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PLATAFORMA SOLAR DE ALMERÍA

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1 General Presentation

The *Plataforma Solar de Almería* (PSA), a dependency of the *Centro de Investi-gaciones Energéticas, Medioambientales y Tecnológicas* (CIEMAT), is the largest concentrating solar technology research, development and test centre in Europe. PSA activities are integrated in the CIEMAT organization as an R&D division of the Department of Energy.

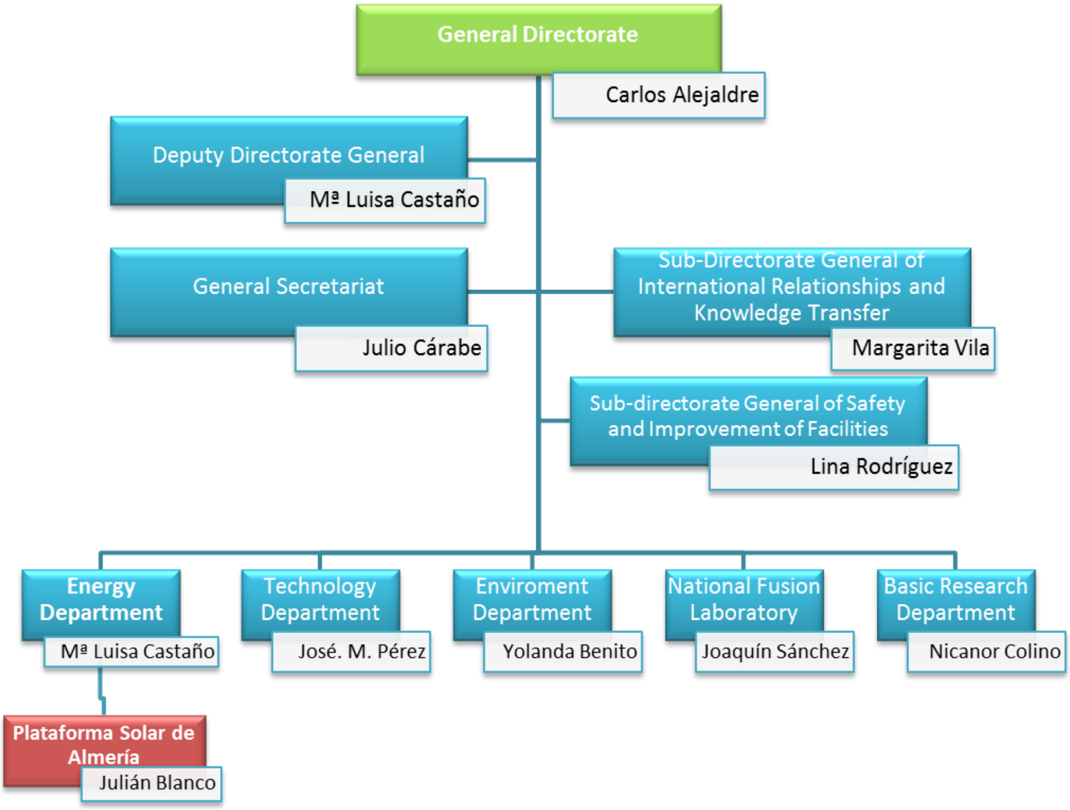


Figure 1. Integration of the PSA in the CIEMAT organization.

The following goals inspire its research activities:

- Contribute to establishing a sustainable clean world energy supply.
- Contribute to the conservation of European energy resources and protection of its climate and environment.
- Promote the market introduction of solar thermal technologies and those derived from solar chemical processes.
- Contribute to the development of a competitive Spanish solar thermal export industry.
- Reinforce cooperation between business and scientific institutions in the field of research, development, demonstration and marketing of solar thermal technologies.
- Strengthen cost-reducing techno-logical innovations contributing to increased market acceptance of solar thermal technologies.
- Promote international technological cooperation, especially in the Mediterranean Area.
- Assist industry in identifying solar thermal market opportunities.

Figure 2. Aerial view of the *Plataforma Solar de Almería*.

Since 2018, research activity at the *Plataforma Solar de Almería* has been structured around four R&D Units under a Technical Coordinator, plus a strong unit to manage and also coordinate all facilities and laboratories, namely the PSA Management Unit. In addition to the different horizontal services (IT services, Instrumentation, Maintenance, Civil Engineering Operation, etc.), two additional facilities (METAS and LECE), physically allocated within PSA but with associated personnel formally outside PSA structure, are also included in this PSA Management unit.

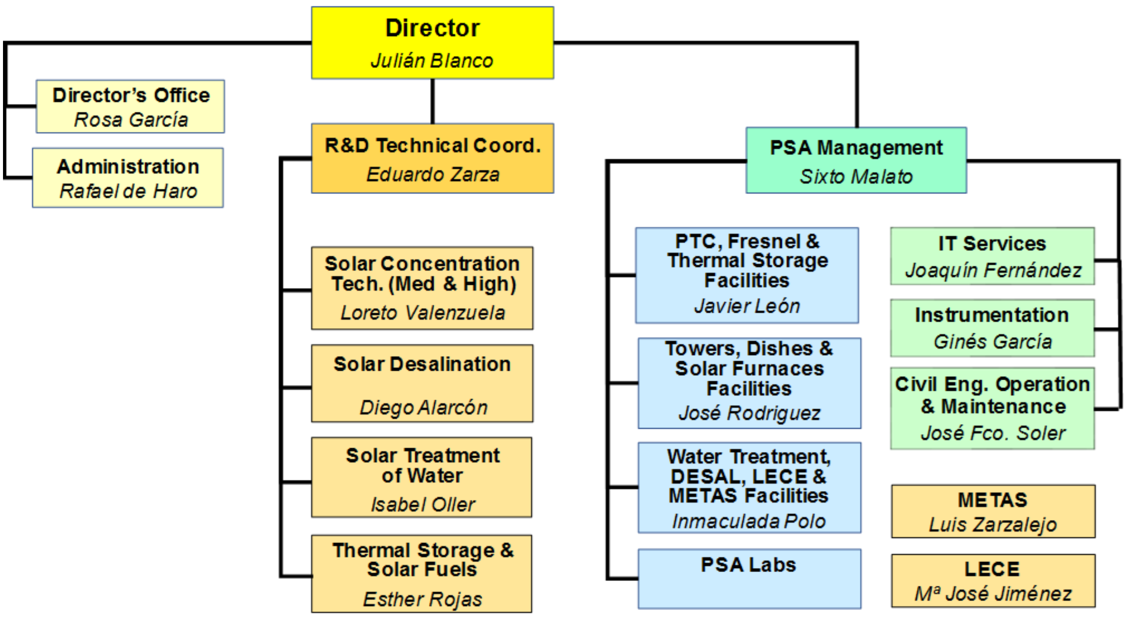


Figure 3. Internal organizational structure of PSA.

The four R&D Units are as follows:

- Solar Concentrating Systems. This unit develops and studies components for solar fields, complete systems and applications of concentrated solar thermal energy technologies, for electricity generation and industrial process heat.
- Solar Desalination. Its objective is to develop brackish water and seawater solar desalination.
- Solar Water Treatment. Exploring the chemical possibilities of solar energy, especially its potential for water detoxification and disinfection.
- Thermal Storage & Solar Fuels. The objective of this Unit is providing solutions to concentrating solar thermal systems to become a dispatchable technology, by thermal storage systems and/or Hydrogen production by thermochemical processes.

Supporting these R&D Units are the Direction and Technical Services Units mentioned above. These units are largely self-sufficient in the execution of their budget, planning, scientific goals and technical resource management. Nevertheless, the four R&D units share many PSA resources, services and infrastructures, so they stay in fluid communication with the Direction and Services Units, which coordinate technical and administrative support services. For its part, the Office of the Director must ensure that the supporting capacities, infrastructures and human resources are efficiently distributed. It is also the Office of the Director that channels demands to the various general support units located at the CIEMAT's main offices in Madrid.

The scientific and technical commitments of the PSA and the workload this involves are undertaken by a team of 135 persons that as of December 2018 made up the permanent staff lending its services to the *Plataforma Solar de Almería*. In addition to this staff, there is a significant flow of personnel in the form of visiting researchers, fellowships and grants handled by the Office of the Director. Of the 128 people who work daily for the PSA, 66 are CIEMAT personnel, 11 of whom are located in the main offices in Madrid.In addition, the 8 persons who make up the DLR permanent delegation as a consequence of its current commitments to the Spanish-German Agreement also make an important contribution. The rest of the personnel are made up of a no less important group given the centre's characteristics. These are the personnel working for service contractors in operation, maintenance and cleaning in the various different facilities. Of these 32 persons, 15 work in operation, 13 in maintenance and 4 in cleaning. The auxiliary services contract is made up of 5 administrative personnel and secretaries, 7 IT technicians for user services, and another 5 persons from the security contract, what makes a total of 17 persons.

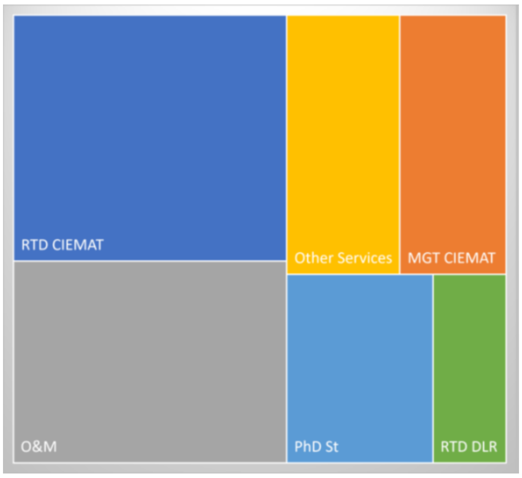


Figure 4. Distribution of permanent personnel at the PSA as of December 2018

The effort CIEMAT has made for the last several years to provide the PSA with the necessary human resources should be emphasized. This continued effort is allowing us to undertake our task with greater assurance of success.

The PSA expense budget has an upward trend, in large part due to higher income, both from European Commission project funding, and from the National Plan for RD&I, although the most important factor was the increase in revenues from research contracted by business.

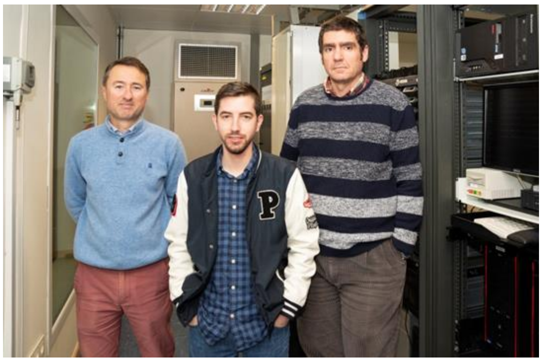
The PSA operating budget in 2018 totals 3.4M Euros (not including R&D personnel or new infrastructure.


(a)


(b)


(c)


(d)


(e)


(f)


(g)

Figure 5. Management and technical services staff grouped in the PSA Management Unit. a) Direction Unit, b) Administration unit, c) Instrumentation unit, d) IT Services unit, e) Operation unit, f) Cleaning and maintenance unit, g) Infrastructure unit.

2 Facilities and Infrastructure

2.1 Parabolic Trough Systems

2.1.1 The DISS experimental plant

This test facility was erected and put into operation in 1998 for experimenting with direct generation of high-pressure-high temperature (100 bar/400°C) steam in parabolic-trough collector absorber tubes. It was the first facility built in the world where two-phase-flow water/steam processes in parabolic-trough collectors could be studied under real solar conditions.

The facility (see Figure 6 and Figure 7) consists of two subsystems, the solar field of parabolic-trough collectors and the balance of plant (BOP). In the solar field, feed water is preheated, evaporated and converted into superheated steam at a maximum pressure of 100 bar and maximum temperature of 400°C as it circulates through the absorber tubes of a 700-m-long row of parabolic-trough collectors with a total solar collecting surface of 3.838 m^2. The system can produce a nominal superheated steam flow rate of 1 kg/s. In the balance of plant, this superheated steam is condensed, processed and reused as feed water for the solar field (closed loop operation).

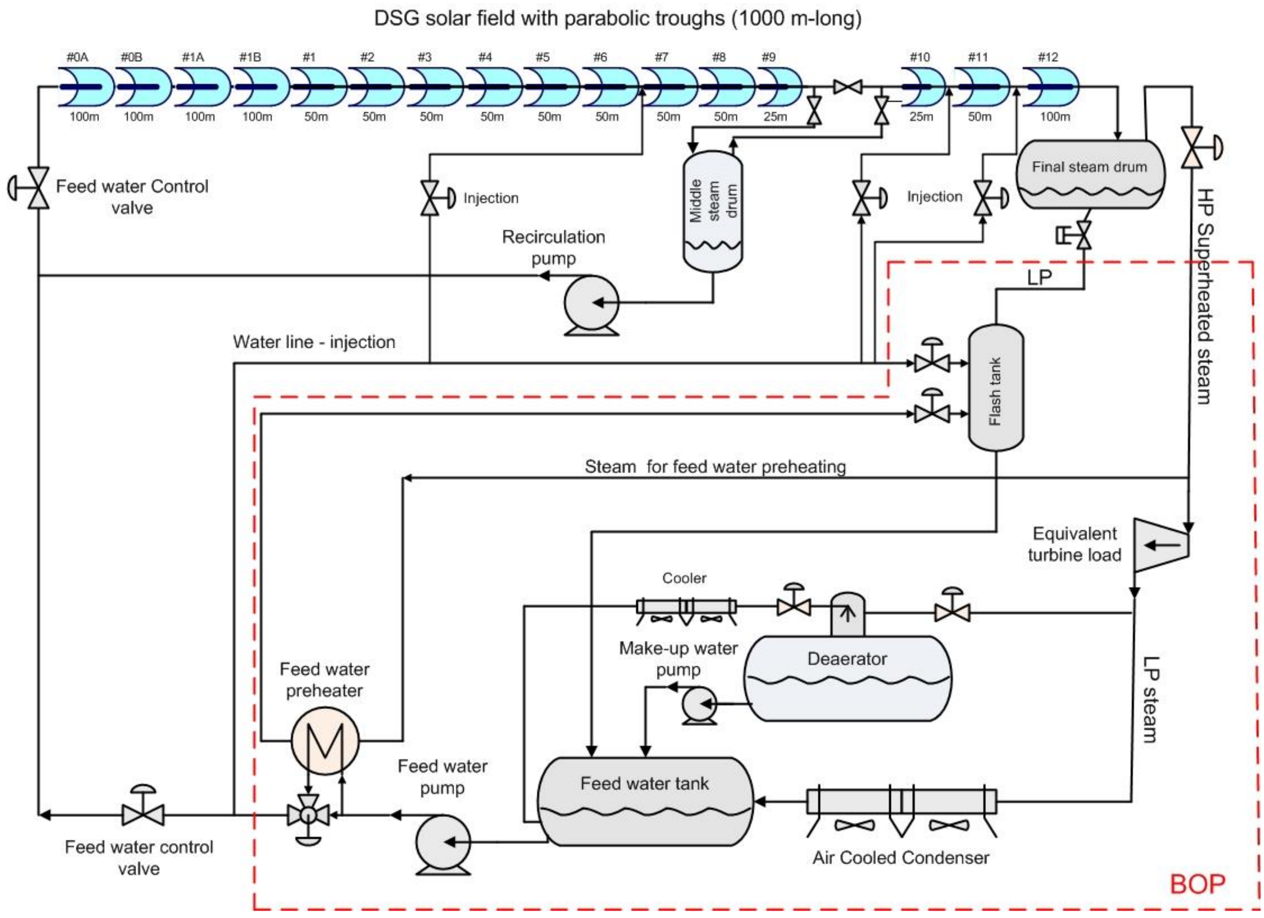


Figure 6. Simplified flow diagram of the PSA DISS loop.

In 2012, within the DUKE Project, three additional parabolic-trough collectors were installed in the solar field and all the absorber tubes were replaced by new ones, to increase up to 500°C the temperature of the superheated steam produced, enabling to generate direct steam at 100bar and 500°C.

Facility operation is highly flexible and can work from very low pressures up to 100 bar. It is also equipped with a complete set of valves allowing the solar field to be configured for Recirculation (perfectly differentiated evaporation and superheating zones), for Once-Through (the intermediate water-steam separator and the recirculation pump located in the solar field are not used in this operating mode) and in Injection mode (feed water is injected in different points along the collector row). The facility is provided with a wide range of instrumentation for full system monitoring (flow rates and fluid temperatures in the various zones of the solar field, pressure drops in collectors and piping, temperature and thermal gradients in the cross sections of the absorber tubes, etc.) and a data acquisition and process control system which has a database where 5-s process data are recorded 24 hours a day.

Among the capacities associated with this facility are the following:

- Component testing for parabolic-trough collector solar fields with direct steam generation (DSG) in their receiver tubes (receivers, ball joints or flexholes, water-steam separators, specific instrumentation, etc.).
- Study and development of control schemes for solar fields with DSG.
- Study and optimization of the operating procedures that must be implemented in this type of solar field.
- Thermo-hydraulic study of two-phase of water/steam in horizontal tubes with non-homogeneous heat flux.

Figure 7. View of the DISS plant solar field in operation

2.1.2 The HTF Test Loop

The HTF test loop was erected in 1997 and it is an ideal facility for evaluating parabolic-trough collector components under real solar energy operating conditions. The facility is appropriately instrumented for qualifying and monitoring of the following components:

- New designs of parabolic-trough collectors (up to 75 m long)
- Parabolic-trough collector mirrors
- Parabolic-trough collector absorber tubes
- New designs of ball-joints or flex-hoses for connecting parabolic-trough collectors in the solar fields.
- Solar tracking systems.

The facility consists of a closed thermal-oil circuit connected to several solar collectors of 75-m long connected in parallel (up to three collectors can be installed in parallel), being able to operate only one at a time (see simplified diagram of the facility in Figure 8). The east-west rotating axis of the solar collectors increases the number of hours per year in which the angle of incidence of the solar radiation is less than 5°. The thermal oil used in this facility (Syltherm 800®) has a maximum working temperature of 420°C and a freezing point of - 40°C.

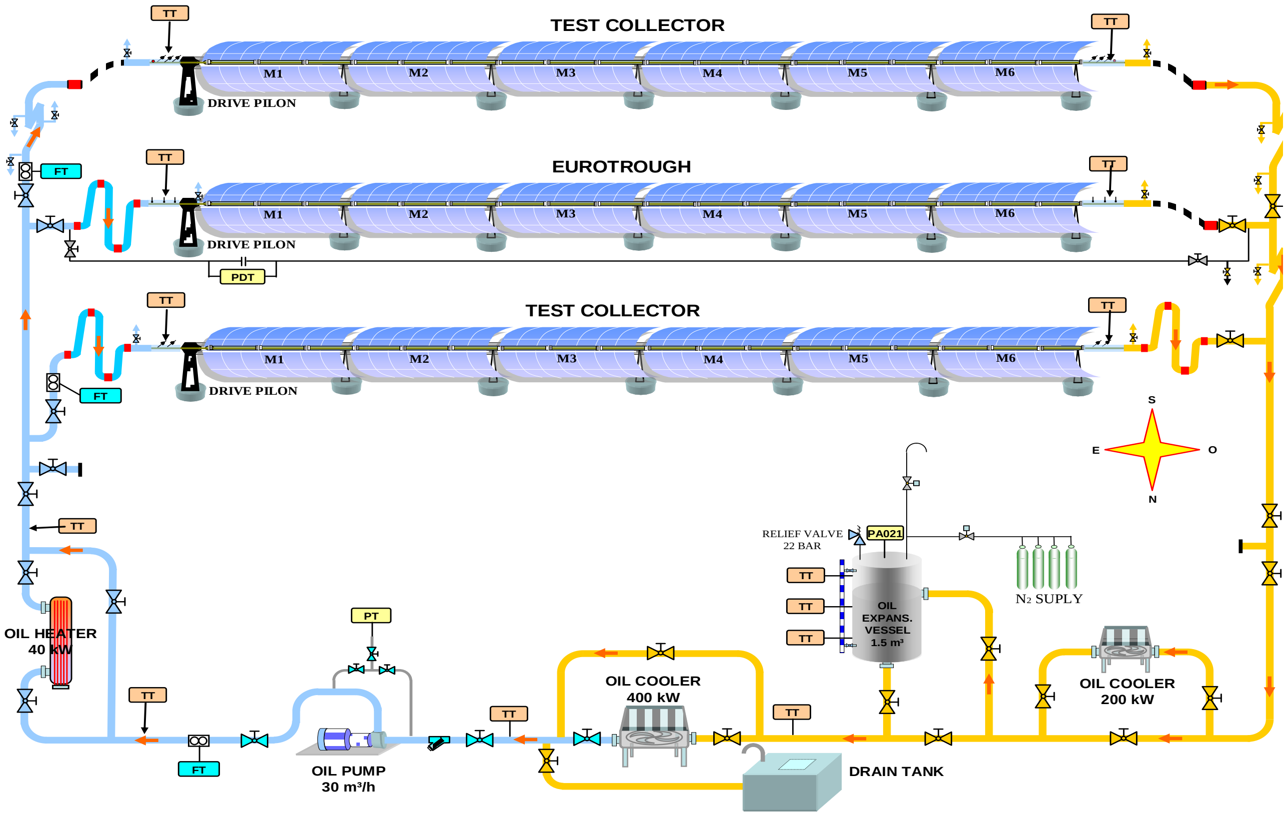


Figure 8. Diagram of the PSA “HTF test Loop”.

The facility's oil circuit, which has a maximum working pressure of 18 bar, is made up of the following elements:

- 1-m^3-capacity oil expansion tank, with automatic nitrogen inertisation.
- Oil circuit sump tank.
- Mechanical-draft oil cooler, with air speed control and 400-kW maximum cooling.
- Centrifugal oil pump, with a flow rate of up to 8.3 litres per second.
- Two 40-kW electric oil heaters.

The first EUROtrough collector prototype developed by an European consortium with the financial aid of the European Commission was installed and evaluated under real working conditions at this facility in 1998 and it this collector is now used to evaluate and qualify new designs of receiver tubes, reflectors and other components for parabolic-trough collectors.

Main activities at the HTF test loop are related to study the optical and thermal performance of complete parabolic-trough collectors (optical efficiency, IAM coefficient, and global efficiency/heat losses) and receiver tubes.

2.1.3 The Parabolic Trough Test Loop (PTTL) facility

This large test facility is implemented in a 420mx180m plot of the PSA and it is composed of two solar fields:

- the North field is designed to install with a E-W orientation complete parabolic trough collectors with a maximum unit length of 180 m. Up to four complete collectors can be installed in parallel.
- the South field is designed to install complete loops of parabolic trough collectors (PTCs), i.e. several collectors connected in series, with a maximum length of 640 m and oriented North-South. Up to four complete loops can be installed in parallel.

Each field is provided with a complete oil circuit installed on a 30mx30m concrete platform between the two fields, and both circuits share: an oil expansion tank with a capacity of 30 m^3, a gas-fired oil heater with a thermal power of 250 kW, a meteorological station equipped with solar radiation, ambient temperature and wind sensors, and the data acquisition system (DAS). Additionally to these common elements, the oil circuit associated to the North and South fields are composed of:

- North field: one oil pump (75 m^3/h) provided with speed control, one oil cooler refrigerated by air (1.5 MWt) able to cold the oil down to 70°C when the ambient air temperature is 40°C, oil piping connecting the circuit to the common elements (i.e., expansion tank and oil heater).
- South field: one oil pump (125 m^3/h) provided with speed control, one oil cooler refrigerated by air (4 MWt), oil piping connecting the circuit to the common elements (i.e., expansion tank and oil heater).

Each oil circuit is also provided with an oil draining tank big enough to receive all the oil existing in the circuit, a complete set of instrumentation to monitor: oil mass flow, pressures and temperatures, as well as control valves to regulate the oil flow to desired values according to the tests.

This outdoor life-size test facility offers the following capacities:

- qualification of complete PTC prototypes assessing their optical peak efficiency, incidence angle modifier and thermal losses,

- evaluation of durability and reliability of PTC mirrors, receiver tubes, ball-joints, flex hoses, sun tracking systems and all the elements installed in complete rows of collectors,
- Evaluation of PTC solar field control algorithms

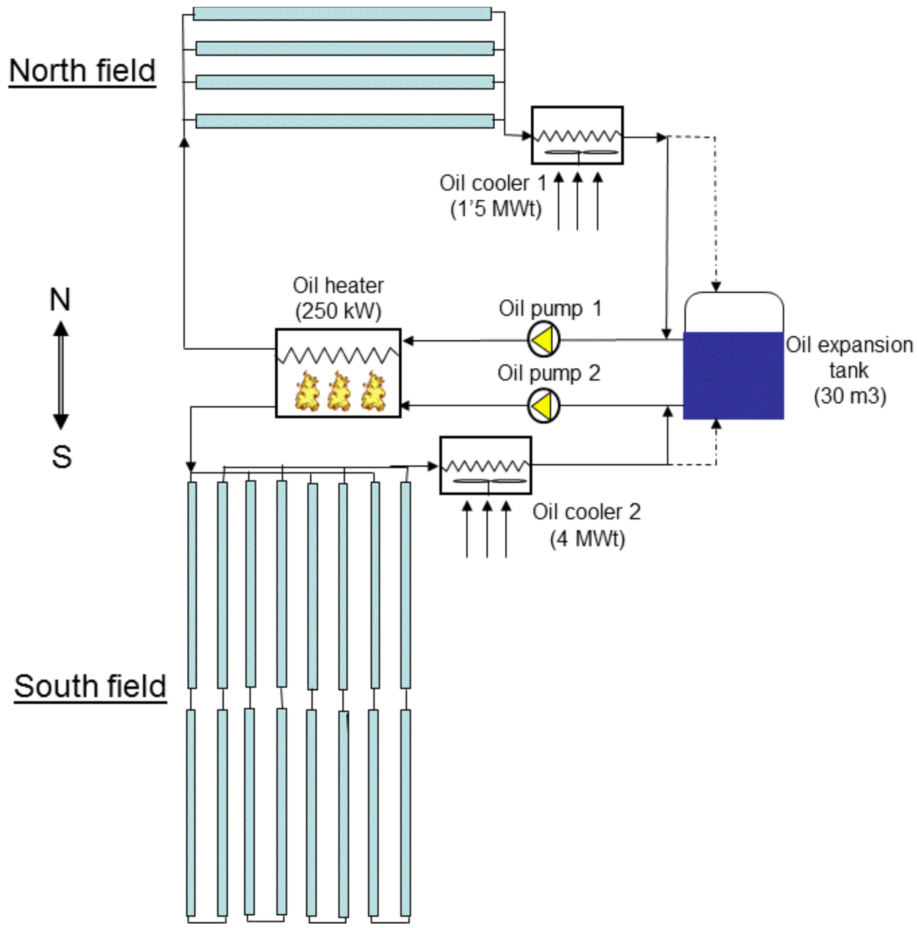


Figure 9. Simplified scheme of the PTTL facility

2.1.4 PROMETEO: Test facility for checking new components and heat transfer fluids for large-parabolic troughs

An experimental closed loop is installed at the North-East area of the *Plataforma Solar de Almería*. It was designed and erected by the company *Iberdrola Ingeniería y Sistemas* in 2010 starting the test campaign along the following year. The pilot plant was transferred to CIEMAT-PSA to be used as testing loop.

The East-West oriented test loop allows the qualification of all collector components and complete collectors of a length of up to 150 m, i.e. structures, reflectors, receivers from 70 to 90 mm and movable joints. It enables sun tracking covering all solar radiation incidence angles in one day thanks to its orientation. It is equipped with high precision instrumentation and controls for precise, quick and automated measurements. Currently there are two parabolic troughs 100 m-long and with an aperture of 7.5 m each one installed in the pilot plant.

The collector modules are connected to the balance of plant (BOP) in parallel or in series configuration using the ad hoc set valve. A pump circulates the silicone heat transfer fluid (SHTF) with a mass flow similar to that of commercial power plants. Mass flow is measured directly using Vortex and differential pressure flowmeter types. A controlled air cooler unit dissipates the collected energy and ensures a constant HTF temperature (±1K) at the inlet of the collector. Sensors for measurement of inlet and outlet temperatures are highly precise and may be calibrated on site. A meteorological station delivers accurate radiation and wind data.

Figure 10. View of the PROMETEO test facility.

2.1.5 TCP-100 2.3-MWth parabolic-trough facility

This test facility was implemented in 2014, and it is composed of the TCP-100 solar field and a thermocline storage tank with 115 m^3 of Santotherm-55 oil.

The TCP-100 solar field is composed of six parabolic-trough collectors, model TERMOPOWER, installed in three parallel loops, with two collectors in series within each loop, see Figure 11. Each collector is composed of eight parabolic trough modules with a total length of 100 m and a parabola width of 5.77 m. The total solar collecting surface of each collector is 545 m^2. The focal distance is 1.71 n, the geometrical intercept factor is ≥0.95, and the peak optical efficiency is 77.5%. The receiver tubes used in this solar field were delivered by Archimede Solar Energy (Italy) and the working fluid is Syltherm®800.

The solar field is connected to a 10 m^3 oil expansion tank for a maximum temperature of 400°C. Thermal energy can be transferred from the solar field primary circuit to a thermocline oil storage tank with a total volume of 176 m^3 and 115 m^3 of Santotherm 55 oil with a maximum working temperature of 300°C.

This test facility is specially designed to perform studies related to control systems for parabolic trough solar fields. This is the reason why two collector loops are provided with the solar tracking system developed by PSA, while the third loop is provided with a commercial solar tracking system with continuous movement.

2.1.6 Innovative Fluids Test Loop (pressurized gases) in parabolic-trough collectors

The purpose of this experimental facility is to study the use of pressurized gases as heat transfer fluid in parabolic-trough collectors, evaluating their behaviour under a diversity of real operating conditions.

The experimental test loop (see Figure 12) is located north of the DISS experimental plant control building, which houses the equipment necessary for its control and data acquisition.

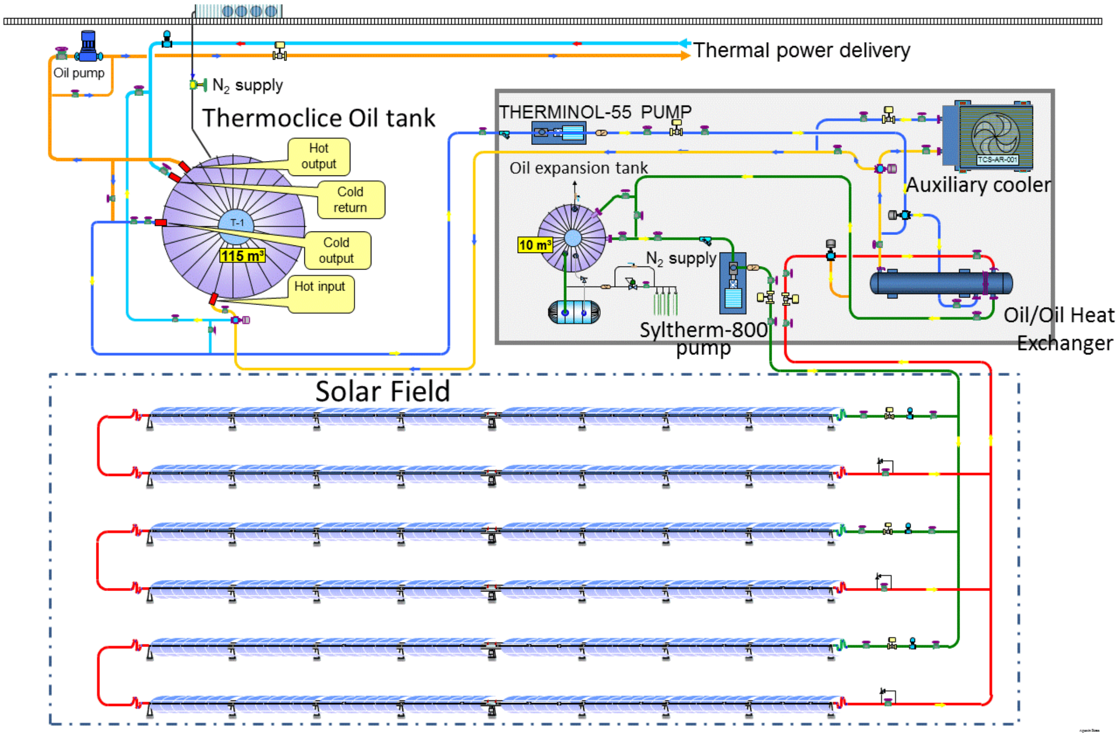


Figure 11. Diagram of the TCP-100 2.3-MWth parabolic-trough facility

Figure 12. View of the IFL experimental facility (with parabolic-troughs) using compressed gas as heat transfer fluid.

The IFL facility was originally designed to work at pressures and temperatures of up to 100 bar and 400°C, and consists of the following components:

- Two East-West-oriented EUROtrough parabolic-trough collectors, each 50 m long with a 274.2-m^2 collector surface. The collectors are connected in series.
- A 400-kW air-cooler able to dissipate the thermal energy in the fluid delivered by the collectors. It has two 4-kW motorized fans.
- A blower driven by a 15-kW motor which supplies the gas flow rate necessary to cool the receiver tubes adequately.
- A data acquisition and control system that allows the temperature, flow rate, pressure, beam solar irradiance and humidity in the system to be completely monitored.
- Automatic control valves that allow precise, safe variation in the collector fluid feed flow rate.
- An auxiliary circuit for filling the main test loop with the gas used as heat transfer fluid.

Since testing at 400°C was successfully completed at the end of 2009, this facility was then upgraded to achieve temperatures of up to 515°C and it was connected to a two-tank molten-salt thermal storage system to test their joint capacity for collecting and storing solar thermal energy with a view to making use of them in dispatchable high-performance thermal cycles. This increase in test loop design conditions to 100 bar and 515°C made the implementation of different improvements necessary (conventional absorber tubes in one of the two collectors were replaced with advanced high-temperature tubes, stainless steel pipes were installed for the high temperature zone and changes were made in the control system).

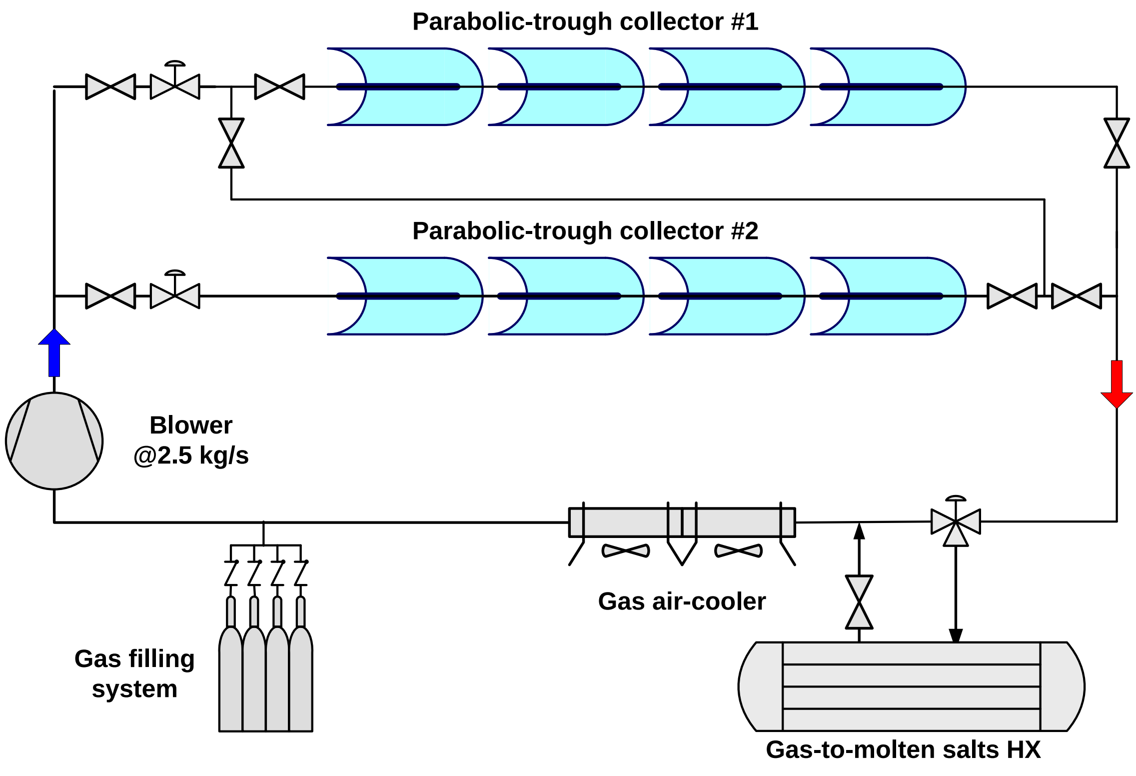


Figure 13. Simplified system diagram of the IFL experimental facility located at the PSA.

2.2 Installations associated with Parabolic Trough Systems

2.2.1 KONTAS: Rotary test bench for parabolic trough ststems

A rotary test bench for parabolic trough collector components, KONTAS, was erected at Plataforma Solar de Almería in 2009. The concept was developed by DLR and within the framework of the Spanish-German agreement between CIEMAT and DLR this test facility is now jointly used by both institutes.

The test bench allows the qualification of all collector components and complete modules of a length of up to 20 m, i.e. structures, reflectors, receivers and flexible joints. It enables for a tracking at any desired angle of incidence of the solar radiation. It is equipped with high precision instrumentation and controls for precise, quick and automated measurements.

The test bench rests on rails directly mounted on top of the foundation. These rails form an inner and an outer ring. The collector itself is mounted on a steel platform with six steel wheels. The rotation of the platform on the rails around the central bearing is performed by motors driving four of these wheels.

The collector module is connected to a heating and cooling unit, which is also situated on the platform. A pump circulates *Syltherm 800®* thermal oil as heat transfer fluid (HTF) with a mass flow similar to that of commercial plants. Mass flow is measured directly using the Coriolis measuring principle avoiding uncertainties of the density. The heating and cooling unit dissipates the energy the hot HTF collected on the way through the module and ensures a constant HTF temperature (±1K) at the inlet of the collector. Sensors for measurement of inlet and outlet temperatures are highly precise and may be calibrated on site. A high precision meteorological station delivers accurate radiation and wind data.

Figure 14. Side view of KONTAS test bench and the heating cooling unit.

2.2.2 Accelerated full lifecycle tests of rotation and expansion performing assemblies (REPAs) for parabolic troughs systems

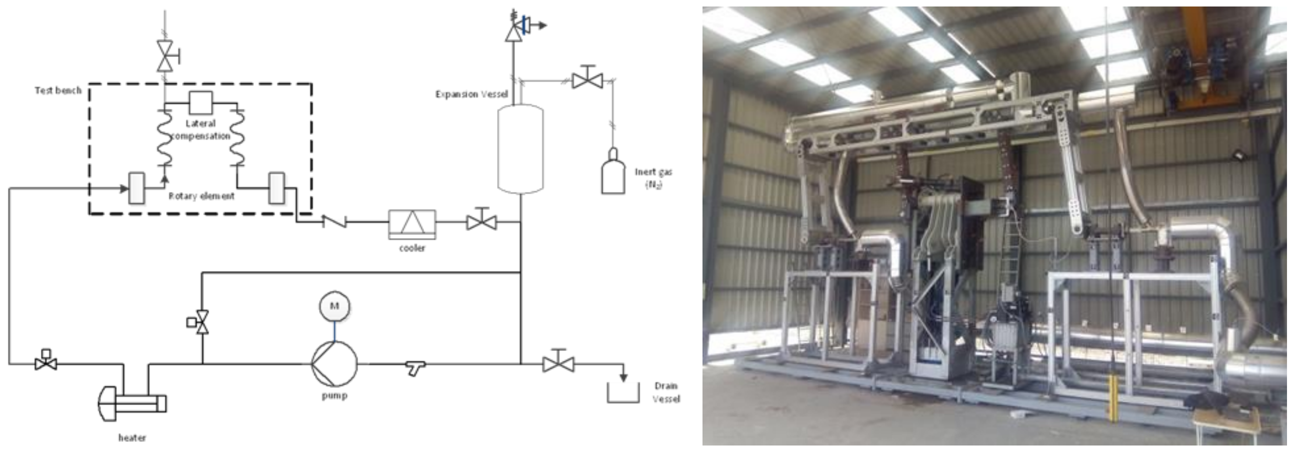
The REPA test facility is the result of merging CIEMAT activities in Task 14.4 of the European project SFERA-II (finished in 2017) and DLR activities within the national German project StaMeP. The facility is now used by CIEMAT-PSA and DLR in the framework of a joint collaboration.

