EVALUATION OF TWO REFLECTIVE COATINGS FOR THE MIRRORS OF THE HIGH RADIATIVE-FLUX SOLAR FURNACE

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Abstract

We present the initial results for the comparative study of two types of reflecting surfaces for solar concentrating systems. We use two identical mirrors with different coatings: The first have an aluminium coating with SIO_2 protection and the second was covered with the commercial film Reflectech®. This cover is used mainly for parabolic trough and has several advantages like a high reflectivity, low maintenance, and resistance to extreme weather conditions. Since this film was developed for concentrating solar applications, the purpose of this study is exploring the potential application of the film in point focus concentrating systems.

1. Introduction.

In the design and development of systems to harness solar energy, the two main requirements for reflective surfaces of solar concentrators are their ability to reflect the maximum possible of solar radiation, *i.e.* their reflectivity in the whole wavelength range of the solar spectrum; and in the other hand, the ability to produce a high quality optical image to allow a better concentration of solar energy, which is accounted by the reflection angular error.

Two different types of optical coatings were tested for the fabrication of the mirrors of the High Radiative-Flux Solar Furnace (HRFSF) [1], which is being developed at Centro de Investigación en Energía, of Universidad Nacional Autónoma de México (CIE-UNAM): evaporated aluminium coated with silicon oxide, and a commercial polymeric reflective film known as Reflectech® [2]. Both reflectivity and image forming properties were tested for these coatings that were applied over the surface of concentrating mirrors.

2. Methodology

Instituto Nacional de Astrofísica, Optica y Electrónica (INAOE, México) supplied two hexagonal, optically smooth ($\lambda/2$), polished concave mirrors, with 3.75 m focal distance and 0.4 m apothem. A total of 409 of these mirrors are being fabricated for the HRFSF. The mirrors were coated by INAOE, one of them with evaporated aluminium and a protective silicon dioxide layer, and the other one with Reflectech®.

Two different tests were carried out: in the first the broadband specular reflectance of both mirrors was measured. The experimental setup is shown in Fig. 1. In these experiments, the mirrors were used as reflective surfaces of the radiation produced by a diffuse tungsten incandescent lamp. The radiation reflectivity was then measured by using a wide-spectrum optical radiometer [3] with the following specifications: spectral range from 0.3 μm $\leq \lambda \leq$ 30 μm and angular acceptance of 0.4°. As shown, the mirror was positioned in such a way that the image of the lamp was in the line of sight of the radiometer. During the tests, the mirrors were simply exchanged, making sure that each one was placed in exactly the same position. Several measurements of the reflected radiation (W/cm^2) were taken for each mirror.

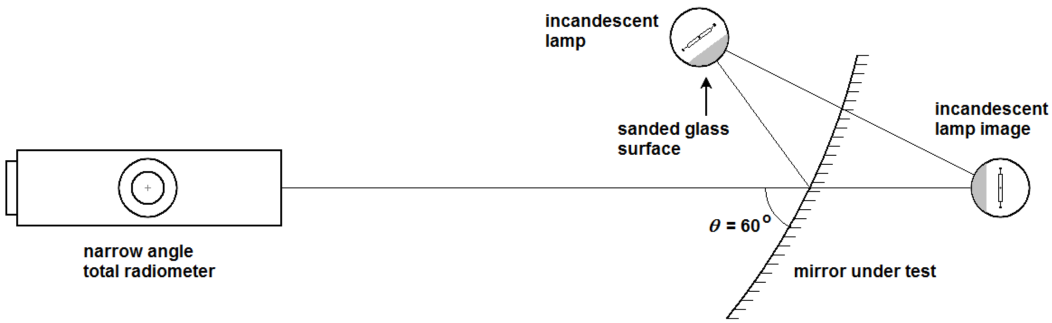


Figure 1. Experimental setup for total reflectivity measurements.

