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Ciemat

Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

PLATAFORMA SOLAR DE ALMERÍA

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ALMERÍA


PLATAFORMA SOLAR
DE ALMERÍA
TABERNAS
ALMERÍA

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Contents

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.

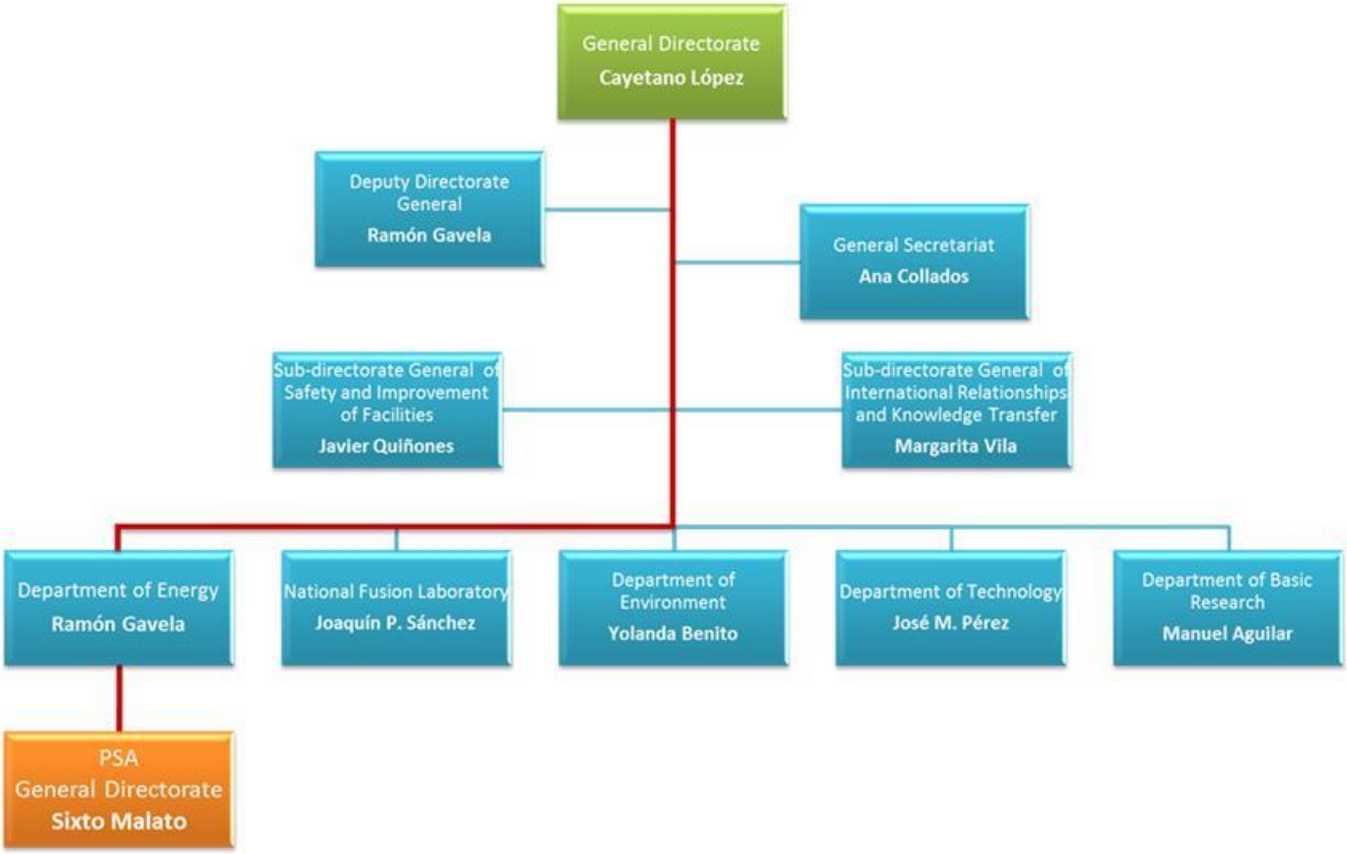


Figure 1.1. Integration of the PSA in the CIEMAT organization

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 1.2. 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 developing new and better ways to produce solar thermal electricity.
- Solar Desalination. Its objective is to develop brackish water and seawater solar desalination.
- Solar Treatment of Water. Exploring the chemical possibilities of solar energy, especially with regards to its potential for water detoxification and disinfection.

Supporting the R&D Units mentioned above are the management and technical services, which are grouped together in the PSA Management Unit. 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 the Management Unit, which coordinates technical and administrative support services. For its part, the Office of the Director must ensure that the supporting capacities, infrastructures and human resources are efficiently distributed. It is also the Office of the Director that channels demands to the various general support units located at the CIEMAT's main offices in Madrid.

The scientific and technical commitments of the PSA and the workload this involves are undertaken by a team of 136 persons that as of December 2014 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 persons who work daily for the PSA, 68 are CIEMAT personnel, 14 of whom are located in the main offices in Madrid.

a)

b)

c)

d)

e)

f)

Figure 1.3. Management and technical services staff grouped in the PSA Management Unit. a) Direction Unit, b) Administration unit, c) Instrumentation unit, d) IT Services unit, e) Operation unit, f) Cleaning and maintenance unit.

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.

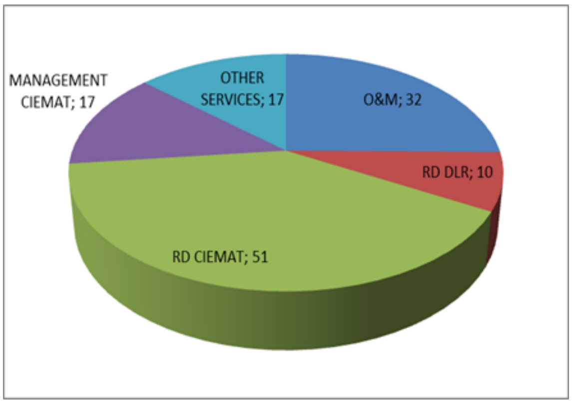


Figure 1.4. Distribution of permanent personnel at the PSA as of December 2013

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 2014 totals 4.02 M Euros (not including R&D personnel or new infrastructure).

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 Fig. 2.1):

- CESA-1 and SSPS-CRS central receiver systems, 5 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 kWth and 40 kWth and a third one with vertical axis 5 kWth.
- A test stand for small evaluation and qualification of parabolic trough collectors, named CAPSOL.

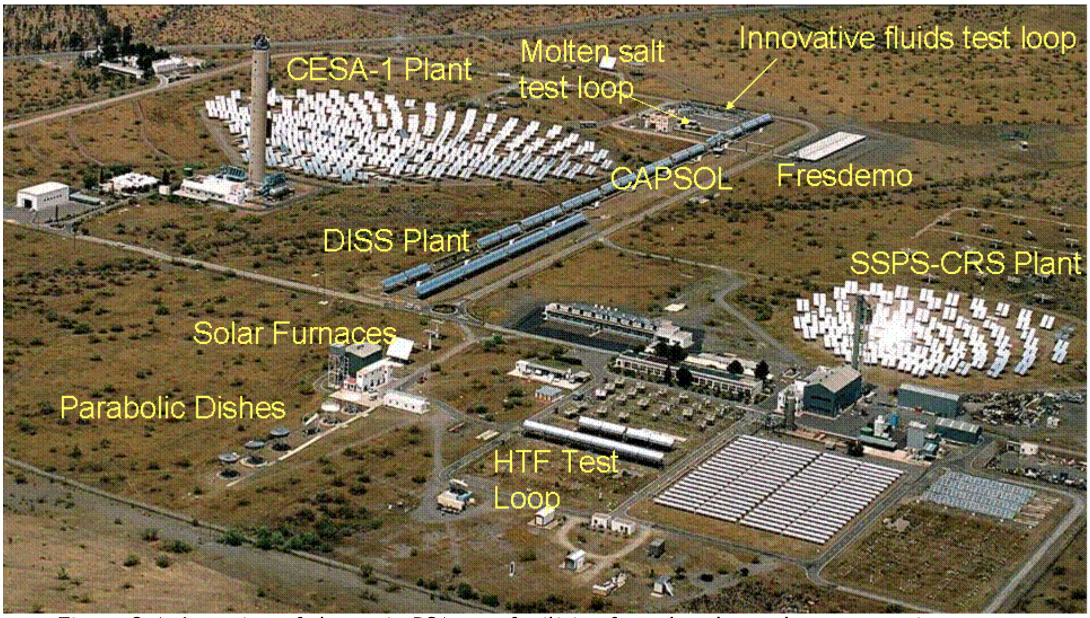


Figure 2.1. Location of the main PSA test facilities for solar thermal concentrating systems

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 5 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 2.2. The CESA-I facility seen from the East with heliostat rows focusing on the medium-height test level (60 m)

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 5 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-kWth capacity range.

Figure 2.3. Aerial view of the experimental SSPS-CRS facility.

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.

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.

Figure 2.4. An autonomous heliostat in the CRS field

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.

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 and KONTAS

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 420ºC 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.

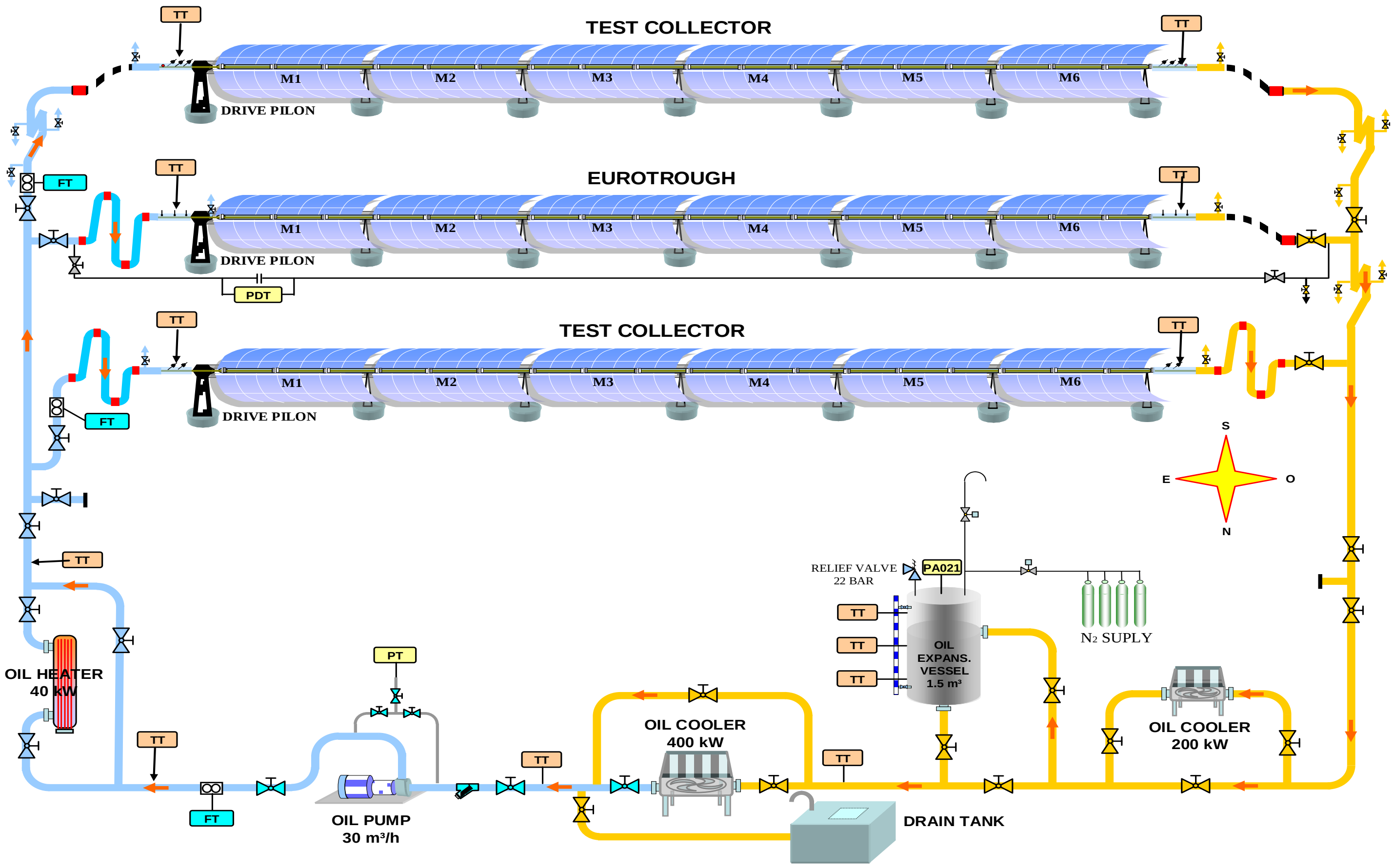


Figure 2.5. Diagram of the PSA "HTF test Loop".

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 Fig. 2.6) 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 500ºC the temperature of the superheated steam produced, enabling to generate direct steam at 100bar and 500ºC.

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.

