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Construction of a rotatory solar collector to supply heat for industrial processes

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1. Introduction

The industrial sector is a significant contributor, accounting for 20% of total greenhouse gas emissions, especially when electricity consumption is not reallocated [1]. However, there is hope for decarbonizing this sector through the utilization of solar heat for industrial processes (SHIP). While flat plate collectors have been predominantly used for industrial solar heat applications, they are limited to temperatures below 80 ºC. This poses a challenge since industrial requirements often demand temperatures exceeding 150 ºC, necessitating the adoption of concentrating solar collectors.

Conventional options like linear Fresnel and parabolic trough collectors can provide solar heat within the 150-300 ºC temperature range. Nevertheless, these collectors were initially designed for much higher temperatures, resulting in elevated installation and maintenance costs when employed within this narrower range. Recognizing this, researchers at Universidad Politécnica de Madrid and Universidad Nacional de Educación a Distancia have proposed an innovative solution called the SunDial [2]. This groundbreaking concentrator comprises a rotary platform adorned with multiple short parallel Fresnel collectors.

Under the framework of the H2020 project ASTEP (GA 884411), two distinct SunDial collectors have been meticulously designed and are presently undergoing installation for testing purposes in Madrid, Spain. Following the successful trial phase, these collectors will be subsequently installed at two industrial sites: one in Corinth, Greece, and another in Iasi, Romania. The collectors have been specifically engineered to deliver a thermal power output of approximately 25 kW, with an anticipated annual yield of 25 MWh. The installation of both collectors at TecnoGetafe, led by F2I2, includes a shared balance of plant infrastructure. UPM will conduct rigorous testing at TecnoGetafe to achieve Technology Readiness Level (TRL) 4 before deploying the collectors to their intended end-user sites, to achieve TRL 5.

This work presents the construction of the SunDial collectors and their commissioning. Section 2 presents the SunDial concept; the detailed design of the concentrators and the balance of plants is shown in Section 3; Section 4 is devoted to present the construction of the concentrators and their current state, whereas the causes for the delay of the commissioning are summarized in Section 5. Finally, Section 6 is devoted to the conclusions of the installation.

2. SunDial concentrators: concept and options

The SunDial concept is patented under four Spanish patents (ES2449167B2, ES2537607B2, ES2578804B2, and ES2596294B2). It involves a rotating platform on which one or more parallel short linear Fresnel collectors are installed [2; 3]. This concept can be tailored for either low or high latitudes, leading to different outcomes, as shown in Fig. 1:

- Low-latitude design: The platform rotates, keeping the sun within the longitudinal plane of the Fresnel fields. From the cross-sectional viewpoint, the sun remains fixed, eliminating the need for mirrors to track the sun throughout the day. This setup aims to cut costs by having only the platform track the sun. However, when the sun is low in the sky, end and cosine losses significantly reduce efficiency, especially at higher latitudes.
- High-latitude design: In this configuration, the platform's rotation keeps the sun within the cross-section of the Fresnel field, minimizing cosine losses and eliminating end losses. This approach necessitates tracking motors for both the platform and the mirrors, which increases costs. Despite this, efficiency remains relatively consistent, even at lower sun altitudes.

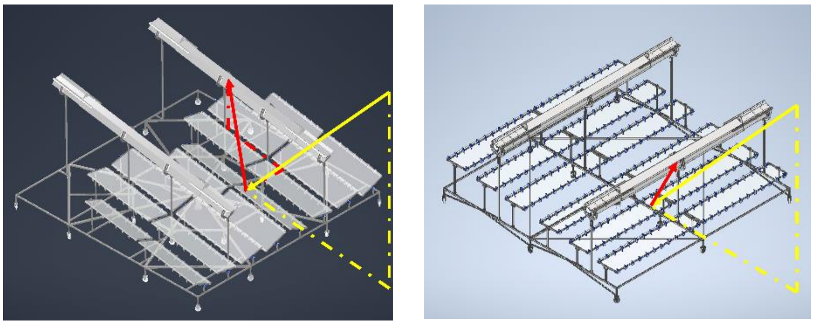

Fig. 1. CAD design and sun position for the low-latitude (left) and high-latitude (right) SunDials.

3. The ASTEP system: design of the balance of plant

The ASTEP system comprises not only the concentrator but also a phase change material storage system and a connection to the demand. Previous studies have analysed both series and parallel connections between the SunDial and the storage system, with the former proving to be the superior solution [4]. However, the installation commissioned by F2I2 does not include the PCM storage system or the heat exchange to the demand, which is tested at TRL 4 in UPCT premises. The whole ASTEP concept, including both the SunDial and the PCM-based storage system together with the control system, will be implemented and tested in the end-users premises to achieve TRL 5. In the installation commissioned by F2I2, heat is dissipated by two air coolers, one emulating the thermal storage in charging mode (maximum power 20 kW) and the other simulating the industrial load (14 kW). Fig. 2 presents a detailed design of the solar platform being installed by F2I2, including a close-up view of the balance of plant.

