ASTEP project: status and progress at 2024

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Abstract

Solar thermal energy for industrial processes (SHIP) is gaining relevance for meeting industrial thermal energy demands. This method offers a twofold advantage: reducing fossil fuel consumption and emissions while establishing a distinct market niche for solar technology. The ASTEP project, funded by the European Commission focuses on an innovative SHIP concept. Integrating modular designs—SunDial solar collectors from and phase-change material thermal storage—ASTEP employs a flexible control system. It aims to demonstrate its capability to fulfill a significant portion of industrial heat demand above 150 ºC in latitudes challenging for existing designs.

Keywords: Solar Heat for Industrial Processes (SHIP), Concentrating Solar Power (CSP), Thermal Storage System (TES).

1. Introduction

Solar thermal energy for industrial processes (SHIP) is gaining increasing importance as one of the ways to meet the high thermal energy demand required by industry. This implies a double benefit: firstly, by using a renewable energy source, fossil fuel consumption is reduced, and therefore, pollution and greenhouse gas emissions to the atmosphere are diminished; secondly, heat for industrial processes becomes a new market niche for solar technology, which can lead to a reduction in the cost of solar collectors through economies of scale in manufacturing and advances in the learning curve in implementation.

According to the National Renewable Energy Laboratory (NREL) of the United States (Kurup & Turchi, 2015), the European Union (EU) has been a leader in the use, development, implementation, and monitoring of SHIP plants over the past decade. However, to date, this has largely been limited to heat loads below 150 ºC. The next step in the large-scale adoption of solar process heating is to develop technologies and methodologies for the production of solar thermal energy applied to industrial processes reliably and above 150 ºC, which will expand the exploitation possibilities.

Currently, there are just over a hundred operational SHIP systems in Europe, according to the SHIP plant database of IEA Task 49 (http://ship-plants.info/), and only about twenty of them operate at temperatures above 150 ºC, and it can be achieved with parabolic trough or linear Fresnel collectors (Montes et al., 2018). The main objective of the ASTEP project (Application of Solar Thermal Energy to Processes) is to develop a new concept of solar energy applied to industry (SHIP) and demonstrate its viability at two relevant industrial demonstration sites located in two different climatic regions: Iasi in Romania and Corinth in Greece. To this end, two demonstrators of the technology are being built, able to supply thermal energy to meet heat demands above 150 ºC and cooling under the conditions required by the industrial processes of the respective industries.

The project objectives can be summarized into three:

1. Develop the various technologies involved in the ASTEP concept: the SunDial solar collector, the thermal storage system based on phase change materials, and the integration of the technologies along with the control system.
2. Demonstrate the ASTEP technology on a 25 kW scale at two relevant industrial sites. To this end, the concepts of the three main subsystems (SunDial, thermal storage, and integrated concept system) are being built and will be installed, tested independently in the laboratory, and sent to the end-users for technology

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testing in integrated and relevant real operating conditions.

3. Evaluate the sustainability of the ASTEP concept. The benefits of the ASTEP technology cover not only environmental aspects but also political and socio-economic aspects. Various tools are used for its evaluation, such as life cycle analysis, calculation of CAPEX, OPEX, and Levelized Cost of Heat (LCOH), social life cycle analysis, and social acceptance.

The following sections briefly describe the main technologies of the project as well as the case studies in which they will be tested. Subsequently, the current state of the project and preliminary results are presented, and finally, the work to be carried out until the end of the project is outlined.

2. ASTEP project and case studies

2.1. SunDial, the rotatory Fresnel solar collector

Solar collectors for industrial processes are generally either flat type without concentration (or with small concentration), linear Fresnel collectors, and parabolic trough collectors. The latter two are able to reach temperatures well above 150 ºC but are adapted systems that come from the power generation technology, generally with a high maintenance cost. ASTEP proposes an innovative concept, the SunDial, whose main objective is to limit installation, maintenance, and operation requirements.

The SunDial is a rotating Fresnel collector consisting of a horizontal platform that rotates around a vertical axis, with a linear concentrator installed on the platform. The solar field consists of curved mirrors parallel to the receiver line that are used as a concentrator. To limit its cost and meet necessary requirements, these curved mirrors are derived from flat mirrors that are bent in situ, simplifying the installation.

