H2020: ASTEP Project

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Solar Heat for Industrial Processes (SHIP)

The European project ASTEP (Application of Solar Thermal Energy to Processes), coordinated by the Energy Engineering Department at UNED has as objective providing solar energy of high quality and reliability for industrial processes, for both heating and cooling demands in continuous operation. For this purpose, the project proposes an innovative concept of rotating solar collector, named SunDial, which must overcome the current system limitations, allowing high temperature operations for high latitude localizations.

The project ASTEP [1] is categorized within the European H2020 research projects focused on renewable heat and cooling generation and energy supply with low cost and emissions.

The project was awarded to a consortium coordinated by UNED and formed by 16 partners from 9 European countries (Spain, United Kingdom, Cyprus, Italy, Greece, Romania, France, Poland and Ireland). They will combine their knowledge and expertise in research and business.

The project started on May the 1st of 2020 and, during the next four years, the solar collector SunDial (Fig. 1) will be adapted to supply a significant percentage of the heating and cooling demand for the process industry. It will be done for temperatures and latitudes where the current designs have failed.

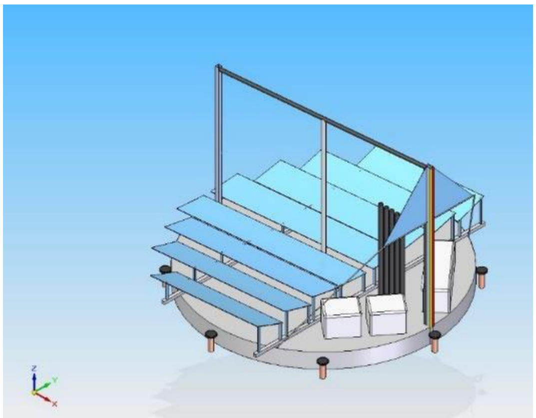

Fig 1. Collector solar SunDial

The SunDial is the result of 4 Spanish patents [2-5] and 2 international ones that belong to UPM and UNED [6-7]. The SunDial is a rotatory Fresnel collector that consists of a horizontal platform that rotates around a vertical axis, with a Fresnel type linear concentrator on top of the primary concentrating mirrors. These mirrors are curved following am arc of a circle and are located in parallel with the receiver, directing the radiation towards its whole length.

Similarly, these mirrors can be fixed or not, rotating around their longitudinal axis to obtain a two-axis solar tracking and improving the average solar optical performance. In order to reduce the radiation losses at the end of the receiver, some solutions are proposed: such as the introduction of a mirror that would reflect the rays that, on the contrary, would not hit on the receiver (fig. 1), modifying the slope of the platform (fig. 2) and/or enlarging the tube.

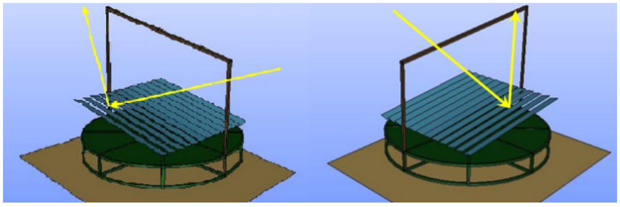

Fig 2. Effect of the slope of the mirrors

They are technical solutions that will be analysed and optimized during the project development to provide a system adapted for different locations and the working temperature of the industrial processes. Specifically, the project proposes the installation of two large prototypes in industrial environments according to the established objective of reaching TRL 5 (Technology Readiness Level):

- Pasteurization process, generating heat at 175ºC in a dairy factory located in Greece (37.93 N).
- Preheating process over 220 ºC in a steel factory for metallic tubes processing in Romania (47.1 N).

Currently, there are 111 SHIP plants operating in Europe, according to the IEA database, task 49 [8]. 17 of them work with temperatures higher than 150 ºC, and only in 6 European countries. The challenge is to supply heat above this temperature and in higher latitudes, using a Fresnel concentrator, which is a technology with high potential for cost reduction. For the Romanian test site, a two-axis-tracking SunDial will be selected in order to reach this objective.

This collector will be integrated with a thermal energy storage system based on PCM (Phase change materials) and they will be managed by a control system to keep the continuous operation for the whole day. This objective will be reached for some of the summer days.

If the objectives are quantified, the project seeks to meet the following challenges:

- Reach up to 135 kWh of thermal production per day and 25 MWh of annual thermal production in each case study.

- Avoid the emission of 5.7 t of CO_2 and 5 kg of NOx into the atmosphere.
- Save the consumption of 2 t of Natural Gas.