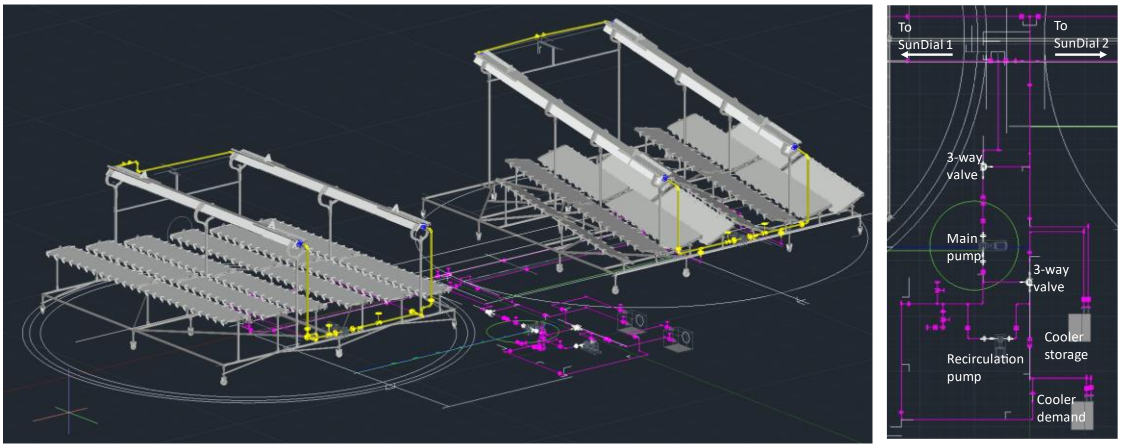

Fig. 2. Detail design of the platform where both concentrators will be tested (left) and balance of plant of the installation (right).

The balance of plant includes a primary pump to circulate thermal oil through the SunDial, a three-way valve to bypass the SunDial (to be used at end-user sites when the sun is unavailable but the storage is not depleted), a recirculation pump and a three-way valve to keep the temperature and mass flow at the demand inlet constant, and two air-coolers to mimic storage (charging condition) and demand. Additionally, each concentrator includes a large recirculation system to maintain a sufficiently high mass flow through the receiver tubes, which are 70 mm in diameter [4].

4. Commissioning of the concentrators

To install the SunDial concentrators, three elevated circular rail paths were initially commissioned. These rail paths are fitted using adjustable-height feet, allowing the installation of the SunDial over irregular flooring. Moreover, as the rails are elevated, HTF tubes can be installed beneath them without necessitating excavation. Fig. 3 (left) shows a set of blue rail paths and another set, colored green, being installed in the rear area. A square platform is installed on top of these rail paths. This platform is supported by a central support with an axial bearing at the center, and wheels that roll on the rail paths. The platform comprises several small triangular or rectangular structures that can fit within a shipping container. Fig. 3 (right) depicts an installed platform on the rail path (prior to being galvanized).

Fig. 3. Installed rail-paths of the SunDial (left); and rotatory platform of the SunDial installed on top of the rail-paths (right).

Mirror lines and receivers are affixed on the platform. The mirrors for each line are 6-8 m long, depending on the design. In the low-latitude SunDial, mirrors and receivers are tilted longitudinally 10º to minimize end and cosine losses. Conversely, in the high-latitude design, the field is tilted from the cross-sectional view, meaning the mirrors' height increases as they are positioned further from the sun. Each mirror line has three supports, with a bearing connected to one or two plates that hold the mirror structure. The project uses 3-mm thick standard mirrors. Mirrors are bent using a patented mechanism where gripper-like plates hold the mirrors. These pairs of plates separate at their bottom part, rotating and causing the mirror to bend. Fig. 4 (left) displays a test mirror bent using this method. The central images show preliminary installations for high latitudes (middle-left) and low latitudes (middle-right), while the right figure illustrates the final assembly of mirror lines ready for installation.

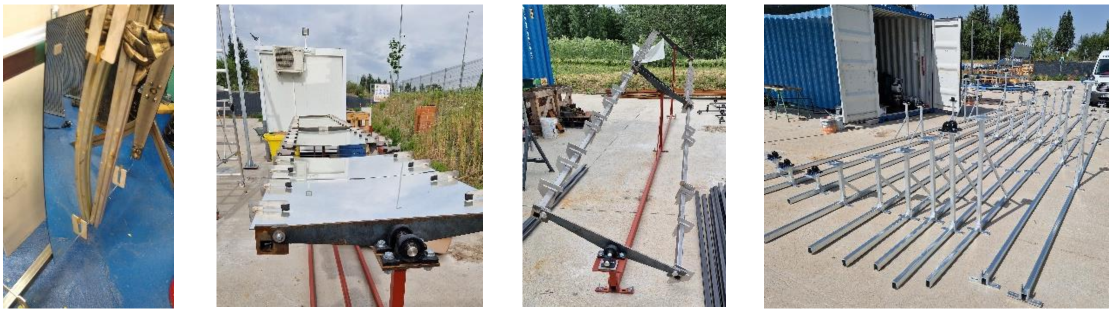

Fig.4. Bent mirror testing the bending-methodology (left), preliminary structures of the mirror lines for high latitudes (middle-left) and low latitudes (middle-right) and final designs ready to be installed (right).