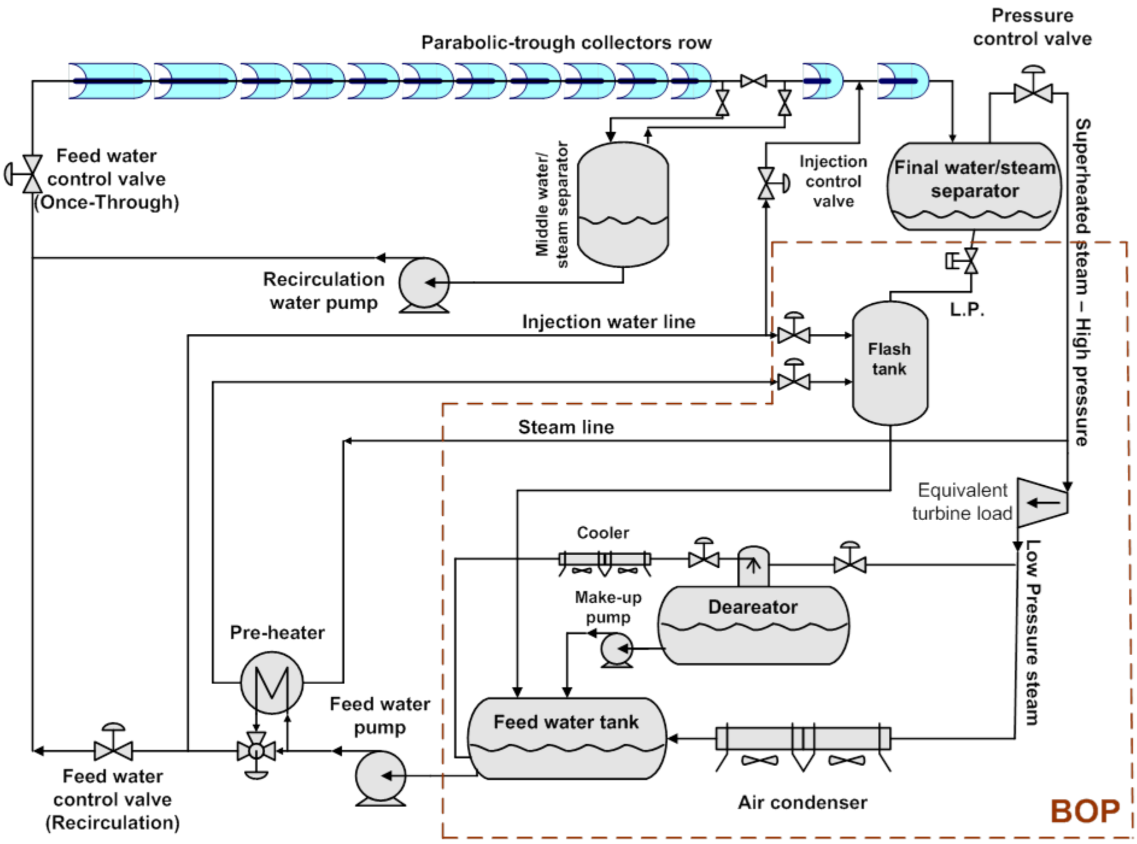


Figure 2.6. Simplified flow diagram of the PSA DISS loop

Among the capacities associated with this facility are the following:

- Component testing for parabolic-trough collector solar fields with direct steam generation 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 direct steam generation.
- 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 2.7. 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 2.8. 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 400ºC was successfully completed at the end of 2009, this facility was then upgraded to achieve temperatures of up to 515ºC 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 515ºC 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).

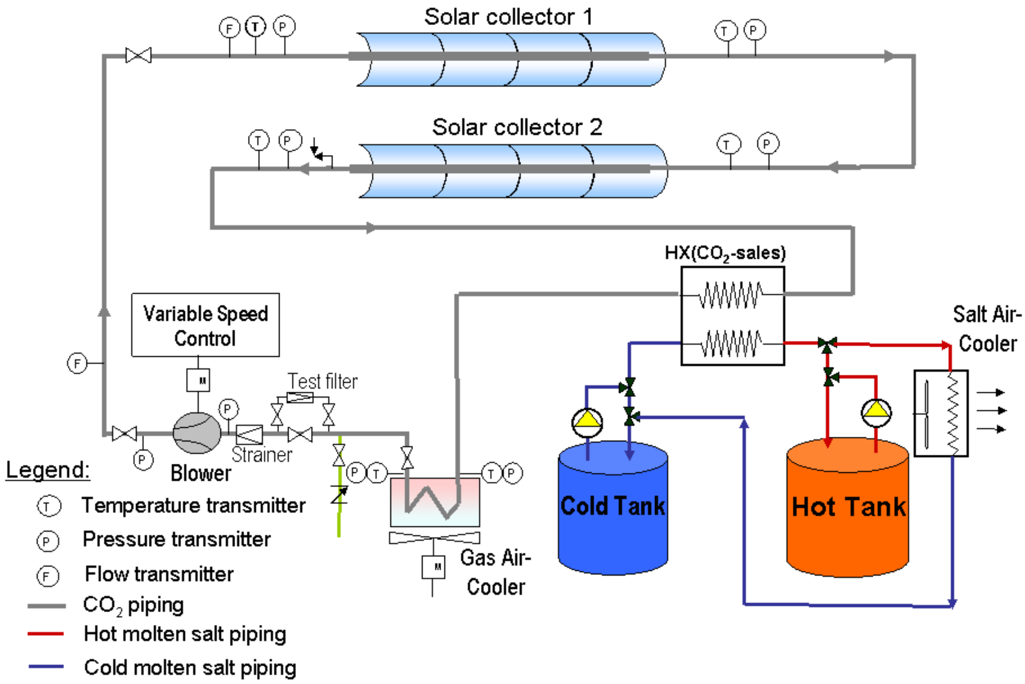


Figure 2.9. Simplified system diagram of the innovative fluids test loop connected to a molten-salt thermal storage system.

The molten-salt thermal storage system basically consists of (Fig. 2.9):

- 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-kWth 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 eigth 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-m3 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 300ºC

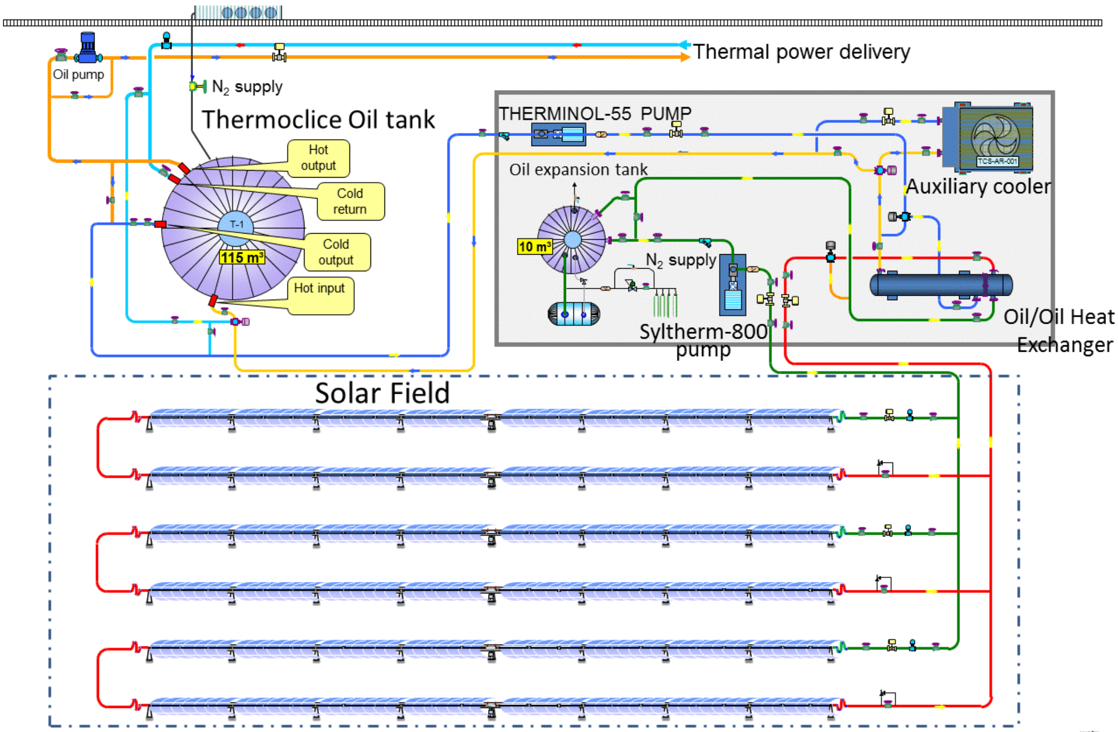


Figure 2.10. Diagram of the TCP-100 2.3-MWth parabolic-trough facility

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 PTC (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 70ºC 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

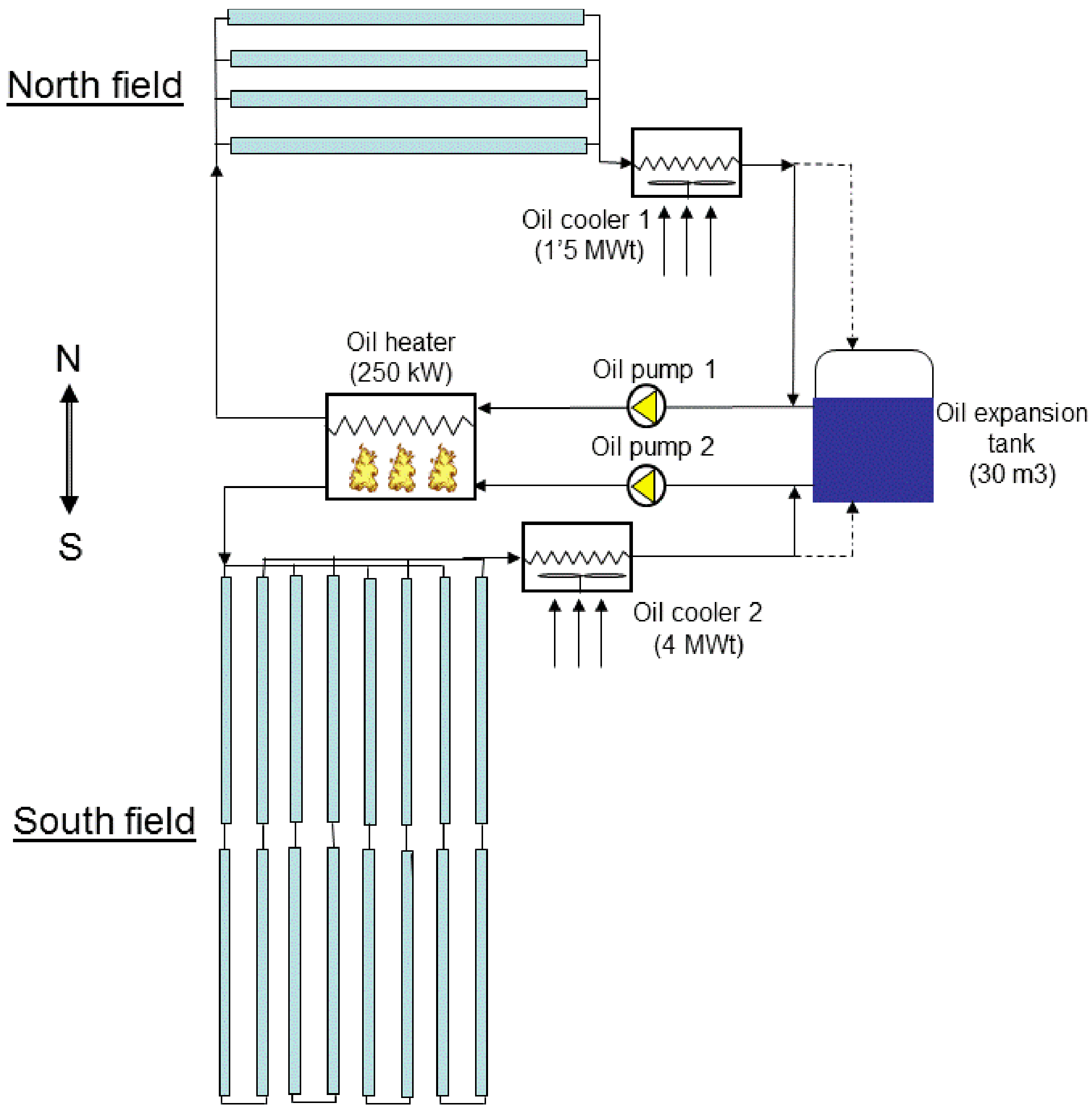


Figure 2.11. Simplified scheme of the PTTL facility

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 1,433 m^2, distributed among 1,200 facets mounted in 25 parallel rows spanning the length of the loop. This collector loop is designed for direct steam generation at a maximum pressure of 100 bar and maximum temperature of 450ºC.

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.


Figure 2.12. Photo of the linear Fresnel concentrator erected at the PSA.

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.

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 ±0.3ºC in a 100 to 200ºC 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 2.13. 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 2.14. Side view of Kontas test bench and the heating cooling unit.

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 (Fig. 2.15) is a 7.5 m diameter parabolic dish, able to collect up to 40 kWth 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 (Fig. 2.16) 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 kWth. The focal distance is 4.1 m and the maximum concentration is 16,000 suns at the focus.

These concentrators can be used for any experiment requiring a focus with the characteristics above mentioned (50 kWth maximum and 16,000 suns peak concentration at the focus). The tracking consists in a two-axis azimuth-elevation system.

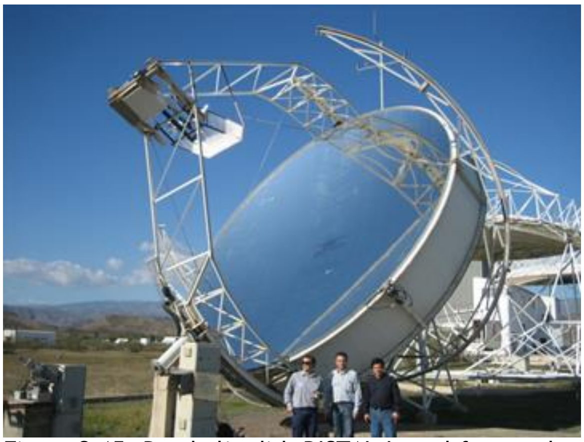


Figure 2.15. Parabolic-dish DISTAL-I used for accelerated materials ageing at PSA.

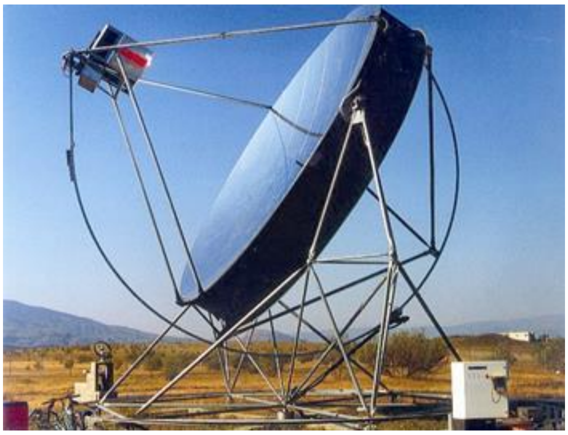


Figure 2.16. View of a parabolic-dish DISTAL- II.

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 2.1.2.5).

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 kWth maximum and a maximum concentration of 16.000 suns at the focus. The tracking system is azimuth-elevation.