The test bench is divided into two functional sections, the so called kinematics unit, to hold and move the pieces REPAs to be tested, and the balance of plant unit for supplying the conditioned heat transfer fluid (see Figure 15, a).

The balance of plant unit is composed of a variable speed HTF pump which circulates the HTF through a pipe with an adapted electrical heater collar type before passing through REPA to be tested, placed in the kinematics unit. The return line runs directly to the suction side of the pump closing the circuit. The system is connected to an expansion vessel able to compensate the volume difference caused by the density variation of the working fluid when its temperature changes.

The kinematics unit (see Figure 15, b) is prepared to accommodate test samples of ball joints and flexible hoses with varying and adjustable geometries, e.g. focal lengths. It is prepared to accomplish both rotational and translational movements with the following characteristics:

- Drive pylon: modified EuroTrough drive pylon structure
- Rotating angle is 205° and stow position in 25° facing down
- Up to 45° of lateral motion, representing absorber tube thermal expansion
- Prepared for dimensions of new PTC designs (focal lengths from 1m to 2.3m)
- Measurement of the reaction forces and torques of the assemblies under testing



(a) (b)

Figure 15. Schematic diagram of the REPA test loop at PSA (a) and north view of the test facility (b).

2.3 Central Receiver Systems

The PSA has two exceptional facilities for the testing and validation of central receiver technology components and applications. The SSPS-CRS and CESA-1 facilities enable projects to be undertaken and technologies validated in the hundreds of kilowatts range. They are outdoor facilities specially conditioned for scaling and qualifying systems prior to commercial demonstration.

2.3.1 The 6 MWth CESA-1 Plant

The CESA-1 plant (see Figure 16) was inaugurated in May 1983 to demonstrate the feasibility of central receiver solar plants and enable the development of the necessary technology. At present, the CESA-1 plant is a very flexible facility operated for testing subsystems and components such as heliostats, solar receivers, thermal storage, solarized gas turbines, control systems and concentrated high flux solar radiation measurement instrumentation. It is also used for other applications that require high photon concentrations on relatively large surfaces, such as in chemical or high-temperature processes, surface treatment of materials or astrophysics experiments.

Figure 16. The CESA-I facility seen from the North.

Direct solar radiation is collected by the facility's 330 x 250-m south-facing field of 300 39.6-m^2 heliostats distributed in 16 rows. The heliostats have a nominal mean reflectance value of 0.91, the solar tracking error on each axis is 1.2 mrad and the reflected beam image quality is 3 mrad. The CESA-1 facility has the most extensive experience in glass-metal heliostats in the world, with first generation units manufactured by SENER and CASA as well as second generation units with reflective facets manufactured by ASINEL and third generation facets and prototypes developed by CIEMAT and SOLUCAR. In spite of its over 20 years of age, the heliostat field is in good working condition due to a strategic program of continual mirror-facet replacement and drive mechanism maintenance and replacement.

To the north of the CESA-1 solar field are two additional areas used as test platforms for new heliostat prototypes, one located 380 m away from the tower and the other 500 m away from the tower.

The maximum thermal power delivered by the field onto the receiver aperture is 6 MWth at a typical design irradiance of 950 W/m^2, achieving a peak flux of 3.3 MW/m^2. 99% of the power is focused on a 4-m-diameter circle and 90% in a 2.8-m circle.

2.3.2 The SSPS-CRS 2.5 MWth facility

The SSPS-CRS plant was inaugurated as part of the International Energy Agency's SSPS (Small Solar Power Systems) project in September 1981. Originally conceived to demonstrate continuous electricity generation, it initially used a receiver cooled by liquid sodium that also acted as the thermal storage medium. At present, this test facility is mainly devoted to testing small solar receivers in the 200 to 500 kWth capacity range.

The heliostat field is composed of 91 39.3 m^2 first generation units manufactured by Martin-Marietta. A second field north of it has 20 52-m^2 and 65-m^2 second-generation heliostats manufactured by MBB and ASINEL.

Figure 17. Aerial view of the experimental SSPS-CRS facility.

The original SSPS-CRS heliostat field was improved several years ago with the conversion of all of its heliostats into completely autonomous units powered by photovoltaic energy, with centralized control communicated by radio using a concept developed and patented by PSA researchers. This first autonomous heliostat field, which does not require the use of channels or cabling, was made possible by financial assistance from the Spanish Ministry of Science and Technology's PROFIT program.

The nominal average reflectivity value of the field is actually 90%, the solar tracking error is 1.2 mrad per axis and the optical reflected beam quality is 3 mrad. Under typical conditions of 950 W/m^2, total field capacity is 2.5 MWth and its peak flux is 2.5 MW/m^2. 99% of the power is collected in a 2.5-m-diameter circumference and 90% in a 1.8-m circumference. The 43-m-high metal tower has three test platforms. The two first are located at 28 and 26 m and are prepared for testing new receivers for thermochemical applications. The third test platform is at the top of the tower at 43 m, and houses an enclosed room with crane and calorimetric test bed for the evaluation of small atmospheric-pressure volumetric receivers, and solar reactors for hydrogen production. The tower infrastructure is completed with a 4-TN-capacity crane and a 1000-kg-capacity rack elevator.

The SSPS-CRS tower is equipped with a large quantity of auxiliary devices that allow the execution of a wide range of tests in the field of solar thermal chemistry. All test levels have access to pressurized air (29 dm^3/s, 8bar), pure nitrogen supplied by cryogenic plant, where liquid N_2 is stored in a liquid tank with a 6 TN capacity (Fig. 10). This installation is safe and efficient to operate and it is extremely versatile to provide all the possible variants. The proposed plant will be able to provide flow rates from 70 kg/hour to 250 kg/hour with autonomy of several days or even weeks. There also steam generators with capacity of 20 and 60kg/h of steam, cooling water with a capacity of up to 700 kW, demineralized water (ASTM type 2) from a $8m^3$ buffer tank for use in steam generators or directly in the process, and the data network infrastructure consisting of Ethernet cable and optical fibre.

A hybrid heat flux measurement system to measure the incident solar power that is concentrated by the heliostat field is located at the SSPS-CRS tower. This method comprises two measurement systems, one direct and the other indirect. The direct measurement system consists of several heat flux sensors with a 6.32 mm front-face diameter and a response time in microseconds. These micro sensors are placed on a moving bar, which is mounted in front of the reactor window. The indirect measurement system works optically with a calibrated CCD camera that uses a water-cooled heat flux sensor as a reference for converting grey-scale levels into heat flux values.

At 25 m level, a cantilever with heat shield can be used to position a (optical or IR) camera only a few meters from the aperture.

Figure 18. An autonomous heliostat in the CRS field.

2.4 Parabolic DISH Systems

2.4.1 Accelerated ageing test bed and materials durability

This installation consists of 4 parabolic dish units, 3 DISTAL-II type with 50 kW total thermal power and two-axis sun tracking system, and 1 DISTAL-I type with 40 kW total thermal power and one-axis polar solar tracking system. In the 4 dishes, the initial Stirling motors have been replaced by different test platforms to put the materials or prototypes at small scale of high concentration receivers and perform accelerated temperature cycling. With fast focusing and defocusing cycles, the probes placed in the concentrator focus stand a large number of thermal cycles in a short time interval, allowing an accelerated ageing of the material. These platforms can be used for a large variety of applications: materials tests, air-cooled volumetric receivers tests (metal or ceramic), tests of small-size receivers prototypes with or without heat transfer fluid, etc.

The DISTAL-I concentrator (Figure 19) is a 7.5 m diameter parabolic dish, able to collect up to 40 kW_{th} energy, which is applied to the probes to obtain the accelerated ageing. The concentrator is made of a stretched membrane, which maintains the parabolic shape with a small vacuum pump. It has 94% reflectivity and can concentrate the sunlight up to 12,000 times in its 12-cm diameter focus. It has a focal distance of 4.5 meters and polar solar tracking. The three parabolic dishes DISTAL-II (Figure 20) were erected at PSA in 1996 and 1997, using the stretched membrane technology. These parabolic dishes have a diameter slightly larger than the DISTAL-1 above described (8.5 m) and the thermal energy delivered in the focus is 50 kW_{th}. The focal distance is 4.1 m and the maximum concentration is 16000 suns at the focus. These concentrators can be used for any experiment requiring a focus with the characteristics above mentioned (50 kW_{th} maximum and 16,000 suns peak concentration at the focus). The tracking consists in a two-axis azimuth-elevation system.

The test bed for durability and accelerated materials ageing is complemented with the laboratory for the assements of the durability and carachterization of materials under concentrated solar radiation existing at PSA, which is described in the laboratories section of this document (section 3.4), and with the durability and accelerated materials ageing laboratory existing at Madrid (section 3.7).

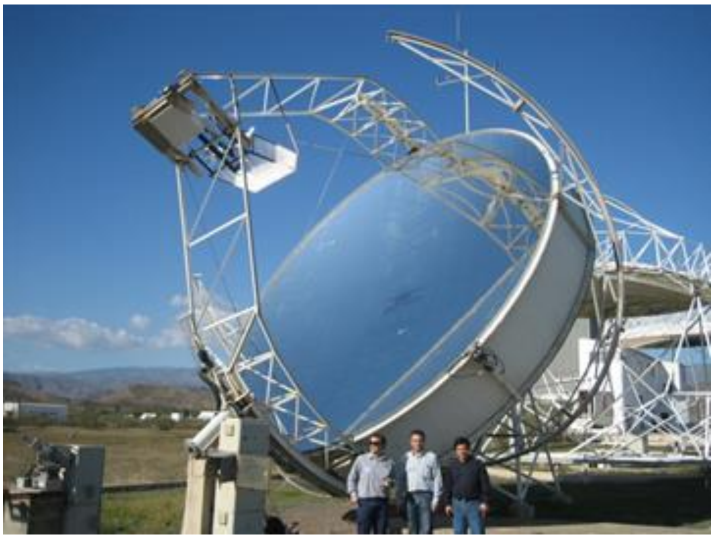


Figure 19. Parabolic-dish DISTAL-I used for accelerated materials ageing at PSA.

Figure 20. View of a parabolic-dish DISTAL- II.

2.4.2 EURODISH

Under the Spanish-German EUROdish Project, two new dish/Stirling prototypes were designed and erected (see Figure 21), discarding the stretched-membrane technology and applying a moulded composite-material system. These parabolic dishes can be used to test new prototypes of Stirling engines, or to perform any other test requiring a focus with 50 kWth maximum and a maximum concentration of 16.000 suns at the focus. The tracking system is azimuth-elevation.

2.5 Installation of Solar Furnaces

2.5.1 SF-60 Solar Furnace

The SF60 consists basically in a 120 m^2 flat heliostat that reflects the solar beam onto a 100 m2 parabolic concentrator which in turn concentrates the incoming rays on the focus of the parabola, where the tested specimens are placed. The incoming light is regulated by a louvered shutter placed between the heliostat and the concentrator. Finally a test table movable on three axis is used to place the specimens in the focus.

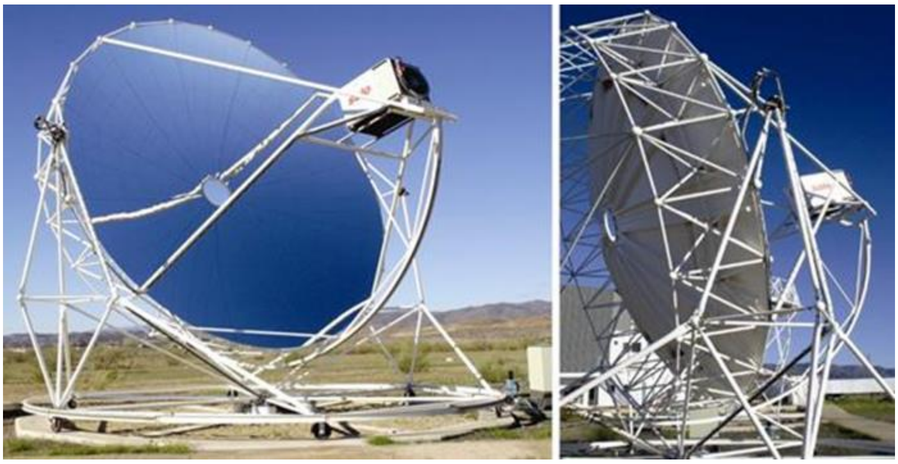


Figure 21. Front and back views of the EURODISH.

In this furnace, the heliostat collects solar radiation and redirects it to the concentrator. The heliostat's reflective surface is made up of flat, non-concentrating facets, which reflect the sun's rays horizontally and parallel to the optical axis of the parabolic-dish concentrator, continuously tracking the sun.

The only heliostat associated with the SF-60 consists of 120 flat facets, with 1 m^2 reflecting surface each. These facets have been designed, manufactured, assembled and aligned by PSA technicians. Every facet is composed of a 1 m^2 reflecting surface and 3 mm thick Rioglass flat mirror silvered on its back (second surface mirror). Solar Furnace Technicians are also responsible of a new method of fixation of the facet on a frame that minimizes deformation of the reflecting surface. Figure 22 and Figure 23 show the heliostat installed in this solar furnace and a detail of the back side of the facet respectively.

Figure 22. HT120 heliostat with new PSA facets.

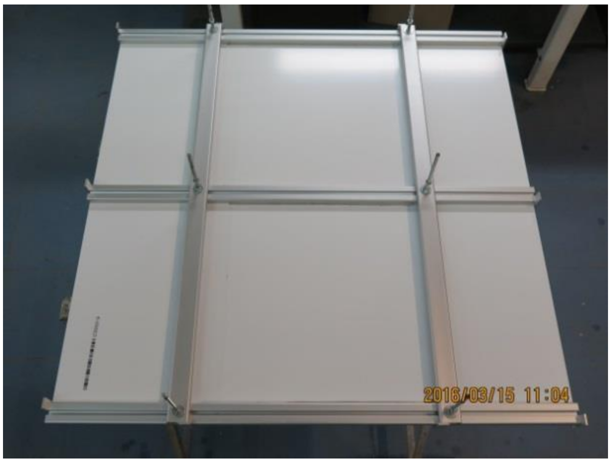


Figure 23. Back side of facet.

The parabolic concentrator is the main feature of this solar furnace. It is made of spherically curved facets distributed along five radii with different curvatures depending on their distance from the focus. It concentrates the incident sunlight from the heliostat, multiplying the radiant energy in the focus.

The shutter (attenuator, see Figure 24) consists of a set of horizontal louvers, which turn on their axis to control the amount of sunlight incident on the concentrator. The total energy in the focus is proportional to the radiation that goes through the shutter.

The test table is a mobile support for the test pieces or prototypes to be tested that is located under the focus of the concentrator. It moves on three axes (X, Y, Z) perpendicular to each other and positions the test sample with great precision in the focal area.

The combination of all of the components described lead to the flux density distribution in the focus which is what characterizes a solar furnace. This distribution usually has a Gaussian geometry and is characterized by a CCD camera hooked up to an image processor and a lambertian target. The characteristics of the focus with 100% aperture and solar radiation of 1000 W/m^2 are: peak flux, 300 W/cm^2, total power, 69 kW, and focal diameter, 26 cm.

Figure 24. HT120 heliostat in tracking.

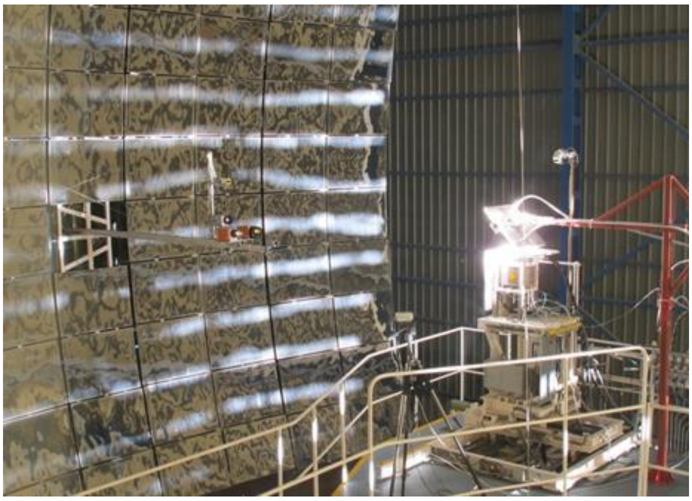


Figure 25. Interior view of the PSA SF-60 Solar Furnace in operation

2.5.2 SF-40 Solar Furnace

The SF-40 furnace consists mainly of an 8.5-m-diameter parabolic-dish, with a focal distance of 4.5 m (see Figure 26). The concentrator surface consists of 12 curved fiberglass petals or sectors covered with 0.8-mm adhesive mirrors on the front. The parabola thus formed is held at the back by a ring spatial structure to give it rigidity and keep it vertical. The new SF40 solar furnace reaches a peak concentration of 5000 suns and has a power of 40 kW, its focus size is 12 cm diameter and rim angle a= 50.3°. Its optical axis is horizontal and it is of the “on-axis” type that is parabolic concentrator, focus and heliostat are aligned on the optical axis of the parabola.

It basically consists of a 100 m^2 reflecting surface flat heliostat, a 56.5 m^2 projecting area parabolic concentrator, slats attenuator, and test table with three axis movement.

The focus of the SF40 is arranged on the vertical plane. In order to work on the horizontal plane, the beam rays incident in focus is rotated 90°, using a tilted, cooled mirror placed at the focal area, which turn the beam to the horizontal plane. The facility is completed with a gas system and vacuum chamber -MiniVac 2-, which allows tests in controlled atmosphere and vacuum, so that the specimens are not oxidized during tests.

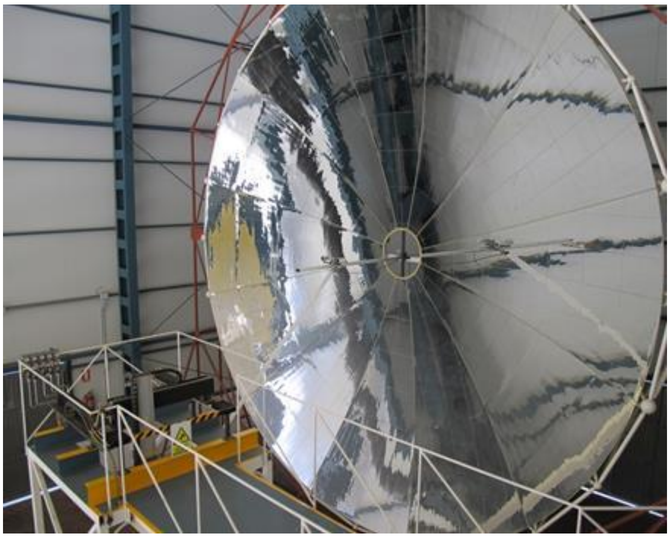


Figure 26. Interior of the SF-40 solar furnace, showing the parabolic concentrator.

2.5.3 SF-5 Solar Furnace

Designed and built at the PSA, this system is in operation from 2012 and is focused to tests that require high radiant flux, strong gradients and very high temperatures.

It is called SF5 -Solar Furnace 5, by its 5 kW power-, reaches concentrations above 7000 suns, its focus diameter is 2.5 cm, and is mainly devoted to heat treatment of materials at high temperature, under vacuum and controlled atmosphere conditions, for which a vacuum chamber, called Spherical Chamber, provided with a gas system are used.

It differs substantially from that existing PSA Solar Furnace SF60 and most operating solar furnaces, as it operates in a vertical axis, i.e., parabolic concentrator and heliostat are vertically aligned on the optical axis of the paraboloid, while that in most existing solar furnaces, are horizontally aligned. The main advantage of vertical axis solar furnaces is that the focus is arranged in a horizontal plane, so that the samples may be treated on a horizontal surface, just placing them directly in the focus, without a holder, avoiding problems of loss of material by gravity in those tests in which the treatment requires surface melting of the specimens.

It basically consists of a 8.7 m^2 concentrator mirror, placed upside-down with the reflecting surface facing the floor, on a 18 m high metallic tower; in the centre of the base of the tower there is a 100 m^2 flat heliostat, whose centre of rotation is aligned with the optical axis of the concentrator. At the top of the tower, in the test room, and 2 m below the vertex of the concentrator, there is a test table. Finally, under the test table and at floor level of the test room, a louver attenuator is placed.

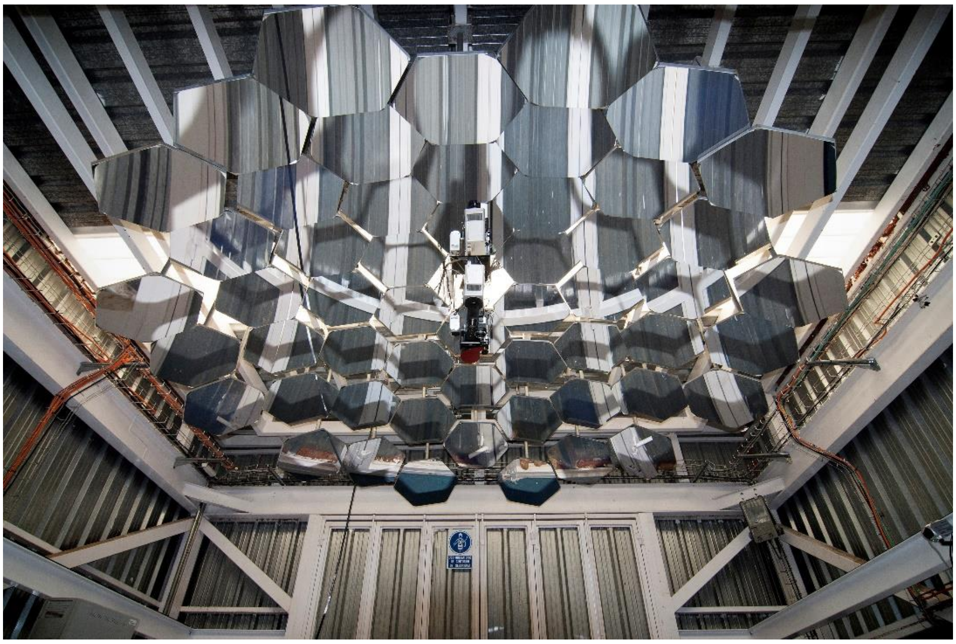


Figure 27. Concentrator of the SF-5 Furnace.

2.6 Thermal Storage Systems

2.6.1 Molten Salt Test Loop for Thermal Energy Systems

This molten salt test loop is a replica of a thermal energy storage system with molten salts and a two-tank configuration. With 40t of molten salts plant, this facility basically consists in:

- Two tanks, one vertical, for hot molten salts, and another horizontal, for cold molten salts.
- A thermal oil loop that can be used for heating the salt up to 380°C and cooling it to 290°C.
- A CO_2-molten salt heat exchanger for heating the salt up to 500°C with CO_2 supplied by parabolic trough collectors.
- Two flanged sections, where different components for this type of loops (e.g. valves, flow meters, heat trace, pumps…) can be tested.

Being a set up which is a reduced scale of a commercial two-tank molten salt storage system, everything related to this type of systems can be tested in this facility. Some applications of this facility are:

- Checking of components (pumps, valves, flowmeters, etc.) for their use in a molten salt medium.
- Optimization of procedures in normal operation for a two-tank system configuration.
- Optimization of procedures in risk situations for a two-tank system configuration. Designing recovery procedures.
- Validation of models and simulation approaches for molten salt thermal systems.
- Characterization of heat exchangers for molten salt/oil.
- Characterization of heat exchangers for molten salt/gas.
- Characterization of thermocline tanks.

Figure 28. Molten Salt Test Loop (MOSA) for Thermal Energy Systems.

2.7 Experimental Solar Desalination Installations

2.7.1 Multi-Effect Distillation Facilities

2.7.1.1 Solar Multi-Effect Distillation Facility

This facility is composed of the following subsystems:

- A 14-stage multi-effect distillation (MED) plant
- A field of stationary large-size flat plate solar collectors
- A water-based solar thermal storage system
- A double effect (LiBr-H_2O) absorption heat pump
- A fire-tube gas boiler

The multi-effect distillation unit is made up of 14 stages or effects, arranged vertically with direct seawater supply to the first effect (forward feed configuration). At a nominal 8 m^3/h feedwater flow rate, the distillate production is 3 m^3/h, and the thermal consumption of the plant is 190 kW_{th}, with a performance ratio (number of kg of distillate produced per 2326 kJ of thermal energy consumed) over 9. The saline concentration of the distillate is around 5 ppm. The nominal temperature gradient between the first cell and the last one is 40°C with a maximum operating temperature of 70°C in the first cell. The system heat transfer fluid is water, which is heated as it flows through the solar collectors and energy collected is then transferred to the storage system. The hot water from this storage system provides the MED plant with the thermal energy required for its operation.

The solar field (AQUASOL-II) is composed of 60 stationary flat plate solar collectors (Wagner LBM 10HTF) with a total aperture area of 606 m^2 and is connected with a thermal storage system (40 m^3)

through a heat exchanger (More details about the solar field are supplied within its specific subsection).

The double effect (LiBr-H_2O) absorption heat pump is connected to the last effect of the MED plant. The low-pressure saturated steam (35°C, 56 mbar abs) generated in this last effect supplies the heat pump evaporator with the thermal energy required at low temperature, which would otherwise be discharged to the environment, cutting in half the thermal energy consumption required by a conventional multi-effect distillation process. The fossil backup system is a propane water-tube boiler that ensures the heat pump operating conditions (saturated steam at 180°C, 10 bar abs), as well as operating the MED plant in the absence of solar radiation.

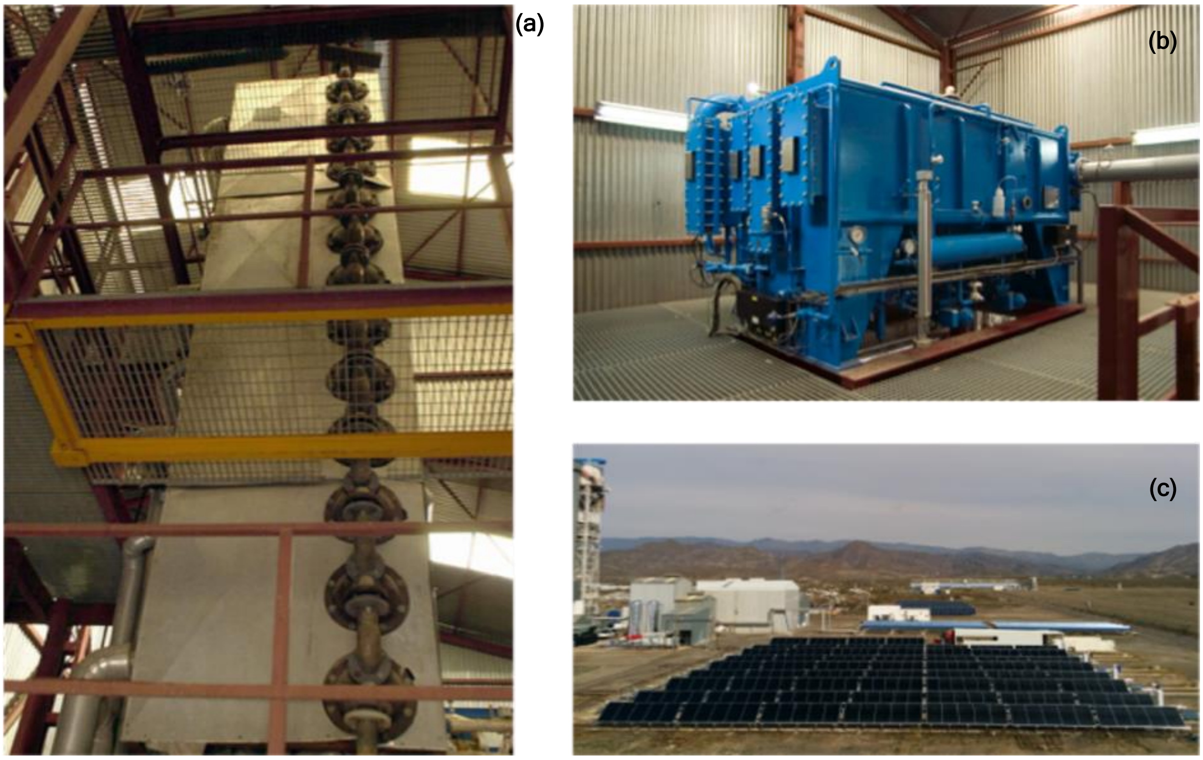


Figure 29. The PSA SOL-14 MED Plant (a), double-effect LiBr-H_2O absorption heat pump (b) and 606-m^2 flat plate solar collector field (c).

2.7.1.2 Test-Bed for Solar Thermal Desalination Applications

The purpose of this facility is the study of the efficiency of large-aperture static solar collectors and its behavior in the coupling with thermal desalination systems minisat 60-90°C temperature levels.

The collector model installed is an LBM 10HTF with an aperture area of 10.1 m^2, manufactured by Wagner & Co. The static solar field is composed of 60 collectors with a total aperture area of 606 m^2 and a total thermal power output of 323 kW_{th} under nominal conditions (efficiency of 59% for 900 W/m^2 global irradiance and 75°C as average collector temperature). It consists of 4 loops with 14 large-aperture flat plate collectors each (two rows connected in series per loop with 7 collectors in parallel per row), and one additional smaller loop with 4 collectors connected in parallel, all of them titled 35° south orientation. Each row has its own filling/emptying system consisting in two water deposits, from which the heat transfer fluid is pumped to the collectors at the beginning of the operation and where all the water volume in the collectors is spilt either at the end of the operation or when a temperature limit is reached (above 100°C). The solar field has flow control valves that allow to have an equal distributed flow rate without further regulation. In addition, the facility has an air cooler that allows the entire energy dissipation from the solar field, which is useful for efficiency tests at different temperature levels. The five loops of collectors are connected with a thermal storage system through a heat exchanger. The thermal storage system consists of two water tanks connected to each other for a total storage capacity of 40 m^3. This volume allows the sufficient operational autonomy for the fossil backup system to reach nominal operating conditions in the desalination plant.

The flexibility of the solar field allows the operation of each loop independently, through their own valves and pumping system. Each loop is connected to an individual heat exchanger that offers the possibility of coupling it with any low-temperature thermal desalination system for testing purposes.

Figure 30. The 606-m^2 large-aperture flat plate solar collector field (AQUASOL-II).

2.7.2 CSP+D test facilities

2.7.2.1 CSP+D Test Bed: Integration of MED Thermal Desalination & Solar Thermal Power Plants

This facility is devoted to the research of the coupling between concentrating solar power (CSP) plants and Desalination (CSP+D). The testing facility is composed of two steam generators (250 kW and 500 kW) fed by thermal oil coming from a parabolic trough solar field able to deliver thermal oil with temperatures up to 400°C and an auxiliary electrical power system that raises the temperature if required. The steam generators are able to produce steam at different pressures, which allow recreating any of the typical intermediate extractions or the exhausted steam available at a turbine of a thermal power plant. The low pressure steam is obtained by making the steam from the generators to flow through two different pipe sections (12-inch diameter) equipped with control valves, which allows achieving saturated steam at two different levels: 0.074 bar/42°C (nominal flow rate of 119 kg/h, maximum flow rate of 360 kg/h) and at 0.16 bar/58°C (nominal flow rate of 195 kg/h, maximum flow rate of 360 kg/h). Both, the high- and low-pressure steam can be used as motive and entrained vapour, respectively, in a train of four steam ejectors coupled to the PSA MED plant, simulating the behaviour of a MED plant working with thermal vapour compression (TVC-MED). The steam ejectors can work in a wide range of pressure conditions for the motive steam (40 - 6 bar; 4 - 2 bar), which also makes this test bed useful for the characterization of such kind of devices. The low-pressure steam can also be condensed through two conventional air condensers without passing by the steam ejectors, with the aim of allowing research in CSP cooling topics. The flexibility of the test facility also allows the on-site evaluation of innovative dry coolers prototypes for their comparison with respect to the conventional air condensers currently available at the market.

(a) (b)

Figure 31. View of the outside of the CSP+D test bed building with the air coolers (a) and partial view of the interior of the CSP+D test bench (b).

2.7.2.2 NEP: The facility for Polygeneration Applications

Polygeneration is an integral process for the purpose of producing two products from one or several resources. In the case of solar energy, it makes use of the thermal energy from a solar field for several simultaneous applications, such as generating electricity, desalting water for drinking water supply and the rest for domestic hot water (DHW).

The purpose of this facility is the preliminary study of the behaviour of a parabolic trough solar field of small concentration ratio, the determination of its feasibility as a heat source in polygeneration schemes, in particular in CSP+D requiring temperatures around 200°C. The collector selected was the Polytrough 1200 prototype by NEP Solar. It has a production of 15.8 kW per module (0.55 kW/m^2) under nominal conditions, with a mean collector temperature of 200°C, and efficiency over 55% in the range of 120-220°C (for 1000 W/m^2 of direct normal irradiance).

The field is configured with eight collectors placed in 4 parallel rows, with 2 collectors in series within each row. This configuration supplies 125 kW of thermal energy. The temperature of the thermal oil can be up to 220°C, so different schemes for making use of the thermal energy for polygeneration can be evaluated.

Currently the solar field is also being used to generate steam for supplying the double-effect absorption heat pump coupled to the PSA MED plant.

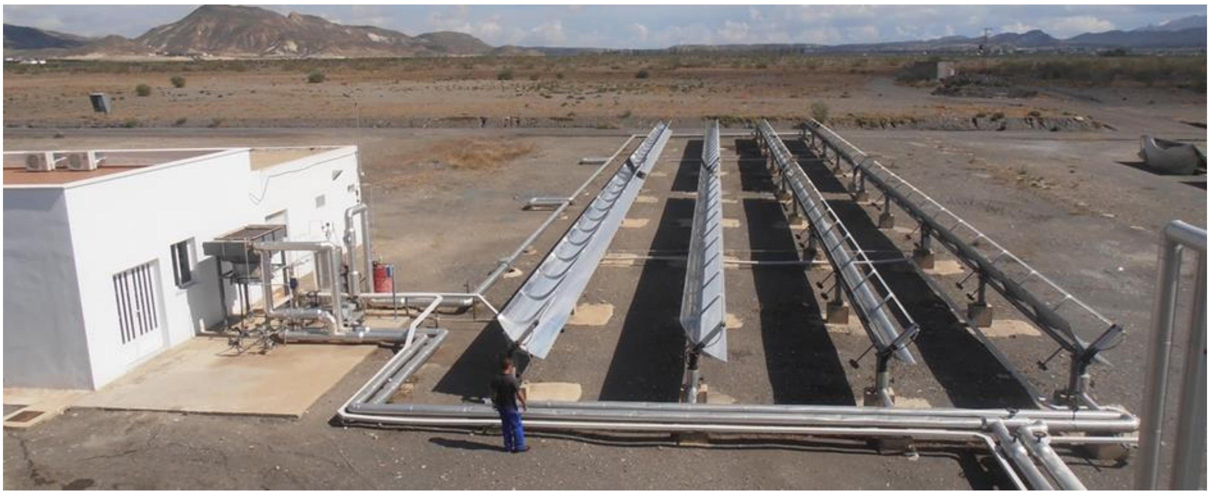


Figure 32. NEP PolyTrough 1200 solar field.

2.7.3 Membrane Desalination Test Facilities

2.7.3.1 Test-Bed for Solar Membrane Distillation Applications at Pilot-Scale

The installation is designed for evaluating solar thermal desalination applications. There are two solar fields of flat-plate collectors available: one of 20 m^2 with two parallel rows of five collectors in series (Solaris CP1 Nova, by Solaris, Spain), and another one of 40 m^2 with four large-aperture collectors in parallel (LBM 10HTF, by Wagner Solar, Spain). Both fields are connected to water storages of 1500 liters acting as heat buffers for thermal regulation and storage, and have a distribution system which enables simultaneous connection of several units. The test-beds allow for a stationary heat supply using the thermal heat storage or for direct supply of solar energy without buffering. The installation is fully automated and monitored (temperatures and flows) and allows for heat flow regulation. The maximum thermal power is 7 kW_{th} in one case and 14 kW_{th} in the other, and hot water can be supplied with temperature up to about 90°C.

The installation has a separate water circuit that can be used for cooling (about 3.5 kW_{th}) in the desalination units and as a device for supplying simulated seawater, with the possibility of working in open or closed loop. In the latter case, both the distillate and brine flows are collected and mixed together to be fed again into the desalination units after passing through a heat dissipation system. The installation currently operates with Membrane Distillation modules and has a wide range of different commercial and pre-commercial units from different commercial manufacturers. The list of MD modules that have been evaluated or are under evaluation is:

1) Plate and frame air-gap (AG) MD commercial modules from Scarab (total membrane area 2.8 m^2).

2) Two plate and frame permeate-gap (PG) MD prototypes from Keppel Seghers (both with total membrane area 9 m^2), a compact one (M33) and another which is split in three separate modules connected in series for higher energy recovery (PT5).

3) Spiral-wound PGMD commercial modules Oryx 150 from Solar Spring (10 m^2).

4) Two spiral-wound AGMD modules from Aquastill with membrane areas of 7 m^2 and 24 m^2 each.

5) WTS-40A and WTS-40B units from Aquaver, based on multi-effect vacuum membrane distillation technology using modules fabricated by Memsys (5.76 m^2 and 6.4 m^2 total membrane area respectively).

(a) (b)

Figure 33. Internal (a) and external (b) views of the Membrane Distillation experimental test bed within the PSA low-temperature solar thermal desalination facility.

2.7.3.2 Bench-Scale Unit for Testing Membrane Distillation applications in Air-Gap, Permeate-Gap and Direct Contact Configurations

The installation consists of a test-bed with a small plate and frame module (Figure 34)that can be used for evaluating direct-contact, air-gap or permeate-gap membrane distillation. The module is made of polypropylene and designed so that the membrane can be replaced very easily. The module has a condensation plate on the cold side to operate on air-gap configuration, but it can be closed at the bottom to operate on permeate-gap keeping the distillate inside the gap or spared to operate on direct-contact mode. The effective membrane surface is 250 cm^2.

The installation has two separate hydraulic circuits, one on the hot side and another on the cold side. On the hot side, there is a tank of 80 liters equipped with an electric heater (3 kW) controlled by a thermostat (90°C maximum), and circulation is made from the storage and the feed side of the module by a centrifugal pump. On the cold side there is a chiller (800 W at 20°C) controlled by temperature and water is circulated between a cold storage of 80 liters and the module. The circuit is heat insulated and fully monitored for temperature, flow rate and pressure sensors, connected to a SCADA system.

2.7.3.3 *Bench-Scale Unit for Flat Sheet Membrane Distillation Testing*

The facility is a high precision laboratory grade research equipment (Figure 35) designed for testing fundamental and feasibility test trials on membrane distillation. It possesses the following unique features that are essential for representative and scalable results:

1) Cell format with representative flow distribution. The cell size is sufficient for flow distribution and regime to be applicable to full-scale MD technology.
2) Adjustable MD channel configuration to all channel variants (PGMD, AGMD, DCMD, VMD, VAGMD).
3) Temperature precision of 0.5°C.
4) Driving force temperature difference controllable.
5) Fully automated control system and large range of possible parameter settings by touch screen PLC.
6) Practical A4 format for membrane and condenser foil materials.

Figure 34. Bench-scale unit for testing membranes on isobaric MD.

Figure 35. Bench-scale unit for testing MD with flat-sheet membranes.