The second test consisted in capturing images of the sun produced by both mirrors and comparing them to ray tracing simulations in order to determine the optical error of the surfaces. Figure 2 shows the experimental arrangement: a small flat elliptical 25 millimetre mirror is used to redirect radiation from the sun to the mirror under test. The reflection of the concave mirror can be observed on a screen located to the focal distance for the tested mirror. The image on the screen is captured with a CCD sensor of a 16-bit digital camera.

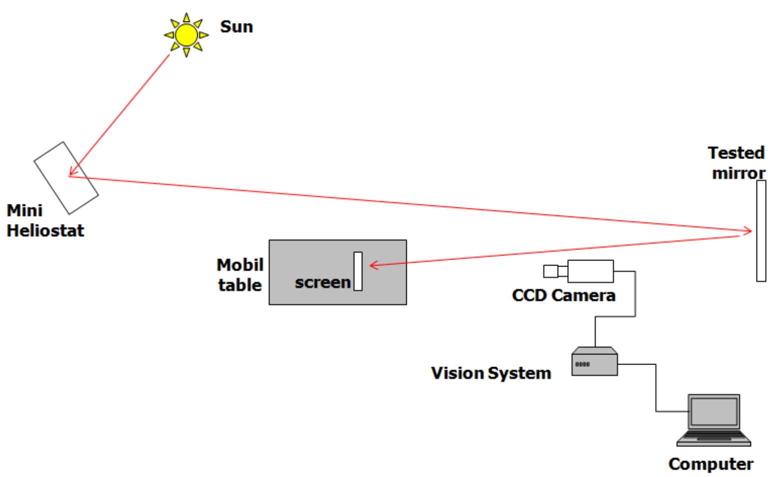


Figure 2. Experimental setup for evaluation of mirror image quality.

The images obtained were compared with the results of a ray tracing program, called Tonalli (sunshine in Aztec Language) [4]. The code calculates the irradiance flux on a focal plane by using with the convolution technique. We assume that the error distribution corresponds to a normal distribution with a global standard deviation. The sun's model was a standard solar radiation cone [5], as for instance in the CIRCE2 ray tracing code [6]. To determine the optical error of the mirrors, the program simulated the solar concentration in the focal plane in order to determine the error that best fits the profile of the images obtained experimentally.

3. Results.

In the reflectivity test the following average values were obtained with the radiometer, for both mirror coatings:

$$I_{al} = 3.34 \pm .03 \text{ mV} \quad \text{(aluminium coated mirror)}$$
$$I_{rf} = 3.25 \pm .02 \text{ mV} \quad \text{(Reflectech® coated mirror)}$$

This result indicates that the difference between the reflectance is approximately 2.7%, slightly better for the aluminium coated mirror.

In figure 3, we can observe an example of the images obtained in the second test for both mirrors. These images were analyzed with a computer program developed with MATLAB® to calculate their irradiance profile. The program normalizes the images and calculates the fraction of energy captured for different average radius from the centre of the image; i.e., the intercept factor.

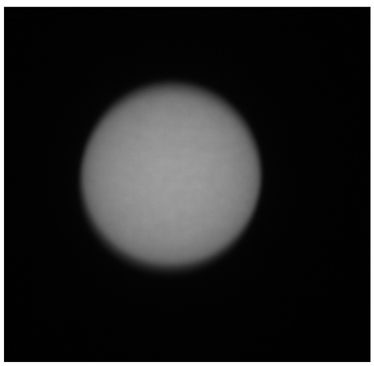
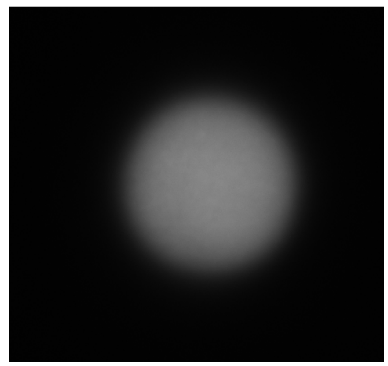
(A)  (B) 

Fig. 3 (A) Image from the Sun obtained from aluminium coated mirror. (B) Image from Reflectech® coated mirror.