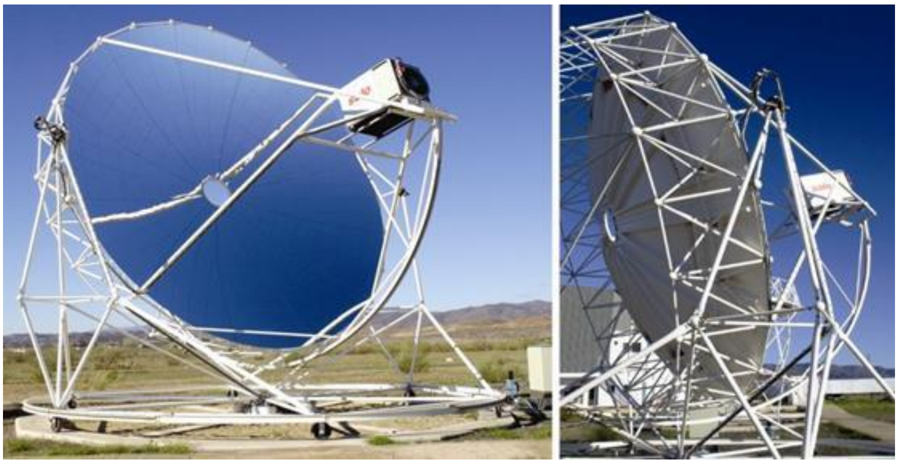


Figure 2.17. Front and back views of the EURODISH

2.1.1.4 The Solar Furnaces at PSA

Solar furnaces reach concentrations of over 10,000 suns, the highest energy levels achievable in a solar concentrating system. Their main field of application is materials testing, either in ambient conditions, controlled atmosphere or vacuum, or 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.

La PSA has three solar furnaces called the SF-60, SF-5 and SF-40. The SF-60 and SF-5 are completely operative, while the SF-40 will be available in 2013.These three furnaces are described below.

SF-60 Solar Furnace

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 28 flat facets with a total surface of 120 m^2 and 92% reflectivity. Its focal distance is 7.45 m.

Figure 2.18. Exterior view of the PSA SF-60 in operation.

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.

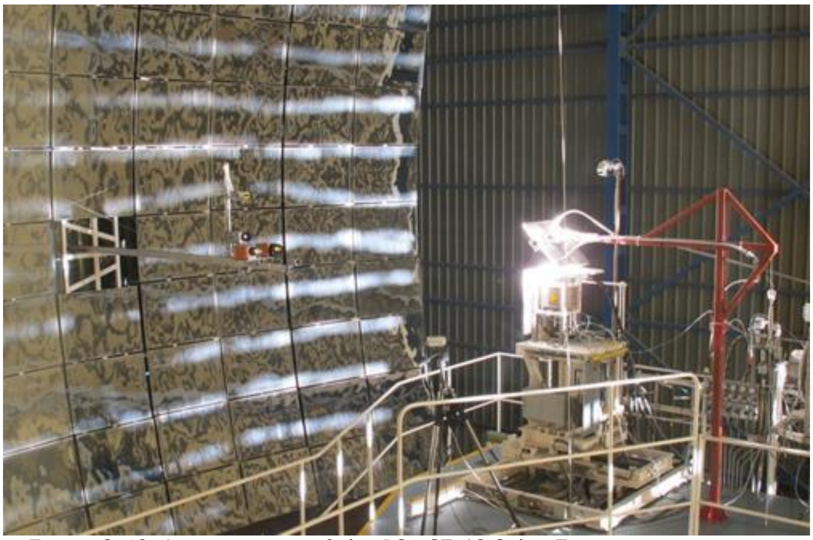


Figure 2.19. Interior view of the PSA SF-60 Solar Furnace in operation.

The shutter (attenuator) 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.

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 of 5000 suns and has a power of 40 kW, its focus size is 12 cm diameter and rim angle a= 50.3°. Its optical axis is horizontal and it is of the “on-axis” type that is parabolic concentrator, focus and heliostat are aligned on the optical axis of the parabola.

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

The focus of the SF40 is arranged on the vertical plane. In order to work on the horizontal plane, the beam rays incident in focus is rotated 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, so that the specimens are not oxidized during tests.

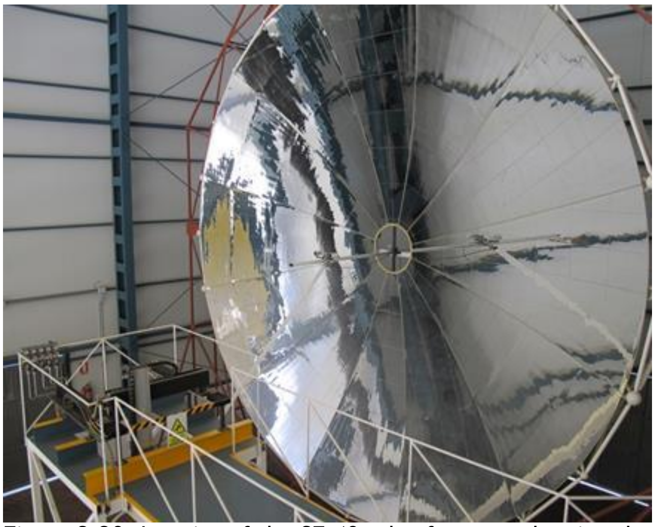


Figure 2.20. Interior of the SF-40 solar furnace, showing the parabolic concentrator.

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 center of the base of the tower there is a 100 m^2 flat heliostat, whose center 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 2.21. 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 2.22. 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 2.23. 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 1750ºC
b) Tests under pure Oxygen atmosphere
c) Tests under H_2O steam with other gases simultaneously.
d) Tests under corrosive atmosphere up to 1,000ºC

- 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 600ºC), 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 (Fig. 2.24a).
- Nicolet Magna IR Spectrophotometer (Fig. 2.24b).
- *Portable Optosol absorber characterization equipment*: This equipment measures solar absorptance and thermal emittance of selective absorbers at 70ºC, both on flat substrates and absorber tubes. The device for measuring absorptance has an integrating sphere with two detectors (Fig. 2.22c). For measuring emissivity, it has a semi-cylindrical tunnel which emits infrared radiation at 70ºC (Fig. 2.24e).
- QUV weathering chamber, Q-PANEL, for accelerated ageing tests (Fig. 2.24d).
- BROOKFIELD LVDV-I+ Viscometer.
- KSV CAM200 goniometer for measuring contact angles (Fig. 2.24f).
- Kilns. There are three kilns for thermal treatment:
  - 120x100x300 mm kiln with a maximal temperature of 1200ºC.

- Controlled atmosphere kiln with a maximal temperature of 800ºC.
- 500x400x600 mm forced convection kiln with a maximal temperature of 550ºC.

Figure 2.24. Advanced optical coatings laboratories equipment.

2.1.2.3 Solar reflector durability analysis and optical characterization labs

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 2 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:

- 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 S2R2, 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 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. 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 +120ºC), 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 50ºC (450L).
- Erichsen 608/1000L salt spray chamber with temperatures from 10 to 50ºC.
- ATLAS UV-Test radiation chamber where UV light (with a peak at 340 nm), condensation and temperature can be applied.
- Hönle UVA Cube Ultraviolet radiation chamber.
- KÖHLER HK300M acid rain chamber, 300 L and temperatures up to 70ºC and humidity up to 100%, to apply the Kesternich test.
- SC100 Machu test bath, with a solution of HCl.

- Vöstch VCC3 0034 weathering chamber to test the material resistance against corrosive gasses (335L).
- 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 30ºm/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 analyze the possible detachment of the paint layers.
- Several devices for application of thermal cycles specially designed at the PSA.


Figure 2.25. PSA solar reflector optical characterization lab (left) and durability analysis lab (right)

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 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).

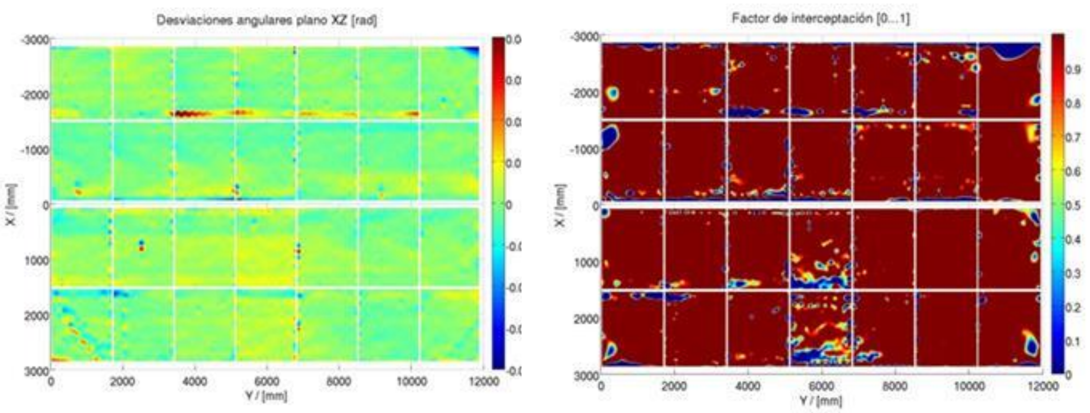


Figure 2.26. Angular deviations (left) and intercept factor (right) of a parabolic-trough collector module analysed by photogrammetry

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).

2.1.2.5 ACCELERATED AGEING AND DURABILITY OF MATERIALS LAB

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 (200ºC to 1200ºC 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 (Fig. 2.27) that can reach fluxes of up to 1400 kW/m^2

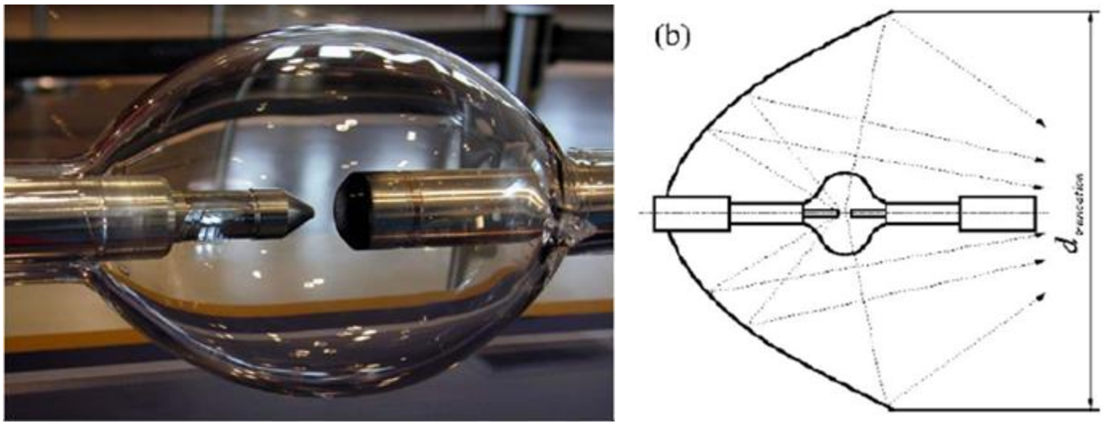


Figure 2.27. Xenon lamp used in the solar Simulator and configuration of the lamp and concentrator

2.1.2.6 Porous Characterization Lab

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) <u>Volumetric test-bed</u>

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.

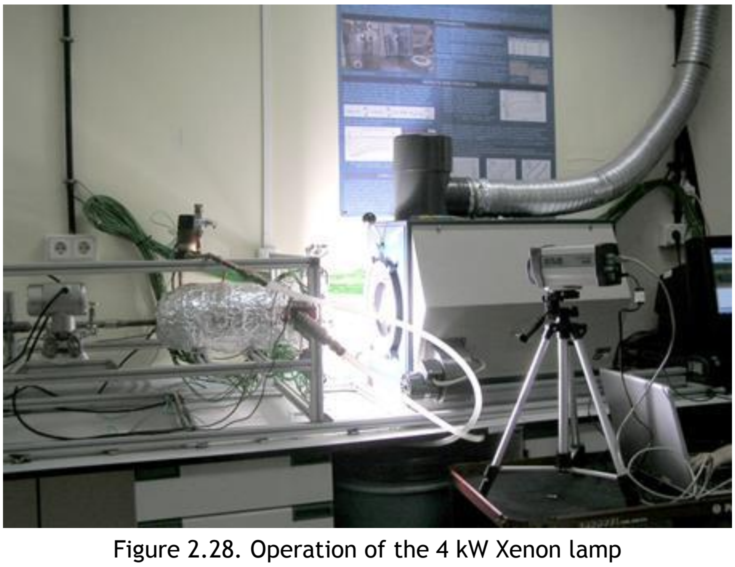


Figure 2.28. Operation of the 4 kW Xenon lamp

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 €/kWth) 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 (Fig. 2.29) and dynamic (Fig. 2.30) thermal characterization of porous beds.

Figure 2.29. Front view of the lab-scale regenerative storage system in static arrangement.

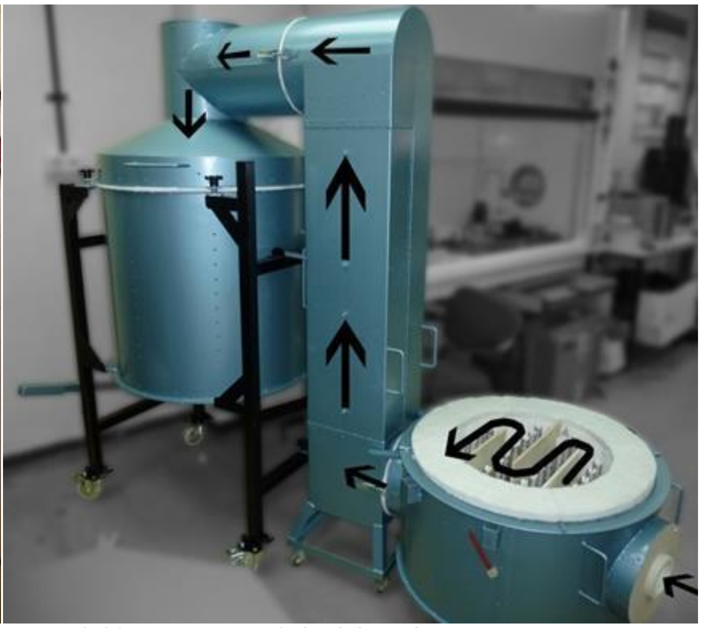


Figure 2.30 Front view of the lab-scale regenerative storage system in dynamic arrangement.

