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1. General Presentation

The Plataforma Solar de Almería (PSA), a dependency of the Centro de Investigaciones 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.

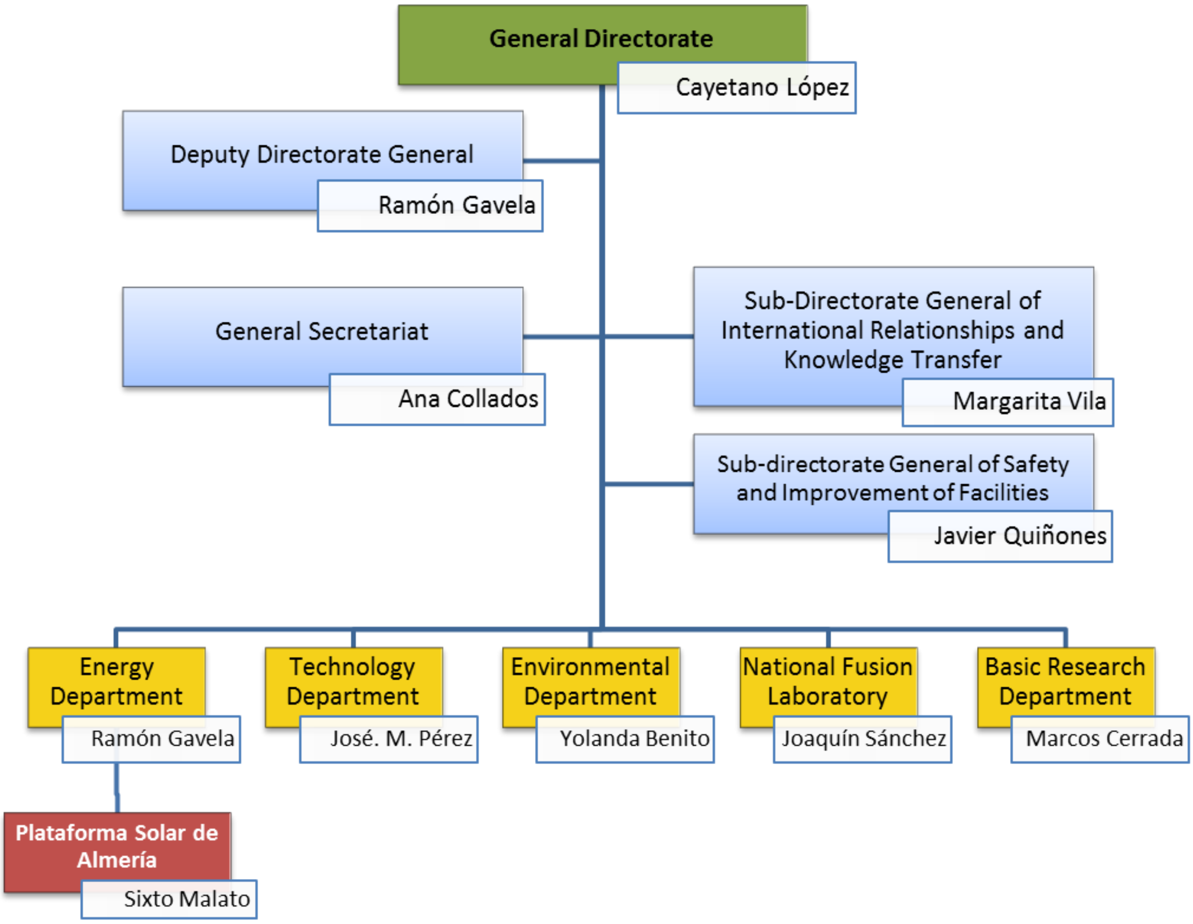


Figure 1. Integration of the PSA in the CIEMAT organization

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 North-South 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 2012, research activity at the Plataforma Solar de Almería has been structured around three R&D Units:

- Solar Concentrating Systems. This unit is devoted to to promote and contribute to the development of solar concentrating systems, both for power generation and for industrial processes requiring solar concentration, whether for medium/high temperatures or high photon fluxes.
- Solar Desalination. Its objective is new scientific and technological knowledge development in the field of brackish and sea water solar desalination.
- Solar Water Treatment. Exploring the chemical possibilities of solar energy, especially its potential for water detoxification and disinfection.

Supporting the R&D Units mentioned above are the management services offered by the Administrative Department and the Office of the Director, the technical services, which includes maintenance, operation and civil engineering services and are grouped together in the Infrastructure Management Unit, the IT services and the Instrumentation services. These units are largely self-sufficient in the execution of their budget, planning, scientific goals and technical resource management. Nevertheless, the three R&D units share many PSA resources, services and infrastructures, so they stay in fluid communication with all the above services units, the Administrative Department and the Office of the Director. For its part, the Office of the Director must also 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 2015 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 127 people who work daily for the PSA.

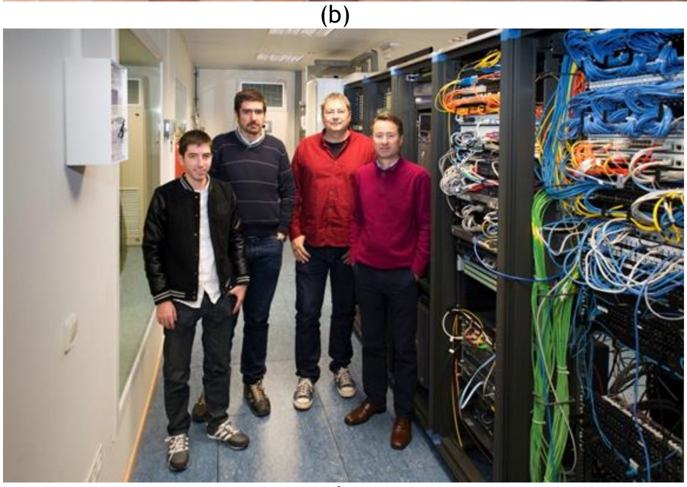
In addition, the 10 persons who make up the DLR permanent delegation as a consequence of its current commitments to the Spanish-German Agreement also make an important contribution.

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.

(a)

(b)

(c)

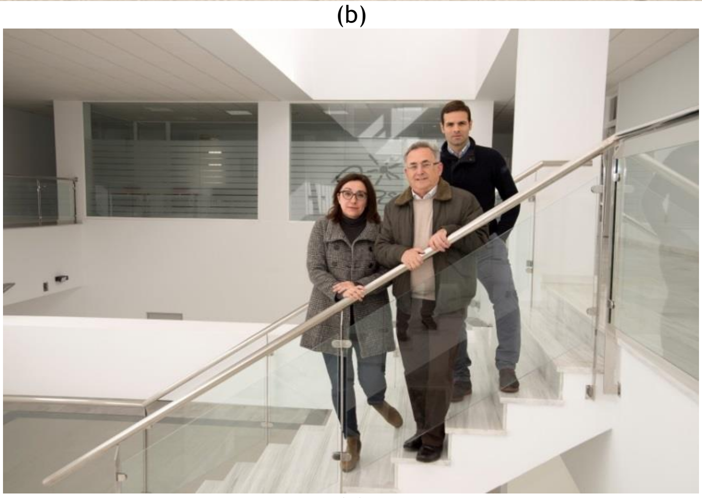


(d)

Figure 3. Management staff grouped at PSA. a) Office of the Director, b) Administrative dept., c) Instrumentation Services unit, d) IT Services unit.

(a)

(b)



(c)

Figure 4. Technical services staff grouped at PSA. a) Operation unit, b) Cleaning and Maintenance unit, c) Infrastructure Management unit.

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 2015 totals 3.6 M Euros (not including R&D personnel or new infrastructure).

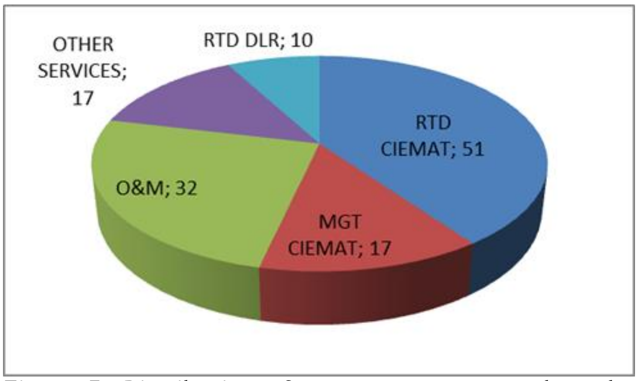


Figure 5. Distribution of permanent personnel at the PSA as of December 2015

2. Facilities and Infrastructure

2.1 Experimental Installations and Laboratories Existing at PSA for Solar Thermal Concentrating Systems

2.1.1 PSA Experimental facilities for solar thermal concentrating systems

At present, the main test facilities available at the PSA related to solar thermal concentrating systems are (see Figure 6):

- CESA-1 and SSPS-CRS central receiver systems, 6 and 2.5-MWth respectively.
- DISS 2.5-MWth test loop, an excellent experimental system for two-phase flow and direct steam generation for electricity production research with parabolic-trough collectors in different working conditions, up to 500ºC and 100bar.
- The FRESDEMO "linear Fresnel" technology loop.
- An Innovative Fluids Test Loop
- TCP-100 2.3-MWth parabolic-trough collector field with associated 115-m^3 thermal oil storage system
- The Parabolic Trough Test Loop (PTTL) facility
- A parabolic-trough collector test facility with thermal oil (the so-called HTF Test loop) for qualification of components and complete collectors.
- 4-unit dish/Stirling facility, named DISTAL, and 2 EuroDish units.
- A group of 3 solar furnaces, two of them with horizontal axis 60 kW_{th} and 40 kW_{th} and a third one with vertical axis 5 kW_{th}.
- A test stand for small evaluation and qualification of parabolic trough collectors, named CAPSOL.

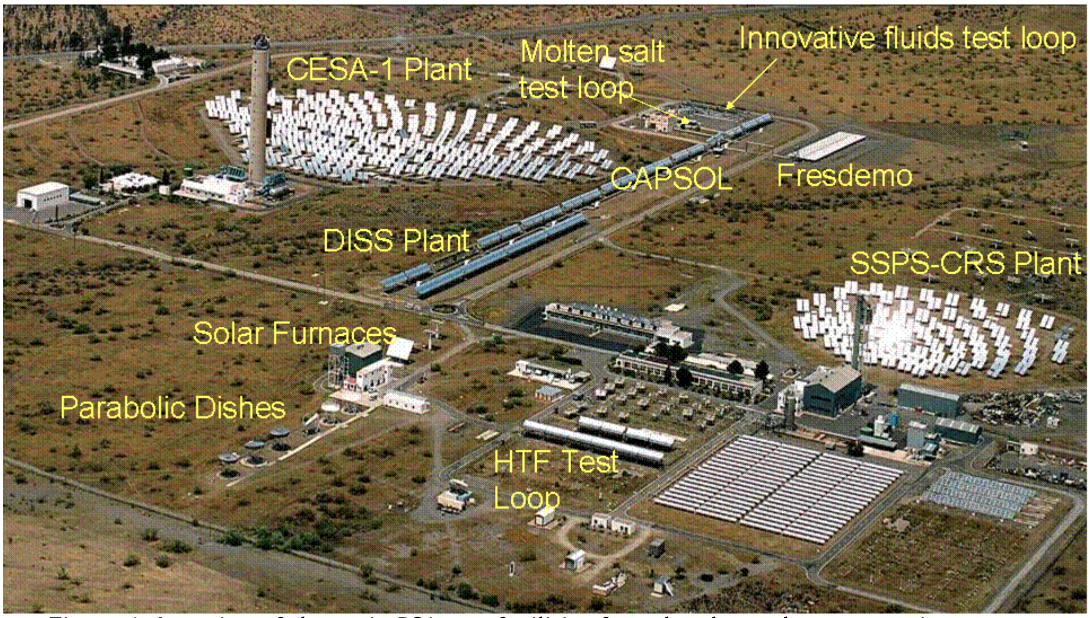


Figure 6. Location of the main PSA test facilities for solar thermal concentrating systems

These experimental installations and other with less importance are described in detail in next sections, grouped by the type of technology used (Central receiver systems, Line-focus collectors and Parabolic Dishes), having a special section for the Solar Furnaces for very high concentration and/or temperature tests.

2.1.1.1 Central Receiver Facilities: CESA-1 and CRS

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

The 6 MWth CESA-1 Plant

The CESA-1 plant 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 7. 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.

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 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 kW_{th} 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 8. Aerial view of the experimental SSPS-CRS facility.

The original 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 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 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 (29dm^3/s, 8bar), pure nitrogen supplied by two batteries of 23 standard-bottles (50dm^3/225bar) each, 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.

Figure 9. An autonomous heliostat in the CRS field.

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.

2.1.1.2 Linear Focusing Facilities: HTF, DISS, Innovative Fluids Loop, FRESDEMO, CAPSOL, KONTAS and Prometeo

At present, PSA has several linear-focusing solar collector facilities for both parabolic-trough and Linear Fresnel collectors. Many of these experimental installations, such as the innovative fluids test loop or the DISS plant, are the only one of their kind, and place the PSA in a privileged worldwide position for research and development of new parabolic-trough collector applications. The main characteristics of these facilities are briefly explained below.

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. 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 5º. The thermal oil used in this facility (Syltherm 800®) has a maximum working temperature of 420°C and a freezing point of -40ºC.

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 is now used to evaluate and qualify new designs of parabolic-trough collectors, receiver tubes, reflectors and other components for parabolic-trough collectors. Main activities 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.

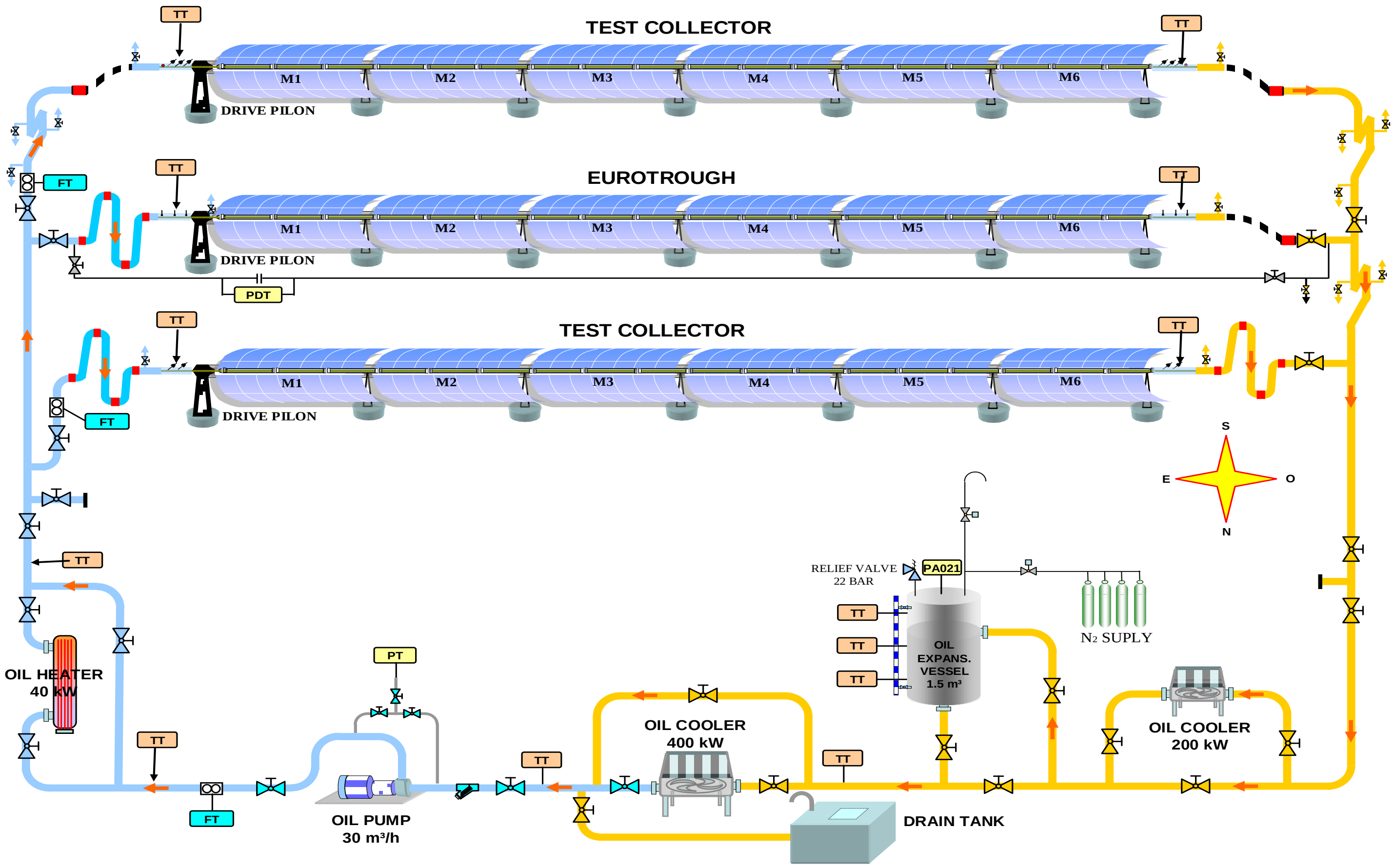


Figure 10. Diagram of the PSA "HTF test Loop".

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/400ºC) 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 11) 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 400ºC 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).

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.

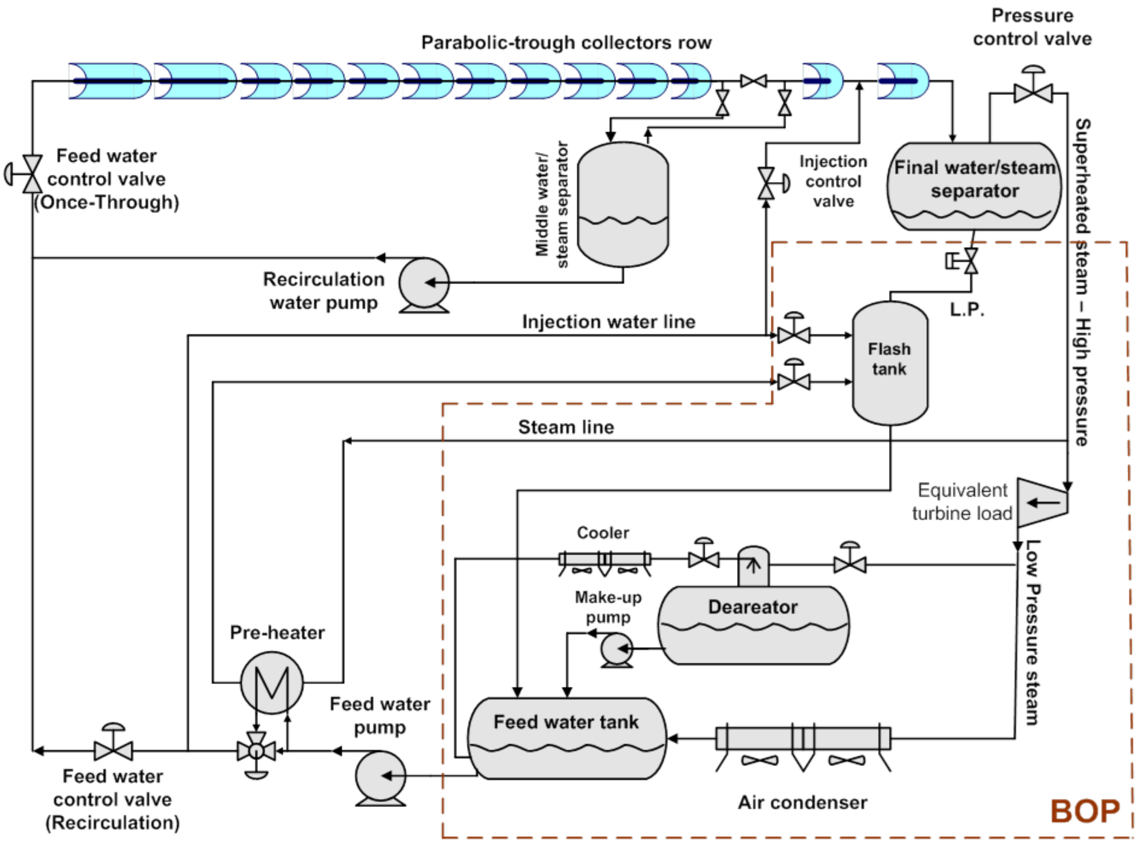


Figure 11. Simplified flow diagram of the PSA DISS loop

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 12. View of the DISS plant solar field in operation

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 working fluids in parabolic-trough collectors, which has not been done to date, evaluating their behaviour under a diversity of real operating conditions.

The experimental test loop is located north of the DISS loop control building, which houses the equipment necessary for its control and data acquisition.

Figure 13. View of the pressurized gas test loop connected to a molten-salt thermal energy storage

The facility was originally designed to work at pressures and temperatures of up to 100 bar and 400ºC, 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 necessary to cool the collectors adequately.
- A data acquisition and control system that allows the temperature, flow rate, pressure, irradiation and humidity in the loop to be completely monitored.
- Automatic control valves that allow precise, safe variation in the collector fluid feed flow rate.
- A secondary loop for filling the test loop with gas.

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 Collector 2 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).

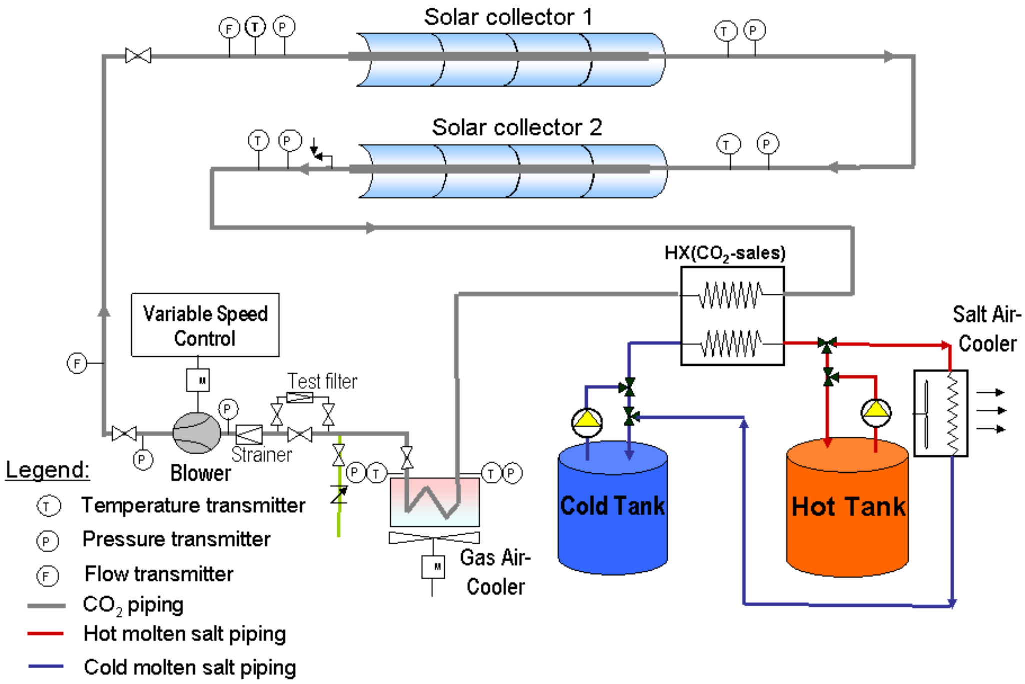


Figure 14. Simplified system diagram of the innovative fluids test loop connected to a molten-salt thermal storage system.

The molten-salt thermal storage system basically consists of (Figure 14):

- Two 39-ton salt tanks, hot and cold, able to provide about six hours of thermal storage.
- A 344-kW air cooler to cool the salt with ambient air.
- A 344-kW gas/salt exchanger providing the salt circuit with the solar energy collected in the innovative fluids test loop.

The thermal storage system is also connected to a small 344 kW_{th} thermal oil loop, with VP-1 oil, allowing the thermal storage system to be charged and discharged by using this thermal oil system, with a salt/oil heat exchanger. This oil circuit consists of: expansion tank, drainage tank, oil heater, salt/oil heat exchanger and oil cooler.

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. Each collector is composed of eight parabolic trough module 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 are PTR70, manufactured by SCHOTT, 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 400ºC. 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.

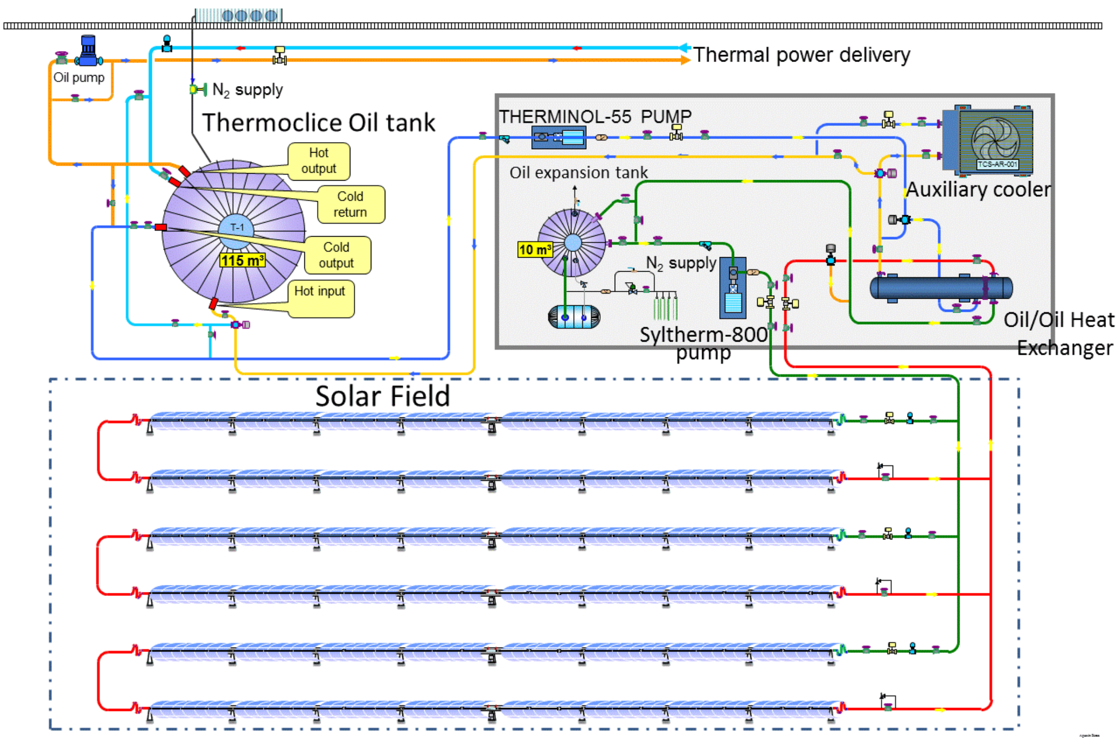


Figure 15. Diagram of the TCP-100 2.3-MWth parabolic-trough facility

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.

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 m3, 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 40ºC, 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

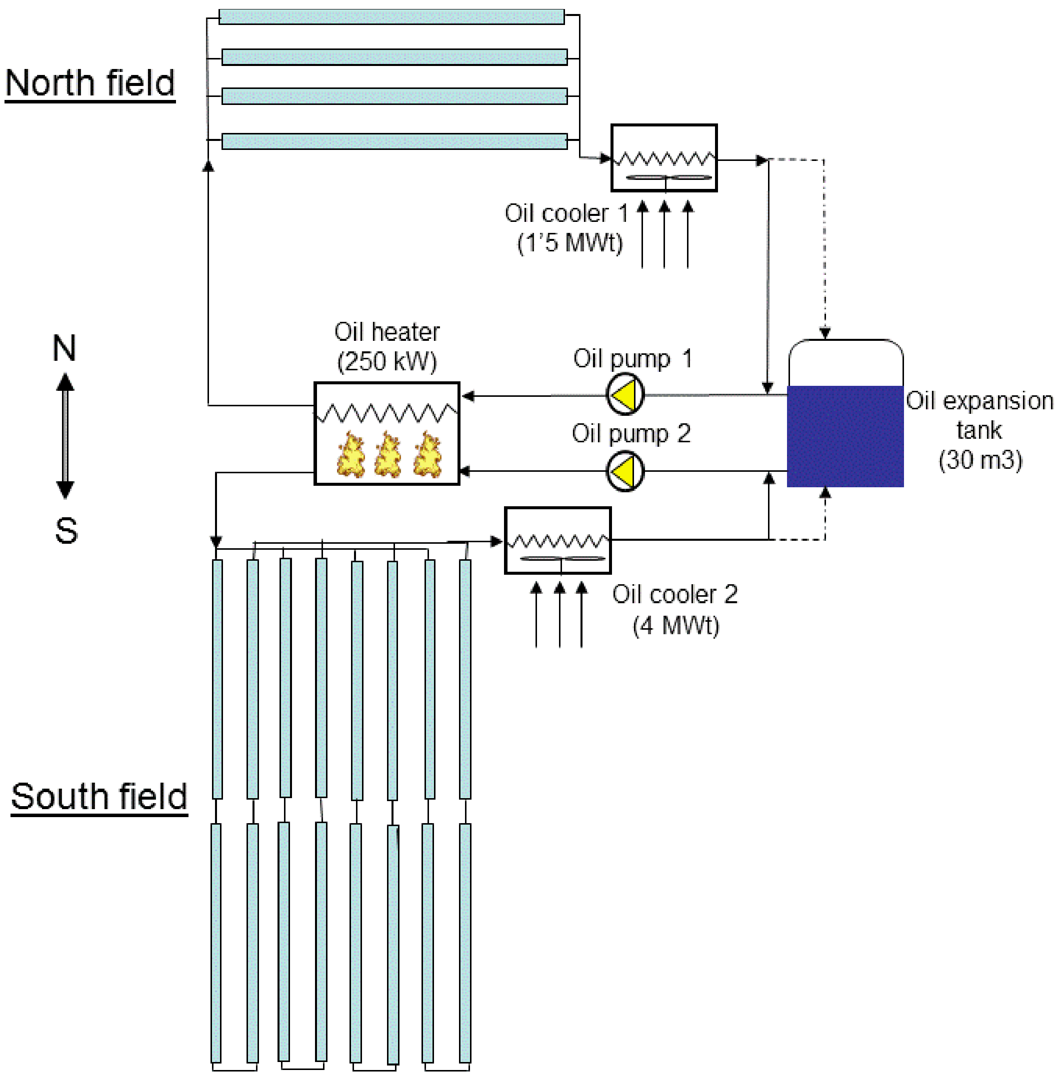


Figure 16. Simplified scheme of the PTTL facility

The FRESDEMO Loop

The FRESDEMO loop is a "Linear Fresnel concentrator" technology pilot demonstration plant. This 100m-long, 21-m-wide module has a primary mirror surface of 1433 m^2, distributed among 1200 facets mounted in 25 parallel rows spanning the length of the loop. This collector loop is designed for DSG at a maximum pressure of 100 bar and maximum temperature of 450°C.

This pilot facility is presently connected to the piping system of the PSA DISS plant from where it is supplied with solar steam at different pressures and temperatures for testing in the three working modes: preheating, evaporation and superheating.

CAPSOL Facility

CAPSOL is a concentrating solar thermal energy test facility designed and built at the PSA for testing of small-sized, high-precision parabolic-trough solar collectors under real environmental conditions.

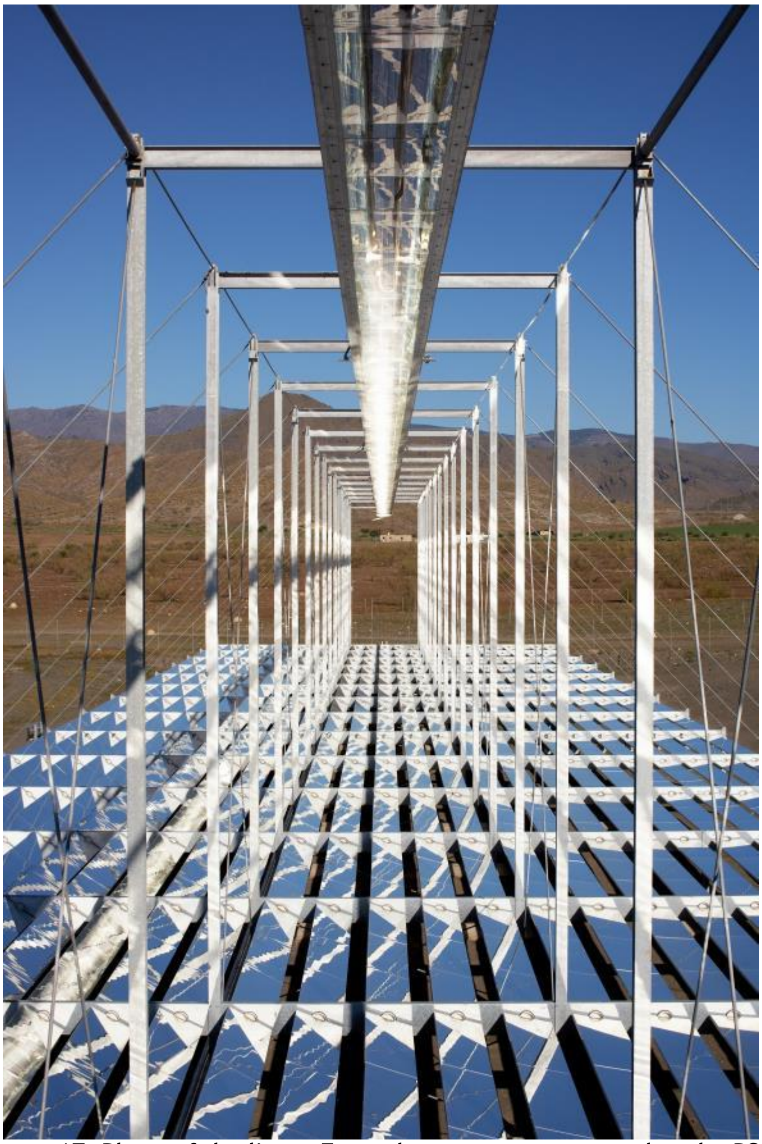


Figure 17. Photo of the linear Fresnel concentrator erected at the PSA.

The facility is designed to operate with pressurized water under a wide range of operating conditions: fluid temperatures from ambient to 230ºC, flow rates from 0.3 to 2.0 m^3/h and pressures up to 25 bar. It also allows testing of different collector orientations and sizes (apertures up to 3 m). High-precision instrumentation has been installed for measuring all of the parameters required for adequate evaluation of parabolic-trough collectors. In particular, the facility has a mass flowmeter (Coriolis-type, with a ±0.1% measurement accuracy), a pyrheliometer (Eppley, with 8 $\mu V/Wm^{-2}$ sensitivity) and two types of temperature sensors at the inlet and outlet of the solar field (4-wire PT-100 with an accuracy of ±0.3°C in a 100 to 200°C range). In addition to these instruments, the facility has sensors for measuring other parameters, such as fluid temperature at various points in the circuit, pressure, tank level, ambient temperature, wind speed and direction, etc.

