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

Solar Collector Systems

https://doi.org/10.52825/solarpaces.v2i.763



Published: 15 Oct. 2024

# Developing Deformable Facets for Heliostats: An Increased Solar Concentration for Thermochemical Applications with Central Tower Receivers

Juan Pablo González-López[1], Ricardo A Pérez-Enciso[2], Pablo Sosa-Flores[2], and Claudio A Estrada[1]

[1] Instituto de Energías Renovables, Universidad Nacional Autónoma de México, Mexico.

[2] Universidad de Sonora, Mexico.

Correspondence: C.A. Estrada, cestrada@ier.unam.mx.

**Abstract.** In the present article a new design of a deformable facet and a heliostat with several deformable facets is presented. Previous work has been made around designing heliostats with concentrating facets in the facilities of the Plataforma Solar de Hermosillo. The evaluation and design process of facets and their evolution is also shown and reviewed. The facet design was initially conceived as a parabolic trough surface, however, through a modification of the facet, the surface was transformed into a concave surface. The resulting spot produced by the facet assumes nearly a spherical surface. A heliostat constructed with these facets shows similar optical performance with a previous one made with spherical facets; this spherical heliostat has a higher peak and mean flux. Nevertheless, the deformable facet heliostat presents a simpler construction and structure. A comparison between both heliostats will be presented.

**Keywords:** Heliostats, Concentrating Heliostats, Central Receiver Technology, CSP Technology, Facets

## 1. Introduction

The Experimental Field of Central Tower Technology (CEToC, by its acronym in Spanish) is a facility located at the Plataforma Solar de Hermosillo (PSH), in the City of Hermosillo, Sonora, Mexico. This facility is part of the National Laboratory of Solar Concentration and Solar Chemistry [1], whose purpose is the development of solar concentration and solar chemical technology in Mexico. Originally, the CEToC was conceived as a test field for a broad diversity of heliostats. The field was initially constructed with flat and canted heliostats of 36 $m^2$, which produced an approximated 6 $m^2$ spot at the Lambertian target. Since solar towers is the technology that is better adapted to thermochemical production of solar fuels [2], one of the current purposes of our research group is to transform this facility into a solar thermochemical system, through the modification of the current optical geometry using the same truss structure of the previous flat facets heliostats. However, solar towers operate typically around 750 K, and this temperature is not enough to achieve high temperature solar chemistry (around 1000 K) [3]. In SolarPACES 2022 Conference, a spherical facet concentrating heliostat was presented [4]. A significant raise in the concentration ratios was achieved with respect to the flat facet original heliostat. Further experimental campaigns and tests have been carried out since 2021. With the aim of having cheaper and easier facets to build than spherical ones, and considering other developments [5], a new concave facet concept has been developed. The purpose of this article is to present an alternative design of a concave facet using the same basic heliostat structure and to present the results in comparison with the spherical concentrating heliostat.

## 2. Ray-trace simulation of alternative facet proposals

The first facets that were considered cheaper and easier to build than the spherical ones were the parabolic troughs. Several configurations for the distribution of parabolic trough facets in heliostats were explored to determine their solar concentration characteristics. Ray tracing simulations have been performed to evaluate these configurations. Configurations vary in number, orientation, and location of facets. Figure 1 shows the three configurations studied: 12, 18 and 25 facets each one. All configurations had to retain a surface area of 36 $m^2$ for the heliostat. The software used to carry out the ray tracing simulation was Tonatiuh (created by the National Center for Renewable Energies, in Spain), which uses the MonteCarlo method [6].