Concerning the receiver, it has yet to be installed. The receiver structure was purchased from a Fresnel company. It consists of a trapezoidal cavity body extended longitudinally by four elements to achieve a total length of over 8 m. While the receiver's base belongs to the company, its holding structure could not be used due to the specifics of the SunDials. Consequently, an innovative system based on S-shaped plates was developed, as shown in Fig. 5. Although the receivers have not been installed, they have been assembled next to the rotating platforms.

Fig. 5. Detail view of the supporting structure design (left) and receiver assembled next to the SunDial (middle and right)..

Lastly, the piping will be installed. All piping spools have already been produced, including connections to all sensors and actuators. The piping design features a unique point with a very constrained design: the passage through the central support. Rotating joints were chosen for this purpose, but it's worth noting that two joints are required per platform (in-flow and out-flow), and both are installed in the central support axis. Moreover, the inner diameter of the support is only 140 mm, leaving minimal space for the installation of pipes with elbows (3/4" piping is used for the connection). Fig. 6 depicts the design of this connection, the pre-manufactured spools, and the central support with one tube inside. One rotating joint is installed on the support's lower part and the other on the upper part, which necessitates two elbows in each spool to change the tube's position

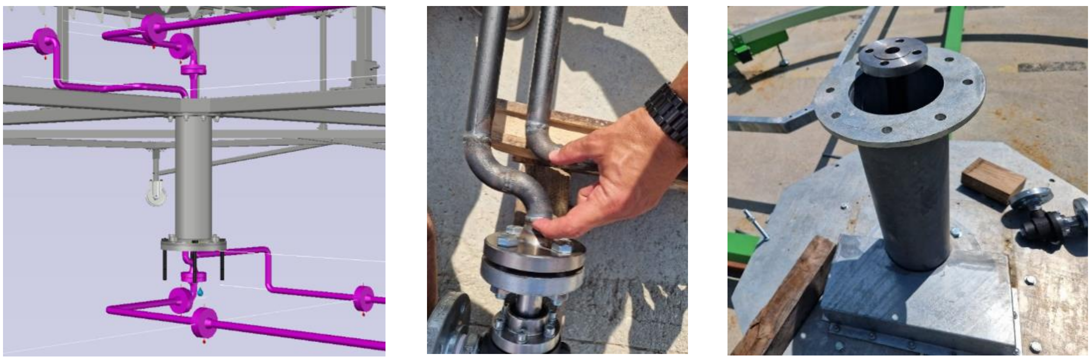

Fig. 6. Detail view of the supporting structure design (left) and receiver assembled next to the SunDial (middle and right).

4.1 Delays

Although testing was originally slated to conclude by October 2022, the project has encountered numerous delays. These setbacks can be attributed to various factors, such as the need to redesign many elements during construction, the absence of a detailed piping design at the onset of construction, and delays from suppliers. Moreover, we experienced an unusual flooding event that destroyed many already installed devices and components, leading to further delays of several months. Fig. 7 displays an image of the flooding that occurred in December 2022.

Fig. 7. Images of the test site during the flooding.

Under the current circumstances, it is anticipated that construction will conclude in October 2023, with electrical connections and oil-filling taking place in early November, and testing occurring from Novembre to January. At the time when this paper is written, the actual state of the installation is as presented in Fig. 8.

Fig. 8. Present state of the installation.

5. Conclusions

As part of the ASTEP project, two innovative solar collectors designed for solar heat for industrial processes are being installed for testing. The construction has progressed more slowly than anticipated over the last two years due to numerous challenges encountered. Testing is now expected to commence in September 2023 and continue until November. Afterwards, the systems will be decommissioned and transported to two industrial sites, where they will undergo testing for one year in a relevant environment (TRL6).

Acknowledgments

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References

[1] IEA (2021), Greenhouse Gas Emissions from Energy: Overview, IEA, Paris https://www.iea.org/reports/greenhouse-gas-emissions-from-energy-overview.

[2] J. Muñoz-Antón el al., IP Conference Proceedings 2126, 060007 (2019).

[3] J. Cano et al., A new thermal-solar field configuration: The rotatory fresnel collector or sundial, Energies 14 (14) (2021). doi:10.3390/en14144139.

[4] Barnetche, M. et al.,Optimum integration of latent heat storage in a solar thermal system for industrial processes: in series or in parallel?, Applied Thermal Engineering, 121090, 2023.