This test facility makes it possible to find the efficiency parameters required for characterizing small parabolic-trough collectors: peak optical-geometric efficiency, incident angle modifier, overall efficiency and thermal losses when collectors are out of focus. The stationary state conditions needed for performing these tests are reached thanks to the inertia of the expansion tank and auxiliary heating and cooling systems. The data acquisition and control system facilitates monitoring and recording of the parameters measured as well as system operation from the control room.

Both complete small-sized parabolic-trough collectors and their components, such as absorber tubes, reflectors or tracking systems, can be tested in this facility. Furthermore, the facility also allows analysis of technical aspects of the collectors, such as materials durability, structural resistance, component assembly, etc. under real operating conditions.

Figure below shows a photo of the CAPSOL test facility with two prototypes of small-size parabolic-trough collectors installed.

Figure 18. CAPSOL solar thermal test facility for small-size parabolic-trough collectors.

KONTAS: Rotary test bench for parabolic trough collectors

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 19. Side view of Kontas test bench and the heating cooling unit.

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 Syltherm 800® thermal oil as heat transfer fluid (HTF) 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.

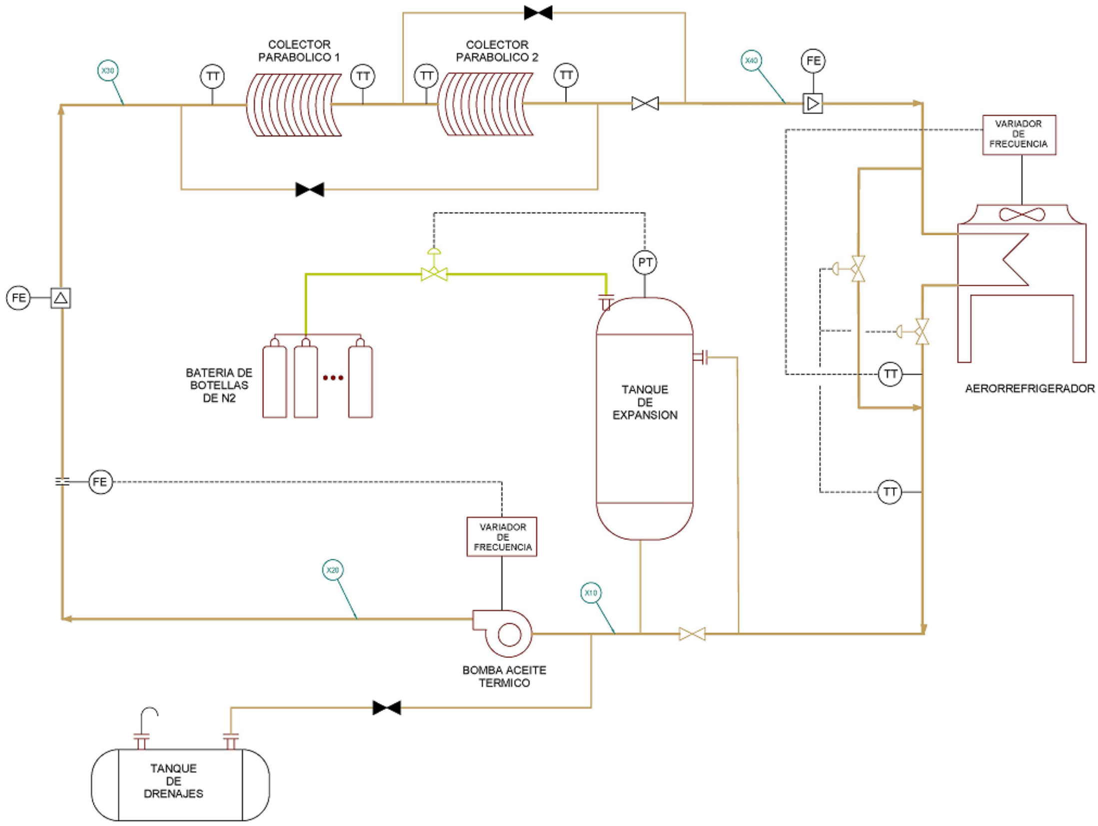


Figure 20. Scheme of the PROMETEO test facility.

2.1.1.3 Parabolic DISH Systems

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 21) 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 22) were erected at PSA in 1996 and 1997, using the stretched membrane technology. These parabolic dishes have a diameter slightly larger than the DISAL-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.

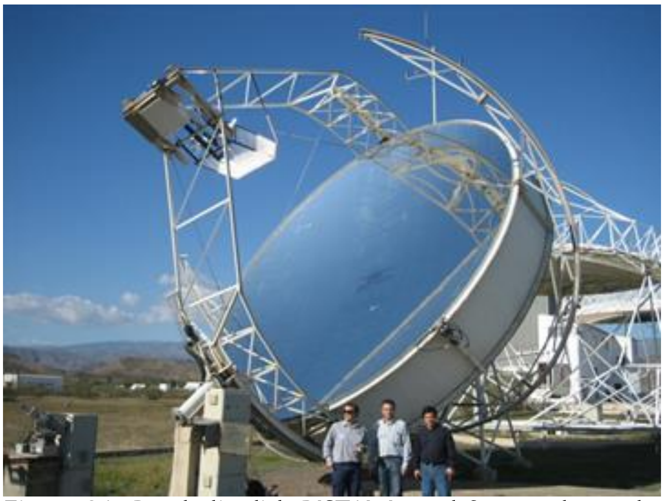


Figure 21. Parabolic-dish DISTAL-I used for accelerated materials ageing at PSA.

Figure 22. View of a parabolic-dish DISTAL- II.

The test bed for durability and accelerated materials ageing is complemented with the Materials Laboratory existing at PSA, which is described in the laboratories section of this document (section 2.1.2.1), and with the durability and accelerated materials ageing laboratory existing at Madrid (section 2.1.2.6).

EURODISH

Under the Spanish-German EUROdish Project, two new dish/Stirling prototypes were designed and erected, 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 kW_{th} maximum and a maximum concentration of 16.000 suns at the focus. The tracking system is azimuth-elevation.

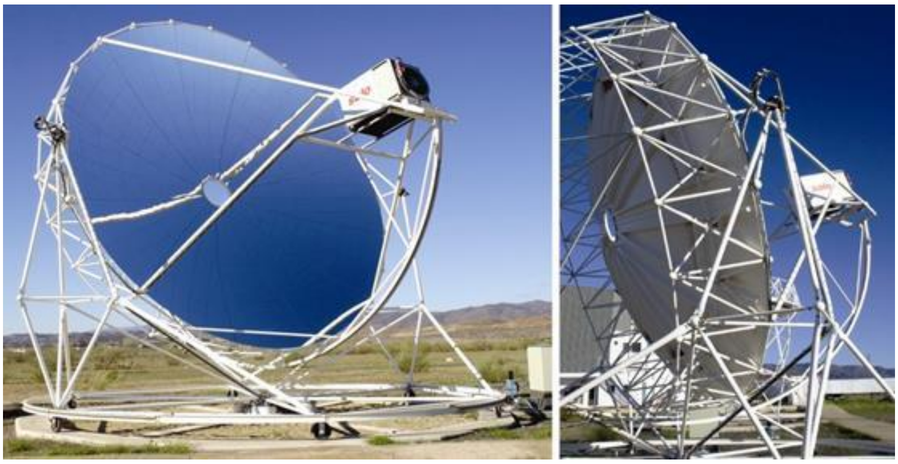


Figure 23. Front and back views of the EURODISH

2.1.1.4 The Solar Furnaces at PSA

Solar furnaces can be defined as optical systems that concentrate solar radiation in a small area called focus where high temperatures and thermal fluxes can be reached. They can reach concentrations of over 10000 suns, the highest energy levels achievable in a solar concentrating system. Their main field of application are materials testing, either at room conditions, controlled atmosphere or vacuum, and solar chemistry experiments using chemical reactors associated with receivers.

A solar furnace essentially consists of a continuously solar-tracking, flat heliostat, a parabolic-dish concentrator, an attenuator or shutter and the test zone located in the concentrator focus.

The flat heliostat reflects the incoming solar beams on the parabolic-dish concentrator, which in turn reflects them on its focus (the test area). The amount of incident light is regulated by the attenuator located between the concentrator and the heliostat. Under the focus, a test table movable in three directions (East-West, North-South, up and down) places the test samples in the focus with great precision.

There are three solar furnaces fully operational at the PSA: Solar furnace SF60 which has been in operation from 1991, solar furnace SF5, in operation from 2012 and solar furnace SF40 which started operating in 2014.

SF-60 Solar Furnace

The SF60 consists basically in a 120 m^2 flat heliostat that reflects the solar beam onto a 100 m^2 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.

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 24 and Figure 25 show the new heliostat and a detail of the back side of the facet respectively.

Figure 24. HT120 heliostat with new PSA facets.

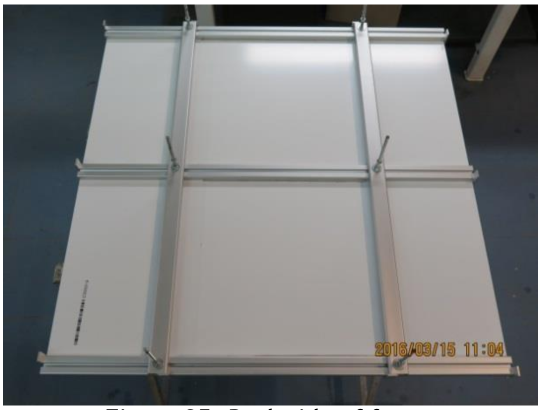


Figure 25. Back side of facet.

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.

Figure 26. HT120 heliostat in tracking.

The shutter (attenuator, see Figure 26) 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.

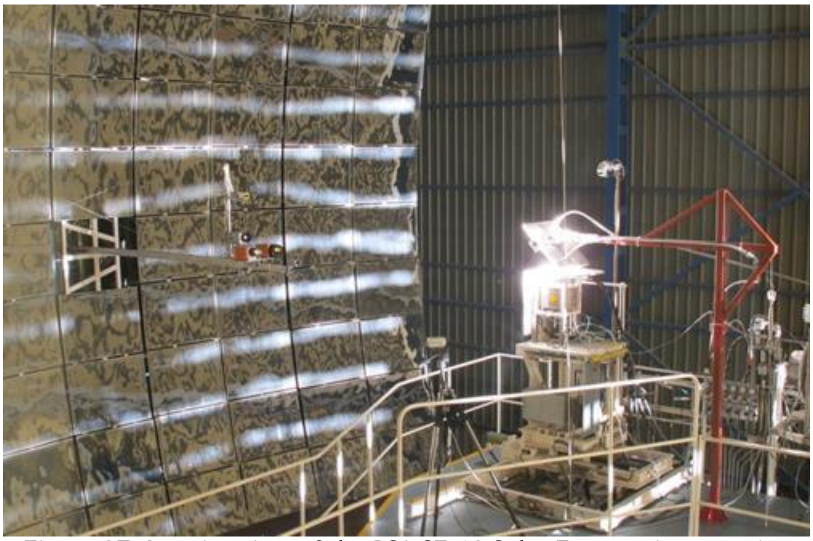


Figure 27. Interior view of the PSA SF-60 Solar Furnace in operation

SF-40 Solar Furnace

The new SF-40 furnace consists mainly of an 8.5-m-diameter parabolic-dish, with a focal distance of 4.5 m. 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 above 6000 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 90º, 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.

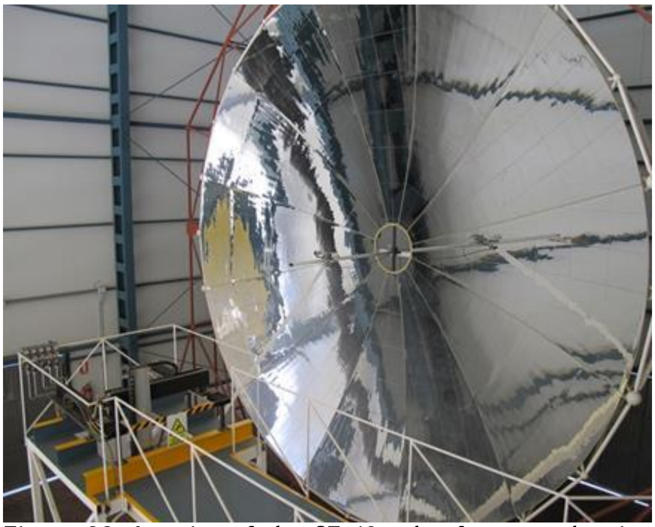


Figure 28. Interior of the SF-40 solar furnace, showing the parabolic concentrator.

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 25 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 29. Concentrator of the SF-5 Furnace.

2.1.2 Laboratories of the Solar Concentrating Systems Unit

2.1.2.1 Materials Laboratory

Inside of the Solar Furnace control building, the PSA has its Materials Laboratory devoted mainly to the metallographic preparation and the analysis of test pieces treated with concentrated solar energy, and in next future, characterization of solar test by thermogravimetry.

It has 65 m^2 divided in three rooms, every one of them dedicated to different kind of analyses:

- The Metallography Room
- The Microscopy Room
- The Thermogravimetry Room

The lab's equipment is currently as listed below:

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 75ºC 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 30. View of the Metallography Room in the Materials Lab at PSA

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 60Kg
- Balance: Mettler Toledo classic max 320g / min 10mg

(a) (b)

Figure 31. View of a) the Microscopy Room in the Materials Lab, b) Thermogravimetric balance inside of its Room at Materials Lab.

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:

a) Tests under pure Hydrogen atmosphere up to 1750°C
b) Tests under pure Oxygen atmosphere
c) Tests under H_2O steam with other gases simultaneously.
d) Tests under corrosive atmosphere up to 1000°C

- CEM System (Controled evaporator mixer system) for steam supply.
- Fixed Gas Detector: Dräger Polytron SE Ex, with a control system Regard 1.

The PSA also has 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.

2.1.2.2 Advanced Optical Coatings Laboratories

The PSA advanced optical coatings lab has equipment for development and complete study of new selective coatings for absorbent materials used in solar concentrating systems at medium and high temperature (up to 600°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 laboratory has sufficient equipment 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 of this lab is also used for optical characterization of solar reflectors. A summary of the equipment available is given below:

- Perkin Elmer LAMBDA 950 Spectrophotometer (Figure 32a).
- Perkin-Elmer Frontier FTIR spectrophotometer equipped with a gold-coated integrated sphere manufactured by Pike (Figure 32b)
- *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 (Figure 32c). For measuring emissivity, it has a semi-cylindrical tunnel which emits infrared radiation at 70°C (Figure 32e).
- QUV weathering chamber, Q-PANEL, for accelerated ageing tests (Figure 32d).
- BROOKFIELD LVDV-I+ Viscometer.
- KSV CAM200 goniometer for measuring contact angles (Figure 32f).
- 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 550ºC.

Figure 32. Advanced optical coatings laboratories equipment.

2.1.2.3 Solar reflector durability analysis and optical characterization laboratories

The PSA optical characterization and solar reflector durability analysis laboratories, which are the result of a joint collaborative project between CIEMAT and DLR, have the necessary equipment to completely characterize the materials used as reflectors in solar concentrating systems. These labs allow the characteristic optical parameters of solar reflectors and their possible deterioration to be determined. The optical analysis lab has the following equipment for both quantitative and qualitative measurement of the reflectance of solar mirrors (see Figure 33, left):

- 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 SR2, 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.

The 2 solar reflector durability analysis labs are 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 33, right). 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 simulation 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 70°C 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 Figure 34).
- Ineltec CKEST 300 test chamber for humidity and condensation testing with temperatures up to 70ºC (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/m^3.
- 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 analyse the possible detachment of the paint layers.
- Several devices for thermal cycles specially designed at the PSA.

Figure 33. PSA solar reflector optical characterization lab (left) and durability analysis lab (right)

Figure 34. Climate chamber with corrosive gases.

Along with these labs, 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, a heliostat test bench was recently installed to test the influence of blocking on the coatings lifetime. Finally, the laboratories are equipped with accessories necessary for their proper use, such as precision scales, thermo magnetic stirrer, drier, tools for manipulating and cutting reflectors (both first and second surface), instrumentation for measuring pH, conductivity, oxygen, etc.

2.1.2.4 Testing laboratory of Receiver tubes for Parabolic Troughs

The PSA testing laboratory of receiver tubes has developed a test bench called HEATREC for measuring heat loss of single receiver tubes under laboratory conditions. 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.

HEATREC 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.

The laboratory is equipped with tools and devices for proper manipulation and monitoring of receiver tubes.

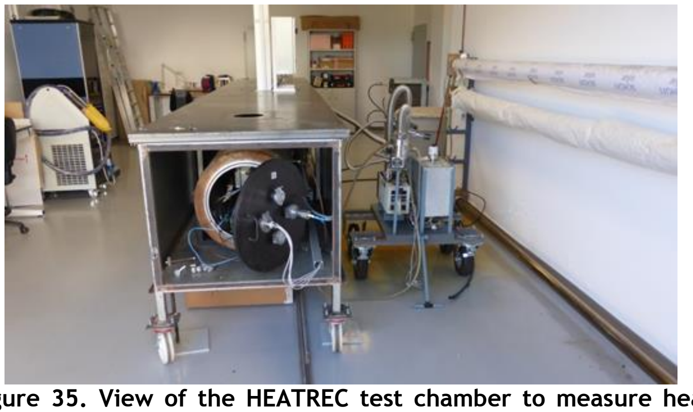


Figure 35. View of the HEATREC test chamber to measure heat losses in solar receiver tubes

2.1.2.5 Geometric characterization of reflectors and structural frames

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.). For the geometric characterization of these concentrators, the Plataforma Solar de Almeria has a laboratory in which 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
- Etc.

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).

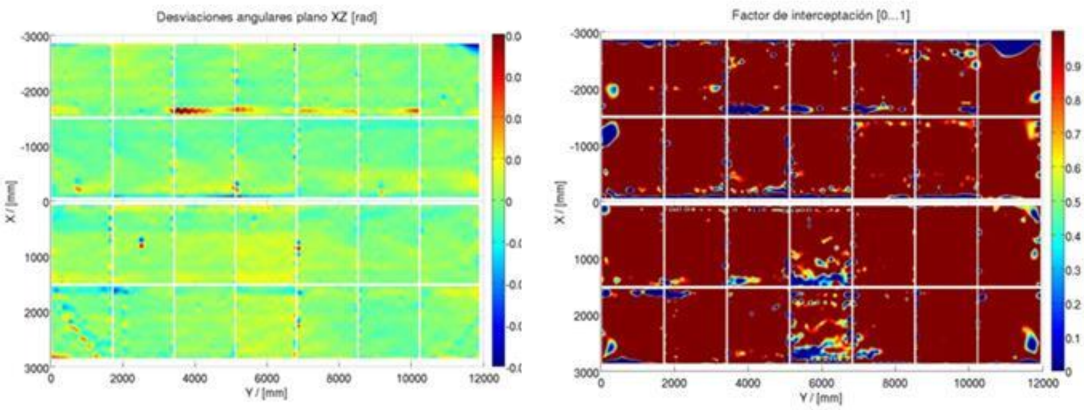


Figure 36. Angular deviations (left) and intercept factor (right) of a parabolic-trough collector module analysed by photogrammetry

The equipment and resources currently available at the PSA for photogrammetric measurements are:

- CANON EOS5D MarkII 22-Mpixel Camera.
- CANON EF 20mm f/2.8 USM and CANON EF 24mm f/2.8 USM lenses.
- Photomodeler Scanner 2012 photogrammetry software.

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).

2.1.2.6 ACCELERATED AGEING AND DURABILITY OF MATERIALS LABORATORY

Solar thermal power plants are at the beginning of their mass commercial exploitation. One of the greatest challenges for the technology consists of diminishing insofar as possible, the risk associated with its main components, such as the solar receiver. These components are subjected to very high solar flux (up to 1200 kW/m^2) and high temperatures (200°C to 1200°C depending on the heat transfer fluid selected). The greatest technological risk of this type of plant is associated with the selection of suitable materials with which to manufacture the receiver, especially their durability under real operating conditions, recalling that the characteristic lifecycle of such plants is around 20-25 years.

From this perspective and in an international context, methodologies are beginning to be developed that approach the problem of accelerated ageing of these components and materials. This includes study of 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 accelerated ageing and durability of materials laboratory comprises the solar dishes facility described in section 2.1.1.3 and the following capabilities located respectively at PSA and CIEMAT-Moncloa (Madrid):

- A laboratory equipped with 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; and for materials analysis, optical and electronic microscopes, micro hardness tester, thermal scale, x-ray dispersion analysis, etc.
- A 4-kW solar simulator, installed in CIEMAT-Moncloa made up of a Xenon lamp and a parabolic concentrator (Figure 37) that can reach fluxes of up to 1400 kW/m^2.

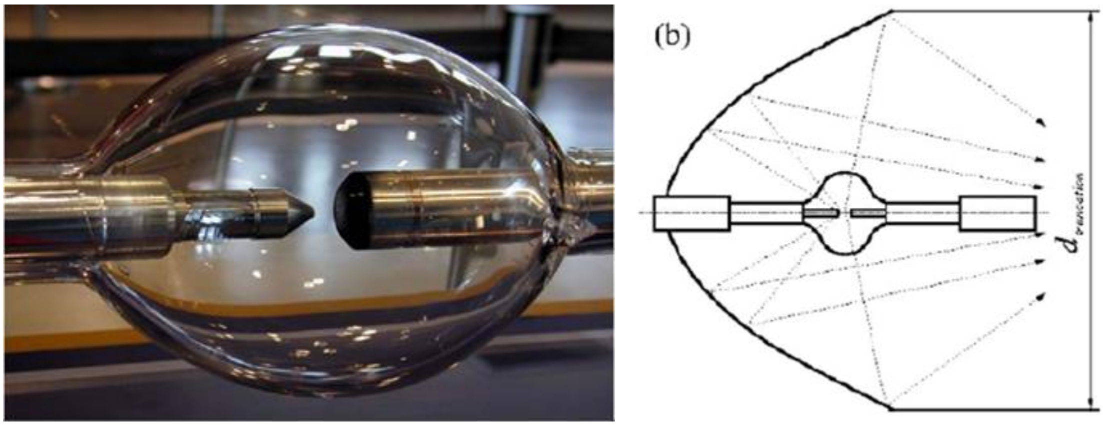


Figure 37. Xenon lamp used in the solar Simulator and configuration of the lamp and concentrator

2.1.2.7 Porous Characterization Laboratory

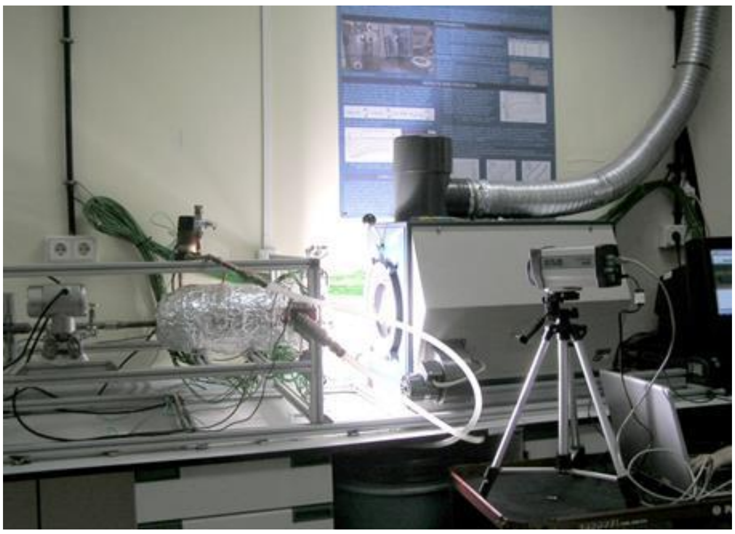
This lab has been recently installed at CIEMAT-Moncloa (Madrid) site with the aim of studying in depth the solar volumetric technology. This lab was specially designed to study new volumetric absorbers and configurations, materials, and storage solutions.

The lab is composed of two main installations:

a) Volumetric test-bed

This installation was designed for the test of new volumetric configurations and its ageing. The main equipment installed is:

- 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,
- Extraction system: with 1 k-type thermocouple, 1 PT100 sensor, an air mass flow-rate measurement, and an air blower.



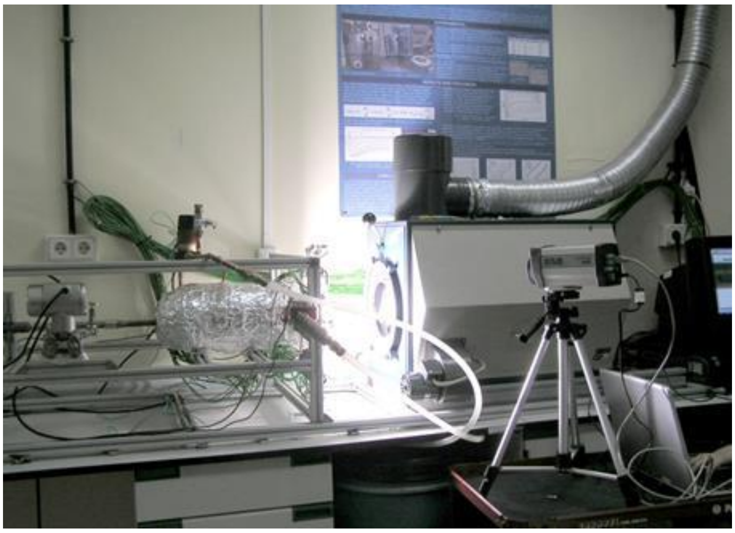


Figure 38. Operation of the 4 kW Xenon lamp

Moreover, the installation has the flexibility to study:

- The pressure difference across the volumetric absorber for different fluid density and fluid velocity, for the determination of the main properties described by the Forchheimer extension to Darcy's law: the viscous permeability coefficient and, the inertial permeability coefficient. A differential pressure drop system is installed, with the previously described installation, for the properties determination

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.

b) <u>Regenerative thermal storage test-bed</u>

In order to identify economically competitive options (< 20 €/kW_{th}) on materials and geometries for the packed beds used as thermocline heat storage, CIEMAT-PSA has developed a lab-scale thermocline storage system (of about 0.1 m^3) as experimental loop for static (Figure 39) and dynamic (Figure 40) thermal characterization of porous beds.

The two possible configurations are:

- Static configuration: In this 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: In this configuration, the experimental loop allows an agile characterization of the global storage at different working temperatures, filler materials, charges and discharges strategies, etc.
- The system consists of six power heating resistor with a total power of 15000 watts electric energy. They heat the air up to a target temperature (maxi-

mum temperature limited by the resistor is 1000°C) by means of a temperature controller. An amount of 35 K-type thermocouples units of 400 mm long are used. The behaviour of the tank is measured at 7 levels with 5 measurement each level.

Figure 39. Front view of the lab-scale regenerative storage system in static arrangement.

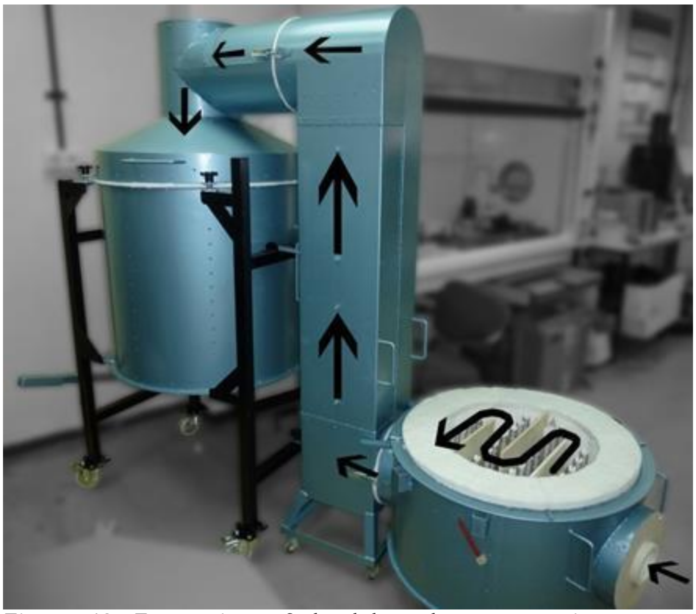


Figure 40. Front view of the lab-scale regenerative storage system in dynamic arrangement.

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.

2.1.2.8 Solar Hydrogen Evaluation Laboratory

Application of solar concentrating technologies to high-temperature processes is another field of enormous importance in PSA. The best known application so far is bulk electricity generation through thermodynamic cycles, but other applications have also been demonstrated, such as production of hydrogen and solar fuels.

Some high temperature endothermic reactions for converting solar energy into chemical fuels are been investigated by CIEMAT-PSA through a range of indirect water-splitting techniques, as well as hybrid systems involving solar-driven fossil fuels transformation to hydrogen. For this purpose a versatile solar characterization loop is placed in our installations in Madrid, a scheme of which is shown in Figure 41.

The Solar Hydrogen Laboratory is located at CIEMAT Moncloa (Madrid) and has the following capabilities:

- A laboratory equipped with the instrumentation necessary for evaluation of innovative processes for hydrogen production: A tubular furnace, a high-temperature kiln; and for analysis, a gas chromatograph (Varian CP4900) equipped with a molecular sievecolumn and a TCD detector etc.
- 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.

Figure 41. Solar Simulation Loop for evaluation of hydrogen production processes

2.1.2.9 PSA Radiometry Laboratory

The PSA Radiometry Laboratory came up of the need to verify measurement of highly important radiometric magnitudes associated with solar concentration, i.e., 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 also available in this lab for this purposeThe accuracy of gages is within ±3% with a repeatability of ±1%.

The Radiometry Laboratory has three black bodies as references for calibrating IR sensors for measuring temperature 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 1000ºC accurate to ±0.25% and with a resolution of 1ºC. 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 150ºC 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 42. View of the PSA Radiometry laboratory.

Figure 43. IR sensor calibration using a black body.

2.2 Experimental Installations for Solar Desalination of Water

2.2.1 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 CPC (compound parabolic concentrator) solar collectors
- A water 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 factor (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 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) produced 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 44. The PSA SOL-14 MED Plant (left), double-effect LiBr-H_2O absorption heat pump (upper right) and 500-m^2 CPC solar collector field (bottom right)

2.2.2 AQUASOL-II Solar Field Facility

The purpose of this facility is the study of the efficiency of large-aperture static solar collectors and its behaviour in the coupling with thermal desalination systems at 60-90°C temperature levels. The collector selected was 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 permit to have an equal distributed flow rate without further regulation. Also, 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.

Figure 45. The 606-m^2 large-aperture flat plate solar collector field (AQUASOL-II)

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.

2.2.3 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. 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.

Figure 46. View of the outside of the CSP+D test bed building with the air coolers (left) and partial view of the interior of the CSP+D test bench (right)

2.2.4 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, desalinating water for drinking water supply and the rest for heating sanitary water (ACS).

Figure 47. NEP PolyTrough 1200 solar field

The purpose of this facility is preliminary study of the behaviour of a parabolic trough solar field of small concentration ratio, 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 an efficiency over 55% in the range of 120-220°C (for 1000 W/m^2 of direct normal irradiance).

The field is configured in 8 collectors placed in 4 parallel rows, with two collectors in series in 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 going to be used to generate steam for supplying the double-effect absorption heat pump coupled to the PSA MED plant.

2.2.5 Test-bed for Solar Thermal Desalination applications

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 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 litres 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 one, and hot water can be supplied with temperature up to about 90°C.

Figure 48. Internal (left) and external (right) views of the Membrane Distillation experimental test bed within the PSA low-temperature solar thermal desalination facility

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 loop or closed loop. In the latter case, both the distillate and brine fluxes are collected and mixed together, to be fed again into the desalination units after a heat dissipation system. The installation currently with Membrane Distillation (MD) modules, and has a wide range of different commercial and pre-commercial units from all manufacturers. The list of MD modules that have been evaluated or are under evaluation is:

- Plate and frame AGMD commercial modules from Scarab (total membrane area 2.8 m^2).
- Two plate and frame LGMD 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).
- Spiral-wound LGMD commercial modules Oryx 150 from Solar Spring (10 m^2).
- Two spiral-wound AGMD modules from Aquastill with membranes area of 7 m^2 and 24 m^2 each.
- WTS-40A and WTS-40B unit from Aquaver, based on multi-stage vacuum membrane distillation technology using modules fabricated by Memsys (5.76 m^2 and 6.4 m^2 total membrane area respectively).

2.2.6 Bench-scale Unit for testing vacuum membrane distillation

The installation consists of a test-bed for evaluating the behaviour of different membranes in a vacuum membrane distillation. The unit is equipped with a transparent membrane module, where pieces of membrane can be tested. An on-board feed vessel allows for the application of different types of feed. This feed is transported alongside of the membrane by a fluid pump that expels the remaining feed as brine. The feed can be heated to a set temperature by an electric heating element that is installed in the feed vessel. On the other side of the membrane an under-pressure is created by a vacuum pump. When hot feed passes on the front side of the membrane, vapour (or other substances in the gas phase) is sucked through the membrane to the other side. The vapour passes through a condenser then, and the resulted condensate is collected in a distillate tank. Before entering the tank, a sampler unit allows for collecting distillate samples for a quality check.

Figure 49. Laboratory unit for testing membranes on vacuum MD

2.2.7 Bench-scale Unit for testing isobaric membrane distillation in different configurations

The installation consists of a test-bed with a small plate and frame module 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 litres 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 litres and the module. The circuit is heat insulated and fully monitored for temperature, flow rate and pressure sensors, connected to a SCADA system.

2.2.8 Bench-scale unit for tests with forward osmosis and pressure-retarded osmosis

The installation consists of a test-bed with two small plate and frame modules of 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 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 50. Bench-scale unit for testing membranes on isobaric MD

Figure 51. Bench-scale unit for testing FO and PRO

2.2.9 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 microfiltration (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 52. Test bed for FO-RO combination research

2.3 Experimental Installations for Solar Detoxification and Disinfection of Water

The unit of Water Solar Treatment has different facilities and instrumentation related with the application of technologies for water purification (decontamination and disinfection). Since 2010, and as one of the activities co-funded by the Ministry of Science and Innovation under 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) and FEDER, the facilities were update and new scientific instrumentation and facilities has been acquired for solar water treatment unit activities (SolarNova Project).

2.3.1 Solar Treatment of Water Facilities

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

- Solar CPC (compound parabolic-trough 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.
- Experimental culture camera.

Solar CPC pilot plants

A number of solar photo-reactors are currently installed at PSA facilities (Figure 53). 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 37º from the horizontal to increase 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.