Two designs of the SunDial device are considered, illustrated in Fig. 1. In the first, the working condition for this Fresnel system is that the sun must be in the symmetry plane of the concentrator, i.e., the system must rotate in the azimuth angle during the day. In this design, the mirrors are fixed to the structure. The compactness of the system and the fixed mirrors lead to a low-cost solution with high focusing accuracy.

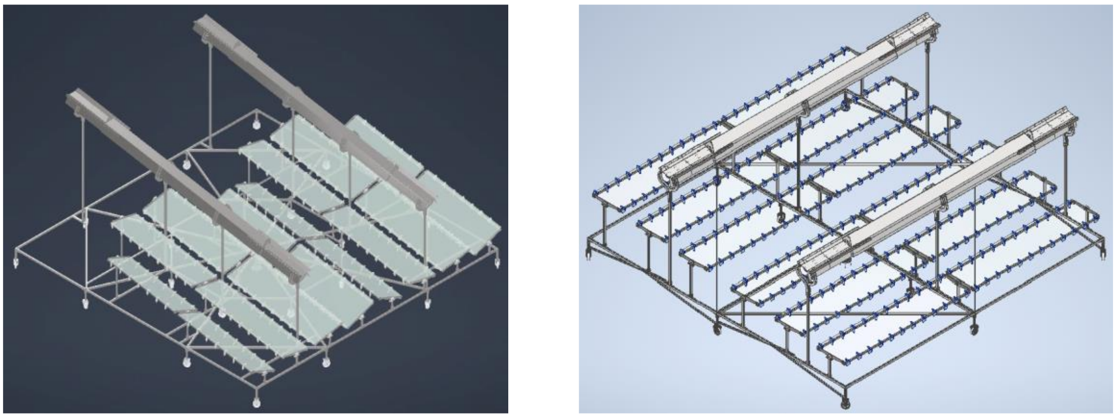

Fig. 1: CAD of the two versions of the SunDial with solar tracking system on one (left) and two (right) axes, for the Mandrekas and AMTP case studies, respectively

In the second design, the SunDial consists of several rows of rotating mirrors instead of fixed ones. The mirrors and the receiver are installed on the rotating platform that rotates around a vertical axis to keep the sun within the transversal plane of the collector. At the same time, the mirrors will rotate around their longitudinal axis to reflect towards the receiver as the sun's altitude varies. Thus, the system follows the sun using a two-axis tracking system, i.e., the platform rotates with the sun's azimuth angle, and the tilt angle of the mirrors changes following the solar altitude. This solution shares the previous one's advantages in terms of cost reduction, simplicity, and compactness. The additional tracking system (mirror tilt) introduces some complexity—and the corresponding cost—but provides higher performance, allowing the use of Fresnel technology at altitudes where conventional technologies cannot operate.

2.2. Thermal energy storage system

As a thermal energy storage (TES) system, a system based on phase change materials (PCM) with passive heat transfer enhancement inserts, in the form of fins, is being developed. The goal is to store excess solar thermal energy during peak solar resource hours and deliver it according to the end-user's demand under controlled power conditions.

The passive design includes the application of honeycomb structures located in a casing and shaped as multi-tubes with integrated elements that enhance heat transfer. The heat transfer fluid flows through the internal tubes, and the PCM is stored on the casing side, filling the structure created by the honeycomb.

The development of the system includes the selection of the phase change material, the design of the inserts, the method for their manufacture, the design of the accumulators, and the testing of thermal performance and potential corrosion. The accumulator and the inserts designs are shown in Fig. 2.