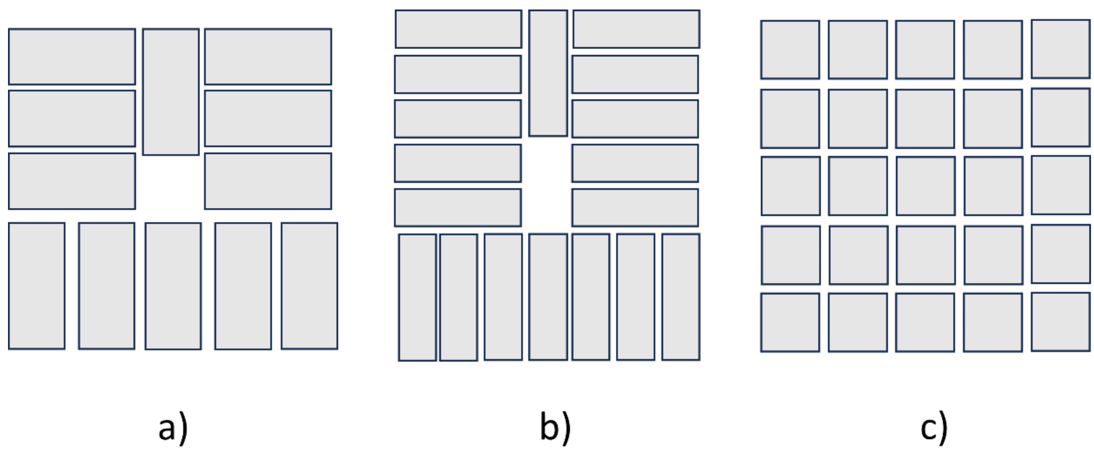



***Figure 1***. *Distribution proposals for the new concentrating facets. The proposed configurations consist of a) 12 (2 x 1 $m^2$), b) 18 (2 x 0.8$m^2$) or c) 25 (1.2 m x 1.2 m) parabolic trough facets.*

Previous works carried out at the PSH show a significant increase in the concentration ratios using parabolic trough facets with respect to planar facets [5]. In addition, it presents a remarkable simplicity in its manufacture and a significant reduction in cost. To reach the necessary temperatures for thermochemical applications, optical systems must have concentration ratios between 200-300 suns. This condition sets a target in the ray tracing simulations of the alternative designs. Figure 2 shows the line profiles resulting from parabolic trough heliostat designs 12, 18, and 25 and the line profile of a spherical facet heliostat at the winter solstice, equinox, and summer solstice at 12 p.m. and 10 a.m.

Based on Figure 2, the worst-case scenario (summer solstice at 10 a.m.) sets that the mean flux of a 12 parabolic trough facets heliostat is of approximately 10 suns, which is the more economic design between the proposals. Our purpose is to build 9 more heliostats, and, if this concentration ratio is considered, the solar field would yield 90 suns. However, with the implementation of a second stage concentrator at the top of the receiver, this quantity would yield up to 270 suns (three times the concentration ratio) [7], which is an acceptable goal to perform high temperature thermochemical applications.

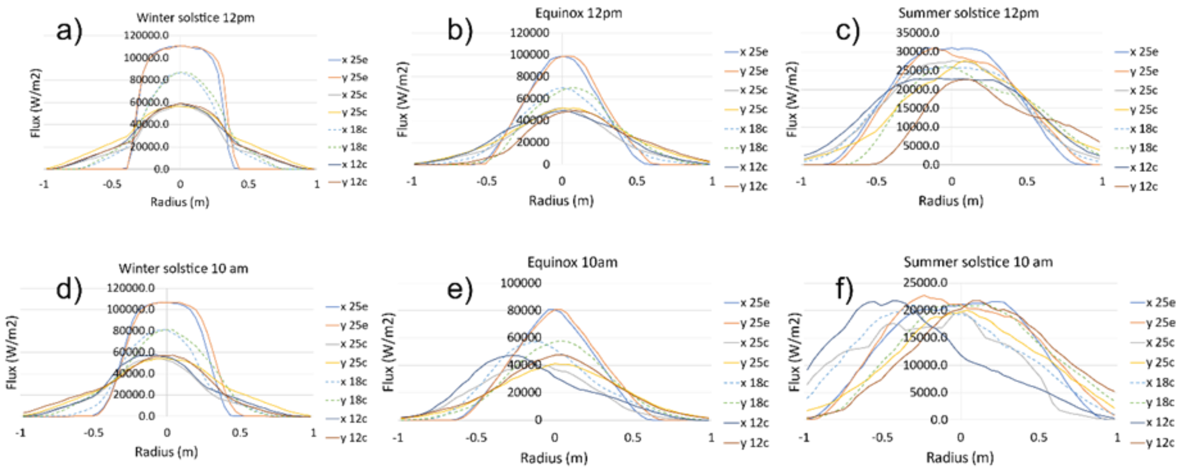



***Figure 2.*** *Solar concentration profiles of the parabolic trough heliostat designs (12, 18 and 25) and the profiles of a heliostat with spherical facets; on the winter solstice, equinox, and summer solstice at 12 p.m. and 10 a.m. x and y represent horizontal and vertical profiles. "e" means spherical, and "c" means parabolic trough.*

## 3. Layout of Experimental Field of Central Tower Technology in Plataforma Solar de Hermosillo

The facility of the CEToC in the PSH counts with heliostats positioned in three main focal lengths, which are 40 m, 55 m, and 72 m away from the Lambertian target at the top of the tower. Figure 3 shows a layout of the solar field. The circled heliostats in the layout correspond to the locations of the heliostats that will be presented in this work. The F0 corresponds to the spherical facet heliostat and F1 is the parabolic trough facets heliostat. Both heliostats are located at the focal length of 72 m.