2.7.3.4 *Bench-Scale Unit for Tests with 2-stage Forward Osmosis and Pressure-Retarded Osmosis*

The installation consists of a test-bed with two small plate and frame modules of forward osmosis (FO) which can be connected in series or in parallel. There is, therefore, one pump for the draw solution and two for the feed solution, each with variable flow and flow-rate measurements. The hydraulic circuit has been modified so that the modules can be operated in pressure retarded osmosis (PRO) mode. For that purpose, steel pipes and a high-pressure pump (3 L/min; up to 17 bar) are installed in the draw side, and cells with operational pressure up to 15 bar are used. The cells have each a total effective membrane area of 100 cm^2, and hydraulic channels in zig-zag 4 mm wide and 2 mm deep. The system uses one container for the draw solution and two for the feed solutions, each placed on a balance in order to measure changes in the mass flow rates of the draw solution and the feed solution of each cell. The containers have an automatic dosing system to keep the salinities constant. The system has two conductivity meters for low salinity and one for high salinity, as well as pressure gauges in each line and temperature readings.

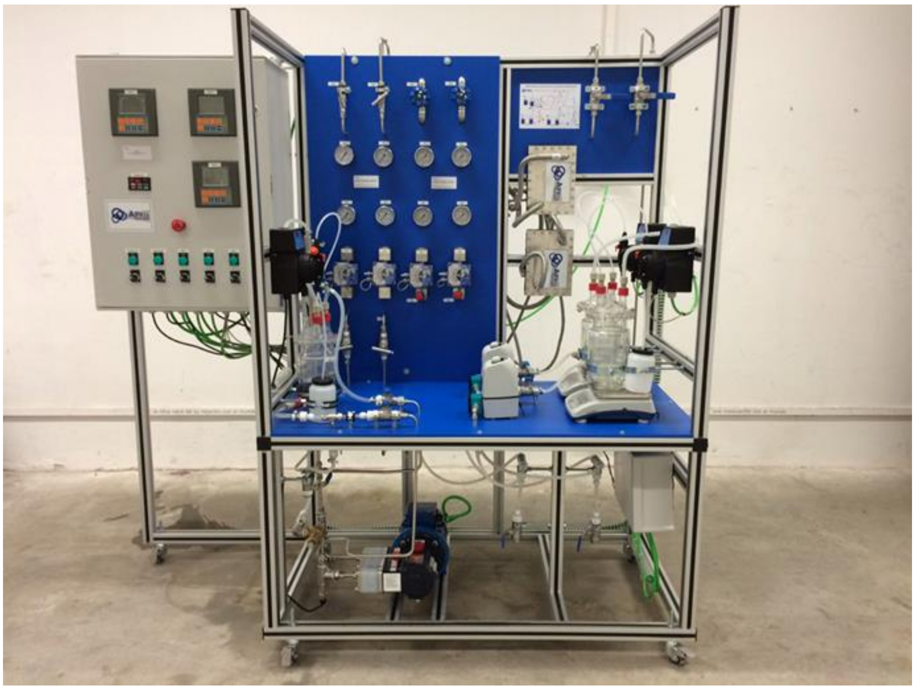


Figure 36. Bench-scale unit for testing FO and PRO.

2.7.3.5 Pilot Plant for Studying Combinations of Forward Osmosis and Reverse Osmosis

The plant has three different units that can be coupled in different ways between them: (i) a forward osmosis; (ii) reverse osmosis; (iii) microfiltration. The forward osmosis (FO) unit uses a 4” spiral-wound Cellulose Triacetate (CTA) membrane with eleven membrane leaves of 1.5 m^2 surface each, supplied by HTI. The nominal flow rate is 3.6 m^3/h. The reverse osmosis (RO) unit has 4 vessels that can be connected in series or in parallel, each of which hosting 4 membranes. The nominal flow rate is 3 m^3/h, and the pumping system is able to work at different pressures up to a maximum of 80 bar. The unit is designed so that SWRO, BWRO or NF membranes can be used. Finally, there is a MF unit with 3 m^3/h nominal flow rate. The installation is completely monitored with pressure sensors, conductivity- and flow-meters, and is designed in a flexible way regarding the interconnection of the units, so that FO can be used as a pre-treatment for RO, or NF can be used in combination with FO, and even the FO can be used in PRO mode using the pumping system of the RO unit.

Figure 37. Test bed for FO-RO combination research.

2.8 Experimental Solar Detoxification and Disinfection Installations

The main facilities related with solar water purification are listed and described below:

- Solar CPC (compound parabolic collector) pilot plants.
- Solar simulators.
- Pilot plants for biological treatment.
- Ozonation pilot plant.
- Nanofiltration pilot plant.
- UVC-pilot plant.
- Test facility for photocatalytic production of hydrogen based on solar energy.
- Wet Air oxidation pilot plant.
- Experimental culture camera.

2.8.1 Solar CPC pilot plants

Since 1994 several CPC pilot plants have been installed at PSA facilities (Figure 38). Basically, the solar pilot plants are built by modules which can be connected in series. Each module consists of a number of photo-reactors placed on the focus of an anodized aluminum mirror with Compound Parabollic Collector (CPC) shape to optimize solar photons collection in the photo-reactor tube. The modules are place on a platform titled at 37° from the horizontal to maximize the global solar collection of photons through the year. In addition, the pilot plants may be equipped with added systems for different purposes, for example: sedimentation tanks (for catalyst recovery), heating and cooling systems for temperature control during the experiments, coupling with other treatment technologies like bio-treatment, ozonation, etc. A summarize of the already installed solar CPC reactors is shown in Table 1.

Table 1. Summarize of CPC pilot plants at PSA facilities.

Year	CPC (m^2)	Total/illuminated volume (L)	Flow or static	Tube diameter (mm)	Added systems/Characteristics
1994	3x3	250/108	Flow	50	
2002	15	300	Flow	32	
2004 (CADOX)	4	75/40	Flow	50	- 50L ozonation system - Biological water treatment system - Monitoring (pH, T, ORP, O_2, flow rate, H_2O_2, O_3), control (pH, T, flow rate)
2007 (SOLEX)	3.08(x2)	40/22	Flow	32	- Twin prototypes - Plexiglass screen - Monitoring dissolved O_2 and temperature - Specially developed for photo-Fenton applications
2008 (FIT)	4.5	60/45	Flow	50	- Monitoring (pH, T, O_2, flow rate) and control (T (20-55°C), flow rate). - 100 L sedimentation tank for catalyst separation
2010 (FIT-2)	4.5	60/45	Flow	50	- -Monitoring (pH, T, O_2, flow rate) and control (T (20-55°C), O_2, flow rate) - -Sedimentation tank
2011 (HIDRO-CPC)	2.1	25/14.24	Flow	32	- -Coupled with H_2 generation pilot plant
2011 (CPC25)	1	25/11.25	Flow	50	
2013 (ELECTROX)	2	40/25	Flow	50	- Coupled with electro-photo-Fenton plant
2013 (NOVO75)	2	74/68.2	Flow	75	- Monitoring (pH, T, O_2, flow rate) and control (T, O_2, flow rate)
2013 (CPC25)	1	25/11.25	Flow or static	50	- Variable volume, versatile for different volume of water
2013 (SODIS-CPC)	0.58(x2)	25/25	static	200	- Low cost, no recirculation system
2016 (NOVO 75 V1.0)	2.03 (x2)	34 or 53	Flow or static	75	- Two module of collectors: CPC versus U-mirror type alternatively used - Tubes installed in vertical position - Air injection in tubes - Monitoring (pH, T, O_2, flow rate) and control (T, O_2, flow rate) - - Automatic control system for filling the system accordingly to incident energy - - Solar panel for water heating

As mentioned in table 1, CADOX photoreactor was hooked up to a 50L-ozonation system with an ozone production of up to 15 g O_3/h. It is completely monitored (pH, T, ORP, O_2, flow rate, H_2O_2, O_3) and controlled (pH, T, flow rate) by computer. Besides, and connected to this photo-reactor, there is a biological water treatment system consisting of three tanks: a 165 L conical tank for wastewater conditioning before treatment, a 100 L conical recirculation tank and a 170 L flat-bottom fixed-bed aerobic biological reactor. The fixed-bed reactor is filled with Pall®Ring polypropylene supports that take up 90-95 L and can be colonized by active sludge from a MWWTP.

(a)

(b)

Figure 38. View of several CPC photo-reactors for purification of water. a) CPC facilities I, b) CPC facilities II.

A 2m^2 CPC collector with 10 borosilicate glass tubes (50 mm diameter), illuminated volume of 25 L and a total volume of 40 L is connected to four electrocells for experimental research on electro-photo-Fenton processes for decontamination and disinfection of water.

In 2016, a new pilot plant with two modules of 2 m^2-collectors with different mirror shape (CPC and U mirror type) has been installed at PSA (Figure 40). It is composed by a feeding polypropylene tank of 192 L of total volume and a preparation tank of 92.5 L, connected by gravity to the CPC and U type photoreactors. The last presents 1.98 m^2 of irradiated surface with a recommended operating volume of 53 L. The whole pilot plant is equipped and automatically controlled by a UVA solar sensor. In addition, the pilot plant is equipped with a solar water heating panel which permits to increase the temperature of water prior to discharge it in the photoreactors.

Figure 39. Electro-Fenton pilot plant coupled with a 2 m^2 CPC (ELECTROX).

Figure 40. View of new CPC and U-type photoreactors (NOVA 75 V 1.0).

2.8.2 Solar simulators

Along with these pilot-plant facilities, there are two solar simulators provided with xenon lamps for small-scale water decontamination and disinfection experiments. In both systems, the radiation intensity can be modified and monitored. One of the solar simulator XLS+ contains a UV filter (Suprax) with wavelength limitation to 290 nm simulating external solar radiation. Temperature can be also modified and controlled in both systems by a cooling system (SUNCOOL) (Figure 41).

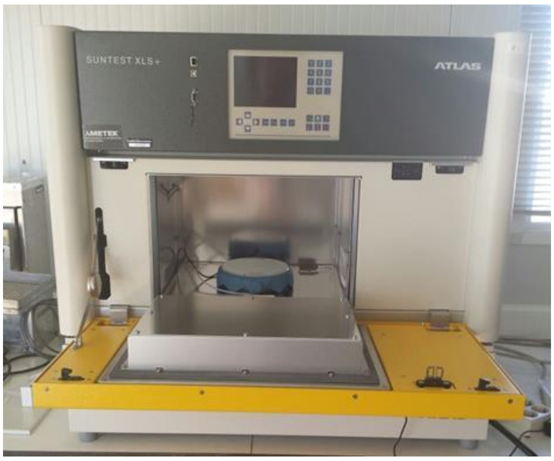


Figure 41. Solar simulator SUNTEST XLS+.

2.8.3 Ozonation pilot plant

The ozonation system has a contact column reactor with total volume of 20L (minimum operation volume of 8L), reagents dosing system and pH automatic control. The pilot plant is equipped with pH and redox sensors, inserted in the recirculation line. In 2016, new instrumentation has been added to the ozonation pilot plant: (i) equipment for humidity elimination in the ozone gas outlet (Figure 42.a); (ii) Thermo-catalytic ozone destructor (Figure 42.b); (iii) dissolved ozone sensor (Figure 42.c). This ozonation system works in batch mode allowing its combination with other technologies such as CPC photoreactors and the UV pilot plant.

(a) (b) (c)

Figure 42. a) Equipment for humidity elimination in ozone gas outlet; b) Thermo-catalytic ozone destructor; (c) Dissolved ozone sensor.

2.8.4 Nanofiltration pilot plant

The nanofiltration (NF) system has two working modes, in series and in parallel. The basic system consisted of two FILMTEC NF90-2540 membranes, connected in parallel, with a total surface area of 5.2 m^2. These polyamide thin-film composite membranes work at a maximum temperature of 45°C, a maximum pressure of 41 bar and a maximum flow rate of 1.4 $m^3\ h^{-1}$, whereas operation pH range is 2-11. A third membrane was installed later and so the filtration total surface area was increased to 7.8 m^2. pH control permits the cleanings and to evaluate the separation of different compounds in the membranes depending on the pH value. A dosing pump is also included for studying the effect of biocide addition. It has a feeding tank of 400 L (Figure 43.a). In 2016 the nanofiltration system has been automatized by including electro-valves and automatic acquisition of the signals from the different instruments (flow, pressure, temperature, etc.) with the final aim of controlling by a computer (software Labview was employed, Figure 43.b) the generation of permeate and concentrate flow rates.

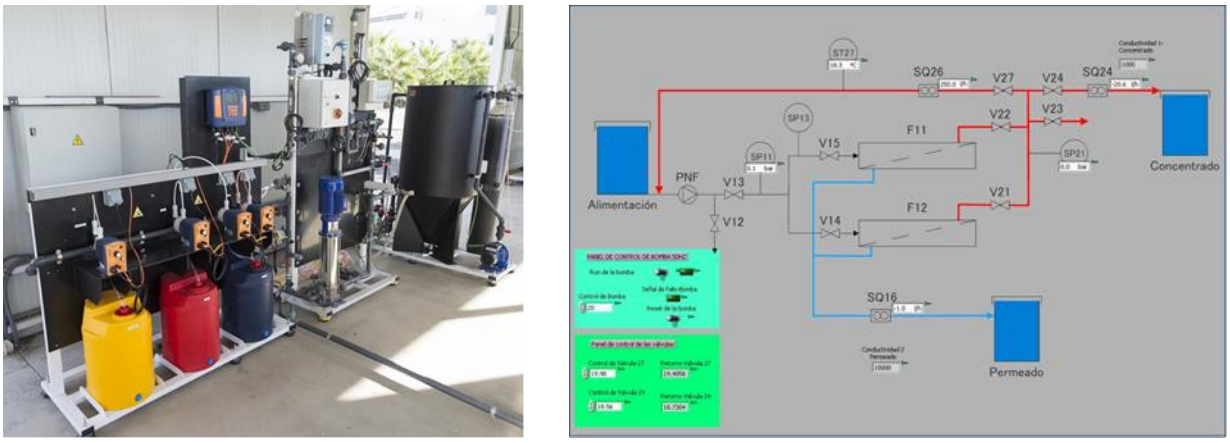


Figure 43. a) Nanofiltration pilot plant photo; b) New lavbiew interface for control and automatic operation of the pilot plant.

2.8.5 UVC-H_2O_2 pilot plant

Ultraviolet (UV) pilot plant was designed to treat and disinfect water for purposes and research and comparison with the solar technologies. This plant consists of three UV-C lamps (max. flow rate 25 m^3 h^{-1}, 254 nm peak wavelength, 400 Jm^{-2} max. power) connected in series, with the flexible configurations for single lamp, two or three lamps in recirculating batch mode or continuous flow mode. Lamps power and flow rate can be regulated according to the needs of the water. Furthermore, the plant is equipped with a dosage system of reactants (acid, base and hydrogen peroxide). The total volume per batch of this plant is 200-250 L, with illuminated volume of 5.5 L per lamp module. The system is equipped with pH and dissolved oxygen sensors in-line and connected to a PROMINENT controller for automatic data acquisition of both parameters (Figure 44).

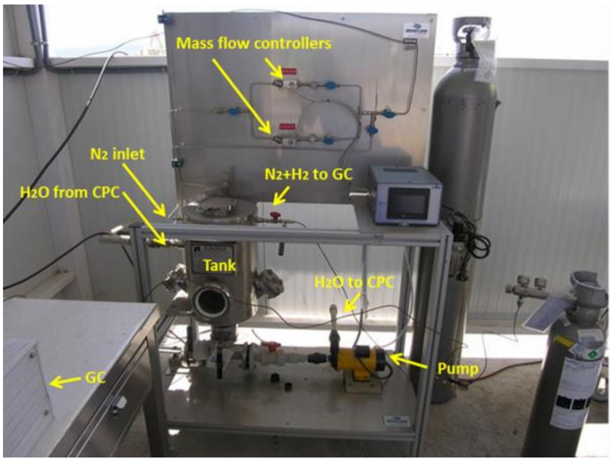
Figure 44. VC pilot plant installed at PSA facilities.

2.8.6 Biological pilot plant

A biological pilot plant with a double depuration system (Figure 45.a) has an Immobilized Biomass Reactor (IBR) system with a total volume of 60-L: three IBRs of 20-L each one; and a Sequencing Batch Reactor (SBR) system: two SBRs 20-L each one. These modules use the same reception tank (200L) as well as the pH and oxygen dissolved control systems and electronic equipment. In addition, this plant can be operated in continuous or in batch mode. For the batch operation, two conical decantation tanks (40-L) are used. Data acquisition of three MULTIMETERS (M44 CRISON) is done by means of programmable relays and the main parameters are monitored by a SCADA system

2.8.7 Photocatalytic generation of hydrogen pilot plant

This plant is connected to a CPC photo-reactor for the simultaneous removal of organic contaminants contained in aqueous solutions and hydrogen generation. The pilot plant consists on a stainless steel tank with a total volume of 22 L, fitted with gas and liquid inlet and outlet and a sampling port. Two parallel mass flow controllers are used to control the desired N_2 gas flow into the reactor headspace during the filling step. The CPC photo-reactor coupled with this system was described above in table 1 (Figure 45.b).



(a) (b)

Figure 45. a) Biological pilot plant installed at PSA facilities. b) Solar pilot plant for photocatalytic generation of hydrogen.

2.8.8 Wet Air Oxidation pilot plant

A pilot plant designed and installed in 2016 as a harsh pre-treatment to reduce the complexity of industrial effluents and reaction time of a subsequent solar advanced oxidation process (AOP). This pilot plant operation allows different combinations of temperature and pressure, various proportions of oxygen and nitrogen, oxidants as peroxide and peroxymonosulfate before heating and/or pressurized the system, and the use of different metallic salts as catalyst. The Wet Air Oxidation pilot plant consists of a stainless steel reactor with a total volume of 1000 mL, a magnetic stirrer, a breakup disk, liquid reagents injector prepared to operate under 200 bar and a maximum temperature of 300°C, thermo-probe, pressure sensor (until 250 bar) and a cooling-heating jacket, all made of stainless steel. The Wet Air Oxidation pilot plant includes an automatic system of control and data acquisition of diverse parameters such as pressure, temperature, reagents dosses and mixture.

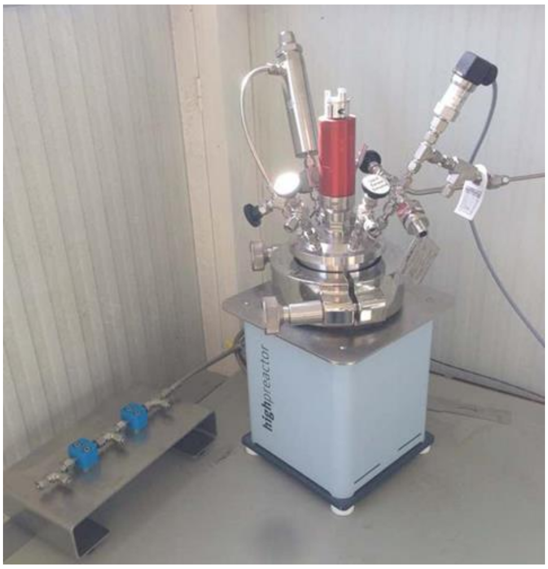


Figure 46. Wet Air Oxidation Pilot plant.

2.8.9 Solar UVA monitoring equipment

UV and global solar radiation data monitoring and storage system is composed by different pyranometers (Figure 47), including global solar radiation in the range of 310 – 2800 nm (Kipp and Zonen CMP-6 with sensitivity 5 – 20 V W^{-1} m^{-2}, max. value: 2000 W m^{-2}), and the global UVA radiation in the range 300 – 400 nm (Kipp and Zonen CUV-5 with sensitivity 1 mV W^{-1} m^{-2}, max. value: 100 W m^{-2}). Besides this, a spectral photometer with double channel was installed to monitor the solar spectral irradiance at the location of the solar tests. This equipment (AVANTES) has UVA sensors and filters to measure in the whole spectral range of 200 – 1100 nm.

(a) (b) ©

Figure 47. CUV-5 radiometer (a). View of all solar UV radiometers (inclined and horizontal setup) used in the Solar Water Treatment Unit (b and c).

2.8.10 Cultivation chamber

The culture crop chamber of 30 m^2 is used for treated wastewater re-use experience since 2014 (Figure 48). This controlled chamber is made of polycarbonate of 10 mm thick to avoid ultraviolet radiation supported by white rolled steel (Sendzimir). The shoulder height is 2.5 m with a roof slope of 40%. The camera consists of 4 individual areas of 3x2.5 m^2. Each area is equipped with temperature and humidity sensors, and a cooling and heating system.

Figure 48. Cultivation chamber for wastewater crops irrigation reuse at PSA facilities.

The crop camera is equipped with a global solar radiometer for measuring the incident solar radiation. So, through this probe an opaque plastic cover located on the top of the camera can be automatically fold and re-fold to reduce the incidence of irradiance inside the crop camera. Finally, the roof slope of each area acts as windows which can be automatically opened and closed to favour the airflow inside each area and enhance the efficiency of the temperature control. The measured of sensors (temperature, humidity and solar radiation) and temperature control of each individually area (by the cooling and heating system, windows and top plastic cover) is made using the Ambitrol® software which permits to keep a comfortable temperature for crops approximately to 25°C during the different seasons.

2.9 Experimental Installations for the Evaluation of the Energy Efficiency in Building

The Building Component Energy Test Laboratory (LECE), one of the facilities at the *Plataforma Solar de Almería* (PSA), is part of the Energy Efficiency in Building R&D Unit (UiE3) in the CIEMAT Energy Department's Renewable Energies Division. The UiE3 carries out R&D in integral energy analysis of buildings, integrating passive and active solar thermal systems to reduce the heating and cooling demand. This unit is organised in two lines of research focusing on Energy Analysis in Urban Environments, and Experimental Energy Analysis of Buildings and Building Components. The test facilities described are under the last of these. They integrate several devices with different capabilities as summarised below:

1) Test cells: The LECE has five test cells, each of them made up of a high-thermal-insulation test room and an auxiliary room. The test room's original south wall can be exchanged for a new wall to be tested. This makes experimental characterisation of any conventional or new building envelope possible.

2) PASLINK Test cell: The Spanish PASLINK test cell incorporates the Pseudo-Adiabatic Shell (PAS) Concept. This system detects heat flux through the test cell envelope by means of a thermopile system, and compensates it by a heating foil device. The inner surface in the test room consists of an aluminium sheet which makes it uniform to avoid thermal bridging. It also has a removable roof that enables horizontal components to be tested. The cell is installed on a rotating device for testing in different orientations.

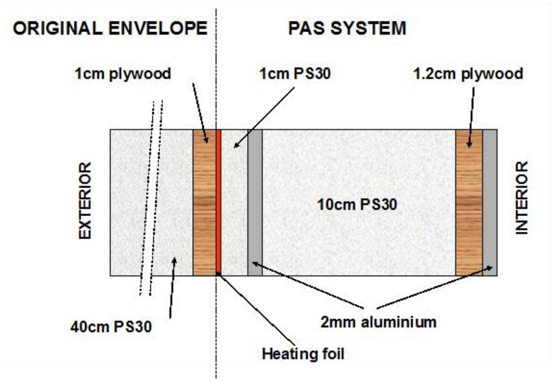
3) CETeB Test cell: This is a new test cell for roofs. The design of this test cell solves some practical aspects related to roof testing, such as accessibility and structural resistance. An underground test room allowing easy access to the test component is used for this.

4) Solar Chimney: This was constructed for empirical modelling experiments and validating theoretical models. Its absorber wall is 4.5 m high, 1.0 m wide and 0.15 m thick, with a 0.3-m-deep air channel and 0.004-m-thick glass cover. A louvered panel in the chimney air outlet protects it from rodents and birds. The air inlet is protected by a plywood box to avoid high turbulences from wind. The inlet air flow is collimated by a laminated array so that the speed component is in the x-direction only.

5) Single-zone building: This is a small 31.83 m^2 by 3.65 m high simple single-zone building built in an area free of other buildings or obstacles around it that could shade it except for a twin building located 2 m from its east wall. Its simplicity facilitates detailed, exhaustive monitoring and setting specific air conditioning sequences that simplify its analysis for in-depth

development and improving energy evaluation methodologies for experimental buildings.

(a)



(b)

(c)

(d)

Figure 49. (a) CIEMAT's PASLINK test cell carrying out a thermal test of a PV module, (b) Schematic drawing of the PAS system, (c) Detail of the rotating device, (d) Exterior of the CETeB Test cell.

6) The PSE ARFRISOL C-DdIs are fully instrumented Energy Research Demonstrator Office Building Prototypes which are in use and monitored continuously by a data acquisition system. The CIEMAT owns 3 of 5 of these "Contenedores Demostradores de Investigación, C-DdIs" (Research Energy Demonstrators Building Prototypes), built under the ARFRISOL Project. Each of them is an office building with approximately 1000 m^2 built area. One of them is also at the PSA and the others in different locations representative of Spanish climates. These C-DdIs are designed to minimize energy consumption by heating and air-conditioning, whilst maintaining optimal comfort levels. They therefore include passive energy saving strategies based on architectural and construction design, have active solar systems that supply most of the energy demand (already low), and finally, conventional auxiliary systems to supply the very low demand that cannot be supplied with solar energy, using renewable energy resources, such as biomass insofar as possible.

These prototypes were built for high-quality measurements recorded during monitoring to support research activities on thermal comfort, building energy evaluation and both active and passive systems integrated in the buildings.

(a) (b) (c)

Figure 50. (a) Solar Chimney. Configuration including Phase Change Material tiles, (b) Reference single-zone building, (c) ARFRISOL Building Prototype in use.

3 Laboratories

3.1 Laboratory for the geometrical characterization of solar concentrators - GeoLab

The concentrators used in solar thermal systems (heliostats, parabolic-trough collectors, parabolic dishes, Fresnel lenses, etc.) require high precision concentration of the solar radiation for it to be suitable and most of it incident on the receiver component (receiver tubes in parabolic-trough collectors, receivers in tower systems, parabolic dishes, Fresnel lenses, etc.). The laboratory of the Concentrating Solar Systems Unit has a specific activity line for the geometric characterization of these concentrators. Photogrammetry is used to quantify the optical quality of:

- Parabolic-trough collector facets
- Parabolic-trough collector modules
- Heliostat facets
- Heliostats
- Fresnel lenses and reflectors
- Parabolic dishes
- Structural frames
- …

Photogrammetry consists of three-dimensional modelling of any object from photographs that capture it from different angles. Based on these photographs, the three-dimensional coordinates (x, y, z) can be calculated for the points of interest on the object being modelled. Photogrammetry modelling is precise up to 1:50000 (precisions on the order of 0.1 mm for parabolic-trough collector facets and 0.6-0.7 mm for 12-m-long parabolic-trough modules).

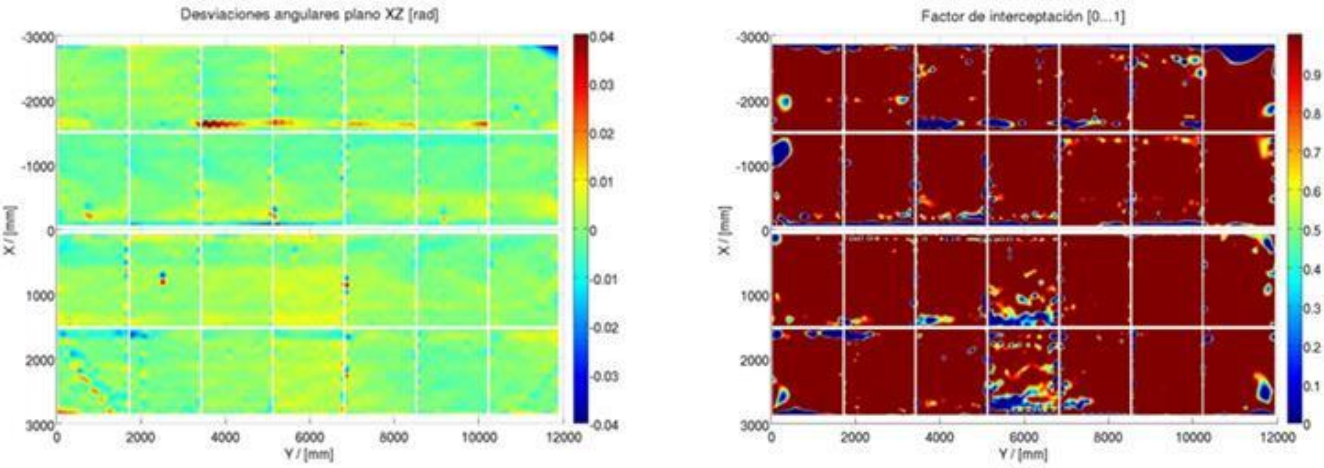
The equipment allocated to this activity at PSA is composed of:

- CANON EOS5D MarkII 22-Mpixel Camera.
- CANON EF 20mm f/2.8 USM and CANON EF 24mm f/2.8 USM lenses.
- Photomodeler Scanner 2017 photogrammetry software.
- LEYCA P20 laser scanner

Additionally, a software package for model analysis and calculation of relevant parameters for 2D and 3D geometries in the MatLab environment has been developed in house.

Among the parameters that can be calculated from the model built by photogrammetry are:

- Deviations of real from theoretical surface on coordinates x, y, z.
- Gravity deformation between different concentrator orientations.
- Angular deviation from the normal vector to the surface compared to the theoretical normal vector.
- Deviation of reflected rays on the reflective surface of the module compared to the theoretical concentrator focus.
- Intercept factor.
- (Calculation of other relevant parameters by request).



(a) (b)

Figure 51. Angular deviations (a) and intercept factor (b) of a parabolic-trough collector module analysed by photogrammetry.

3.2 Laboratory of optical characterization and solar reflector durability analysis - OPAC

The PSA optical characterization and solar reflector durability analysis laboratory, which is the result of a joint collaborative project between CIEMAT and DLR, has the necessary equipment to completely characterize the materials used as reflectors in solar concentrating systems. This laboratory allow the characteristic optical parameters of solar reflectors and their possible deterioration to be determined. The following equipment is available in the laboratory of optical characterization of solar reflectors (see Figure 52 a):

- Three portable specular reflectometers, Devices and Services Model 15R-USB, for measuring specular reflectance at 660 nm at different aperture angles (3.5, 7.5, 12.5 and 23 mrad).
- One portable specular reflectometer, Devices and Services model MWR, for measuring specular reflectance at 460, 550, 650 and 720 nm and at different aperture angles (2.3, 3.5, 7.5, 12.5 and 23 mrad).
- Reflectometer prototype for measuring specular reflectance in a 5 cm diameter with spatial resolution of 10 pixel/mm, which measures at various wavelengths and aperture angles (model SR^2, designed and patented by DLR).
- Perkin Elmer Lambda 1050 spectrophotometer, with 150-mm integrating sphere and specular reflectance accessory with 0 to 68° incidence angles (URA).
- Nikon D3 camera and 90 cm Cubalite kit for photos of specular surfaces without parasitic reflections.
- Zeiss Axio microscope model CSM 700 (with magnifications of 5, 10, 20, 50 and 100) for finding the profiles and roughness of highly reflective surfaces.
- Hitachi S3400 electronic scan microscope (SEM) with EDX analysis.
- Parstat 4000 impedance system to analyse the corrosion of reflector materials.
- General Purpose Optical bench as accessory for the Perkin Elmer Lambda 1050 spectrophotometer with advanced features for mounting optical devices for the development of new measurement instruments.

- Attension Theta 200 Basic tensiometer for static and dynamic contact angle assessment, which is a key parameter to study the performance of the anti-soiling coatings applied to solar reflectors and receiver tubes.

The solar reflector durability analysis laboratory is designed for accelerated ageing tests of these materials with the purpose of predicting in a short time, the behaviour of these materials during their useful lifetime (see Figure 52 b). To do this, the environmental variables producing degradation of solar reflectors when they are exposed to outdoor conditions are applied in a controlled manner, both separately and in combination. The following equipment is available for these accelerated ageing tests:

- ATLAS SC340MH weathering chamber for temperature (from -40 to+120°C), humidity (from 10 to 90%), solar radiation (from 280 to 3000 nm) and rainfall of 340L.
- Vötsch VSC450 salt spray chamber with temperatures from 10 to 50°C (450L).
- Erichsen 608/1000L salt spray chamber with temperatures from 10 to 50°C.
- Two ATLAS UV-Test radiation chambers where UV light (with a peak at 340°nm), condensation and temperature can be applied. One of the chambers also includes rain simulation.
- Hönle UVA Cube Ultraviolet radiation chamber.
- KÖHLER HK300M acid rain chamber, 300 L and temperatures up to 70ºC and humidity up to 100%, to apply the Kesternich test.
- SC100 heatable water bath, to perform the Machu test, according to the Qualitest guideline.
- Vöstch VCC3 0034 weathering chamber to test the material resistance against corrosive gasses (335L, see Fig. X2).
- Ineltec CKEST 300 test chamber for humidity and condensation testing with temperatures up to 70°C (300L).
- Memmert HCP108 weathering chamber to apply humidity (20-95 %) and temperature (20-90°C with humidity and 20-160 °C without humidity).
- Two Nabertherm LT 24/12 and LT 40/12 Muffle Furnaces.
- Control Técnica/ITS GmbH sandstorm chamber with wind speeds up to 30 m/s and dust concentrations up to 2.5 g/m³.
- Erichsen 494 cleaning abrasion device to test the degradation due to the cleaning brushes, with several cleaning accessories.
- Taber 5750 linear abraser to check the materials resistance against the abrasion.
- Lumakin A-29 cross-cut tester to analyze the possible detachment of the paint layers.
- Several devices for thermal cycles specially designed at the PSA.

Along with the equipment installed indoor in the Lab, there are a series of outdoor test benches for exposing materials to outdoor weather conditions and comparing their degradation with those found in the accelerated ageing tests, to study the effectiveness of special coatings, to optimize the cleaning strategy and to analyse the soiling rate. In addition, two heliostat test benches were recently installed, one to test the influence of blocking on the coatings lifetime and another one to accelerate the reflectors degradation due to UV radiation under outdoor weather conditions. Finally, the laboratory is equipped with accessories necessary for their proper use, such as precision scales, thermo magnetic stirrer, drier, ultrasonic bath for sample cleaning, tools for reflector samples preparation (cutting and polishing), safety cabinets, instrumentation for measuring pH, conductivity, oxygen, etc.

(a) (b)

Figure 52. OPAC solar reflector optical characterization lab (a) and durability analysis lab (b)

3.3 Radiometry laboratory – RadLab

The activity line devoted to Radiometry came up of the need to verify measurement of highly important radiometric magnitudes associated with solar concentration. These magnitudes are solar irradiance ("flux" in the jargon of solar concentration) and surface temperature of materials (detection by IR). At the PSA different systems are used to measure high solar irradiances on large surfaces. The basic element in these systems is the radiometer, whose measurement of the power of solar radiation incident on the solar receiver aperture depends on its proper use. The measurement of this magnitude is fundamental for determining the efficiency of receiver prototypes evaluated at the PSA and for defining the design of future central receiver solar power plants. Calibration of radiometers is performed in a specific furnace for this purpose.

Figure 53. View of the PSA Radiometry equipment.

The calibration of the reference radiometer is radiant calibration referenced to blackbody simulators as source standards. The calibration of the reference radiometer is transferred to the commercial sensors by comparison in a calibration furnace that uses a graphite plate that radiates homogenously and symmetrically when an electrical current passes through it. The calibration constant obtained with this method translates voltage to irradiance on the front face of the sensor. The accuracy of gages calibrated in this way is within ±3% with repeatability of ±1%. A black body can be used as a source of thermal radiation for reference and calibration of IR devices (infrared cameras and pyrometers) that use thermal radiation as the means of determining the temperature of a certain surface.

The equipment associated to this activity also includes three black bodies used as references for calibrating IR sensors devoted to temperature measurement with guaranteed traceability between 0 and 1700°C:

- The MIKRON 330 black body is a cylindrical cavity which can provide any temperature from 300 to 1700°C accurate to ±0.25% and a resolution of 1°C. Its emissivity is 0.99 in a 25-mm-diameter aperture.
- The MIKRON M305 black body is a spherical cavity that can supply any temperature between 100 and 1000°C accurate to ±0.25% and with a resolution of 1°C. Its emissivity is 0.995 in a 25-mm-dia. aperture.
- The MIKRON M340 black body is a flat cavity and can provide any temperature from 0 to 150°C accurate to ±0.2°C and a resolution of 0.1°C. Its emissivity is 0.99 in a 51-mm-aperture.

These black bodies have a built-in PID control system and the temperature is checked by a high-precision platinum thermocouple.

Figure 54. IR sensor calibration using a black body.

3.4 Laboratory for the assessment of the durability and characterization of materials under concentrated solar radiation - MaterLab

This activity line of the laboratory is focused on the study and evaluation of how the concentrated solar radiation affects the performance and durability of materials. This is especially important for materials used for central receivers, thus requiring an accelerated ageing to study the durability of the most critical components of solar thermal power plants, not only absorbent materials, but also surface treatment and coatings that increase their absorptance. It is therefore necessary to find out and study the mechanisms of the physical degradation, fatigue and breakage of these materials at high temperatures under concentrated solar radiation.

The equipment associated to this activity is composed of devices located both indoor and outdoor. The indoor devices are devoted to the metallographic preparation and the analysis of test pieces treated with concentrated solar radiation and eventually thermal cycling for accelerated aging, and characterization of solar test by thermogravimetry. These devices are inside the Solar Furnaces control building and located in four rooms, every one of them dedicated to different kind of analyses:

- The Metallography Room
- The Microscopy Room
- The Thermogravimetry Room
- The Thermal Cycling Room

The lab's equipment located in these rooms is listed below:

3.4.1 Metallography Room

- Automatic cut-off machine: Struers Secotom
- Manual cut-off machine: Remet TR60
- Mounting press: Struers Labopres-3
- Vacuum impregnation unit: Struers Epovac
- Polisher: Tegrapol-15 automatic with Tegradoser-5 dosing system
- Metallographic polisher 2 plates: LS1/LS2 (Remet)
- Grinder: Remet SM1000
- Ultrasonic bath: Selecta Ultrasons-H 75°C with heater
- Fume cupboards: Flores Valles VA 120 960 M-010-02
- Power Source programmable: Iso-Tech IPS 405 for electrochemical attack
- Analytical sieve shaker: Retsch AS 200 Control (Sieves: 20, 10, 5, 2.5 y 1.25 mm and 710, 630, 425, 315, 250, 160, 150, 90, 53 y 32 µm)
- Digital Camera with reproduction table

Figure 55. View of the Metallography Room in the Solar Furnaces building

3.4.2 Microscopy Room

- 3D Optical Surface Metrology System: Leica DCM 3D
- Leica DMI 5000 optical microscope with Leyca-IM50 image acquisition system and motorized table.
- Olympus optical microscope Union MC 85647.

- Struers micro hardness tester Duramin HMV-2 with visualization system and software micro Vickers hardness tester HMV-AD 3.12.
- Manual hardness tester
- Surface Finish Measuring Unit ZEISS Surfcom 480 with data processor
- Balance: Mettler E2001/MC max 60 kg
- Balance: Mettler Toledo classic max 320g / min 10mg

(a) (b)

Figure 56. View of a) the Microscopy Room, b) Thermogravimetric balance inside of its Room.

3.4.3 Thermogravimetry Room

- The thermogravimetric Balance SETSYS Evolution18 TGA, DTA, DSC (Temperature range ambient to 1750°C) equipped with a compact recirculating cooler (Julabo FC1600T) and a thermostatic line to 200°C, with a security box for tests in presence of H_2, and adapted to connect a controlled evaporator mixer and a MicroGC simultaneously to the equipment. This thermogravimetic Balance has different possibilities of tests:
  - Tests under pure Hydrogen atmosphere up to 1750°C
  - Tests under pure Oxygen atmosphere
  - Tests under H_2O steam with other gases simultaneously.
  - Tests under corrosive atmosphere up to 1000°C
- CEM System (Controlled evaporator mixer system) for steam supply.
- Fixed Gas Detector: Dräger Polytron SE Ex, with a control system Regard 1.