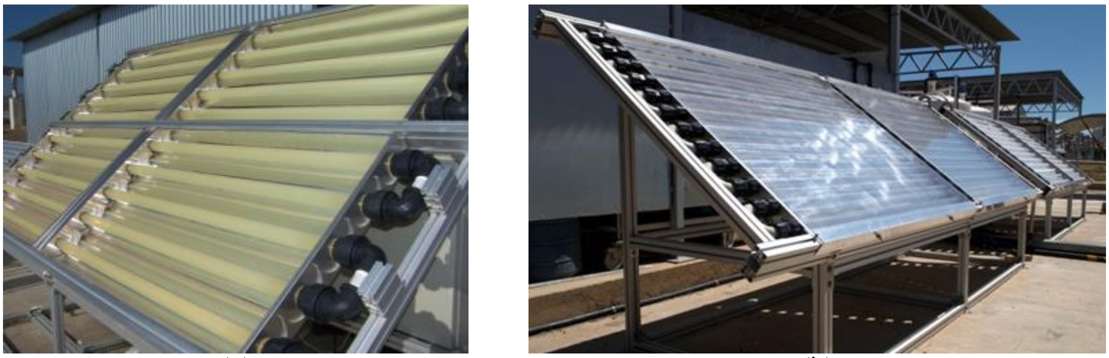
Year	CPC (m^2)	Total/illuminated volume (L)	Flow or static	Tube diameter (mm)	Added system/Characteristic
1994	3	250/108	Flow	50	
2002	15	300	Flow	32	
2004 (CADOX)	4	75/40	Flow	50	-50L ozonation system -Biological water treatment system -Monitoring (pH, T, ORP, O_2, flow rate, H_2O_2, O_3), control (pH, T, flow rate).
2007 (SOLEX)	3.08(x2)	40/22	Flow	32	-Plexiglass screen
2008 (FIT)	4.5	60/45	Flow	50	-Monitoring (pH, T, O_2, flow rate) and control (T, flow rate). -Sedimentation tank
2010 (FIT-2)	4.5	60/45	Flow	50	-Monitoring (pH, T, O_2, flow rate) and control (T, O_2, flow rate). -Sedimentation tank
2011	2.1	25/14.24	Flow	32	-Couple with H_2 generation pilot plant
2011	1	25/11.25	Flow	50	

Year	CPC (m^2)	Total/illuminated volume (L)	Flow or static	Tube diameter (mm)	Added system/Characteristic
(CPC25)					
2013	2	40/25	Flow	50	-Couple 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

Figure 53. View of several CPC photo-reactors for purification of water

Since 1994 several CPC pilot plants have been installed at PSA facilities. The oldest CPC pilot plant consists of 3 m^2 modules. The total system volume is about 250 L and the absorber tube holds 108 L (illuminated volume). In 2002, a new 15 m^2 collector for experiments of volumes up to 300 L was installed. In 2004 other CPC system (CADOX) was developed for photo-Fenton applications (Figure 54(a)), this system 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.

Two twin prototypes (SOLEX, 2007) were set up to perform simultaneous experiments under same experimental conditions. Each SOLEX prototype consists of two CPC modules with a total illuminated collector surface of 3 m^2, a total volume of 40 L (22 L illuminated). The photo-reactor tube has external diameter of 32 mm (Figure 54(b)).



(a) (b)

Figure 54. CPC photo-reactors placed at PSA facilities a) CADOX, b) SOLEX

In 2008, a photo-reactor for solar water disinfection (FITOSOL) was installed (Figure 55(a)). The solar reactor consists of two CPC mirror modules, each one with ten borosilicate-glass tubes. In this system, 45 L of the 60 L total volume are irradiated. The irradiated collector surface is 4.5 m^2. The reactor is equipped with pH and dissolved oxygen sensors. The water post-treatment pilot plant consists of a 100 L tank for separating the TiO_2 from the treated water. It is used for disinfection tests with water polluted by all kinds of microorganisms and aimed for the reuse of water from wastewater treatment plants. This reactor was equipped with a temperature control system to perform controlled temperature experiments (20 - 55° C).

In 2011, a new CPC reactor was installed and coupled with a pilot plant for photocatalytic hydrogen production. This CPC reactor is composed by 16 Pyrex glass tubes. The total volume for working in the system is 25 L, in which 14.24 L constitute the irradiated volume and the total area irradiated is 2.1 m^2. Besides, a large CPC photo-reactor for water disinfection (FITOSOL-2) made of 20 borosilicate glass tubes with a 60 L total treatment capacity and an illuminated area of 4.5 m^2 was also installed (Figure 55(b)). It is used for disinfection tests with water polluted by all kinds of microorganisms and aimed for the reuse of water from wastewater treatment plants. It has a temperature control system that allows working at constant temperatures ranging from 20 to 55ºC and injected air in different sites of the piping.

(a) (b)

Figure 55. CPC photo-reactors placed at PSA facilities for water disinfection a) FITOSOL, b) FITOSOL 2.

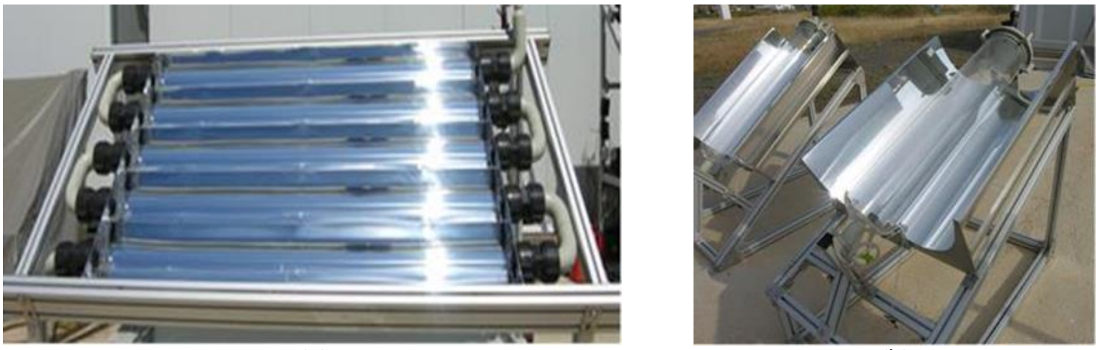
A 2 m^2 CPC collector with 10 borosilicate glass tubes (50 mm diameter) was built in 2013. Total illuminated surface of 2 m^2, an illuminated volume of 25 L and a total volume of 40 L (Figure 56(a)). This new pilot plant was installed for experimental research on electro-photo-Fenton processes for decontamination and disinfection of water. Later, a non-CPC reactor (NOVO75) with 75 mm pathlegth for SODIS water disinfection was designed and constructed. It was made of 12 tubes of 75 mm external diameter and 1.5 m length. It is equipped with a temperature control system that allows working at constant temperatures ranging from 20 to 55°C, several dissolved oxygen measurement points and air injection points to analyze the effects that oxygen injected in the line has on photocatalysis (Figure 56(b)). Total illuminated surface of 2 m^2, total volume of 74 L with 68 L illuminated water volume.

(a) (b)

Figure 56. a) 2-m^2 CPC pilot plant. b) New design of solar pilot plant (NOVO75) for solar photocatalytic treatment of wastewater.

Other solar pilot photo-reactors for solar water disinfection were also setup in these facilities:

- A CPC photo-reactor (CPC25) for photocatalytic and photo-Fenton disinfection experiments with total treatment capacity from 7 to 25 L. The system has a total illuminated surface of 1 m^2, an illuminated volume of 11.25 L and a total volume of 25 L. It has de capability to be modified reducing the total volume of water to be adapted for different experimental works (Figure 57(a)).



(a) (b)

Figure 57. New CPC photo-reactors installed in 2010 for solar water disinfection applications: a) CPC25 versatile, b) CPC-SODIS reactor.

- Two CPC (CPC-SODIS) photo-reactors for static-batch or discontinuous operation. Both static batch systems can treat 25 L of water completely exposed to solar radiation. The reactors have 0.6 m^2 of aperture CPC mirror, a photo-reactor borosilicate glass tube (outer diameter = 20 cm) (Figure 57(b)).

Solar simulators

Along with these pilot-plant facilities, there are two solar simulators provided with xenon lamps for small-scale water detoxification and disinfection experiments. In both systems, the radiation intensity can be modified and monitored. In addition, the new solar simulator XLS+ installed in 2014 contains a UV filter (Suprax) with wavelength limitation to 290 nm simulating external solar radiation. Temperature can be also modified in both systems by a cooling system (SUNCOOL) (Figure 58).

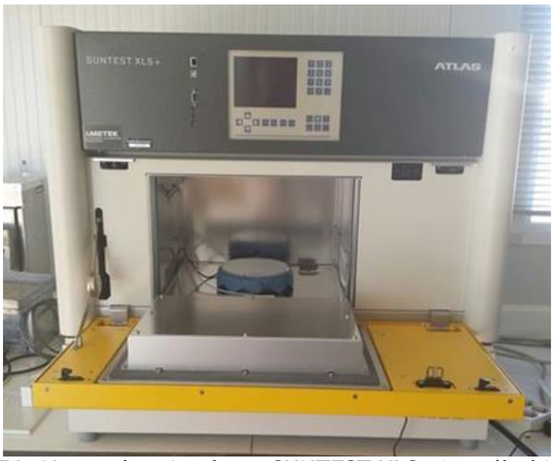


Figure 58. New solar simulator SUNTEST XLS+ installed in 2014.

Ozonation pilot plant

The ozonation system was installed in 2010 and modified in 2014 to improve the mass transfer of the ozone from the gas to the liquid phase (wastewater) and to eliminate several problems such as foam formation during the initial stage of ozone reaction with industrial wastewater with high content in dissolved organic carbon. A new contact column reactor was designed, with total volume of 20L (minimum operation volume of 8L). In addition, reagents dosing system and pH automatic control were installed. The pilot plant is equipped with pH and redox sensors, inserted in the recirculation line. This new ozonation system can work in batch and continuous mode allowing its combination with other technologies such as the UV pilot plant (Figure 59, left).

Nanofiltration pilot plant

The nanofiltration (NF) system was upgraded (2014) with the objective of having two working modes, in series and in parallel. Besides this enhancement, the new filtration system is equipped with different options of membranes cleaning for improving their lifetime. The previous 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 45ºC, 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 and so the filtration total surface area was increased to 7.8 m^2. In addition a new system of pH control was acquired to improve 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. A new feeding tank of 400 L of total volume was also installed (Figure 59, right).

Figure 59. (left) New contact column reactor for ozonation system. (right) New configuration of the improved Nanofiltration membrane pilot plant.

UVC-H_2O_2 pilot plant

A new ultraviolet pilot plant was designed and acquired in 2014 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^3h^{-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 60).

Figure 60. UVC pilot plant installed at PSA facilities.

Biological pilot plant

A biological pilot plant with a double depuration system was acquired in 2010 (Figure 61(a)). It has an Immobilised Biomass Reactor system with a total volume of 60-L: three IBRs of 20-L each one; and a Sequencing Batch Reactor 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 the three MULTIMETERS (M44 CRISON) is done by means of programmable relays and the main parameters are monitored by a SCADA system

(a) (b)

Figure 61. a) Biological pilot plant installed at PSA facilities. b) Solar pilot plant for photocatalytic generation of hydrogen.

Hydrogen pilot plant

A pilot plant for photocatalytic hydrogen production was also acquired in 2011. This plant is connected to a CPC photo-reactor for the simultaneous removal of organic contaminants contained in aqueous solutions. The pilot plant for photocatalytic generation of hydrogen 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 couple with this system was describe above.

Solar UVA monitoring equipment

In 2014, within the framework of 'Plan E', the UV and global solar radiation data monitoring and storage system was upgraded with two new pyranometers (Figure 62), measuring the 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.

Figure 62. CUV-5 radiometer (left). View of all solar UV radiometers (inclined and horizontal setup) used in the Solar Water Treatment Unit (right).

Cultivation chamber

The culture crop chamber of 30 m^2 is used for treated wastewater re-use experience was since 2014 (Figure 63). 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. 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 25ºC during the different seasons.

Figure 63. Cultivation chamber for wastewater crops irrigation reuse at PSA facilities.

2.3.2 PSA Water Technologies Laboratory

Under 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 listed. There are two rooms destiny for: i) chemicals and other consumables storage. It is a 30-m^2 storeroom with direct access from outside. It is organized on numbered and labeled 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 analyze the data from the experiments carried out at the PSA. The 4 technical rooms are listed and described below:

- General laboratory
- Chromatography laboratory
- Microbiology laboratory
- Microscopy laboratory

General laboratory

The main laboratory is 94 m^2 (Figure 64). 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 biological and chemical oxygen demand. Recently an Automatic Solid Phase Extraction (ASPEC) has been acquired for working with low concentrations of pollutants and a coating equipment to produce immobilized photo-catalysts. Jar-Test system for the experimental analysis and optimization of physic-chemical processes for water treatment at laboratory.

Figure 64. General view of the new PSA Water Technologies Lab.

Chromatography laboratory

This lab (Figure 65(a)) is equipped with two high performance liquid chromatographs with diode array detector (HPLC-DAD and UPLC-DAD) with quaternary pump and automatic injection; one gas chromatograph/mass spectrometer (GC/MS) with purge and trap system (analysis of volatile compounds dissolved in water), two ion chromatographs: 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 670º C and a total nitrogen (TN) analyzer with autosampler.

In 2014 several equipment were acquired, an Ultra Pressure Liquid Chromatograph with array diode detector in the UV-Vis (UPLC-DAD) (quaternary pump and automatic injection) was installed. This new equipment (Agilent 1260 UPLC) offers ultrafast analyses of water samples for analytical liquid chromatography results using all types of current and emergent column technologies. It has a diode-array detector with high sensitivity and baseline, and variable wavelength detector. (Figure 65(b)). 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. The system consists of an Agilent 1260 Infinity 2D-

LC system for comprehensive and heart-cutting two-dimensional separations and Triple TOF by a DuoSpray Source combinig Turbo Ion Spray and APCI (Atmospheric Pressure Chemical Ionization) modes. Besides, the system has a Data Acquisition Workstation and a specialized software package (Figure 65(c)).

(a)

(b) (c)

Figure 65. a) General view of the chromatography lab at PSA facilities. b) Ultra fast UPLC-DAD analyser. c) AB SCIEX TripleTOF 5600+ equipment

Microbiology laboratory

A 27-m^2 microbiology laboratory with biosafety level 2 (Figure 66) is equipped with four microbiological laminar flow (class-II) cabinets for handling of samples with microorganisms to be handled with biosafety II, 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.

Figure 66. General view of the microbiology lab at PSA facilities.

Microscopy laboratory

The microscopy lab is 11 m^2 room (Figure 67(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.

(a) (b)

Figure 67. a) SEM (Scanning Electron Microscope). b) Optical microscope for FISH technique

In this room it is also located two optical microscopes: i) A fluorescence and phase contrast combination optical microscope and ii) other microscope installed in 2013 which consist on a 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 67(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.

2.4 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 three lines of research focusing on: 1.-Energetic Analysis of Buildings by simulation, 2.-Study of Passive Systems in Buildings and Urbanism, and 3.-Experimental Energy Evaluation under Real Conditions. 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) Monozone building: This is a small 31.83 m^2 by 3.65 m high simple monozone 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.

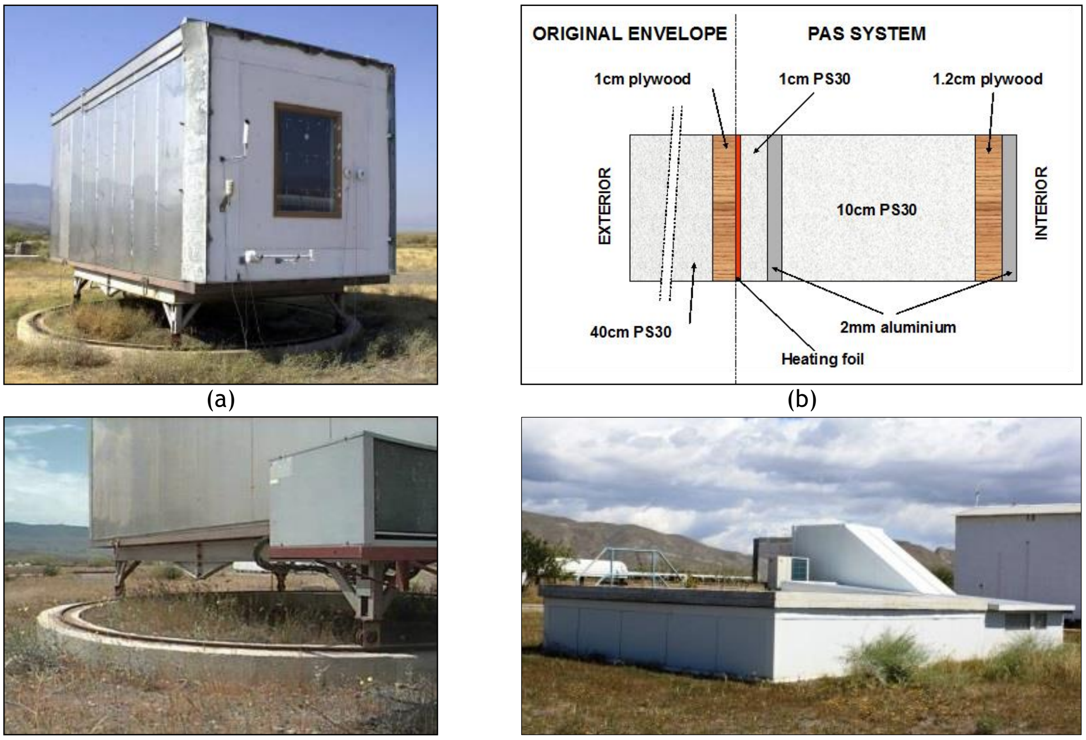


Figure 68. (a) CIEMAT's PASLINK test cell, (b) Schematic drawing of the PAS system, (c) Detail of the rotating device, (d) Exterior of the CETeB Test cell.

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 m2 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 69. (a) Solar Chimney, (b) Reference monozone building, (c) ARFRISOL Building Prototype in use.

3. Solar Concentrating Systems Unit

3.1 Introduction

Activities performed by the Solar Concentrating Systems (SCS) Unit are aimed at promoting and developing solar thermal concentrating systems, both for power generation and for industrial processes requiring solar concentration, whether for medium/high temperatures or high photon fluxes. This PSA Unit is composed of four R&D Groups:

- Medium Concentration Group,
- High Concentration Group,
- Solar Fuels/Solarization of Industrial Processes Group, and
- Thermal Storage Group

Activities in the SCS Unit in 2015 have been very similar to those in 2014, because the legal framework implemented by the Spanish Government in 2013 for solar thermal electricity (STE) plants discourages the Spanish STE sector from investing in R+D activities. This is the main reason why the number of bilateral agreements with Spanish industries was lower than in past years, and most of our activities in 2015 have been performed within the framework of either large European projects (e.g., STAGE-STE, SFERA-II, CAPTURE and EU-SOLARIS), which try to increase the efficiency and competitiveness of the European STE sector, or national projects mainly promoted by R+D centers (e.g., DETECSOL and ALCCONES).

This PSA Unit has also devoted in 2015 a significant effort to standardization activities within the Spanish sub-committee AEN/CTN2016 SC117 and the international committee IEC/TC-117, thus contributing to the preparation of new standards that have been issued in 2015 (i.e., UNE-206010) or will be issued in 2016 related to STE plants and their components.

We have also continued with our efforts to enlarge the number of collaborations with entities from other countries. To this extent, the thematic network ESTCI, which is coordinated by this Unit, with five Latin American countries (i.e., Mexico, Chile, Argentina, Colombia and Brazil) and Portugal are strengthening our collaboration with them in the field of solar thermal concentrating technologies. This network will be very soon the seed of joint projects with R+D groups from these countries.

Last but not least, dissemination activities to spread the knowledge of concentrating solar thermal systems inside and outside Spain have been important in 2015 also.

Activities and results achieved in 2015 by the four R&D Groups of the PSA USCS Unit are summarized in the sections below.

3.2 Projects

Concentrating Solar Thermal Energy for Iberoamérica, ESTCI

Participants: CIEMAT (Spain), CENIDET (Mexico), DICTUC (Chile), EPM (Colombia), Grupo Ibereólica (Spain), PUCC (Chile), SOLINOVA (Brazil), UAEMex (Mexico), UFPE (Brazil), UNAM (Mexico), UNINORTE (Colombia), UNLP (Argentina)

Contacts: Eduardo Zarza (Technical coordinator), eduardo.zarza@psa.es

Funding agency: Programa CYTED. Red Temática Ref.714RT0487.

Background: There are many Latin American Countries with good solar resources that could be used to supply a significant fraction of their energy needs. Since Spain has a great experience and know-how about concentrating solar systems and their applications, collaboration between Spain and these countries would be very interesting and of mutual benefit.

Objectives: The dissemination in Latin American countries of the experience and know-how gained by PSA about concentrating solar systems and their applications. The strengthening of scientific collaboration between PSA and R+D groups from these countries, together with the preparation of future joint projects, are also included in the objectives.

Achievements in 2015: ESTCI is a thematic network coordinated by PSA and supported by the Ibero-American Program CYTED (www.cyted.org). It was launched in January 2014 with a planned duration of 4 years. Five major activities have been developed in 2015:

- The maintenance of the official web page of ESTCI (www.redcytedestci.org)
- The survey of the legal framework existing in Argentina Brazil, Chile, Colombia and Mexico regarding solar concentrating systems installation and use was finished and the final report with the results of this survey will be published in 2016.
- The survey of the solar radiation data currently available in these countries (i.e., Argentina Brazil, Chile, Colombia and Mexico) was finished and the final report with the results of this survey will be published in 2016.
- Dissemination activities by PSA researchers, who gave a 2-day training course in Pirassununga (Brazil) to explain the basic principles, different technologies, applications and commercial potential of concentrating solar thermal systems (Figure 70). A one-day Seminar with the title "*Desenvolvimento da Tecnologia CSP: Oportunidade para o Brasil*" was organized by the University of Sao Paulo and held on November 26th in collaboration with partners from Spain, Mexico, Colombia, Argentina and Brazil. Additionally, other workshops and courses have been organized in Brazil and Colombia.

- Several options for a small-size (<100 kW) hybrid renewable system suitable for Latin-American participating countries were proposed by the Partners, and the option finally selected to be developed in detail during 2016-2017 is composed of small parabolic trough collectors feeding a small steam turbine coupled to a small electricity generator. A biomass boiler would assure the full dispatchability of the system. All the Partners will collaborate in 2016-2017 to develop this hybrid system, and a prototype will be implemented and evaluated if additional funds are found for this purpose.

This thematic network is creating a strong and fruitful relationship among all the Partners, thus fulfilling one of its main objectives.

Figure 70. ESTCI Project partners in the meeting held at Pirassununga (Brazil) in November 2015.

Standardization Activities at Spanish and International Level. Technical Committees IEC/TC117 and AEN/CT206

Participants: From Spain: ABENER, ABENGOA, ACS-COBRA, AENOR, ALATEC, AICIA, ARIES, ASTROM, CENER, CIEMAT, CSP Services, CTAER, ELECNOR, Garrigues, GTAER, Iberdrola Ingeniería, PROTERMOSOLAR, SAMCA, Schott Solar, SENER, TECNALIA, TEKNIKER; From Germany: DLR, NOVATEC Solar, SUNTRACE, Fraunhofer; from France: CEA and SolarEUROMED; From Italy: ENEA and Archimede Solar; From other countries: IEECAS (China), LNEG (Portugal), Solar Design Co. (United Kingdom), EVORA University (Portugal)

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

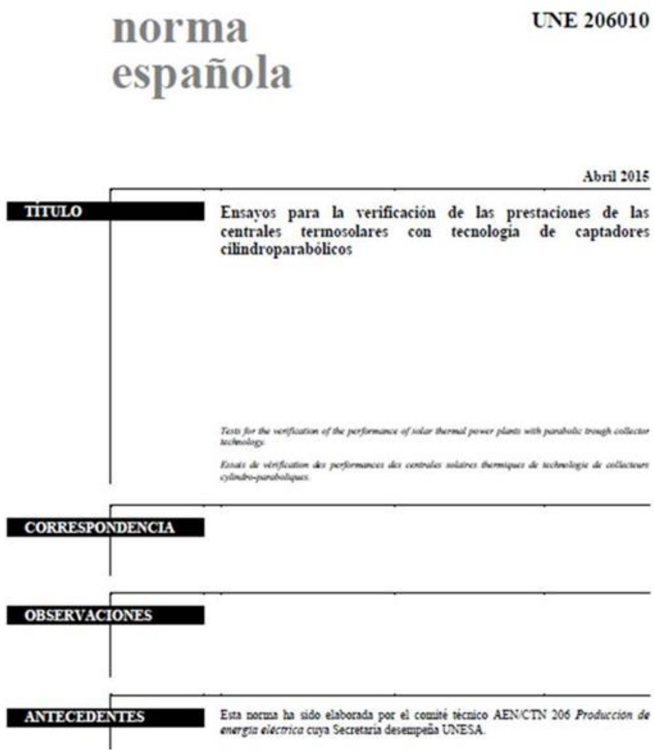
Funding agency: CIEMAT, European Commission, FP7 ENERGY-2013-IRP

Background: Since Solar Thermal Electricity (STE) plants are a relatively young technology, the STE 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 2015: PSA has participated with a significant contribution in the international and national standardization committees IEC/TC-117 and AEN/CTN-206 coordinating several working groups and participating in all the groups. As Coordinator of the working Groups WG1 and WG3 of the subcommittee AEN/CTN206 PSA has contributed in 2015 to the development of three new standards within these two working groups:

- "*Tests for the verification of the performance of solar thermal power plants with parabolic trough collectors*". This new standard was issued by AENOR in April 2015 with the reference UNE-206010
- "*Tests for the verification of the performance of solar fields with parabolic trough collectors*". This new standard was almost finished in 2015 and it is expected to be issued by AENOR in 2016.
- "*Characterization of thermal storage systems for concentrating solar thermal systems with parabolic trough collectors*". The text of this new standard was finished in 2015, with a final review during the last quarter of the year and it is therefore expected to be published by AENOR in 2016.



norma española

UNE 206010

Abril 2015

TÍTULO

Ensayos para la verificación de las prestaciones de las centrales termosolares con tecnología de captadores cilindroparabólicos

Tests for the verification of the performance of solar thermal power plants with parabolic trough collector technology.

Essais de vérification des performances des centrales solaires thermiques de technologie de collecteurs cylindro-paraboliques.

CORRESPONDENCIA

OBSERVACIONES

ANTECEDENTES

Esta norma ha sido elaborada por el comité técnico AEN/CTN 206 *Producción de energía eléctrica* cuya Secretaría desempeña UNESA.

Figure 71. Front page of the new standard UNE 206010 issued in 2015.

PSA has also contributed in 2015 within the WG2 of AEN/CTN-206 to the development of several standards related to qualification of components (e.g., parabolic trough collectors, receiver tubes for parabolic trough collectors, solar reflectors and working fluids), for concentrating solar thermal systems. Several of these new standards will be issued in 2016.

Within the framework of IEC/TC-117, PSA has coordinated in 2015 the Team PT62862-1-1, which is devoted to the development of a new IEC standard on "Terminology" for concentrating solar thermal systems. More than 130 comments made by the members of this Team to the draft standard initially proposed in 2014 have been discussed and clarified in 2015. It is expected that this IEC standard will be finished in 2016.

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 2017)

Background: Commercial deployment of concentrating solar thermal (CST) technologies grown significantly in the last ten years. In 2006 there were 354 MW_e installed around the world and in currently more than 3 GW_e, with about 2.3 GW_e coming from Spanish CSP plants, are installed around the world. To reduce the installation and O&M costs and improve the efficiency of CST systems is needed to optimize existing developments and look for new innovative solutions.

Objectives: The project DETECSOL aims to advance in the development of new components and solutions to improve the efficiency of CST technology. The specific objectives of the project are:

- 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.

Results in 2015: During 2015 a review about the use of CO_2, helium, nitrogen and air as heat transfer fluids in solar receivers of parabolic troughs was conducted. The CO2 was identified as suitable fluid thanks to the efficiency achieved. This fluid working in supercritical conditions has been considered in a preliminary study of a tubular solar receiver for tower systems (Task 1.1). A selective coating stable in air up to 700°C is under development. The degradation of the coating is slow with temperature over 500°C due to the diffusion of the infrared reflector layer in the stainless steel substrate. To minimize this effect, the use of a double layer of platinum is under study (Task 1.3).

Concerning solar reflectors and concentrators, a new geometry obtained by mean of inverse Monte-Carlo ray tracing was defined. The new geometry can be applied to line-focus collectors when a more homogeneous concentrated heat flux profile is needed, comparing the profile to the one obtained with parabolic troughs (Task 2.1). A review of durability studies of solar reflectors have been also conducted during 2015. The experimental work related to the durability analysis of solar reflectors exposed to corrosive gases was initiated. An accelerated aging test chamber, some outdoor sites for the exposition of reflectors samples, and a test procedure have been prepared and defined (Task 2.2). It is ready the selection of a reflector material to be used as secondary concentrator; accelerated aging of the material fixed to the concentrator structure material using different glues o adhesive materials will be analysed (Task 2.3).

And regarding thermal energy storage systems, different test procedures for analysing the performance and reliability of control valves and pressure transmitters in direct contact with molten salts, have been performed (Task 3.1). Concerning new storage materials development, liquid crystals are under study and promising results were obtained using compounds that presents clearing temperature of 250°C with clearing enthalpy of around 55 kJ/kg, which are suitable values for Solar Heat for Industrial Processes (SHIP) applications (Task 3.2).

3.3 Medium Concentration Group.

3.3.1 Introduction

During 2015, the Medium Concentration Group (MCG) has conducted activities in the field of development, testing, and evaluation of components for line-focusing solar collectors (OCT, OPAC, DETECSOL and STAGE-STE WP8 projects). Furthermore, the testing of a new silicone fluid for parabolic-troughs fields (SITEF project), and modelling and simulation of solar power plants with parabolic-troughs using different heat transfer fluids (DETECSOL and STAGE-STE WP11 projects) are also activities carried out in this year. On the other hand, the analysis on how to integrate nowcasting systems with simulation models (DNICast project) has been conducted.

(a)

(b)

Figure 72. Medium Concentration Group staff working a) at the Plataforma Solar de Almería in Tabernas (Almería) and b) at the CIEMAT Headquarters in Madrid.

Finally, the research activity addressing DSG in parabolic-trough collectors (DUKE and STAGE-STE WP11 projects) should also be pointed out. A description of the relevant activities conducted by the MCG in 2015 is provided below.

3.3.2 Projects

Research and development of optical layers for solar receivers, OCT

Participants: CIEMAT, International and Spanish private companies

Contacts: Ángel Morales, angel.morales@ciemat.es
Gema San Vicente, gema.sanvicente@ciemat.es

Funding agency: CIEMAT and International and Spanish private companies.

Background: The improvement of solar absorbers and antireflective coatings promote the CSP technologies as the efficiency of the systems can be increased and for a longer period of time.

Objectives: Development of durable antireflective (AR) coatings on glass envelopes for solar application and air stable selective absorbers for medium and high temperature applications.

Achievements in 2015: A new improvement of the AR coating has been achieved, obtaining a film more resistant to abrasion without hardly modify the preparation process. The effect of using different heating rates during coating preparation has been also studied, and in addition the possibility of using the heat treatment which produces tempered glass to densify the AR coating has been also verified, resulting in energy savings when this type of glass is used as substrate.

Selective absorber stable in air at 500°C, developed for parabolic-trough collectors, has been improved to increase the operating temperature up to 700°C with similar optical properties: absorptance = 0.96 and emittance (@400°C) = 0.09. Preliminary tests have shown a good behaviour after two months at 700°C in air with no platinum diffusion on the substrate which is the main degradation mode observed in this absorber. On the other hand, a black, non-selective coating has been developed on alumina spheres for volumetric receiver absorber with a solar absorptance higher than 0.95 and a thermal stability of 700°C (Figure 73).

Figure 73. Uncoated and coated alumina spheres.

Optical Characterization and Durability Analysis of Solar Reflectors, OPAC

Participants: CIEMAT-PSA and DLR

Contacts: Aránzazu Fernández García, arantxa.fernandez@psa.es
Florian Sutter, florian.sutter@dlr.de

Funding agencies: German Federal Ministry of Economics and Technology (BMWi); Nematia Ingeniería Integral S.L.; Taiwan Glass Group; Rioglass Solar S.A.

Background: One of the key aspects to assure the feasibility of solar concentrating technologies is to achieve suitable solar reflector materials. Proper accelerated ageing tests are needed to predict the durability of solar reflectors under outdoor conditions. Guarantees required for highly efficient components can only be given by applying appropriate standardized testing methods.

Objectives: This collaborative project between CIEMAT and DLR is devoted to establish appropriate optical qualification and durability test methods of solar reflectors. The degradation processes of these solar reflectors are investigated under accelerated aging conditions and in several outdoor exposure sites with the goal of establishing lifetime prediction models.

Achievements in 2015: Microscopic comparison of the excited degradation mechanisms outdoors and under accelerated aging of aluminum reflectors permitted to select the most suited tests to realistically age the materials (see Figure 74). During 2015 correlations were derived to relate laboratory testing to outdoor exposure for each of the detected degradation mechanisms individually, making it possible to predict the specific degradation at different exposure sites and times based on accelerated aging. Based on the individual correlations, a four-step testing sequence has been defined for three outdoor reference sites.

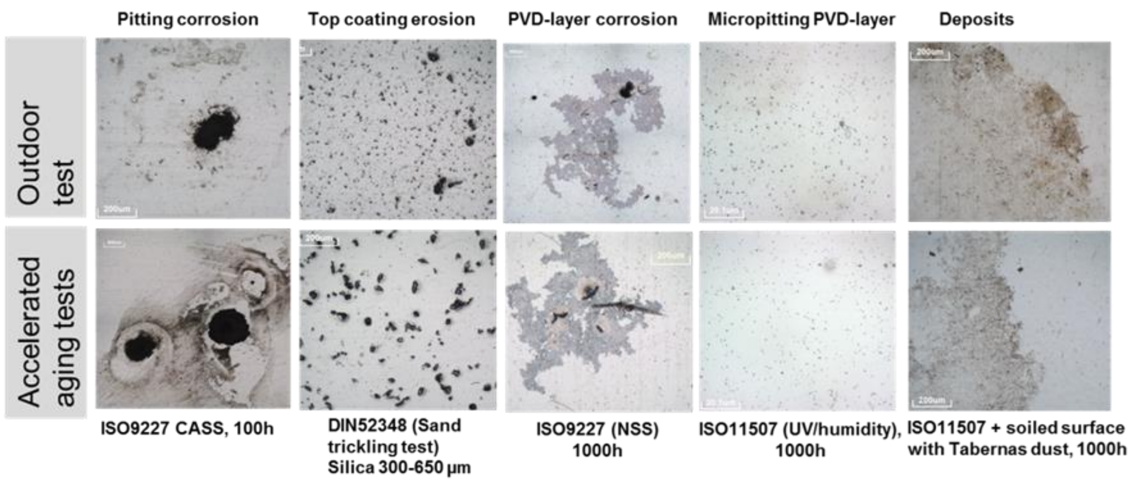


Figure 74. Microscopic comparison of natural degradation mechanisms with corresponding effects appearing under accelerated aging conditions, for aluminum reflectors.

Concerning glass-based reflectors, both a basic and an advanced testing program of accelerated aging were defined. Comparison of results obtained with those from outdoor exposed samples will give information about their representativeness. Also, a new simple sand erosion device was developed, according to the DIN 52348 standard. It consists of a sand trickling method, where particles acted by gravity from a height of 1.65 m impinge on a rotating sample. According to results achieved, this device has demonstrated to be suitable enough to reproduce the larger defects identified during real outdoor exposure.

In addition, OPAC group has actively participated during 2015 in standardization activities (SolarPACES Task III and AENOR), both in reflectance measurements and durability testing of solar reflectors.