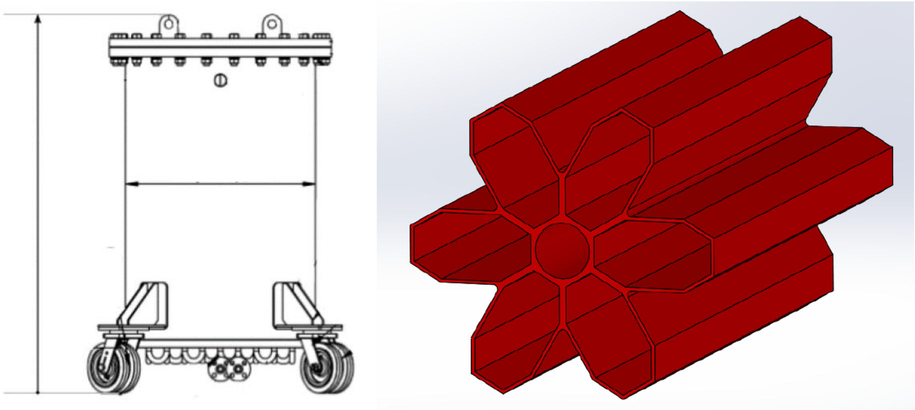

Fig. 2: CAD of the accumulators and the inserts of the TES

3. Case studies

2.3. Case studies

Mandrekas:

The company MANDREKAS is a dairy industry located in Corinth (latitude 37.93º N), thus near the so-called solar belt, where solar concentration systems can be installed at a lower cost. The industry produces all types of yogurt, dressings (tzatziki sauce), and dairy desserts. For their production, they need both steam generation at 8 bar (175 ºC) to pasteurize the milk and refrigeration to store their products at temperatures around 5 ºC.

The concentrator developed for this case study must be designed to minimize capital and maintenance costs. Therefore, the first design of SunDial is proposed, so that the vertical rotation axis belongs to the symmetry plane. The working condition for this Fresnel system is that the sun must be in the symmetry plane of the concentrator, i.e., the system must rotate in the azimuth angle during the day. Therefore, the platform must be placed on some sets of wheels that are guided in a circular motion.

The mirrors are fixed on a flat platform that rotates following the sun in the azimuth angle. The tilt of each mirror is defined in the reference position (when the receiver and the sun define the virtual symmetry plane of the system). By minimizing moving parts, maintenance and operation are also straightforward, achieving a robust and reliable system.

ArcelorMittal Tubular Products:

ArcelorMittal is the world's leading steel and mining company. In particular, ArcelorMittal Tubular Products – Iași (AMTP), which belongs to the European division of tubular products of ArcelorMittal, is dedicated to the manufacture of welded steel tubes for various applications. This industry is located in Iași (Romania), at a latitude of 47.1º N. One of the key finishes for AMTP products is the so-called color coating, which consists of a thin layer of colored protective/decorative material (epoxy, water-based, thermoplastic, etc.) that covers the entire outer surface of the tube. To apply this color coating, the tubes must be preheated to a temperature of 220 ºC.

In this case, the solar concentrator must be installed in locations with relatively high latitude, so the SunDial design with two-axis solar tracking will be used. In this case, the working condition for this Fresnel system is that the sun must be in the transverse plane of the concentrator, i.e., the system must rotate in the azimuth angle during the day so that the longitudinal component of the incident solar radiation is zero. Therefore, the platform must be placed on some sets of wheels that are guided in a circular motion.

Since the sun's altitude varies throughout the day and year, the mirrors must be installed on longitudinal rotation axes so that their transverse tilt adapts to the sun's altitude. This implies a higher cost compared to the single axis tracking system, but it eliminates both cosine factor losses and end losses. As a result, the variation of the incident thermal power will only be due to shading losses, which are less significant than cosine factor losses and end losses when the sun's altitude is very low. Additionally, it eliminates the need for a fixed longitudinal tilt of the platform and transverse mirrors, which implies a cost reduction.

2.4. ASTEP concept for the case studies

Fig. 3 shows the proposed integrated system for Mandrekas. The storage system is arranged in series with the SunDial and the demand. The SunDial must generate between 2 and 20 kW of thermal power when there is solar irradiation, while the storage system must store or supply between 0 and 15 kW. To meet the thermal requirements of the industry, a heat exchanger that functions as an evaporator, with a power of 8 kW, and another exchanger that emulates the feed to an absorption chiller for cold production, with a power of 6 kW, are planned.