3.4.4 Thermal Cycling Room

It includes the instrumentation necessary for thermal cycling:

- two muffle furnaces,
- a high-temperature kilns,
- a weathering chamber,
- an air-cooled volumetric receiver test loop and associated instrumentation;
- optical and electronic microscopes,

The indoor devices located in the four rooms described above are complemented by an electronic microscope installed in its own room, which is shared by the AMES and SCS units, and with the following specifications.

- Scanning electronic microscope (SEM) - Hitachi, model S-3400N II, high/low vacuum, secondary electron image, backscattered electron image, cooling stage and magnification 5x to 300.000x.
- Energy dispersive x-ray spectrometer (EDS) Quantax 400

Besides, the SEM room also has environmental secondary electron detector (ESED), a critical point dryer and sputterer.

The outdoor equipment is composed of several solar-dish concentrators located close to the PSA solar furnaces building. These solar dishes are used for thermal cycling under real solar conditions, with very high solar flux (up to 1200 kW/m^2) and high temperatures (from 200°C to 1200°C) and are equipped with different test benches for volumetric and tube configuration testing.

3.5 Receivers testing and characterization for concentrating solar thermal systems - SRTLab

This activity line comprises both linear tube-type receivers and volumetric air receivers. The equipment associated to linear receivers is located at PSA and the two main test devices are: a) a test bench called HEATREC (see Figure 57, a), for measuring heat loss of single receiver tubes under indoor laboratory conditions, and b) an outdoor test bench called RESOL (see Figure 57, b), for measuring optical efficiency of single receiver tubes under natural solar radiation. Heat loss measurements can be done under vacuum conditions to avoid convection outside the glass tube, thus obtaining a more uniform temperature along the receiver section and looking for the heat loss by radiation. In addition, is possible to determine heat loss at different vacuum levels in the space between the metallic absorber tube and the glass envelope. The emissivity of the selective coating can be then inferred from these measures. The optical efficiency test is done by evaluating the slope of the temperature of a fluid (water) circulating inside the receiver tube vs the time during an interval of steady state solar radiation when heat losses are null. The optical efficiency is calculated from an energy balance of the system. The test provides in one measurement the receiver optical efficiency, i.e. the combined value of the absorptance and transmittance of the receiver tube.

(a)

(b)

Figure 57. View of the HEATREC test chamber to measure heat losses in solar receiver tubes (a) and RESOL test bench to measure receiver's optical efficiency (b).

HEATREC device lets to characterize heat losses of receiver tubes with inner diameter greater than 62 mm and tube length lower than 4.5 m. Measurements can be performed for absorber temperature ranging from 100°C to 500°C. The vacuum in the test chamber can be set up to around 10^{-2} mbar. RESOL is currently configured to measure standard receiver tubes for parabolic troughs, i.e. tubes 4060 mm-long and with absorber tube diameter of 70 mm.

Besides HEATREC and RESOL, the activity line devoted to linear receivers is equipped with tools and devices for proper manipulation and monitoring of receiver tubes.

3.6 Advanced Optical Coatings Laboratory - OCTLAB

This laboratory line is devoted to the development and complete study of new selective coatings for absorbent materials used in solar concentrating systems at medium and high temperature (up to 700°C), as well as for anti-reflective treatments for glass covers used in some receiver designs, such as receiver tubes in parabolic-trough collectors. The equipment devoted to this activity line is sufficient to characterize and evaluate coating developments, and to evaluate the behaviour of other treatments available on the market or developed by other public or private institutions. The equipment associated to this line may be also used for optical characterization of solar reflectors, thus complementing the equipment specifically devoted to the activity line devoted to testing and characterization of solar reflectors.

A summary of the equipment available for advanced optical coatings is given below:

- Perkin Elmer LAMBDA 950 Spectrophotometer (Figure 58.a).
- Perkin-Elmer Frontier FTIR spectrophotometer equipped with a gold-coated integrated sphere manufactured by Pike (Figure 58.b)
- *Portable Optosol absorber characterization equipment*: This equipment measures solar absorptance and thermal emittance of selective absorbers at 70°C, both on flat substrates and absorber tubes. The device for measuring absorptance has an integrating sphere with two detectors. For measuring emissivity, it has a semi-cylindrical tunnel which emits infrared radiation at 70°C.
- LEICA DM4 M optical microscopy with image acquisition system and software for image analysis (Figure 58.c).
- QUV weathering chamber, Q-PANEL, for accelerated ageing tests (Figure 58.d).
- BROOKFIELD LVDV-I+ Viscometer.
- BRUKER DektakXT stylus profilometer with optical camera and software for surface analysis (Figure 58.e).
- KSV CAM200 goniometer for measuring contact angles (Figure 58.f).
- Kilns. There are three kilns for thermal treatment:
  - 120x100x300 mm kiln with a maximal temperature of 1200°C.
  - Controlled atmosphere kiln with a maximal temperature of 800°C.
  - 500x400x600 mm forced convection kiln with a maximal temperature of 550°C.

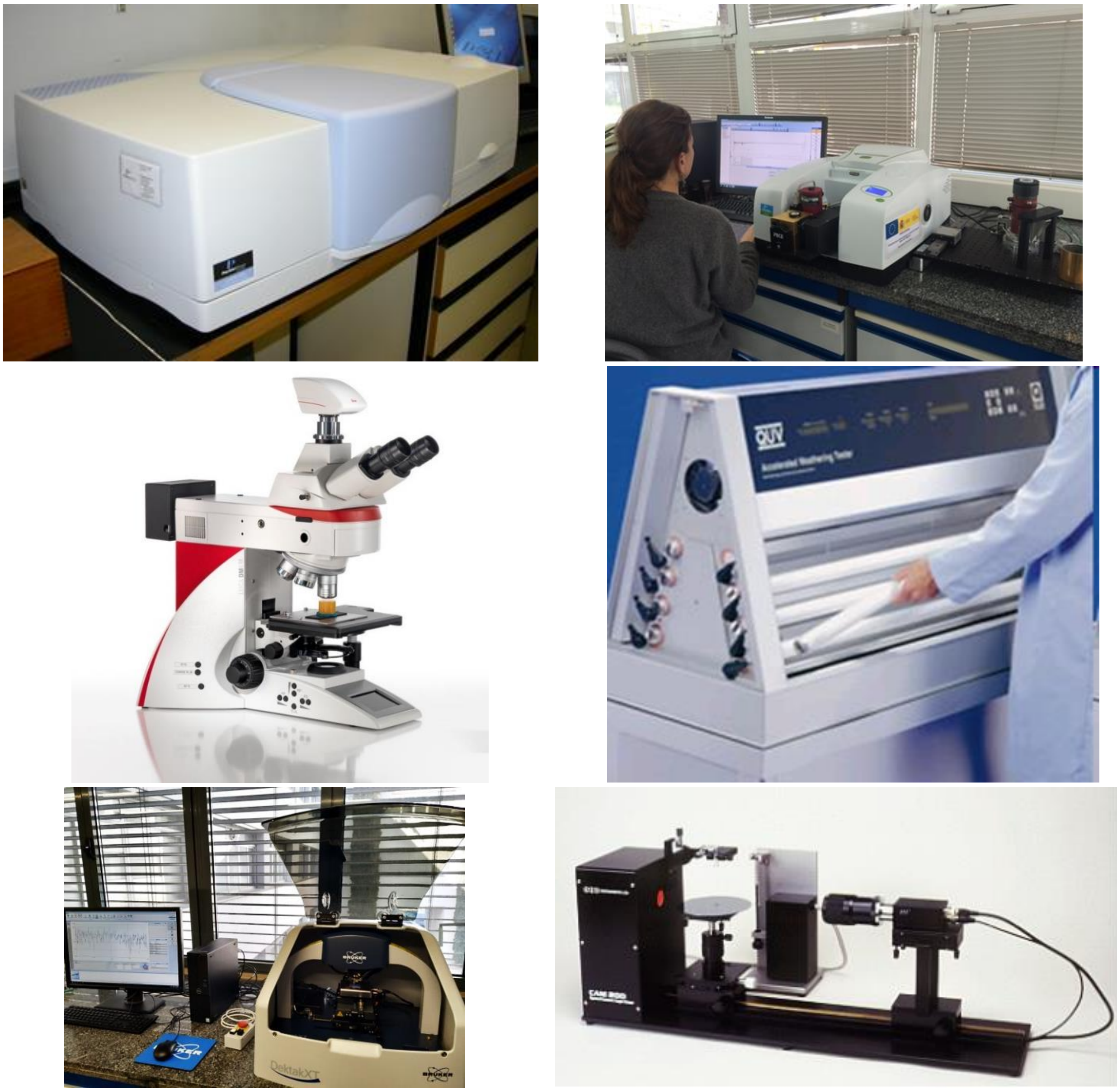


Figure 58. Advanced optical coatings laboratories equipment.

3.7 Porous media laboratory for solar concentrating systems - POMELAB

The porous media laboratory located in CIEMAT-Moncloa (Madrid) comprises three main facilities, and some other techniques for the characterization of porous materials used for central receiver systems with air as heat transfer fluid.

1) Thermal characterization of volumetric absorbers

Its main component is a test bench designed for the thermal test of new volumetric absorbers and configurations and its ageing in steady and dynamic conditions. The main components installed in this test bench (Figure 59) are:

- A 4 kWe solar simulator made up of a Xenon lamp and a parabolic concentrator that can reach fluxes of up to 1500 kW/m^2;

- Receiver sub-system: with 24 K-type thermocouples, 2 surface thermocouples and an infrared camera;
- Helicoidal Air-Water Heat Exchanger sub-system: with 4 PT100 sensors, a water mass flow-rate measurement, a water pump and 2 surface thermocouples; and
- Extraction system: with 1 k-type thermocouple, 1 PT100 sensor, an air mass flow-rate measurement, and an air blower.

This test bench has the flexibility to study the extinction coefficient of different mediums, which can be used as a tool to approximate radiation analysis in semi-transparent mediums following the Bouger's law.

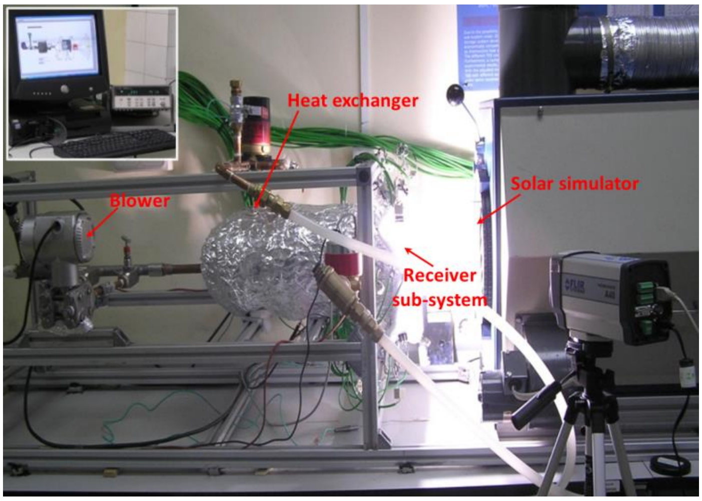


Figure 59. Test bench for volumetric receiver testing.

2) Thermal evaluation of porous beds in regenerative systems

Previous facility is complemented by an indoor facility to study thermal storage materials for high temperature using air as heat transfer fluid. This facility is composed of a thermocline storage test bench of about 0.1 m^3 as experimental loop for static and dynamic thermal characterization of porous beds. The system consists of:

- Six power heating resistor with a total power of 15000 watts electric energy able to heat air up to a target temperature (maximum temperature limited by the resistor is 1000°C) by means of a temperature controller.
- 35 K-type thermocouples units of 400 mm long are used to measure the material temperature. The behaviour of the tank is measured at 7 levels with 5 measurement each level.
- 35 T-type thermocouples units are used to measure the vessel outlet temperature in order to calculate thermal losses to the environment.
- The total power consumption is recorded, with a three-phase electrical measurement, to match the energy balances and the heat losses.

Moreover, the external surface temperature mapping is registered by a thermograph camera, which offers a complete image of the external chassis of the tank.

The two possible configurations of this test bench are (Figure 60):

- Static configuration: the experimental loop allows the characterization of effective thermo-physical parameters of the bed; material thermal conductivity, thermal losses, stored energy, etc. for different filler materials.
- Dynamic configuration: the experimental loop allows an agile characterization of the global storage at different working temperatures, filler materials, charges and discharges strategies, etc.

(a) (b)

Figure 60. Test bench for porous material characterization. Static configuration (a), dynamic configuration (b).

3) Measurement of the pressure drop up to 300°C

This facility measures the pressure difference across porous materials, such as volumetric absorbers or filler materials, for different fluid velocities. Moreover, it is able to measure the pressure difference at ambient temperature and for air temperatures up to 300°C.

Then the main properties described by the Forchheimer extension to Darcy's law are derived: viscous permeability coefficient and, inertial permeability coefficient. The main components are:

- Sodeca Blower with velocity control
- Hastinik ball valve of 1 ½″.
- Airflow anemometer
- Nabertherm heating resistor
- Honeywell pressure difference-meter

Moreover, different techniques have been developed for the evaluation and measurement of several important geometric parameters of porous materials such as the porosity and specific surface area.

Figure 61. Test bench for pressure difference measurement with configuration up to 300°C.

3.8 Laboratory for evaluation of materials and components for molten salt circuits - BES

Molten salts are becoming not only a standard thermal storage medium, but also a working fluid for central receiver solar plants. However, there are still open questions regarding the durability of components and materials currently available at the market for molten salt circuits. Keeping this in mind, a specific activity line was implemented in the laboratory of Concentrating Solar System Unit for this purpose. The equipment associated to this activity is installed indoor at PSA and it is composed of two test benches, BES-I and BES-II (Figure 54) especially designed and manufactured for:

(a) (b)

Figure 62. Test benches BES-I (a) and BES-II (b) for evaluation of molten salt components.

1) The validation and checking of different types of valves for their use in molten salt loops. Various tests can be offered, such as leak test, validity for design conditions test, cold zone test, and packing life test.

2) The validation and checking of different types of pressure transmitters for their use in molten salt loops. Various tests can be offered, such as constant pressure test, and pressure variation test.

3) The validation of other components and auxiliary equipment (heat tracing, insulation, etc.) for their use in molten salt loops. Components with a nominal diameter from 2” up to 6” can be evaluated in these test benches.

These tests are carried out under real working conditions up to 600°C and 40 bar.

3.9 Laboratory for the assessment of materials for thermal storage systems ATYCOS

The performance of phase change materials (PCM) for latent storage is usually evaluated with differential scanning calorimetry (DSC) or T-history techniques. Nevertheless, it is important to check their behaviour under service conditions in order to assure their feasibility as storage media. For this purpose, this laboratory has three set ups: HDR and AgH devices, where the PCM is tested in atmospheric air, and SUBMA where the PCM is tested in inert atmospheres. The main features of these devices are the following:

HDR:

- Small furnace under ambient air atmosphere
- Accurate control of heating/cooling rates
- Sample temperature monitoring
- Allows melting/freezing cycles up to 500ºC
- Subsequent cycles or cycles with stand-by periods
- Sample size: 2-5 g

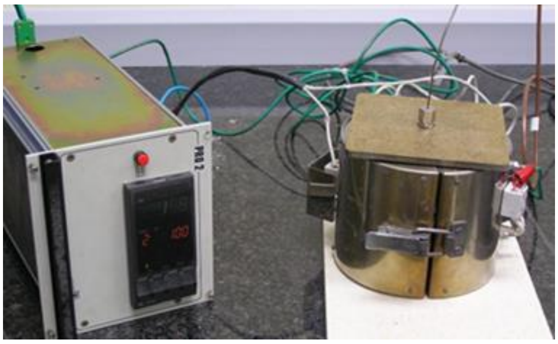


Figure 63. The HDR device.

SUBMA:

- Small closed device inside a furnace
- Allows tests under inert atmosphere (N2, Ar)
- Furnace temperature and gas flow control
- Sample temperature monitoring
- Allows melting/freezing cycles up to 500ºC
- Subsequent cycles or cycles with stand-by periods
- Sample size: 30-40 g

Figure 64. The SUBMA device.

AgH:

Furnace under ambient air atmosphere
Accurate control of heating and cooling
Allows melting/freezing cycles up to 350ºC
Subsequent cycles or cycles with stand-by periods
Sample size: 10-20g

Figure 65. The AgH device.

3.10 Laboratory for the characterization of materials for solar fuel production

Some specific activities are studied at the laboratory of the Solar Fuels Group to support at lab scale the PSA R&D activities related to solar hydrogen. These activities include the following topics: (1) Exploring new materials as candidates for thermochemical cycles and (2) Development of innovative solar reactors as fluidised bed reactors.

In the first category, some specific activities are foreseen, that include new materials that improve kinetics and reduce working temperatures of current materials used in thermochemical cycles. These materials are synthesized in the laboratory (or purchased on the market) and assayed for the thermochemical cycles under different reaction conditions.

For material characterization, a versatile electric furnace loop is available at CIEMAT's Solar Hydrogen Laboratory shown in Figure 66. The laboratory is equipped with the instrumentation necessary for evaluation of innovative processes for hydrogen production. Horizontal tubular furnace: high-temperature kiln with maximum operating temperature of 1600°C suitable for a variety of laboratory and pilot applications; coupled with a gas chromatograph (Varian CP4900) equipped with a molecular sieve column and a TCD detector, etc

Figure 66. Indoor Solar Simulation Loop for evaluation of materials for thermochemical cycles.

Furthermore, in order to qualify these materials, it is of upmost importance to assess the damage induced by thermal shock on consecutive cycles. For this purpose, materials are subjected to cycling heating under well-controlled conditions. Several important physical-thermal, mechanical, and chemical properties of the relevant materials can be identified when assessing the influence of treatments onto a solid substrate.

For special purposes, some other equipments are available to complete the characterization of these materials: A Thermogravimetric Equipment STA 449 F1 for simultaneous TGA-DSC analysis. This equipment has two exchangeable furnaces: a SiC for high temperature reaction (1600°C) and water vapour kiln up to 1200°C. Finally, a temperature furnace perfectly suited for cycling candidate's materials is available. This furnace has special heating elements made of molybdenum disilicide providing temperatures of about 1650°C with a precise temperature control, also in the lower temperature range (Figure 67).

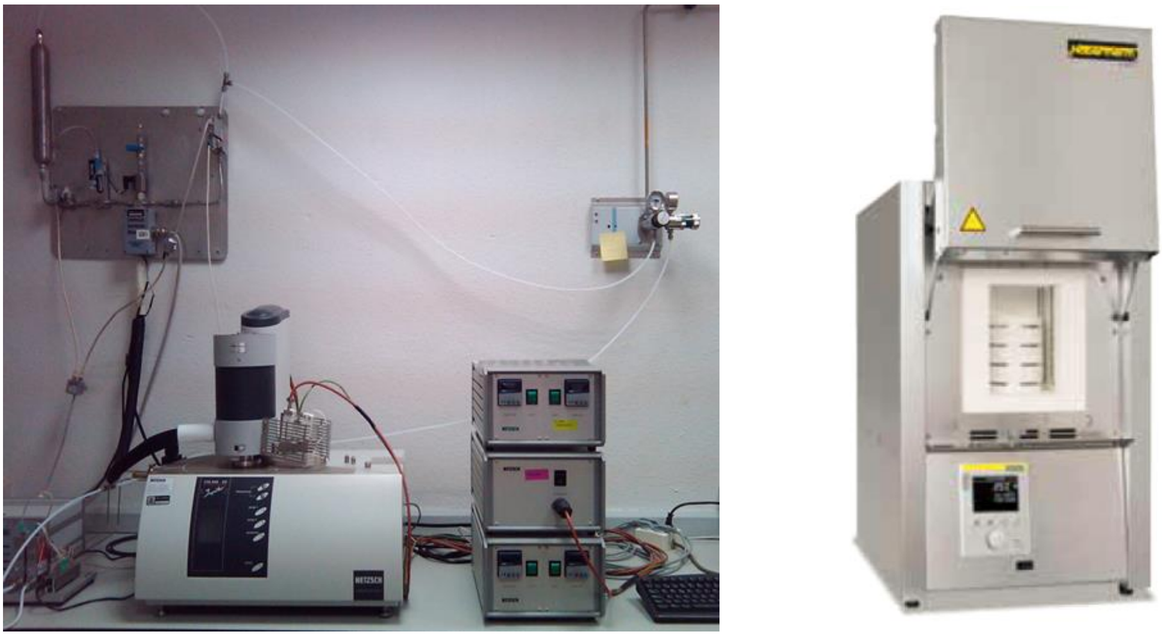


Figure 67. Thermogravimetry analyser and 1,650°C electric furnace.

3.11 Laboratory for qualification of industrial endothermic processes using concentrating solar technologies

For qualification of industrial endothermic processes, a research bench has been designed and assembled. The reactor was designed for operation in the 60kW Solar Furnace at the *Plataforma Solar de Almería* (PSA). Tests are performed pursuing to advance in novel solar reactor concepts through the development of innovative solar reactors as fluidized bed reactors. As the only way to introduce concentrated solar radiation into a low expansion fluidized bed is from the top, a vertical beam must be provided. For the testing device, see Figure 68, this is done with a 45°-tilted, water cooled mirror located close to the focus.

Fluidized beds as chemical reactors present several advantages that include a high rate of heat and mass transfer, low pressure drops, and uniform temperature distribution. This concept is being applied for development and testing of a solar powered fluidized bed reactor for the extraction of oxygen from lunar regolith. This is done by the reduction of one constituent of lunar soil, ilmenite ($FeTiO_3$), with hydrogen, and the subsequent electrolysis of the obtained water.

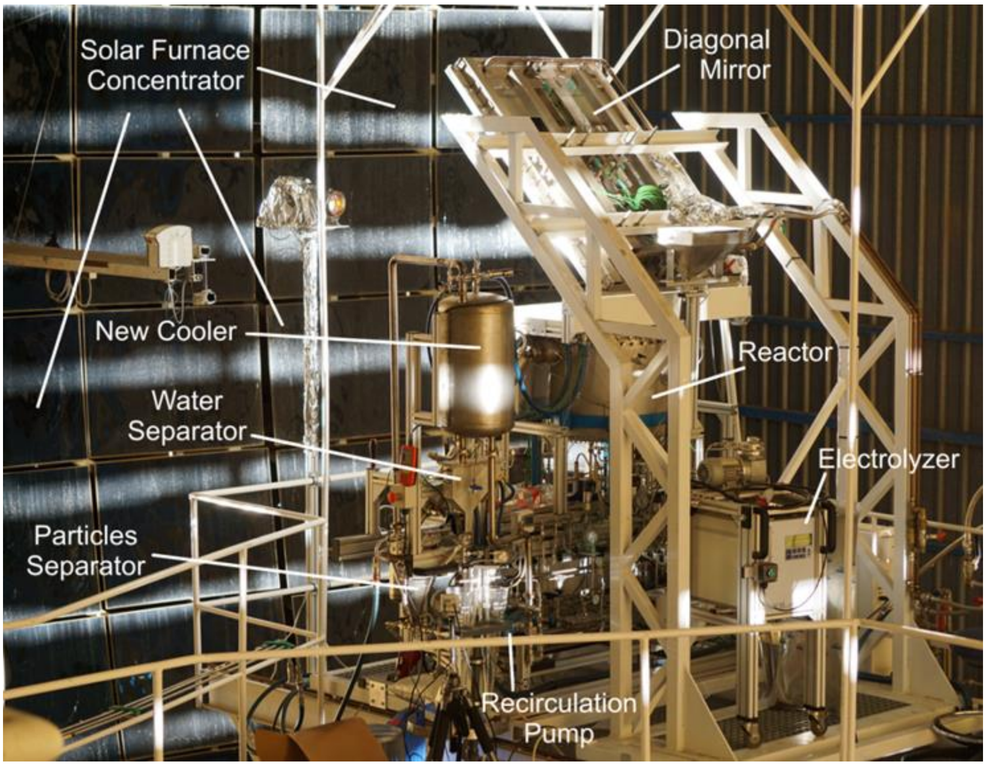


Figure 68. Testing of Alchemist plant in a solar furnace to produce oxygen form regolite.

The general goal for these tests is to improve the understanding of fluidized bed hydrodynamics by completing the following objectives:

- Identify the gas flow demand of the main fluidized bed in the reactor as a function of the temperature.
- Operate the reactor at 900°C solely heated with concentrated solar power.
- Demonstrate water production from the reaction of the ilmenite with hydrogen.

3.12 PSA Water Technologies Laboratory - WATLAB

Within the scope of the SolarNova Project funded by the Ministry of Science and Innovation within the Special State Fund for Dynamization of Economy and Employment (*Fondo Especial del Estado para la Dinamización de la Economía y el Empleo – Plan E*) a new laboratory was built in 2009. Since them, acquisitions of new instrumentation have been done within the SolarNova Project. The PSA water technologies laboratory consists of 200 m^2 distributed in six rooms: two rooms for chemicals and other consumables storage. It is a 30-m^2 storeroom. It is organized on numbered and labelled stainless steel shelving with refrigerators and freezers for samples and standards keeping; ii) A 17-m^2 office with three workstations where visiting researchers can analyse the data from the experiments carried out at the PSA. In addition, 4 technical rooms are also part of the laboratory and are listed and described below:

- General lab
- Chromatography lab
- Microbiology lab
- Microscopy lab

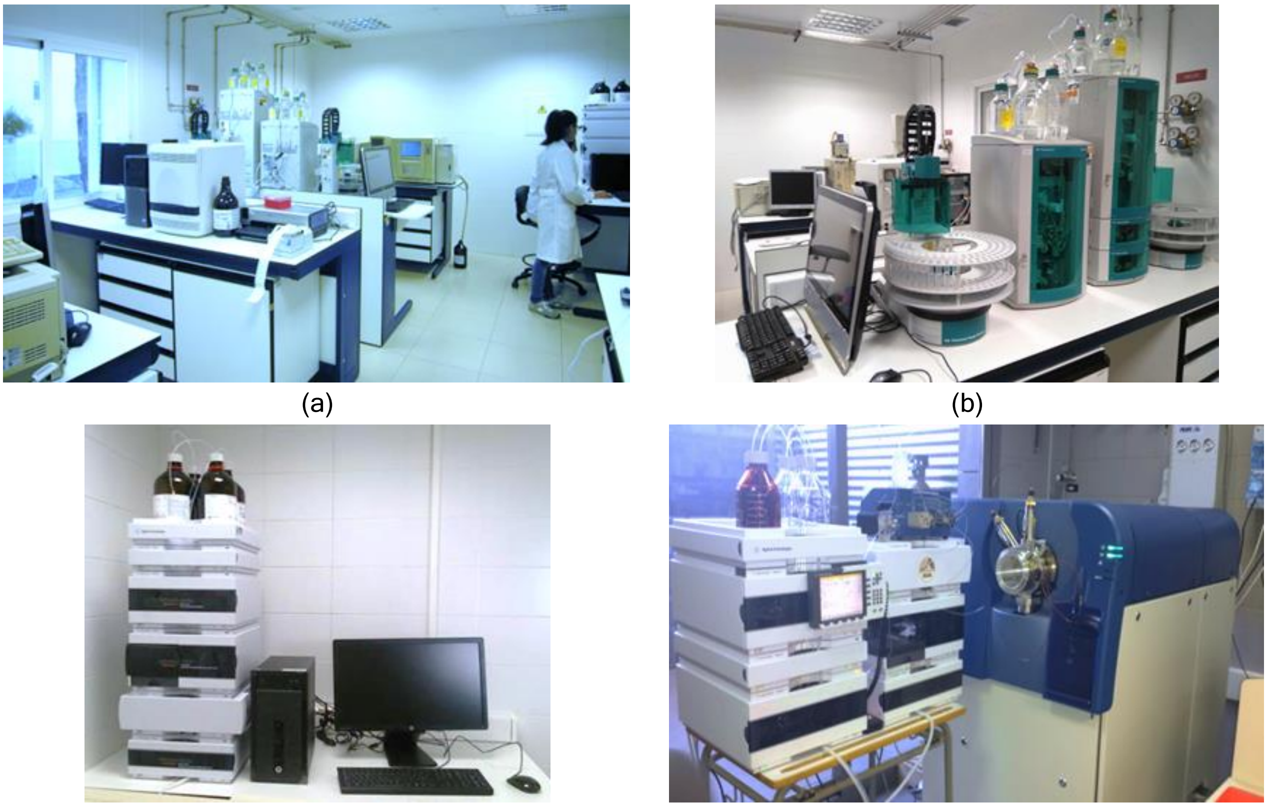
3.12.1 General laboratory

The main laboratory is 94 m^2 (Figure 69). It is equipped with four large work benches, two gas extraction hoods, a heater, a kiln, ultrasonic bath, three centrifuges, two UV/visible spectrometers, a vacuum distillation system, ultrapure water system, pH gauge and conductivity-meter, and precision-scale table. In addition, it has a centralized gas distribution system, UPS, three-pin plugs connection and safety systems (extinguishers, shower, eyewash, etc.). The laboratory is also equipped with *Vibrio fischeri* and activated sludge respirometry toxicity measurement devices, biodegradability measurement by two respirometers for suspended activated sludge and for immobilized activated sludge, and equipment for the analysis of BOD and COD. Jar-Test system for the optimization of separation of solids for water treatment.

Figure 69. General view of the new PSA Water Technologies Lab.

3.12.2 Chromatography laboratory

This lab (Figure 70.a) is equipped with three high performance liquid chromatographs with diode array detector (HPLC-DAD and two UPLC-DAD) with quaternary pump and automatic injection; an Automatic Solid Phase Extraction (ASPEC) which permits working with low concentration of pollutants and two ion chromatographs (Figure 70.b): one configured for isocratic analysis of amines and cations (Metrohm 850 Professional IC), and another for gradient analysis of anions and carboxylic acids (Metrohm 872 Extension Module 1 and 2) with conductivity detectors (Methrom 850 Professional IC detector). Two total organic carbon (TOC) analyzers by catalytic combustion at 670°C and total nitrogen (TN) analyzer with autosampler are also included. In addition, an AB SCIEX TripleTOF 5600+ was acquired to detect and identify non-targeted or unknown contaminants present in wastewater or generated (transformation products) during the water treatments: Triple TOF by a DuoSpray Source combining Turbo Ion Spray and APCI (Atmospheric Pressure Chemical Ionization) modes. Besides, the system includes metabolomics statistical package to analyze multiple samples from multiple experiments and identified possible chemical and biological markers (Figure 70.c).



(a) (b) (c) (d)

Figure 70. a) General view of the chromatography lab at PSA facilities. b) Metrohm Ion chromatograph System. C) Agilent Ultra-fast UPLC-DAD analyzer. c) SCIEX TripleTOF 5600+ equipment.

3.12.3 Microbiology laboratory

A 47-m^2 microbiology laboratory with biosafety level 2 (Figure 71) is equipped with four microbiological laminar flow (class-II) cabinets, two autoclaves, three incubators, a fluorescence and phase contrast combination optical microscope with digital camera attachment. Besides, automatic grow media preparer and plaque filler and a filtration ramp with three positions are available. This lab is also equipped with ultra-fast real-time quantitative PCR (Polymerase Chain Reaction) equipment, fluorospectrometer and spectrophotometer NanoDrop for genetic quantification of micro-volumes. A ‘Fast Prep 24’ was also acquired, it is a high-speed benchtop homogenizer for lysis of biological samples, needed for further analyses of genetic material samples. Homogenizer stomacher 400 Comecta equipment was acquired to blend food samples, stirring and storage is a reproducible way without any risk of cross contamination between samples.

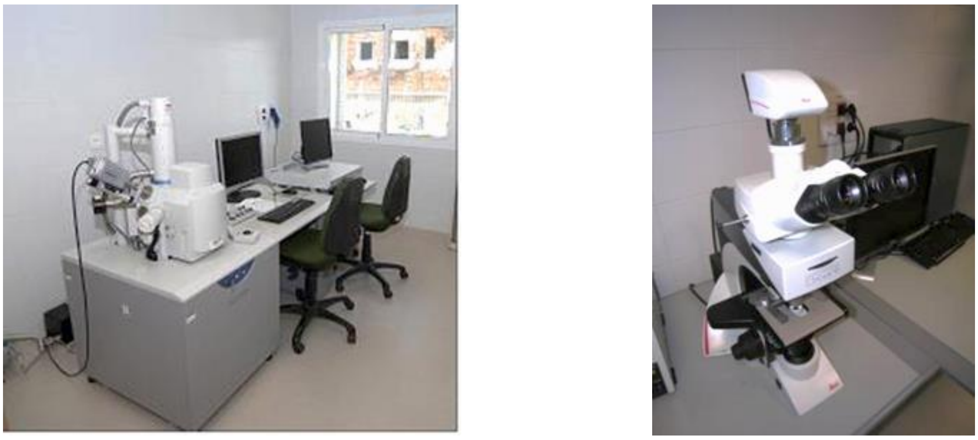
3.12.4 Microscopy laboratory

The microscopy laboratory is 11 m^2 room (Figure 72.a). A Scanning Electron Microscope (SEM) is located in this room. For the preparation of microbiological samples and catalysts to be analyzed in the SEM, the system is completed with a metal coater and critical point dryer. In this room it is also located two optical microscopes: i) A fluorescence and phase contrast combination optical microscope and ii) FISH microscope (Leyca) with fluorescence module to develop the FISH (Fluorescent in situ hybridation) technique for visualization of DNA hibrydation with specific probes in live cells used for monitoring of key microorganisms within a heterogeneous population (Figure 72.b). In addition, the system is completed by a station for photographic documentation, consisted in UV-trans-illuminator to detect and visualize DNA, RNA and proteins. It also includes a documentation station with a camera to take images of DNA, RNA and proteins.

Figure 71. General view of the microbiology lab at PSA facilities.

3.13 PSA radiometric net

The PSA has had a meteorological station since 1988, primarily for measuring integral solar radiation (global, direct and diffuse radiation), but also for other generic meteorological variables (temperature, wind speed and direction, relative humidity and atmospheric pressure, accumulated precipitation, etc.). The old station was completely remodelled in 2005 following the strictest requirements of quality and precision in the measurement of solar radiation according to the Baseline Surface Radiation Network guidelines. This station is called METAS station since 2012 (Figure 73).



(a) (b)

Figure 72. a) SEM (Scanning Electron Microscope). b) Optical microscope for FISH technique.

The METAS station instruments are in the highest range of solar radiation measurement. All the radiation sensors are ventilated-heated and have a temperature measurement sensor. This equipment provides the best information on solar radiation and more general atmospheric variables, and can be used for filtering input data and validating spectral models. They are used for:

- Measurement of the terrestrial radiation balance. Incoming and outgoing shortwave and long-wave radiation is measured at 30 m
- Solar radiation component characterization: (global, direct and diffuse)
- UV and PAR spectral bands
- Vertical wind profile: wind speed and direction at 2, 10 and 30 m
- Vertical temperature and humidity profile at 2 and 10 m
- Miscellaneous weather information: rain gauge, barometer and psychrometer

Figure 73. General view of the new PSA radiometric station.

Additionally, a set of complementary structures for the calibration of radiometers has been installed near to this meteorological station following the standardized international procedures (ISO-9059 and ISO-9846). On the one hand a high performance tracker with the possibility of carrying 2 reference pyreheliometers (absolute cavity radiometer PMOD PMO6-CC) and a total of 19 field pyreheliometers has been installed close to METAS; on the other hand 3 calibration benchs with capacity to carry 20 pyranometers each one have been placed at 50 meters of METAS (Figure 74). These facilities are operated in collaboration with the Instrumentation Unit.

Since the beginning of 2018 there are seven new radiometric stations fully operational all around the PSA area. These stations are equipped with first-class pyranometers and pyrheliometers, 2-axis solar trackers and have data acquisition systems Campbell CR1000 (METAS has a CR3000).

Figure 74. Calibration facilities.

These eight stations, which constitute the radiometric network of the PSA (Figure 75), register synchronously at 1 second and 1 minute. All recorded data are stored in a relational database management system that will allow access to solar radiation data registered through a web platform (under construction). Thus, the homogenization of procedures as measure, data acquisition, quality control, storage and treatment are included in the objectives.

Figure 75. PSA radiometric stations.

4 Solar Concentrating Systems Unit

4.1 Introduction

The aim of the activities carried out by the Solar Concentrating Systems Unit (USCS in its Spanish acronym) is to promote and develop Concentrating Solar Thermal (CST) systems for both power generation and industrial process heat, whether for medium/high temperatures or high photon fluxes. This PSA Unit is composed by two R&D Groups: the Medium Concentration (MC) Group and the High Concentration (HC) Group.

The MC group mainly works in the development of line-focus solar collector technology (parabolic troughs and linear Fresnel systems) and the HC group is focused in the development of point-focus technology, for solar tower systems, parabolic dishes or even the development and application of solar furnaces. Regardless of whether each group has its activities focused on a type of concentrating solar thermal technology, there are cross-cutting activities, common to both groups, related to the development and evaluation of optical concentrators (support/sun-tracking structures, reflectors), development of optical coatings for solar components (absorber, glass covers), durability analysis, etc. These horizontal activities are carried out by the USCS staff in the framework of research project of the Unit but also in projects involving other research units of the *Plataforma Solar de Almería*.

A great effort also continued to dissemination activities, through participation in national and international conferences, workshops, seminars and Master courses to promote the knowledge about concentrating solar thermal energy technologies and their applications in general, new research on the topic and existing gaps that still exist to increase the commercial penetration of this energy technology.

In addition, as part of our research work, four USCS's members defended their PhD theses in 2018.

4.2 Projects

New developments for a more efficient solar thermal technology, DETECSOL

Participants: CIEMAT

Contacts: Eduardo Zarza, eduardo.zarza@psa.es

Funding agency: MINECO -Retos Investigación 2014: Proyectos I+D+i (Ref. ENE2014-56079-R) (Jan 2015 – Dec 2018)

Background: Commercial deployment of concentrating solar thermal (CST) technologies has grown significantly. The installed capacity of STE (Solar Thermal Electricity) plants in the World was 354 MW_e in 2016, while it is currently of about 5 GW_e (2.3 GW_e in Spain). However, optimization of existing technology and innovative solutions are needed to reduce the installation and O&M costs.

Objectives: The project DETECSOL aims to advance in the development of new components and solutions to improve the efficiency of CST technologies, with the following objectives:

- Study the use of alternative heat transfer fluids (HTFs) in solar receivers

- Improve the performance of solar receivers suitable for their use with new HTFs
- Improve the performance of solar reflectors used as primary or secondary concentrators
- New methodologies and solutions in the short-, medium- and long-term development of solar thermal energy storage systems.

Achievements of the project: The use of CO_2 in tubular receivers has been investigated, for both parabolic troughs and solar tower systems. But also, the development of volumetric air receivers was part of the research activity in heat transfer fluids for solar receivers. With regards to the volumetric receiver technology, up to 26 volumetric absorbers were built and tested, 6 of them with homogeneous porosity and 20 of them with heterogeneous porosity, using commercial metallic meshes. It was demonstrated and increase of thermodynamic efficiency using heterogeneous porosities.

A selective coating for tower receivers, which is stable in air up to 700°C, was developed. The coating has a solar absorptance of 0.955 and thermal emittance of 021@700°C. The durability of absorber samples was evaluated at 800°C for 3 months, proving there was no degradation of the optical properties, adhesion problems or cracking of the layers.

The application of antireflective coatings (AR) on quartz windows of receivers or thermochemical reactors for central tower systems has been also studied, increasing the solar transmittance of glass around 5ppt, from 0.93 to 0.975. The effect of heating temperature in the AR coating preparation was also investigated, concluding that the coating goes on densifying as the heating temperature increases and that the coating abrasion resistance is remarkably improved with the heating temperature increases too.