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 (maximum temperature limited by the resistor is 1000ºC) 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.

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.

2.1.2.7 Solar Hydrogen Evaluation Lab

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 2.31.

Figure 2.31. Solar Simulation Loop for evaluation of hydrogen production processes

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 (1600ºC) and water vapour kiln up to 1200 ºC.

2.1.2.8 PSA Radiometry Lab

The PSA Radiometry Lab came out of the need to verify measurement of highly important radiometric magnitudes associated with solar concentration. These magnitudes are solar irradiance ("flux" in the jargon of solar concentration) and surface temperature of materials (detection by IR).

At the PSA different systems are used to measure high solar irradiances on large surfaces. The basic element in these systems is the radiometer, whose measurement of the power of solar radiation incident on the solar receiver aperture depends on its proper use. The measurement of this magnitude is fundamental for determining the efficiency of receiver prototypes evaluated at the PSA and for defining the design of future central receiver solar power plants.

A black body can be used as a source of thermal radiation for reference and calibration of IR devices (infrared cameras and pyrometers) that use thermal radiation as the means of determining the temperature of a certain surface.

Figure 2.32. View of the PSA Radiometry laboratory.

The Radiometry Laboratory has three black bodies as references for calibrating IR sensors for measuring temperature with guaranteed traceability between 0 and 1700ºC. The MIKRON 330 black body is a cylindrical cavity which can provide any temperature from 300 to 1700ºC accurate to ±0.25% and a resolution of 1ºC. 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 flay cavity and can provide any temperature from 0 to 150ºC accurate to ± 0.2ºC and a resolution of 0.1ºC. 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.

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 kWth, 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 40ºC with a maximum operating temperature of 70ºC 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 is composed of 60 stationary flat plate solar collectors (Wagner LBM 10HTF) with a total aperture area of 606 m^2 arranged in four loops (two rows connected in series per loop with 7 collectors in parallel per row) and an additional loop with 4 collectors connected in parallel. The solar field is 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.

Figure 2.33. 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)

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.

2.2.2 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 ºC 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 2.34. 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)

2.2.3 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 2.35. 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.

2.2.4 Low temperature Solar Thermal Desalination applications facility

The installation consists of a test-bed for evaluating solar thermal desalination applications. It comprises a 20 m^2 solar field of flat-plate collectors (Solaris CP1 Nova, by Solaris, Spain) with a thermal heat storage (1500 litres), connected to a distribution system which enables simultaneous connection of several units. The thermal heat storage allows for a stationary heat supply to the applications connected to the test-bed but can also be bypassed 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 kWth, and it supplies hot water with temperature up to about 90°C.

Figure 2.36. 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 kWth) 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 operates with membrane distillation modules, and has a wide range of different commercial and pre-commercial prototypes from all manufacturers. The list of membrane distillation modules that have been evaluated or are under evaluation is:

1. Plate and frame AGMD commercial modules from Scarab (total membrane area 2.8 m^2).
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).
3. Spiral-wound LGMD commercial modules Oryx 150 from Solar Spring (10 m^2).
4. Two spiral-wound AGMD modules from Aquastill with membranes area of 7 m^2 and 24 m^2 each.
5. 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).

2.2.5 Bench-scale Unit for testing 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 2.37. Laboratory unit for testing membranes on vacuum MD

2.2.6 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 that 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 ºC 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 ºC) 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.

Figure 2.38. Laboratory unit for testing membranes on isobaric MD

2.2.7 Pilot plant for studying combinations of forward osmosis and reverse osmosis

The plant has three different units that can be coupled in different ways between them: (i) a forward osmosis; (ii) reverse osmosis; (iii) microfiltration.

The forward osmosis (FO) unit uses a 4” spiral-wound Cellulose Triacetate (CTA) membrane with eleven membrane leaves of 1.5 m^2 surface each, supplied by HTI. The nominal flow rate is 3.6 m^3/h.

The reverse osmosis (RO) unit has 4 vessels that can be connected in series or in parallel, each of which hosting 4 membranes. The nominal flow rate is 3 m^3/h, and the pumping system is able to work at different pressures up to a maximum of 80 bar. The unit is designed so that SWRO, BWRO or NF membranes can be used.

Finally, there is a MF unit with 3 m^3/h nominal flow rate.

The installation is completely monitored with pressure sensors, conductivity and flow-meters, and is designed in a flexible way regarding the interconnection of the units, so that FO can be used as a pre-treatment for RO, or NF can be used in combination with FO, and even the FO can be used in PRO mode using the pumping system of the RO unit.

Figure 2.39. Test bed for FO-RO combination research

2.3 Experimental Installations for Solar Detoxification and Disinfection of Water

2.3.1 Water Solar Treatment Facilities

The solar detoxification and disinfection facilities consist of several solar CPC (compound parabolic-trough collector) pilot plants, pilot plants for biological treatment, ozonation, and nanofiltration for water treatment, an UV-disinfection system and a test facility for photocatalytic production of hydrogen based on solar energy.

Solar photo-reactors

Regarding the pilot plants employing CPCs, the oldest (1994) consists of three 3 m^2 modules tilted 37º from the horizontal. 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. There are also two twin prototypes (refitted in 2007 and called SOLEX) to facilitate simultaneous experiments under same experimental conditions. Each SOLEX prototype consists of two CPC modules with a total illuminated collector surface of 3.08 m^2, a total volume of 40 L (22 L illuminated). The photo-reactor tube external diameter is 32 mm. This facility can be covered with Plexiglass transparent to solar-UV, allowing to work at higher temperatures for photo-Fenton process (Fig. 2.40). Since 2004 other CPC system (with 50 mm tubes diameter, more suitable for photo-Fenton applications), with a tank and a recirculation pump (75 L), has been 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 (Fig. 2.36(b)) 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. The process is completely automatic and is instrumented with pH, REDOX potential, dissolved oxygen, and temperature sensors. Furthermore, pH and dissolved oxygen are automatically controlled by dose pumps.

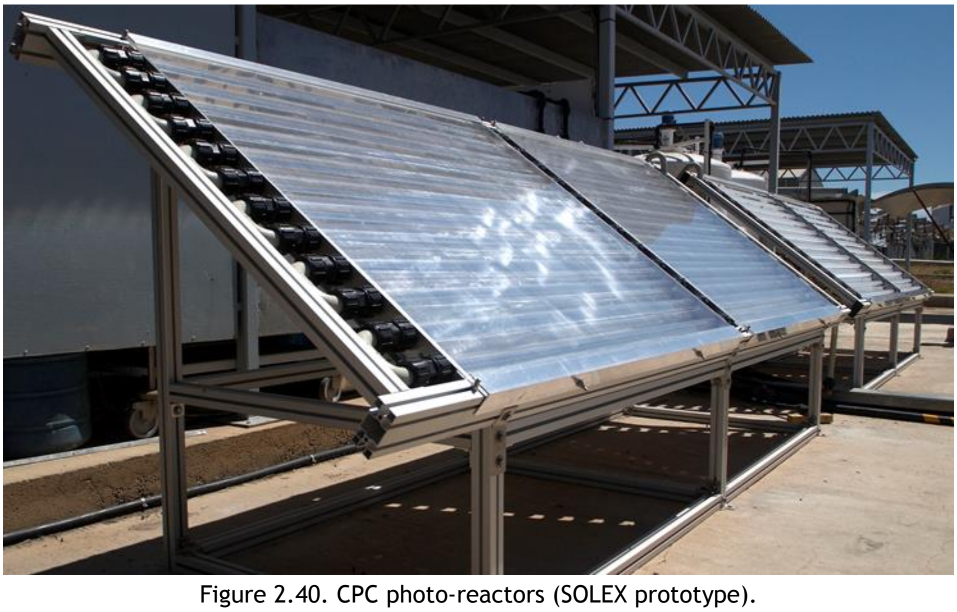


Figure 2.40. CPC photo-reactors (SOLEX prototype).

In addition, there are several prototype CPC photo-reactors for water disinfection applications. One of these systems consists of two 50 mm outer diameter borosilicate-glass tubes installed in the reflector focus and mounted on a fixed platform tilted 37º (local latitude) and connected in series. The illuminated collector surface area is 0.42 m^2. The total volume of the system is 14 L and the illuminated volume is 4.7 L. In November 2008, a photo-reactor for solar disinfection (FITOSOL) was installed. It consists of two components, a CPC solar reactor and a pilot post-treatment plant arranged on an anodized aluminium platform tilted 37º. 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, inserted in the tube and connected to a Crison MULTI44 controller for automatic data acquisition of both parameters. The water post-treatment pilot plant consists of a 100 L tank for separating the TiO_2 from the treated water. A heating and cooling system was designed and installed in this photo-reactor to maintain the water temperature constant between 15 and 45°C. Different air injection points have been also added to photo-reactor to increase the oxygen dissolved in the system as well as several sampling points.

Other solar pilot photo-reactors for solar water disinfection were also setup in 2013 (Fig. 2.41): two CPC photo-reactors (CPC25), for duplicate photocatalytic disinfection experiments (suspended and immobilized TiO_2) and photo-Fenton with total treatment capacity from 7 to 25 L. Each system is made of five borosilicate glass tubes, with a total illuminated surface of 1 m^2, an illuminated volume of 11.25 L and a total volume of 25 L; two CPC (CPC-SODIS) photo-reactors for discontinuous operation. Both static batch systems can treat 25 L of water completely exposed to solar radiation. The reactors have 0.58 m^2 of aperture CPC mirror, a photo-reactor borosilicate glass tube (outer diameter = 20 cm). 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. 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 55°C, several dissolved oxygen measurement points and air injection points to analyse the effects that oxygen injected in the line has on photocatalytic disinfection.

Figure 2.41. General view of several CPC reactors for decontamination and disinfection of water.

Along with these pilot-plant facilities, there are two solar simulators provided with xenon lamps for small-scale water detoxification and disinfection experiments in which radiation intensity and temperature can be modified and monitored.

Additionally, in 2014, as one of the activities 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*) new scientific instrumentation and facilities were acquired for solar water treatment unit activities (SolarNova Project). The solar water detoxification facility, auxiliary systems and piping and instrumentation for the membrane system and ozonation pilot plant were enhanced. Besides, a UVC/H_2O_2 pilot plant was constructed.

Ozonation pilot plant

The ozonation system was modified 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 (Fig. 2.42, left).

Figure 2.42. (left) New contact column reactor for ozonation system. (right) New configuration of the improved Nanofiltration membrane pilot plant.

Nanofiltration pilot plant

The nanofiltration (NF) system was modified 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 45°C, a maximum pressure of 41 bar and a maximum flow rate of 1.4 $m^3 h^{-1}$, whereas operation pH range is 2-11. A third membrane was installed 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 (Fig. 2.42, right).

UVC-H_2O_2 pilot plant

A new ultraviolet pilot plant was designed and acquired to treat and disinfect water for purposes and research and comparison with the solar technologies. This plant consists of three UV-C lamps (max. flow rate 25 $m^3 h^{-1}$, 254 nm peak wavelength, 400 J m^{-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 (Fig. 2.43).

Figure 2.43. New UVC pilot plant. Three medium pressure UV lamps (254 nm) inserted in stainless steel frame (left view). Automatic dosing pumps for automatic control of pH and H_2O_2 addition (right view).

Enhancement of FITOSOL reactor

The 'FITOSOL' CPC photo-reactor prototype was modified. This system has 20 borosilicate glass tubes with a 60 L total treatment capacity and a CPC collector surface of 4.5 m^2. 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 year, a temperature control system was acquired to permit experiments at constant temperature in the range of 20 - 55°C (Fig 2.44).

Figure 2.44. Module for temperature control in a CPC pilot plant for water disinfection.

Solar UVA monitoring equipment

Within the framework of ‘Plan E’ the UV and global solar radiation data storage system of this group has been also updated and improved by the acquisition of two pyranometers (Fig. 2.45), one will measure 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 other will monitor 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}).

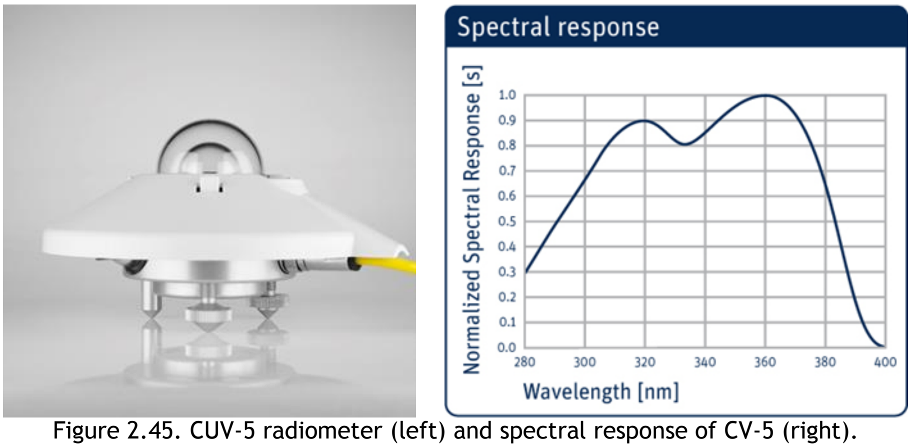


Figure 2.45. CUV-5 radiometer (left) and spectral response of CV-5 (right).

Besides this, a spectral photometer with double channel has been also acquired to evaluate the activity of different photo-catalysts taking into account their spectral response and activity. This new system will permit the evaluation of the incoming solar radiation in very short and specific wavelength ranges where new materials are photo-active but where commercial pyranometers and radiometers cannot measure

(Fig. 2.45 and 2.46). This new equipment (AVANTES) has UVA sensors and filters to measure in the whole spectral range of 200 – 1100 nm.