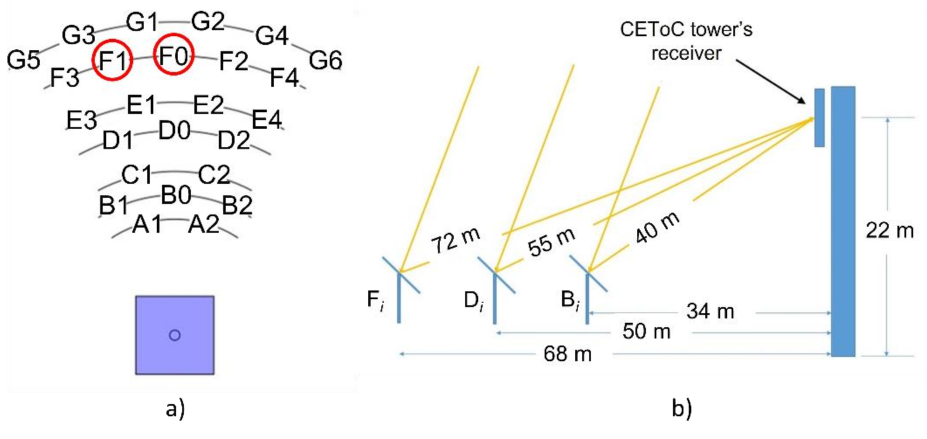
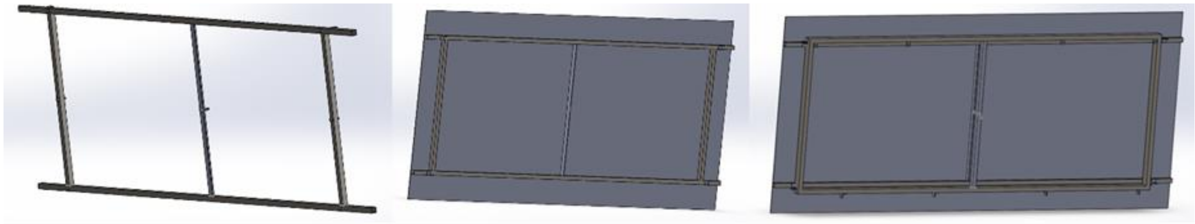



***Figure 3****. a) Arrangement of heliostats in the CEToC and, b) Three focal lengths of heliostats in the CEToC. F0 and F1 heliostats located 72 m from the Lambertian objective.*

## 4. Parabolic cylindrical and concave facets

The mechanical design of a parabolic cylindrical facet consists of a deformable glass mirror, which can take a parabolic-cylinder finish through flexion points located in strategic segments of the frame that supports the mirror. Bending is produced by screws at those points. Previous work has been carried out at the PSH to build deformable facets [8]. The layout is made up of two frames: the curvature frame and the canting frame. Figure 4 shows a) the curvature frame and b) the canting frame.



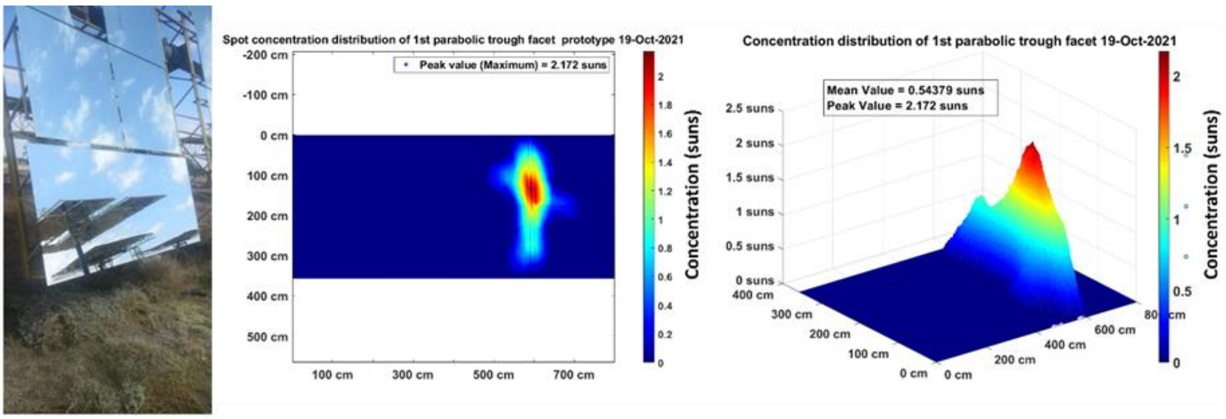
a) b) c)