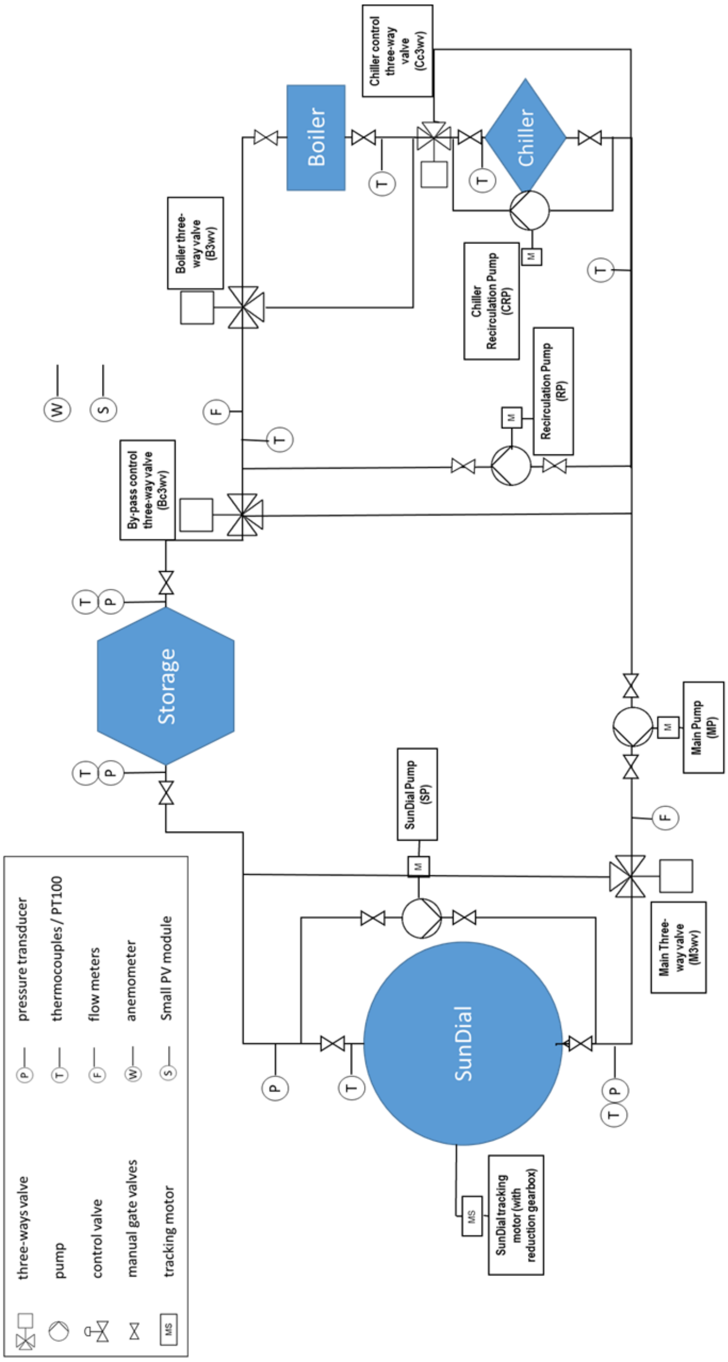

Fig. 3: Diagram of the ASTEP concept for the Mandrekas case study

Since the dairy industry does not operate on weekends, there is no heat demand on these days, but the cold demand remains unchanged. Therefore, the system must be able to operate with two demands, one of them for 24 hours, 7 days a week. The defined control strategy, with the systems arranged in series, provides enough margin to select the nominal power for the process heat. As a compromise solution, a nominal thermal power of 8 kW was selected, which will need to be operational from 9 am to 5 pm from Monday to Friday.

Finally, the control strategy must ensure the dispatch of energy not only in terms of energy utilization but also in terms of selecting the type of load (process heat, cold, or both) to be covered at any given time, to minimize the impact of the hysteresis inherent in the thermal storage system and to accommodate possible uncertainties related to the received solar energy.

Likewise, Fig. 4 shows the proposed design for AMTP, which has storage in series with SunDial and the demand.