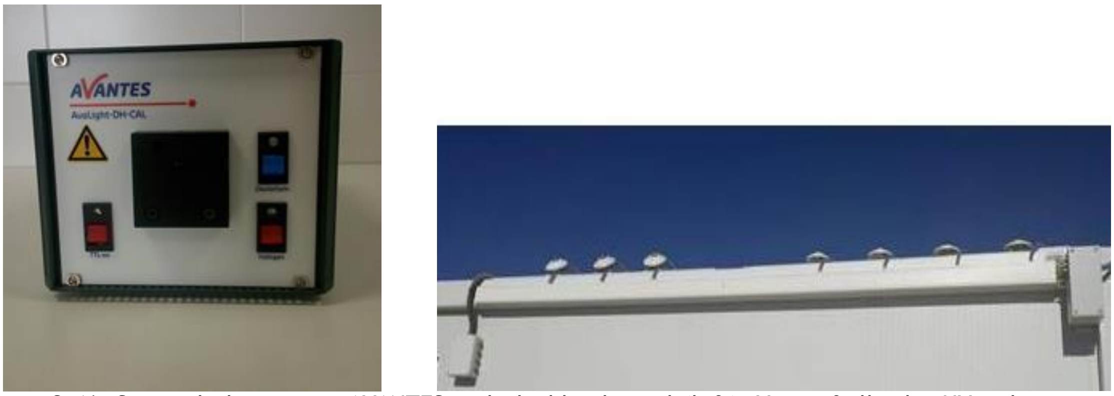


Figure 2.46. Spectral photometer AVANTES with double channel (left). View of all solar UV radiometers (inclined and horizontal setup) used in the Solar Water Treatment Unit (right).

On the other hand, an experimental greenhouse was installed in 2014. This new chamber of cultivation under controlled conditions of 30 m^2 for in-vivo testing of the feasibility of irrigation reuse of treated wastewater located in the DETOX facilities of PSA. The cover is made of polycarbonate of 10 mm to avoid ultraviolet radiation. The camera consists of 4 individual areas of $3{\times}2.5m^2$. Each area is equipped with controlled system of temperature, humidity, irrigation system and aeration (Fig. 2.47).

Figure 2.47. Cultivation chamber for wastewater crops irrigation reuse at PSA facilities.

2.3.2 PSA Water Technologies Laboratory

The laboratory for water analysis and research of PSA consists of 6 rooms along 200 m^2. The main laboratory is 94 m^2. 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. A Jar-Test system was also acquired for the experimental analysis and optimization of physic-chemical pre-treatment processes for water treatment at bench scale.

Chromatography laboratory

This lab (Fig. 2.48) 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) analysers by catalytic combustion at 670°C and a total nitrogen (TN) analyser with autosampler.

Figure 2.48. General view of the chromatography lab at PSA facilities.

Microbiology laboratory

A 27-m^2 microbiology laboratory with biosafety level 2 (Fig 2.49) is equipped with four microbiological laminar flow (type II) cabinets for handling of samples with microorganisms class II, two autoclaves, three incubators, two fluorescence and phase contrast combination optical microscopes with digital camera attachment. Besides, automatic grow media preparer and plaque filler and a filtration ramp with three positions are available.

Figure 2.49. General view of the microbiology lab at PSA facilities.

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, FISH microscope 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. 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. The documentation system permits to detect presence of DNA at different sizes after PCR standard protocol and electrophoretic separation. This technique adds information on modifications of microbial populations in a heterogeneous community, like in activated sludge systems of wastewater treatment plants.

The Scanning Electron Microscope (SEM) room is 11 m^2. For the preparation of microbiological samples and catalysts to be analysed in the SEM, the system is completed with a metal coater and critical point dryer.

A 30-m^2 storeroom with direct access from outside for chemicals and other consumables storage. It is organized on numbered and labelled stainless steel shelving with refrigerators and freezers for samples and standards keeping.

A 17-m^2 office with three workstations where visiting researchers can analyse the data from the experiments carried out at the PSA.

In 2014, the Solar Treatment of Water Research Group Laboratory has acquired new equipment as described below:

- Ultra Pressure Liquid Chromatograph with array diode detector in the UV-Vis (UPLC-DAD) (quaternary pump and automatic injection). This new equipment (Agilent 1260 UPLC) offers ultra-fast analyses of water samples for analytical liquid chromatography results using all types of current and emergent column technologies. It permits to perform gradients of up to 4 different solvents, with pressure up to 600 bar, with a degasser and automatic purge valve integrated into pump module. This equipment has variable volume auto sampler and reduced carryover, thermostated column compartment, selection of detectors at different flow cells to fit application needs regarding flow ranges (nano-scale, micro-scale, standard and preparative applications) and pressures). It has a diode-array detector with high sensitivity and baseline, and variable wavelength detector. (Fig. 2.50).

Figure 2.50. Ultra fast UPLC-DAD analyser

- The equipment so-called 'Fast Prep 24' is a high-speed benchtop homogenizer for lysis of biological samples, needed for further analyses of genetic material samples. It permits simultaneous homogenization of 24 samples in 2ml tubes, 12 samples in 15ml tubes, 48 samples in 2ml tubes or 2 samples in 50ml tubes takes place within 40 seconds. (Fig. 2.51, left).
- A micro-centrifuge has been also acquired in 2014. The centrifugation of small samples is important for many biological applications, such as pelleting nucleic acids or proteins from solution, microfiltration of small aqueous samples or simply to gather those last precious drops of liquid into the bottom of the tube. This equipment was acquired for preparing biological samples for PCR (Polymerase Chain Reaction) analysis (Fig. 2.51, right)

Figure 2.51. Left: ‘Fast prep 24’ biological homogenizer. Right: Micro-centrifuge.

- Homogenizer stomacher 400 Comecta. This equipment will permit food samples blending, stirring and storage is a reproducible way without any risk of cross contamination between samples (Fig. 2.52).

Figure 2.52. Stomacher 400.

- 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, which includes two 1260 Infinity binary pump and a 2D-LC valve, a degasser, an autosampler equipped with a Thermostat module, and a Thermo Column Compartment, where a Proshell 120 EC C18 (2.7 um, 4.6 x 50 mm) column has been installed. The HPLC system is connected to the Triple TOF by a DuoSpray Source combining Turbo Ion Spray and APCI (Atmospheric Pressure Chemical Ionization) modes. A Data Acquisition Workstation is provided including two Dell OptiPlex 9010 Computers and two Dell 23” Monitors, intended for system control/acquisition and data treatment. Specialized software package include Analyst TF 1.6, MultiQuant V.3.0, PeakView, MasterView and MarkerView V1.2.1. (Fig. 2.53).

Figure 2.53. AB SCIEX TripleTOF 5600+ equipment.

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.

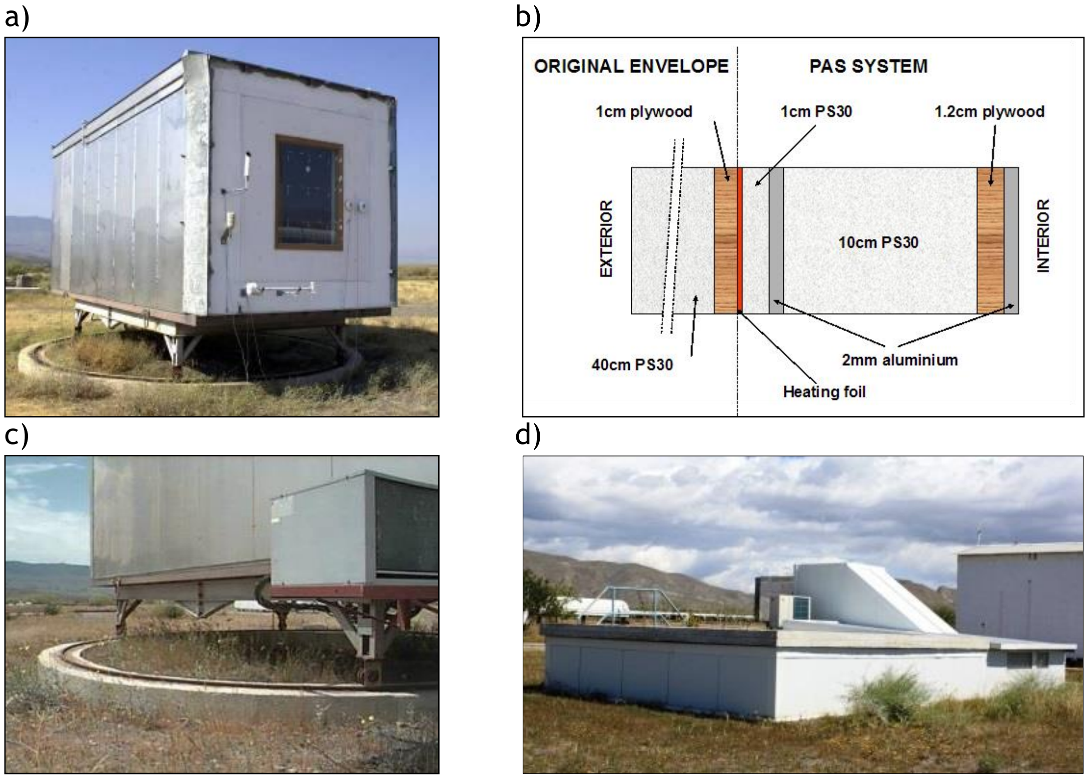


Figure 2.54. (a) CIEMAT's PASLINK test cell, (b) Schematic drawing of the PAS system, (c) Detail of the rotating device, (d) Exterior of the CETeB Test cell.

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.

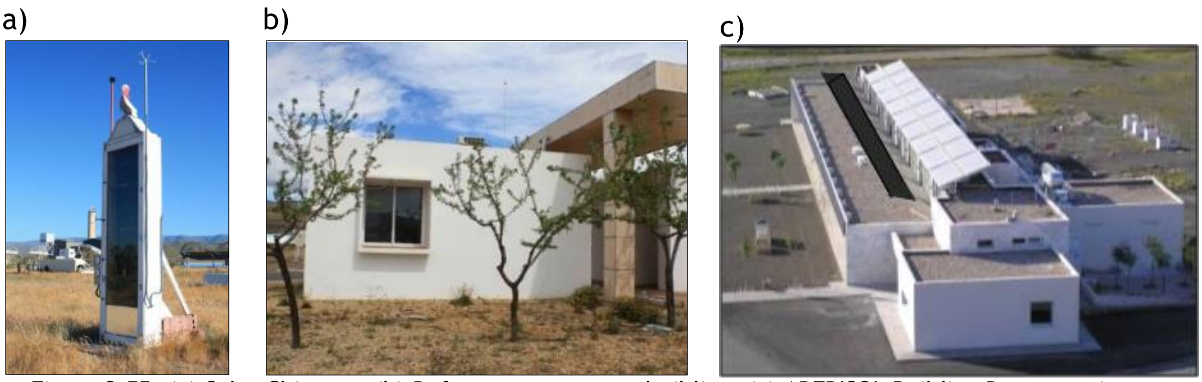


Figure 2.55. (a) Solar Chimney, (b) Reference monozone building, (c) ARFRISOL Building Prototype in use.

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.

3. Solar Concentrating Systems Unit

3.1 Introduction

The main purpose of the Solar Concentrating Systems Unit (USCS in its Spanish acronym) is to promote and contribute to the development of 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 Unit consists of three R&D Groups:

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

In 2014, most of the activities in the USCS Unit have been related to international projects. The consolidation of the changes implemented by the Spanish Government in the legal framework for solar thermal electricity (STE) plants in Spain have put this sector in a critical situation and the priority of the plant owners at present is not the improvement of their plants but the survival in the very discouraging economic environment they have to face now. The limits imposed by the Government to the annual electricity yield of the STE plants make any effort for the innovation or technology improvement unprofitable. This is a quite regrettable situation, because it discourages the Spanish STE sector from investing in R+D activities.

In contrast with the situation in Spain, other countries (e.g., Morocco and South Africa) consider STE plants a promising option for their energy supply and important new projects for big STE plants were launched in 2014. NOOR-2 (200 MWe with parabolic trough technology) and NOOR-3 (150 MWe with central receiver technology) launched in Morocco at the end of 2014 are good examples.

In 2014, the USCS Unit had also participated in outstanding European projects (i.e., SFERA-II, EU-SOLARIS and STAGE-STE), which try to increase the efficiency and competitiveness of the European STE sector. We have also coordinated a thematic network with five Latin American countries (i.e., Mexico, Chile, Argentina, Colombia and Brazil) to strength our collaboration with them in the field of solar thermal concentrating technologies. This network will be the seed of future collaborations with R+D groups from these countries.

The sections below summarize the more important activities and results achieved in 2014 within the three R&D Groups of the USCS Unit.

3.2 Medium Concentration Group.

3.2.1 Introduction

During 2014 the Medium Concentration Group (MCG) has worked in the field of development, testing, and evaluation of components for line-focusing solar collectors, modeling and simulation of solar power plants with parabolic-trough collectors (PTCs) using different heat transfer fluids and analysis of how to integrate nowcasting systems with simulation models (DNICast project), research on direct steam generation in PTCs (DUKE and GEDIVA projects), and thermal energy storage systems both sensible and latent heat storage concepts (OPTS and REELCOOP projects).

Relevant projects of the MCG in 2014 are summarized below.

a) 

b) 

Figure 3.1. Medium Concentration Group staff working a) at the Plataforma Solar de Almería in Tabernas (Almería) and b) at the CIEMAT Headquarters in Madrid.

3.2.2 Projects

Research and development of optical layers for solar receivers

Participants: CIEMAT-PSA, 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 efficiency of solar thermal electric (STE) technology is strongly linked to the development of materials which improve the collection of energy coming from the sun. In this way, the development of both durable antireflective coatings and stable selective coatings for the receivers represents a big challenge for the technology.

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

Achievements in 2014: A new licence agreement has been signed with the Italian company Soltigua for the commercial exploitation of the AR coatings developed in OCT for parabolic trough collectors and linear Fresnel collectors. Moreover, the AR coatings for low iron soda lime glass have been optimized. A bi-layer system prepared by sol-gel technology with only one heat treatment avoids Na diffusion from the glass and leads to solar transmittance values of 98%.

A two layer selective absorber for solar receivers has been optimized for industrial heat applications, stable in air at 300°C, with a solar absorptance of 0.955 and a thermal emittance at 200°C as low as 0.16. It consists of two layers on AISI 304 or 316 stainless steel produced by sol-gel technology. This preparation method is protected by Spanish and European patent. Two meter long prototypes have been successfully prepared. This absorber is now being evaluated by Soltigua in order to sign a license agreement for commercial exploitation.