***Figure 4.*** *a) Curvature frame of deformable facet, b) mirror glued on curvature frame and, c) mirror with curvature frame fixed over the canting frame.*

The curvature frame is a frame made of a squared tubular profile. Over this frame a mirror is glued. The dimension of the mirror is 2.6 m x 1.15 m. Once the mirror and the curvature frame are assembled, this arrangement is then mounted onto the canting frame. The canting frame is the responsible of mounting the facet onto the heliostat´s truss. The canting frame is a rectangular tubular profile. The canting frame gives the capability of canting the facets to concentrate more the heliostat's image, in such way that the images of all 12 facets are focused in a single aim point on the Lambertian target.

The idea of making the reflective surface the double of size than the spherical facets is to make easier the flection of the facet in such a way that, applying a mechanical stress in some points of the facet, this would trigger a homogeneous bending all along the facet and, therefore, obtaining a smooth curvature.

Initially, the facet was conceived to be a parabolic trough facet. Hence, it would produce a lineal image in the Lambertian target. The first prototype was constructed with just a few points of stress to bend the facet in one axis (causing a parabolic trough). The first prototype was constructed, and the image produced by the prototype was projected at the Lambertian target on October 19$^{th}$, 2021. This prototype was mounted on a heliostat's truss with focal length of 72 m regarding the target. Once mounted, stress was applied in the stress points. Figure 5a shows the first parabolic cylindrical facet prototype mounted onto the truss of the F1 heliostat. Figure 5b and 5c presents the resulting spot of this first prototype. A 1000 W/m$^2$ DNI (Direct Normal Irradiance) and a reflectivity of 0.84 was considered in the image processing.




a) b) c)

***Figure 5****. a) First prototype of deformable facet mounted onto the truss of heliostat F1, b) resulting spot concentration distribution of the first prototype and, c) 3D concentration distribution of the first deformable facet prototype.*

Nonetheless, an opportunity was observed, and the facet was reworked with more stress points, creating finally a quasi-focal point image (i.e., concentrating in two axes). Modifications were made to improve this prototype. Figure 6 shows the resulting spot produced by the improved facet. Same conditions of DNI and reflectivity of Figure 5 were considered.

The image produced was of a focal point optical system. The facet counts with 9 stress points on its structure.

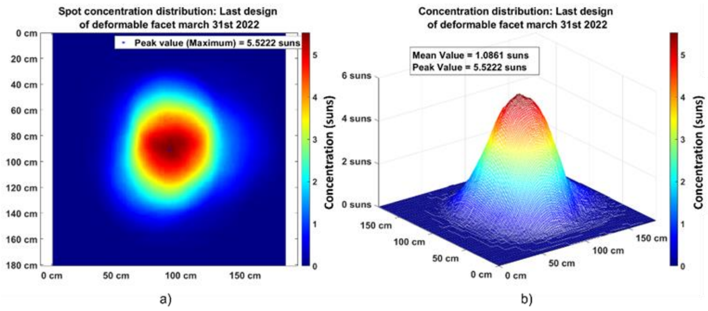



***Figure 6**. a) Resulting spot of last design deformable facet, b) 3D concentration distribution of last design of deformable facet.*

## 5. Heliostats

### 5.1 Deformable facet heliostat F1

The dimensions of the reflective surface of deformable facets were thought to conserve an area of 36 $m^2$ on the heliostats, so instead of having 25 squared facets, there would be 12 canted rectangular facets of 3 $m^2$ each. Furthermore, dimensions of canting frame were designed to fit the squared array of the truss of previous heliostats. Thus, the truss is not meant to be changed to mount these new facets. A heliostat was built using these deformable facets. In this case, this heliostat is built with 11 deformable facets due to its truss and its transmission of 180° (stow position is downwards). Additionally, these heliostats are built with two facets mounted vertically and five horizontally. Figure 7 presents the deformable facet heliostat F1 completely built.