Direct Normal Irradiance Nowcasting Methods for Optimized Operation of Concentrating Solar Technologies, DNIcast

Participants: OME, CENER, UniPatras, METEOTEST, ARMINES, RIUUK, SMHI, DLR, TROPOS, CIEMAT, MeteoSwiss, CyI

Contacts: Lourdes González Martínez, lourdes.gonzalez@ciemat.es

Funding agencies: European Commission,FP7-ENERGY-2013.2.9.2.

Background: The efficient operation of concentrating solar technologies (CSTs) requires reliable forecasts of the incident irradiance for two main reasons: (i) for better management of the thermodynamic cycle, as it becomes possible to dynamically fine tune some of its parameters (flow rate of HTF or the defocusing mirrors), (ii) because electricity production can be optimally connected to the grid.

Objectives: The main objective is to establish a portfolio of innovative methods for the nowcast of DNI and to combine these methods, validate the nowcasts and assess the influence of improvement in DNI nowcasting on nowcasting of CSP and concentrating photovoltaic (CPV) power plants output.

Achievements in 2015: Since the solar plant outputs are in relation with the incoming solar energy, the nowcasted DNI will be combined with plant performance models to allow the nowcasting of the plant output. The first step is the definition of typical power plants using different physical principles to utilize concentrated sunlight for electricity production. Three CSP reference plants and four CPV plants have been defined (technology, dimentions, etc.). These desigs will be the start point for the development of simulation model and the final study of the impact of DNI nowcasting on annual electricity yield. One of the sevent reference plants has been definded by us. It is a 35 MWel parabolic trough plant with Eurotrough 100 parabolictrough collectors, water as heat transfer fluid and without storage. This work has been compiled by DLR and CIEMAT in a comprehensive report (Milestone Report 18) in December 2015.

Development and Demonstration of the DSG once-through concept, DUKE

Participants: DLR-Institute of Solar Research (coordinator), CIEMAT-PSA (subcontract)

Contacts: Jan Fabian Feldhoff, jan.feldhoff@dlr.de
Loreto Valenzuela, loreto.valenzuela@psa.es

Funding agency: German Federal Ministry for the Federal Ministry for Economic Affairs and Energy (BMWi).

Background: DSG is an alternative process for parabolic-trough power plants, in which the HTF and the fluid used in the power block cycle are the same. In this project three solar field configurations were studied, i.e. recirculation, once-through and injection modes. The favoured concept was the recirculation mode, in which the evaporation and the superheating sections are separated by a steam drum.

Objectives: The project DUKE is dedicated to the so-called once-through concept and has two main goals: (i) analysis of the once-through concept under real solar conditions, and (ii) detailed system analysis for comparison of recirculation and once-through mode.

Achievements in 2015: During 2015, the test campaign continued and newly designed control structures for the once-through configuration were advanced. The control structures analysed lead to a variety of changes compared to former control strategies. The main difference is that the temperature control of the fluid (water-steam) is done using: (a) inlet mass flow control to calculate a gross mass flow based on feedforward on effective irradiation, which includes DNI and incidence angle modifier (IAM) effects; and (b) two faster control loops acting in two different injectors work together. The first one controls the temperature before the superheating injection while the second injector controls the outlet steam temperature. This configuration allows for a faster reaction during disturbances. The control scheme has been studied in simulations and experiments throughout the year 2015 (Figure 75), and it was concluded that a reliable temperature control concept is now available for commercial application to solar fields for DSG configured in once-through mode. An economic analysis revealed that cost savings of 10 to 25% for the steam generation might be possible by using once-through solar fields at locations with very good direct normal irradiance conditions. However, if sites with many days of clouds events are considered, recirculation mode with its inherent buffer may remain the more robust choice.

Silicone Fluid Test Facility, SITEF

Participants: DLR (coordinator), CIEMAT-PSA, Wacker Chemie AG, TSK Flagsol Engineering GmbH, Senior Flexonics GmbH, TÜV NORD SysTec GmbH & Co. KG

Contacts: Loreto Valenzuela, loreto.valenzuela@psa.es

Christoph Hilgert, christoph.hilgert@dlr.de
Javier León, javier.leon@psa.es

Funding agencies: Solar-ERA.NET Transnational Call CSP 2 2014; MINECO – Retos 2014 Acciones de programación Conjunta Internacional (Ref. PCIN-2014-083); German Federal Ministry of Economy and Energy, and German Federal Ministry of Innovations, Science and Research.

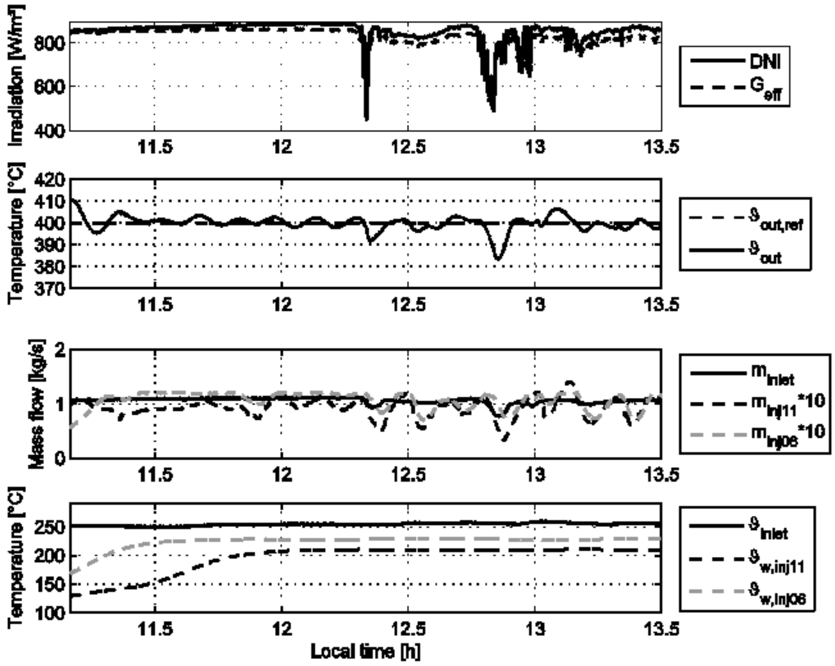


Figure 75. Control test for outlet temperature stabilization at 1000 m DISS test loop on June 24, 2015.

Background: Silicone based heat transfer fluids (SHTF) have been used in the past as HTFs in medium scale installations such as PTC test loops. SHTFs are pumpable below 0°C, environmental-friendly, low in hydrogen formation, almost odourless and very low in acute toxicity. Until now, SHTFs are not used in commercial plants because are currently far more expensive than the mixture of diphenyl oxide and biphenyl (DPO/BP).

Objectives: The SITEF project aims to demonstrate the loop scale functionality and applicability of a new Wacker Chemie AG silicone heat transfer fluid named HELISOL 5A® and associated PTC components at temperatures up to 450°C. Such operation temperatures are beyond state of the art in PTC power plants and increase the over-all power plant efficiency.

Achievements in 2015: The national Spanish sub project (national funding through SolarERA-NET) started in January 2015, but the German project suffered a delay and officially starts in January 2016. In any case, during this first year of project CIEMAT has initiated the operation of the PROMETEO pilot plant (Figure 76) with the existing heat transfer fluid, Syltherm 800®, to verify functionality of all the equipment and components (circulation pump, valves, ball joints installed in the interconnections, collectors tracking system, etc.). The results were satisfactory and at the end of the year, it was decided that the system was ready to drain the existing fluid and introduce the new SHTF manufactured and supplied by Wacker Chemie AG, and start its testing at medium temperature (below 400°C) in the solar collectors. In parallel, DLR, TSK Flagsol, and CIEMAT have started the engineering work in order to perform a technical upgrade of the pilot plant to be operated at least with fluid temperatures up to 450°C, which mainly implies new receiver tubes, a new system to cool down the heat transfer fluid coming from the outlet of the solar field, and a hot storage tank.

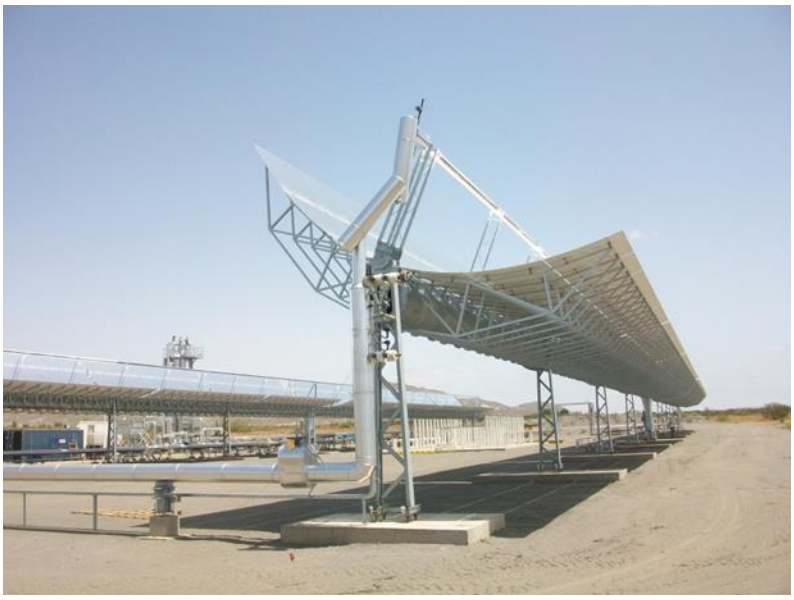


Figure 76 View of the PROMETEO solar test facility used in the SITEF project, located at Plataforma solar de Almería (PSA).

3.4 High Concentration Group.

3.4.1 Introduction

2015 has been the start-up year of four new projects in which the High Concentration group (HCG) is involved. Two of them financed by the MINECO: the PRESOL project, in collaboration with the University of Almería and the University of Huelva; and the DETECSOL project in which, in collaboration with our colleagues from the Medium Concentration Group, we are working on the development of the component technology for the next generation of Solar Thermal Power Plants. On the other hand, the ALCCONES project, funded by Comunidad de Madrid, is a continuation of the research activities started with the SOLGEMAC project which finished in 2014. And finally, the CAPTURE project, funded by European Commission, and in collaboration with several R&D institutions and companies, wherein a new concept of tower power plants coupling an atmospheric volumetric receiver with a gas turbine will be developed.

Last but not less, the activity of heliostats testing continues with a high implication of group staff: several heliostats prototypes has been tested during 2015 in our facilities, thus supporting companies in the product development, and improving our testing protocols adding new equipment for a more in-depth evaluation of the different prototypes.

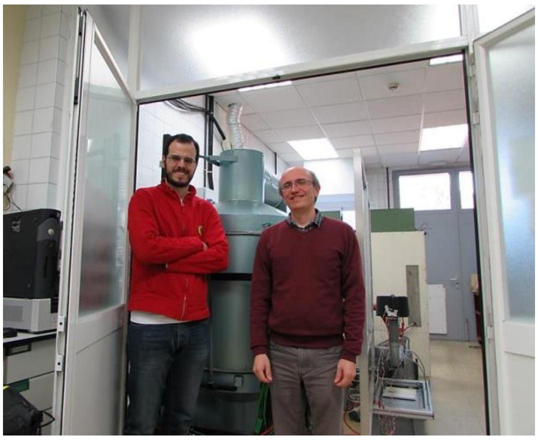


Figure 77. High Concentration Group staff working at the Plataforma Solar de Almería (left) and CIEMAT-Madrid (right).

3.4.2 Projects

Competitive Solar Power Towers, CAPTURE

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

Contacts: Jesús Fernández-Reche, jesus.fernandez@psa.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. Being a strategic technology field of the High Concentration Group CIEMAT has worked on this technology since 1990 having tested more than 15 different volumetric receiver prototypes in the last 20 years.

Objectives: The aim 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 (Figure 78). This not only increases cycle efficiencies but also avoids frequent transients and inefficient partial loads.

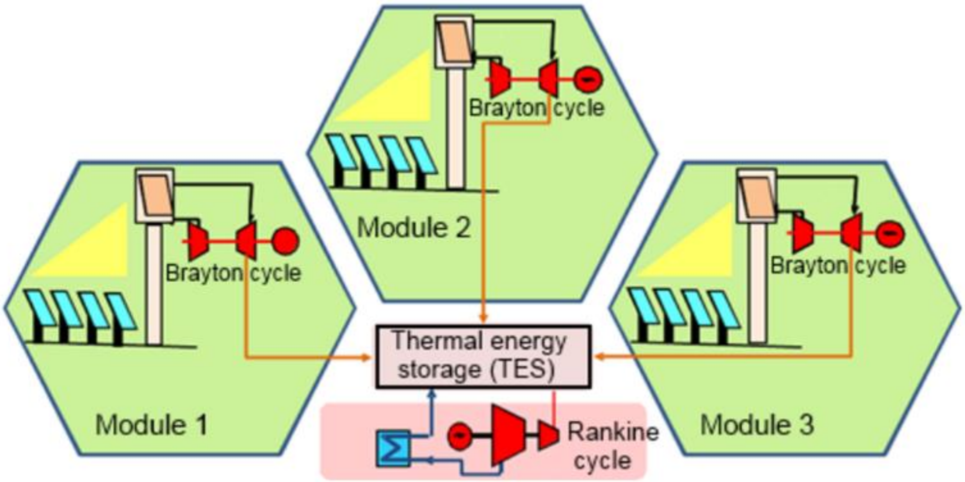


Figure 78. Decoupled Solar Combined Cycle (DSCC).

Achievements in 2015: This project started in May 2015, and the first steps were the definition of the different subcomponents: receiver, regenerator, gas turbine; and all the interconnection to be integrated in a final loop of 250 kW_{th} by the end of the projects. CFD and dynamic simulations have been carried out during these first eight month to define several prototypes that will be tested in solar simulators and/or parabolic dishes in order to confirm model results and define the final properties of components to be installed in the final loop.

In particular, the work carried out in this first period by PSA in collaboration with CENER and FRAUNHOFER-IKTS was focused on the definition of the absorbers to be used as volumetric receivers on the loop prototype, performing several simulations with different geometries and configurations in order to find out the best ones for solar testing during the first half of 2016.

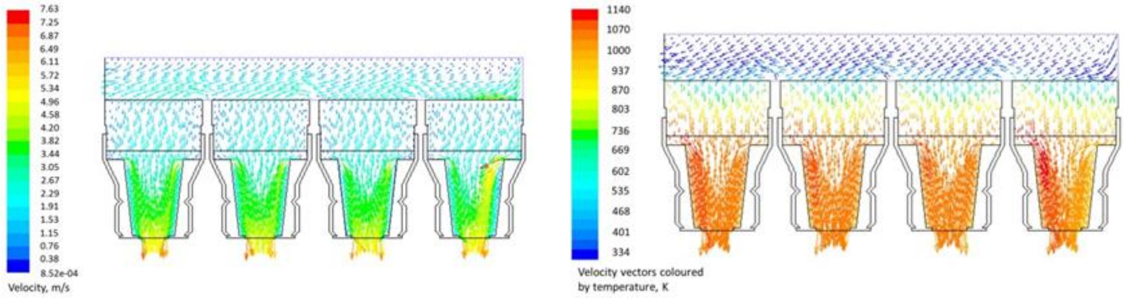


Figure 79. CFD simulations of one of the different configurations under analysis.

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

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

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

Funding agency: Ministerio de Ciencia e Innovación, Plan Nal. I+D+i (2013). Subprograma de Proyectos de Investigación Fundamental, ENE2014-59454-C3-3-R.

Background: Power generation from Solar Power Towers (SPTs) where DNI is a critical input is experiencing a rapid growth worldwide. The greatest 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 2015: 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 power plants. During the design of these plants it 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 parameter and at present, these plants are designed, built and operated without knowing this local parameter.

Nowadays digital cameras are used in many scientific applications for their ability to convert available light into digital images. Its broad spectral range, high resolution and low signal to noise ratio, make them an interesting device in solar technology. A method for atmospheric extinction measurement based on digital images has been presented. The possibility of defining a measurement setup in circumstances similar to those of a tower plant increases the credibility of the method. This procedure is currently being implemented at PSA (Figure 80).

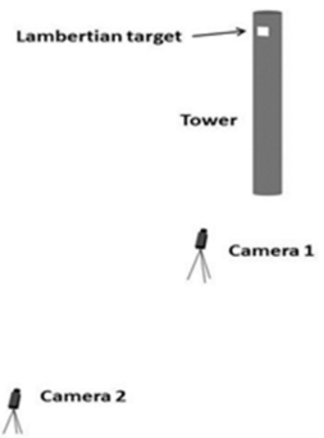


Figure 80. Digital cameras take images of the target

Storage and Conversion of Concentrating Solar Power, ALCCONES

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

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Antonio Ávila, antonio.avila@ciemat.es

Funding agency: Program of R&D activities between research groups of "Comunidad de Madrid", S2013/MAE-12985.

Background: The technology used up to now reaches 18-20% of nominal performance in the conversion of solar radiation to electricity and the investment cost is still high. Therefore, it is required to improve the efficiency of their thermal conversion processes and thermal storage systems.

Objectives: CIEMAT's participation is focused on the analysis of the behaviour of innovative thermal fluids to achieve higher working temperatures and develop a better integration with more efficient thermodynamic cycles, and the improvement of solar receiver designs to work more efficiently at high temperatures and high solar irradiance.

Achievements in 2015: Concerning the task devoted to the use of innovative heat transfer fluids, a comparison between a commercial fluid (a molten salt) and a supercritical one (s-CO_2) has been performed by CFD simulation of a molten-salt tubular receiver previously tested at the Plataforma Solar de Almería. Results showed that the heat gained by s-CO_2 at the outlet of the receiver module was greater than the one obtained by molten salt. Furthermore, a first estimation of the operating conditions for the supercritical fluid was obtained and an optimisation of the s-CO_2 tubular receiver is proposed as future work.

Regarding the topic related to the improvement of solar receiver designs, the study of different configurations of metallic volumetric absorbers has been developed in order to improve the convective heat transfer between solid and fluid (air), and minimize both the pressure drop and the radiative heat losses. For that purpose, several different metallic absorbers based on overlying wire meshes have been tested at lab scale using a solar simulator. Experimental results have also been used to validate a numerical model carried out for the analysis of these configurations.

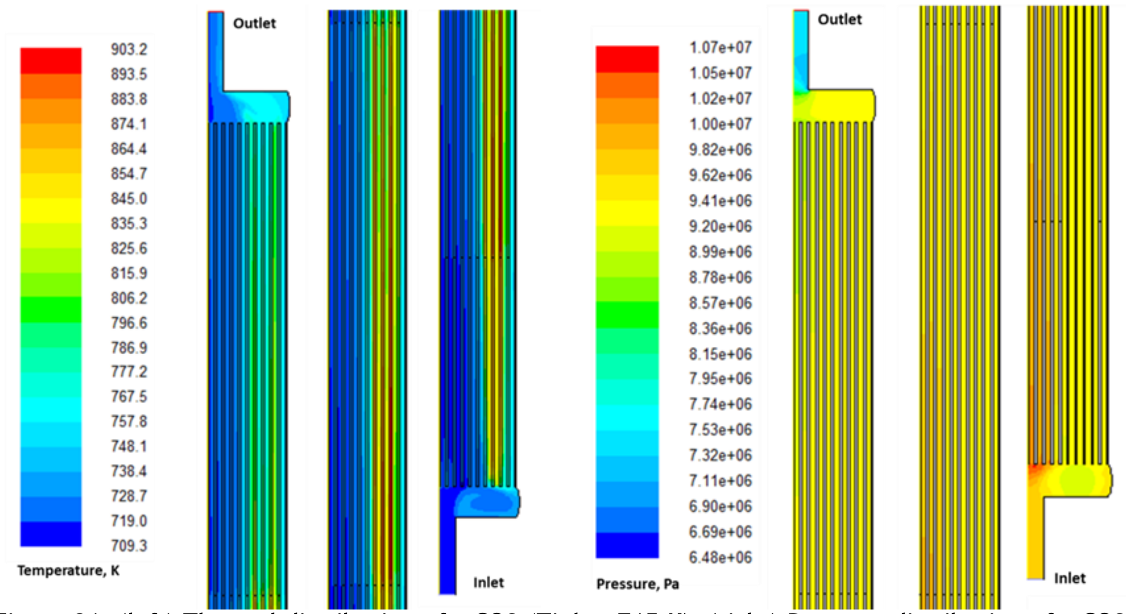

Figure 81. (left) Thermal distribution of s-CO2 (Tinlet=715 K), (right) Pressure distribution of s-CO2 (Tinlet=715 K).

Tests and Evaluation of Heliostats Prototypes

Participants: CIEMAT-PSA

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Raúl Enrique, raul.enrique@psa.es

Funding agency: Several Spanish and foreign companies.

Background: Deployment of Solar Central Receiver power plants has induced companies to design and build heliostat prototypes to be installed in different projects that are currently under development worldwide. Since the beginning of the activities at PSA, CIEMAT has been developing testing procedures for characterizing heliostats performance (Table 2).

Table 2. PSA Standard Heliostats Test Protocol

Items	Test	Explanation
1	**Characterization of the Local Control** **T1.** Behaviour of the local control with specific master control basic instructions (tracking, emergency stop, cleaning, shutdown, etc.). **T2.** Performance test of local control in case of failure or emergency. **T3.** Check heliostat angular speeds of both pure azimuth and zenith movements.	**T1.** The goal is to check the heliostat operative status before starting the test campaign **T2.** For safety reason, the goal is to check the heliostat reaction to critical operation cases e.g. high wind, emergency stop, motor failure etc. **T3.** Verify if angular speeds fulfil the design specifications.

Items	Test	Explanation
2	**Optical surface state** Qualitative checking of mirror waviness and canting errors prior to start optical quality test of the heliostat.	Qualitative checking of mirror waviness and/or canting error for better understanding current optical status. Canting correction if necessary.
3	**Campaign to characterise the optical quality of the heliostat** **T1.** Testing of optical quality of individual facets. **T2.** Optical quality test of the heliostat as a whole. **T3.** Test diurnal evolution of the optical quality of the heliostat.	Real pictures of both facets (sample) and whole heliostat are taken at different times of the day and outdoor temperatures to know the corresponding optical quality
4	**Campaign to characterise the tracking quality of the heliostat** **T1.** High frequency test for checking canonical heliostat tracking movement. **T2.** Repeatability of the heliostat pointing from different standby points. **T3.** Diurnal evolution test of tracking.	Test tracking accuracy repeatability by taking long series of both high and low frequencies images. Limited duration from few minutes to whole day tracking.
5	**Power consumption** **T1.** Total power consumption test of the heliostat **T2.** Test power consumption by local control only	Measure power consumption for whole day of tracking drives and local controller.
6	**Wind test** Heliostat Test under critical wind condition (speed, direction)	Checks the deviations of the heliostat tracking and optics quality under *critical* wind values, i.e., out of heliostat nominal working operation.

Objectives: To completely characterize heliostats prototypes performance: Optical, tracking and energy following test presented in Table 2.

Achievements in 2015: During the year 2015 three heliostat prototypes have been tested and evaluated at PSA in the test bench called Heliostat Testing Platform, located to the northern of the CESA-1 Heliostat Field.

In addition to the traditional testing techniques, this year 2015 a new measuring tool has been used with excellent results, the so called laser-scanner device, in order to explore the heliostat surface to find out its geometrical features directly (Figure 83 and Figure 84).

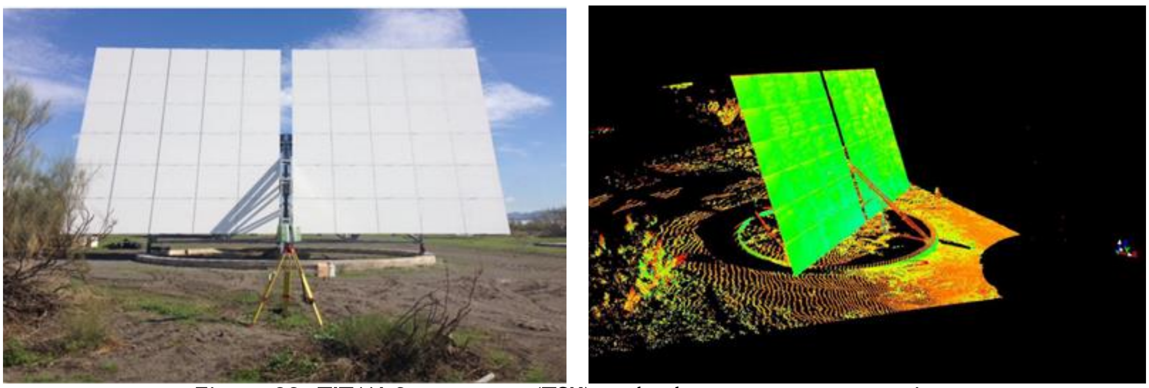


Figure 82. TITAN-2 prototype (TSK) under laser-scanner measuring

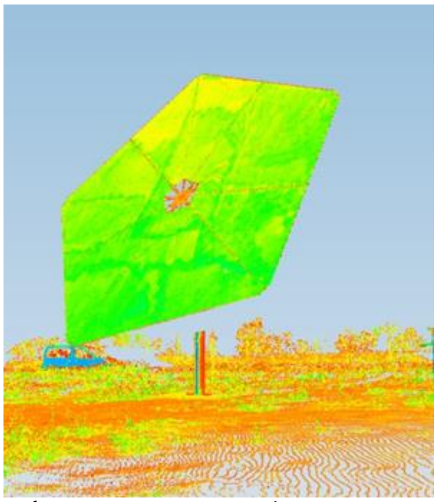


Figure 83. STELLIO prototype (SBP) under laser-scanner measuring

3.5 Solar Fuels/Solarisation of Industrial Processes Group

3.5.1 Introduction

Solar Thermal Electricity (STE) is a very promising renewable source of energy. The best known application so far is bulk electricity generation through thermodynamic cycles. However, other applications such as production of hydrogen and high-temperature heat production are also relevant.

The lines of activity are focused in 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.

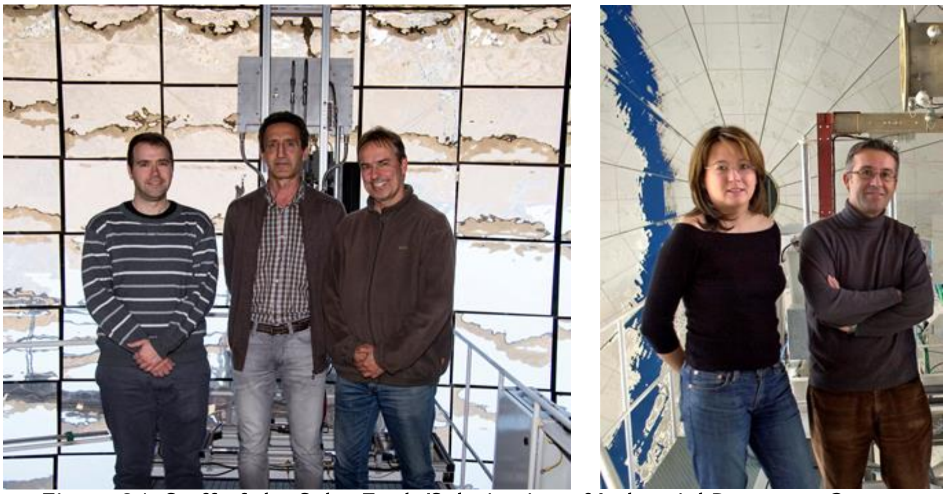


Figure 84. Staff of the Solar Fuels/Solarisation of Industrial Processes Group.

3.5.2 Projects

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

Participants: APTL, DLR, Hygear, HELPRES, CIEMAT-PSA.

Contacts: Athanasios G. Konstandopoulos, agk@cperi.certh.gr
Alfonso Vidal, alfonso.vidal@ciemat.es

Funding agency: European Commission, FCH-JU-2012.

Background: The HYDROSOL-Plant project aims to 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: The specific objectives are: (i) construction of a solar hydrogen production demonstration plant in the 750 kW range to verify the developed technologies for solar thermochemical H_2O splitting, (ii) operation of the plant and demonstration of H_2 production and storage on site (at levels higher 3 kg/week), and (iii) detailed techno-economic study for the commercial exploitation of the solar process.

Achievements in 2015: In 2015, CIEMAT has been focused on the preparation of the platform, which will host the HYDROSOL-Plant. This action has been completed and the platform is ready for occupation. The receiver-reactor, as a fully assembled and fully functional system, will be mounted on the platform placed at height of 28 m. The 2nd floor (4 metres below) will accommodate the rest of the peripheral components.

In Figure 85, a photograph of the remodelled room is given. The front has been designed to accommodate the three receivers according to the final configuration for the reactor array. The final configuration for the HYDROSOL reactor is showed in Figure 86. The solar chemical reactor, schematically depicted consists of a 3 cylindrical cavity-receiver containing a windowed aperture and a CPC and located in an equilateral triangle. Space between optical axis was determined based on vertical space available on the tower and operation variables like spillage losses and control temperature.

Figure 85. Photograph of the front thermal shield.

Figure 86. Final reactor configuration

In the previous plant, Hydrosol-3D, up to 70% of the incoming irradiative power is lost due to thermal re-radiation of the hot absorber surface. This reduces the overall efficiency of the hydrogen production considerably. Throughout this year, a preliminary simulation has been carried out to get an optimized homogeneous flux that provided a low spillage. This simulation has been finished and recommendations were given.

Clean technologies for solar hydrogen production based on mixed-ferrites thermochemical cycle, HITERSOL

Participants: ABENGOA Hydrogen, CIEMAT

Contacts: María Maynar, maria.maynar@abengoahidrogeno.com
Alfonso Vidal, alfonso.vidal@ciemat.es

Funding agency: CTA-IDEA. June 1, 2014 – December 31, 2015

Background: Some high temperature endothermic reactions for converting solar energy to chemical fuels have been investigated around the world. Many of the activities to this point dealt with identifying, developing, and assessing improved receiver/reactors for efficient running of thermochemical processes for the production of H_2.

Objectives: Hitersol pursued to develop clean technologies for solar hydrogen production based on water splitting by mixed-ferrites thermochemical cycle. To achieve this aim, an installation was designed, constructed and commissioning within a previous project named SolH2. Present collaboration pursued to complete the evaluation of a 200 kW pilot plant erected in PSA (see Figure 87).

Achievements in 2015: During the year 2015, CIEMAT carried out different activities of the project, such as construction, commissioning and implementation of the Supervisory Control And Data Acquisition (SCADA) system in collaboration with ABENGOA, and a preliminary simulation of the heliostat field and the heliostats required with the reactor design. The results of this part of the campaign should provide information of: cycle duration, feasibility of changing the reflection angle of the

Figure 87. Photograph of the reactor for SolH2 tests at CRS Plant.

heliostats quickly enough and realization of the necessary temperature levels in order to achieve the best performance (e.g. homogeneous flux, low spillage etc.). Some problems that remain to be resolved have already been detected (e.g., the flux directed at the central point of the reactor needs to be distributed differently to cover the needs of the peripheral points).

Main conclusions of this study were that the amount of power needed for the reaction requirements are achievable and also that the restrictions of the flux distribution on the chamber becomes a limitation. At this stage, definition of the heliostats strategy is complete and operating conditions before the experimental campaigns have been defined.

Storage and Conversion of concentrated thermal solar energy, ALCONNES

Participants: IMDEA Energía (Coordinator), University J. Carlos I, ICP-CSIC and CIEMAT. SENER and ABENGOA Hidrógeno.

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

Funding agency: Community of Madrid.

Background: The ALCONNES project is a very ambitious initiative which 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.

Objectives: 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, CIEMAT will explore the possibility of the use of new perovskite materials as candidates for thermochemical cycles.

Achievements in 2015: Some work conducted in 2015 was focused to study the technical feasibility of chemical reactors concepts based on direct heated fluidised bed reactors. A fluidised bed reactor located in a solar dish has been operated. The fluidised reactor is a refractory lined steel cavity of about 200 mm diameter aperture. Commercial Ni-ferrite were selected as a model material for solar experiments at a fluidised bed reactor. The granular material or bed is introduced at the reactor as a power and is moved by means of N_2 as fluidised gas.

Test campaign was made in a continuous mode, filling the reactor with a controlled amount of material and N_2 is flowed through the bed to ensure an acceptable moving bed height and residence time. First results were focused on determining the best operating conditions: minimum gas velocity, height of the bed, etc.

Furthermore, our research efforts in this project were directed towards preparation and synthesis of the perovskites materials in the laboratory, such as LaxSr1-xMnyAl1-

yO3 and LaxSr1-xFeyAl1-yO3, and testing, improving the kinetics and reducing the working temperatures.

Comparability between the different materials was established by TGA experiments under various reaction conditions. TGA experiments showed different weight losses between different samples (Figure 88). First hydrolysis tests carried out with this material indicated that the recovery of O_2 is not complete under the operation conditions.

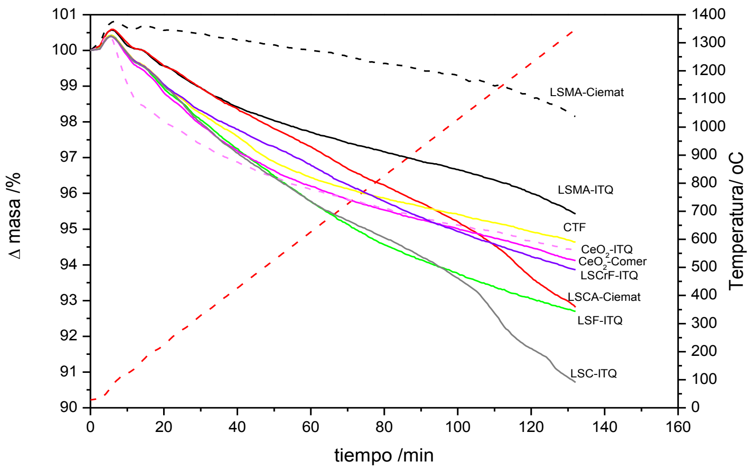


Figure 88. TGA experiments showing weight losses of studied materials.

Release of Oxygen from Lunar Regolite using concentrated solar energy. ORESOL

Participants: CIEMAT-PSA.

Contacts: Thorsten Denk; thorsten.denk@psa.es

Funding agency: European Commission FP6-ERA-STAR Regions, ESP2007-29981-E.

Background: The ORESOL project originated from the "ERA-STAR Regions" program, a joint initiative between Andalusia and Bremen (Germany). PSA continued the activity due to the unique possibility to investigate a promising type of solar chemical reactor for reactions that need the processing of large quantities of solids.

Objectives: The principal goal of the project is the 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.

Achievements in 2015: The behaviour of the solar reactor and the peripheral components was thoroughly tested under non-solar conditions. This included especially the operation of the reactor with the window installed to determine the pressure losses of all upstream and downstream elements. An important milestone was the relocation of the system from the laboratory (where the assembly and cold pre-tests were done) to the experimental platform, the SF60 Solar Furnace.