In addition, the ASTEP system will allow reaching other important objectives for the project:

- Reduce maintenance requirements, which in the Greek case is guaranteed because the mirrors will be fixed.
- Avoid introducing changes in current industrial processes.

These objectives are intended to be achieved through the development of some tasks in which the UNED will be intensively involved, in collaboration with the other partners of the ASTEP project:

- Carrying out thermo-fluid-mechanical simulations that allow characterizing the operation of the different elements (figs. 3 and 5).
- Development of in-home tools to simulate its steady and transient behaviour (fig. 4).
- Laboratory tests for the cases of the storage system and, selection and assembly of the mirrors.
- Carrying out tests of the prototypes within the facilities of the Polytechnic University of Madrid (UPM) and the Polytechnic University of Cartagena (UPCT), which will allow the consortium researchers access to an important database to improve their developments.

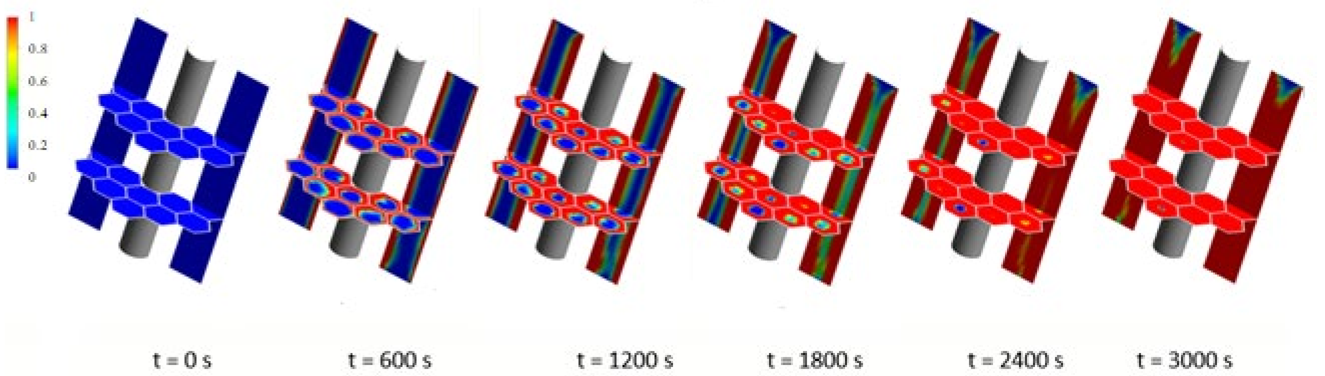

Fig 3. Time history of the fluid volume fraction in the storage system

Figure 3 shows the evolution of the solid fusion process during the loading stage, obtained through computational fluid dynamics (CFD) simulations obtained by the company ANALISIS-DSC.

This model will be validated through laboratory tests and will allow the development of dynamic tools focused on characterizing the integration of this system with the solar collector.

One of the key points of the project is the characterization of the collector, which will be carried out through the development of specific tools by the UPM and the UNED, based on developments of both universities.

As a first step, it is necessary to know the concentration of solar rays on the receiver (fig. 4), which will be obtained based on a ray-tracing tool developed at UPM.

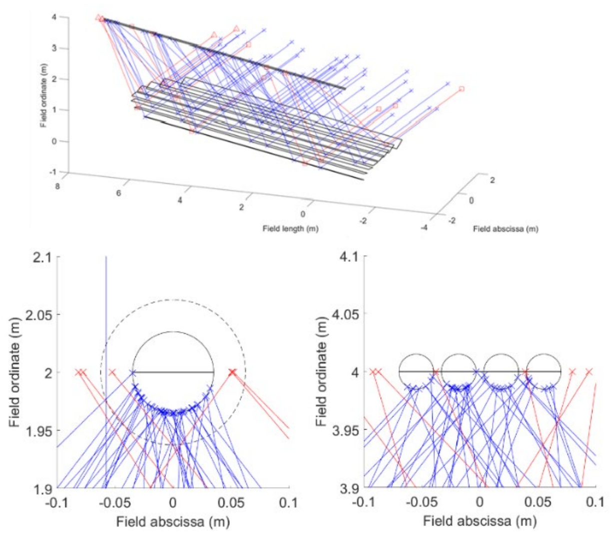

Fig 4. Assessment of the optical performance of the SunDial

In order to obtain a good concentration of the solar rays, the mirrors will be curved. For this reason, it is necessary, on the one hand, to test whether the mirrors support the local stresses generated and, on the other hand, to evaluate the deformation of the mirror to analyse whether the concentration will be the adequate or not (fig. 5).