***Figure 7**. Deformable facet heliostat F1.*

### 5.2 Spherical facet heliostat F0

The heliostat with spherical facet F0 was presented at SolarPACES 2022 [4]. It consists of 25 squared canted facets. The structure is composed by a cross-piece structure that is fixed on yellow frames that are used as canting frames on the truss of heliostat and a trellis over the cross-piece made up by six 14-gauge metal sheets. The trellis has a curvature in the front edge, which is the edge that receives the mirror, and by mechanical sagging is bonded to the structure. Figure 8 shows the design of the spherical facet.

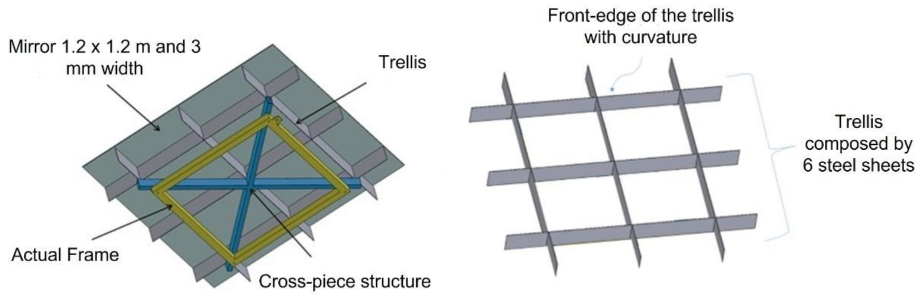



***Figure 8***. *Structure of the new facet with spherical shape.*

## 6. Comparison between deformable facet heliostat and spherical facet heliostat

Several experimental campaigns have been performed in PSH; images of resulting spots of both heliostats have been obtained and analyzed. These campaigns have involved both heliostats to compare their optical performance. Images of the spherical heliostat were taken near midday on February 2, 2023, whereas images of the deformable facet heliostat were taken near midday on February 7, 2023. The main result is that performance of the deformable facet heliostat is comparable with that of the spherical heliostat. Peak concentration is of 42 suns for spherical heliostat, and for deformable facet heliostat is of 33 suns, taking into consideration that deformable facet heliostat has 3 $m^2$ less of area. This implies that with another facet (which is the normal design including 12 facets and not 11) this magnitude would increase between 35-40 suns. Moreover, the deformable facet heliostat has a more economical design. Figure 9 shows the concentration profiles comparison between the spherical facet heliostat and the deformable facet heliostat.