Figure 4 and 5 show the difference between the average radii for different intercept fractions. The graph shows that the aluminium coated mirror has a slightly better intercept factor for larger radii. Table 1 presents the values of the radii that span 70%, 80% and 90% of the concentrated energy.

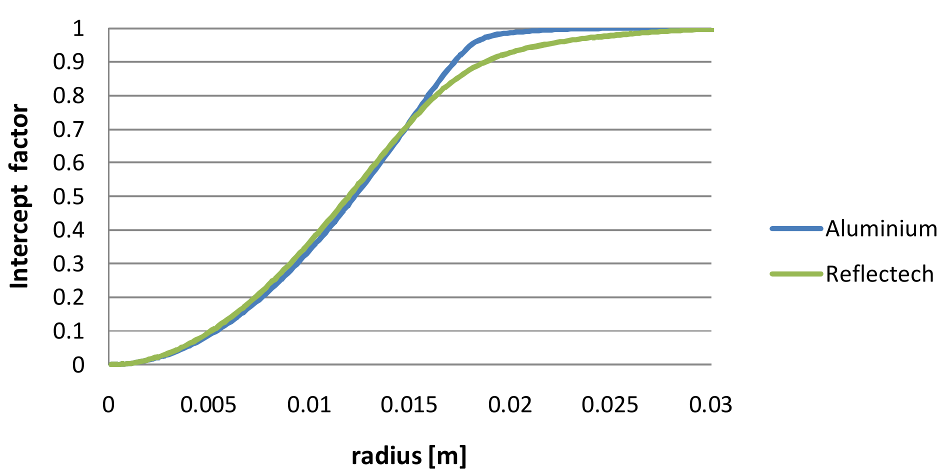


Fig. 4 Intercept factor as function of radius for aluminium coated mirror and Reflectech® coated mirror

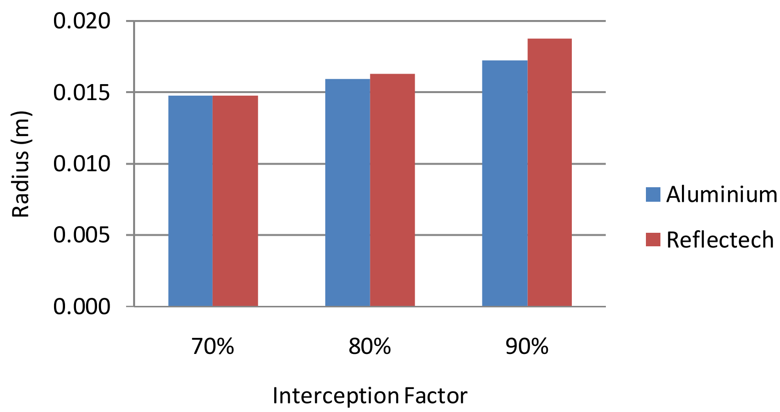


Figure 5 Radii for fixed values of intercept factor

Table 1. Radii for discrete values of intercept factor

Interception Factor	**Radius [cm]**	**Radius [cm]**	**Difference**
	Aluminium	Reflectech®	
0.7	1.67	1.76	5.4%
0.8	1.92	2.06	7.4%
0.9	2.49	2.60	4.6%

Figure 6 corresponds to the simulation carried out with a ray tracing program (called Tonalli) for the mirror with aluminium coat, assuming a standard solar angular brightness distribution. For this solar model, the optical error necessary to fit the simulation to the experimental results is close to zero. It can be seen that the results obtained with the program are no so close to the experimental profile. A possible explanation for this disagreement may be that brightness distribution assumed for the sun does not reflect the real conditions occurring during the experiment.

For the case of Reflectech®, the best fit to the experimental results is obtained when the optical error was considered as 0.72 mrad.