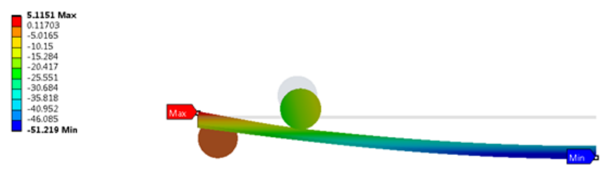

Fig 5. Finite element simulations to analyse the shape of deformed mirror

Once the concentration is known, the useful energy absorbed by the heat transfer fluid must be estimated by subtracting the energy dissipated on the receiver (fig. 6). The thermal loss models developed at the UNED will be used for this task.

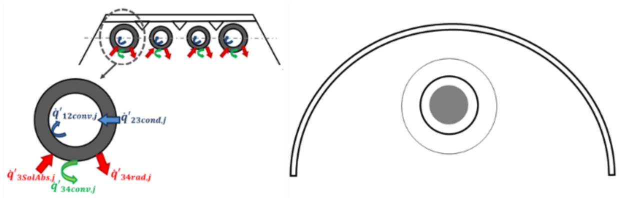

Fig 6. Raised receiver designs and thermal model scheme

The thermal losses will be given by expressions such as Eq. 1 [9].

$$\dot{q}''_{perd} = \dot{q}''_{abs} - F'_{crit} \cdot [\dot{q}''_{abs} - \dot{q}''_{crit}] + \dot{q}''_{perd,soportes} \quad Ec.\ 1$$

In such a way that the outwards heat flux per unit area ($\dot{q}''_{perd}$) is expressed as a function of the heat absorbed per unit area ($\dot{q}''_{abs}$), the thermal losses in receiver supports ($\dot{q}''_{perd,soportes}$) and two characteristic parameters of each receiver ($\dot{q}''_{crit}$, F'_{crit}) defined by equations 2 and 3 [9].

$$\dot{q}''_{crit} = \sigma \cdot \varepsilon_{ext} \cdot (T_{fe}^4 - T_{ext}^4) + h_{ext} \cdot (T_{fe} - T_{ext}) \quad Ec.\ 2$$

$$F'_{crit} = \frac{1}{\frac{U_{crit}}{U_{rec}} + 1}\ ;\ U_{crit} = 4 \cdot \sigma \cdot \varepsilon_{ext} \cdot T_{fe}^3 + h_{ext} \quad Ec.\ 3$$

Both parameters are defined as a function of the outwards heat transfer coefficients for the specific receiver (h_{ext} y ε_{ext}) and, the inlet temperature of the fluid at the receiver (T_{fe}) and the external conditions (T_{ext}).

The objective is to obtain the total energy transmitted to the transfer fluid over a year, which will be obtained as a result of the integration of these tools (fig. 7), in which the energy is plotted for five years at the end user located in Corinth (Greece).

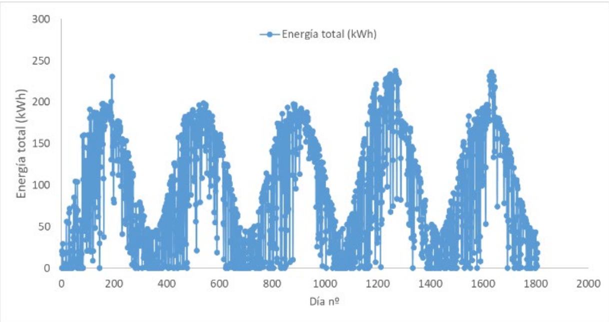

Fig 7. Total energy, in a hour-by-hour basis, transferred to the fluid

The subsequent integration of the receiver model with the models dedicated to the storage and other systems, both in their pseudo-steady and dynamic versions, will allow the complete analysis of the installation and a correct design of the control systems, which will contribute to optimize their behaviour.

Therefore, a large part of the success of the project will lie in the results obtained from the models, developed by UNED and other project partners, since only small adaptations at the testing facilities will be allowed.

As a result of the project, it is expected to develop an economic and sustainable alternative that is able of covering a relevant part of the heat demand for the industry at medium temperatures (150-300 ºC).

References:

[1] https://www.astepproject.eu/

[2] Patent ES2578804B2

[3] Patent ES1138715U

[4] Patent ES2537607B2

[5] Patent ES2713799A1

[6] Patent WO/2016/166388A1

[7] Patent WO/2016/166390A1

[8] Database for applications of solar heat integration in industrial processes (2018) http://ship-plants.info/

[9] Barbero, R. Desarrollo de un modelo teórico para la caracterización del rendimiento térmico en colectores solares. Aplicación a tecnologías de generación eléctrica (2018). Tesis doctoral en Tecnologías Industriales (UNED)

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