Besides the work on the hardware of the reactor, a study was done with the goal to simplify the concentrator system for the operation on the lunar surface. While a conventional Solar Furnace (Figure 89, left) consists of a flat heliostat (1), a building for weather protection, an attenuator (2) to compensate for the varying solar radiation flux, the concentrator (3), an additional, water cooled diagonal mirror (5) to achieve a vertical beam, and the reactor (4) on an elevated working platform, the simplified and especially lightweight version (Figure 89, right) uses an off-axis concentrator that allows to leave the reactor on the ground. The hardware can be reduced to the flat heliostat (1), the off-axis concentrator (3), and the reactor (4). The performance, especially the achievable peak flux, is slightly reduced, but this is not relevant for this application. Due to its appearance, the concentrator was dubbed "mussel-concentrator".

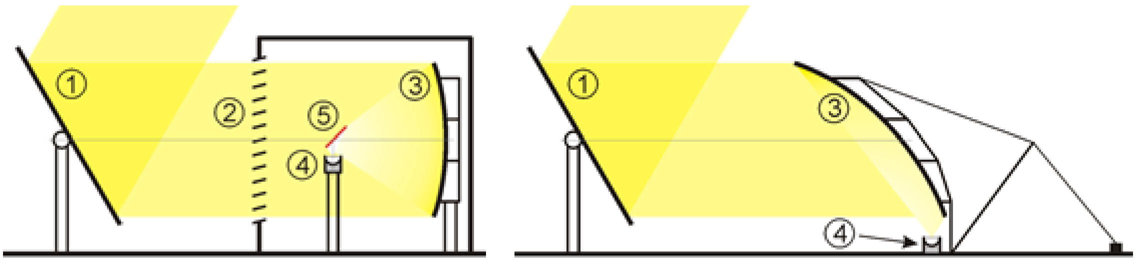


Figure 89. Left: Conventional Solar Furnace. Right: Off-axes ("mussel") concentrator.

3.6 Thermal Storage Group.

3.6.1 Introduction

The Thermal Storage Group (TSG) was born in 2015 to give more visibility to those activities on storage that the SCS Unit was performing since 2004. Composed by people formerly in the MCG, it deals with most of the storage activities of the unit. The technical activities in 2015 have been focussed on studying the feasibility of storage media, testing components for molten salt loops (valves, pressure gauges) and modelling the behaviour of Thermal Energy Storage System (TESS). The networking activity has been very strong this year, and has permitted the SCS Unit to play an important role in most international working groups on thermal storage (SolarPACES, IEC-TC116, EERA).

Figure 90. Members of the Thermal Storage Group.

3.6.2 Projects

Research Cooperation in Renewable Energy Technologies for Electricity, REEL-COOP

Participants: UPORTO (coordinator), UoR, DLR, UoE, CIEMAT, ENIT, IRESEN, YU, ONYX, MCG, Termo, Sol, ZE, AES, CDER.

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

Funding agency: European Commission, FP7- ENERGY.2013.2.9.1

Background: In order to change the fact that today still 17% of the world population have no access to electricity, with 2 out of every 3 living in rural areas of Africa and Asia, and to achieve "electricity for everyone" by 2030, the expansion rate has to double. Besides, in developed countries electricity demand is higher than supply and prices are increasing at high rates; where only 18% of the electricity comes from renewable sources (20% in EU).

Objectives: The aim is to develop, construct and teste three prototypes:

- Prototype#1: a building integrated PV system (with ventilated facades),
- Prototype #2: a hybrid (solar/biomass) micro-cogeneration ORC system, and
- Prototype #3: a hybrid concentrating solar/biomass mini-power plant (P1).

A special effort is being made to transfer and disseminate the developed technologies by organising Workshops on Renewable Electricity Technologies open to junior researchers and outside public.

Achievements in 2015: The main contribution of CIEMAT is the development of an, already patented, own design of thermal storage for latent heat with low-thermal conductivity phase change materials. The search for a suitable phase change material (PCM) in the required temperature range (130ºC-170ºC) showed that most of the candidates that literature proposes had to be discarded (C1, P2). The chosen PCM does not show an attractive phase change enthalpy, but it is stable under cycling and does not degrade. This fact, as well as the limiting efficiency of the ORC machine of the project (15% at the highest), imposes a size of the storage prototype not feasible to be installed in the P#3 system in Tunis. The required arrangements for testing the latent prototype at PSA facilities have begun.

Figure 91. Heat exchanger, which will become a latent storage prototype, at its reception at PSA.

Solving Energy Storage for DSG plants: liquid crystals as phase change materials

Participants: CIEMAT, University of Valladolid[1]

Contacts: Rocío Bayón, rocío.bayón@ciemat.es

Funding agency: European Commission (FP7-ENERGY-2013-IRP), Community of Madrid, and Secretaria de Estado de Investigación, Desarrollo e Innovación, Convocatoria 2014)

Background: DSG is seen as one of the most promising approaches to reduce the levelized electricity cost (LEC) for Solar Thermal power plants. Using storage materials that change phase from solid to liquid statically, electrical power decreases during discharge due either to a decrease of steam generation rate, when working at constant temperature and pressure of the heat carrier, or to a decrease of electrical efficiency, when working with sliding pressure.

Objectives: A new concept which involves storage material changing phase from one liquid state to another. Liquid crystals (LCs) are substances thatexhibit a sequence of one or more transitions involving intermediate fluid phases, called mesophases. Thus, a nearly constant power curve is possible, and an efficient exchange of energy is assured since convection is the main heat transfer mechanism.

Achievements in 2015: Several liquid crystal compounds have been selected taking into account reported high clearing enthalpy and simple synthetic route. In collaboration with the University of Valladolid some LCs have been prepared. These LCs

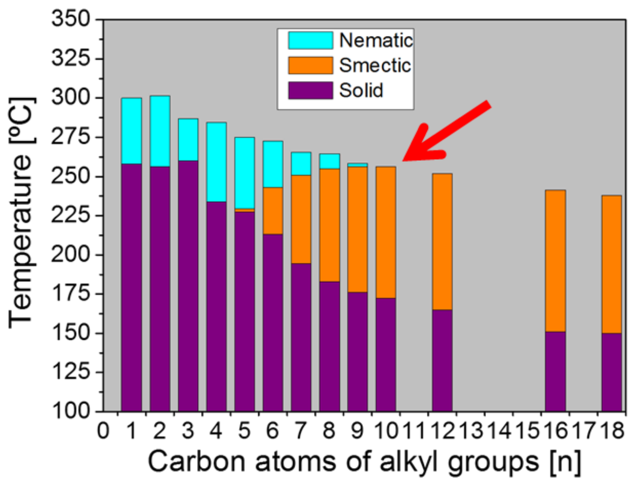


Figure 92. Phase transition temperatures with the alkyl chain length for biphenyl derivatives.

show clearing temperature[2] and enthalpy values similar to those reported in literature, but unfortunately some of them decompose after clearing transition. However,

[1] Through a Collaboration Agreement
[2] Temperature at which the mesophase liquid becomes isotropic liquid

the 4’-decyloxybiphenyl-4-carboxylic acid (10-BPhCOOH) shows no signs of decomposition, so it has been further characterized (P3, C2). Although more thermal stability tests are required, these preliminary results are very promising and further studies on other liquid crystals with carboxylic acid as functional group are scheduled.

Procedures for testing molten salt equipment and components

Participants: CIEMAT-PSA

Contacts: Margarita Rodriguez, marodriguez@psa.es

Funding agency: Secretaria de Estado de Investigación, Desarrollo e Innovación, Convocatoria 2014, ENE2014-56079-R.

Background: Current thermal storage systems (TES) in CSP plants use molten salt as their storage media. This molten salts are very corrosive, have a high superficial tension and a rather high solidification point (around 240°C). These specific features are an obstacle to the application of any of the current standard procedures for testing hydraulic components to those to be place in a molten salt circuit.

Objectives: Development of adequate testing procedures for components –such as valves, pressure transducers, pumps, etc– to be allocated in molten salt hydraulic circuits.

Achievements in 2015: Commercial valves of different configurations and types have been tested, refining the testing procedures initially proposed in the now close OPTS project. Procedures for evaluating pressure transducers have been proposed and verified with a commercial product (P4). The available facilities have been enlarged with BES-II, which is similar in scheme to BES-I, but allows working at much higher temperature and pressure values.

Figure 93. BES-II: Test bench with molten salts at high temperature.

4. Solar Desalination Unit

4.1 Introduction

The Solar Desalination Unit (UDeS in its Spanish acronym) has the objective of new scientific and technological knowledge development in the field of brackish and seawater solar desalination. Main current research lines are the following:

A) Multi-Effect Distillation (MED) using solar thermal Energy and/or hybrid solar/gas systems.
B) Introduction of Double Effect Absorption Heat Pumps (DEAHP) into solar MED plants, coupled with advanced control strategies.
C) Integration of desalination technologies into solar thermal electricity plants (CSP+D).
D) Development of integrated solutions based on Membrane Distillation (MD) technologies driven by solar thermal energy.
E) Development of integrated solutions based on the combination of Forward Osmosis (FO), Reverse Osmosis (RO) and MD processes driven by solar thermal energy.
F) Integration of solar thermal powered RO desalination systems (Organic Rankine Cycle (ORC), steam engines).
G) Development of solar polygeneration integrated solutions (power/cooling/water/heat production) based on small parabolic trough technology.
H) Development of integrated solutions for salinity gradient power generation: reverse electrodialysis (RED) and pressure retarded osmosis (PRO).

Solar desalination is a growing interest topic as it is demonstrated by the exponential increase in the number of publications in SCI journals on this subject during the last decade as well as the interest showed by private companies of the sector.

This year has meant the consolidation of the PSA Solar Desalination Unit as a world reference in the field of solar thermal desalination. The wide range of available experimental facilities covers almost all the current innovative technological solutions proposed to solve the problem of water scarcity and the intensive energy use of desalination processes. Indeed, the number of petitions from external organizations to perform research placements in our facilities has increased regarding previous years. The joint organization together with the European Desalination Society (EDS) of a yearly course about solar desalination is another proof of this reference position.

The international relevance of the developed activities is clearly demonstrated by the current following positions hold by the unit:

- 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).
- Coordination of EERA Subprogramme on CSP and Desalination (CSP+D).

During 2015 research activities were developed within the framework of projects covering both national and international activities with academic and industrial involvement.

Figure 94. Members of the UDeS Unit.

4.2 Projects

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

Participants: GrAT (Coord.), PCSD, GLF, HPPF, CIEMAT-PSA

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 ex-changes on Sustainable Consumption and Production (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 2015: The main activities during 2015 were related to capacity building, in order to train a core group from the tourist sector in each country on the project methodology. The PSA team participated in a series of courses in Philippines and Thailand. The Reduce courses took place in Bangkok and Manila from 16th to 27th of February. The Replace+Redesign training took place in Puerto Princesa (Philippines) from 20th to 25th of April, and in Kanchanabury (Thailand) from the 18th to the 23rd of May. For each course, several handbooks were also elaborated disseminating various tools and techniques to improve the energy and resource efficiency in their operations, and access to greener technology.

In addition, the 1st project Conference was organized in Krabi (Thailand), from the 26th to the 27th of September, and a series of audits were performed in some establishments in order to assess current weaknesses and opportunities for implementation of energy and resource efficiency measures. Regarding institutional collaborations, two meetings were held in Bangkok at the end of January between personnel from PSA and the Ministry of Natural Resources and Environment (Department of Water Resources and Pollution Control Department) on the one hand, and the National Science Technology and Innovation Policy Office on the other hand.

Figure 95. One of the courses in Thailand.

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

Participants: WIP, University of Palermo, FUJIFILM, REDSTACK, CIEMAT-PSA, University of Edinburgh, Universitat Politecnica de Catalunya

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 2015: The project started in May 2015. During this period, a theoretical analysis of the maximum obtainable performance targets of conventional evaporation-based separation technologies such as MED and MD was carried out. MED system operation was considered at temperature above 70ºC, since scaling is negligible in a closed loop system where solutions can be selected to avoid irreversible salt precipitations. Also, the option to enhance externally the energetic efficiency through vapour regeneration by adsorption/desorption cycles was considered. Regarding lower temperature options, the use of forward osmosis using switchable polarity solvents was analysed and discarded due to the high energy consumption required for regeneration. Finally, the University of Almería was included as third party in order to help with the experimentation through CIESOL.

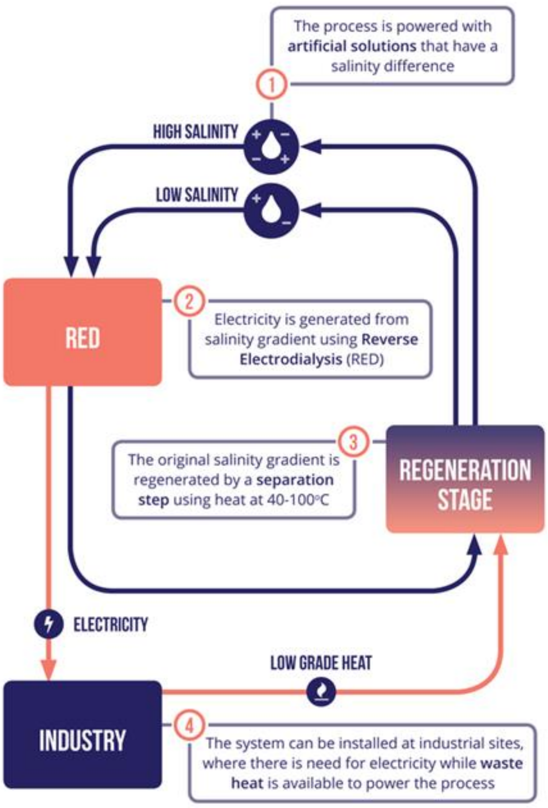


Figure 96. Diagram of the RED HtP process.

Research and Development of New Treatments for the Quality Improvement of Acid Mining Waters, TAAM

Participants: SACYR, SADYT (CIEMAT-PSA as a subcontractor), CABAL Geólogos Consultores, AGQ Mining & Bioenergy

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

Funding agency: CDTI (Ministry of Economy and Competitiveness), INNTERCONECTA Program

Background: Tinto and Odiel rivers, in the province of Huelva (Spain), are deeply contaminated as a consequence of the mining activity. During the last years, several research lines have been started aiming to the passive treatment of the acid leachates. However, the high concentration of the contaminants makes necessary the development of new techniques with better economic feasibility than the current ones.

Objectives: CIEMAT-PSA collaborates within the Research Line 4 of the project, whose main objective is to investigate the effectiveness of treating acid waters with the reverse osmosis process powered by solar thermal energy.

Achievements in 2015: During this period, the experimental assessment of a thermal powered desalination pilot plant based on a steam engine has been carried out at PSA under real climatic conditions. The full system is powered with the saturated steam at 10 bar (abs) generated by a solar field composed of parabolic-trough collectors of small aperture. During the expansion process of this saturated steam, pressure is transmitted to the saline water in order to reach the required nominal pressure to drive a desalination process based on reverse osmosis. After the conclusion of the expansion process, the exergy content of the exhausted steam is used to feed a one-effect flash evaporation box in order to increase the conversion factor of the desalination process. Model development of the different components and validation using experimental data has been also carried out.

Control and energy management strategies in production environments with support of renewable energy, ENERPRO. Efficient energy control and management of solar thermal desalination systems, EFFERDESAL.

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

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

Funding agency: MINECO, Plan Estatal I+D+i 2013-2016.

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 project ENERPRO/ EFFERDESAL 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 objectives are: (i) Dynamic modeling of solar-gas hybrid desalination plants, (ii) Analysis of energy storage systems and auxiliary systems for energy cost reduction, (iii) Design of simplified models for control purposes, (iv) Development of MPC strategies for desalination plants, (v) Coupling of solar desalination plants to supply water to greenhouses and buildings, and (vi) Testing of control algorithms both in simulation and in the real installations.

Achievements in 2015: In this first year of the project, the following relevant results have been obtained:

- First control loops tested at the solar distillation membrane facility towards its optimal automatic operation. The experimental results show that the establish times have been reduced as well as the use of the non-renewable devices (air-cooler and electric heaters). Award to the best research work in the field of Control Engineering given at "Jornadas de Automática 2015".

- First experimental campaign at AQUASOL-II facility aimed to model the solar field, the heat exchanger and the air-cooler.

- Air-cooler control loop tested at AQUASOL-II solar field with good results. The objective is to maintain the solar field inlet temperature at desired values to perform efficiency tests.

5. Water Solar Treatment Unit

5.1 Introduction

The main objective of the Unit for Water Solar Treatment is the use of solar energy for promoting photochemical processes in water at ambient temperature for treatment and purification applications. Our knowledge about solar detoxification and disinfection systems and processes at pilot and pre-industrial scale is backed by 25 years of research activity. Close collaborations with highly recognized international research and academic institutions have been established since several years ago. This involved in the FP4, FP5, FP6, FP7 EU and H2020 programs, all of them related to environmental, material sciences, chemical engineering, chemistry and microbiology. At present, several R&D projects are running in collaboration with different International Institutes and Universities. Most of them aim to improve the chemical and microbiological quality of contaminated waters by optimizing advanced water treatment technologies, mainly those which use solar energy.

Figure 97. Staff of the Water Solar Treatment Unit

The research activities already consolidated by this unit are:

- Solar photocatalytic and photochemical processes as tertiary treatment of wastewater for the removal of pollutants of emerging concern and common and antibiotic resistant bacteria.
- Solar photocatalytic and photochemical processes for the remediation of industrial wastewaters (pharmaceuticals, pesticides, landfill leachates, textile and wine industry).

- Integration of Advanced Oxidation Processes (AOPs)with standard water treatment technologies (NF/UF; Ozone, Bioprocesses, etc.) for improving efficiency and reducing costs.
- Photocatalytic efficiency of new materials under solar light in pilot reactors (CPC).
- Photocatalytic and photochemical processes for water disinfection in different scenarios (different wastewaters and drinking, resistant pathogens).
- Pilot and Demo solar photo-reactors for different purposes (drinking water, water reclamation, irrigation, etc.), either water decontamination or water disinfection.

5.2 Projects

Reducing the water cycle demand in vegetables process industry by novel water treatment: reuse for vegetables washing and agricultural reuse, WATER4CROP

Participants: CIEMAT-PSA; Univ. Rey Juan Carlos (coordinator).

Contacts: Pilar Fernández Ibáñez, pilar.fernandez@psa.es
M. Inmaculada Polo López mpolo@psa.es

Funding agency: Programa Estatal de Investigación, Desarrollo e Innovación Orientada a los Retos de la Sociedad, 2013-2016.

Background: Water scarcity is currently a big issue in many areas of the world. This scenario leads us to explore different ways to save fresh water, like the reuse of wastewater effluents for agriculture. AOPs have demonstrated to be a promising treatment to enhance the wastewater effluents quality, reducing the presence of emerging pollutants (chemical and biological) to regulated limits (RD 1620/2007).

Objectives: The main objective is the assessment of several AOPs (i.e. O_3/H_2O_2, solar photo-Fenton, H_2O_2/solar radiation) for the treatment of fresh-cut industry wastewater (FCWW) contaminated with E. coli O157:H7, Salmonella and a cocktail of pesticides in pilot reactors and further reuse for raw-eaten crops irrigation in an experimental greenhouse.

Achievements in 2015: Secondary effluents (SE) from the Municipal Wastewater Treatment Plant of “El Bobar” (Almeria) were treated by solar photo-Fenton (10/20 mg/L of Fe^{2+}/H_2O_2) and H_2O_2/solar (20 mg/L). Inactivation of naturally occurring E. coli, total coliforms, E. faecalis and Salmonella sp were evaluated. Total inactivation of bacteria (below the detection limit, 2CFU/mL) was achieved in both treatments, although different resistance profiles were observed. Order of inactivation: Salmonella > E. coli > Total coliforms > E. faecalis) (Figure 98). After that, treated SE was used for crops irrigation assays. Seeds of lettuce and radish were sow and growth till collection (radish: 1.5 months and lettuce: 3 months) using the treated SE. The fate of microorganisms after irrigation reuse test was done according to previous works.

Results of radish leaf and fruit, lettuce leafs and peat showed a complete absence of pathogens, demonstrating the capability of these solar processes as tertiary treatment of SE for further reuse in agriculture. Moreover, a multi-detection method of HPLC has been developed for quantification of a cocktail of 9 pesticides commonly used in agriculture.

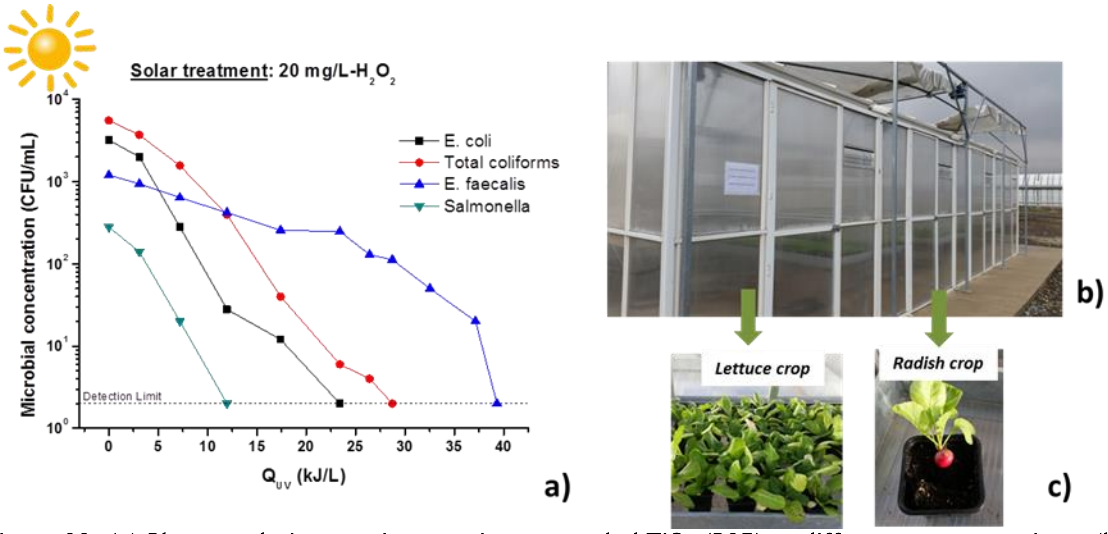


Figure 98. (a) Photocatalytic experiment using suspended TiO_2 (P25) at different concentrations. (b) Real time q-PCR (7500-Fast, Applied Biosystem) at PSA laboratory. (c) Inactivation of L. jordanis in distilled water using two enumeration techniques: real time q-PCR with EMA dye (empty symbols), and pour plate counting technique (solid symbols).

New strategies based on solar photochemical processes and integration of other advanced techniques for the treatment of complex effluents, AQUAFOTOX

Participants: Textile Engineering Department-UPV; Chemical Technology Institute-UPV; CIEMAT-PSA (coordinator).

Contacts: Sixto Malato Rodríguez (Technical Coordinator), sixto.malato@psa.es
Isabel Oller Alberola, isabel.oller@psa.es

Funding agency: Ministerio de Ciencia e Innovación, Plan Nal. I+D+i (2012). Subprograma de Proyectos de Investigación Fundamental.

Background: Wastewater treatment plants installed in EU are based in efficient activated sludge or other advanced bio-treatments. But these processes are not usually effective against complex industrial wastewater containing toxic and/or bio-recalcitrant substances. Therefore, it is recommended to develop more efficient wastewater treatment processes by designing strategic approaches for reducing costs and increasing efficiency.

Objectives: The main objective is the design of a novel strategy which would allow the efficient treatment of complex industrial wastewater by the combination of several advanced processes: (i) combination of AOPs with membrane technologies; (ii) combination of those technologies with bio-treatments and so reducing operating costs from reagents and energy; (iii) the use of solar energy in AOPs.

Achievements in 2015: During the last year, it has been defined the best treatment option for cork boiling wastewater based on an optimized physic-chemical pre-treatment with 0.5 g/L of $FeCl_3$, a subsequent solar photo-Fenton treatment (which showed higher efficiency than ozonation process in terms of mineralization percentage attained) and finally a nanofiltration purification step was applied with the aim of obtaining a permeate stream with enough quality for being reused in the own cork boiling process. The whole treatment line as well as the separation extraction procedure followed for identification of non-target contaminants by LC-ESI-QTOF-MS is shown in Figure 99.

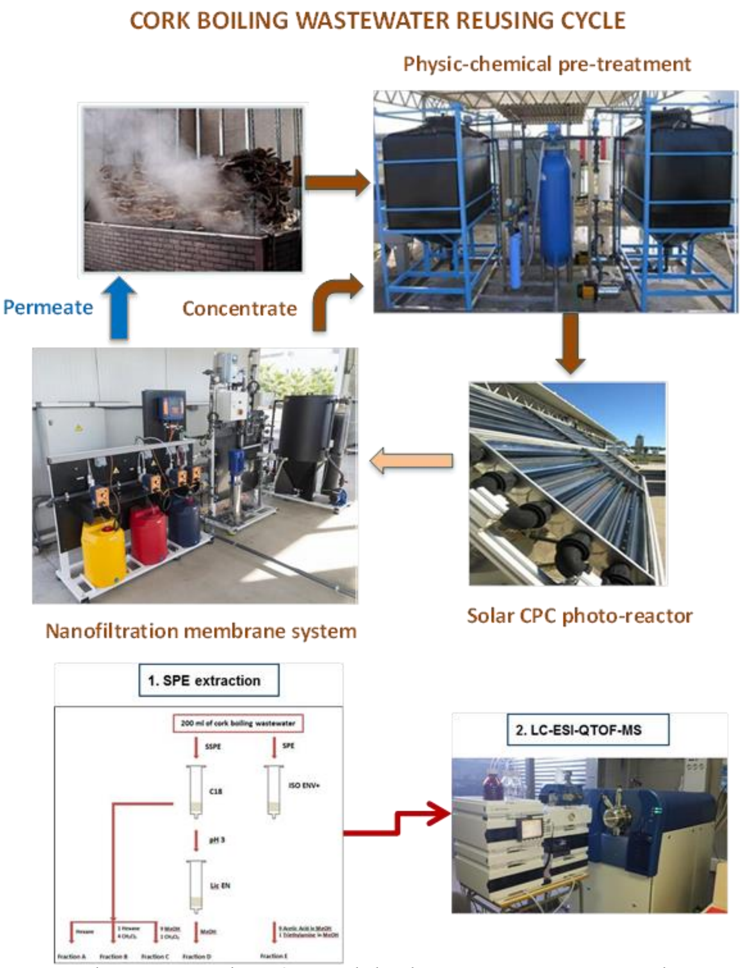


Figure 99. Proposed treatment line for cork boiling wastewater remediation and reuse.

Regarding landfill leachate treatment, physic-chemical pre-treatment was firstly optimized by reducing pH to 5 and the addition of 0.5 to 0.75 g/L of $FeCl_3$. Solar photo-Fenton process was applied until attaining an elimination of 35% of dissolved organic carbon which corresponded to a biodegradability of 0.3 (highly biodegradable). Then, the immobilize biomass reactor (IBR) was adapted to the partially treated landfill leachate though an accumulation of ammonia was detected (670 mg/L). With the aim of favouring autotrophic nitrification, sodium bicarbonate was added and so 62% of ammonia was reduced. In addition, the characterization of the microbial population in the IBR by amplification and DNA measurement in general bacteria 16rDNA and aminooxidant bacteria (AOB) by PCR techniques was carried out.

Fundamental and solar pilot plant scale studies of photocatalytic hydrogen production with simultaneous removal of water pollutants, HIDROPILSOL

Participants: CIEMAT-PSA

Contacts: M. Ignacio Maldonado Rubio, mignacio.maldonado@psa.es

Funding agency: Ministerio de Ciencia e Innovación, Plan Nal. I+D+i (2013). Subprograma de Proyectos de Investigación Fundamental. Reference CTQ2013-47103-R.

Background: The present project is intended to deepen into the knowledge of the heterogeneous photocatalytic processes for obtaining hydrogen from water and organic contaminants that might be dissolved on it, taking the research to a pre-industrial solar pilot plant scale.

Objectives: The main objectives are (i) to determine the semiconductor "composite" that yields a larger efficiency of hydrogen generation from water and organic pollutants at pilot-plant scale, (ii) to scale-up the process from laboratory to pilot-plant scale, and (iii) to perform mechanistic studies of the process.

Achievements in 2015: The performance of the Au/TiO_2 catalyst was tested when real wastewaters containing mixtures of other organics than formic acid were used in the process. This would give an idea of the potential for H_2 generation combined with wastewater treatment, avoiding the use of pure (and costly) organics reagents. Figure 100 shows the results of using two different types of wastewaters for this purpose: a municipal wastewater collected from a sewage treatment plant of Almería (Spain) and a wastewater from a fruit juice bottling plant. As can be seen, and although the industrial wastewater has 6 times higher initial DOC content than the domestic one (600 vs. 100 mg L^{-1}), the later gives a better H_2 production.

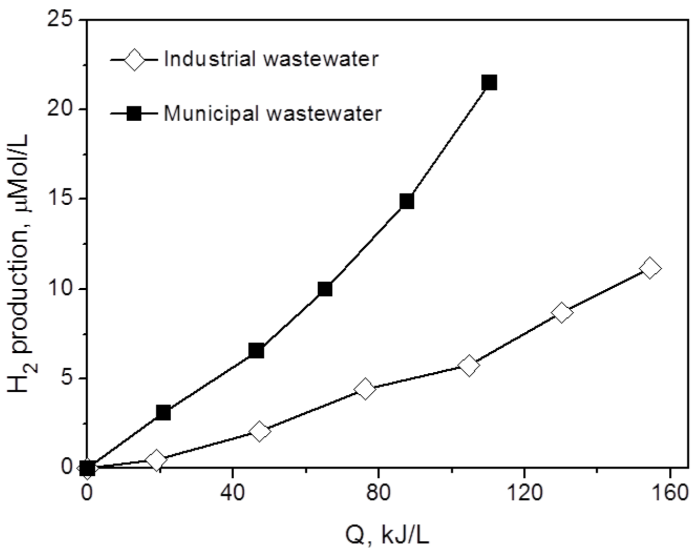


Figure 100. H_2 production vs. energy accumulated into the photoreactor (305-550 nm) as a function of the type of real wastewater used. 25 L of 0.2 g·L-1 Au/TiO_2 slurries. In both cases pH was adjusted to 3. Total irradiation time of 5 h.

Thus, the increase of the reactivity is not just a matter of organic concentration, but also a consequence of the chemical nature of the compounds that could be present in real wastewaters. Also, the performance of these wastewaters in comparison with formic acid or other organic synthetic solutions (methanol or glycerol) is around two orders of magnitude lower, pointing towards the importance of other aqueous compounds that could reduce the photocatalyst activity.

6 Horizontal R&D and Innovation activities

6.1 Scientific and Technological Alliance for Guaranteeing the European Excellence in Concentrating Solar Thermal Energy, STAGE-STE

Participants: CIEMAT (Spain), DLR (Germany), PSI (Switzerland), CNRS-PROMES (France), FRAUNHOFER (Germany), 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), CRS4 (Italy), INESC-ID (Portugal), IST-ID (Portugal), SENER (Spain), HIT-TITE (Turkey), ACCIONA (Spain), SCHOTT (Germany), ASE (Italy), ESTELA (Belgium), ABENGOA SOLAR (Spain), KSU (Saudi Arabia), UNAM (Mexico), SUN (South Africa), CSERS (Libya), CSIRO (Australia), FUSP (Brazil), IEECAS (China), UDC (Chile), UCAM (Morocco), FBK (Italy), CNIM (France) and COBRA (Spain).

Contacts: Julian Blanco Galvez (Project Coordinator), julian.blanco@psa.es,
Ricardo Sanchez (Project Manager), ricardo.sanchez@psa.es

Funding agency: European Commission, FP7-ENERGY-2013.10.1.10

Background: STAGE-STE project is an IRP (Integrated Research Programmes) initiative addressed to integrate and finance the activities of EERA (European Energy Research Alliance) Joint Programme on Concentrating Solar Power (JP-CSP). EERA (www.eera-set.eu) is an organization involving more than 150 European energy research institutions and officially one of the pillars of the EU SET-Plan (http://setis.ec.europa.eu). EERA main objective is to reinforce the collaboration in the development of energy technologies (through joint R&D) and support the competitiveness of European industry at international level. To this end, STAGE-STE consortium (equivalent at beginning of the project to EERA JP-CSP) involves a large majority of EU research organizations relevant to CSP/STE (Solar Thermal Electricity) topic.

Objectives: To convert the STAGE-STE consortium into the natural reference institution for STE/CSP research in Europe providing to both the Commission and the Industry a natural gatekeeper for R&D investment and technology transfer in the field. This is intended to be achieved with the alignment of the different STE EU national research programs and addressing a comprehensive number of coordinated and integrating activities to lay the foundations for long-lasting research cooperation in Europe, such as:

- Joint activities to foster the use of existing research facilities.
- Training activities and exchange of researchers to facilitate the co-operation between research organisations.
- Transfer of knowledge activities to reinforce the partnership with industry.
- International cooperation activities.

Achievements in 2015: With regard to the Coordination and Supporting Activities (CSA), during 2015 National Working Groups has started to operate in countries involved (Cyprus, France, Germany, Italy, Portugal, Spain, Switzerland and UK) with regard to the potential alignment of national programmes. These groups have elaborated individual “Concept Notes” to define the national position on such alignment to be discussed at specific European workshop in 2016. An IP repository was created by EERA and 177 know-how items, offered to be shared among the participants, were initially introduced. Also, so far, the following foreground related items were reported: 16 patents, 5 exploitable foreground assets, 217 dissemination events and 171 publications.

Figure 101. 2nd General Coordination Meeting (Le Bourget Du Lac, France), 30th June-1st July 2015

With regard to the research activities in WP12 (Point Focusing STE technologies), during 2015 a new direct-indirect flux measurement method has been proposed after a review of existing flux measurement systems integrated in commercial plants. CIEMAT is leading WP11 (Line-focusing STE technologies) where a complete and comprehensive medium temperature solar collectors database has been created providing full information of a large number of flat plate, evacuated tubes, CPCs, parabolic troughs, linear Fresnel and other collectors (openly available at www.stage-ste.eu/keydocuments/solarthermalcollectors.php). In this WP CIEMAT is also working in a TRNSYS model for DSG solar power plants.

CIEMAT is also leading WP10 (Solar Desalination) where a new code of El-Dessouky-Ettouney complex-model for parallel-feed LT-MED plants has been implemented and validated in EES. In WP9 (Solar Fuels) CIEMAT has completed during 2015 the testing of a 150 kW_{th} two-cavity “beam-down” batch reactor for syngas production from carbonaceous feedstock, mounted on a custom-built platform at the CRS tower (PSA). In WP8 (Materials for Solar Receivers and STE Components) CIEMAT is collaborating, among many other activities, in a Round Robin test of parabolic trough receivers. Finally in WP7 (Thermal Energy Storage) CIEMAT is leading Task 7.3 (Advanced Thermal Storage Systems) proposing and developing alternative solutions for existing and new CSP/STE technologies. Fruther descrption of these activities can be found below.

WP8: Materials for Solar Receivers and STE Components

Participants: CIEMAT-PSA, DLR (WP8 coordinator), CNRS, Fraunhofer-ISE, ENEA, CEA, LNEG, CNR, CENER, Tecnalia, Cranfield University, Tekniker, IST-ID, SENER, HITIT Solar Enerji, SCHOTT Solar, Archimede Solar Energy, Abengoa Solar NT, COBRA.