Figure 3.2. Selective absorber and borosilicate glass AR coating developed in CIEMAT/PSA

Optical Characterization and Durability Analysis of Solar Reflectors, OPAC

Participants: CIEMAT and DLR

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

Funding agencies: German Federal Ministry for Economic Affairs and Energy (BMWI), European Union Seventh Framework Programme, Abeinsa Energía S.A., ALANOD GmbH & Co. KG and Flabeg GmbH.

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 solar reflectors are investigated under accelerated aging conditions and in several outdoor exposure sites with the goal of establishing lifetime prediction models.

Achievements in 2014: A productive research activity was performed under the framework of the Alumir project, started in 2012 and funded by the BMWI, the German Federal Ministry for Economic Affairs and Energy. Projects partners are DLR, CIEMAT and three aluminium manufacturers from Germany. The goal is to develop new accelerated test standards for aluminium mirrors with protective top coatings that correlate with outdoor tests and allow a proper characterization of the materials. During 2014, an intensive test campaign under artificial aging conditions was performed (both extending the testing time of traditional experiments and applying innovative ones) and degradation mechanisms identified were compared with those obtained in 9 outdoor exposure sites. As a result, some preliminary correlations between indoor and outdoor conditions were found.

Figure 3.3. Aluminum reflector samples exposed in a desert area.

Concerning glass-based reflectors, an extensive accelerated aging test campaign was conducted with mirrors that were also in outdoor operation in Spain and Australia during three years. The degradation of the outdoor exposed mirrors was analysed microscopically and compared to the degradation appearing under accelerated aging. Additionally, several silvered-glass samples from different manufacturers were placed outdoor and exposed to the open air in key sites.

Technical support and services were offered to industry, through specific agreements with several companies to evaluate the optical quality and the durability of their products under several accelerated aging conditions in order to assess and improve their performance.

Optical and Thermal Performance of Parabolic-Trough Collectors and Components

Participants: CIEMAT

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

Funding agencies: CIEMAT, SolarNOVA (Spanish government C.N. ICT-CEPU2009-0002), and international and national private companies.

Background: The deployment of parabolic-trough collector technology for solar thermal electricity (STE) in last years has originated the need of testing components for the PTCs solar fields under outdoor conditions for determining their optical and thermal performance.

Objectives: Outdoor testing for determining the optical and thermal performance of parabolic-trough collectors of large-size and their components, mainly solar receivers. The activity includes the testing and evaluation of this type of solar components in different outdoor test benches.

Achievements in 2014: During 2014, the outdoor testing of solar receivers manufactured by the Chinese company Royal Tech CSP has been initiated. A set of 18 receivers tubes model RTUVR-2014S1404 supplied by this company was installed in one of the PTC collectors of the HTF PTC test loop. The optical performance (combined value of the absorptance and transmittance) and thermal performance (heat loss up to 400°C) of these receivers are under testing.

The construction of a new test facility for testing PTC units (up to 150 m-long), oriented in East-West direction, and complete PTC loops (up to 600 m-long), oriented in North-South direction, was finished in 2014 (León et al., 2014). The commissioning of the BOP of the test bench - so-called PTTL facility (acronym of Parabolic Trough Test Loop) – finished in November 2014. Now, it is ready for being used within the framework of research projects or bilateral contracts with public bodies or industrial partners interested in the research, development and/or testing of components for solar fields working with thermal oil as heat transfer fluid. The heat transfer fluid used in this test facility is silicon oil that works up to 395°C.

Figure 3.4. View of BOP of the PTTL facility at the PSA.

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, Cyl

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

Funding agencies: UE, Seventh Framework Programme. EU-7FP- ENERGY.2013.2.9.2. Grant agreement no: 608623. (Oct. 2013 – Sept 2017).

Background: The efficient operation of CST requires reliable forecasts of the incident irradiance for two main reasons: for better management of the thermodynamic cycle because it becomes possible to dynamically fine tune some of its parameters (flow rate of HTF or the defocusing mirrors) and 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 to assess the influence of improvement in DNI nowcasting on nowcasting of CST and CPV plant output.

Achievements in 2014: A comprehensive report on the requirements of nowcasting systems has been compiled by DLR and CIEMAT, as deliverable D2.1 in March 2014. The report has been presented at the First End User Workshop held in Madrid in May 7th, 2014 and at the DNICast project meeting held in Paris in July 10th and 11th, 2014. The report has the following chapter structure:

- Fundamentals: Includes an overview on todays' CSP and CST systems as well as a definition of important terms like "nowcasting," "temporal resolution," or "spatial resolution."

- How does nowcasting help to operate the plant?: Provides a description of concepts for nowcasting in different technical configurations. Based on these applications, characteristic numbers are defined and used to derive requirements for the nowcasting systems.

- Compilation of requirements for nowcasting systems: Reveals that we can distinguish between applications with moderate accuracy demands (usually dealing with electricity production scheduling over a horizon of one or several days) and applications with high accuracy demands and need for spatial resolution (to improve operation of the plant on a basis of seconds to 60 minutes).

Nowcasting system development should focus on the application with moderate accuracy demands. Even applications with high accuracy demands have to be considered as quite challenging for the nowcasting method development.

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

Participants: Institute of Solar Research - DLR (coordinator), CIEMAT (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: Direct steam generation (DSG) is an alternative process for parabolic-trough power plants, in which the heat transfer fluid and the fluid used in the power block cycle are the same. Within the framework of the DISS project three solar field configurations were studied, i.e. recirculation, once-through and injection modes. The favored 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 three main goals:

- Analysis of the once-through concept under real solar conditions,

- Enabling solar direct steam generation at 500°C at the DISS test facility, and

- Detailed system analysis for comparison of recirculation and once-through mode.

Achievements in 2014: During the first semester of 2014, the test facility was not running as planned due to technical problems with the main feed water pump. Therefore, an extension of the project execution was requested and, once the pump was completely repaired, an intensive test campaign was executed to advance in the testing of new design control structures for the once-through configuration. The control schemes analysed use standard proportional-integral (PI) controllers that are combined with feedforward terms based on reliably measurable disturbances (Feldhoff et al., 2014). In the new control structures implemented, controller gains and integration times are adapted depending on load situation (inlet mass flow and irradiation) from pre-calculated design ('gain scheduling'). This new approach improves the controller performance. Comparing to previous control schemes tested in the DISS test facility, the new control structure is composed of two or three separate controllers in order to reduce reaction times: The outlet temperature is always controlled by an injection flow (controller A). The temperature before this injection is controlled by the inlet mass flow (controller B), which can be improved and robustness added, if a second injection in the evaporation section is used (controller B2). Reliability of these control schemes was checked. The test campaign confirmed the design strategy and the underlying system characteristics. Further improvements are foreseen to be tested in summer of 2015.

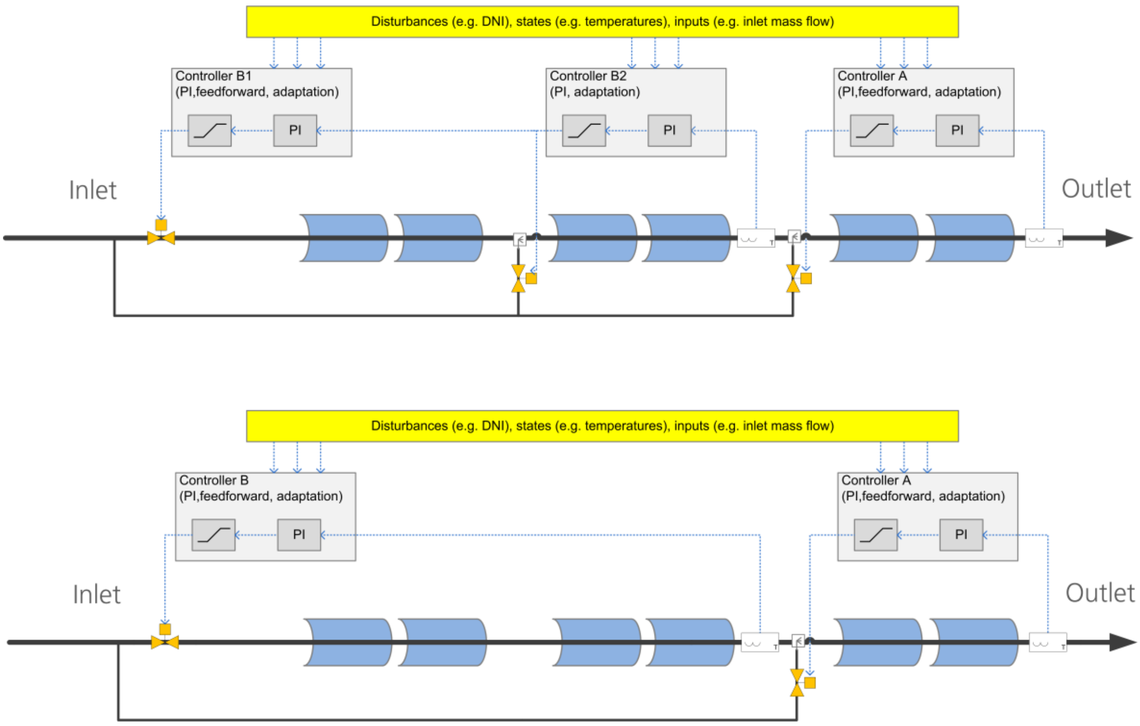


Figure 3.5. Two variants of control loop splitting (Feldhoff et al., 2014).

Thermo-hydraulic studies of concentrated solar systems with parabolic-trough collectors for direct steam generation, GEDIVA

Participants: CIEMAT-PSA

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

Funding agency: Spanish Ministry of Economy and Competitiveness (Proyectos de Investigación Fundamental no Orientada), Ref. ENE2011-24777

Background: Modelling the behaviour of parabolic-trough collectors (PTCs) using water-steam as working fluid represents a particular challenge such as simulating the phase transition of the two-phase flow in the tubes, where different flux patterns can exist and even more, the non-homogenous heat flux (up to 40 kW/m2) in the outer surface.

Objectives: Perform thermo-hydraulics studies of different configurations of solar fields with PTCs using water/steam as working fluid and generating pressurized hot water, saturated or superheated steam. Guidelines including recommendations about appropriate working conditions and configurations of solar fields subject to different process heat demands will be prepared.

Achievements in 2014: The activities defined within this project have been completed this year with the development of a simulation model for direct steam generation of a loop of parabolic-trough collectors with the TRNSYS software tool. This model is the basis for preparing models of complete DSG solar fields and performing yearly simulations to obtain the power output according to the site and TMY.

During this last year of the project, simulations for analysing specific aspects of the thermo-hydraulics of DSG in the receiver of parabolic-trough collectors have been also completed. A commercial computational fluid dynamics (CFD) code, STAR-CCM+, has been used to simulate the steady-state and dynamic behaviour of the DISS solar test facility located at the PSA. Two articles and one PhD thesis contain details of this work (Lobón et al., 2014). On the other hand, a 3D model for single-phase flow has been also developed to study the thermal behaviour of the solid parts of receivers in PTCs. For the fluid domain a unidimensional approximation has been applied. The whole code is developed from the elemental (PDEs) governing equations and is implemented in MatLab® (Serrano-Aguilera et al., 2014).

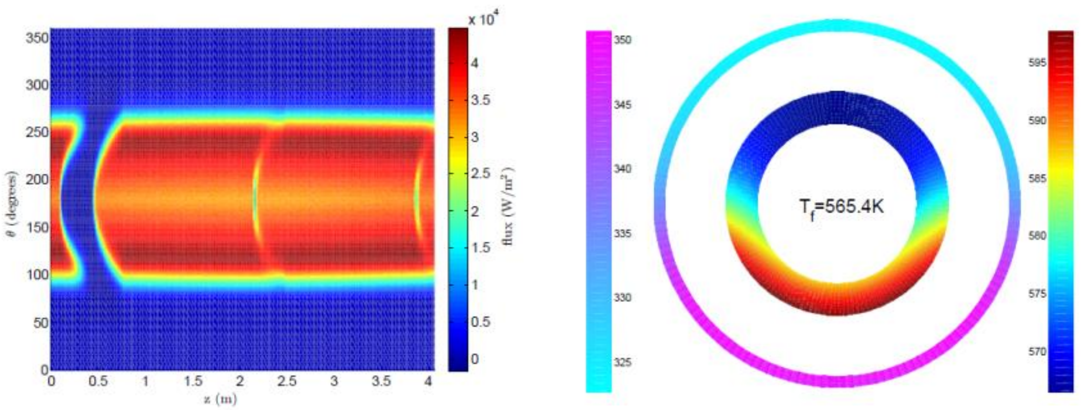


Figure 3.6 View of flux distribution on the steel absorber provided by the optical model (left) and temperature distribution at the receiver outlet section (glass envelope and steel absorber) for specific irradiation and superheated steam conditions in the receiver tube of a PTC (right).

OPtimization of a Thermal energy Storage system with integrated steam generator, OPTS

Participants: ENEA (leader), CIEMAT, CEA, CNRS, Fraunhofer, Weizmann, CREF-CyI, Ansaldo, ACS-COBRA, LNEG and TKT

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

Funding agency: FP7-ENERGY-2011-1

Background: Reducing cost of the storage system is a priority within the CSP community since it can contribute up to 20% of the total CSP plant cost and has a great impact on O&M cost. New improvements, either by technological breakthroughs or by improving current technologies, are required.

Objectives: Development of a new Thermal Energy Storage up to demonstration level consisting of a single tank using stratifying molten salts at 550°C maximum temperature and integrating the Steam Generator (SG) feeding the turbine. The SG can be either positioned directly into the tank or as an external shell-and-tube once-through SG.

Achievements in 2014: The Components test device with molten salt at high temperature and pressure (Rodríguez-García et al., 2014) has been used to test two different valves with special packaging. The results of the tests have helped to check the proper functioning of the valves with molten salt at maximum operation temperature, checking their sealing and packing –including verification of the absence of cold spots in the packing-.