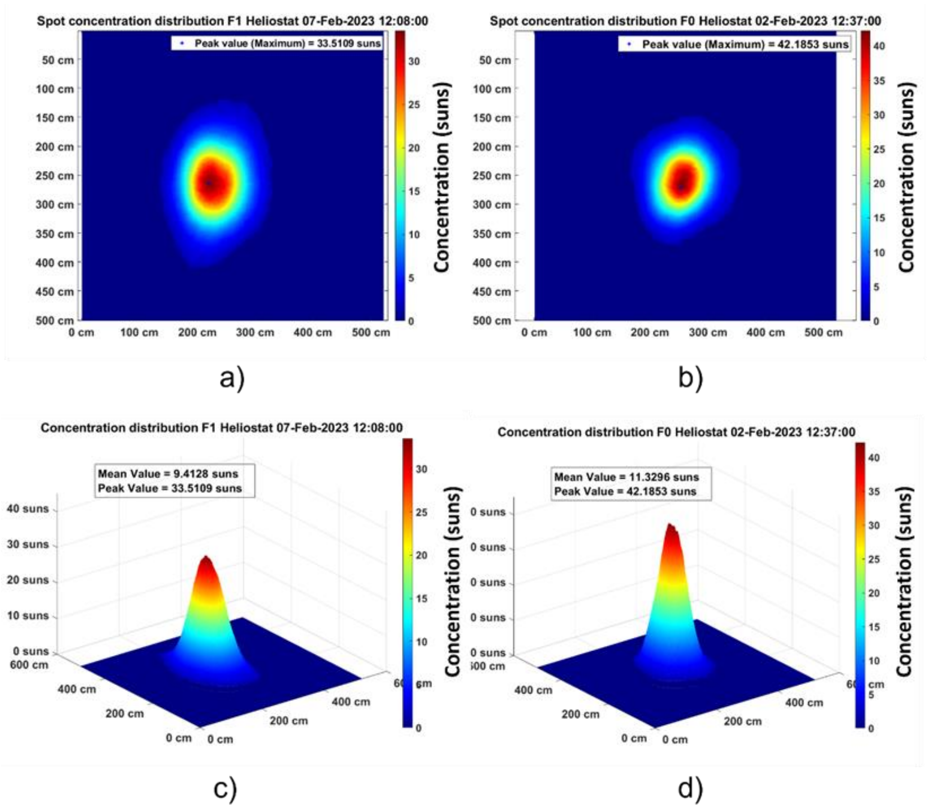



***Figure 9***. *a) Image produced by deformable facet heliostat, b) image produced by spherical facet heliostat, c) concentration profiles of the deformable facet heliostat, and d) concentration distribution of the spherical facet heliostat.*

# 7. Conclusions

The design, construction and evaluation of deformable facet heliostat have been presented. The design process was shown, and the decisions taken during the process were explained based on the purposes of this research.

A comparison of concave facet heliostat and spherical facet heliostat was presented, finding that the optical performance of deformable facet heliostat is comparable with that of spherical one, with a significantly more economic design. The deformable facet heliostat yields a peak concentration of 33 suns, with a mean concentration of 9.4 suns considering the whole spot.

It is possible to perform high temperature thermochemical applications with the construction of another 8 heliostats with these deformable facets.

Presumably, the surface created by these deformable facets is nearly spherical. This is all due to the resulting spot formed by the individual facets or by the heliostat as a whole. However, further analysis should be performed to confirm this hypothesis.

# Data availability statement

Raw data were generated at PSH. Derived data supporting the findings of this study are available from the corresponding author C.A. Estrada on request.

# Author contributions

**J.P. González-López:** Methodology, Software, Formal Analysis, Data Curation, Heliostat Manufacturing & Construction, Writing – Original Draft, Writing – Review and Editing, Visualization.: **R.A. Pérez-Enciso:** Conceptualization, Methodology, Ray-tracing Analysis, Formal Analysis, Technical Support, Supervision, Heliostat Manufacturing & Construction.: **Pablo Sosa-Flores:** Conceptualization, Methodology, Technical Support, .: **C.A. Estrada:** Conceptualization, Methodology, Formal Analysis, Writing - Review and Editing, Visualization, Supervision, Resources.

# Competing interests

The authors declare no competing interests.

# Acknowledgements

The authors thank the University of Sonora and the National Autonomous University of Mexico for allowing us to use their facilities for experimentation. We also thank the DGAPA-UNAM for financing the project through the PAPIIT AG101422 grant. Likewise, Juan Pablo González thanks CONAHCYT for the scholarship he has.

# References

[1] Laboratorio Nacional de Sistemas de Concentración Solar y Química Solar. (n.d.). Retrieved May 2, 2022, from http://www.concentracionsolar.org.mx/

[2] Romero, M., & Steinfeld, A. (2012). Concentrating solar thermal power and thermochemical fuels. In Energy and Environmental Science (Vol. 5, Issue 11, pp. 9234–9245). https://doi.org/10.1039/c2ee21275g

[3] Pitz-Paal, R., Botero, N. B., & Steinfeld, A. (2011). Heliostat field layout optimization for high-temperature solar thermochemical processing. Solar Energy, 85(2), 334–343. https://doi.org/10.1016/j.solener.2010.11.018

[4] González-López, J. P., Pérez-Enciso, R. A., Pérez-Rábago, C. A., & Estrada, C. A. (n.d.). Development of Concentrating Heliostats for High Temperature Solar Chemical Applications. https://cms2022.solarpaces-conference.org/presentations/time

[5] Sosa-Flores, Pablo, et.al. (2022). Diseño de mini-heliostatos de 6 $m^2$ con espejos concentradores. Memorias de la XLVI SNES (https://snes46.anes.org.mx).

[6] Centro Nacional de Energías Renovables. (2017). Tonatiuh. (https://www.cener.com/documentacion/TONATIUH.pdf)

[7] Duffie J. & Beckman W. (2013). Solar Engineering of Thermal Processes, 4th edición, p. 337-344.

[8] Rosales Valles, M. M. (2014). Diseño, puesta en operación y evaluación de un helióstato con facetas deformables [Universidad Nacional Autónoma de México]. http://www.concentracionsolar.org.mx/images/pdf/tesis/m3_militza.pdf