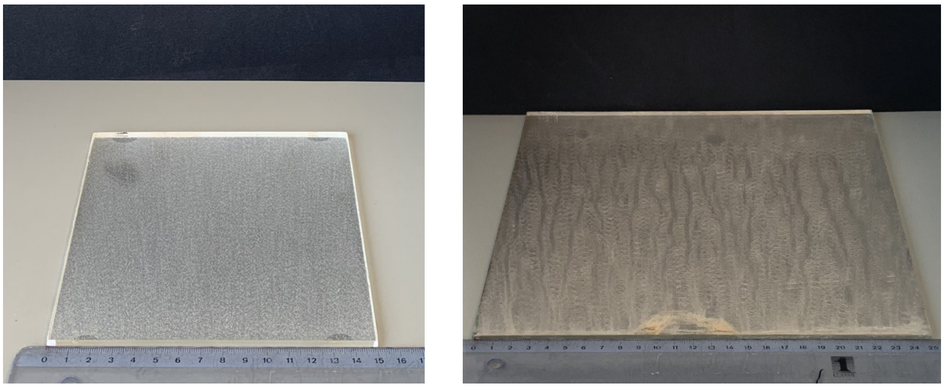

Figure 3. *Glass mirrors used to compare the Condors' performance. Eroded sample (left) and Soiled sample (right)*

The testing matrix is presented in the table below. It depicts the different measurements carried out for a single silvered glass mirror sample. The same matrix has been used for the three different mirrors samples used in this study.

Table 1. *Testing matrix used to evaluate the effect of different parameters on the optical accuracy of the Condor reflectometer*

	Condor 1			**Condor 2**			**Condor 3**		
	Op 1	**Op 2**	**Op 3**	**Op 1**	**Op 2**	**Op 3**	**Op 1**	**Op 2**	**Op 3**
Rd 1	1	1	1	1	1	1	1	1	1
	2	2	2	2	2	2	2	2	2
	3	3	3	3	3	3	3	3	3
Rd 2	1	1	1	1	1	1	1	1	1
	2	2	2	2	2	2	2	2	2
	3	3	3	3	3	3	3	3	3
Rd 3	1	1	1	1	1	1	1	1	1
	2	2	2	2	2	2	2	2	2
	3	3	3	3	3	3	3	3	3

Regarding the three different Condors used in this study, these are:

- University of Derby, UoD: Brand new device,
- OPAC Lab, CIEMAT/DLR: 1.5 years of Operation,
- Cranfield University, CU: 8 years of Operation.

3. Results and Discussion

In this section, results are presented and analyzed by the mirror's type. This highlights any potential effect that the surface roughness could have on the variation of specular reflectance measured using the different Condors.

For the clean silvered glass mirror, the difference in specular reflectance measured by the three different Condors is low. A maximum difference of 0.25% has been observed between the Specular reflectance measured by the CU device and the CIEMAT/DLR device (Figure 4). Also, it has been found that the standard deviation between all different measurements performed is minimal, with 0.04% for UoD device measurements and 0.05% for both CU and CIEMAT/DLR devices.

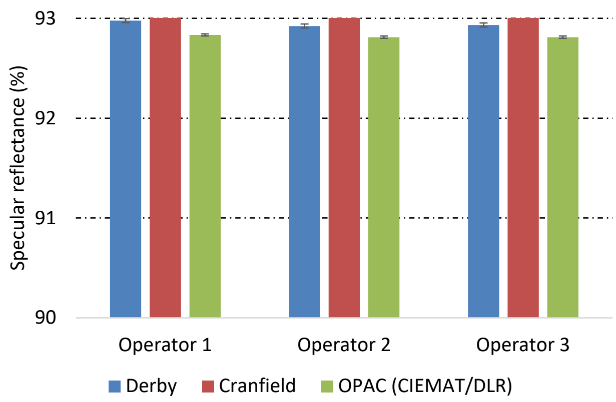

Figure 4. *Solar weighted specular reflectance of clean silvered glass mirror using three different Condors*

For the eroded sample, the difference in specular reflectance measured using the three different Condors can be observed (Figure 5). All three operators have reported higher values of specular reflectance when using the CU Condor device. However, the CIEMAT/DLR Condor has been giving the lower specular reflectance measured for this sample amongst the three used devices.

Due to the high surface roughness, a dispersion of specular reflectance values has also been reported on the measurements performed. For this eroded sample, the StDev was around 0.3% for CIEMAT/DLR device, 0.38% for the CU and up to 0.6% for UoD Condor device.