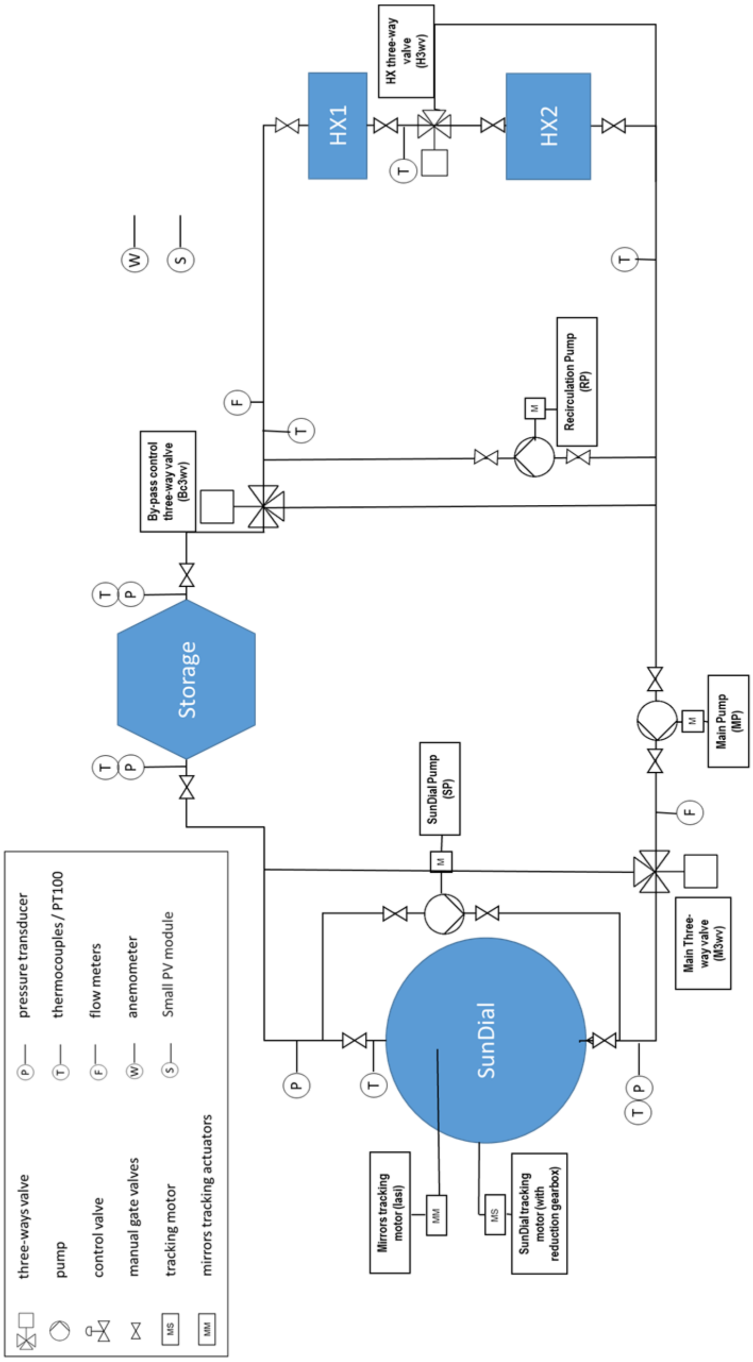

Fig. 4: Diagram of the ASTEP concept for the AMTP case study

The main differences between the Mandrekas and AMTP cases are the demand and location. Since solar irradiation at AMTP is reduced during the winter, the SunDial needs a second solar tracking system, which requires an additional motor per line of mirrors with its corresponding control system.

While the demand at Mandrekas consists of an evaporator and an absorption chiller, at AMTP it is composed of a furnace to preheat the steel tubes before coating them with paint. Similarly to the previous case, it was decided to incorporate two oil-oil heat exchangers of 7 kW each, which will feed this furnace. Thus, thanks to the defined control strategy, there is room to select the size of the heat exchangers and to minimize hysteresis in the storage system by modulating the use of one independently or both simultaneously. In this case, the industry operates 18 hours a day from Monday to Saturday.

4. Current state and preliminary results

During the initial stage of the project, the design, sizing, and selection of prototypes and the necessary components for implementation were carried out. During this first stage, numerous preliminary results were obtained to evaluate the designs. For example, Fig. 5 and Fig. 6 present some results from the simulation models.