Contacts: Aránzazu Fernández García, arantxa.fernandez@psa.es, Tasks 8.1 and 8.3
Rafael López Martín, rafael.lopez@psa.es, Task 8.2.4
María Isabel Roldán Serrano, mariaisabel.roldan@psa.es, Task 8.2.6

Background: The study of new solar receiver designs is a required investigation due to the need to improve their thermal performance at high temperatures. In addition, it has appeared several methods for the measurement of parameters in linear receivers and it is necessary to validate them.

Objectives: CIEMAT's participation is focused on: (i) developing methods of accelerated ageing for reflectors that provide estimations of degradation over lifetime; (ii) comparing test benches for heat losses measurement of line focusing receivers; (iii) analysing the suitability of enhanced materials for high temperature applications; (iv) investigating the occurrence of abrasion under desert conditions and simulate it under laboratory conditions.

Achievements in 2015: Concerning the topic related to the development of a guideline for durability testing of solar reflectors (Task 8.1), a revision of the applied accelerated aging methodologies of the partners (CEA, CENER, CIEMAT/DLR, LNEG and Tecnalia) was conducted. This revision was used to elaborate a round robin test to compare methodologies and protocols. The initial optical characterization of the acquired reflector samples was already conducted. Also, reflector samples that have been exposed outdoors in commercial plants were analysed by CIEMAT/DLR to identify the degradation mechanisms appearing during operation.

Regarding to Task 8.2.4, it has been measured heat losses of 5 linear receivers of two different manufacturers (SCHOTT, Archimede Solar Energy). These measurements are compared in the framework of a Round Robin Test between CENER, DLR, CIEMAT and ENEA.

Task 8.2.6 focuses on the selection of the best configuration for a pebble absorber made of alumina with improved absorptance. Several configurations have been characterized by theoretical and experimental methods (ray-tracing studies, Computational Fluid Dynamics (CFD) simulation and testing in a solar simulator facility) to predict their thermal behaviour (see Figure 102). Furthermore, three different coatings are being analysed in order to improve the optical properties of the alumina pebble.

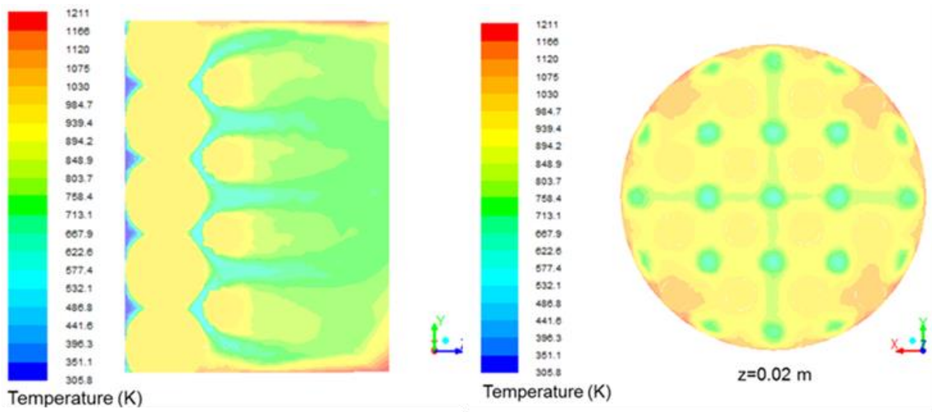


Figure 102. Predicted thermal distribution of a preliminary configuration for an alumina pebble receiver (cross and front sections, Task 8.2.6).

With respect to the study of the erosion of reflectors under desert conditions (Task 8.3), a revision of the available standard was conducted, and a summary of the used testing conditions was prepared. Three different testing setups (closed loop, open loop and sand trickling) are under investigation by CIEMAT/DLR with the goal of properly reproducing the outdoor degradation.

WP10: Solar Thermal Electricity + Desalination

Participants: CIEMAT-PSA (WP10 coordinator), FISE, ENEA, CEA, CYI, LNEG, CENER, UEVORA, UNIPA, SENER, HITTITE, FBK

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

Background: Combined electricity and fresh water production by means of solar thermal concentrating technologies can be proposed as a solution in many locations of the world where water scarcity usually coincides with the availability of high solar irradiation levels.

Objectives: The main objective is to answer the basic question about under which conditions a solar thermal cogeneration scheme can be more feasible than the separate production of power by a STE plant and the use of such power to run a desalination process.

Achievements in 2015: During 2015, research activities within STAGE-STE WP10 have been focused in the literature review, identification and development of mathematical models for the different conventional thermal desalination technologies

(MED and MSF[3]), new developments in low-temperature thermal distillation processes as well as reverse osmosis process. During the second year of the project, the tasks related with the state of art and model development of Multiple Effect Distillation with Thermal Vapour Compression (MED-TVC), reverse osmosis and membrane distillation processes have been successfully concluded. During this year, a review of the state of the art of the different cooling processes available at commercial CSP plants has also been performed in order to be able to quantify the water savings than the coupling of desalination processes into a CSP plant can provide.

WP11: Line-focusing STE Technologies

Participants: CIEMAT-PSA (WP11 coordinator), CNRS, Fraunhofer-ISE, ENEA, CEA, LNEG, CTAER, CENER, Tecnalia, University of Evora, Cranfield University, Tekniker, SENER, HITIT Solar Energy, Acciona Energía, Archimede Solar Energy, Abengoa Solar NT, COBRA.

Contacts: Loreto Valenzuela, loreto.valenzuela@psa.es

Background: A big deployment of large commercial solar fields for electricity generation, specially using PTCs has appeared in the last 10 ten years. In addition, it has been identified by different stakeholders the big potential for the application of line-focusing solar collectors' technology for distributed power and process heat generation, and solar heating and cooling applications.

Objectives: CIEMAT's participation is focused on: (i) explore and develop new concepts of medium temperature line-focusing collectors; (ii) work in the modelling and simulation of PTCs fields using water-steam as heat transfer fluids; (iii) define and validate dynamic solar field testing procedures; (iv) define and analyse new methodologies for on-site characterization of line-focus collectors and their components in large commercial solar fields.

Achievements in 2015: Concerning the topic of medium temperature line-focusing solar collectors, CIEMAT has contributed in the preparation of a solar collectors database, which currently contains information of 74 collectors and can be updated with information of new developments (see Figure 103). The database has been jointly prepared by Tecnalia, CIEMAT, CENER, University of Evora and Fraunhofer-ISE.

CIEMAT defined the layout of a 30 MW_{th} solar field with PTCs for direct steam generation that is being analysed with TRNSYS to calculate the annual thermal and electric output, and with RELAP to analyse thermo-hydraulic phenomena in the solar receivers, with special focus on the two-phase flow region.

A review of the state-of-art of quasi-dynamic and dynamic testing procedures of solar collectors and solar fields was finalised. CIEMAT and Fraunhofer-ISE prepared a list of requirements that was sent to industrial partners participating in the project to col-

[3] Multi-stage flash Distillation

lect information about type of data and test that can be performed in the solar fields of existing commercial power plants with PTCs.

Finally, CIEMAT is coordinating the working groups of thermal inspection of receivers, inspection of reflectance/soiling of reflectors, and inspection of other components (structures, tracking mechanisms, etc.) in large solar fields. During 2015 these working groups were formed and the activities were launched. CIEMAT and CENER conducted a test campaign in the HTF test loop to validate some methodologies, including a method to check the performance of tracking mechanisms of parabolic troughs.

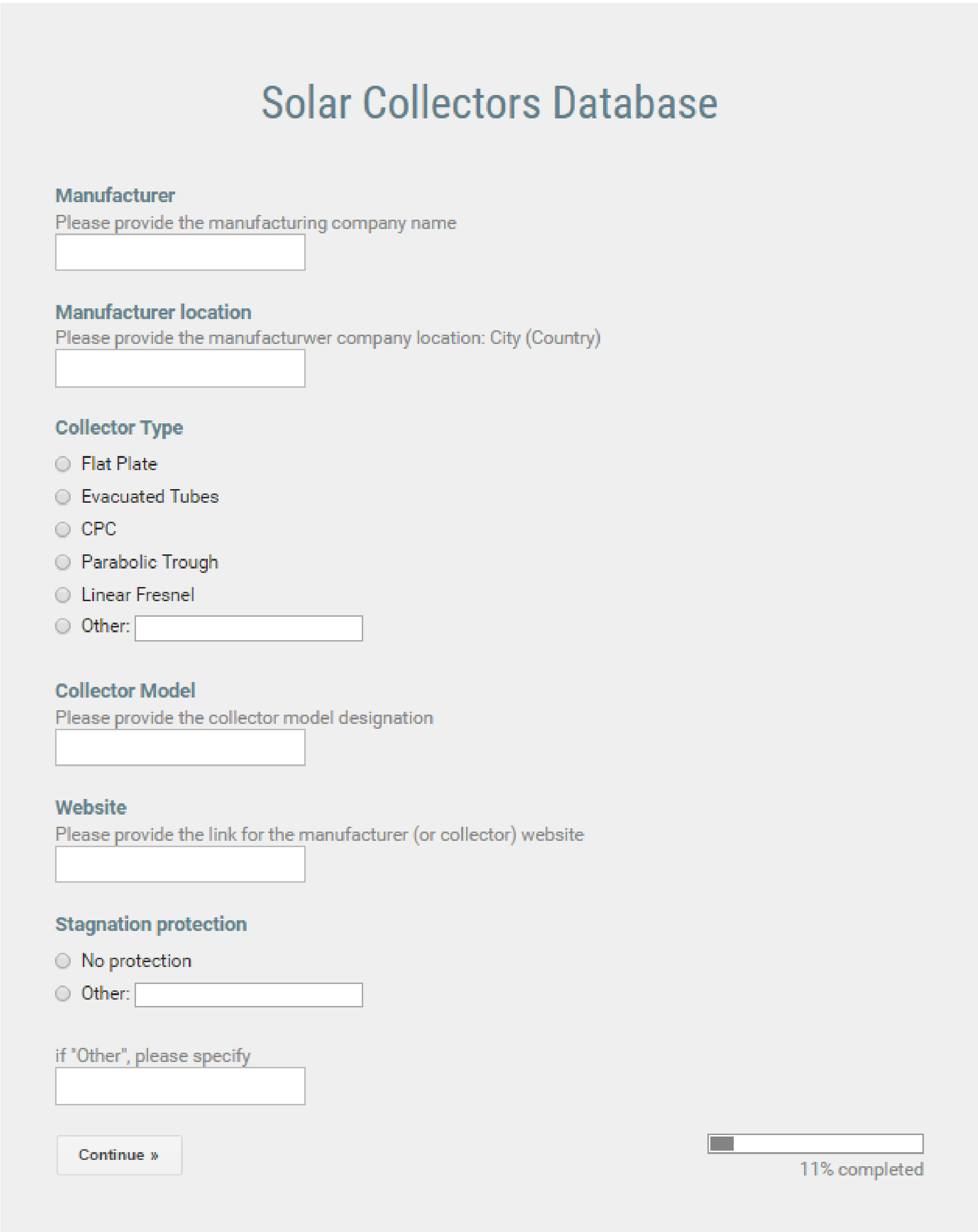


Figure 103. View of one of the windows to collect information of a new collector to be included in the medium temperature solar collectors database. (http://www.stage-ste.eu/keydocuments/solarthermalcollectors.php)

WP12: Point-focusing STE Technologies

Participants: CENER (WP12 coordinator), CIEMAT-PSA, CNRS, CYI, Tekniker, SENER, COBRA, UEVORA, CRAN, ASNT, DLR, CTAER, FISE, CRS4, LNEG, IMDEA, ETHZ, FBK, INECS-ID.

Contacts: Jesús Fernández-Reche, jesus.fernandez@psa.es

Background: Solar tower systems have become an alternative to PTCs plant in the last 2 year, being the selected technology for most of the promoted solar power plants nowadays. But still some improvement must be achieved to reduce cost and increase performance of such kind of power plants.

Objectives: WP12 is focused in two main aspects, i.e. development of low cost heliostats fields (including heliostat deployment and calibration) and high concentration optical systems, and enhanced receiver concepts. CIEMAT’s participation is focused on: (i) analysis and development of low cost heliostats and (ii) development of a new flux measurement system suitable to work in commercial solar tower power plan without high operation and maintenance interferences.

Achievements in 2015: Concerning the topic of the development of low cost heliostats, CIEMAT-PSA has led a survey of heliostats development recovering the state of the art in the field and making conclusions about functional specifications and recommendations on cost reduction potential on heliostats and heliostat fields. In addition, an excel tool has been prepared for heliostat components sensitivity analysis. With the support of this tool, a small heliostat prototype will be designed and tested at PSA.

The other task which CIEMAT is working in, consist in the development of a flux measurement system for commercial solar tower power plants, led by CTAER. Until now, a state of the art of flux measurement systems has been prepared and some proposal for integrating flux measurement systems on commercial plant with minimum impacts have been shared between task partners.

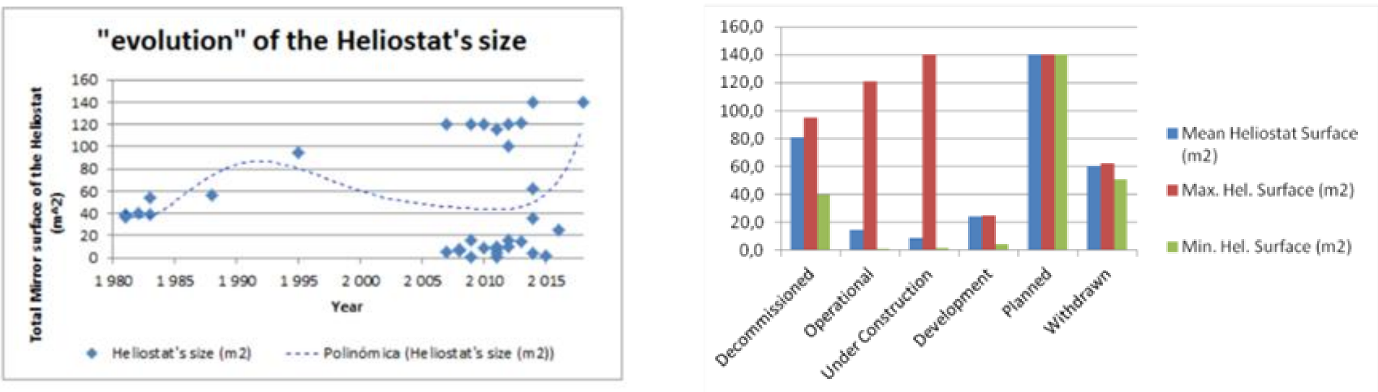


Figure 104 State of the art of heliostats development.

6.2 The European Solar Research Infrastructure for Concentrated Solar Power, EU-SOLARIS

Participants: CTAER (Spain), CIEMAT (Spain), CNRS (France), DLR (Germany), ENEA (Italy), CyI (Cyprus), ESTELA (Belgium), MINECO (Spain), LNEG (Portugal), SELKUC U (Turkey), GUNAM (Turkey), U. EVORA/IPES (Portugal), APTL (Greece), WEIZMANN (Israel), CRESS (Greece).

Contacts: Eduardo Zarza (Technical coordinator), eduardo.zarza@psa.es

Funding agency: European Commission, FP7-INFRASTRUCTURES-2012-1

Background: An effort is needed to maintain Europe at the forefront of the Concentrating Solar Thermal and Solar Chemistry technologies. The scientific communities, industries and universities involved must be efficiently linked and the European RI must be coordinated to provide the most complete, high quality RI portfolio, facilitating researchers' access to them through a single access point.

Objectives: The creation of a new legal entity to explore and implement new and improved rules and procedures for Research Infrastructures (RI) for Concentrating Solar Thermal (CST) and Solar Chemistry technologies, in order to optimize European RI development and Research and Technology Development (RTD) coordination in this field (www.eusolaris.eu/).

Achievements in 2015: PSA activities in 2015 were mainly devoted to the WP2 ("Legal status & User access policies") of this project, undertaking its overall coordination and the development of Tasks 2.5 ("Users support") and 2.6 ("Access rules"). The deliverable ID2.6 "Access Rules" was prepared and issued by PSA in 2015, as well as a first draft of the document ID2.5 "Users support". The experience gathered in the SFERA project regarding Access to research infrastructures has been incorporated by PSA in the guidelines and rules proposed for Access and Users during the operational phase of EU-SOLARIS. PSA has also participated in many tasks of work packages 3 and 4 of EU-SOLARIS, with special dedication to those tasks related to prepare the list of Services and Research Infrastructures (RIs) both currently available and also proposed by the Partners to improve their capacities. So, an updated version of the complete list of services currently available at European level for concentrating solar thermal systems was prepared and issued by PSA in September 2015.

One of the main achievements in 2015 was the selection of ERIC (European Research Infrastructure Consortium) as the most suitable legal form for the new legal entity of EU-SOLARIS (provided that the member countries will decide to go ahead with the implementation of the legal entity after the conclusion of the current preparatory phase).

Additionally to the third yearly report of the project (covering the period November 2014-October 2015) many other documents related to legal issues (internal law, rules for membership, guidelines for Intellectual Property Rights and Technology Transfer, Selection process for Users, etc.) were issued in 2015 by the partners of EU-SOLARIS, with the legal support of GARRIGUES (project subcontractor). All these documents were approved by the Partners. PSA has also participated in the Steering Committee of EU-SOLARIS, with two meeting in 2015.

It has been clearly detected in 2015 that one of the main challenges for EU-SOLARIS to become a reality is to find a way to ensure both independence to the existing RIs that would be under the umbrella of EU-SOLARIS and an integrated and effective management of the EU-SOLARIS RIs as a whole. The success of EU-SOLARIS will greatly depend on how this basic principle is fulfilled.

Figure 105. 6th EU-SOLARIS Steering Committee Meeting, Rome.

6.3 Solar Facilities for the European Research Area: Second Phase, SFERA II

Participants: CIEMAT-PSA (coordinator), DLR (Germany), CNRS (France), PSI (Switzerland), ETHZ (Switzerland), ENEA (Italy), CEA (France), INESC-ID (Portugal), UEVORA (portugal), UNILIM (France), ESTELA (Belgium) and UTV (Italy).

Contacts: Isabel Oller Alberola (Technical Coordinator), isabel.oller@psa.es
Ricardo Sánchez (Project Manager and Transnational Access Coordinator), ricardo.sanchez@psa.es

Funding agency: European Commission, FP7-INFRASTRUCTURES-2012-1.1.1

Background: CSP Research Infrastructures in Europe have served through the last 30 years as research tools to demonstrate the concept feasibility by exploring different pathways on how to produce high temperature heat, electricity and, solar fuel using concentrating solar radiation. Nowadays, the key point is to cooperate with the industry in order to gain a significant market share.

Objectives: The purpose of this project is to integrate, coordinate and further focus scientific collaboration among the leading European research institutions in solar concentrating systems that are the partners of this project and offer European research and industry access to the best-qualified research and test infrastructures.

Achievements in 2015: Second coordination meeting of SFERA II project was hosted by DLR in Cologne (Germany) the 15th of April, 2015 (Figure 106).

SFERA II project is divided into three main activities: Networking, Transnational Access and Join Research Activities. Results obtained through 2015 in Research Activities lead by CIEMAT will be gathered in this annual report within activities of E42 unit.

Regarding Networking activities, it must be mentioned that the 2nd SFERA-II Doctoral Colloquium was held from the 2nd to 4th of March, 2015, and it was organized by ETHZ. There were 50 PhD students registered from all partners of the project.

The 2nd USP (external user selection panel of experts) meeting for free Transnational Access to the SFERA-II facilities took place in Odeillo (at PROMES premises) on the 29th of April, 2015, coordinated by the Access Manager (Ricardo Sánchez, CIEMAT). CIEMAT-PSA received in SFERA-II 2015 Access campaign 29 user proposal forms, including 1 user proposal form to access the third-party beneficiary UAL-CIESOL. After the USP meeting, 21 user proposal forms were finally accepted while 8 of them were rejected, being one of them the only proposal received to access CIESOL. It should be stressed that 3 proposals came from the industry, namely Yokogawa Europe B.V., S.C. IPEE AMIRAL TRADING IMPEX S.A., and BMES.

Figure 106. SFERA-II second coordination meeting held at DRL headquarters in Cologne (15th April 2015).

Rotation and Expansion Performing Assembly, REPA

Participants: CIEMAT-PSA, DLR

Contacts: Javier León, javier.leon@psa.es
Christoph Hilgert, christoph.hilgert@dlr.de

Background: One of the weakest parts in a PTCs field is the interconnection between fixed and mobile elements, where failures happen frequently. In that sense, the construction of a circuit containing an ad-hoc test bench was thought independently by both partners CIEMAT-PSA and DLR.

Objectives: Design and implementation of a new test facility for evaluation of linear receiver tubes connections as ball-joints, flexible hoses, hybrid devices formed by a flexible hose and a swivel joint, and any other solution that can arise in the future.

Achievements in 2015: The design of both, the test bench and the circuit where it will be connected, were finished along this year. A concrete platform where the new facility will be mounted is already done. Most of the sections of the new facility including the oil pump, expansion vessel and main valves were also purchased, and the construction of the test loop started late in December. In the Figure 107 it is depicted the test bench where devices to be tested will be installed.

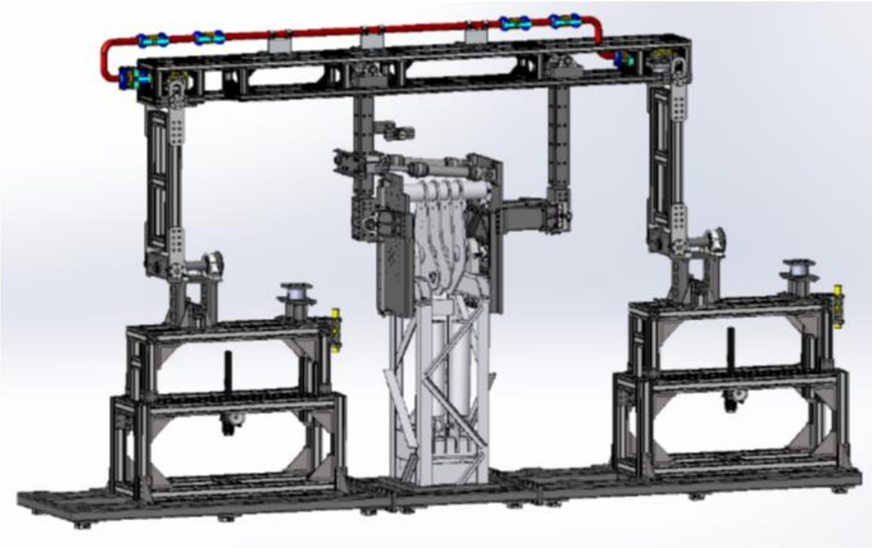


Figure 107. Scheme of the REPA test bench for evaluation of linear receiver tubes connections.

Several variables will be measured in the test circuit such as friction and pressure drop in the devices to be tested as well as their durability when working in long duration cycles of rotation and expansion under changing temperature conditions. Once the loop is completed, the housing containing the assembly will be erected immediately after. It is foreseen to have the loop into operation in the second quart of 2016.

6.4 MEDiterranean DEvelopment of Support schemes for solar Initiatives and Renewable Energies, MED-DESIRE

Participants: Puglia Region - Regional Ministry for Economic Development - Industrial Research and Innovation Department (Lead Partner); ARTI (Italy), MATTM (Italy), ENEA (Italy), AAE (Spain), IAT (Spain), CIEMAT-PSA (Spain), ANME (Tunisia), LCEC (Lebanon) and NREA (Egypt).

Contacts: Ricardo Sanchez (Technical coordinator), ricardo.sanchez@psa.es

Funding agency: Co-funded by the European Union through the ENPI CBC MED Programme 2007-2013.

Background: For the effective commercial development of distributed solar technologies in a country is necessary to consider different factors, since this development must be approached from a multidisciplinary perspective, taking into account factors of different nature. Otherwise, the effort from the administration can be unsuccessful and even counterproductive to a large extent. It also requires the participation of actors of diverse nature: engineering firms, R&D, component and systems manufacturers, investors, developers, promoters and management. To be effective, any program for the implementation of distributed solar energy systems in a country must take into account all these participants and provide the necessary legal and administrative framework to ensure proper coordination and synergy between the activities of all of them.

The commercial deployment of solar thermal electricity plants has shown that there is a lack of standards for this sector, which is considered an important needed step to foster the industrial development. Obviously, other barriers such as expertise, incentives and cost of components and systems cannot be left out of the equation.

Objectives: The main objective is to facilitate the take up of distributed solar energy and energy efficiency in the target regions, i.e. Tunisia, Lebanon and Egypt, by implementing a certification programme for testing photovoltaic components and systems, by increasing competences of local technicians and professionals, and by raising public awareness on the related benefits for the environment and for sustainable local development.

Achievements in 2015: A report on the identification of main technical barriers in the Mediterranean regions that can be improved through a certification scheme was finalised and submitted to all partners. This report includes the analysis of the results of the questionnaire received from the PV industry in the three target countries, i.e., Lebanon, Egypt and Tunisia along with a SWOT analysis for the situation in the three countries. A second report on the qualification procedures scheme to be implemented in the target Mediterranean countries was finalised and submitted to all partners. This report includes a brief introduction of the conformity assessment procedure, identifying the bodies involved and their requirements to perform their activities, and the measurement methods which allow the identification and analysis of PV module failures. For each method we explain the basis, indicate current best practice, and explain how to interpret the images.

CIEMAT has participated in a workshop titled The Quality Supply Chain of Solar Photovoltaic which has been carried out in Egypt on 28th July 2015, and also in Lebanon on 10th and 11th November 2015, and has contributed in the elaboration of the technical brochure on the photovoltaic technology titled ‘Get your power from the Sun’, addressed to end consumers. CIEMAT has also collaborated in drafting the new technical requirements for PV installations included in the ANME document related to the Pro Volt Programme, Bat Sol Project.

Furthermore, CIEMAT has contributed and revised the report ‘Capacity building and Training’, and also the report/brochure ‘Solar standards and certification’, both documents printed in 2015 for the dissemination of part of the results of the project.

Finally, CIEMAT attended the EGETICA energy fair together with the other two Spanish partners, i.e., IAT and AAE (in their Spanish acronym), where one of our member gave a talk on the main activities carried out throughout the project and the results obtained for the benefits of the target countries.

Figure 108. EGETICA conference room.

6.5 Automatic Control Group

6.5.1 Introduction

The Automatic Control group belongs to the Direction unit and its purpose is to collaborate with the different R+D units in the research activities carried out by developing dynamic models of solar thermal plants, designing control algorithms and applying optimization techniques to improve the operation of the systems. In 2015, the Automatic Control group addressed diverse activities mainly related with the international project HYSOL and the national one ENERPRO (in collaboration with the desalination unit):

1. Dynamic models based on first principles for components used in solar thermal facilities (heat recovery systems flue gases from gas turbines, molten salt heat exchangers, molten salt storage systems and solar fields with novel industrial collectors).
2. Design of simplified models for control purposes (air-coolers, heat exchangers, gas heaters …).
3. Automatic control techniques (predictive, feedforward, split range, feedback linearization) applied to solar thermal plants (two-tank indirect molten salt loop, solar furnace, membrane distillation system and multi-effect distillation unit).
4. Optimization studies (estimation of thermal losses and heat transfer correlations and multi-effect distillation operation).

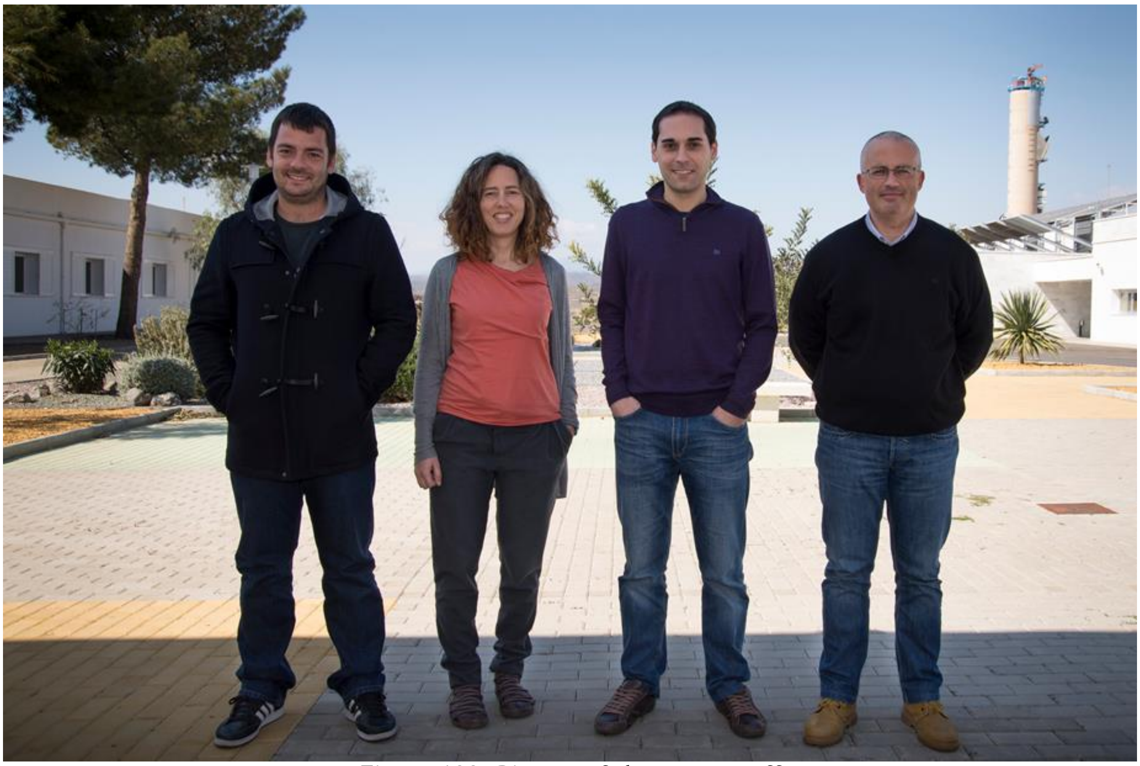


Figure 109. Picture of the group staff

6.5.2 Projects

Innovative Configuration for a Fully Renewable Hybridcsp Plant, HYSOL

Participants: ACS-COBRA, CIEMAT-PSA, ENEA, IDIE, AITESA, DTU-MAN-SYS, UPM, SDLO-PRI.

Contacts: Lidia Roca, lidia.roca@psa.es
Javier Bonilla, javier.bonilla@psa.es

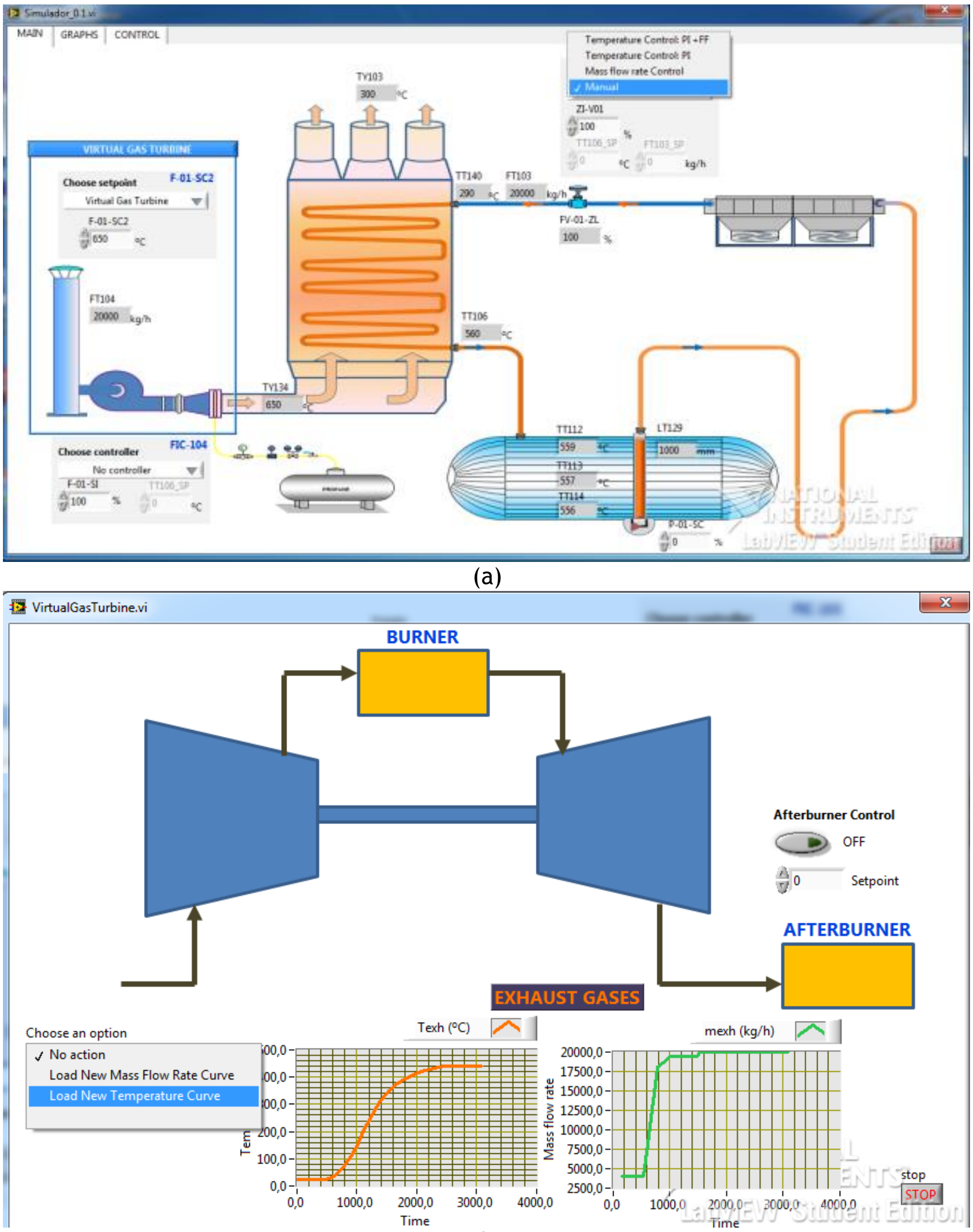
Funding agency: European Commission (FP7-ENERGY-2012).

Background: One of the main challenges in power plants based on renewable energies is to supply power to the electrical grid in a stable, firm and reliable manner. Hybrid technologies, such as the combination of CSP with biomass plants, could be a solution to produce energy continually.

Objectives: The main goal of the HYSOL project is the study, design, optimization and construction of a pre-industrial demonstrator based on an innovative hybridization configuration of CSP and biogas for a 100% renewable power plant. A pre-industrial scale demonstrator is being set up in an existing CSP plant. The demonstrator is based on an aeroderivative gas turbine (AGT) exhaust gases simulator coupled with a heat recovery system (HRS) (gas-molten salt).

Achievements in 2015: The following main achievements have been obtained in 2015.