Correlations for estimating heat transfer between molten salts and the steam generator have been obtained by modelling the 300 kWth molten salt prototype located at ENEA centre in Casaccia with commercial computational fluid dynamic (CFD) software. After validating the physical model by experimental data, local heat transfer coefficients of molten salts have been calculated and from here a correlation has been proposed as function of dimensionless numbers.

Figure 3.7. Testing device with molten salt filling oven.

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

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

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

Funding agency: FP7-ENERGY-ENERGY.2013.2.9.1

Background: REELCOOP was born to develop renewable electricity generation technologies and promoting cooperation between EU Partner Countries and Mediterranean Partner Countries, in order to change the facts that today still 1.2 billion people (17%) live without electricity, with 2/3 in rural areas of Africa and Asia; since 1990 the progress has been modest, and to achieve "electricity for everyone" by 2030, the expansion rate has to double; in developed countries electricity demand is higher than supply and prices are increasing at high rates; and only 18% of the electricity comes from renewable sources (20% in EU).

Objectives: Three prototypes for renewables are going to be developed, constructed and tested:

- 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 (Krüger et al., 2014).

A special effort will be done to transfer and dissemination regarding the developed technologies. Cooperation between EU and Mediterranean Countries will be promoted also by the organisation of Workshops on Renewable Electricity technologies (4, one every year) open to junior researchers and outside public.

Achievements in 2014: The main contribution of CIEMAT-PSA is the development of the, already patented, own design of thermal storage for latent heat with low-thermal conductivity phase change materials. With a special geometry where the heat transfer fluid (steam or saturated water) and phase change material (PCM) are located in spiral channels, the heat transfer is expected to be good enough, in spite of the low thermal conductivity of the PCM, due to the large heat exchange area and the small distance between PCM and HTF.

Since the ORC engine to be coupled with can operate in the temperature range 130°C-170°C a deep research on available PCMs has been done. Eight PCMs referred in the literature have been considered and tested. Surprisingly, most of them have to be discarded as storage materials for latent storage for this range of temperature due to hazardous gas emissions, degradation, supercooling or/and corrosion issues. Manufacturing a spiral channels geometry equipment has become a quite challenging aspect since a specific tool to shape the channels from coils of sheet steel is required.

In the first REELCOOP Workshop, "State-of-the art on Renewable Electricity Generation", (Rabat, Morocco), CIEMAT-PSA contributed with the lecture on Concentrated Solar Power.

3.3 High Concentration Group.

3.3.1 Introduction

Activity of High Concentration Group (HCG) in 2014 framed on financed projects has been focused on the finishing of SOLGEMAC project activities and the solar testing of the HF-ISO project. Special importance has the beginning of two horizontal projects: SFERA-II and STAGE-STE where HC Group is involved in the joint research activities devoted to development of methodologies for thermal characterization of materials at high temperatures, for flux measurement on commercial tower power plants, and development of cheaper technology components (i.e. heliostats).

Other important role of the HC Group on the industrial sector has been the testing of central receiver system components developed by both, national and foreign companies. Several heliostats prototypes have been tested at PSA facilities during 2014, thus supporting companies on the product development.


Figure 3.8. High Concentration Group staff working at the Plataforma Solar de Almería (left) and CIEMAT-Madrid (right).

3.3.2 Projects

Modular, Efficient and Manageable High Flux Solar Thermal Power Systems, SOLGEMAC

Participants: IMDEA Energía (Coordinator), URJC, CIEMAT-USCS, CIEMAT-DQ, INTA, UAM, TORRESOL Energy Investment; Hynergreen Technologies

Contacts: Mónica Álvarez de Lara Sánchez, monica.alvarezdelara@ciemat.es

Funding agency: Program of R&D activities between research groups of "Comunidad de Madrid", co-funded with the European Social Fund. S2009/ENE-1617

Background: Concentrated Solar Power is focused in the cost reduction by means of increasing efficiencies. In order to identify high-efficient configurations and geometries for the absorbers used as volumetric receivers, lab-scale tests and models for the evaluation of open volumetric receivers are in constant development for electricity generation and thermochemical process.

Objectives: To establish the knowledge for modular, efficient and manageable concentrated solar energy systems, dish-stirling and multitower solar systems for urban areas, by getting higher efficiencies for volumetric receivers and reactors at ultra-high solar fluxes/temperatures.

Achievements in 2014: Ciemat HCG was the coordinator of the task named "Solar receivers/reactors for high fluxes and high temperatures", where homogeneous porosity SiC channels and alloy 601 mesh absorbers, as reference, and alloy 310 absorbers with gradual porosity, were evaluated at different test conditions. When comparing the results it is observed that for medium to high incident radiation/air flow ratio, the gradual porosity absorbers present similar or better behaviour than the others.

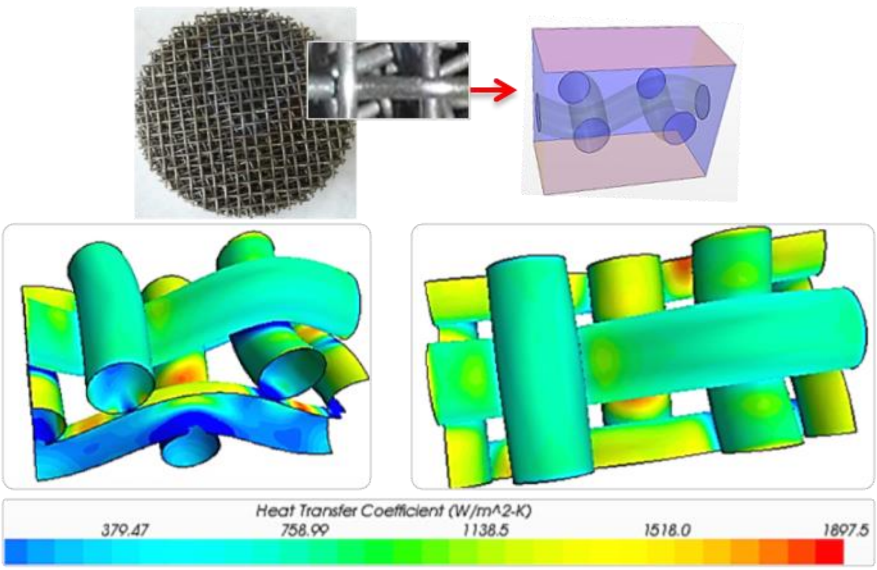


Figure 3.9. Absorber representative structure and model results

In order to complete the characterization and select the better absorbers to optimize the design, pressure drop test of each absorber design were carried out. In addition, fluid dynamic and thermal simulations were carried out in order to be validated with the experimental results and to facilitate the scale-up of the absorbers designs.

Some progresses of the Porous Materials Laboratory were carried out, such as improvements of volumetric absorbers test-bed for the 4kW solar simulator, a new 7kW solar simulator was procured and a new facility for pressure drop measurements between room temperature up to 3000C was set up.

Development of a High Flux Density Insulation System for Solar Receivers, HF-ISO

Participants: DLR, Arnold GmbH (Germany), CIEMAT-PSA (Spain, subcontracted by DLR).

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

Funding: German Federal Ministry for the Environment, Nature, Conservation and Nuclear Safety, Promotional Reference 0325392A.

Background: In the EU-project SolHyCo, a solar-hybrid micro-turbine system with a solar tube receiver for pressurized air was built and tested. During the tests, the receiver had excessive heat losses. Primary reason was the poorly designed insulation cavity of the receiver, showing gaps due to the thermal expansion of the material.

Objectives: The principal goal of the HF-ISO project was the design, construction, test, and evaluation of an improved insulation cavity for the SolHyCo receiver. Solar powered tests should be done between 500 and 800°C air outlet temperature. Total operation time should exceed 100 hours.

Achievements in 2014: After having finished 11 non-solar tests at the end of 2013, the planned campaign with concentrated solar power was performed from January to March 2014. It consisted of 28 tests, 22 of them with concentrated solar radiation (fig. 3.10) and the other 6 with the aperture closed by a cover to determine the thermal properties of the new insulation. Main task of PSA-Ciemat was the operation of the heliostat field, support for the receiver operation, and the initial analysis and statistical evaluation of the obtained data. The receiver outlet air temperature was increased stepwise in 13 solar and 3 non-solar test days from 400°C on beginning of January up to 800°C in the middle of February. Then, the long term behaviour was tested in another 9 solar and 3 non-solar tests until end of March. The total of 112 hours of solar operation time with an air outlet temperature above around 400°C clearly exceeded the envisaged 100 hours. However, the detailed analysis of the data and the insulation material showed that the particular conditions of solar applications like inhomogeneous and fluctuating load led to an intolerable degradation of the chosen materials. Further research is needed.

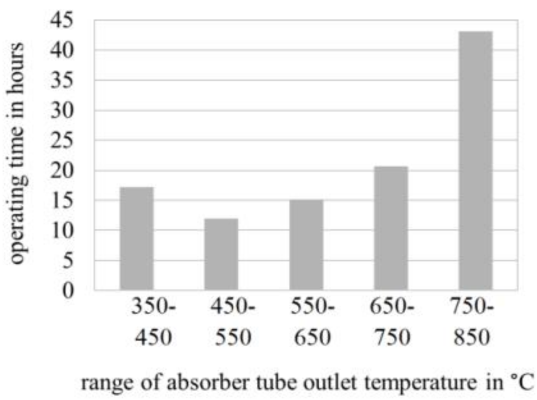


Figure 3.10. Operation hours vs. temperature.

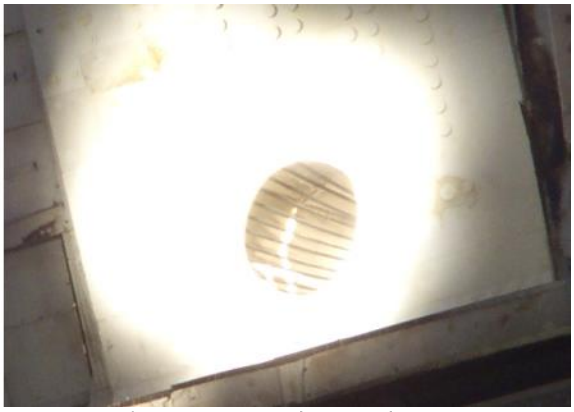


Figure 3.11. Receiver during solar operation.

Optical and tracking performance of heliostats and heliostats components

Participants: CIEMAT-PSA

Contacts: Rafael Monterreal, rafael.monterreal@psa.es
Raúl Enrique, raul.enrique@psa.es

Funding: 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 PSA activity, CIEMAT has been developing testing procedures for characterizing heliostats performance.

Objectives: To completely characterize heliostat prototypes performance: Optical (focal distance, canting, normal vector deviations from the model), energy (total power, flux mapping) and tracking (low and high frequency effects, control deviation, wind influence) performance.

Achievements in 2014: This activity has required an additional effort from the HCG staff in 2013 due to the interest of the industrial sector to develop new heliostat prototypes that increase performance, reducing component and on-site deployment costs at the same time. Three different heliostat prototypes have been tested during 2014 under real operating conditions at the PSA. The complete testing includes optical performance, described as the optical error (in mrad); as well as testing of the control of the heliostat, the tracking mechanisms and behaviour under wind loads.

Connecting with this activity, a proposal for standardization of heliostats performance tests has been prepared and is ready to share with the I+D centres who participate in the different standardization groups (AENOR, SOLARPACES, IEC).

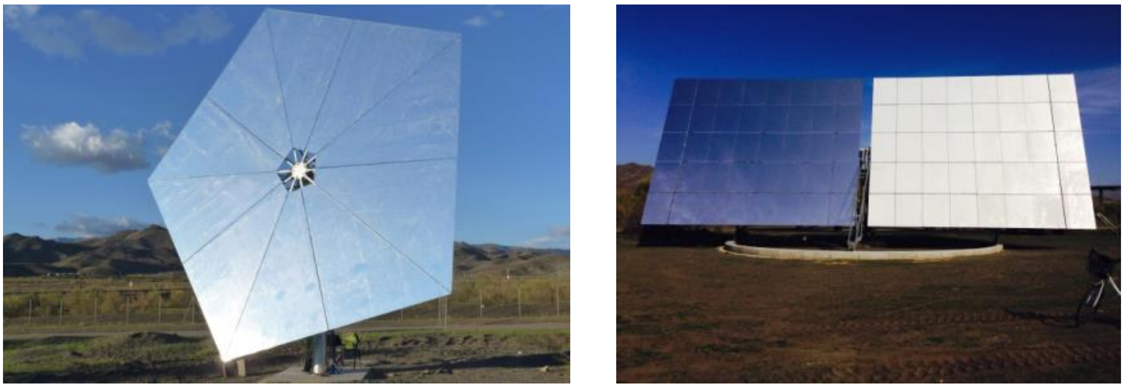


Figure 3.12. Two heliostats prototypes tested along 2014

Radiometry Laboratory Activities

Participants: CIEMAT

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

Funding agency: CIEMAT, European Commission (FP7-INFRASTRUCTURES-2008-1) through the SFERA II Project

Background: The Plataforma Solar de Almeria (PSA) Radiometry Laboratory arose out of the need to verify measurements of important radiometric magnitudes associated with solar concentration. These magnitudes are the solar irradiance ("flux" in the solar concentration jargon) and surface temperature of the materials (IR detection). In this sense, we are participating in the European SFERA Project within the "Flux and Temperature" activity to define flux and temperature measurement standards. We are also undertaking other matters related to radiometry such as atmospheric attenuation of solar radiation, flux measurement in commercial Solar Power Plants, emittance determination, spectral reflectance and transmittance determination (300-900nm), etc.

Objectives: Testing at the PSA requires measurement of high temperatures (>1000ºC) on the surface of materials. In some cases, quartz windows are even necessary to be able to work in an inert atmosphere to prevent rapid oxidation of the materials. The quartz window allows most of the solar radiation to go through, but keeps most of the infrared spectrum emitted by the hot surfaces from getting out in the opposite direction. The use of thermocouples is the method most commonly used even though it is well known that contact methods are not suitable for measuring surface temperatures. Therefore, infrared detectors are required (non-contact measurement) that allow the radiation emitted by the hot surface to be distinguished from the solar radiation reflected by the same surface.

Achievements in 2014: A theoretical study of the temperature measurement uncertainty due to solar radiation reflected by the sample when working at 3320 and 4720 nm narrow bands has been performed. An experimental test has been also performed to study the solar blind behaviour by comparison with the IMPAC solar-blind pyrometer, which uses a pass-band filter centered at 1400 nm.