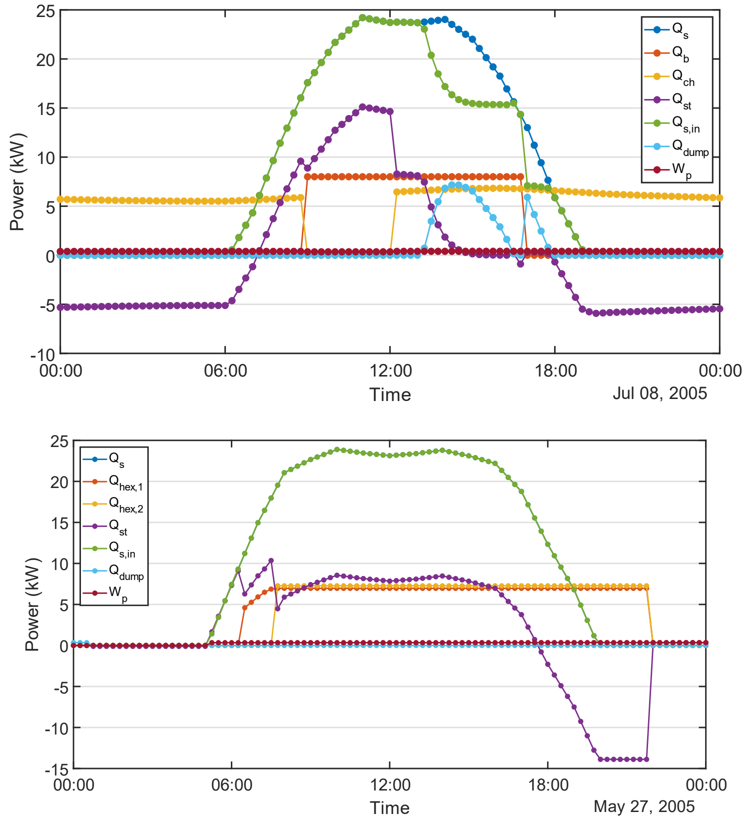

Fig. 5: Power flows in the SunDial, storage, and demand for a day with high solar resource in Mandrekas (up) and AMTP (down)

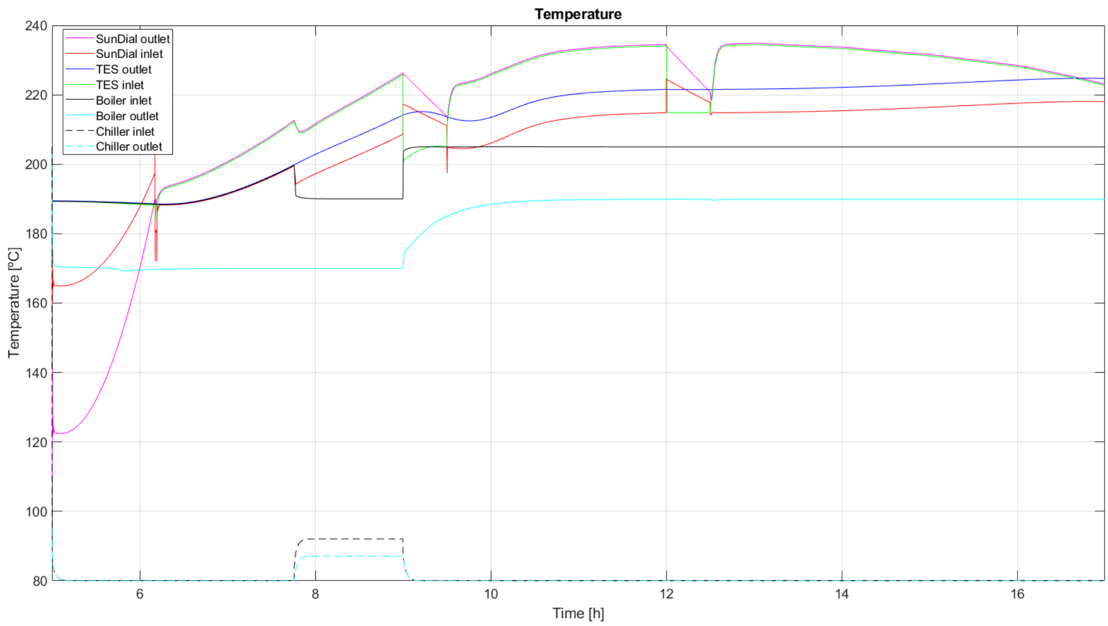

Fig. 6: Dynamic simulation of the ASTEP system for Mandrekas in a scenario with variable solar radiation due to cloud cover

After the design stage concluded, the SunDial and TES prototypes started construction in Madrid (UPM) and Cartagena (UPCT) & Wroclaw (Wroclaw University), respectively. Fig. 7 and Fig. 8 show the current construction status of the two SunDial collectors, while Fig. 9 shows one of the storage tanks.