1. In the scope of the dynamic modeling of the power plant, new models have been implemented: gas turbine and molten salt tank, while the heat recovery system model has been improved. Simulation results have been evaluated and compared among partners using different modeling and simulation tools.
2. An experimental campaign in the molten salt test loop at PSA (MOSA facility) has been carried out in order to calibrate and validate the dynamic models.
3. Control strategies to safely operate and improve the plant performance have been tested in simulation taking advantage of the developed dynamic models.
4. Plant operation is currently being studied and optimized by means of optimization algorithms
5. An operation and training tool for the demonstrator is presently being developed. This tool includes a Supervisory Control And Data Acquisition (SCADA) system, a dynamic model of the plant and a control scheme. This tool will be useful to train plant operator and to test and validate the dynamic models, as well as the control strategies.



(a)

(b)

Figure 110. HYSOL operation and training tool. (a) Main window. (b) Virtual gas turbine window

7 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 deploy-ment of solar thermal energy applications. Through this program, about forty 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 thirty years of experience to new generations of university graduates.

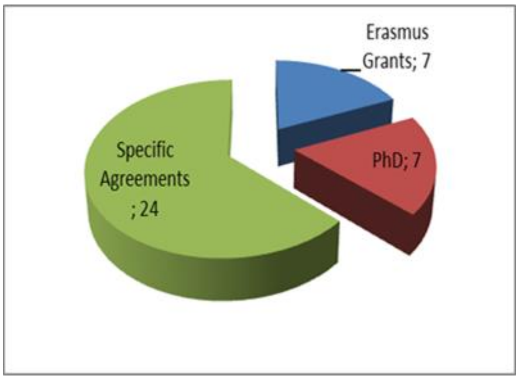


Figure 111. Distribution of PSA students (2015)

The main features of this training program are:

- Management of the Ph.D. fellowship program in association with an annual 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 specific educational cooperation agreements with other entities for sending students to the PSA (Universities of Granada, Almería, URJC-Madrid, UPM-Madrid, TU-München-Germany, Aachen-Germany Karlsruhe-Germany, Kempte-Germany, Dalarna-Sweden, Unesco-IHE-Netherlands, Politecnico di Torino-Italy, Venice-Italy, UIR- Morocco, Antofagasta-Chile, Santiago de Chile-Chile, UNLP-Argentina, Veracruzana-Mexico, Medellín-Colombia, INAT-Tunisia, USDB-Algeria, etc.)

The PSA is a founding member of the 'Alliance of European Laboratories on Solar Thermal Concentrating Systems' (SolLab). This virtual laboratory is made up of 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.

Founding in 2004 of SolLab opened new possibilities for scientific development of researchers in training at the PSA. One of the joint SolLab activities is an annual seminar for Ph.D. students from the five different institutions (Doctoral Colloquium), which is part of the activities of the European project so-called SFERA-II (Solar Facilities for the European Research Area - Second Phase) at the same time. The 11th SOLLAB was organized by the ETHZ and took place in Melchsee-Frutt, Switzerland. The Colloquium was held between the 2nd and 4th of March 2015. Afterwards, the SFERA Winter School was hosted in Zurich from the 5th to the 6th of March, 2015. It was focused on thermal storage.

8. Events

11/01/2015
Lecture
Invited keynote lecture of S. Malato in 3rd Water Research Conference. 11-14 January, 2015. Shenzhen, China.

13/01/2015
Lecture
Invited Conference of S. Malato in Harbin Institute of Technology, Campus Shenzen University, China.

14/01/2015
Technical visit
A group of engineers and officers from Shanghai Electric (China) visited PSA as part of the training activities in Spain related to solar thermal power plants.

15/01/2015
Institutional visit
A high level Delegation from the Ministry of Industry and Trade of Vietnam, headed by the Deputy Minister Mr. Quoc Hung, and invited by the Spanish Agency for International Development Cooperation (AECID), visited in detail the PSA installations and research facilities with the aim of establishing a bilateral institutional collaboration scheme.

21/01/2015
Technical visit
A group of 45 students from the University of Granada, coordinated by Prof. E. Alameda, visited PSA as part of the complementary training activities program of the Energy Systems Master Courses in Civil Engineering.

26/01/2015
Technical visit
A delegation of 13 persons from Ethiopia, invited by Aora Solar, visited PSA to receive information about ongoing research activities on CSP technologies, regarding the great potential development in this country.

27/01/2015
Official Meeting
The 6th Task Meeting of the IEA Solar Heating and Cooling Program (Task 46) was celebrated at PSA, including working sessions and technical visit to the research facilities.

03/02/2015
Doctoral Thesis
Sara Miralles defended the Doctoral Thesis “Elimination of micro-contaminants by combining membrane processes (nanofiltration) and advanced oxidation processes”. University of Almeria.

04/02/2015
Lecture
Invited lecture of R. Bayón in the workshop on “El almacenamiento de la electricidad”, held at Seville (Spain) and organized by the Foundation Gas Natural on February 4th, 2015.

20/02/2015
Technical visit
Prof. B. Negrou from the University of Ourgla in Algeria, visited the PSA installations in the frame of the international technological collaboration activities.

23-27/02/2015
Dissemination and divulgation
J. Fernández gave lectures at the 1st Course on Solar Thermal Energy in the Summer School of the University of La Plata (Argentina), held on February 23-27 in La Plata.

25/02/2015
Technical visit
A group of 25 persons from the Science and Technology Park of Almeria (PITA) involving multidisciplinary local actors on business economy, visited the PSA installations to know in deep about the research and technology development activities and also to hold scientific collaborations in the development of their projects.

09/03/2015
Technical visit
A delegation of the company Renova Energia from Sao Paulo, Brazil, visited PSA to receive information about ongoing research activities on CSP technologies.

08-09/04/2015
International Advisory Committee
J. Blanco participated in the constitution and first official meeting of SERC (Solar Energy Research Center) International Advisory Committee. Santiago de Chile, Chile.

10/04/2015
Lecture
Invited lecture of L. Valenzuela representing CIEMAT in the capitalization event "*The role of renewable energy in the Mediterranean Region: from buzz to action*" during EnergyMED 2015 (Naples, Italy) on April 10th. This event was promoted by the Italian Ministry of Environment, Land and Sea within the project MED-DESIRE. The title of the presentation done by Dra. Valenzuela was "The CSP for small and medium sized installations"

13/04/2015
Technical visit
A group of 35 students from the Polytechnic University of Cartagena, coordinated by Prof. A. Urbina, visited PSA as part of the complementary training activities program of the Master Course on Renewable Energy Systems.

16/04/2015
Technical visit
A group of 20 members from the Industrial Technical Engineers College (COITI) of Almeria visited the PSA, as a reference technological center located in the province, aiming to know in detail the scientific facilities and R&D activities.

21-22/04/2015
International Committee
Participation of F. Martin in Alger at the 1st Bilateral Meeting Algeria-Spain for the Cooperation on Scientific Research and Technology Development, organized by the SEIDI of the Spanish Ministry of Economy and Competitiveness and the Ministry of High Education and Scientific Research of Algeria, representing the PSA in the Spanish delegation composed by different public and private entities.

23/04/2015
Doctoral Thesis
Elisabet Ortega defended the Doctoral Thesis "Inactivación de microorganismos presentes en agua mediante foto-Fenton solar a pH neutro". University of Almeria.

23-24/04/2015
Dissemination and networking
Gines García and Jose Liria presented PSA at the '2as Jornadas de Empleo Joven. Escuela de Formación Agraria Campomar', Almeria.

23-24/04/2015
Workshop
Organization of a workshop for the *Thermal Energy Storage Working Group - SolarPACES Task III*, held at CIEMAT premises in Madrid (Spain) on June 23rd-24th, 2015,

chaired by E. Rojas and R. Bayón in CIEMAT-PSA. M. Rodriguez participated in the meeting too.

28/04/2015
Lecture
Invited lecture of Eduardo Zarza at SolarTR-3 (3rd Turkish Solar Electricity Conference and Exhibition) held at the Middle East Technical University , Ankara (Turkey) in April 27th-29th. http://gunam.metu.edu.tr/ol

03-05/03/2015
Dissemination and networking
11th SolLab Doctoral Colloquium took place in Melchsee-Frutt (ETH, Zurich), Switzer-land with the participation of 9 PhD students and 2 supervisors from PSA.

12/05/2015
Lecture
Invited keynote lecture of S. Malato in E-MRS (European Materials Research Society) Meeting. Symposium B. Materials for applications in water treatment and water split-ting. May 11-15, 2015. Lille, France.

13/05/2015
Doctoral Thesis
Noelia Miranda defended the Doctoral Thesis "Degradación de contaminantes emer-gentes mediante TiO_2 inmovilizado e irradiación solar". University of Almeria.

14/05/2015
Technical visit
Organized from the Spanish CDTI Office in Rabat, a delegation of the Energy Agency of Morocco, MASEN, visited PSA installations with the aim of outlining the possibilities of collaboration in different specific areas regarding the electricity generation CSP technologies.

19/05/2015
Technical visit
A group of 10 technics of the company VZS from Switzerland, coordinated by Mr. J. Beat, visited the PSA installations to know details about the facilities and ongoing research activities on CSP technologies.

19/05/2015
Technical visit
The PSA hosted the visit of the Cuban delegation headed by the President of CUBA-SOLAR, Mr. L. Bérriz, promoted by the Technical Office of Cooperation of Spanish Embassy in Cuba, in the frame of the ongoing Cooperation Agreement with CIEMAT, with the aim of improve the training of specialists on renewable energy technologies in Cuba.

20/05/2015
Lecture
Invited lecture of S. Malato in Master Interuniversitario en Química de Campus de Excelencia Interuniversitario CEIA3.

22/05/2015
Lecture
Invited lecture of S. Malato in Workshop “Metals, water and sun" 2015”. Univ. of Almeria, May 21-22, 2015.

28/05/2015
Lecture
Invited lecture of E. Rojas about “*Lines and trends in the R+D related to solar thermal power plants: the role of the R+D centers*”, at the Universidad Complutense de Madrid, on May 28th.

29/05/2015
Technical visit
A group of 20 students and professors from the Autonomous University of Madrid, visited PSA as part of the training activities of the Master Course on Energies and Fuels for the Future, coordinated by Prof. P. Ocón.

03-04/06/2015
Scientific Committee
Participation of E. Zarza in the fourth meeting of the Scientific Committee of CIC-Energigune (Energy Cooperative Research Centre) organized by CIC-Energigune and held in Vitoria (Spain) on 3-4 June 2015.

09/06/2015
Lecture
Conference of S. Malato in IV Ciclo de Conferencias de la Facultad de Ciencias de la Universidad de Córdoba.

09-12/06/2015
Course
J. Blanco, D. Alarcón and G. Zaragoza participated in the training course *Desalination with Solar Energy* held at PSA and organized jointly by European Desalination Society and CIEMAT.

16/06/2015

Lecture

Invited lecture of J. Blanco in EWACC (Energy, Water & Climate Change in the Mediterranean, Building Bridges between Europe, the Middle East and North Africa). Cyprus Institute, Nicosia, Cyprus, 15-17 June 2015.

16/06/2015

Technical visit

Invited by CIEMAT, a delegation represented by Prof. Azevedo from the United Nations Industrial Development Organization (UNIDO) Office in Brazil, visited the PSA installations to know about the research and technology development activities on concentrated solar thermal power and to identify possible future collaborations.

22/06/2015

Technical visit

Invited by Torresol, a group of 6 students from the MASDAR Institute of Science and Technology of United Arab Emirates, visited PSA as part of the training activities of the Master Course on CSP.

24/06/2015

Official Meeting

Hosted by CIEMAT, the board of CTAER Patronage had a strategic meeting in PSA and visited the research facilities.

24-25/06/2015

Official Committee

J. Blanco participated in the EERA ExCo + JPCs Summer Strategy Meeting. Amsterdam, 24-25 June, 2015.

02/07/2015

Technical visit

A group of 13 persons from Termopower, invited by Stsolar, visited PSA installations mainly focused on concentrated solar energy systems, as part of their training activities.

03/07/15

Oral presentation

Invited oral presentation by G. Zaragoza in the 2nd International Workshop on Membrane Distillation and Innovative Membrane Operations in Desalination and Water Reuse, Ravello (Italy) 1-4 July 2015.

03/07/2015
Technical visit
A group of 20 students and professors from the Polytechnic University of Madrid, visited PSA, as part of the training activities of their Master Course on Renewable Energies, carried out with collaboration of CIEMAT.

10/07/2015
Doctoral Thesis
Alberto de la Calle defended the Doctoral Thesis "Contribuciones al modelado dinámico de procesos termoquímicos en instalaciones termosolares”. UNED, Madrid.

17/07/2015
Doctoral Thesis
Margarita Jiménez defended the Doctoral Thesis entitled “Desarrollo de nuevas estrategias basadas en fotocatálisis solar para la regeneración de aguas de una industria agro-alimentaria”. University of Almeria.

21/07/2015
Lecture
Invited Conference of S. Malato in XXXV Biennial Meeting of the Royal Spanish Chemical Society. 19th to 23rd July 2015 in A Coruña, Spain

23/07/2015
Technical visit
A Portuguese delegation visited PSA in the frame of Sfera activities, represented by Mr. L. Guerra from University of Lisboa and Mrs. A. Nunes from SECIL, S.A., to know details about the facilities and ongoing research activities on CSP technologies.

05/08/2015
Technical visit
A group of engineers and officers from the Tianjin Climate Centre and the University of Shandong (China) visited PSA as part of the training activities in Spain, related to solar energy applications.

09/09/2015
Lecture
Invited key lecture of P. Fernández-Ibáñez ‘Photocatalytic water disinfection: new materials and solar applications’ at the Joint RSC Ireland – UK&I SPC Meeting on Photocatalysis, Queen’s University Belfast, UK.

22/9/2015
Lecture
Sixto Malato was Plenary Speaker at the ‘1er Congreso Colombiano de Procesos Avanzados de Oxidación’. Manizales, Colombia, 21-24 September 2015.

23/09/2015
Lecture
Invited lecture of P. Fernández-Ibáñez entitled ‘Drinking water disinfection using solar energy (possibilities in the UK)’ for the 8th Conference of the UK Network on Potable Water Treatment & Supply. Invited lecture. Cranfield Univ., London, UK.

29/09/2015
Lecture
Invited lecture of J. Blanco in IWLIME 2015 (International Workshop in Lithium, Industrial Minerals and Energy). University of Antofagasta, Chile, September 29th – October 1st, 2015.

30/09/2015
Lecture
Invited lecture of J. Blanco in the course “Solar energy applied to industrial processes and water treatment”. University of Antofagasta, Chile, September 30th, 2015.

01/10/2015
Technical visit
A group of 25 persons from REELCOOP (REnewable ELectricity COOPeration) visited the PSA installations to know in detail about recent advances in concentrated solar thermal power and to identify possible future collaborations.

4/10/2015
Lecture
Conference of S. Malato in the workshop “S.O.S. Ozama”, held at Rep. Dominicana and organized by the Embajada de España en Rep. Dominicana.

05/10/2015
Scientific Committee
Participation of E. Zarza in the yearly meeting of Thematic Network Coordinators of the Programa Iberoamericano de Ciencia y Tecnología para el Desarrollo (CYTED), organized by CYTED and held in Montevideo (Uruguay) on October 5th, 2015.

09/10/2015

Doctoral Thesis

Stefanos Papoutsakis defended the Doctoral Thesis “Enhancing the photo-Fenton treatment of contaminated water by use of ultrasound and iron-complexing agents”. École Polytechnique Federale de Lausanne, Switzerland.

16/10/2015

Lecture

Keynote lecture of E. Rojas about “*Thermal/Thermochemical storage*” at the SolarPACES 2015 Symposium held at Cape Town (South Africa) on October 13th-16th, 2015.

16/10/2015

Institutional event

S. Malato participated in the Annual Meeting “Alto Consejo Consultivo en I+D+I de la Presidencia de la Generalitat Valenciana” hosted by the President of the Regional Goverment of Valencia. Palacio de la Generalitat, Valencia.

18/10/2015

Lecture

Sixto Malato was Invited Speaker in MEDITERRANEAN FORUM ON WATER RESOURCES. Matera, Italy, 18 – 22 October 2015.

22/10/2015

Lecture

Sixto Malato was Invited Speaker in Workshop “Application and Implication of Nanotechnology for Water and Wastewater Treatment” Organized by COST ENTER (ES1205). Athens, Greece.

28/10/2015

Regional Legislation

The Regional Government of Andalucía presented the approval of the Energy Strategic Plan 2020, with the contribution of the PSA in several contents of the document related to the energy research and technological development schemes.

03/11/2015

Workshop

E. Zarza chaired a round table on Operation and Maintenance of Solar Thermal Power Plants, at the *Primer Simposio sobre Tecnologías Termosolares de Concentración*, organized by CTAER and held at Seville (Spain) on November 3rd and 4th, 2015.

5/11/2015

Lecture

Sixto Malato was Plenary Speaker in the 8th Congress on Environmental Application of Advanced Oxidation Processes (VIII EPOA) and 2nd Iberoamerican Congress on Advanced Oxidation Processes (II CIPOA), held in Belo Horizonte – Brazil, on November 03 to 06, 2015.

06/11/2015

Technical visit

A group of 22 students and professors from the University of Málaga, visited PSA as part of the training activities of the Bachelor Degree on Energy Engineering, coordinated by Prof. F. Casares.

09-11/11/2015

Course

S. Malato delivered the course entitled "WATER AND WASTEWATER DECONTAMINATION BY SOLAR RADIATION" in the Graduate Program of Sanitary, Environment and Hydraulic Resources at Federal University of Minas Gerais, Belo Horizonte-MG, Brazil. This course compromised 15 hours.

11/11/2015

Lecture

Invited lecture of A. Fernández on "The reflectance of the solar fiend in CSP plant", at the *CSP Today Seville 2015: 9th International Concentrated Solar Thermal Power Summit,* held in Seville (Spain) on November, 11-12, 2015.

12/11/15

Lecture

Invited keynote lecture by G. Zaragoza in the International Conference "Investigación, Desarrollo e Innovación en Sostenibilidad Energética", Quito (Ecuador), 11-13 November 2015.

19/11/2015

Institutional Meeting

The University of Almeria hosted the act for the renewal of the Collaboration Agreement between UAL, CIESOL and PSA, with the presence of the Deputy Director of CIEMAT, Ramon Gavela, and the Rector of the University, Carmelo Rodríguez, marking 10 years of successful joint activities.

23-24/11/2015

Dissemination and divulgation

E. Zarza and J. Fernández participated in the training course on Concentrating Solar Thermal Systems, organized by the University of Sao Paulo within the framework of the CYTED thematic network "ESTCI", and held at Pirassununga (Brasil) on November 23rd-24th 2015.

25/11/2015

Lecture

Invited lecture of S. Malato in "First workshop on nanostructured materials for light harvesting technologies: from solar fuels to energy storage". IMDEA Materials Institute, Madrid, 25-26 November 2015.

1/12/2015

Lecture

Invited lecture of S. Malato in the workshop "NUEVOS CONCEPTOS DEL USO DE LA RADIACIÓN SOLAR PARA DESCONTAMINACIÓN DEL AGUA", held at Univ. del Valle (Cali, Colombia) organized by Solar Decathlon 2015.

03/12/2015

Institutional Award

The Subdelegate of Gouvernment in Almería, Andrés García Lorca, presided the commemorative act of the Spanish Constitution, where the PSA received an honour distinction recognizing the labour developed as an exemplary institution in the compliance of their assignments in the Almeria province sphere, with presence of the General Director of CIEMAT, Cayetano López Martínez.

03/12/2015

Lecture

Invited lecture of E. Zarza on "*Solar thermal power plants: current status and main R+D Lines*" at the Universidad Autónoma de Madrid on December 3rd, 2015.

4/12/2015

Institutional visit

The Rector of University of Almería, Prof. Carmelo Gómez, accompanied by the Vice-Rector of R&D, Prof. Antonio Posadas, visited in detail the diverse research facilities receiving technical information from PSA researchers about activities and showing the capabilities for potential collaborations in R&D and educational activities.

09/12/2015

Official Committee / Lecture

J. Blanco was invited to attend the special SET-Plan Meeting to present CSP/STE Stakeholder position with regard to EC CSP Issues Paper. Brussels.

13/12/2015

Lecture

Invited lecture of Eduardo Zarza at IRSEC-2015 (*International Renewable and Sustainable Energy Conference)* held at Marrakech and Ouarzazate (Morocco) in December 11th-13th. http://www.med-space.org/irsec15/eduardo-zarza

22/12/2015

Social Act

The Director of PSA, Sixto Malato, invited to all the personnel to the Social Act where the overall resume of R&D activities carried out along the year 2015 and the planning for next year were exposed, with the participation of the heads of PSA research units.

9. Publications

PhD Thesis

De la Calle, A (2015). Contribuciones al modelado dinámico de procesos termoquímicos en instalaciones termosolares. UNED. (Best PhD award given at UNED).

Jiménez Tototzintle, M. (2015). Desarrollo de nuevas estrategias basadas en fotocatálisis solar para la regeneración de aguas de una industria agro-alimentaria. (Unpublished doctoral dissertation). Universidad de Almería, Almería.

Ortega Gómez, E. (2015). Inactivación de microorganismos presentes en aguas mediante foto-Fenton solar a pH neutro. Universidad de Almería, Almería.
https://www.educacion.gob.es/teseo/imprimirFicheroTesis.do;jsessionid=D06F4E913AB0536A761FE4A26C1774F2

Miranda García, N. (2015) Degradación de Contaminantes Emergentes mediante TiO2 Inmovilizado e Irradiación Solar. Universidad de Almería, Almería.
https://www.educacion.gob.es/teseo/imprimirFichaConsulta.do;jsessionid=B895E75BEBEE2AB69857B398F77E81E7?idFicha=385662

Miralles Cuevas, S. (2015). Eliminación de micro-contaminantes mediante combinación de procesos de membrana (nanofiltración) y procesos avanzados de oxidación. Universidad de Almería, Almería.
https://www.educacion.gob.es/teseo/imprimirFichaConsulta.do;jsessionid=B32BC337BB3CC28904B39AA57BF97AC9?idFicha=377942

Papoutsakis, S. (2015). Enhancing the photo-Fenton treatment of contaminated water by use of ultrasound and iron-complexing agents. Ecole Polytechnique Federale de Lausanne, Switzerland
http://infoscience.epfl.ch/record/215317

Solar concentrating systems unit

SCI PUBLICATIONS

Almeida Costa Oliveira, F., Guerra Rosa, L., Cruz Fernandes, J., Rodríguez, J., Cañadas, I., Magahães, T., Shohoji, N.,. Nitriding VI-group metals (Cr, Mo and W) in stream of NH3 gas under concentrated solar irradiation in a solar furnace at PSA (Plataforma Solar de Almería). Solar Energy. 114 (2015) 51–60.

Bouaddi, S., Ihlal, A., Fernández-García, A. (2015). Soiled CSP solar reflectors modeling using dynamics linear models. Solar Energy 122, 847-863.

Ebert, M., Arnold, W., Avila-Marin, A., Denk, T., Hertel, J., Jensch, A., Reinalter, W., Schlierbarch, A., Uhlig, R. (2015). Development of insulation for high flux density receivers. Energy Procedia 69, 369-378. SolarPACES 2014.

Feldhoff, J.F., Hirsch, T., Pitz-Paal, R., Valenzuela, L. Transient models and characteristics of once-through line focus systems. Energy Procedia 69, 626-637. SolarPACES 2014.

Fernández-García, A., Rojas, E., Pérez, M., Silva, R., Hernández-Escobedo, Q., Manzano-Agugliaro, F. (2015). A parabolic-trough collector for cleaner industrial process heat. Journal of Cleaner Production 89, 272-285.

González-Pardo, A. , González-Aguilar, J., Romero, M. Analysis of glint and glare produced by the receiver of small heliostat fields integrated in building façades. Methodology applicable to conventional central receiver systems". Solar Energy, Volume 121, November 2015, pages 68-77.

Gutiérrez-López, J.,.Levenfeld, B., Várez, A., Pastor, J.I.,.Cañadas, I.,Rodríguez, J.. The densification, mechanical and magnetic properties of Ni–Zn ferrites sintered in a solar furnace. Study of Ceramics International. (2015) Volume 41, Issue 5, Part A, 2015, Pages 6534–6541

Hernández-Escobedo, Q., Rodríguez-García, E., Saldaña-Flores, R., Fernández-García, A., Manzano-Agugliaro, F. (2015). Solar energy resource assessment in Mexican states along the Gulf of Mexico. Renewable and Sustainable Energy Reviews 43, 216-238.

D. Krüger , A. Kenissib, S. Dieckmann, H. Schenkc, C. Boudend, A. Babae, A. Oliveiraf, J. Soares, E. Rojas, R. Ben Cheikhi, F. Oriolij, D. Gasperinik, K. Hennecke, H. Schenk. (2015) Pre-Design of a Mini CSP plant. Energy Procedia 69, 1613-1622 SolarPACES 2014 Proceedings.

Li, B., Oliveira, F.A.C., Rodríguez, J., Fernandes, J.C., Rosa, L.G. Numerical and experimental study on improving temperature uniformity of solar furnaces for materials processing. Solar Energy, Volume 115, May 2015, Pages 95-108

Martinez Plaza, D., Cañadas Martínez, I., Mallol Gasch, G., Téllez Sufrategui, F., Rodríguez García, J. A case study of the feasibility of using solar concentrating technologies. for manufacturing ceramics. Journal of Cleaner Production 87 977-991.

Montecchi, M., Delord, C., Raccurt, O., Disdier, A., Sallaberry, F., García de Jalón, A. Fernández-García, A., Meyen, S., Happich, C., Heimsath, A., Platzer, W. (2015). Hemispherical reflectance results of the SolarPACES reflectance round robin. Energy Procedia 69, 1904-1910. SolarPACES 2014.

Rojas, E., Bayón, R., Zarza, E. (2015). Liquid Crystals: A different approach for storing latent energy in a DSG plant. Energy Procedia 69, 1014-1022. SolarPACES 2014.

Roldán, M.I., Avila-Marin, A., Alvarez-Lara, M., Fernández-Reche, J. (2015). Experimental and numerical characterization of ceramic and metallic absorbers under lab-scale conditions. Energy Procedia 69, 523-531. SolarPACES 2014.

Serrano-Aguilera, J.J., Valenzuela,L., Fernández-Reche, J. (2015). Inverse MCRT method for obtaining solar concentrators with quasi-planar flux distribution. Energy Procedia 69, 208-217. SolarPACES 2014.

Sutter, F., Fernández-García, A., Heller, P., Anderson, G. (2015). Durability testing of silvered-glass mirrors. Energy Procedia 69, 1568-1577. SolarPACES 2014.

BOOK CHAPTERS

Roldán, M.I., Fernández-Reche, J., Valenzuela, L., Vidal, A., Zarza, E. (2015). "CFD Modelling in Solar Thermal Engineering" en Engineering Applications of Computational Fluid Dynamics. Ed. Maher A.R. Sadiq Al-Baghdadi, International Energy and Environment Foundation (www.IEEFoundation.org). Cap. 2, pp. 47-84. ISBN-13: 978-1511788786.

PRESENTATION AT CONGRESSES

ORAL PRESENTATIONS

Apostol, I. ; Saravanan, K. V.; Rodriguez, J. ; Cañadas, I.; Ramos, C. Concentrated solar energy used for sintering magnesium titanates for electronic applications. 9th International Conference on Materials Science & Engineering (BRAMAT 2015). Brasov, Rumanía. March, 2015.

Ballestrín, J.,. Monterreal, R., Carra, M.E.,Reche, J., Barbero, F.J., Marzo, A. Measurement of solar extinction in tower plants with digital cameras. 21st SolarPACES Conference, October 13-16, 2015. Cape Town, South Africa.

Bonilla, J., Rodríguez-García, M., Roca, L., Valenzuela, L. Object-Oriented Modeling of a Multi-Pass Shell-and-Tube Heat Exchanger and its Application to Performance Evaluation. *1st IFAC Conference on Modelling, Identification and Control of Nonlinear Systems*, Saint Petersburg, Russia, June 24-26, 2015.

Bayón, R., Rojas, E.. Characterization of organic PCMs for medium temperature storage. The Energy & Materials Research Conference (EMR2015). Published in "Materials and Technologies for Energy Efficiency", Editor: A. Méndez-Vilas BrownWalker Press 2015, pp. 157-161.

Delord, C., Girard, R., Fernández-García, A., Martínez-Arcos, L., Sutter, F. Soiling and degradation analysis of solar mirrors. *21st SolarPACES Conference*, October 13-16, 2015. Cape Town, South Africa.

Feldhoff, J.F., Hirsch, T., Pitz-Paal, R., Valenzuela, L. Analysis and potential of once-through steam generators in line focus systems – Final results of the DUKE Project. *21st SolarPACES Conference*, October 13-16, 2015. Cape Town, South Africa.

Fernández-García, A., Sutter, F., Heimsath, A., Martínez-Arcos, L., Reche-Navarro, T., Schmid, T. Simplified analysis of solar-weighted specular reflectance for mirrors with high specularity. *21st SolarPACES Conference*, October 13-16, 2015. Cape Town, South Africa.

Iparraguirre, I., Huidodro, A., Fernández-García, A., Valenzuela, L., Horta, P., Sallaberry, F., Osorio, T., Vega, J.M. Solar thermal collectors for medium temperature applications: a comprehensive review and updated database. *International Conference on Solar Heating and Cooling for Buildings and Industry - SHC Conference 2015*. Istambul, Turkey, December 2-4.

Márquez, J.M., López-Martín, R., Valenzuela, L., Zarza, E. Test bench HEATREC for heat loss measurement on solar receiver tubes. *21st SolarPACES Conference*, October 13-16, 2015. Cape Town, South Africa.

Sallaberry, F., Bello, A., Burgaleta, J.I., Fernández-García, A., Fernández-Reche, J., Gómez, J.A., Herrero, S., Luepfert, E., Morillo, R., San Vicente, G., Sanchez, M., Santamaría, P., Terradillos, J., Ubach, J., Valenzuela, L. Standards for components in concentrating solar thermal power plants – status of the Spanish working group. *21st SolarPACES Conference*, October 13-16, 2015. Cape Town, South Africa.

Sallaberry, F., Valenzuela, L., García de Jalón, A., León, J., Bernard, I.D. Standardization of in-site parabolic trough collector in solar thermal power plants. *21st SolarPACES Conference*, October 13-16, 2015. Cape Town, South Africa.

Sansom, C., Fernández-García, A., Sutter, F. Contact cleaning of polymer film solar reflectors. *21st SolarPACES Conference*, October 13-16, 2015. Cape Town, South Africa.

Serrano-Aguilera, J.J., Valenzuela, L.. Transient validation of RELAP5 model with the DISS facility in once-through operation mode. *21st SolarPACES Conference*, October 13-16, 2015. Cape Town, South Africa.

Wette, J., Sutter, F., Fernández-García, A. Correlating outdoor exposure with accelerated aging tests for aluminum solar reflectors. *21st SolarPACES Conference*, October 13-16, 2015. Cape Town, South Africa.

POSTERS

Ballestrín, J.,. Rodríguez, J., Carra, M.E., Cañadas, I., Roldán, M.I., Barbero, F.J., Marzo, A. Pyrometric method for measuring emittances at high temperatures. *21st SolarPACES Conference*, October 13-16, 2015. Cape Town, South Africa.

Bayón, R. Storing latent heat with liquid crystals. Is it a feasible option?. *European Conference on Liquid Crystals-2015*, organized by the University of Manchester and held at Manchester (United Kingdom) on September 7-11, 2015.

Bonilla, J., de la Calle, A., Rodríguez-García, M.M., Roca, L., Valenzuela, L. Experimental callibration of heat transfer and thermal losses in a shell-and-tube heat exchanger. 11th *International Modelica Conference 2015*, September 21-23. Paris, France.

Cundapí, R., Moya, S.L., Valenzuela, L. Approaches to the modeling of a solar field for direct steam generation of industrial use. *XXXIX Semana Nacional de Energía Solar 2015*, October 5-9, Ciudad de San Francisco Campeche, Camp., México.

González-Pardo, A., Denk, T. A novel off-axis solar concentrator providing a vertical beam. *21st SolarPACES Conference, 13 - 16 October 2015, Cape Town, South Africa.*

Hirsch, T., Schoredter-Homscheidt, M., Wilbert, S., Martín-Chivelet, M., González, L., Biencinto, M. Towards the Definition of Requirements for Direct Normal Irradiance Nowcasting Systems. *21st SolarPACES Conference*, October 13-16, 2015. Cape Town, South Africa.

Hofer, A., Valenzuela, L., Janotte, N., Burgaleta, J.I., Arraiza, J., Montecchi, M., Sallaberry, F., Horta, P., Carvalho, M.J., Alberti, F., Kramer, K., Heimsath, A., Platzer, W., Scholl, S. State of the art of performance evaluation methods for concentrating collectors. *21st SolarPACES Conference*, October 13-16, 2015. Cape Town, South Africa.

Roca, L., Bonilla, J., Rodríguez-García, M.M., Palenzuela, P., de la Calle, A., Valenzuela, L. Control strategies in a thermal oil – molten salt heat exchanger. *21st SolarPACES Conference*, October 13-16, 2015. Cape Town, South Africa.

Rodriguez, M. Stability of D-mannitol upon melting/freezing cycles under controlled inert atmosphere. *SHC 2015, Int. Conf. on Solar Heating and Cooling for Buildings and Industry*, organized by GÜNDER, ESTIF and SHC-IA and held at Istanbul (Turkey) on December 2-4, 2015.

Vidal, A. Thermochemical solar hydrogen production integrated into a power plants—a case study on the performance and economy of a 19 MW solar thermal power plant. *21st SolarPACES Conference*, 13 - 16 October 2015, Cape Town, South Africa.

Solar Desalination Unit

SCI PUBLICATIONS

Ali Altaee, Adel Sharif, Guillermo Zaragoza, Ahmad Fauzi Ismail, Evaluation of FO-RO and PRO-RO designs for power generation and seawater desalination using impaired water feeds, Desalination, Volume 368, 15 July 2015, Pages 27-35, ISSN 0011-9164.

A. Cipollina, E. Tzen, V. Subiela, M. Papapetrou, J. Koschikowski, R. Schwantes, M. Wieghaus & G. Zaragoza (2015) Renewable energy desalination: performance analysis and operating data of existing RES desalination plants, Desalination and Water Treatment, 55:11, 3120-3140.

Alberto de la Calle, Javier Bonilla, Lidia Roca, Patricia Palenzuela, Dynamic modeling and simulation of a solar-assisted multi-effect distillation plant, Desalination, Volume 357, 2 February 2015, Pages 65-76, ISSN 0011-9164.

Elena Guillén-Burrieza, Diego-Cesar Alarcón-Padilla, Patricia Palenzuela, Guillermo Zaragoza, Techno-economic assessment of a pilot-scale plant for solar desalination based on existing plate and frame MD technology, Desalination, Volume 374, 15 October 2015, Pages 70-80, ISSN 0011-9164.

P. Horta, G. Zaragoza & D.C. Alarcón-Padilla (2015) Assessment of the use of solar thermal collectors for desalination, Desalination and Water Treatment, 55:10, 2856-2867.

Patricia Palenzuela, Diego-César Alarcón-Padilla, Guillermo Zaragoza, Large-scale solar desalination by combination with CSP: Techno-economic analysis of different options for the Mediterranean Sea and the Arabian Gulf, Desalination, Volume 366, 15 June 2015, Pages 130-138, ISSN 0011-9164.