Durability analysis of solar reflectors in corrosive atmospheres, such as industrial areas, was also investigated. Three reflector materials were subjected to accelerated aging tests which combined a number of environmental parameters, such as temperature, relative humidity, time, and controlled concentrations of the most prevalent air pollutants (H_2S, SO_2 and NO_2). The pattern of degradation caused by H_2S in silvered glass reflectors mainly consisted in corrosion spots and clusters. EDS microanalyses revealed the effective reaction between the sulphurous gas and the metallic parts of the silvered glass reflectors. Conversely, aluminum reflectors did not corrode in the presence of H_2S. As a validation of the selected accelerated parameters, samples were also exposed at five targeted outdoor sites, including oil-refinery and thermal-power-plant environments.

With regard to the testing of components for hydraulic circuits using molten salts, commercial valves of different configurations and types have been tested. A procedure for evaluating valves packing with much more flexibility since it does not require the packing to be embedded in the valve was designed. In this activity, the collaboration with different manufacturers has been very fruitful.

It was proposed the use of liquid crystals (LC) as PCMs, in order to avoid all the limitations in heat transfer of solid to liquid PCM with low thermal conductivity. Several promising LC were subjected to thermal cycling in order to verify their expected long term performance. Unfortunately all the tested materials degradated. It seems that having high phase change temperature and enthalpy imply promoting the materials degradation.

Finally, a comparative study was carried out to compare the performance of two 55MW$_e$ solar power plants, one using EuroTrough-type parabolic troughs (PTs) and BP/DPO as heat transfer fluid and the second one using larger aperture PTs with 90mm-∅ receiver tubes and CO_2 as heat transfer fluid. Both plants use a thermal energy storage system with molten salts. The results shown that the yearly efficiency was up to 13.22% while the efficiency obtained for the reference plant using thermal oil was 12.33% (see Figure 76). A basic economic analysis was carried out to estimate the savings with respect to the reference technology, being 7% in terms of LCOE. It was also conducted a comparative analysis to compare the performance of solar tower plants with volumetric air receiver coupled to a basic Rankine cycle, regenerative Rankine cycle and regenerative Rankine cycle with reheating, for 3 different locations in Spain, South Africa and US.

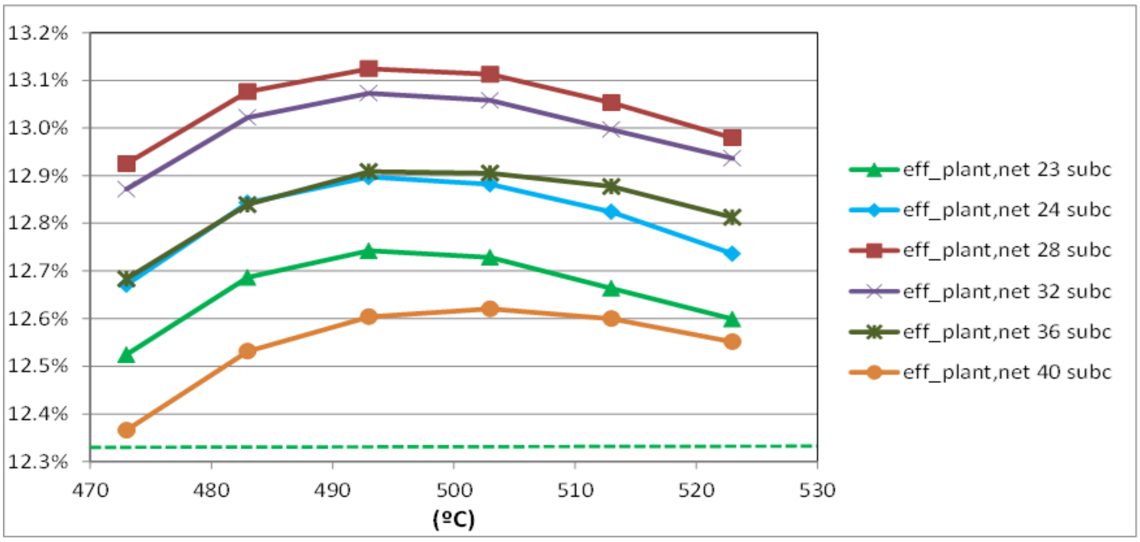


Figure 76. Annual net yield of a reference CSP plant with parabolic troughs and thermal oil, on a discontinuous line, and of a new CSP plant with parabolic troughs and CO_2, for different output temperature values and number of subfields in the solar field.

<u>Raising the Lifetime of Functional Materials for Concentrated Solar Power Technology, RAISELIFE</u>

Participants: DLR, Brightsource, Fraunhofer, CIEMAT-PSA, MASCIR, Dechema, CNRS, Universidad Complutense de Madrid, INTA, Corning, Laterizi Gambetolla (Soltigua), Vallourec.

Contacts: Aránzazu Fernández García, arantxa.fernandez@psa.es
Angel Morales, angel.morales@ciemat.es

Funding agency: EU-H2020- NMP-16-2015.

Background: The materials of concentrating solar thermal technologies are exposed to harsh outdoor conditions and are targeted to maintain their initial properties. Therefore, one crucial aspect is to improve the practical understanding of long-term in-service degradation on the performance of the functional material and its impact on the overall performance of the technology components and systems.

Objectives: It focuses on extending the in-service lifetime of five key materials for concentrated solar power technologies: 1) protective and anti-soiling coatings of primary reflectors, 2) high-reflective surfaces for heliostats, 3) high-temperature secondary reflectors, 4) receiver coatings for solar towers and line-focus collectors, 5) corrosion resistant high-temperature metals and coatings for steam and molten salts.

Achievements in 2018: During the third year of the project, CIEMAT-PSA's activities related to the durability analysis of primary reflector coatings (front anti-soiling coatings and back-side paints) were continued. In particular, 17 reflector types were outdoor exposure in 9 testing sites including Spain, Morocco, France, Israel and Chile (see Figure 77) and 2 anti-soiling coatings were deeply evaluated under outdoor conditions at the PSA during the whole year. Another activity already accomplished was the first analysis of the reflector samples exposed in the outdoor test bench (after 21 months of exposition), which goal is to study the influence of the real concentrated solar radiation on the durability of the materials. Moreover, batches of corrosivity coupons (aluminum, zinc, copper and steel) were placed in several sites in order to evaluate the corrosivity class of the locations. Regarding to accelerated tests, new combined tests were performed (see Figure 78) with the aim of simulating the mirrors behaviour outside. Concerning the activities about the durability of high-temperature mirrors for secondary concentrators, the accelerated aging test campaign of the state-of-the-art reflectors sent by the developer (Fraunhofer) was accomplished and the corresponding experiments with the improved mirrors was designed. Additionally, the solar test bench for the experiments under real concentrating solar radiation at the PSA solar furnace was improved to undertake the trial campaign to be perfomed in 2019. Within Task 3.5, optical properties of CIEMAT-PSA's selective absorber have been improved, adding an infrared reflector on the stainless steel substrate. This layer is electroplated chromium that presents higher infrared reflectance and good thermal stability. Solar absorptance is 0.955 in both absorbers and thermal is reduced from 0.13 on stainless steel substrate to 0.09 in chromium coated stainless steel. Thermal durability of both materials is being studied and after eighteen months at 400°C there is no any degradation in optical properties. Also, precursor solution developed at CIEMAT-PSA, to prepare antireflective coatings for glass covers of solar receivers, has been optimized and solar transmittance is higher than 0.97 and mechanical properties of the coating have been improved resulting in a higher resistance to abrasion-erosion degradation.

Figure 77. Test bench exposed outdoor for reflector samples at the PSA (RAISELIFE project).

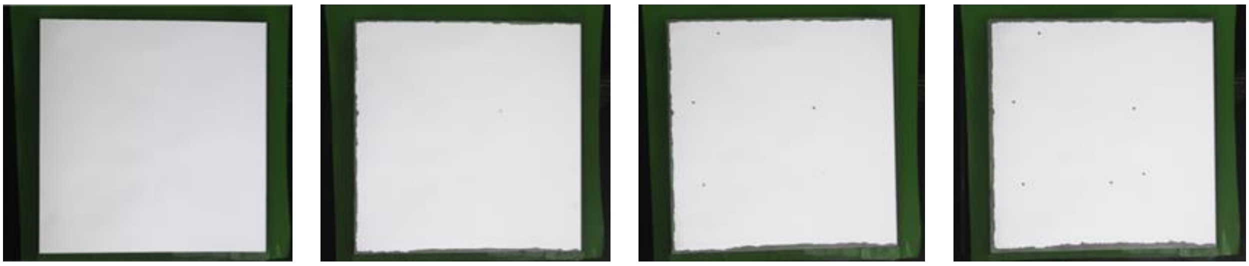


Figure 78. Corrosion evolution of reflector samples in CASS chamber (RAISELIFE project).

Water Saving for Solar Concentrating Power, WASCOP

Participants: CEA, DLR, CIEMAT-PSA, Cranfield University, Fundación Tekniker, MASEN, Rioglass Solar, Archimede Solar Energy, OMT Solutions, Hamon D´Hondt, AMIRES.

Contacts: Aránzazu Fernández García, arantxa.fernandez@psa.es

Funding agency: EU-H2020-LCE-02-2015.

Background: CSP plants use significant amounts of water to function properly. Water is a restricted resource in the parts of the world where the majority of CSP plants are installed. Water saving is therefore one of the major issues to ensure a financially competitive position of CSP plants and their sustainable implementation.

Objectives: To develop a revolutionary innovation in water management of CSP plants, a flexible integrated solution (or toolbox) comprising different innovative technologies and optimized strategies for the cooling of the power block and the cleaning of the solar field, with the aim of a significant reduction in water consumption (up to 90%).

Achievements in 2018: CIEMAT-PSA is involved in this project through its Solar Concentrating Technologies, Thermal Storage and Solar Fuels, and Desalination Units. During the third year of the project, the selected anti-soiling (AS) coatings for reflectors and absorber tubes were applied to begin the outdoor exposure. The AS coating for absorber tubes is based in producing hydrophobic surfaces meanwhile the AS coatings for reflectors use a different mechanism to decrease the soiling. Samples of both components began the outdoor exposure campaign in PSA during the first quarter of 2018. This will last at least one year to cover the climate conditions of all the weather stations. The glass absorber samples were exposed in a device which allows studying the influence of inclination and direction in soiling in addition to the effectiveness of the anti-soiling coating, while the reflector samples were exposed in four different test benches to study several cleaning methods. Also, several outdoor test campaigns were started during 2018 with different technologies (dust barriers, low-cost soiling sensor and ultrasonic cleaning systems) in order to minimize the water consumption (see Figure 79). Most of them are on their completion phase and will be finished in 2019. Regarding the testing loop of the new hybridized cooler prototype, during 2018 all the instruments (pressure transmitters, flow meters, pumps, valves), equipment (surface condenser, steam generator, condensate tank), and electrical and control material required in the testing loop have been purchased and received at PSA. Also, the equipment manufactured by the French company Hamon d'Hondt (Wet and Dry cooling towers) has been received at PSA facilities. Civil works have been also performed to implement the equipment required in the testing loop (see pictures of some instruments, equipment received and civil works performed in Figure 80). Finally, all the technical specifications needed for the detailed engineering and mechanical assembly required in the testing loop have been prepared and the companies to perform these works have been contracted. In relation of using a latent storage system as either indirect or direct cooling system, the commercial PCMs feasible for this application have a cost that makes this approach non attractive enough when comparing with the additional energy gained. Hence, this concept and approach has been disregarded.

(a) (b)

Figure 79. Dust barrier test bench (a) and ultrasonic cleaning system (b).

Figure 80. Picture of the material received and civil works performed to welcome the equipment.

<u>Soluciones termosolares para integración en procesos industriales, SOLTERMIN</u>

Participants: CIEMAT, University of Almería

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Angel Morales, angel.morales@ciemat.es

Funding agency: MINECO -Retos Investigación 2017: Proyectos I+D+i (Ref. ENE2017-83973-R) (Jan 2018 – Dec 2021)

Background: Commercial deployment of concentrating solar thermal (CST) technologies has grown significantly, with about 5GW_e of installed capacity worldwide for electricity generation. However, the commercial use of concentrated solar thermal energy is still very limited, despite the fact that more than 66% of total energy consumption in the industrial sector is dedicated to industrial heat processes.

Objectives: The project SOLTERMIN is developed by the Solar Concentrating Systems Unit and the Desalination Unit of the PSA. The project aims to advance in the development of new components and solutions to facilitate the integration of concentrated solar thermal technologies as thermal energy provider in industrial processes, with the following objectives:

- Development of a linear Fresnel solar collector for its integration in industries, including the development of a light-weight and optimized primary concentrator design to reduce optical losses and the development of an absorber coating valid up to 400°C and stable in air.
- Research on solar components for tower systems devoted to industrial process applications, including innovative and optimized heliostat designs and volumetric air receivers.
- Study of the durability and reliability of solar reflectors installed in industrial environments.
- Integration of linear Fresnel solar systems in different industrial processes: a) from a food and drink industry; and b) multi-effect distillation (MED) plant with steam ejectors. And integration of a solar tower system coupled to a Brayton cycle and a MED plant.

Achievements in 2018: During this year the project has started and the main activity has been focused to the development of a linear Fresnel prototype (see Figure 81), which is under construction at PSA, and to study different possibilities to develop innovative heliostat design with self-aligning optics. The development of selective coatings stable in air for medium temperature (400°C) and high temperature (700°C) application is under development.

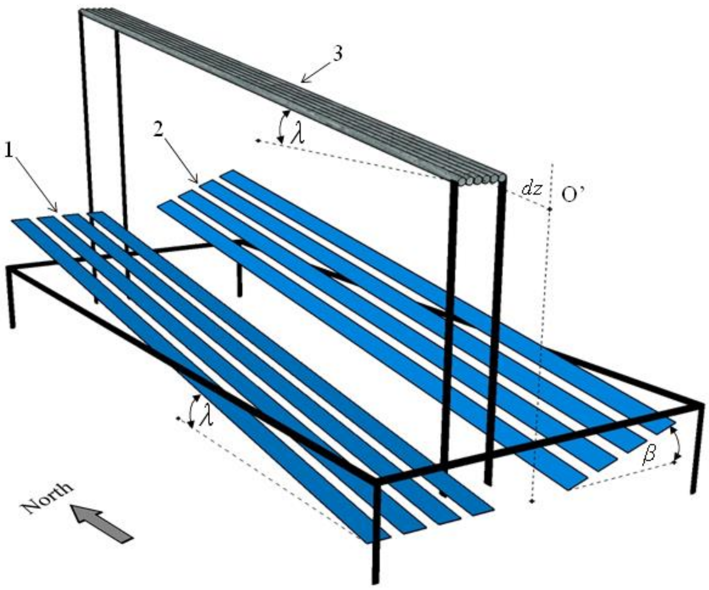

Figure 81. Simplified sketch of a linear Fresnel solar collector prototype under development in the SOLTERMIN project.

Standardization activities at Spanish and international level, Technical Committees *IEC/TC117* and *AEN/CT206*

Participants: ABENER, ABENGOA, AENOR, AICIA, CENER, CIEMAT,Iberdrola Ingeniería, PROTERMOSOLAR, SAMCA, Schott Solar, SENER, TECNALIA, TEKNIKER; DLR, Fraunhofer, CEA, ENE, Archimede Solar; IEECAS, LNEG

Contact: Eduardo Zarza Moya, eduardo.zarza@psa.es

Funding agency: CIEMAT

Background: Since Concentrating Solar Thermal (CST) systems are a relatively young technology, the CST sector is still experiencing a lack of standards. This lack of standards is a barrier for the development of the technology and the evaluation and qualification of components.

Objectives: The scope of the international committee IEC/TC-117 implemented within the umbrella of the International Electrotechnical Commission, and the committee AEN/CTN-206 within the Spanish AENOR is the development of standards for the STE sector by putting together the experience of R&D centres, Industries, Engineering companies, components manufacturers and promoters.

Achievements in 2018: The PSA unit of Concentrating Solar Systems has contributed significantly to standardization activities at both international and national levels in 2018. This contribution has been channelled via the international standardization committees IEC/TC-117 and the Spanish sub-committee AEN/CTN206/SC117.

At Spanish level, besides the coordination of the working Group WG1 of AEN/CTN206 SC117, we have contributed to the development of two new Spanish standards issued in 2018

- UNE 206016:2018 "*Paneles reflectantes para tecnologías de concentración solar*" (Reflector panels for concentrating solar technologies)
- UNE 206015:2018 "*Fluidos de transferencia de calor para centrales termosolares con tecnología de captadores cilindroparabólicos. Requisitos y ensayos*" ("Heat transfer fluids for solar thermal power plants with parabolic trough collector technology. Requirements and tests")

At international level, within the framework of IEC/TC-117, we have participated in the development of two new IEC standards published in 2018:

- IEC 62862-1-1 "Solar thermal electric plants - Part 1-1 Terminology"
- IEC 62862-3-2 "Solar thermal electric plants - Part 3-2 Systems and components - General requirements and test methods for large-size parabolic-trough collectors".

The USCS has also participated in the following IEC/TC117 project teams during 2018:

- Project Team 62862-3-3 "Solar thermal electric plants - Part 3-3: Systems and components – General requirements and test methods for solar receivers". Publication of this IEC standard is expected by 2019.
- Project Team 62862-2-1 "Solar thermal electric plants - Part 2-1: Thermal energy storage systems – Characterization of active, sensible systems for direct and indirect configurations".
- Project Team 62862-3-1 "Solar thermal electric plants – Part 3-1: General requirements for the design of parabolic trough solar thermal electric plants". Publication of this IEC standard is expected by 2019.
- Project Team 62862-4-1 "Solar thermal electric plants – Part 4-1: General requirements for the design of solar tower plants".

4.3 Medium Concentration Group

4.3.1 Introduction

The Medium Concentration group has continued its activities in the field of development, testing, and evaluation of components for line-focus solar collectors (DETECSOL, SOLTERMIN, and INSHIP projects), testing of a new silicone fluid for parabolic troughs (SIMON project), modeling and simulation of power plants with parabolic-troughs using different heat transfer fluids (DETECSOL and INSHIP projects), water saving technologies for power plants (WASCOP and SOLWATT projects), and testing of functional materials (RAISELIFE project). Besides, the participation of the members of the group in different standardization committees (national and international) has continued being relevant and the collaboration with the industry continues in the context of collaboration agreements or technical services has continued being noticeable.

(a)

(b)

Figure 82. Medium Concentration Group staff working a) at Plataforma Solar de Almería in Tabernas (Almería) and b) at CIEMAT Headquarters in Madrid.

4.3.2 Projects

Measuring and modelling near-specular solar reflectance at different incidence angles

Participants: DLR (coordinator), CIEMAT-PSA, ENEA, Fraunhofer ISE, University of Zaragoza.

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Florian Sutter, florian.sutter@dlr.de (DLR)

Funding agency: SolarPACES (IEA).

Background: The SolarPACES Reflectance Guideline provides a tool to obtain comparable reflectance measurements to characterize different solar mirror materials. However, the method has significant drawbacks, mainly due to the lack of current measurement equipment. In order to overcome such drawbacks, research institutes have developed prototype reflectometers over the past years.

Objectives: To improve the current version of the SolarPACES Reflectance Guideline, the improvement of existing reflectometers to characterize specular reflectance at different incidence angles, and to conduct a Round Robin test to compare the different measurement methods.

Achievements in 2018: This project (leaded by DLR) is being developed by the group of experts cooperating within the "Reflectance Measurements" sub-group of the SolarPACES Task III (leaded by CIEMAT-PSA). The first goal of the project was sucessfully acomplished during 2018 with the publication of an improved version of the reflectance guideline, titled "Parameters and method to evaluate the reflectance properties of reflector materials for Concentrating Solar Power Technology" (version 3.0) in March 2018. In addition, a workshop was held on the 10th July 2018 at the CIEMAT-PSA, with the participation of DLR, CIEMAT-PSA, ENEA, Fraunhofer ISE and University of Zaragoza. Main results achieved during 2108 are the following:

- Four experimental reflectometers developed by different research organizations have been improved in order to measure solar-weighted off-normal near-specular reflectance.
- Fraunhofer and ENEA's approach is to measure monochromatically and to apply different Total Integrated Scatter models to compute spectral behavior. DLR/Ciemat and University of Zaragoza measured directly in the range [320-2500] nm.
- A Round Robin test was carried out at θ_i = 10°, 30°, 60° and φ = 15 mrad. Beam divergence of the reflectometers was set to 4.7 mrad to simulate the sun disc.
- Good agreement (σ = 0.38%-p) was obtained for the silvered-glass mirror, with constant reflectance up to θ_i = 60° (see Figure 83). Therefore, near-normal measurement is sufficient for silvered-glass mirrors.
- A decrease with θ_i was measured for the anti-soiling coated glass, polymer and aluminum mirror. ENEA improved its' EMA-TIS model to describe off-normal behavior. Significant deviations were measured among the labs (up to σ = 2.31%-p) for the aluminum mirror at θ_i = 60°. Consequently, innovative mirrors require deeper analysis than standard silvered-glass mirrors.

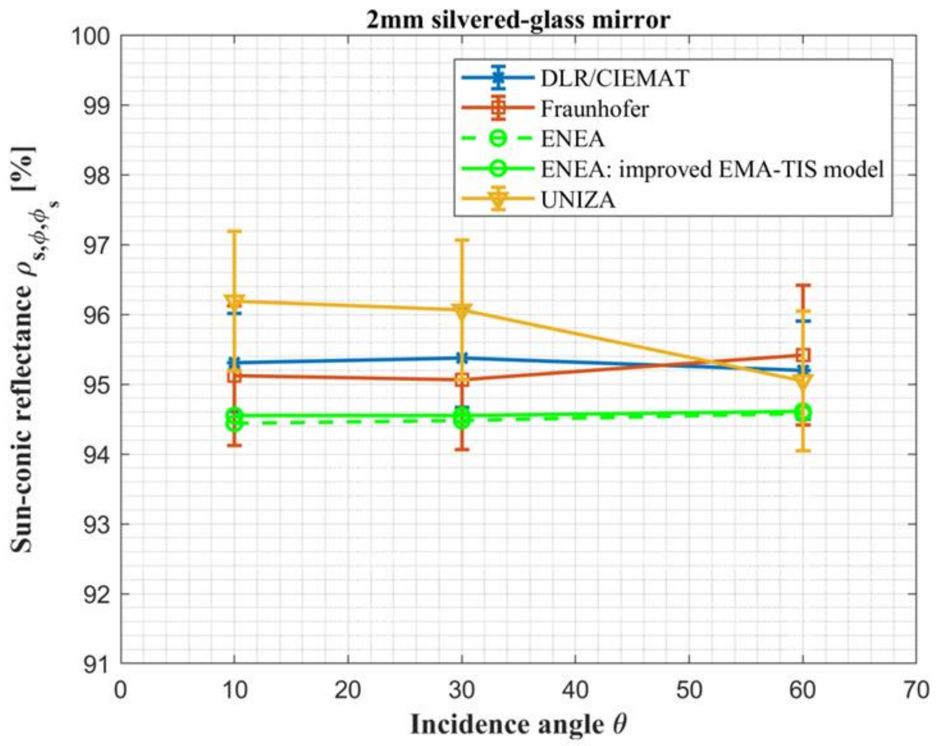

Figure 83. Results of sun-conic reflectance of a 2 mm silvered-glass mirror for the different institutes at several incidence angles.

Solving Water Issues for CSP Plants, SOLWATT

Participants: TSK, CEA, DLR, CIEMAT-PSA, Cranfield University, Fundación Tekniker, Rioglass Solar, Ingeniería para el Desarrollo Tecnológico, FENIKS, Barcelona Supercomputing Center, Bright Source Industries, AMIRES.

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Funding agency: EU-H2020-LCE-11-2017

Background: Water consumption is a major issue for the commercial deployment of CSP/STE plants in desertic areas. Several technical innovations for water saving have been identified and some of them are already under development in the H2020 WASCOP project. SOLWATT is somehow the continuation of the work initiated in WASCOP.

Objectives: The main objective of SOLWATT is the testing and validation in a real commercial environment of important innovations for water saving in CSP/STE plants. These innovations include: antisoiling coatings for mirrors and receiver tubes, advanced cleaning systems, water recovery systems for the BOP and cooling tower effluents, cooling thermal energy storage and a plant O&M optimizer including soiling rate forecast.

Achievements in 2018: SOLWATT started in May 2018 and CIEMAT-PSA is involved in this project through its Solar Concentrating Technologies and Desalination Units (USCS and UDeS). The activities of the USCS in 2018 are summarized hereinafter.

The time schedule for the five courses to be given at PSA (i.e., three knowledge exchange and transfer courses devoted to plant designers, engineers, researchers and post-graduate students, and two practice-oriented training courses devoted to O&M technicians) has been defined. Two courses out of these five will be devoted to mirror cleaning, while the other three will be devoted to water recovery and cooling. The draft plan for the two courses devoted to mirror cleaning has been prepared in collaboration with Crandfield University thus defining the list of talks composing each course and the partner(s) in charge of each talk. The main effort devoted by the Solar Concentrating Technology Unit to SOLWATT in 2018 was focused on the preparation of a technical questionnaire and the test plan&methodology for each of the innovations that will be installed at La Africana solar power plant and tested under real operating conditions during the last two years of SOLWATT. The objective of the questionnaires is to collect important information about the requirements and technical specifications of the prototypes that must be installed and tested at La Africana plant. This information will be essential to avoid unforeseen problems during the implementation phase because potential problems will be identified well in advanced and proper solutions will be discussed and implemented. A first draft of the Test Plan&Methodology for the prototypes to be installed at La Africana plant was also prepared in 2018 and was distributed to the partners involved in each innovation for comments. The technical questionnaires initially prepared and distributed by PSA have been improved and partially filled in by the relevant partners, thus defining the requirements associated to the implementation and testing of each innovation. The questionnaires and Test Plan&Methodology for the following prototypes have been prepared: mirrors with anti-soiling coating, receiver tubes with anti-soiling coatings, mirrors provided with soiling sensors, a water recovery system, a cooling thermal storage system, ultrasonic cleaning device and dust barriers.

Silicone fluid maintenance and operation, SIMON

Participants: DLR (coordinator), CIEMAT, Wacker Chemie AG, TSK Flagsol Engineering GmbH, Senior Flexonics GmbH, TÜV NORD SysTec GmbH & Co. KG, Innogy SE, Rioglass Solar, S.A. Flucon Fluid Control GmbH, Ruhrpumpen GmbH

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Funding agencies: Solar-ERA.NET Transnational Call CSP 4.3 2016; MINECO – Retos 2017 Acciones de programación Conjunta Internacional (Ref. PCIN-2017-009) (Oct 2017-Sep 2019); German Federal Ministry of Economy and Energy and German Federal Ministry of Innovations, Science and Research (Jan 2018-Dec 2019).

Background: Silicone based heat transfer fluids (SHTF) have been used in the past as heat transfer fluids in medium scale installations such as PTC test loops e.g. at PSA (Spain), NREL (USA) and elsewhere (DOW, Syltherm 800®). SHTFs are pumpable below 0°C, environmental-friendly, low in hydrogen formation, almost odourless and very low in acute toxicity. Until now, such fluids are not used in large-scale commercial CSP power plants because available SHTFs are currently far more expensive than the widely used eutectic mixture of diphenyl oxide and biphenyl (DPO/BP). The development, testing and demonstration of reliability, performance, and competitiveness of new SHTFs are of great interest of the CSP sector.

Objectives: The SIMON (Silicone fluid maintenance and operation) project is close related to the SITEF project (2016 and 2017) and has the objective to accelerate the market introduction of two

HELISOL® products: HELISOL®5A and HELISOL®XA with improved viscosity properties, and associated parabolic troughs solar field's components (REPAs and receiver tubes) at temperatures up to 450°C. Such operation temperatures are beyond state of the art in PTC power plants and increase the overall power plant efficiency. This innovate project is based on a German-Spanish cooperation making use of the so called PROMETEO and REPA test facilities located at *Plataforma solar de Almería* (PSA).

Achievements in 2018: During this year the proof of concept of the heat transfer fluid HELISOL®5A, manufactured and supplied by Wacker Chemie AG, was completed at the PROMETEO pilot plant. The proof of concept consisted of 1300 h of solar operation, with 520 h of operation at temperature of around 425°C and 50 h of overheating at 450°C, which were completed in September 2018. During the proof of concept at 425°C the temperatures at the inlet and outlet of the solar field were ≈ 370-380°C and 425°C, and the pressure in the expansion vessel of the test facility varied between 13 and 22 bar. Figure 84 corresponds to an exemplary operational graph with the main process variables during an overheating test at 450°C. Besides this experimentation, in May 2018 there was executed a full release test of hot HTF (close to 400°C) to the atmosphere to demonstrate that no self-ignition occur and to analyse temperature contributions and other effects in the surroundings to the zone where the fluid release was provoked.

In October 2018 the HTF HELISOL®5A was replaced by HELISOL®XA to perform similar testing at PROMETEO test facility. At the same time this new silicone fluid was introduced in the REPA test facility to perform a continuous ageing testing at 450°C for 3000h. At the end of the year the ageing test was not yet complete.

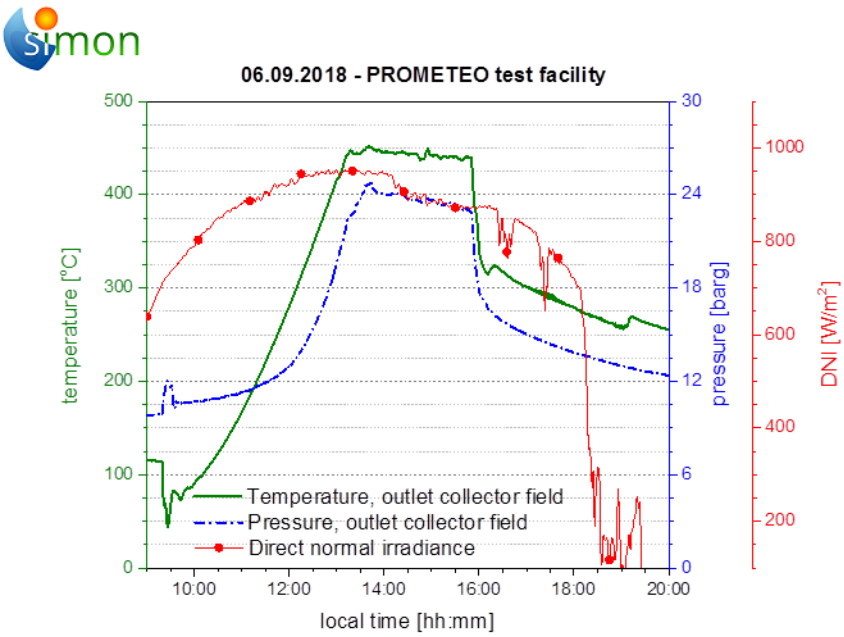

Figure 84. SIMON project: Experimental data during continuous operation of PROMETEO test facility with HELISOL® 5A at 450°C.

Integrating National Research Agendas on Solar Heat for Industrial Processes, INSHIP

Participants: Fraunhofer, CIEMAT, AEE INTEC, FBK, UEVORA, CYI, CRES, ETHZ,CEA, METU, EERA.

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Funding agencies: H2020-LCE-2016-ERA.

Background: Worldwide 66% of heat is generated by fossil fuels and 45% of it is used in Industry as Process Heat. Despite process heat is recognized as the application with highest potential among solar heating and cooling applications, Solar Heat for Industrial Processes (SHIP) still presents a modest share of about 0.3% of total installed solar thermal capacity.

Objectives: The main objectives are grouped as:

- coordination objectives: a more effective and intense cooperation between EU research institutions.
- research objectives: to ensure efficient integration of existing Solar Thermal technologies into low and medium temperature processes, to develop technological solutions for high temperature processes and to foster an integration of SHIP in the overall energy system.

Achievements in 2018: The work of the USCS of CIEMAT-PSA has been in WP3 "Technology and applications to medium temperature SHIP (150°C to 400°C)" and WP5 "Hybrid energy systems and emerging process technologies".

The WP3 of the project is composed of four tasks. The USCS is involved in all of them and coordinates Task 3.1 "Solar driven steam generation" and Task 3.4 "Compact and building envelope-integrated solar field components". The other two tasks are for the study of components of balance of plants, and to durability and reliability of solar concentrator components taking into consideration the possible specificities of industrial environment. Within WP3 next deliverables have been finished, with the coordination or participation of USSC:

- Internal Deliverable D3 - Characterization of Direct Steam Generation operation modes: check parameters and objective functions.
- D3.1 Guidelines for solar steam integration in steam networks
- D3.3 Industrial environment conditions for solar collector degradation
- D3.4 Survey of existing automated mirror cleaning technologies
- D3.5 Standardization requirements for BoP

In addition, as part of the activities planned for the D3.7 "Solar field sizing driven BOP dimensioning", CIEMAT-PSA has collaborated with CRES (Greece) in the definition and preparation of a dimensioning tool for solar field providing thermal energy in the medium temperature range, which has been implemented in Excel, and it will be available for all the community to perform calculation to provide a fast and reliable dimensioning of modular BoP.

The WP5 of the project is composed of five tasks and the USCS is involved in Task 5.1, which is devoted to process integration and energy storage management, and in Task 5.3, devoted to hybrid energy supply systems.

In the Research Activity 5.1.1 of Task 5.1 (WP5) have been completed:

- Identification of case study (milk pasteurization process) as result of discussion with AEE-INTEC, the parabolic-trough collector (NEP-Polytrough 1800) and HTF (pressurized steam).
- Development of PTC simulation model and draft of solar field design.

The first deliverable D5.1.1d “Quasi-dynamic flexible model to simulate a solar field with PTCs and TESS for SHIP in TRSNYS” is under preparation and will be ready in September 2019.

The starting of the research activity 5.3.2 of Task 5.3 (WP5) will start in 2019.

4.4 High Concentration Group.

4.4.1 Introduction

In 2018, the High Concentration group continues to make a clear commitment to volumetric receiver technology, both on a small scale, studying the optical and thermal properties of different types of absorbers and their influence on their thermal efficiency (DETECSOL, ALCCONES, SOLTERMIN), and through its participation in two projects financed by the H2020 programme (CAPTURE and NEXTOWER), in which the operating temperature of the central tower systems is extended above 600°C so that these systems can be coupled to more efficient power cycles (high-temperature gas cycles). Both European projects are in the final phase where they will begin to offer experimental results in the coming months.

(a) (b)

Figure 85. High Concentration Group Staff working at the *Plataforma Solar de Almería* (a) and CIEMAT-Madrid (b).

One of the important achievements of this year, which reinforces the development side of CIEMAT's activities, is the license agreement for the commercialization of an atmospheric attenuation measurement device to the Spanish company BCB. This device has been developed under the umbrella of the PRESOL Project (Spanish project ID: ENE2014-59454-C3-3-R) and, after a year of testing at the PSA, is ready to be commercialized, consisting of a low-cost solution and maintenance for the real-time measurement of the atmospheric extinction of solar radiation in central tower systems.

4.4.2 Projects

<u>Competitive Solar Power Towers, CAPTURE</u>

Participants: CENER (Coordinator), TEKNIKER, CIEMAT-PSA, FRAUNHÖFER-IKTS, BLUEBOX ENERGY LTD, CEA, FCT GMBH, SONCEBOZ SA, HAVER&BOECKER, TSK FLAGSOL, K-CONTROLS LTD, EDF, EUREC EESV.

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Antonio Ávila-Marín antonio.avila@ciemat.es

Funding agency: European Commission, H2020-LCE-2014-2015

Background: Volumetric atmospheric air receiver technology is a promising alternative to increase receiver efficiency of Solar Tower Power Plants. CIEMAT-PSA works on this technology since 1990 testing more than 15 different volumetric receiver prototypes in the las 20 years; being a strategic technology field of High Concentration Solar Group.

Objectives: The project global objective is to increase plant efficiencies and reduce levelized cost of electricity by developing all relevant components that allow implementing an innovative plant configuration consisting on a multi-tower decoupled advanced solar combined cycle approach that not only increases cycle efficiencies but also avoids frequent transients and inefficient partial loads, thus maximizing overall efficiency, reliability as well as dispatchability; all of which are important factors directly related to cost competitiveness on the power market.

Achievements in 2018: The activity carried out during 2018 within the framework of the project consisted of the final selection of the absorbers to be installed in the volumetric air receiver, as well as the detailed engineering of each of the components forming part of the experimental loop of the CAPTURE concept, which began to be installed in the PSA' CRS tower at the end of 2018 and which will be tested during 2019.

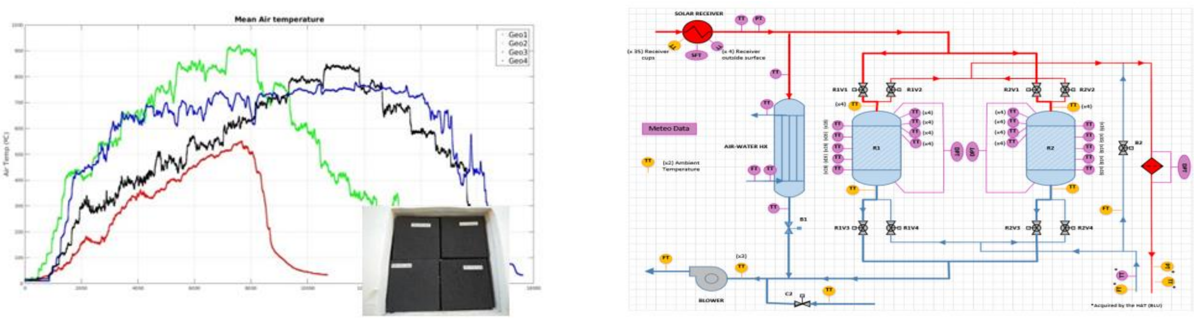

Figure 86. Final selection of absorber for CAPTURE receiver and sketch of the testing loop at PSA.

Advanced materials solutions for next generation high efficiency concentrated solar power (CSP) tower systems, NEXTOWER

Participants: ENEA (coordinator), kth, polito, ciemat, iccram, uoxf, urm1, sANDVIK mt, BEWARRANT, CERTIMAC, R2M SOLUTIONS, LIQTECH, CALEF, SILTRONIX, GREEN CSP, ENGICER, UNE.

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Antonio Ávila-Marín, antonio.avila@ciemat.es

Funding agency: European Commission. H2020-NMBP-2016-2017. Grant Agreement number: 721045

Background: While volumetric air CSP towers are socially and technically appealing, for their great environmental sustainability and the potential for electrical and thermal power generation, their industrial exploitation has been significantly slowed down by the materials used for the core component (i.e. the high temperature solar receiver) which is affected by limitations in maximum working temperatures and in-service overall durability, mainly due to failure by thermal cycling.

Objectives: NEXTOWER project aims at demonstrating high-performance durable materials for the next generation of concentrated solar power (CSP) air-based tower systems, making them commercially competitive in the energy market beyond 2020. While CSP towers are socially and technically appealing for their great environmental sustainability and the potential for electrical and thermal power generation, their industrial exploitation has been significantly slowed down by the materials used for the core component (i.e. the high temperature solar receiver) which is affected by limitations in the maximum working temperatures and in-service overall durability, mainly due to failure by thermal cycling.

NEXTOWER responds by taking a comprehensive conceptual and manufacturing approach that starts by optimizing for durability the ceramic materials to achieve 20-25 years of maintenance-free service receiver components, while increasing their operating temperature for thermodynamic efficiency at the system level and possible unprecedented applications downstream, such as the direct interfacing with a Brayton cycle or the supply of zero-emission heat for industrial/chemical processing. The actual exploitation of the hotter air (up to 800°C) is then crucially tied to the development of a high-temperature thermal storage, here inspired by nuclear fission GEN-IV technology and based on liquid lead by means of new corrosion resistant steels.

Achievements in 2018: The activities carried out this year have focused on the testing of new materials, geometries, solutions to improve durability of ceramic volumetric absorber maintaining, at the same time, the high thermal performance of the achieved solutions. In parallel, the engineering of the SOLEAD facility is finished and ready to be installed at the PSA during next year.