Clearly, the error obtained for the Reflectech® film, is considerably higher than in the case of the aluminium coating. Nevertheless, this error does not represent a significant problem for the overall system, when combined with other sources of error, such as the alignment of the mirrors, the curvature, and tracking errors.

Additional tests are being designed to obtain the real angular brightness distribution of the Sun simultaneously with the concentrated solar images, for each type of reflective surface. This will allow knowing the real solar profile at the moment of acquiring the images, and will improve the correspondence between the image profiles and the results obtained with the ray tracing program.

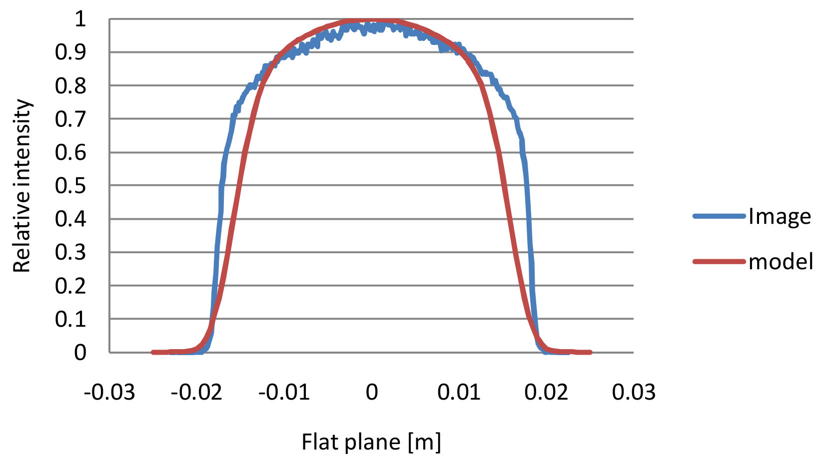


Figure 6. Experimental and simulated solar image profiles for the mirror coated with evaporated aluminium.

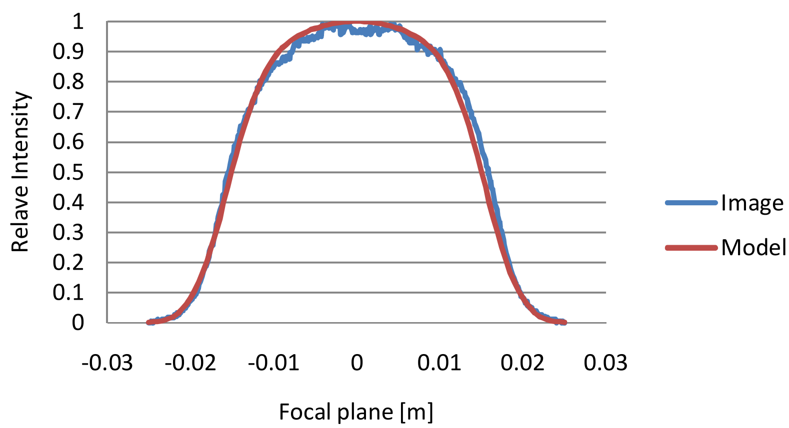


Figure 7. Experimental and simulated solar image profiles for the mirror coated with Reflectech® film.

4. Conclusions

Results show significant differences in the total reflectance of the two coatings, being that of the evaporated coating is 2.7% higher than that of the commercial polymeric film. Also significant differences are obtained in the images at the focal plane. By comparing with ray tracing simulations, optical errors were determined. Despite the fact that the optical errors are much larger for the film than for the aluminium coating, they are still less than 1 mrad. This is not significant in many applications, so it is concluded that, within certain limits, the Reflectech® coating seems appropriate for point focus concentration systems.

Acknowledgements

This work was partially supported by CONACYT (México) grant 56918. The authors thank Drs. Sergio Vázquez Montiel and Fermin Ganados Agustín of INAOE for providing the mirror samples. J. J. Quiñones Aguilar is acknowledged by technical support.

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