P. Palenzuela, D.C. Alarcón-Padilla, G. Zaragoza, J. Blanco, Comparison between CSP+MED and CSP+RO in Mediterranean Area and MENA Region: Techno-economic Analysis, Energy Procedia, Volume 69, May 2015, Pages 1938-1947, ISSN 1876-6102.

Patricia Palenzuela, Guillermo Zaragoza, Diego-César Alarcón-Padilla, Characterisation of the coupling of multi-effect distillation plants to concentrating solar power plants, Energy, Volume 82, 15 March 2015, Pages 986-995, ISSN 0360-5442.

Alba Ruiz-Aguirre, María Inmaculada Polo-López, Pilar Fernández-Ibáñez & Guillermo Zaragoza (2015) Assessing the validity of solar membrane distillation for disinfection of contaminated water, Desalination and Water Treatment, 55:10, 2792-2799.

Alba Ruiz-Aguirre, Diego-César Alarcón-Padilla & Guillermo Zaragoza (2015) Productivity analysis of two spiral-wound membrane distillation prototypes coupled with solar energy, Desalination and Water Treatment, 55:10, 2777-2785.

Khaled Touati, Alberto de la Calle, Fernando Tadeo, Lidia Roca, Thomas Schiestel & Diego-César Alarcón-Padilla (2015) Energy recovery using salinity differences in a multi-effect distillation system, Desalination and Water Treatment, 55:11, 3048-3055.

BOOK CHAPTERS

Patricia Palenzuela, Diego-César Alarcón-Padilla, Guillermo Zaragoza. Concentrating Solar Power and Desalination Plants. ISBN 978-3-319-20534-2. (2015) Ed. Springer.

ORAL PRESENTATIONS

Altaee, A., Sharif, A. & Zaragoza, G. Dual stage PRO process for power generation from different feed resources. EuroMed 2015. Desalination for Clean Water and Energy. Palermo, Italy, 10-14 May 2015.

J.A. Andrés-Mañas, A. Ruiz-Aguirre, F.G. Acién, G. Zaragoza. Experimental evaluation of vacuum multi-effect membrane distillation systems for saline water treatment. Presentación oral. Desalination for the Environment Clean Water and Energy, Euromed 2015. Palermo (Italy), 10-14 Mayo 2015.

Gil, J.D., Ruiz-Aguirre, A., Roca, L., Zaragoza, G., Berenguel, M. Solar membrane distillation: A control perspective (2015) 2015 23rd Mediterranean Conference on Control and Automation, MED 2015 - Conference Proceedings, art. no. 7158843, pp. 796-802.

Moudjeber, D.E., Ruiz-Aguirre, A., Ugarte-Judge, D., Mahmoudi, H. & Zaragoza, G. Solar desalination by air gap membrane distillation: a case study from Algeria. EuroMed 2015. Desalination for Clean Water and Energy. Palermo, Italy, 10-14 May 2015.

Ortega-Delgado, B., Palenzuela, P., Alarcón-Padilla, D. C. & García-Rodríguez, L. Quasi-steady state simulations of multi-effect distillation plants coupled to parabolic trough solar thermal plants. EuroMed 2015. Desalination for Clean Water and Energy. Palermo, Italy, 10-14 May 2015.

Palenzuela, P., Alarcón-Padilla, D. C., Zaragoza, G. Preliminary experimental characterization of a pilot-scale multi-effect distillation plant. EuroMed 2015. Desalination for Clean Water and Energy. Palermo, Italy, 10-14 May 2015.

Ruiz-Aguirre, A., Andrés-Mañas, J.A. & Zaragoza, G. Comparative characterization of different commercial spiral-wound membrane distillation units. EuroMed 2015. Desalination for Clean Water and Energy. Palermo, Italy, 10-14 May 2015.

G. Zaragoza, A. Ruiz-Aguirre, J.A. Andrés-Mañas. A Comparative Analysis of Commercial Membrane Distillation Modules for Desalination: Challenges and Opportunities. Presentación oral. 2nd International Workshop on Membrane Distillation and Innovating Membrane Operations in Desalination and Water Reuse. Ravello (Italy) 1-4 Julio 2015.

G. Zaragoza. “Perspectives of solar desalination”. Presentación oral invitada. 2nd International Conference “Investigación, Desarrollo e Innovación en Sostenibilidad Energética”, Quito (Ecuador), 11-13 Noviembre 2015.

G. Zaragoza. Suitability of membrane distillation for wastewater treatment using solar energy. Presentación oral. 3W Conference, Bangkok (Thailand), 28 Enero 2015.

G. Zaragoza, O. Ceberio, P.A. Davies, G. Papadakis, R. Schwantes, E. Tzen. Renewable energy desalination: status of technology development, research and commercialization. Presentación oral. Desalination for the Environment Clean Water and Energy, Euromed 2015. Palermo (Italy), 10-14 Mayo 2015.

G. Zaragoza, A. Ruiz-Aguirre, J.A. Andrés-Mañas. Membrane Distillation: Ready for the Market? Comparative Assessment of Commercial Systems. Presentación oral. Desaltech 2015. International Conference on Emerging Water Desalination Technologies in Municipal and Industrial Applications. San Diego (USA) 28-29 Agosto 2015.

Zaragoza, G., Horta, P., Palenzuela, P., Alarcón-Padilla, D. C. Solar desalination: constraints and opportunities of different technologies based on energy efficiency and cost. The International Desalination Association World Congress on Desalination and Water Reuse 2015, San Diego, CA, USA, August 30 – September 4, 2015.

POSTERS

J.A. Andrés-Mañas, A. Ruiz-Aguirre, F.G. Acién, G. Zaragoza. Experimental Comparison of Two different Vacuum Multi-Effect Membrane Distillation Systems. Poster. 2nd International Workshop on Membrane Distillation and Innovating Membrane Operations in Desalination and Water Reuse. Ravello (Italy) 1-4 Julio 2015.

Palenzuela, P., Cornejo L., Alarcón-Padilla, D. C., Zaragoza, G. Opportunity for solar membrane distillation in Chile: case study in Arica. EuroMed 2015. Desalination for Clean Water and Energy. Palermo, Italy, 10-14 May 2015.

A. Ruiz-Aguirre, J.A. Andrés-Mañas, G. Zaragoza. Study of combination of Membrane Distillation and Advances Oxidation Processes for removing microorganisms of municipal wastewater. Poster. 2nd International Workshop on Membrane Distillation and Innovating Membrane Operations in Desalination and Water Reuse. Ravello (Italy) 1-4 Julio 2015.

SCI PUBLICATIONS

Amor, C., De Torres-Socías, E., Peres, J.A., Maldonado, M.I., Oller, I., Malato, S., Lucas, M.S. Mature landfill leachate treatment by coagulation/flocculationcombined with Fenton and solar photo-Fenton processes. J. Hazar. Mat., 286, 261-268, 2015.

Byrne, J.A., Dunlop, P.S.M., Hamilton, J.W.J., Fernández-Ibáñez, P., Polo-López, I., Sharma, P.K., Vennard, A.S. A Review of Heterogeneous Photocatalysis for Water and Surface Disinfection. Molecules. 20 (2015) 5574-5615.

Cabrera Reina, A., Santos-Juanes Jordá, L., Casas López J.L., Maldonado Rubio M.I., García Sánchez J.L., Sánchez Pérez J.A. Biological oxygen demand as a tool to predict membrane bioreactor best operating conditions for a photo-Fenton pre-treated toxic wastewater. J. Chem. Technol. Biotech. 90 (2015) 110-119.

Cabrera Reina, A., Santos-Juanes, L., García Sánchez, J.L., Casas López, J.L., Maldonado Rubio, M.I., Li Puma, G., Sánchez Pérez, J.A. Modeling the photo-Fenton oxidation of the pharmaceutical 1 paracetamol in water including the effect of photon absorption (VRPA). Applied Catalysis B: Environmental. 166-167 (2015) 295-301.

Carra, I., Sánchez Pérez, J.A., Malato, S., Autin, O., Jefferson, B., Jarvis, P. Application of high intensity UVC-LED for the removal of acetamiprid with the photo-Fenton process. Chemical Engineering Journal, 264 (2015), 690-698.

Carra, I., Sirtori, C., Ponce-Robles, L., Sánchez Pérez, J.A., Malato, S., Agüera, A. Degradation and monitoring of acetamiprid, thiabendazole and their transformation products in an agro-food industry effluent during solar photo-Fenton treatment in a raceway pond reactor. Chemosphere, 130, 73-81, 2015.

De Torres-Socías, E., Prieto-Rodríguez, L., Zapata, A., Fernández-Calderero, I., Oller, I., Malato, S. Detailed treatment line for a specific landfill leachate remediation. Brief economic assessment. Chemical Engineering Journal, 261, 60–66, 2015.

Fernández-Ibáñez, P., Polo-López, M.I., Malato, S., Wadhwa, S. ,Hamilton, J.W.J., Dunlop, P.S.M., D'Sa, R., Magee, E., O'Shea, K., Dionysiou, D.D., Byrne, J.A. Solar photocatalytic disinfection of water using titanium dioxide graphene composites. Chem. Eng. J. 261 (2015) 36-44.

Ferro, G., Castro-Alferez, M., Polo-Lopez, M.I., Rizzo, L., Fernández-Ibañez, P. Urban wastewater disinfection for agricultural reuse: effect of solar driven AOPs in the inactivation of a multidrug resistant E. coli strain. Applied Catalysis B: Environmental, 178 (2015) 65-73.

Ferro, G., Polo-López, M.I., Martínez-Piernas, A.B., Fernández-Ibáñez, P., Agüera, A., Rizzo, L. Cross-Contamination of Residual Emerging Contaminants and Antibiotic Resistant Bacteria in Lettuce Crops and Soil Irrigated with Wastewater Treated by Sunlight/H2O2. Environmental Science and Technology, 49, (2015), 11096-11104.

Fiorentino, A., Ferro, G., Alferez, M.C., Polo-López, M.I., Fernández-Ibañez, P., Rizzo, L. Inactivation and regrowth of multidrug resistant bacteria in urban wastewater after disinfection by solar-driven and chlorination processes. Journal of Photochemistry and Photobiology B: Biology. 148 (2015) 43-50.

García-Fernández, I., Fernández-Calderero, I., Polo-López, M.I., Fernández-Ibáñez, P. Disinfection of urban effluents using solar TiO2 photocatalysis: A study of significance of dissolved oxygen, temperature, type of microorganism and water matrix. Catalysis Today. 240 (2015) 30-38.

Giménez, J., Bayarri, B., González, O., Malato, S., Peral, J., Esplugas, S. Advanced Oxidation Processes at Laboratory Scale: Environmental and Economic Impacts. ACS Sustainable Chem. Eng., 3 (2015), 3188−3196.

Giménez, J., Bayarri, B., González, O., Malato, S., Peral, J., Esplugas, S. A Comparison of the Environmental Impact of Different AOPs: Risk Indexes. Molecules, 20, 503-518, 2015.

Jiménez--Tototzintle, M., Maldonado, M. I., Rodríguez, E. M., Hernández-Ramírez, A., Saggioro, E., Carra, I., Sánchez Pérez, J.A. Supported TiO2 solar photocatalysis at semi-pilot scale: Degradation of pesticides found in citrus processing industry wastewater, reactivity and influence of photogenerated species. J. Chem. Technol. Biotech. 90 (2015) 149-157.

Jiménez-Tototzintle, M., Oller, I., Hernández-Ramírez, A., Malato, S., Maldonado, M.I. Remediation of agro-food industry effluents by biotreatment combined with supported TiO2/H2O2 solar photocatalysis. Chemical Engineering Journal 273 (2015) 205-213.

Keogh, M.B., Castro-Alférez, M., Polo-López, M.I., Fernández Calderero, I., Al-Eryani, Y.A., Joseph-Titus, C., Sawant, B., Dhodapkar, R., Mathur, C., McGuigan, K.G., Fernández-Ibáñez, P. Capability of 19-L polycarbonate plastic water cooler containers for efficient solar water disinfection (SODIS): Field case studies in India, Bahrain and Spain. Solar Energy 116 (2015) 1-11.

Malato, S., Fernández-Ibañez, P., Poulios, I., Mantzavinos, D. Selected contributions of the 8th european meeting on solar chemistry and photocatalysis:environmental applications (SPEA 8). Catalysis Today Vol. 252. 2015.

Mantzavinos D., Malato, S. Solar chemistry and photocatalysis: environmental applications. Photochemcial and Photobiological Sciences, Vol 14 (3), 2015.

Mendes Saggioro, E., Sousa Oliveira, A., Forsin Buss, A., de Paiva Magalhaes, D., Pavesi, T. Jiménez, M., Maldonado, M. I., Vieira Ferreira, L. F., Costa Moreira, J. Photo-decoloration and ecotoxicological effects of solar compound parabolic collector pilot plant and artificial light photocatalysis of indigo carmine dye. Dyes and Pigments 113 (2015) 571-580.

Mendes Saggioro, E., Sousa Oliveira, A., Pavesi, T., Jiménez Tototzintle, M., Maldonado, M. I., Correia, F.V., Costa Moreira, J. Solar CPC Pilot Plant Photocatalytic Degradation of Indigo Carmine Dye in Waters and Wastewaters Using Supported-TiO2: Influence of Photodegradation Parameters. Inter. J. Photoenergy. 2015 (2015), 656153.

Miralles-Cuevas, S., Oller, I., Agüera, A., Ponce-Robles, L., Sánchez Pérez, J.A., Malato, S. Removal of microcontaminants from MWTP effluents by combination of membrane technologies and solar photo-Fenton at neutral pH. Catalysis Today, 252, 78-83, 2015.

Miralles-Cuevas, S., Oller, I., Sánchez Pérez, J. A., Malato, S. Application of solar photo-Fenton at circumneutral pH to nanofiltration concentrates for removal of pharmaceuticals in MWTP effluents. Environ Sci Pollut Res 22, 846–855, 2015.

Ortega-Gómez, E., Ballesteros Martín, M.M., Carratala Ripolles, A., Fernández Ibañez P., Sánchez Pérez J.A., Pulgarín, C. Principal parameters affecting virus inactivation by the solar photo-Fenton process at neutral pH and μM concentrations of H2O2 and Fe2+/3+ Applied Catalysis B: Environmental, 174-175 (2015) 395-402.

Papoutsakis, S., Afshari, Z., Malato, S., Pulgarin, C. Elimination of the iodinated contrast agent iohexol in water, wastewater and urine matrices by application of photo-Fenton and ultrasound advanced oxidation processes. J. Environ. Chem. Eng., 3 (2015), 2002–2009.

Papoutsakis, S., Brites-Nóbrega, F.F., Pulgarin, C., Malato, S. Benefits and limitations of using Fe(III)-EDDS for the treatment of highly contaminated water at near-neutral pH. J. Photochem. Photobiol. A: Chem. 303, 1-7, 2015.

Papoutsakis, S., Miralles-Cuevas, S., Gondrexon, N., Baup, S., Malato, S., Pulgarin, C. Coupling between high-frequency ultrasound and solar photo-Fenton at pilot scale for the treatment of organic contaminants: An initial approach. Ultras. Sonochem., 22, 527-534, 2015.

Papoutsakis, S., Miralles-Cuevas, S., Oller, I., Garcia Sanchez, J.L., Pulgarin, C., Malato, S. Microcontaminant degradation in municipal wastewater treatment plant secondary effluent by EDDS assisted photo-Fenton at near-neutral pH: An experimental design approach. Catalysis Today, 252, 61-69, 2015.

Polo, D., García-Fernández, I., Fernández-Ibáñez, P., Romalde J.L. Solar water disinfection (SODIS): Impact on hepatitis A virus and on a human Norovirus surrogate under natural solar conditions. Int. Microbiology, 18 (2015) 41- 49.

Poulios, I., Malato, S., Mantzavinos. D. Photocatalysis Science and Applications. Appl. Catal. B: Environ.,178 (2015), 1.

Rivas, G., Carra, I., García Sánchez, J. L., Casas López, J.L., Malato, S., Sánchez Pérez, J.A. Modelling of the operation of raceway pond reactors for micropollutant removal by solar photo-Fenton as a function of photon absorption. Appl. Catal. B: Environ., 178 (2015), 210-217.

Ruiz-Aguirre, A., Polo-López, M.I., Fernández-Ibáñez, P., Zaragoza, G. Assessing the validity of solar membrane distillation for disinfection of contaminated water. Desalination and Water Treatment, 55, (2015) 2792-2799.

Spasiano, D., Marotta, R., Fernández-Ibañez, P., Malato, S., Di Somma, I. Solar photocatalysis: history, principles, materials, reactors, some commercial and pre-industrialized applications. A comprehensive approach. Applied Catalysis B: Environmental, 170-171 (2015) 90-123.

Vilar, V.J.P., Malato, S., Dionysiou D.D. Advanced oxidation technologies: advances and challenges in Iberoamerican countries de Environ. Sci. Pollut. Res. 22 (2). 2015.

OTHER BOOKS AND JOURNALS

Carra Ruiz, I., Sánchez Pérez, J. A., Malato, S., Agüera, A., Casas López, J. L. Application of the photo-Fenton process for the removal of persistent pollutants: operation parameters. Editorial CIEMAT, Madrid, Spain. ISBN 978-84-7834-733-9. 201 pag. 2015.

Jiménez Tototzintle, M., Maldonado Rubio, M.I., Oller Alberola, I., Hernández Ramírez, M.A. Desarrollo de nuevas estrategias basadas en fotocatálisis solar para la regeneración de aguas de una industria agro-alimentaria. Editorial CIEMAT. Colección de documentos CIEMAT. ISBN: 978-84-7834-742-1. 2015, 262.

Maldonado Rubio, M. I., Suárez Gil, S., Miranda García, N. Degradación de Contaminantes Emergentes mediante TiO2 Inmovilizado e Irradiación Solar. Editorial Ciemat. Madrid (Spain). ISBN 978-84-7834-735-3. 2015.

Miralles Cuevas, S., Oller Alberola, I., Sánchez Pérez, J.A., Malato, S. Eliminación de micro-contaminantes mediante combinación de sistemas de membrana (nanofiltración) y procesos avanzados de oxidación. Editorial CIEMAT, Madrid, Spain. ISBN 978-84-7834-737-7. 339 pag. 2015.

Ortega Gómez, E., Sánchez Pérez, J.A., Ballesteros Martín, M.M., Fernández-Ibáñez, P. Inactivación de microorganismos presentes en aguas mediante foto-Fenton solar a pH neutro. Editorial CIEMAT. Colección de documentos CIEMAT. ISBN: 978-84-7834-744-5. Noviembre 2015, 215 pag.

PRESENTATION AT CONGRESSES

GUEST LECTURES

Fernández-Ibáñez, P. Drinking water disinfection using solar energy (possibilities in the UK). 8th Conference of the UK Network on Potable Water Treatment & Supply. Invited lecture. Cranfield University, London, UK, 23 September 2015.

Fernández-Ibáñez, P. Lecture in Zero Carbon Resorts for Sustainable Tourism: "Reduce, replace and redesign" Training course in Thailand. 5 hours. Kanchanaburi, Thailand, 23rd-28th May, 2015.

Fernández-Ibáñez, P. Lecture in Zero Carbon Resorts for Sustainable Tourism: "Reduce" Training course in the Philippines. 5 hours. Manila, Philippines, 23th-27th February, 2015.

Malato, S. Invited Lecture "Eliminación de contaminantes en agua y otras aplicaciones de los proceso avanzados de oxidación mediante energía solar". Workshop Metales, agua y sol. Almería, 21-22 Mayo 2015.

Malato, S. Invited Lecture "Tratamiento de agua mediante radiación solar: historia y aplicaciones". IV Ciclo de conferencias de la Facultad de Ciencias de la Univ. de Córdoba. 9 de Junio de 2015.

Malato, S. Invited Lecture in "photocatalysis for water detoxification" en Harbin Institute of Technology, Campus Shenzen University , China. January 13th, 2015.

Malato, S. Invited Lecture in Ciclo de Conferencias "I+D en Química" en Master interuniversitario en Química de Campus de Excelencia Interuniversitario CEIA3. 20 de Mayo de 2015.

Malato, S., Fernández-Ibáñez, P., Oller, I., Polo-López, M.I., Maldonado, M.I. Water and Wastewater Treatment: Applications with Solar Photocatalysis. 3rd Water Research Conference. Shenzhen, China, 11th – 14th January, 2015. Invited Lecture.

Malato, S., Maldonado, M.I., Fernández, P., Oller, I., Polo, I. Decontamination and disinfection of water by solar photocatalysis: the pilot plants of the Plataforma Solar de Almeria. E-MRE Meeting. Symposium B. Materials for applications in water treatment and water splitting. May 11-15, 2015. Lille, France. Invited Lecture.

Polo López, M.I. Lecture in Zero Carbon Resorts for Sustainable Tourism: "Reduce" Training course in Thailand. 5 hours. Bangkok, Thailand, 16th-20th February, 2015.

Polo López, M.I. Lecture in Zero Carbon Resorts for Sustainable Tourism: "Reduce" Training course in the Philippines. 5 hours. Manila, Philippines, 23th-27th February, 2015.

Polo López, M.I. Lecture in Zero Carbon Resorts for Sustainable Tourism Replace Professional and Redesign Innovation Course. 4 hours. Puerto Princesa, Palawan, Philippines, 20th -25th April, 2015.

PLENARY LECTURES

Malato, S., Fernández-Ibáñez, P., Maldonado M.I., Oller, I., Polo, I., Sánchez J.A. Solar AOPs: overview of processes and photoreactors. VIII Meeting on Environmental Applications of Advanced Oxidation Processes and II Iberoamerican Congress of Advanced Oxidation Technologies. Belo Horizonte, Brasil. 3-6th November 2015. Book of abstracts PL011. Plenary Lecture.

Malato, S., Fernández-Ibáñez, P., Maldonado, M.I., Oller, I., Polo, I. Integración de los procesos avanzados de oxidación con otros procesos de tratamiento de aguas. 1º Congreso colombiano de oxidación avanzada, Manizales (Colombia) 21-24 Sept. 2015. Conferencia plenaria

Polo–López, M.I., Malato, S., Fernández-Ibáñez, P., Oller, I., Maldonado, M.I. Water purification by solar photocatalysis: techniques and technologies. 1st International Water Nexus Conference 2015. Catalysis for water purification. Daegu, Korea, 28-30 October, 2015. Plenary Lecture.

ORAL PRESENTATIONS

Castro-Alférez, M., Polo-López, M. I., Fernández-Ibáñez, P. Solar Disinfection of Water: treatment decay model (SODIWA). 11th SolLab Doctoral Colloquium on Solar Concentrating Technologies. Melchsee-Frutt, Switzerland, 2nd - 4th March, 2015. Oral communication 42.

Castro-Alférez, M., Polo-López, M. I., Marugán Aguado, J., Fernández-Ibañez, P. Mechanistic model for bacteria photo-inactivation in water using solar radiation: new understanding of solar disinfection. European Society for Photobiology, ESP 2015 Congress. Aveiro, Portugal, 31th August - 4th September, 2015.

Fernández Ibáñez, P., Polo López, M. I., Castro, M., Oller, I., Zaragoza, G. Assessment of solar AOPs for disinfection of effluents of urban wastewater. 3W Expo 205+CPPE Expo 2015. BITEC, Bangkok, Thailand, 28t^{h}-31th January, 2015. Oral communication 23, Session 8: Membrane bioreactor, Reuse and Zero Discharge.

Fernández-Ibáñez, P., Castro-Alférez, M., Polo-López, M.I., Marugán, J. Mechanistic model for bacteria photo-inactivation in water using solar radiation. 4th European Conference on Environmental Applications of AOPs. Athens, Greece. 21-24 October 2015. Oral communication C1-12, Book of abstracts, p. 93.

Fernández-Ibáñez, P., Malato, S., Maldonado, M.I., Oller, I., Polo-López, M.I. Photocatalytic water disinfection: new materials and solar applications. Joint RSC Ireland – UK&I SPC Meeting on Photocatalysis, Queen's University Belfast, UK. 9th September 2015.

Ferro, G., Polo-López, M.I., Martínez-Piernas, A.B., Fernández-Ibáñez, P., Agüera, A., Rizzo, L. Evaluation of cross-contamination of residual emerging contaminants and multi-drug resistant bacteria in lettuce crops irrigated with wastewater treated by sunlight/H_2O_2. Environmental protection in a multi-stressed world: challenges for science, industry and regulators. SETAC Europe 25th Annual Meeting. Barcelona, Catalonia, Spain, 3rd -7th May, 2015. Oral communication 663, p. 176.

Fiorentino, A., Ferro, G., Castro Alferez, M., Polo-López, M.I., Fernández-Ibañez, P., Rizzo, L. Inactivation of antibiotic resistant bacteria in urban wastewater by solar advanced oxidation processes. Environmental protection in a multi-stressed world: challenges for science, industry and regulators. SETAC Europe 25th Annual Meeting. Barcelona, Catalonia, Spain, 3rd -7th May, 2015. Platform communication 423, pag. 111.

Malato, S. Curso ”Water and wastewater decontamination by solar radiation” in the Graduate Program of Sanitary, Environment and Hydraulic Resources at Federal University of Minas Gerais, Belo Horizonte-MG, Brazil. November 9th to 11th, 2015. 15 hours.

Malato, S. Ponencia en “Escuela de Formación en Procesos de Oxidación Avanzada”. Univ. de Caldas, Manizales, Colombia. 21-24 septiembre de 2015.

Malato, S. Ponencia en First workshop on nanostructured materials for light harvesting technologies: from solar fuels to energy storage. IMDEA Materials Institute, Madrid, 25-26 November 2015.

Malato, S. Ponencia en Nuevos Conceptos del Uso de la radiación solar para la descontaminacion de aguas. Univ. del Valle, Cali, Colombia. 1-4th Diciembre, 2015.

Malato, S. Ponencia en seminario “SOS OZAMA”. Pontificia Universidad Católica Madre y Maestra (PUCMM), Rep. Dominicana, 14 de octubre de 2015.

Malato, S. Ponencia en Workshop “Application and Implication of Nanotechnology for Water and Wastewater Treatment” Organized by COST ENTER (ES1205), Working Group 1. Athens, Greece, 22 October 2015.

Malato, S., Fernández-Ibáñez, P., Maldonado, M.I., Oller, I., Polo, I. Descontaminación de aguas utilizando radiación solar: un proceso doblemente sostenible. XXXV Reunión Bienal de RSEQ, La Coruña 19 a 23 de Julio 2015. Libro de resúmenes (ISBN 978-84-606-9786-2). Oral invitada. Sesión S8, pp. 385.

Malato, S., Miralles, S., Sánchez-Pérez, J.A., Oller, I., Agüera, A., Llorca, M. Treatment of real effluents by nanofiltration and solar photo-Fenton: analytical and toxicology assessment. 4th European Conf. on Environmental Appl. of Advanced Oxid. Proc., 21-24 October 2015, Athens. Book of Abstracts B2-7. Oral.

Maldonado, M.I., Oller, I., Polo-López, M.I., Fernández-Ibañez, P., Miralles, S., Malato, S. Plataforma Solar de Almería: 25 años de innovación en el tratamiento de aguas. Jornadas de Vanguardias en Ciencia y Tecnología para la Innovación en la Gestión del Agua. Madrid, 21 y 22 de Septiembre 2015. Comunicación oral.

Oller, I. Integrated Advanced Technologies for the remediation of Industrial wastewaters: case studies. Oral communication in 1st Summer School on Environmental Applications of Advanced Oxidation Processes. University of Salerno, Department of Civil Engineering. Fisciano (Italy), 15th-16th June, 2015.

Oller, I., Malato, S. Wastewater Treatment by Solar driven AOPs: design and applications. Oral communication in 1st Summer School on Environmental Applications of Advanced Oxidation Processes. University of Salerno, Department of Civil Engineering. Fisciano (Italy), 15th-16th June, 2015.

Oller, I., Miralles, S., Ponce-Robles, L., Agüera, A., Malato, S., Trinidad-Lozano, M.J., Yuste, F.J. Cork boiling wastewater regeneration and reuse by combination of advanced oxidation technologies. VIII Meeting on Environmental Applications of Advanced Oxidation Processes and II Iberoamerican Congress of Advanced Oxidation Technologies. Belo Horizonte, Brasil. 3-6th November 2015. Book of abstracts OR054. Oral.

Oller, I., Ponce, L., Fernández-Ibañez, P., Malato, S. Integration of Advanced Technologies (Biological treatment and Solar based chemical oxidation) for Industrial Wastewater Remediation. International Exhibition on Water, Environmental and Chemical Engineering (3W EXPO+CPPE 2015). Bangkok (Thailand) 29th-31st January, 2015. Oral communication. Session 9: Industrial & Hazardous Management.

POSTERS

Abeledo-Lameiro, M.J., Reboredo-Fernández, A., Polo-López, M.I., Fernández-Ibáñez, P., Ares-Mazás, E., Gómez-Couso, H. Photocatalytic inactivation of the waterborne protozoan parasite Cryptosporidium parvum using TiO2/H2O2 under simulated and natural solar conditions. 4th European Conference on Environmental Applications of AOPs. Athens, Greece. 21-24 October 2015. Poster communication PP3-31, pg 211.

Castro-Alférez, M., Polo-López, M.I., Fernández-Ibáñez, P. Mechanistic model of E. coli inactivation by solar disinfection process (SODIS). IV Minisimposio de Investigación en Ciencias Experimentales. Universidad de Almería, Almería, España, 13 de Noviembre, 2015

Fernández-Ibáñez, P., Oller, I., Malato, S., Maldonado, M.I., Polo-López, M.I. Solar Treatment of water at Plataforma Solar de Almería. 3W Expo 205+CPPE Expo 2015. BITEC, Bangkok, Thailand, 28th-31th January, 2015.

Hobbs, M., Jarvis, P., Carra, I., Jefferson, B., Oller, I., Malato, S., Agüera, A., Martínez, A. Photocatalytic degradation of the herbicide quinmerac. Kinetics and transformation products. 4th European Conf. on Environmental Appl. of Advanced Oxid. Proc., 21-24 October 2015, Athens. Book of Abstracts PP2-49. Poster.

Maldonado, M.I., Malato, S., Fernández-Ibáñez, P., Polo-López, M.I., Oller, I., Peral, J. Solar pilot plant facility for photocatalytic generation of hydrogen. Solar Fuels Network. International Discussion Meeting. Solar Fuels: Moving from Materials to Devices. Poster 17. Royal Society, London, 7th -8th July, 2015.

Maldonado, M.I., Malato, S., Fernández-Ibáñez, P., Polo-López, M.I., Oller, I., Peral, J. Solar pilot plant facility for photocatalytic generation of hydrogen. Solar Fuels Network. International Discussion Meeting. Solar Fuels: Moving from Materials to Devices. Royal Society of Chemistry, London. 7-8 Julio, 2015.

Miralles-Cuevas, S., Oller, I., Llorca, M., Rodríguez-Mozaz, S., Sabater, C., Castillo, M.A., Agüera, A., Petrovic, M., Fernández-Ibáñez, P., Malato, S. Assessment of acute and chronic toxicity in real MWTP effluents treated by different AOPs. SETAC Europe 25th Annual Meeting. Environmental protection in a multi-stressed world: challenges for science, industry and regulators. Barcelona, 3-7 Mayo de 2015.

Ponce Robles, L., Agüera, A., Oller Alberola, I., Malato S. Cork boiling wastewater regeneration and reuse. IV Minisimposio de Investigación en Ciencias Experimentales. Universidad de Almería, Almería, España, 13 de Noviembre, 2015

Román Sánchez, I.M., Segura, M., Sánchez Pérez, J.A., Ortega Gómez, E., Fernández-Ibáñez, P. Cost analysis of photo-Fenton disinfection in real municipal wastewater. 4th European Conference on Environmental Applications of AOPs. Athens, Greece. 21-24 October 2015. Poster communication PP3-29, pg 210.

Automatic Control Group

SCI PUBLICATIONS

Beschi, M., Berenguel, M., Visioli, A., & Yebra, L. J. (2015). On reduction of control effort in feedback linearization GPC strategy applied to a solar furnace. Optimal Control Applications and Methods. doi:10.1002/oca.2194

Bonilla, J., Dormido, S., & Cellier, F.E. (2015). Switching moving boundary models for two-phase flow evaporators and condensers. *Commun. Nonlinear Sci. Numer. Simul.*, 20(3), 743–768. doi:10.1016/j.cnsns.2014.06.035

De la Calle, A., Bonilla, J., Roca, L., & Palenzuela, P. (2015). Dynamic modeling and simulation of a solar-assisted multi-effect distillation plant. *Desalination*, 357, 65–76. doi:10.1016/j.desal.2014.11.008

PRESENTATION AT CONGRESSES

ORAL PRESENTATIONS

Bonilla, J., Rodríguez-García, M.-M., Roca, L., & Valenzuela, L. (2015). Object-Oriented Modeling of a Multi-Pass Shell-and-Tube Heat Exchanger and its Application to Performance Evaluation. In 1st Conference on Modelling, Identification and Control of Nonlinear Systems (MICNON) (pp. 107–112). Saint-Petersburg, Russia.

Fernández, D., & Yebra, L. J. (2015). Comparison case between Modelica and specialized tools for building modelling. In MATHMOD 2015: 8th Vienna International Conference on Mathematical Modelling (pp. 890–895). Vienna: Vienna University of Technology.

Gil, J. D., Ruiz-Aguirre, A., Roca, L., Zaragoza, G., & Berenguel, M. (2015). Solar membrane distillation : a control perspective. In 23rd Mediterranean Conference on Control and Automation (MED) (pp. 836–842).

Bonilla, J., de la Calle, A., Rodríguez-García, M.-M., Roca, L., & Valenzuela, L. (2015). Experimental Calibration of Heat Transfer and Thermal Losses in a Shell-and-Tube Heat Exchanger. In Proc. 11th International Modelica Conference (pp. 873–882). Versailles, France. doi:10.3384/ecp15118873

de la Calle, A., Roca, L., & Bonilla, J. (2015). Inversión de la causalidad computacional en el modelado dinámico. Caso práctico de una planta de generación de hidrógeno solar. In Actas de las XXXVI Jornadas de Automática (pp. 534–541). Bilbao.

Gil, J. D., Ruiz-aguirre, A., Roca, L., Zaragoza, G., Berenguel, M., & Guzmán, J. L. (2015). Control de plantas de destilación por membranas con apoyo de energía solar – parte 1 : esquemas. In Actas de las XXXVI Jornadas de Automática (pp. 937–943). Bilbao.

Gil, J. D., Ruiz-aguirre, A., Roca, L., Zaragoza, G., Berenguel, M., & Guzmán, J. L. (2015). Control de plantas de destilación por membranas con apoyo de energía solar – parte 2 : resultados. In Actas de las XXXVI Jornadas de Automática (Vol. 1, pp. 944–950). Bilbao.

Roca, L., Bonilla, J., Rodríguez-García, M.-M., Palenzuela, P., de la Calle, A., & Valenzuela, L. (2015). Control strategies in a thermal oil – molten salt heat exchanger. 21st SolarPACES Conference.