Forecast of Solar Radiation at the Receiver of a Solar Power Tower, PRESOL

Participants: CIEMAT-PSA, Almería University, Huelva University.

Contact: Jesús Ballestrín, jesus.ballestrin@psa.es

Funding agency: This research has been funded by the Spanish government in the framework of the PRESOL project (Ref. ENE2014-59454-C3-3-R) with ERDF funds.

Background: Power generation from Solar Power Towers (SPT) -where DNI is a critical input- is experiencing a rapid growth worldwide. The greater challenge posed by these large solar installations is the grid integration. To this end, it is crucial to have an accurate forecast of the DNI levels reaching the receiver, which affects not only the plant operation but the energy price market.

Objectives: The project goal is to produce a short-term forecast of the DNI reaching the SPT receiver. To this end, we propose to forecast the DNI arriving to the heliostat field and develop techniques to determine and forecast the reflected solar radiation attenuation on its path to the receiver.

Achievements in 2018: Atmospheric extinction of solar radiation reflected by heliostats to receiver is recognized as an important cause of energy loss in the increasingly large solar tower plants. During the design of these plants would be desirable extinction maps similar to those of direct normal irradiance. Unfortunately, the reality is that there is currently no reliable measurement method for this quantity and at present these plants are designed, built and operated without knowing this local parameter.

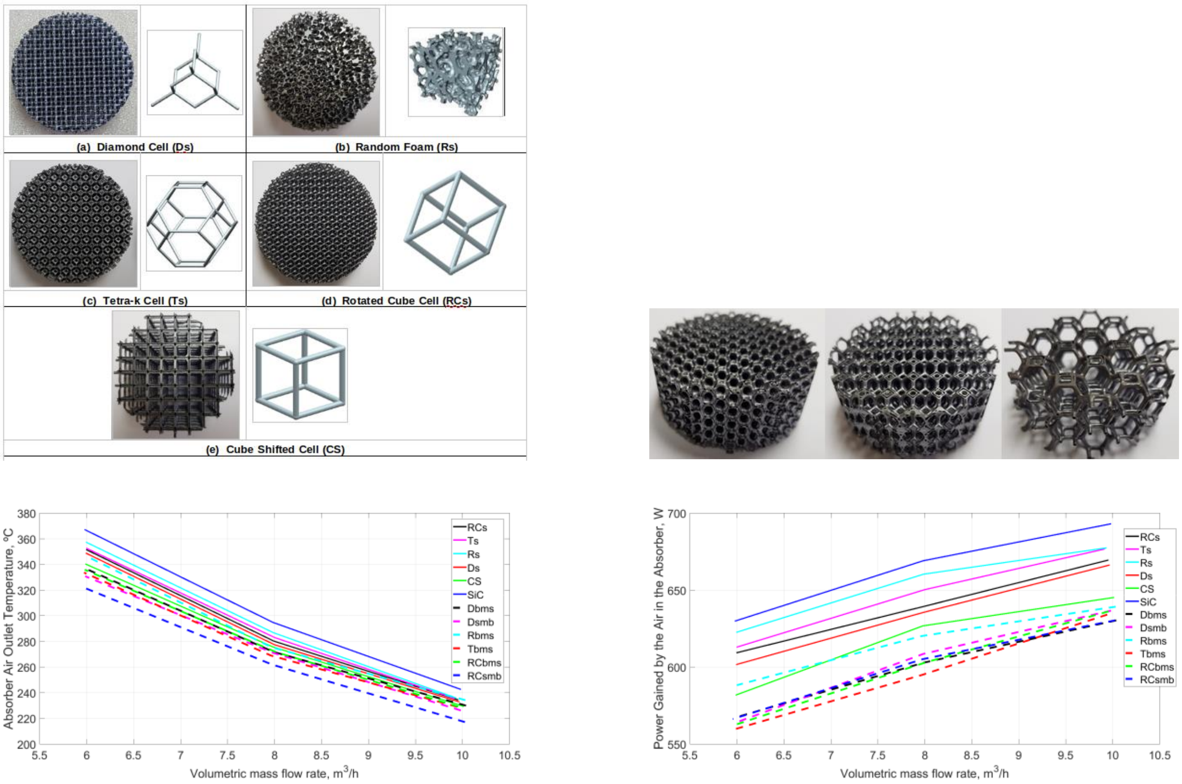

Figure 87. Alternatives for volumetric absorber design (Single and gradual porosity) and results achieved so far (NEXTOWER project).

Currently, a reliable solar extinction measurement system (Figure 88, a) is daily working at *Plataforma Solar de Almería* (PSA). The system is based on two high-performance digital cameras and a lambertian target that allow a measurement of the solar extinction 741.63±0.01 meters away in the spectral range of 400-1000 nm with an absolute uncertainty of less than ±2%. After a year of extinction measurements, it has been possible to analyse the daily and seasonal variability of the extinction phenomenon and know the annual extinction average value at PSA. Knowing the daily extinction guidelines at the site will be helpful in the daily operation of the plant. We consider it the first time that such a detailed study on extinction has been presented on a site.

Currently, the measure of solar extinction is available on-line in the control room of the CESA-1 facility at PSA, facilitating the daily operation tasks (Figure 88, b). Note that this is the first time that it occurs in a solar tower plant. During this year, several CSP promoters have shown interest in the extinction measurement system described, which has led to a commercialization process through an external engineering company.

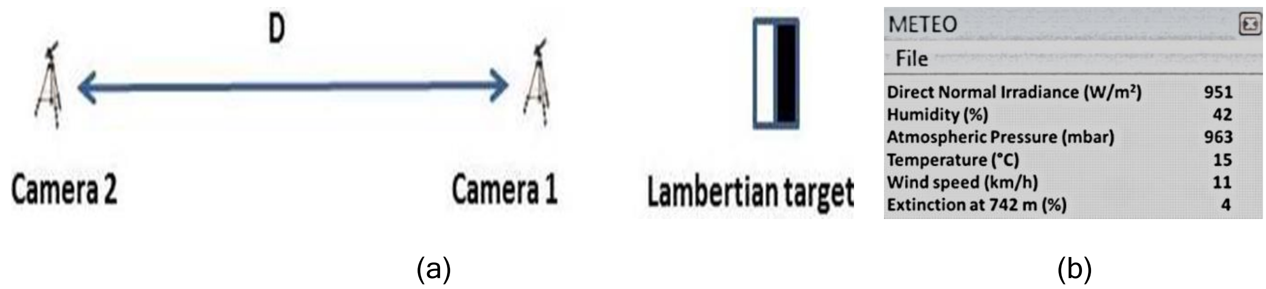

Figure 88. Digital cameras take images of the target (a) and On-line measurement of the solar extinction in the control room of CESA-1 facility at PSA (b).

<u>Storage and conversion of concentrating solar power, ALCCONES</u>

Participants: IMDEA Energía-UPAT (Coordinator), CIEMAT-PSA, URJC-GIQASOL, CSIC-IPCPA, SENER, AH, EA.

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Funding agency: Comunidad de Madrid, S2013/MAE-12985

Background: During the last years, concentrating solar power has been the renewable energy with the highest year-on-year growth rate. Nevertheless, the technology used up to now reaches 18-20% of nominal performance in the conversion of solar radiation to electricity and the investment cost of solar thermal electricity plants is still high. Therefore, it is required to improve the efficiency of their thermal conversion processes and turn solar energy into a dispatchable one by the integration of thermal storage systems.

Objectives: The participation of the USCS is focused on: i) analysing the behaviour of innovative thermal fluids to achieve higher working temperatures and developing a better integration with more efficient thermodynamic cycles; ii) improving solar receiver designs to work more efficiently at high temperatures and solar irradiance.

Achievements in 2018: The USCS of CIEMAT-PSA performed an exhaustive study of graded porosity concept during first years of the project, and then a numerical computational fluid dynamics (CFD) approach was set up. For that purpose, the first step was the numerical analysis of the heat transfer coefficient (HTC) between the air flow and six detailed staggered stacked plain-weave wire mesh screens, the second is to produce correlations of the HTC. Finally, the CFD approach was compared and validated with experimental results. Figure 89 shows the local volumetric HTC and the Nusselt number of one of the meshes studied compared with literature data.

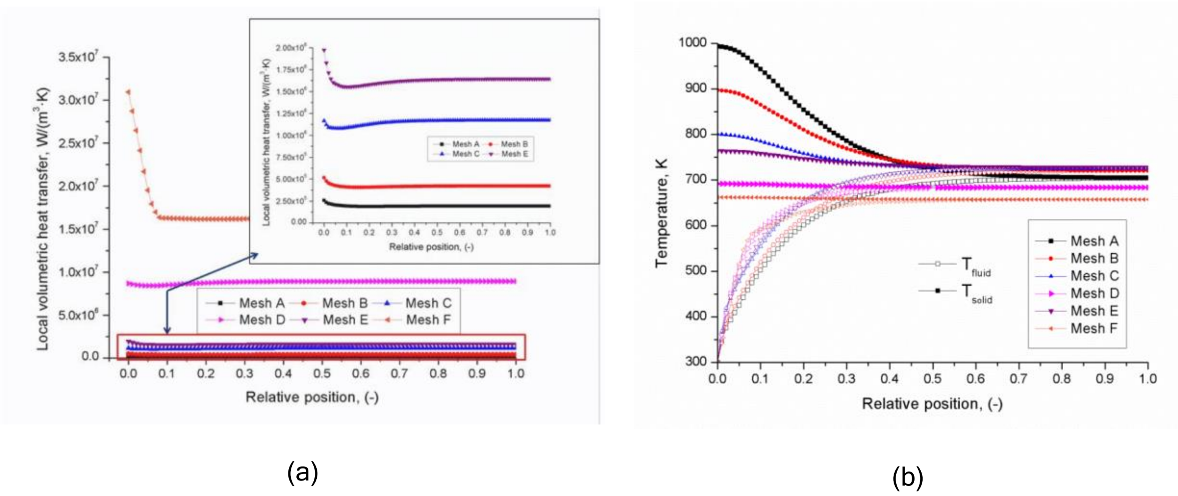


Figure 89. Results of the local volumetric heat transfer coefficient as function of the relative absorber depth (a) and solid and fluid temperature profiles (b) for six different dense wire mesh absorbers.

Storage and conversion of concentrating solar power, SPIRE

Participants: GHENOVA, CAPSUN, CIEMAT-PSA.

Contact: Rafael Monterreal, rafael.monterreal@psa.es

Funding agency: CDTI, FEDER-INNTERCONECTA 2016

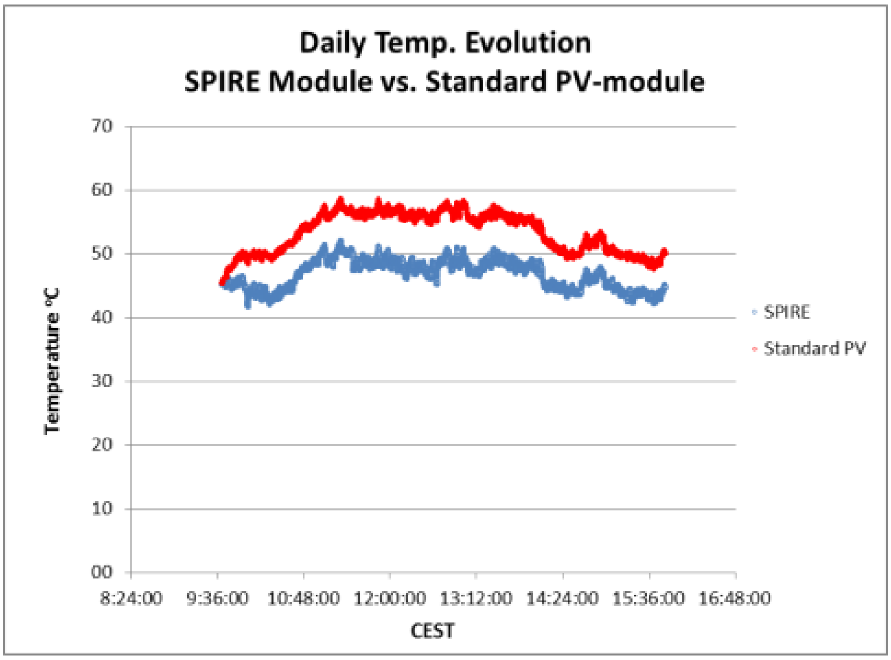
Background: CAPSUN Technologies and GHENOVA Ingeniería have jointly developed the SPIRE project, a disruptive technology that integrates the best characteristics of Photovoltaic (PV) Plants and Concentrated Solar Plants (CSP). By means of a selective optical filter, the light spectrum is divided. The filter allows the efficient passage of radiation used by the photovoltaic panel (mainly visible light) while reflecting 40% of the energy (mainly blue light and infrared).

Objectives: The SPIRE project is currently in its final validation phase. The objective is to evaluate under real conditions the behaviour of the SPIRE modules, both in their aspect related to CSP (selective specular reflection and concentration) and in their performance as an element of a PV plant. The modules will be mounted on a heliostat of the PSA solar field of the CESA-1 plant for this purpose and an exhaustive campaign of tests and evaluation under real working conditions will be carried out.

Achievements in 2018: SPIRE modules have been tested and evaluated at *the Plataforma Solar de Almería*, comparing their performance against conventional PV-modules, both in power performance and module working temperature throughout the day. The specular reflection of the SPIRE modules on a lambertian target has also been tested, as well as the capacity to collect/concentrate the solar radiation in a certain area on the target surface.

(a)

(b)



(c)

Figure 90. Image of the tested hybrid facets at focal spot (a and b) and results of tested PV coated panels (c).

5 Thermal Storage and Solar Fuels Unit

5.1 Introduction

The Thermal Storage and Solar Fuels Unit (ATYCOS in its Spanish acronym) was formally launched in 2018 due to a reorganization of the former Concentrating Solar Systems Unit lead by Dr. E. Zarza. People of this former unit have joined forces to help turning concentrating solar thermal systems into a dispatchable technology by designing improved thermal energy storage systems and/or by producing Hydrogen through thermochemical processes.

During 2018, apart of shaping the new unit, ATYCOS researchers have been actively working in international, national and local funded projects, already running – like NESTER, WASCOP, INSHIP, HYDROSOL plant, RESPACE, DETECSOL and ALCCONES - and other new ones – like POLYPHEM and ALCHEMIST-. In addition, a number of technical services have been provided to companies, mainly for testing and characterization of components and equipment for molten salt loops. Taking into account that ATYCOS is composed of 6 researchers, it is worth noting the importance of the work load carried out by this Unit.

Through its experts, the Thermal Storage and Solar Fuels Unit participates actively in several scientific networks (Energy Storage JP of EERA, Task II and III of SolarPACES TCP of the IEA, task 58/33 SHC/ECES TCPs, Spanish association for Hydrogen -AeH2-) and national (AENOR-GT3) and international (IEC- CTN 206/SC 117/GT 03 and ASME-PCT52) standardization committees.

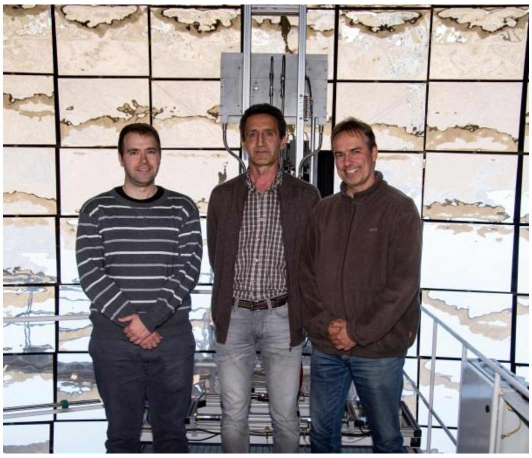
The activities on thermal storage deal with all aspects involved in the development, verification and optimization of efficient Thermal Storage Systems (TSS):

- Proposing new storage media and characterizing some of their properties.
- Testing components for molten salt loops (valves, pressure gauges, vertical pumps, heat tracing, etc.).
- Designing new heat storage concepts with known storage media.
- Testing novel modules for energy storage, both sensible and latent, even in real solar conditions.
- Modelling the behaviour of TSS, with own and commercial programs.
- Optimizing the operation strategies of TSS in order to obtain a maximum advantage of the stored energy.

On the other hand, the activities on Solar Fuels are focused on the following fields:

- Development of hybrid solar/fossil endothermic processes with special attention to low quality carbonaceous materials.
- Pre-commercial scale demonstration of the technical and economic feasibility of water splitting for hydrogen production through the use of thermochemical cycles with concentrated solar energy.
- Technological feasibility of the use of solar thermal energy as the energy supply in high temperature industrial processes.

(a)



(b)

Figure 91. Staff of the Thermal Storage Group (a) and staff of the Solar Fuels Group (b).

5.2 Projects

<u>**Small-Scale Solar Thermal Combined Cycle, POLYPHEM**</u>

Participants: CNRS (coordinator), CEA, CIEMAT, Arraela, Fraunhofer, Kaefer Isoliertechnik, Orcan, Euronovia, Aalborg CSP

Contacts: Esther Rojas, esther.rojas@ciemat.es

Funding agency: H2020-LCE-2016-2017

Background: The technology consists of a solar-driven micro gas-turbine as top cycle and an ORC as bottom cycle. There is no water requirement for cooling. A thermal energy storage is integrated between both cycles. The resulting power block is a solar system able to meet a variable demand of power.

Objectives: The project will build a 60 kW prototype plant with a 2 MWh thermal storage unit and will validate this innovative power cycle in a relevant environment (TRL 5), assess its technical, economic and environmental performances and establish the guidelines for its commercial deployment.

Achievements in 2018: The main contribution of CIEMAT-PSA is on the thermal storage system (TSS). ATYCOS coordinates the WP for the design and simulation of the TSS. This TSS is a thermocline tank with filler.

During 2018 the HTF in the TSS has been identified. The requirements and equipment for testing the filler behaviour and its compatibility with the HTF have been stablished. Several types of special concretes have been considered as filler materials. A first design of the size of the thermocline storage tank has been calculted. ATYCOS reseraches have also contributed to the discussions of the PI&D scheme of the prototype plant to be erected at Themis CNRS premises in France.

Figure 92. Samples of special concrete formulations, manufactured by Arraela.

<u>Thermochemical HYDROgen production in a SOLar monolithic reactor: construction and operation of a 1MW PLANT, HYDROSOL-Plant</u>

Participants: APTL (Greece), DLR (Germany), Hygear (Netherlands), HELPRES (Greece) and CIEMAT-PSA (Spain).

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Alfonso Vidal, alfonso.vidal@ciemat.es

Funding agency: FCH-JU-2012

Background: The principal objective of HYDROSOL-PLANT is the development and demonstration operation of a plant for solar thermo-chemical hydrogen production from water in a 750 kW scale on a solar tower, based on the HYDROSOL technology.

Objectives: Based on the above, the specific Scientific and Technical Objectives of the work proposed within HYDROSOL-PLANT are the following: construct a solar hydrogen production demonstration plant in the 750 kW range to verify the developed technologies for solar thermochemical H_2O splitting. Operate the plant and demonstrate hydrogen production and storage on site (at levels > 3 kg/week). Finally, the proposal is directed to perform a detailed techno-economic study for the commercial exploitation of the solar process.

Achievements in 2018: During 2018, an experimental test campaign was carried out up to April. A protocol was established for the thermal tests to operate two of the three reactors originally mounted on the platform.

The main objectives for the thermal tests performed both on the HYDROSOL-Plant platform on the solar tower was the following:

- to investigate at what extent homogeneous distribution of the solar flux over the aperture of each reactor is possible
- to employ different levels of solar flux in each reactor
- to accomplish a suitable temperature swing between the two reactors, in the case of the solar tower experiments, and in particular of the solar flux.

According to the initial testing protocol, it was decided to heat the reactors consecutively to 1000, 1100, 1200 and 1400°C and to cool them to 900, 1000, 1100 and 1200°C. This means that while one reactor was at a high temperature level of 1400°C simulating the regeneration stage, the temperature of the other reactor had to be maintained at around 1100°C simulating the water splitting step.

An example of the evolution of the temperature in the cavity for a specific ceramic block is presented in Figure 93. It was observed that there is some inhomogeneity during the heating of the different ceramic blocks which indicates a non-uniform flux distribution. An aiming strategy was built upon the concept to prevent the receiver being subjected to excessive temperatures by measuring the temperature at different module segments (Figure 94), and transferring the power from one area to another by changing the heliostats groups.

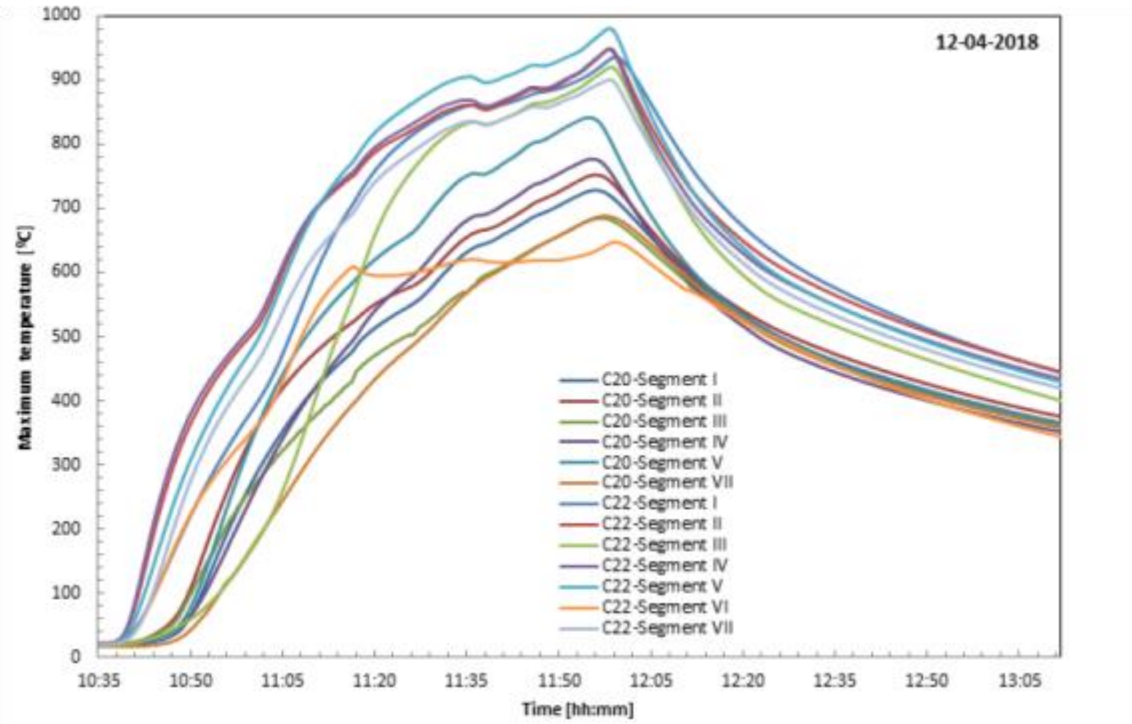
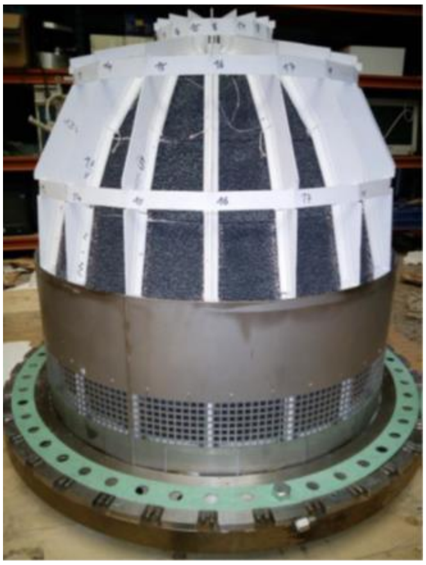
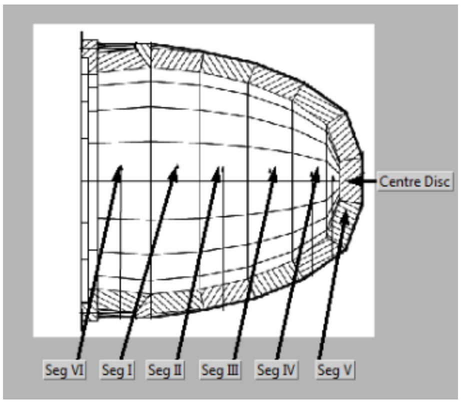


Figure 93. Evolution of temperatures in the different segments of the receivers: C20 (West reactor) and C22 (East reactor).

After several weeks, the thermocouples indicated that the optical parts are not working properly. In fact, after the inspection, some critical parts of the modules were damaged: in particular, the secondary concentrator C22 and the quartz window. Taking into account all these facts, the testing campaign was stopped until the damaged parts were repaired. Once the necessary changes have been made to the secondary, the reactor flange, the segmented ceramic blocks, etc., a test campaign will be carried out with the plant.



(a)



(b)

Figure 94. Detailed view of the absorber and its segments without the external vessel (a). Nomenclature and sketch of the segments of the absorber (b).

<u>Storage and Conversion of concentrated thermal solar energy, ALCONNES</u>

Participants: IMDEA Energia (Coordinator), University J. Carlos I, ICP-CSIC and CIEMAT. SENER (Spanish engineering company) and ABENGOA Hidrógeno (company subsidiary of the ABENGOA group) act as industrial companies with active collaboration and interest in the possible exploitation of the project results.

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Alfonso Vidal, alfonso.vidal@ciemat.es

Funding agency: Community of Madrid.

Background: The ALCONNES project is a very ambitious initiative that involves R&D public institutions, IMDEA Energia (Coordinator), University J. Carlos I, ICP-CSIC and CIEMAT. The program AlCConES (the acronym in Spanish stands for Storage and Conversion of Concentrated Solar Power) focuses its R&D objectives onto the heart of CSP systems, that is the loop involving conversion from high flux solar to thermal energy, including the storage system needed to optimized dispatch on demand for further use of energy in the production of electricity, solar fuels or chemicals.

Within objective 2, CIEMAT is exploring new solar receivers and reactors for the efficient operation at high temperatures and with high penetration of photons for high incident flux. Furthermore, within objective 3, CIEMAT will be focused on new perovskite materials as candidates for thermochemical cycles.

Achievements in 2018: Within objective 3, our research efforts were directed towards preparation and synthesis of the perovskites materials in the laboratory, improving the kinetics and reducing the working temperatures. Commercial perovskites type $La_{0.5}Sr_{0.5}CoO_3$ and $La_xSr_{1-x}Mn_yAl_{1-y}O_3$ have been studied for their application in hydrogen production by thermochemical water splitting. In particular, the $La_{0.5}Sr_{0.5}CoO_3$ material shows degradation after several cycles. Furthermore, the oxygen released in the reduction step was decreased in each consecutive cycle showing that cobalt perovskite is not a stable material.

On the other hand, preliminary tests carried out with $La_xSr_{1-x}Mn_yAl_{1-y}O_3$ indicated both (a) oxygen release in perovskite materials is higher than Nickel ferrites (b) hydrogen production lower than the expected according to the oxygen released in the reduction step (Figure 95).

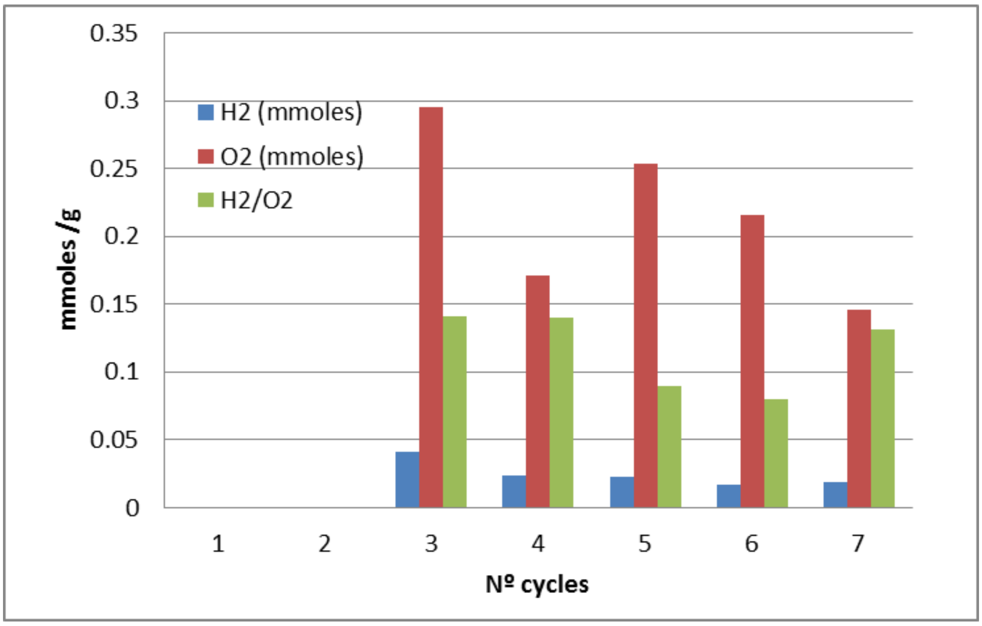

Figure 95. Results of molar ratio for $LaxSr_{1-x}MnyAl_{1-y}O_3$ material tested in 5 cycles.

These results could confirm that reduction cycle of the perovskites at high temperature is accompanied with other reactions with no contribution to the overall efficiency of the thermochemical cycle for hydrogen production and should be taken as a pre-treatment of the material for the actual thermochemical cycle.

Multidisciplinary analysis of indirectly-heated particles receivers/reactors for solar applications in extreme conditions, ARROPAR-CEX

Subproject 3. Methodology and characterization of materials and components for receivers for solar applications under extreme conditions (RESPACE).

Participants: IMDEA Energia (Coordinator), *Centro de Investigación en Nanomateriales y Nanotecnología* (CINN) and CIEMAT.

Contacts: Manuel Romero, manuel.romero@imdea.org
Alfonso Vidal, alfonso.vidal@ciemat.es

Funding agency: *Programa Estatal de Investigación, Desarrollo e Innovación Orientada a los Retos de la Sociedad, en el marco del Plan estatal de Investigación Científica y Técnica y de Innovación* 2013-2016. Ref. ENE2015-71254-C3-2-R.

Background: The research program ARROPAR-CEX proposes a multidisciplinary analysis on novel concepts of indirectly heated receivers/particle reactors for solar applications under extreme conditions. Extreme operating conditions are understood to be those which involve the combination of high irradiance, in excess of 1000 kW/m^2, and very high temperatures, typically above 800°C.

ARROPAR-CEX is divided into three sub-projects, within objective 2, CIEMAT will study new multifunctional ceramic materials for solar applications under extreme conditions, focusing on the development of ceramic components that are adapted to operating conditions beyond the current state-of-the-art.

Thermochemical processes require thermally and chemically stable reactor wall materials, which can withstand severe operating conditions suitable for specific solar fuels production. Reactor materials of construction comprising walls, the cavity lining, insulation, and shell need to fulfil the thermal and chemical requirements of severe operating conditions at high temperatures and under high-flux solar radiation.

Achievements in 2018: Main objective during this year has been to establish a procedural methodology that leads to the reliable qualification of materials, components and solar reactors, and which thus ensures their reliability and durability under extremely demanding operating conditions. This methodology will be validated in real operating conditions of solar radiation by employing Solar Furnace facilities. A previous selection of materials was carried out, and AlN, SiC, ZrO_2-Al_2O_3, Al_2O_3 materials were selected for these tests. These materials were subjected to thermal treatment in inert and , steam, and ageing tests to determine the optimal material for each specific application.

During 2018, CIEMAT performed cyclic oxidation tests with commercial samples. A set of tests were carried out in order to depict some degradation of selected materials to be used as reactor walls and other identified components after operation under specified conditions similar to those foreseen in actual solar chemical reactors.

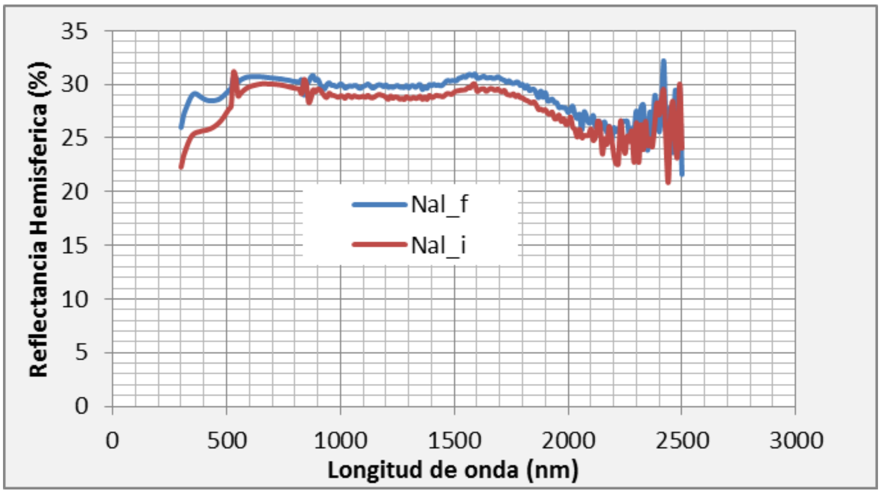

Figure 96. Hemispherical Reflectance curves for NAI samples after 100 cycles.

Preliminary tests on the ageing were performed at Madrid Laboratory using an Electric Furnace. Figure 96 presents the results of hemispherical reflectance of two NAI samples before and after 100 cycles.

The testing conditions have been chosen for the requirement of the receiver to resist temperature higher than 1000°C. These tests are very useful, particularly when they are conducted under the most aggressive conditions that the material may experience. For further comparison, a test campaign with at the Solar Furnace is scheduled next year in real conditions with high solar fluxes.

A Lunar CHEMical In-Situ recource utilization Test plant. ALCHEMIST

Participants: SAS (Belgium), CIEMAT-PSA (Spain), Aavid Thermacore (UK), Ariane Group (France)

Contact: Thorsten Denk; tdenk@psa.es

Funding agency: European Space Agency, Contract ITT AO-9107.

Background: In the last years at the Plataforma Solar de Almería (PSA), there was designed, built, and tested in the Oresol project a full-scale test plant able to reduce ilmenite (a common mineral on the Moon) with the help of hydrogen and concentrated solar power to produce water. The knowledge and practical experience gained in Oresol was the decisive advantage of PSA to be invited by SAS to participate in the ITT.

The project ALCHEMIST is the first ESA payload study that defines the high level details of a lunar ISRU payload operating with the hydrogen reduction process.

Objectives: The principal goal of the study was to determine the requirements of a hydrogen reduction plant operating on the Moon. This includes the sub-systems for excavation of the lunar sand (regolith), the pre-processing like sieving or enrichment, the processing of the regolith with hydrogen at 900°C, and the fluid management for the hydrogen supply, recirculation, and extraction and storage of the product water. Goal of the mission is to produce 100g of water from lunar regolith.

Achievements in 2018: In 2018, the study was carried out like required by ESA. The concept of the reactor and of the fluid management system was the responsibility of PSA. First, basic values like gas velocity, gas flow, reactor geometry (diameter, height), residence time, and power requirements were estimated, calculated and determined. Of special importance is the gas velocity in the reactor. This value is difficult to obtain, because besides the usual parameters like particles size, sphericity, porosity and density, and gas density and viscosity which are determined by gas composition and temperature, the gravity plays a crucial role. As on the Moon it's only 1/6th of Earth's value, there is very few experimental data available. This requires a design with a large margin for the main gas flow parameter.

After that, the basic reactor geometry was designed. Some complementary activities were carried out in parallel. They included a first selection of possible landing sites. The condition is that they are rich in iron oxide (FeO). Of special interest are sites rich in ilmenite ($FeTiO_3$) or pyroclastic deposits (glass beads). The lead candidate of this study (partially due to ESA-demand) was the pyroclastic deposit in the Schrödinger basin on the far side of the Moon near the Schrödinger G volcanic vent. Another complementary work was the planning for a test payload in a parabolic flight to study the behaviour of fluidized beds under lunar gravity.

Finally, a test campaign with the Oresol reactor was scheduled for October and November 2018. These were the first solar tests with this plant since June 2017. Nevertheless, it worked rather well immediately. The main objective of the tests was to increase the proportion of hydrogen in the feed gas (due to safety reasons, the feed gas is mainly argon) to demonstrate the production of 100g water in one single test. The production goal of 100g (Figure 97) of water was finally achieved in another test campaign in the second week of 2019. Hydrogen conversion >90% was demonstrated.

Figure 97. Production of 100g of water from hydrogen reduction of ilmenite demonstrated with the Oresol experiment in PSA's Solar Furnace SF60.

The ALCHEMIST project got a very high positive rating from ESA, and thanks to this success, a second project/study was awarded to be executed in 2019. The goal is to deepen the work of ALCHEMIST to gather all the necessary information to enable ESA to prepare a sound proposal for the ESA Council on Ministerial Level 2019.

6 Solar Desalination Unit

6.1 Introduction

The Solar Desalination Unit (UDeS in its Spanish acronym) has the objective of new scientific and technological knowledge development in the field of desalination and thermal separation processes powered by solar energy.

Main current research lines are the following:

- Large-capacity thermal processes with special emphasis in multi-effect distillation (LT-MED, TVC-MED, ABS-MED)
- Small-capacity thermal processes with special emphasis in membrane distillation (MD) and forward osmosis (FO)
- Co-generation of electricity and desalinated water (CSP+D)
- Salinity-gradient power generation: reverse electrodialysis (RED) and pressure-retarded osmosis (PRO)
- Thermal-driven separation processes for brine concentration and industrial waste water treatment
- Dynamic modeling, process optimization and advanced control strategies in solar desalination processes.

During 2018, the PSA Solar Desalination Unit has continued with its relevant activity in the field of thermal water separation processes using solar energy. New market niches were identified for thermal technologies like MED and MD in the regeneration stage of closed-loop salinity-gradient power generation processes and water recovery from CSP plant effluents. New simulation model development based on neural networks and the implementation of hybrid and multivariable control strategies have allowed and important improvement in the yield of thermal distillation technologies when coupled with a variable source like solar energy.

Figure 98. Members of the UDeS Unit.

The international relevance of the developed activities is clearly supported by the following positions currently hold by the unit:

- Member of the European Desalination Society (EDS) Board of Directors (2016-2019)
- Coordination of the Renewable Energy and Desalination Working Group of the European Water Platform (WssTP)
- Coordination of the Renewable Energy Desalination Action Group of the European Innovation Partnership on Water of the European Commission.
- Operating Agent of SolarPACES (Solar Power and Chemical Energy Systems) Task VI (Solar Energy and Water Processes and Applications).

During the year 2018 research activities were developed within the framework of projects covering both national and international activities with academic and industrial involvement.

6.2 Projects

Zero Carbon Resorts towards Sustainable Development of the Tourism Sector in the Philippines and Thailand (ZCR2)

Participants: Gruppe Angepaste Technologie GrAT (AT) (coordinator), Palawan Council for Sustainable Development PCSD (PH), Green Leaf Foundation GLF (TH), Health Public Policy Foundation HPPF (TH), CIEMAT-PSA (ES)

Contact: Guillermo Zaragoza, guillermo.zaragoza@psa.es

Funding agency: European Commission, SWITCH-Asia Programme.

Background: This project builds upon the success and achievements of the ZCR in the Philippines (2009-2014) for replication and upscaling. Regional approach will be implemented through ZCR intervention in Thailand and Green Certification in the Philippines, while increasing the access to green finance and improving policy exchanges on SCP in tourism in both countries.

Objectives: The overall objective of this project is to contribute to sustainable development of the tourism sector and its value chain in the Philippines and Thailand with a focus on reduction of resource consumption and CO_2 emissions.

Achievements in 2018: During this year this project has concluded with the publication of more results on the evaluation of commercial membrane distillation modules for solar seawater desalination.