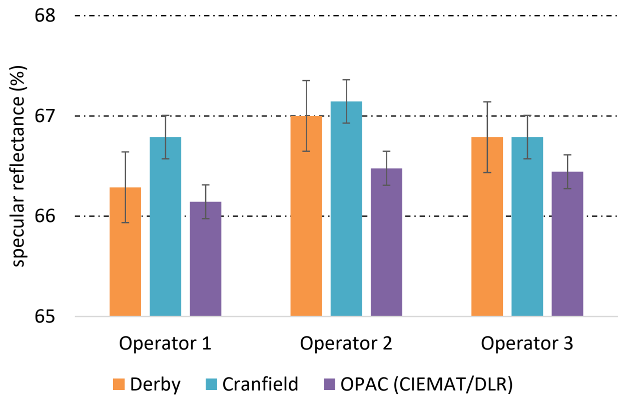

Figure 5. *Solar weighted specular reflectance of eroded silvered-glass mirror using three different condors*

The difference in specular reflectance values using the three Condors is even higher for the soiled sample as shown in the figure below (Figure 6). The CU device always gives high values compared to the other tested Condors. The dispersion of values is much higher in case of soiled surface as the StDev reaches 1.93% for the CU device, 0.6% for the CIEMAT/DLR device and 0.4% for the UoD device. This may be caused by the inhomogeneity of the soiling deposition over the surface.

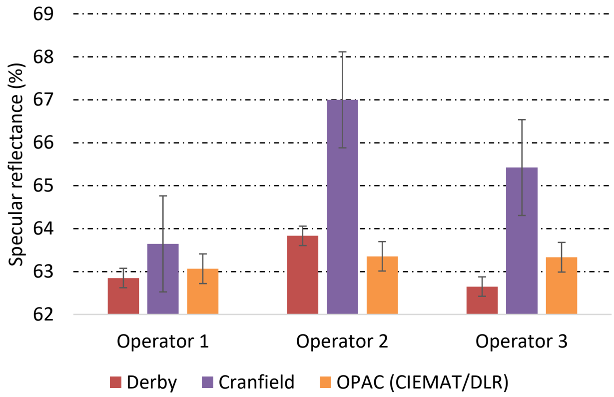

Figure 6. *Solar weighted specular reflectance of soiled silvered-glass mirror using three different condors*

According to Figure 5 above, the general tendency in specular reflectance values could be that CU values > UoD values > OPAC (CIEMAT/DLR) values. However, This is different in Figure 6 where CU values > OPAC (CIEMAT/DLR) values > UoD values except for Operator 2 who confirms the trend obtained in case of eroded sample in Figure 5.

In terms of years of operation, the CU device is the oldest one (8 years of operation), followed by the CIEMAT/DLR device (1.5 years of operation) and the brand-new device from UoD. This means that the years of operation cannot be directly linked to the difference highlighted in reflectance for both soiled and eroded silvered glass samples tested in this study. More tests and analyses need to be done in order to better understand this difference in specular reflectance for both soiled and eroded samples.

Regarding the effect of the operators on the variation of the specular reflectance, it has been found that Operator 2 has been obtaining higher values in comparison to the other two operators, while Operator 1 has been always giving lower values. This shows that measurements can be biased by the Operator and their own way of conducting the measurement even if it is a straightforward manipulation.

4. Conclusion

Results have shown a difference in specular reflectance reported by the three different Condors. It has been found that the Condor from CU, after 8 years of operation, presents generally higher values in comparison with the two other devices. In addition, there was no clear trend related to the years of operation and the higher values observed. So, this difference can be explained either by the high roughness of the measured surfaces which lead to different measured spots with higher variation and therefore different values or to the device itself. It should be noted that the CU Condor is slightly bigger than the two other devices, which means that the LEDs may not be aligned with the other two devices. This may have contributed to the higher values obtained by CU device. However, the question remains why these values have always been higher in comparison with the other devices. To investigate this further, a set of additional tests will be conducted on both silvered-glass and polymer mirrors with different surface conditions. The specular reflectance of the mirrors will be measured also using other optical lab or portable devices to define the erroneous values.

Data availability statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Author contributions

M. Karim: Conceptualization, Methodology, formal analysis; Investigation and Validation, Writing– original draft; C. Sansom, A.Fernandez-García: Methodology, Investigation and Validation, Review & editing; F.Sutter, J.Wette: Methodology, Investigation and Validation; Z. Hussaini, P.King, H.Almond, F.Wiesinger: Review & editing

Acknowledgements

The authors would like to thank Lucía Martínez-Arcos and Tomás Jesús Reche-Navarro for their considerable contribution in this work.

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