As of today, the construction of the SunDials has been completed, and the control system is being fine-tuned, so there are no experimental results from the collectors yet. The three accumulators of the thermal storage system (one for Mandrekas and two for AMTP, as it requires a more constant temperature demand) have been built, assembled, filled with PCM after preparation in the UPCT laboratory, the material has been melted, and testing has finished.

Fig. 7: SunDial with single axis tracking system for the Mandrekas case study, before (left) and after (right) placing the reflectors

Fig. 8: SunDial with two axis tracking system for the AMTP case study

Fig. 9: Accumulator of the storage system and detail of the inserts

Fig. 10 shows an example of the results of the system's charging and discharging process.

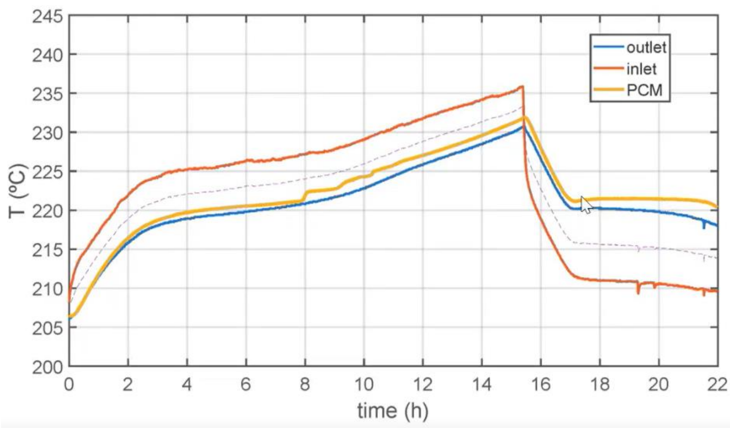

Fig. 10: Experimental results of the charging and discharging process of one of the storage system accumulators

Once all the systems: SunDial, storage system, and control system, are properly tested in the laboratory, the equipment will be disassembled and sent to the end-users, Mandrekas and AMTP. The remaining activities are shown in Table 1.

Tab. 1: Table captions (8 pt) should be centered and placed above the table

T7.1 - Implementation of Concept Design for 2 Test Cases	1-1-2021 a 30-11-2024
T7.2 - Installation & Commissioning on Site	1-8-2024 a 30-11-2024
T7.3 - Monitoring	1-2-2023 a 30-6-2025
T7.4 - Validation	1-12-2024 a 29-6-2025
T8.1 - Life Cycle Assessment (LCA)	1-10-2020 a 30-6-2025
T8.2 - Life Cycle Costing (LCC)	1-7-2021 a 30-6-2025
T8.3 - Social LCA	1-10-2020 a 30-6-2025
T8.4 - Social Acceptance	1-12-2021 a 30-6-2025
T8.5 - Exergy Analysis	1-5-2021 a 30-6-2025

A comprehensive list of results and publications from the project can be found in the ASTEP project community at Zenodo platform (https://zenodo.org/communities/astep/records).

5. Conclusions

This work presents the objectives and the current status of the ASTEP project. The main objective of the project is to develop a new concept of solar energy applied to industry and demonstrate its feasibility in two case studies: the Mandrekas dairy industry and the ArcelorMittal Tubular Products steel industry. In the first case, by producing process heat and cold, and in the second, by producing process heat at high latitude.

To achieve this, the technologies involved in the ASTEP concept have been developed: the rotatory Fresnel solar collector, SunDial; the thermal storage system, based on phase change materials; and the integration of the technologies according to a series layout, along with the control system. Once the designs were completed, the prototypes of the different systems were built and are currently being independently tested at the facilities of the Universidad Politécnica de Madrid (UPM) and the Universidad Politécnica de Cartagena (UPCT). After the tests are concluded, the equipment will be transferred to the end-users in Greece and Romania, where the integration of the ASTEP concept will be tested in an integrated manner and in a relevant environment with real operating conditions.

6. Acknowledgments

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7. References

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