Conversion of Low Grade Heat to Power through closed loop Reverse Electro-Dialysis, RED-Heat-to-Power

Participants: WIP (D) (coordinator), UNIVERSITY OF PALERMO (IT), FUJIFILM (NL), REDSTACK (NL), CIEMAT-PSA (ES), UNIVERSITY OF EDINBURGH (UK), UNIVERSITAT POLITECNICA DE CATALUNYA (ES)

Contact: Guillermo Zaragoza, guillermo.zaragoza@psa.es

Funding agency: European Commission, Horizon 2020 programme

Background: The concept is based on the generation of electricity from salinity gradient using Reverse Electrodialysis with artificial saline solutions operating in a closed-loop. The original salinity gradient is regenerated by a separation step that uses heat at 40 – 100°C.

Objectives: The overall objective is to prove this revolutionary concept, develop the necessary materials, components and know-how for bringing it to the level of a lab prototype generating electricity from low-grade heat at higher efficiencies and lower costs than ever achieved to date. The specific objective of CIEMAT-PSA is to select the most suitable technologies for the regeneration process and the combinations of salts and solvents that can maximise the system performance.

Achievements in 2018: During this year, a test site was built at PSA to evaluate the combination of a reverse electrodialysis stack with an advanced membrane distillation technology to regenerate the salinity gradient. The results reached a record heat efficiency in the MD process (less than 50 kWh thermal energy consumed per m^3 of distillate produced) by using a vacuum-enhanced air-gap configuration with multi-envelopes spiral-wound modules. This design was subsequently used in the pilot plant that was built in the facilities of Fujifilm in Tilburg (The Netherlands) and is currently under demonstration

Figure 99. Pilot-plant for assessment of combined reverse electrodialysis and membrane distillation

<u>**Control and energy management strategies in production environments with support of renewable energy, ENERPRO**</u>

Subproject title: Efficient energy control and management of solar thermal desalination systems, EFFERDESAL

Participants: UAL (ES) (ENERPRO), CIEMAT-PSA (EFFERDESAL)

Contact: Diego-César Alarcón-Padilla, diego.alarcon@psa.es

Funding agency: *Ministerio de Economía y Competitividad, Plan Estatal. I+D+i* 2013-2016 *orientada a los retos de la sociedad*.

Background: Due to increasing demand -for energy and water, most countries are promoting the efficient use of these resources to reduce costs and increase sustainability. Generally, energy efficiency is not only associated with technological improvements, but also with the improvement of control and energy management. This is the main framework of this research project ENERPRO, which is a natural evolution of a previous project, POWER, where both UAL and CIEMAT-PSA subprojects focused on heat/cooling and water management.

Objectives: The main objectives of the subproject are: (1) dynamic modeling of solar-gas hybrid desalination plants; (2) analysis of energy storage systems and auxiliary systems for energy cost reduction; (3) design of simplified models for control purposes; (4) development of MPC strategies for desalination plants; (5) coupling of solar desalination plants to supply water to greenhouses and buildings; and (6) testing of control algorithms both in simulation and in the real installations.

Achievements in 2018: Among the most important activities during this year are the improvement of static and dynamic models for flat-plate solar collector fields, development of new neural network-based models for membrane distillation processes and the development of new multi-variable and hybrid control strategies for solar-powered distillation. Research activities for the identification of the best operating conditions for MED-DEAHP plants, techno-economic assessment of RO+CSP and RO+PV configurations and experimental characterization of the balance of plant for small-aperture parabolic trough solar collector systems have been also concluded during the last year of the project.

<u>Resource recovery from industrial waste water by cutting edge membrane technologies, REWACEM</u>

Participants: FRAUNHOFER INSTITUTE (coordinator) (DE), AEE INTEC (AT), BFI (DE), UNIPA (IT), CIEMAT-PSA (ES), DEUTSCHE EDELSTAHLWERKE (DE), SOLARSPRING (DE), AT&S (AT), ELECTRONIQUEL (ES), DEUKUM (DE), AIZ (AT), USTUTT (DE), TECNOZINCO (IT), PSE (DE)

Contact: Guillermo Zaragoza, guillermo.zaragoza@psa.es

Funding agency: European Commission, H2020 Programme

Background: Production of metal goods brings, along with the generation of a multitude of different wastewater streams as the ones from cooling circuits and gas cleaning, rinsing water and diluted pickling acids from electroplating as well as washing water from casting of tools and automotive components. The high demand of water, often needed in demineralized quality for rinsing or washing purposes, is already a problem for production sites in the semi-arid regions of Southern Europe. Additionally, metal processing consumes plenty of different process fluids like acids, bases, and salts leading to contaminated wastewater streams, which need disposal causing high costs and significant environmental impact in general.

Objectives: The main objective of REWACEM Project is the application and demonstration of innovative and efficient water treatment technologies with the effect of a significant reduction of water use, waste water production, chemical consumption and energy use for the metal production, processing and coating industries. The proposed approach is an integrated system comprising between one and two cutting edge membrane technologies (Diffusion Dialysis (DD) and Membrane Distillation (MD)) which is highly suitable for adaptation to the manifold metal processing branches using low grade waste heat and concentration gradients to provide energy efficient waste water treatment and liquid stream recovery.

Achievements in 2018: During this year, the activities continued with the building of the components of the pilot plant that will be installed at the facilities of the ELECTRONIQUEL company in Gijón (Spain). The objective is to evaluate a combination of diffusion dialysis and membrane distillation for recovering sulfuric acid and copper from the exhausted baths of the copper plating processes and, on the other, reduce the consumption of rinsing water by reusing it after treatment.

Solving water issues for CSP Plants (SOLWATT)

Participants: TSK (coordinator) (ES), CEA (FR), DLR (DE), CIEMAT-PSA (ES), CRANFIELD UNIVERSITY (UK), IK4-TEKNIKER (ES), RIOGLASS SOLAR (ES), INDETEC (ES), FENIKS (ES), BSC (ES), BRIGHTSOURCE (IL), AMIRES (CZ), BERTIN (FR)

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Funding agency: European Commission, H2020 Program

Background: The electricity production from concentrated solar thermal power (CSP) has to cope with two main challenges, the reduction of the water consumption since a high insolation often occurs in locations with a lack of water resources, and also the improvement of the cost-effectiveness of the CSP technology. Water at CSP plants is required for the following tasks: cleaning of the collector solar field, cooling the power block condenser in the case of a water-cooled steam turbine and to make-up water in the steam cycle.

Objectives: The overall purpose of the SOLWATT project is to upscale, implement and demonstrate cost-effective technologies and strategies that bring about a significant reduction of water of CSP plants while ensuring excellent performance of electrical power generation. The SOLWATT approach proposed will tackle all segments of water consumption in a CSP plant by:

- 90 % for reduction of cleaning operations;
- 15 to 28 % for cooling of turbine condenser;
- 90 % for recovery and recycling of water;

Then, a total reduction of water consumption by:

- 35 % for a wet cooled CSP plant
- 90 % for a dry cooled CSP plant

Achievements in 2018: The project is jointly developed by the Solar Desalination Unit (UDeS) and the Concentrating Solar Systems Unit (USSC). UDeS participates in the design of a multi-effect evaporator (MEE) unit to be installed at a real CSP plant (La Africana CSP plant located in Córdoba, Spain), which will treat water from different points of the CSP plant to be recovered and re-introduced again in the process. During 2018 UDeS has been working on the functional and technical specifications of the MEE prototype to be implemented at La Africana. The main effort devoted by USSC was focused on the preparation of a technical questionnaire and the test plan & methodology for each of the innovations that will be installed at La Africana solar plant and tested under real operating conditions during the last two years of SOLWATT. The objective of the questionnaires is to collect important information about the requirements and technical specifications of the prototypes that must be installed and tested at La Africana plant. The technical questionnaires initially prepared and distributed by PSA have been improved and partially filled in by the relevant partners, thus defining the requirements associated to the implementation and testing of each innovation.

Network for Excellence in Solar Thermal Energy Research, NESTER

Participants: CYI (coordinator) (CY), CIEMAT-PSA (ES), ENEA-UTRINN (IT), CNRS-PROMES (FR), RWTH-AACHEN (DE)

Contact: Diego-César Alarcón-Padilla, diego.alarcon@psa.es

Funding agency: European Commission, H2020 Programme

Background: The geopolitical placement of Cyprus offers excellent opportunities for cultivating a research and innovation niche in solar technologies. At the same time, the remoteness of the corresponding centres of Excellence of EU is a major impediment. The NESTER Project strives to enhance the advantages and ameliorate the disadvantages of this geographical placement.

Objectives: The NESTER Project aims in upgrading the scientific and innovation performance of the Cyprus Institute (CyI) in the field of Solar-Thermal Energy. The upgrade will be achieved by embedding the Institute's activities in a network of excellence, which will provide access to the latest know-how and facilities, train CyI's scientific and technical personnel and link it with the European Industry. The substantial investments made/planned by CyI in infrastructure and personnel will thus become more efficient and competitive allowing claim to international excellence.

Achievements in 2018: During the last year of the project the most remarkable activities have been the collaboration in the organization and participation of a winter school, a specific workshop about solar desalination that was held in Cyprus, a mentoring visit to CyI and the reception at PSA of several researchers from CyI in order to collaborate in the fields of solar thermal desalination.

7 Water Solar Treatment Unit

7.1 Introduction

The main objective of the Research Unit of Solar Treatment of Water is the use of solar energy for promoting photochemical processes, mainly in water for treatment and purification applications but also for chemical synthesis and production of photo-fuels. Our knowledge about solar photochemical systems and processes at pilot and pre-industrial scale is backed by 25 years of research activity. The group has been involved in international and European projects from FP4, FP5, FP6, FP7 EU and H2020 program, within the topics of environment, material sciences, chemical engineering, chemistry and microbiology. We are also pioneers in the use of advanced analytical techniques for the evaluation of advanced oxidation treatments.

Our group has organized, in collaboration with CIESOL, "The European Meeting on Solar Chemistry and Photocatalysis: Environmental Applications (SPEA-10") from the 4th to 8th of June 2018. It is a well-established series of events which attracts researchers and professionals from all over the world to discuss advances and recent trends in the field of photocatalysis, solar photochemistry and environment-related applications.

The research activities already consolidated by this unit are the following, cross-linked with the projects and networks summarised below:

- Solar photocatalytic and photochemical processes as tertiary treatment for the removal of pollutants of emerging concern and microorganisms, related with **NEREUS** and **PHOTOCAT** networks, **ECOSAFEFARMING** project and **AQUALITY** Marie Skłodowska-Curie Action.
- Solar photochemical processes for the remediation of industrial wastewaters, related with **TRICERATOPS** project.
- Integration of Advanced Oxidation Processes with other water treatment technologies (NF/UF; Ozone, Bioprocesses, etc.), related with **TRICERATOPS** project and **AQUALITY** Marie Skłodowska-Curie Action.
- Evaluating photocatalytic efficiency of new materials under solar light in pilot reactors, related with **FOTOFUEL** network and **ECOSAFEFARMING** project.
- Photocatalytic and photochemical processes for water disinfection in different scenarios related with **WATERSPOUTT** project and **ALICE** Marie Skłodowska-Curie Action.
- Pilot solar photo-reactors for production of hydrogen and other photo-fuels, related with **FOTOFUEL-II** network and **RATOCAT** project.

7.2 Projects

<u>**Network: New Challenges in Solar Fuels production, FOTOFUEL-II**</u>

Participants: IMDEA Energía (Coord.), CIEMAT-PSA, ICP-CSIC, UPV-CSIC (ITQ), IMDEA Materiales, Institut Catala de Investigacio Quimica, Laboratorio de Luz de Sincrotrón (ALBA-CELLS), UB, UJI, Instituto de Investigación en Energía de Cataluña (IREC)

Contact: S. Malato Rodríguez, sixto.malato@psa.es

Funding agency: Spanish Ministry of Economy and Competitiveness, Network of Excellence (Reference ENE2016-82025-REDT)

Background: According to the IEA report from the COP21 meeting, it will be necessary to reduce emissions by 40-70 % in order to limit the global temperature increase to 2°C with respect to preindustrial values. This will implies an investment of 13.5 trillion $ in energy efficiency and low carbon technologies. In this frame, solar fuels, produced from abundant feedstocks (CO_2, H_2O) and using sunlight as renewable source, represent one of the most promising alternatives to fossil ones.

Objectives: The goal of FOTOFUEL is to significantly advance the development of materials and devices for efficient solar fuels production. With that purpose, synergies and network collaboration will be promoted among the main research groups in this field, providing them, at the same time, with a platform for international exposure.

Achievements in 2018: This network is based on a joint work program on training, dissemination and technology transfer. The main activity in 2018 related with Solar Treatment of Water Unitwas FOTOFUEL School on Solar Fuels In connection with the SPEA10 conference. This school was aimed at PhD students and postdoctoral researchers attending the SPEA10 conference and included lectures on fundamental aspects of solar fuels obtainment by photochemical processes. See: http://fotofuel.org/

Network: New photocatalytic materials and reactors for removal of micropollutants and pathogens, FOTOCAT

Participants: Universitat Rovira i Virgili-URV (Coord.), CIEMAT-PSA, UEX, URL, UAL/CIESOL, ICRA, UPV, URJC

Contact: M. Ignacio Maldonado, mignacio.maldonado@psa.es

Funding agency: Spanish Ministry of Economy and Competitiveness, Network of Excellence (Reference CTM2015-71054-REDT)

Background: To achieve a sustainable use of water resources, it is necessary to increase the volume of reclaimed water. To obtain an effluent of suitable quality for the different uses permitted for reclaimed water it is necessary to reduce the content of pathogens and persistent organic pollutants. This could be achieved through the proper development of photocatalytic processes.

Objectives: The aim of the FOTOCAT network is to achieve a significant progress in the development of materials and photocatalytic reaction systems for the treatment and reuse of wastewater. The research groups that comprise the FOTOCAT network have altogether a wide experience in the synthesis of new catalytic materials, photocatalytic reactor design and implementation of these processes for the treatment and reuse of wastewater, allowing them to face the challenges identified for their industrial application. The various actions planned to be undertaken will contribute to the training of new researchers in the application of photocatalytic processes for water treatment and reuse and the need for its sustainable use.

Achievements in 2018: Network of excellence. The work is based on scientific collaboration and joint implementation of a work program based on cutting-edge research, information, dissemination and communication and technology transfer. The last presential coordination meeting of this network took place the 5th and 6th of June, 2018 in Almería organized by the Solar Treatment of Water Unit of PSA.

Among the activities of this network, a thematic workshop specially focused on related industries. It was held the 18th of July, 2018 in Tarragona with the title “Photocatalytic applications in wastewater treatment”. See: http://fotocat.es/

Network: New and emerging challenges and opportunities in wastewater reuse, NEREUS

Participants: 336 participants from 40 countries (EU and associated countries). NIREAS-International Water Research Center (Cyprus), coord. CIEMAT-PSA is member of managing committee and co-coordinates Working Group 4.

Contact: S. Malato Rodríguez, sixto.malato@psa.es

Funding agency: European Cooperation in Science and Technology, H2020- Cost Action (ES1403)

Background: Treated urban wastewater is currently widely reused to compensate for dwindling water supplies, as it is considered to be a reliable alternative water source. Several knowledge gaps associated with wastewater reuse still exist, including: (a) accumulation of metals/elements in the soil and their subsequent uptake by plants and crops, (b) fate of organic microcontaminants in downstream environments, and (c) epidemiological potential of antibiotic resistant bacteria and/or resistance genes (ARB&ARG) discharged from treated effluent. Contamination of the environment, the food chain, drinking water, etc with ARB&ARG is presently considered a serious public health problem.

Objectives: The Action intends to (i) deliver best-practice recommendations to wastewater reuse in irrigation, (ii) develop uniform means for assessing wastewater quality with respect to contaminants of emerging concern and also ARB&ARG, (iii) establish specifications for technologies able to produce wastewater with minimal levels of such contaminants, and (iv) compile valid and reliable information to be used in regulatory frameworks.

Achievements in 2018: Solar Treatment of Water Unit coordinated WG 4 (Technologies efficient/economically viable to meet the current wastewater reuse challenges) (i) to consolidate knowledge on the fate of microcontaminants during treatment, (ii) to assess the fate of ARB&ARG during biological processes and characterize their removal mechanisms, (iii) to assess the effect of advanced oxidation processes (AOPs) on ARB&ARG, (iv) to assess the economic feasibility of AOPs compared to conventional processes and (v) to identify optimum integrated technologies in terms of global efficiency/compliance with standard parameters. WG4 produced two deliverables (Understanding the contribution of biological processes to antibiotic resistance spread into the environment; The best available technologies able to minimize the release of contaminants of emerging concern, including ARB&ARGs, and fulfil requirements for a safe reuse) and jointly with other WG organised XENOWAC II -Conference (10-12 October 2018, Limassol Cyprus). Deliverables have been upgraded as review papers to be published in scientific journals. See http://www.nereus-cost.eu/

Water Sustainable Point Of Use Treatment Technologies, WATERSPOUTT

Participants: CIEMAT-PSA; Universidad Rey Juan Carlos; University of Strathclyde; University of Malawi; Ecole Polytechnique Federale de Lausanne, National University of Ireland Maynooth, Makerere University; Stellenbosch University; Ecosystem Environmental Services S.A.; Mekelle University; Buckinghamshire New University; Helioz gmbh; Dublin City University; Stichting IHE Delft; Universidad de Santiago de Compostela; Royal College of Surgeons in Ireland (coordinator).

Contact: M. Inmaculada Polo López, inmaculada.polo@psa.es

Funding agency: European Commision. Horizon 2020. H2020-WATER-2014-2015/H2020-WATER-2015-two-stage.

Background: Solar water disinfection (SODIS) is a household water treatment that uses direct sunlight to inactivate pathogens in water using 2-L PET bottles. It is widely accepted in developing countries, but some limitations still affecting the efficiency of this process such as the volume of water to be treated per batch (bottle).

Objectives: The main objective is to increase the user uptake of SODIS by designing and piloting three novel solar based technologies (Solar rainwater reactors, Solar jerrycans and Solar-ceramic filtration) providing larger volumes (≥20L) of treated water per day. CIEMAT objective is to develop, construct and test reactors based on SODIS for disinfection of harvested rainwater providing 125 liters/day of treated water.

Achievements in 2018: During this year, the 4 field prototypes (2 for Uganda and 2 for South Africa) with volume treatment capability of 90 and 140 L built by Ecosystem S.A and previously tested at CIEMAT-PSA have been coupled with rainwater harvesting tanks in their respective final locations in Africa (Figure 100). Currently, the SODIS capability of all field reactors are being assessed by both African partners involved in the project.

On the other hand, the capability of several ceramic filters designed by BUCKS (Waterspoutt partner) considering local material commonly found in Malawi, including clay material, cloth and plastic buckets has been tested at CIEMAT-PSA under controlled conditions. The microbial retention capability of the three types of filters was investigated using E. coli and MS2 in the dark and in combination with sunlight. Results demonstrated a high variability on the retention performance together with several drawbacks on the manufacture and handling of the filters, discarding therefore it use in the field. Additional tested has been also conducted at CIEMAT-PSA using a commercial solar ceramic filters available in Malawi ("SAFI" filter) (Figure 100) and retention results in the dark showed > 6-Log reduction value of E. coli. Nevertheless, this filter showed a reduced SODIS performance. Therefore, currently in Malawi, plastic buckets (tested in 2017 at CIEMAT-PSA) in combination with cloth as pre-filter step are being tested as solar filters technologies for treat drinking water in the field. See also: http://www.waterspoutt.eu/

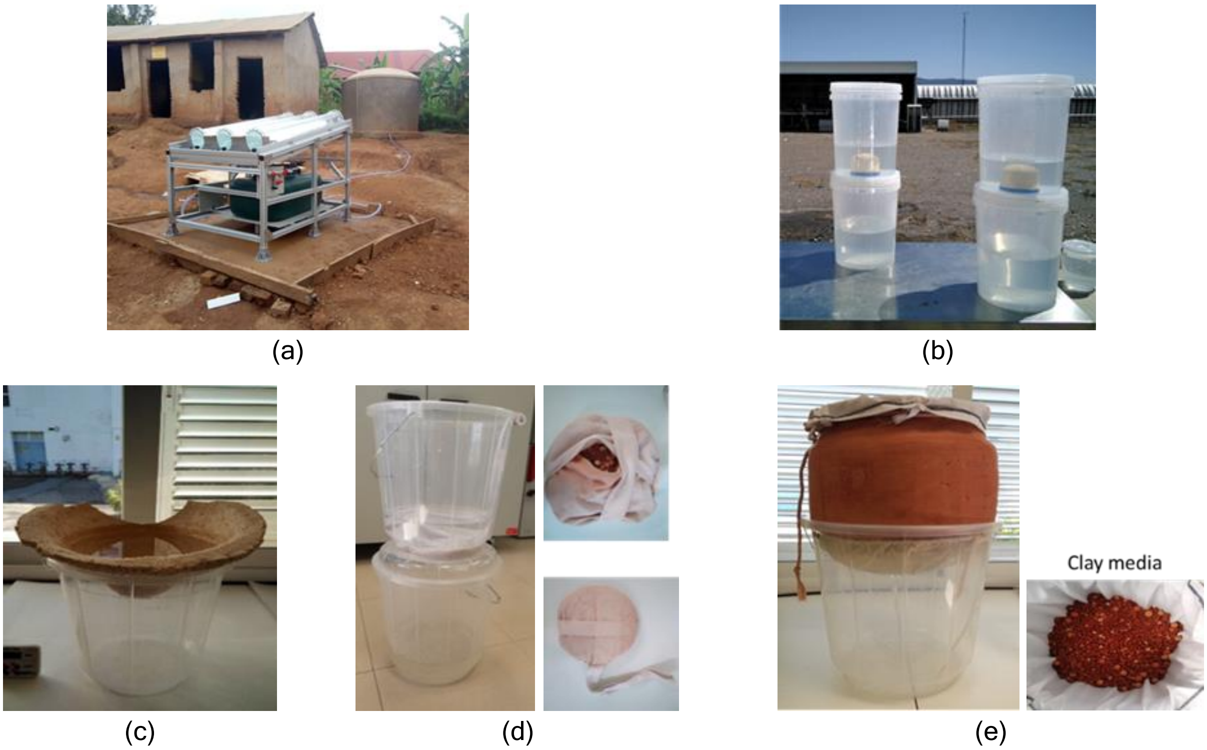


Figure 100. a) Solar reactor prototype installed in Kabuyoga primary school (Uganda); b) Safi filters located under natural sunlight at PSA facilities. Imagens of solar-ceramic filters tested at CIEMAT-PSA: c) Filter 1: Stepped stoneware filter; d) Filter 2: Pillow filter bag; e) Filter 3: Ceramic pot and view of clay media inside pot.

Efficient technologies for removal of contaminants of emerging concern, listed in 2013/39/EC Directive or significant risk substances according to 2008/105/EC Directive, TRICERATOPS

Participants: CIEMAT-PSA, UPV (Escuela politécnica Superior de Alcoy), Instituto Catalán de la Investigación de Agua (ICRA)

Contact: S. Malato Rodriguez, sixto.malato@psa.es

Funding agency: Spanish Ministry of Economy and Competitiveness (Reference CTQ2015-69832-C4-1-R)

Background: The initial hypothesis focuses different advanced oxidation processes, operational procedures and different ways of combining them for wastewater treatment. The project will focus water containing microcontaminants (MCs) of important concern identified by EU or already identified as risk substances for water.

Objectives: (i) Elimination by novel technologies of priority or emerging concern MCs present in wastewaters and listed in EU legislation; (ii) Propose photoreductive electron transfer processes for the elimination of contaminants recalcitrant to oxidation; (iii) Waste and wastewater valorization for elimination of MCs; (iv) Design of new photoreactors based on solar irradiation and LEDs; (v) Integration of nanofiltration processess and novel AOPs.

Achievements in 2018: The elimination of priority MCs (European regulation) has been achieved through novel technologies and evaluated by HPLC / MS. It has been proven that the participation of polyphenols or humic substances in the processes of photooxidation of MC allows improving the performance of the photo-Fenton process. Zerovalent iron has been used as a reducing agent. A photoreactor with iron wool was designed. It has been demonstrated that waste and wastewater can be valorised for its use in the elimination of MCs as well as recovering ammonium at the exit of the biological treatment by means of nanofiltration. The available ozone reactors as well as their coupling to the photoreactors already available have been modified. The parameters and operational variables have been established for the design of the LED reactor prototype. The working ranges of the most important variables of nanofiltration plant operation, integrated with solar AOPs, have been determined. See also: http://www.psa.es/es/projects/triceratops/index.php

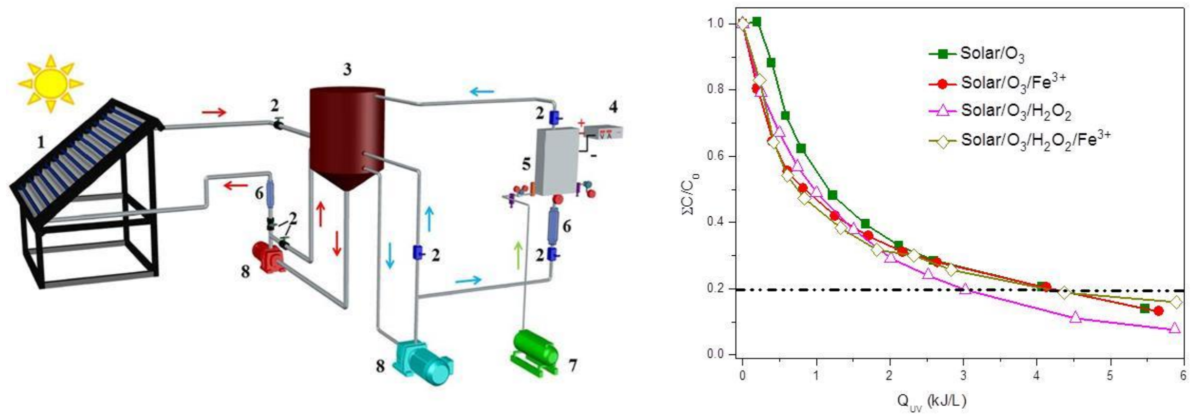


Figure 101. Photo-electro-Fenton pilot plant drawing (a). Results of solar ozonation to treat priority pollutants in water (b).

Accelerate Innovation in Urban Wastewater Management for Climate Change, ALICE

Participants: University of Ulster, Nothern Ireland Water Ltd., The Queen´s University of Belfast, Dublin City University, Dioenergy Ltd., Asociación BC3 Basque Centre for Climate Change, CIEMAT-PSA, GDW ESAMUR, Universita Degli Studi di Macerata, REINN Srl., Aset spa., University of Cyprus, Militos Symvouleutiki A.E.

Contact: Isabel Oller, isabel.oller@psa.es

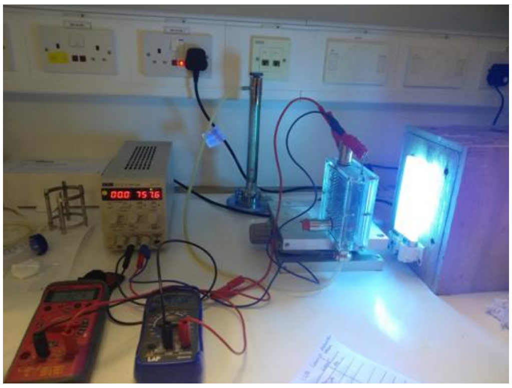
Funding agency: H2020- Marie Skłodowska-Curie Action (RISE) (GA 734560)

Background: The coming decades are likely to see some geographical areas experiencing a higher risk of flooding and other areas exposed to higher risks of droughts. More green and grey infrastructures, implementing increased effluent treatment including cooling and a greater recycling and reuse will pose a challenge in terms of financial sustainability of wastewater facilities.

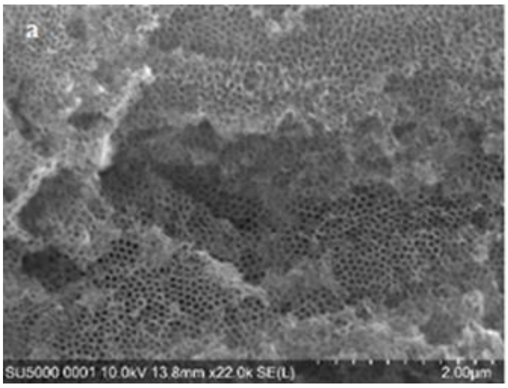
Objectives: Accelerate innovation in urban wastewater management to address the future challenges arising from climate change. The project will identify solutions and seek to remove barriers for their implementation. The aim will be achieved through secondments and the transfer of knowledge, creating an effective interdisciplinary and inter-sectoral cooperation among the partners involved.

Achievements in 2018: In this year, an ESR-secondment from CIEMAT-PSA in Northern Ireland Water Company and in the University of Ulster (in the Nanotechnology and Integrated Bioengineering Centre) took place from September to December 2018. During this collaborative stay, the efficiency of a novel urban wastewater treatment technology based on photo-electrocatalysis (PEC) with new materials has been investigated at laboratory scale (Figure 102). The simultaneous removal of three organic micro-contaminants (diclofenac, terbutryn, and chlorfenvinphos) and the inactivation of E. coli K12 were investigated using two new cathodes (Ti/Pt and carbon felt) and new electrodes made of nanotubes of titania. Results demonstrated a very good efficiency of the PEC technology (Figure 102) but more tests are in progress to deeply investigate the mechanisms of the photoelectrocatalytic system to explain the bacterial inactivation.

On the other hand, at CIEMAT-PSA, the previously developed and tested methodologies for identification of emerging contaminants and pathogens have been assessed in crops irrigated with non-treated and treated urban wastewater by solar processes (H_2O_2/solar and photo-Fenton). Two types of raw-eaten vegetables, i.e. lettuce and radish have been used as model of crops. The analysis of crops clearly showed a significant reduction of the pollutants presence (both emerging contaminants and pathogens) when UWW was solar-treated. See also: https://www.alice-wastewater-project.eu/



(a)



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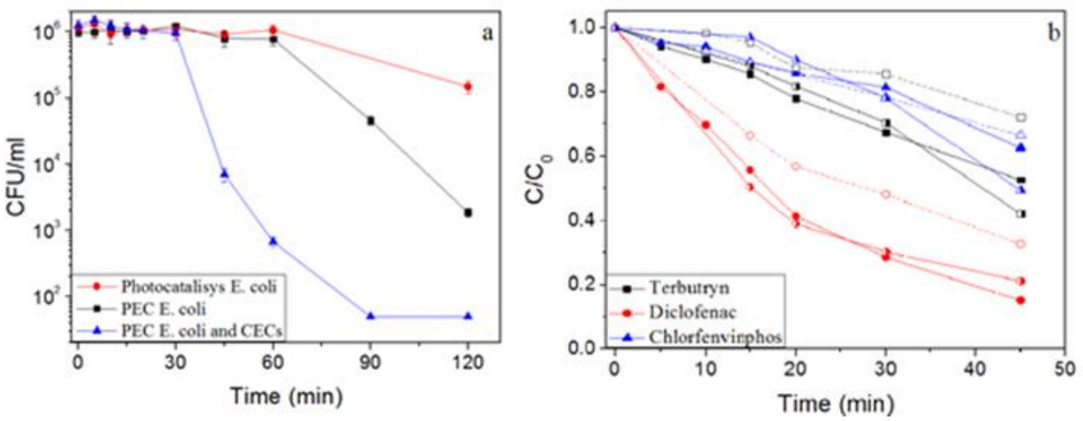

(c)

Figure 102.a) Laboratory scale set-up for photo-electrocatalysis (PEC) experiments; b) SEM image of TiO_2 Nanotubes; c) a-graph: Inactivation profile of E. coli by photocatalysis and carbon felt-PEC treatment both alone and simultaneously with CECs and b-graph: Comparison of CECs degradation during treatment by photocatalysis (open symbol), Ti/Pt-PEC (semi-solid symbol) and carbon felt-PEC test (solid symbol).

Interdisciplinar cross-sectoral approach to effectively address the removal of contaminants of emerging concern from water, AQUALITY

Participants: Universita Degli Studi di Torino, Universita Degli Studi del Piemonte Orientale Amedeo Avogadro, CNRS, Ecole Polytechnique, Karadeniz Teknik Universitesi, LIQTECH International A/S, Societá Metropolitana Axque Torino S.p.A., CIEMAT-PSA, Panepistimio Ioanninon, Universidad Politecnica de Valencia.

Contact: Isabel Oller, isabel.oller@psa.es

Funding agency: H2020- Marie Skłodowska-Curie Action (ITN) (GA 765860)

Background: The complex challenges of the production of safe and clean water requires different levels of action, which include the synthesis of green materials, the development of enhanced water treatment technologies, the implementation of effective legal tools against water pollution and the correct management of the present water treatment facilities.

Objectives: AQUAlity is a multidisciplinary, interdisciplinary and cross-sectoral European Training Network aiming to generate and promote 15 highly skilled scientists with the potential to face the present and future challenges concerning the protection of water resources from Contaminants of Emerging Concern and to develop innovative purification technologies more effective than conventional adsorption and biological treatments.

Achievements in 2018: First Aquality Symposium and Summer School in Photochemistry and Depollution took place in Clermont-Ferrand (France) from the 23rd to the 27th of April 2018. In addition, and as a part of the training activities within AQUAlity project, International Summer School on “Micropollutant Analysis and Abatement” was celebrated in the University of Aalborg in Denmark from the 27th to the 28th of August 2018, together with the Seminar on Advanced Water Purification Technologies (August 29, 2018) and the 2nd AQUAlity Symposium meeting (August 30-31, 2018). Two ESRs (Early Stage Researchers) were incorporated at the Solar Treatment of Water Unit at PSA on May 2018 and started working on “Assessment of novel advanced oxidation processes for removal of disinfection-by-products and CECs from drinking water” and “Application of advanced integrated technologies (membrane and photo-oxidation processes) for the removal of CECs contained in urban wastewater” (Figure 103). For more details visit the website: https://www.aquality-etn.eu/

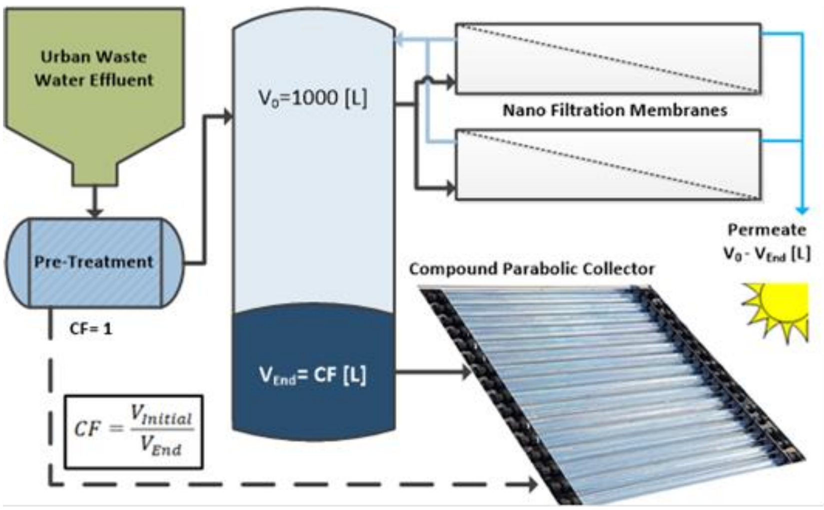

Figure 103. A diagram of the new filtration units and membranes to concentrate CECs during their oxidative degradation and to recover the photo-oxidizing agents making the overall process more effective and compact than the sole AOPs.

Development and testing of a novel photocatalytic system for efficient cogeneration of clean water and hydrogen for ecosafe agriculture, ECOSAFEFARMING

Participants: Istanbul University (Coord.), MIR Arastirma ve Gelistirme A.S. (Turkey), BUT - Brandenburg University of Technology (Germany), University Of Ontario Institute Of Technology (Canada), CIEMAT-PSA.

Contact: Sixto Malato, sixto.malato@psa.es

Funding agency: WATER JPI 2016, ERAN-NET COFUND WATEWORKS 2015 and Spanish Ministry of Economy and Competitiveness (Reference PCIN-2017-131).

Background: There has recently been increasing interest in urban wastewater (UWW) utilization for agricultural and hydrogen production as it agrees with the six main pillars of sustainable energy systems: (i) better efficiency; (ii) better cost effectiveness; (iii) better resources use; (iv) better design and analysis; (v) better energy security; and (vi) better environment.

Objectives: ECOSAFEFARMING project aims to bring a solution to water and energy issues by a new photocatalytic reactor integrating a photoactive photoanode electrode with a membrane stacking with the objective of design an efficient PCED (photocatalysis/electrodyalisis) reactor system for treatment-disinfection and desalination of UWW. In addition, this PCED system is further modified with a photoactive membrane to allow the cogeneration of hydrogen (H2-PCED) from solar (or UV) radiation and wastewater.

Achievements in 2018: CIEMAT-PSA will participate in the ECOSAFEFARMING project in the development and evaluation activities of the proposed PCED reactor and subsequent modification for the cogeneration of clean water and hydrogen (H2-PCED). CIEMAT-PSA will carry out experimentation and reuse analysis of UWW treated for raw eaten crops irrigation to evaluate the capacity of this technological solution to provide regenerated water for agricultural reuse. PCED reactor is being constructed by Istanbul University. No results are available for the moment, as CIEMAT tasks are scheduled in the 2nd and 3rd year of the project.

Rational design of highly effective photocatalysts with atomic-level control, RATOCAT

Participants: University College Cork (Tyndall National Institute-UCC, Ireland, Coordinator), Delft University of Technology (The Netherlands), *Instituto de Ciencia de Materiales de Sevilla*, CSIC (Spain), *Plataforma Solar de Almeria* (PSA), CIEMAT (Spain.)

Contact: M. Ignacio Maldonado, mignacio.maldonado@psa.es

Funding agency: M-ERA.net H2020 through Spanish *Ministerio de Economía y Competitividad* (MINECO). Project PCIN-2017-131.

Background: RATOCAT project aims to develop improved photocatalyst materials along with the processes for their production through atomic-level control of structure and functionality. The target technology is the generation of hydrogen gas from water using solar energy, which is a crucial component of the global transition to renewable energy sources.

Objectives: (i) Absorption of the visible-light solar spectrum by tailoring surface-modified catalyst materials; (ii) Surface modification of catalyst powders with non-critical materials via a deposition process that is scalable to the manufacturing environment; (iii) Wastewater as the feedstock for hydrogen.

Achievements in 2018: A $CuO+TiO_2$ mixture, based on two commercial and well characterized CuO and TiO_2 photocatalyst, has been used to produce hydrogen by solar light irradiation and in presence of different organic compounds (methanol, glycerol, formic acid, and the components of a wastewater coming from the biodiesel industry) acting as sacrificial electron donors. The tested system has shown similar hydrogen generation capacity and energy efficiency than more expensive ones based on the use of noble metal/photocatalyst composites. Formic acid has shown to be the most effective electron donor, although very close amounts of hydrogen are also produced with glycerol, and this is found as a waste compound released in large quantities at the biodiesel industry wastewaters. As seen in previous similar studies, the increase of solution conductivity hampers the hydrogen generation, and a slightly basic solution pH (pH 9) gives the best reaction conditions. Finally, the composite can be recovered and successfully reused giving the ensuing and sustained generation of H_2 while removing more than 50% of TOC.

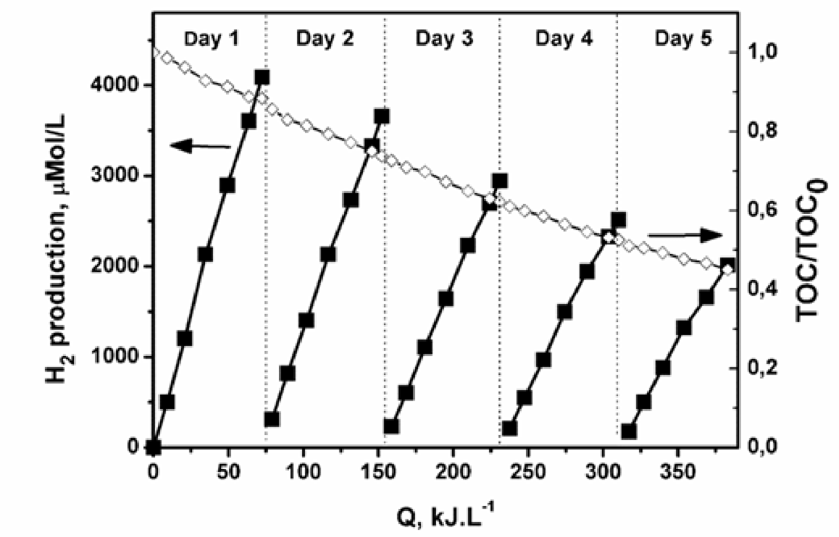

Figure 104. H_2 generation in consecutive photocatalytic experiments using the same aqueous solution and the same sample of TiO_2+CuO (allowed to settle overnight and re-suspended during the day). Reaction conditions: Formic acid = 0.05 M, TiO_2+CuO (10:1) = 0.2 g.L-1, pH = 2-3, V = 25 L.

8 Horizontal R&D and Innovation activities

8.1 Integrating National Research Agendas on Solar Heat for Industrial Processes, INSHIP

Participants: FRAUNHOFER (Germany), AEE-INTEC (Austria), CIEMAT (Spain), DLR (Germany), CNRS (France), ENEA (Italy), ETHZ (Switzerland), CEA (France), CYI (Cyprus), LNEG (Portugal), CTAER (Spain), CNR (Italy), CENER (Spain), TECNALIA (Spain), UEVORA (Portugal), IMDEA (Spain), CRANFIELD (UK), IK4-TEKNIKER (Spain), UNIPA (Italy), IST-ID (Portugal), FBK (Italy), CRES (Greece), METU (Turkey), EERA AISBL (Belgium), UNINA (Italy), UNIFI (Italy), US (Spain), CIC Energigune (Spain).

Contacts: Julian Blanco, julian.blanco@psa.es
Diego Martínez, diego.martinez@psa.es

Funding agency: European Commission, H2020-LCE-2016-ERA

Background: Process heat is recognized as the application with highest potential among solar heating and cooling applications. Solar Heat for Industrial Processes (SHIP) still presents a modest share of about 0.3% of total installed solar thermal capacity. As of today's technology development stage is quite restricted to low temperature applications, so INSHIP is focusing on CSP/STE technologies to widen the scope of industrial applications to a temperature range between 80 - 1500°C. INSHIP project correspond to a new funding scheme (European Common Research and Innovation Agenda-ECRIA) designed by the European Commission as the next step beyond the current Integrated Research Agendas (IRP) and specifically targeting EERA JPs.

Objectives: INSHIP is a framework engaging major European research institutes with recognized activities on SHIP, into an integrated to achieve the coordination objectives of: more effective and intense cooperation between EU research institutions; alignment of different SHIP related national research and funding programs, avoiding overlaps and duplications and identifying gaps; acceleration of knowledge transfer to the European industry, while developing coordinated R&D TRLs 2-5 activities with the ambition of progressing SHIP beyond the state-of-the-art.

Achievements in 2018: In addition to the PSA-CIEMAT contribution to a large number of technical activities (WPs 2 to 5), main role in this project is the coordination of WP6 (Integrated SHIP research infrastructures) and WP8 (Advanced Networking Activities). In the context of WP6, a map of Research Infrastructures (RIs) was created and embedded in the public area of the project website. The mobility program was launched, opening the possibility to all project partners, and approving three of the five submitted proposals by the Independent Panel of Experts. In the context of WP8, after the analysis of needed national and regional innovation strategies on SHIP, a questionnaire was designed and distributed among the partners to carry out a survey on existing SHIP industrial plants, to the assessment of possible scenarios and the potential socio-economic impact of a relevant SHIP deployment in Europe.

Figure 105. INSHIP 2nd General Assembly Meeting (Graz, Austria, 16th-18th January, 2018)

8.2 Network for Excellence in Solar Thermal Energy Research, NESTER

Participants: CYI (Cyprus, Coordinator), CIEMAT-PSA (Spain), ENEA-UTRINN (Italy), CNRS-PROMES (France), RWTH-AACHEN (Germany).

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Background: The NESTER network comprises of four leading institutions (CIEMAT, ENEA, CNRS-PROMES and RWTH - Aachen) with a comprehensive know-how in this field in the field of solar energy research and operating some of the most important facilities worldwide. This network target to enhance CYI capabilities and, as consequence, to positively impact on developing the knowledge economy of Cyprus. The substantial investments made/planned by CYI in infrastructure and personnel will thus become more efficient and competitive allowing claim to international excellence.

Objectives: The NESTER project aims in upgrading the scientific and innovation performance of the Cyprus Institute (CYI) in the field of Solar-Thermal Energy (STE). The upgrade will be achieved by embedding the Institute's activities in a network of excellence, which will provide access to the latest know-how and facilities, train CYI's scientific and technical personnel and link it with the European Industry. A number of activities are proposed in a detailed program which includes training and know-how transfer, seminars and networking events with European, Eastern Mediterranean and Middle East partners, autumn school activities, public outreach and awareness and networking events.

Achievements in 2018: CIEMAT, as a responsible of Work Package 3 of the project (Networking Activities) significantly contributed during 2018 to the achievements of the two secondments realized so far within the project which, in addition to a range of other networking activities (exchange visits, mentoring visits, …), have resulted in Cyprus Institute (CYI) interaction with a range of new networks, media, industry and policy makers and raised the profile of the institute in the field of Solar Thermal Electricity, both among the international academic community, but also the media (project target). Among these activities it should be noticed the realized NESTER school, which was instrumental in training local scientists and allowing them to interact with their peers in the European Research Area as well as the Eastern Mediterranean Region. This has helped CYI with its mission to be a bridge between researchers in these two regions.

9 Training and educational activities

The ruling principle of the *Plataforma Solar de Almería* training program is the creation of a generation of young researchers who can contribute to the deployment of solar thermal energy applications. Through this program, about forty-five students of different nationalities are admitted each year so that we can transmit the knowledge of solar thermal technology accumulated at the PSA in its more than thirty years of experience to new generations of university graduates.

The main features of this training program are:

- Management of the Ph.D. fellowship program in association with an agreement with the University of Almeria (UAL) and with the own program to young researcher of CIEMAT.
- European funded 'Erasmus' grants, for students from other countries, mainly German.
- Management of miscellaneous educational cooperation agreements with other entities for sending students to the PSA (Universities of Complutense-Madrid, Almería, Dalarna-Sweden, Caddy Ayyad- Morocco, Antofagasta-Chile, Antioquia-Colombia, Polytechnic of Timisoara-Romania, *Autónoma de Nuevo León*-Mexico, *Benemerita Autónoma de Puebla*-Mexico, Çukurova -Turkey, *Instituto Tecnológico y de Estudios Superiores de Monterrey*-Mexico, Hamm- Germany, CENIDET- Mexico, Salermo-Italy, Tras-os-Montes and Alto Douro-Portugal, Isfahan-Iran, Polytechnic delle Marche-Italy, *Federal de Minas Gerais- Brazil*, etc.)

The close and enduring collaboration between CIEMAT and University of Almería has allowed for carrying out the second edition of the Official Master's in Solar Energy. The hallmarks of this course, along with its quality, make it attractive proposition for students, both Spanish as well as those from other countries, who want to gain a first-rate qualification in the field of solar energy and its many applications.

Related with the Educational Cooperation Agreement between CIEMAT-PSA and the University of Dalarna (Sweden), from 3rd to 7th September, the "Solar Thermal Power" course was delivered by PSA researchers in the framework of the Master Programme in Solar Energy Engineering. With 5 credits, this course takes part on the 2nd cycle of this Master Programme organized by European Solar Engineering School, ESES (University of Dalarna).

The PSA is a founding member of the 'Alliance of European Laboratories on Solar Thermal Concentrating Systems' (SolLab), a virtual laboratory originally constituted by the main European concentrating solar energy research institutes, that is, PROMES-CNRS in Odeillo (France), the DLR Solar Energy Division in Cologne (Germany), the Renewable Energies Laboratory of the Federal Institute of Technology in Zurich (ETHZ, Switzerland), the Paul Scherrer Institute in Zurich (PSI, Switzerland) and the CIEMAT itself.

In order to promote the higher education of young researchers in the environmental applications of AOPs, as well as to overcome national boundaries and bureaucratic barriers, a group of European scientists founded the "European PhD School on Advanced Oxidation Processes" in June 2014. These scientists have constituted what they call the Management Committee, which is composed of members from different Universities and Research Institutes with a strong and internationally recognized expertise in this field. The PSA is one of the members of this school since its creation.

10 Events

17-18/01/2018

Technical Seminar

Leónidas Perez-Estrada, from the Solar Treatment of Water Unit, was invited to participate in the 4th Agilent Ion-Mobility Mass Spectrometry workshop at University of Utrecht (Holland).

27/02/2018

Official Workshop

Julián Blanco and Eduardo Zarza participated in the final workshop of STAGE-STE in Brussels. The overall situation of the CSP/STE sector was analysed during the workshop and the main results from STAGE-STE project were presented.

26/01/2018

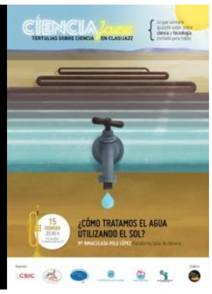
Lecture

Conference of Sixto Malato in the Master of Sustainable Management and Water Technologies of the University of Alicante.

15/02/2018

Divulgation and Dissemination

Inmaculada Polo, from the Solar Treatment of Water Unit, presented the activities performed in this field at the PSA research facilities in "Ciencia Jazz, tertulias sobre la ciencia en Clasijazz" in Almeria, as part of a series of similar scientific topics-speeches organized by the University of Almeria.



27/02/2018

Official Meeting

Prof. Julián Blanco, Eduardo Zarza and Sixto Malato participated in the Steering Committee of the Cooperation Agreement between CIEMAT and DLR at Koln, Germany.

02/03/2018

Doctoral Thesis

Eneko Setién Solas, from the Solar Concentrating Systems Unit, defended the Doctoral Thesis "Effect of concentrated solar radiation in long term aging of solar receivers". University of Almeria.

03/03/2018

Divulgation and Dissemination

The programme 'Los Reporteros' from the regional Canal Sur TV emitted at prime time a short report showing the main PSA research activities and installations, contributing to the science and technology divulgation and dissemination in Andalusia.

08/03/2018

Award

Loreto Valenzuela, from the Solar Concentrating Systems Unit, joint with another seven women, received a distinction in Women's Day from the City Council of Almeria recognizing their personal and professional career in the category "Research".

15/03/2018

Technical Visit and Official Meeting

The final meeting with the international partners involved in the European project STAGE-STE was held at PSA, including technical discussions and a visit to the PSA tests facilities.

27-29/03/2018

Kick-off meeting

The international project team IEC TC117 PT62862-4-1 "Solar thermal electric plants - General requirements for the design of solar tower plants" was launched in Geneva (Switzerland) with the participation of the Solar Concentrating Systems Unit through Jesús Fernández Reche.

03/04/2018

Lecture

Conference of Sixto Malato at Tarapaca University (Chile) invited by AylluSolar in an International Seminar about Wastewater Treatment.

26/04/2018

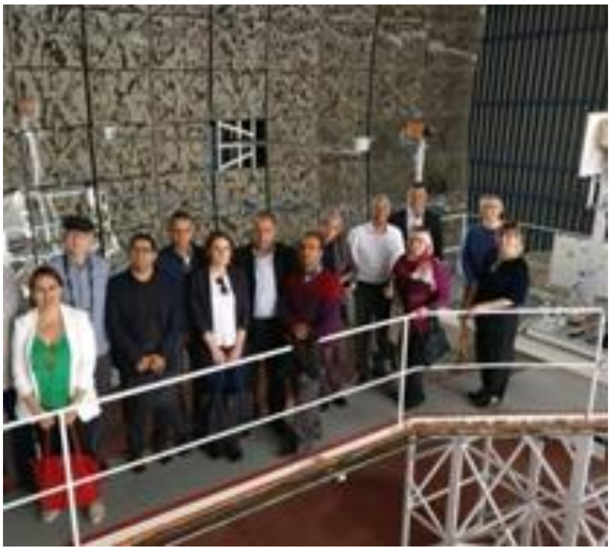
Technical Seminar

Mr. Mike Collins, from Commonwealth Scientific and Industrial Research Organization (CSIRO) Australian federal government agency, gave a presentation on "Enabling small heliostats technology. The CSIRO approach", during his research stage at PSA.

10/05/2018

Technical visit

A Delegation composed by a group of representatives of several official institutions and organisms related to the energy sector from Tunisia, joint with members of the World Bank, visited PSA to receive information about ongoing research activities on CSP technologies.



12/05/2018

Dissemination and divulgation

The scientific divulgation event called *Jamming Show* was held at Centro Cultural Galileo of Madrid (Spain), where Gema San Vicente, from the Solar Concentrating Systems Unit, was participating as invited researcher in the event titled "*Energías Renovables: ¿Son una alternativa del presente o un future incierto?*", to reinforce the exchange of knowledge between society and researchers on renewables energies.

21/05/2018

Technical visit

Paul Gauche (Manager of the Concentrating Solar Power Technologies Department of the National Solar Thermal Test Facility, NSTTF), and Joshua Martin Christian (Facility Manager of NSTTF), from the U. S. DOE visited the PSA facilities to check possible bilateral collaborations.

01/06/2018

Special Guest

Mr. Rainer Weiss, awarded the Nobel Prize in Physics in 2017, was welcomed by the PSA Director Julián Blanco and research staff, and visited the PSA facilities receiving technical information about the overall activities.

04-08/06/2018

European Meeting

Solar Treatment of Water Unit from PSA jointly with the University of Almería (CIESOL centre) have organized the 10th European Meeting on Solar Chemistry and Photocatalysis: Environmental Applications" in El Toyo, Almería (Spain). More than 320 participants from 44 countries attended this European Conference.

05/06/2018

Award

S. Malato received a distinction “Premio Duna” from Grupo Ecologista Mediterráneo (NGO of national impact focused on environmental protection).

18/06/2018

Lecture

Invited lecture of Isabel Oller on ALICE Project thematic workshop titled: “Solar based technologies for disinfection, decontamination and desalination of water for reusing purposes”, organized by ESAMUR and *Consejería de Agua, Agricultura, Ganadería y Pesca of Murcia* (Spain).

20/06/2018

Technical visit

A Chinese Delegation composed by engineers and representatives from power and energy companies, CSP projects owners and developers, visited PSA as part of the activities related to solar thermal power plants, aiming to identify the opportunities of collaboration.

25/06/2018

Technical visit

Marcelo Cortés, Carlos Portillo and Mauricio Trigo, from the University of Antofagasta (Chile) visited PSA to check possible collaborations between this university and PSA.

26/06/2018

Technical visit

A group of 7 staff professors from the Energy Engineering Department of the UNED in Madrid, headed by Dr. Antonio Rovira, visited in detail the PSA installations interested on research and technology development related to solar thermal power plants, with the aim of identifying fields of scientific collaboration.

26/06/2018

Institutional visit

PSA hosted the visit of the Ambassador of South Africa in Spain, His Excellency Mr. Lulama Smuts Ngonyama, to know about state of art on CSP technologies with the aim of establishing a bilateral institutional collaboration scheme.

10/07/2018

Workshop

Aránzazu Fernández, from the Solar Concentrating Systems Unit, organizes the workshop on “Measuring and modelling near-specular solar reflectance at different incidence angles” held at the PSA and sponsored by SolarPACES to discuss standardization issues on specular reflectance measurements.

12/07/2018

Doctoral Thesis

Mario Biencinto Murga, from the Solar Concentrating Systems Unit, defended the Doctoral Thesis “Simulation and optimization of direct steam generation solar thermal power plants with parabolic-trough collectors using a quasi-dynamic model”. UNED.

17/07/2018

Technical visit

A group of engineers from ENEL in Italy invited by Mr. Sebastian Caparrós from CAPSUN Tech. Co., visited PSA facilities as part of the collaboration activities in projects related to solar thermal technologies.

27/07/2018

Doctoral Thesis

Laura Ponce, from the Solar Treatment of Water Unit, defended the Doctoral Thesis “*Tratamiento de aguas residuales mediante procesos basados en la radiación solar y el ozono. Evaluación mediante técnicas analíticas y microbiológicas avanzadas”. University of Almeria*.

05/09/2018

Lecture

Invited lecture of Leonidas Perez-Estrada on the ALICE dissemination week, as part of the thematic workshop titled: “Solar based technologies for water and wastewater treatment for reusing purposes”, organized by ALICE Project partners at Queen’s University, Belfast (Northern Ireland).

11-13/09/2018

Invited Lecture

Jesús Fernández Reche participated as invited speaker on the Congreso Nacional de Estudiantes de Energías Renovables-2018 with the lecture “Concentración Solar. La

Tecnología de Torre Central", as well as collaborated on the development of the congress in different events and round-table sessions. Temixco-Morelos (México).

12/09/2018

Official Meeting and Technical visit

Mª José Jiménez welcomed the participants in the DYNASTEE SUMMERSCHOOL on 'Dynamic Methods for whole Building Energy Assessment', in the frame of the Energy in Buildings and Communities Program of the IEA, carrying out the working sessions and also a technical visit to the PSA research facilities.

22/09/2018

Award

Sixto Malato received a distinction from the Association of Former Students and Honors Friends, recognizing the merits in the excellence studies and professional career, celebrating the 25 years of the Almería University.

01-02/10/2018

Official Meeting

Rocío Bayón, from the Thermal Storage and Solar Fuels Unit, participated in the 4th Experts Meeting of the Task 58 Annex 33 on Compact Thermal Energy Storage, a platform of technology collaboration organized by the Institute for Sustainable Technologies of the Austrian Energy and Environment (AEE-INTEC) in Graz, Austria.

02/10/2018

Workshop

Participation of David Argüelles, from the Solar Concentrating Systems Unit, in the technical workshop held at Casablanca (Morocco) organized by NASEN and WASCOP consortium to discuss innovation to save water for mirror cleaning in solar thermal plants.

02/10/2018

Official Kick-off Meeting

The Kick-off Meeting of the new task 62 of the International Energy Agency on Solar Energy in Industrial Water and Wastewater management took place in Graz (Austria). This task in led by AEE-INTEC and the Solar Treatment of Water Unit from PSA (Isabel Oller) is leading subtask B.

08/10/2018

Technical visit

Mr. Pablo Maldonado, Development Engineer from Enerbosch Co., in Santiago de Chile, visited PSA interested on R&D activities related to solar thermal power plants, with the aim of future international collaboration.

19/10/2018

Technical visit

A group of 12 students from the Master Course on Solar Energy provided by PSA and the University of Almeria, visited in detail PSA facilities in the Inaugural Session of the course as part of the activities program.

25-26/10/2018

Lecture

Loreto Valenzuela presented the results of the Solar-ERA.NET projects SITEF and SIMON about the operational experience at PSA with novel silicone HTFs for parabolic troughs power plants in the “CSP Focus Innovation 2018” held in Xi’an (China), where she was invited as guest speaker.

29-31/10/2018

Lectures

Invited Conferences of Isabel Oller and Sixto Malato at Advanced Oxidation Processes school and “III Congreso colombiano de procesos de oxidación avanzada” at the University of Amazonia, in Florencia (Colombia).

30-31/10/2018

Training course

Ten students from the Master in Solar Energy of the Swedish University of Dalarna, spent two days at PSA receiving classes on topics related to concentrated solar thermal energy technology and its applications.

06/11/2018

Institutional Visit

The General Director of Ciemat, D. Carlos Alejaldre, visited the PSA research facilities receiving in detail technical information about the overall activities.

12/11/2018

Lecture

Isabel Oller was invited by the Andalusian Agency of Knowledge to present the project AQUAlity as a success case of a Marie Skłodowska-Curie Action in ITN modality (MCSA-ITN-2019) at the InfoDay of the University of Almeria.

21/11/2018

Technical visit

A Delegation composed by a group of representatives of MASEN, the Moroccan Agency for Solar Energy, visited PSA to receive information about ongoing research activities on CSP technologies, with the aim of future technical collaboration.

21/11/2018

Technical Seminar

Leonidas Perez-Estrada participated in the Waters Ion-Mobility High Resolution Mass Spectrometry workshop and applications of metabolomic software for the analysis of non-target compounds. Organized by University Institute of Pesticides and Water (IUPA) at the University Jaume I.

28/11/2018

Informative Seminar

The PSA hosted the Information Day about the Energy Challenge of the EU H2020 R&D Program on 'Secure, Clean and Efficient Energy', organized in collaboration with the Directorate of European Programs of the CDTI, the University of Almeria and the Andalusian Agency of Knowledge.

29/11/2018

Technical visit

A Delegation composed by a group of representatives of several official institutions and organisms related to the energy sector from Saudi Arabia, Emirates, Morocco, Malaysia and Chile, invited by the EXTENDA Regional Agency of Andalusia, visited PSA to receive information about ongoing research activities on CSP technologies.

03/12/2018

Doctoral Thesis

Alejandro García Segura, from the Solar Concentrating Systems Unit, defended the Doctoral Thesis "Durability analysis of reflectors used in concentrating solar thermal systems under corrosive gases". University of Almeria.

05/12/2018

Regional Cooperation

Participation of F. Martin, representing the PSA as part of the different public and private entities, in the Working Session to make contributions for defining the 'Industrial Strategy on the Renewable Energy in Andalusia', organized by the Regional Energy Agency.

13/12/2018

Official Meeting and Technical visit

The members of the Evaluation Committee of Access to the ICTS (*Infraestructuras Científicas y Técnicas Singulares*), welcomed by Ricardo Sánchez, celebrated their official meeting at PSA, including working sessions and technical visit to PSA test facilities.

19/12/2018

Doctoral Thesis

Mª Elena Carra Artero, from the Solar Concentrating Systems Unit, defended the Doctoral Thesis "Atmospheric extinction of solar radiation measurements in solar thermal electric plants". University of Almeria.

21/12/2018

Social Act

The Director of PSA, Julián Blanco, invited to all the personnel to the Social Act where the overall resume of R&D activities carried out along the year 2018 and the planning for next year were exposed.

11 Publications

PhD Thesis

Biencinto Murga, Mario (2018). Simulación y optimización de centrales termosolares de generación directa de vapor con captadores cilindroparabólicos usando un modelo cuasidinámico. Universidad Nacional de Educación a Distancia, Madrid.

Carra Artero, Maria Elena (2018). Medida de la extinción atmosférica de la radiación solar en centrales solares termoeléctricas de receptor central. Universidad de Almería, Almería.

García Segura, Alejandro (2018). Durability analyses of reflectors used in concentrating solar thermal systems under corrosive gases. Universidad de Almería, Almería.

Setien Solas, Eneko (2018). Efecto de la radiación solar concentrada en el envejecimiento a tiempos largos de receptores solares de alta concentración. Universidad de Almería, Almería.

Dissertations

Antonio Javier Alonso Martos. *(In Spanish)* "Análisis de renovaciones de aire en edificios mediante técnicas no intrusivas y su comparación con métodos basados en gases trazadores". Master thesis. Mechanical Engineering. Almería University. 13/07/2018. Directors: Manuel Pérez García, María Jose Jiménez Taboada.

Miguel del Águila Cano. *(In Spanish)* "Estudio técnico y propuestas de mejora para la eficiencia energética de la edificación auxiliar del Laboratorio de Ensayos para Componentes de la Edificación (LECE)". Master thesis. Master in Solar Energy. Almería University. 17/09/2018. Director: María Jose Jiménez Taboada.

Solar Concentrating Systems Unit

SCI PUBLICATIONS

Aichouba, A., Merzouk, M., Valenzuela, L., Zarza, E., & Kasbadji-Merzouk, N. (2018). Influence of the displacement of solar receiver tubes on the performance of a parabolic-trough collector. *Energy 159*, 472-481. DOI: 10.1016/j.energy.2018.06.148

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Thermal Storage and Solar Fuels Unit

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M.M. Rodriguez-Garcia, P. Frau, E. Rojas, (2018) Operational experience in an experimental molten salt thermal storage. The MOSA facility, *AIP Conf. Proc.* 2033, 90024, DOI: https://doi.org/10.1063/1.5067118

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PRESENTATION AT CONGRESSES

Guest lectures

T. Denk, (Really) Large Scale and Rather Complete Ilmenite Reduction Demonstrator: Technology and Lessons Learnt. Workshop: Towards The Use Of Lunar Resources, 3-5 July 2018. European Space Research Technology Centre (ESTEC), Noordwijk, the Netherlands. Guest lecture

Oral presentations

T. Sihvonen, J. Lappalainen, E. Hakkarainen and M.M. Rodríguez-García, Perspectives of Experimental and Theoretical Studies on a Thermal Energy Storage Facility, SolarPaces 2018 Conference, Casablanca, Marruecos, 2-5 Octubre 2018.

R. Bayón, M. Biencinto, E. Rojas, N. Uranga. Study of Hybrid Dry Cooling Systems for STE Plants Based on Latent Storage. ISEC2018, 3-5 October, Graz, (Austria).

T. Denk, Full-Scale Terrestrial Demonstrator for Lunar Ilmenite Reduction with Concentrated Solar Power. 69th International Astronautical Congress (IAC), Bremen, Germany, 1-5 October 2018, ESA.

T. Denk, Full-Scale Terrestrial Demonstrator for Ilmenite Reduction with Concentrated Solar Power. 6th European Lunar Symposium at the Les Abattoirs, Toulouse, France. 14-16 May, 2018.

A. Gonzalez, T. Denk and A. Vidal, Thermochemical water splitting hydrogen production projects at CIEMAT-Plataforma Solar, European Hydrogen Energy Conference 2018, Malaga, 14-16/03/2018, Asociación Española de Hidrogeno.

Posters

M.M. Rodríguez-García, J.F. Andreu and A. González-Cuesta, Special Valves for Solar Thermal Power Plants. Tests and Designs. SolarPaces 2018 Conference, Casablanca, Marruecos, 2-5 Octubre 2018.

E. Rojas J.M. Caruncho, A. Bruch, Q. Falcoz, M. M. Rodríguez-García, R. Bayón, M. Karl, R&D on Thermal Storage in POLYPHEM Project, SolarPaces 2018 Conference, Casablanca, Marruecos, 2-5 Octubre 2018.

A. Ferriere, S. Chomette, E. Rojas, J.M. Caruncho, T. Fluri, D. Ipse, R. Aumann, M. Prouteau, J.J. Falsig, The POLYPHEM Project: an Innovative Small-Scale Solar Thermal Combined Cycle, SolarPaces 2018 Conference, Casablanca, Morocco, 2-5 October 2018.

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T. Denk, Basics of Concentrated Solar Power for Moonwalkers. 6th European Lunar Symposium at the Les Abattoirs, Toulouse, France. 14-16 May 2018.

Solar Desalination Unit

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A. Tosi, L. Roca, J. D. Gil, A. Visioli, & M. Berenguel (2018). Multivariable controller for stationary flat plate solar collectors. In Proceedings of the 7th International Conference on Systems and Control (pp. 7-12). Valencia (Spain). Proceedings de congreso.

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A. Chorak, P. Palenzuela, D.C. Alarcón-Padilla, A.B. Abdellah. Experimental characterization of a Double-Effect Absorption Heat Pump-MED system driven by parabolic trough collectors. 6th International Renewable and Sustainable Energy Conference, Rabat (Marruecos), 2018.

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Posters

J.A. Carballo, J. Bonilla, M. Berenguel, J. Fernandez-Reche, G. Garcia, Machine learning for solar trackers. SolarPACES Conference Proceedings, Casablanca, Morocco, October 2-5, 2018.

P. Palenzuela, T. Orth, D.C. Alarcón-Padilla, G. Zaragoza. Performance evaluation of a multi-effect distillation unit with a polymer tube heat exchanger. Desalination for the Environment: Clean Water and Energy, Athens (Greece), 2018.

Water Solar Treatment Unit

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PRESENTATIONS AT CONGRESS

Guest lectures

Sanchez-Perez J.A., Soriano-Molina P., Garcia-Sanchez J.L., Malato S. Solar photo-Fenton as a tertiary wastewater treatment. From mechanisms to reactor design. 19th European Meeting on Env. Chem (EMEC 19). 3rd-6th of December 2018. Royat, Clermont-Ferrand (France) Invited Oral

Plenary presentations

Malato S. Eliminación de microcontaminantes mediante procesos de oxidación avanzada: tecnologías de tratamiento y evaluación de resultados. 3º Congreso Colombiano de Proceso de Oxidacion Avanzada. Florencia (Caquetá. Colombia). 31st October-2nd November, 2018.

Oller I. Monitorización del tratamiento y reutilización de aguas residuales industriales mediante técnicas analíticas y microbiológicas avanzadas. 3º Congreso Colombiano de Proceso de Oxidacion Avanzada. Florencia (Caquetá. Colombia). 31st October-2nd November, 2018.

Oral presentations

Fernández-Ibáñez P., Polo-Lopez M.I., Martinez A., Domingos M., Abeledo-Lameiro M.J., Reboredo-Fernández A., E. Ares-Mazás, H. Gomez-Couso. The Waterspoutt Project: Solar rainwater reactors for water disinfection. The 7th European Bioremediation Conference (EBC-VII) and 11th International Society for Environmental Biotechnology Conference (ISEB 2018). Chania, (Grece), 25th-28th of June, 2018. Oral (Nº 108). E-book of Abstracts (pag. 390).

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Maldonado M. I., Malato S., Oller I. Generación de hidrogeno en planta piloto solar mediante Cu/TiO_2 con eliminación simultánea de contaminantes en fase acuosa. XIII Congreso Español de Tratamientos de Aguas. META 2018. León (Spain) 18th-20th June, 2018. O.6.4., pp. 97. Abstract Book.

Maldonado M.I., Malato S., Nolan M., Colón G., van Ommen J.R., Oller I. RATOCAT project: rational design of highly effective photocatalysts with atomic-level control. International Sustainable Energy Conference - ISEC 2018, 3rd-5th of October, 2018, Graz (Austria) pp. 349-350, Abstract book.

Marcì, G., García-López, E.I., Palmisano, L., Ilkaeva, M., Krivtsov, I., García, J.R., Díaz, E., Ordóñez S., Maldonado, M.I., Malato S. HMF Selective Photo-Oxidation in Aqueous Suspension of Both Bare and H_2O_2 Treated Carbon Nitride Carried Out in a Solar Pilot Plant. 10th European meeting on Solar Chemistry and Photocatalysis: Environmental Applications. Almeria (Spain), June 4-8, 2018. Book of proceedings (ISBN 978-84-17261-27-6). OC -63, page 160-162. Abstract Book.

Michael S.G., Michael-Kordatou I., Polo López M.I., Rocha J., Martinez-Piernas A., Fernandez-Ibáñez P., Agüera A., Manaia C., Fatta-Kassinos D. Removal of antibiotic-resistant bacteria and resistance gene (ARB&ARGs) from urban wastewater effluents by solar- and UV-C-driven oxidation processes. International Conference on Challenges and Solutions related to Xenobiotics and Antimicrobial Resistance in the Framework of Urban Wastewater Reuse (XENOWAC II). Limassol (Cyprus) 10th-12th October, 2018. Book of abstracts.

Nahim-Granados S., Oller I., Malato S., Sánchez-Pérez J.A., Polo-López M.I. Fresh-cut wastewater disinfection by solar processes: a case study of the commercial iron micronutrient (Fe^{3+}-EDDHA) for reuse purpose. IWA regional conference of water reuse and salinity management (IWARESA). Murcia (España), 11th-15th July, 2018. Pag. 77, Abstract book.

Oller I., Ruiz-Delgado A., Roccamante M., Salmerón I., Ponce-Robles L., Malato S. Advanced Oxidation Technologies for removal of Contaminants of Emerging Concern. TRICERATOPS Project. Int. Conf. on Challenges and Solutions related to Xenobiotics and Antimicrobial Resistance in the Framework of Urban Wastewater Reuse: Towards a blue circle society (XENOWAC II). 10th-12th October 2018, Limassol (Cyprus).Abstract book.

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Plakas K., Salmerón I., Oller I., Sirés I., Maldonado M.I., Malato S., Karabelas A. A novel solar photoelectro-Fenton pilot unit for water and wastewater treatment. 11th National Conference on Renewable Energy Sources, Thessaloniki (Greece), 14th-16th March, 2018. Abstract Book.

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Posters

Abeledo-Lameiro M.J., Reboredo-Fernández A., Fernández-Ibáñez P., Polo-López M.I., Ares-Mazás E., Gómez-Couso H. Efficacy of two solar reactors fitted with compound concentrators in the inactivation of Cryptosporidium in harvested rainwater. 10th European Meeting on Solar Chemistry and Photocatalysis: Environmental Application (SPEA10). Almería (Spain), 4th-8th of June, 2018. Poster Nº 178. Book of Proceedings. ISBN: 978-84-17261-27-6 (pag. 751-753).

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Berruti I., Polo-López M.I., Oller I., Manfredi M. Assessment of novel advanced oxidation processes for removal of disinfection by-products and CECs from drinking water. 10th European Meeting on Solar Chemistry and Photocatalysis: Environmental Application (SPEA10). Almería (Spain), 4th-8th of June, 2018. Poster Nº 88. Book of Proceedings. ISBN: 978-84-17261-27-6 (pag. 516-518).

Deemter D., Oller I., Malato S., Amat A.M. Application of Advanced Integrated Technologies (Membrane and Photo-Oxidation Processes) for the Removal of CECs contained in Urban Wastewater. 10th European meeting on Solar Chemistry and Photocatalysis: Environmental Applications. Almeria (Spain), 4th-8th of June, 2018. Book of proceedings (ISBN 978-84-17261-27-6). Poster P89, page 519-520.

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Nahim-Granados S., Oller I., Malato S., Sánchez-Pérez J.A., Polo-López M.I. Commercial fertilizer as effective iron chelate (Fe^{3+}-EDDHA) for fresh-cut wastewater disinfection under natural sunlight. 10th European meeting on Solar Chemistry and Photocatalysis: Environmental Applications. Almeria (Spain), 4th-8th of June, 2018. Book of proceedings (ISBN 978-84-17261-27-6). Poster P87, page 513-515.

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Polliotto, Pomilla, Maurino, Marcì, Bianco Prevot, Nisticò, Magnacca, Paganini, Ponce Robles, Malato, Perez. Magnetic hybrid nanomaterials for the photodegradation of microcontaminats in aqueous environment. 10th European meeting on Solar Chemistry and Photocatalysis: Environmental Applications. Almeria (Spain), 4th-8th of June, 2018. Book of proceedings (ISBN 978-84-17261-27-6). Poster P134, page 634-636.

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Ponce-Robles L., Polo-López M .I., Oller I., Agüera A., Malato S. Strategy for remediation of cork boiling wastewater using a combination of advanced chemical-biological oxidation technologies. Microbiological evaluation. 10th European meeting on Solar Chemistry and Photocatalysis: Environmental Applications. Almeria (Spain), 4th-8th of June, 2018. Book of proceedings (ISBN 978-84-17261-27-6). Poster P236, page 891-893.

Roccamante M., Ruiz-Delgado A., Oller I., Malato S. Advanced Oxidation Processes based on Ozonation for Contaminants of Emerging Concern removal. 10th European meeting on Solar Chemistry and Photocatalysis: Environmental Applications. Almeria (Spain), 4th-8th of June, 2018. Book of proceedings (ISBN 978-84-17261-27-6). Poster P239, page 899-901.

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Ruiz-Delgado A., Roccamante M., Oller I., Malato S. Natural iron complexes from Olive Mill Wastewater for Solar Photo-Fenton degradation of micro-contaminants. 10th European meeting on Solar Chemistry and Photocatalysis: Environmental Applications. Almeria (Spain), 4th-8th of June, 2018. Book of proceedings (ISBN 978-84-17261-27-6). Poster P105, page 560-562.

Ruiz-Delgado A., Plaza-Bolaños P., Malato S., Oller I., Agüera A. Presence and elimination of contaminants of emerging concern through a treatment line for landfill leachate remediation. XVIII Reunion Cientifica de la sociedad española de cromatografía y técnica afines (SECyTA 2018). Granada (Spain) 2nd-4th of October, 2018. Book of Abstracts, ISBN 978-84-17293-61-1, PP. 111. 2018.

Ruíz-Delgado A., García-Gómez E., Plaza-Bolaños P., Malato S., Oller I., Agüera A. Identification and removal of contaminants of emerging concern in landfill leachate. Int. Conf. on Challenges and Solutions related to Xenobiotics and Antimicrobial Resistance in the Framework of Urban Wastewater Reuse: Towards a blue circle society (XENOWAC II). Limassol (Cyprus) 10th-12th October, 2018.

Salmerón I., Oller I., Sirés I., Plakas K.V., Maldonado M.I., Malato S. Application of electro-Fenton and solar photoelectro-Fenton processes for the treatment of membrane concentrates. IWA Regional Conference on Water Reuse and Salinity Management.Murcia (Spain), 11th-15th of June, 2018.

Soriano-Molina P., García Sánchez J.L., Alfano O.M., Conte L.O., Malato S., Sánchez Pérez J.A. Modeling of Solar Photo-Fenton Process with Fe^{3+}-EDDS At Neutral pH. 10th European meeting on Solar Chemistry and Photocatalysis: Environmental Applications. Almeria (Spain), 4th-8th of June, 2018. Book of proceedings (ISBN 978-84-17261-27-6). Poster P91, page 524-526.

Toledo Camacho S. Y., Rey A., Maldonado M. I., Contreras S., Medina F. Photocatalytic hydrogen generation in a solar pilot plant using Pd/TiO_2(-WO_3) based catalyst. 10th European meeting on Solar Chemistry and Photocatalysis: Environmental Applications SPEA10. Almería (Spain). 4th-8th of June, 2018. Book of proceedings (ISBN 978-84-17261-27-6). Poster P13, page 342-344.

Soriano-Molina P., Lorenzo A., Plaza-Bolaños P., Malato S., Sanchez-Perez J.A. Assessment of solar photo-Fenton in raceway pond reactors att neuttrla pH with Fe(III)-EDDS for micropollutantts removal in municipal wastewater treatment plantt effluents of different composition. 19th European Meeting on Env. Chem (EMEC 19). Clermont-Ferrand (France), 3rd-6th of December, 2018.

Energy Efficiency in Building R&D Unit

SCIENTIFIC JOURNALS

B. Porcar, S. Soutullo, R. Enríquez, & M.J. Jiménez. (2018). Quantification of the uncertainties produced in the construction process of a building through simulation tools: A case study. *Journal of Building Engineering 20*, 377-386. DOI: 10.1016/j.jobe.2018.08.008

PRESENTATIONS AT CONGRESS

Guest lectures

M.J. Jiménez. “Round Robin Test Box. Experiment set up and data”. Presented at DYNASTEE Summer School 2018 on Dynamic Calculation Methods For Building Energy Assessment. Organised by INIVE-DYNASTEE and CIEMAT in collaboration with CIESOL. 10-14 September 2018. Almería.

M.J. Jiménez, Y. Olazo, J. Xamán. “From building physics to mathematical models, considering different approaches (linear regression, ARX and RC models). Case study: Round Robin Test Box”. Presented at DYNASTEE Summer School 2018 on Dynamic Calculation Methods For Building Energy

Assessment. Organised by INIVE-DYNASTEE and CIEMAT in collaboration with CIESOL. 10-14 September 2018. Almería.

M.J. Jiménez. “Practical aspects of modelling in different case studies: Integrated PV ventilated systems and other tests in sunny weather conditions”. Presented at DYNASTEE Summer School 2018 on Dynamic Calculation Methods For Building Energy Assessment. Organised by INIVE-DYNASTEE and CIEMAT in collaboration with CIESOL. 10-14 September 2018. Almería.

<u>Oral presentations</u>

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