The measurements, using above filters, were taken with an IR camera prototype in the PSA solar furnace during the test. These two filters are solar-blind and their wavelength bands are not in the atmospheric absorption bands. This makes possible to measure temperature even though the camera is used under other ambient conditions than calibration ones because it is not influenced by the atmospheric absorption. The influence of solar radiation is satisfactorily attenuated due to the low reflectance of the PSA solar furnace mirrors above 2800 nm. This study predicts that the distortion of the reflected solar radiation on temperature measurement decreases as the temperature of the sample increases. The theoretical study also predicts that the temperature thresholds are reduced when the surface reflectance decreases.

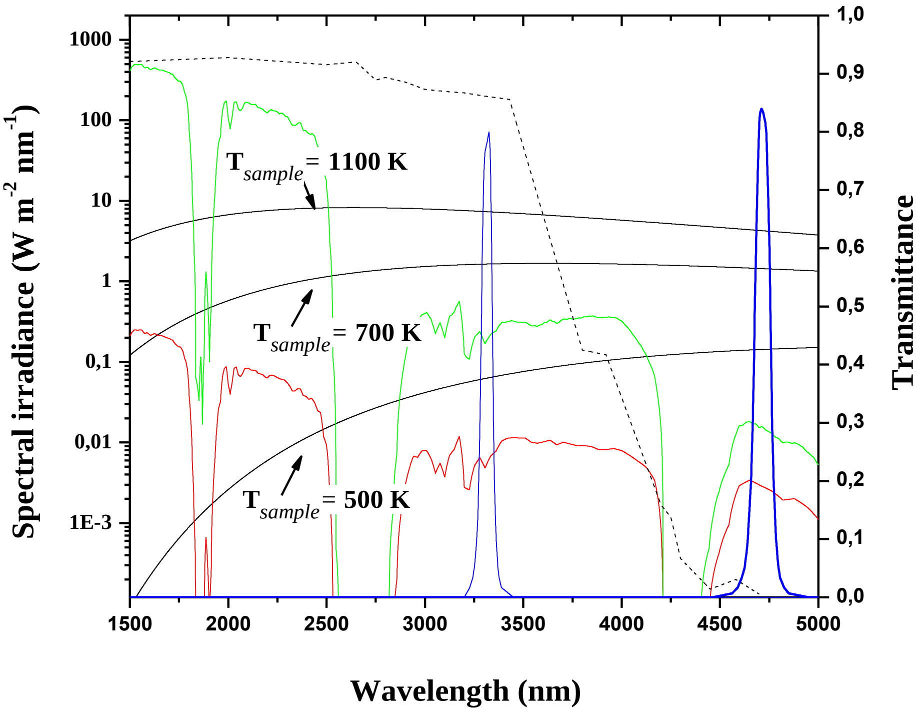


Figure 3.13. Solar spectrum based on a MODTRAN simulation (red line) and solar spectrum reflected by an opaque surface with a reflectance of 0.60 in the PSA solar furnace according to the concentration factor 3034X (green line), thermal irradiance at several temperatures of samples with an emittance of 0.40 (black lines), transmittances of band-pass filters at 3320 nm and 4720 nm (blue lines), and quartz transmittance (dotted line).

Porous Materials Laboratory Activities

Participants: CIEMAT-PSA

Contacts: Antonio Ávila, antonio.avila@ciemat.es

Funding agency: CIEMAT

Background: Since 2010, activities of CIEMAT-PSA concerning volumetric receivers and porous storage media are integrated, at laboratory level, in the facility sited on the CIEMAT headquarters in Madrid. The laboratory is prepared for the evaluation of volumetric absorbers prototypes, the characterization of filler materials for their use as sensible heat storage and the measurement of the pressure drop at different working conditions (air mass flow-rate and air temperature).

Objectives: To improve the knowledge about CSP working with atmospheric air as heat transfer fluid.

Achievements in 2014: During 2014 period “porous material laboratory” facilities were involved mainly in SOLGEMAC project and nowadays in the ALCCONES project. The main advances done were the evaluation of gradual porosity absorbers for its use in volumetric receivers. Moreover, the volumetric absorber test bed was adapted to measure the extinction coefficient of several prototypes.

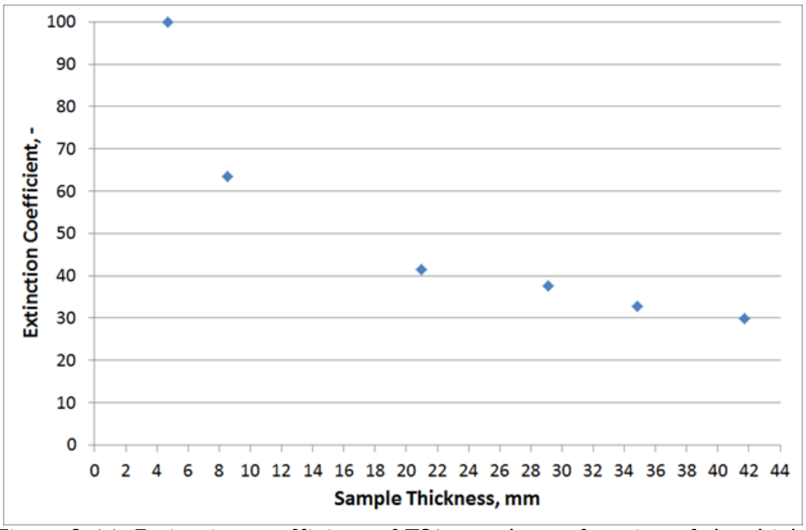


Figure 3.14. Extinction coefficient of TSA samples as function of the thickness

On the other hand, the staff had designed and installed a new controller with an alarm system in the Regenerative thermal storage test-bed. This system allows a precise setting-up, while avoiding any potential danger in the facility.

A new test-bed has been developed for measuring the pressure drop of different porous materials. This facility can measure from volumetric absorber to any porous filler material and any other porous materials. Moreover, it could be run at ambient temperature and up to 300°C air fluid temperature.

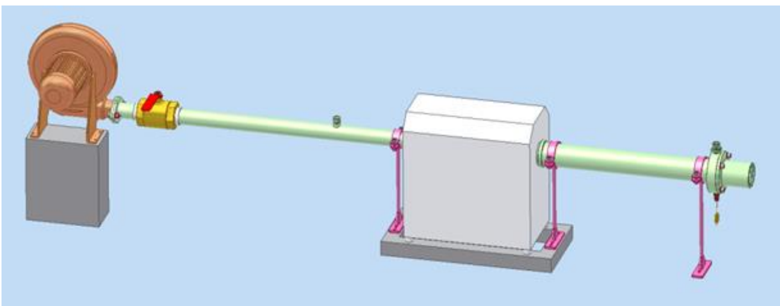


Figure 3.15. Pressure drop facility.

CESA-I facility Refurbishing

Participants: CIEMAT-PSA

Contacts: Raúl Enrique, raul.enrique@psa.es
Jesús Fernández-Reche, jesus.fernandez@psa.es

Funding agency: CIEMAT, SolarNOVA (Spanish government C.N. ICT-CEPU2009-0002).

Background: The CESA-I project, was promoted by the Spanish Ministry of Industry and Energy and inaugurated on May 1983 to demonstrate the feasibility of central receiver solar plants and enable the development of the necessary technology. At present, the CESA-I does not produce electricity, but it is a very flexible facility operate for testing subsystems and components such as heliostats, solar receivers, thermal storage systems, solarized gas turbines, control systems and concentrated high flux solar radiation measurement instrumentation. It is also used for testing some other applications that require high photon concentrations on relatively large surfaces, such as chemical or high temperature processes, materials surface treatments or astrophysics experiments.

Objectives: The main objective in this facility is to perform the required work for the continuous improvement and refurbishment of the facility, in order to have an optimal setup and to be prepared at all levels to accommodate projects to test and validate central receiver technology components.

Achievements in 2014: Along this year, apart from routine maintenance work (i.e. installation of new water cooling circuit up to 82-m tower level, new compressed air circuit, painting of external equipment and installation of new main electric boxes); two main initiatives to improve the optical behaviour of the heliostat field were carried out. The first one consisted of the reposition of 1200 heliostat facets (33% of the field) with new sandwich glass mirror, improving reflectance of the mirrors above 0,94 and also the geometry of the resulting heliostats with the total/partial canting of 136 heliostats. The second one was the implementation and deployment of a new heliostat field control software developed by our I&D PSA staff colleagues. The new control software is expressly designed for the new local control boxes installed last years and makes the operation of the field more effective.


Figure 3.16. New mirror facets installed on the CESA-I heliostat field

3.4 Solar Fuels/Solarisation of Industrial Processes Group

3.4.1 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, but other applications have also been demonstrated, such as production of hydrogen and high temperature solar heat production.

The lines of activity are concentrated 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.

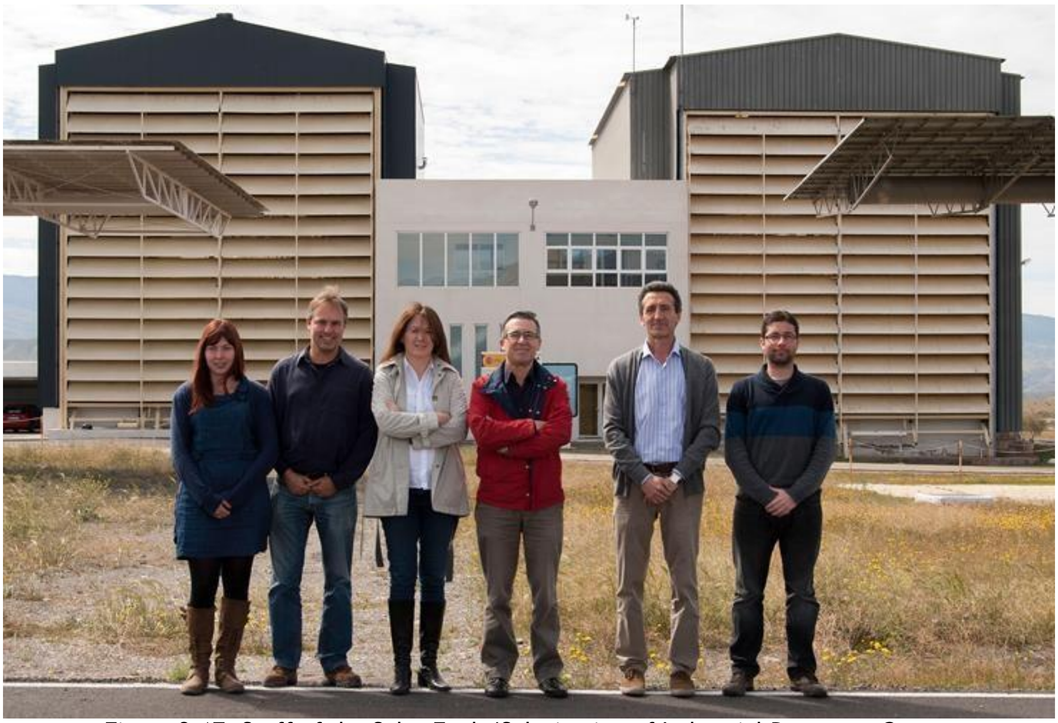


Figure 3.17. Staff of the Solar Fuels/Solarisation of Industrial Processes Group.

3.4.2 Projects

Hydrogen Production by Steam-Gasification of Petcoke, SYNPET

Participants: PDVSA (Venezuela), CIEMAT (E), ETH/PSI (CH)

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

Funding agency: PDVSA, CIEMAT, ETH.

Background: The steam-gasification of petroleum derivatives and residues using concentrated solar radiation is proposed as a viable alternative to solar hydrogen production. PDVSA, CIEMAT and ETH are carrying out a joint project with the goal to develop and test a 500 kW plant for steam gasification of petcoke The engineering design, modelling of the solar reactor and a preliminary experimental campaign were summarized in previous SolarPaces reports. A 500 kW installation has been completed at the SSPS-tower of the Plataforma Solar de Almería during 2009. CIEMAT took over the construction of the whole installation.

Objectives: The project aims at experimental demonstration of the technology in a 500 kWth solar reactor of heavy crude oil solid derivatives, such as petcoke for several applications such as hydrogen production or electricity generation.

Achievements in 2014: Three testing campaigns have been carried out from 2009 to 2012. The objective of these experimental campaigns was to obtain operating experience with the system at power levels approaching the maximum load as well as to solve some structural problems, such as resistance of conical aperture and thermal behaviour of an innovative design of a segmented window, etc.

During this project, a new design of refrigerated quartz window with a diameter of 1400 mm has been developed which represents a technically-challenging for advancing in CRS. The design window would be able to sustain the needed pressure inside of the reactor as well as the high temperatures (up to 1400 ºC). Therefore the inner and especially the outer frames are very solid and equipped with water cooling channels, shown in (Fig. 1). In general, we confirmed a good behaviour of the window configuration during thermal tests up to 1000ºC which were performed introducing air to the receiver.

Final solar chemical testing in 2012 demonstrated the unfeasibility of the present design to operate with steam as carrier gas. Next solar testing will be scheduled for 2015, once identifying possible solutions and determine critical parameters.

Figure 3.18. SYNPET500 reactor receiver window.

A final decision is not already taken. New proposals are being considered based on economic and/or constructive aspects.

Thermochemical HYDROgen production in a SOLar monolithic reactor: construction and operation of a 750 kWth PLANT, HYDROSOL-Plant

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

Contacts: Alfonso Vidal, alfonso.vidal@ciemat.es

Funding agency: European Commission (FCH-JU-2012)

Background: The successful testing and the suitable behaviour of the large-scale reactor in the HYDROSOL series projects and mainly the outcome of the latest FCH-JU co-funded project, HYDROSOL-3D, dedicated to the provision of all main design specifications of such a pilot plant, have provided a basis for the design of a whole plant. HYDROSOL-Plant comes thus as the natural continuation of such an effort for CO_2-free hydrogen production in real scale.

Objectives: The main objective of the HYDROSOL-Plant project is the development, verification and 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.

Achievements in 2014: In 2014, CIEMAT has been in charge of preparation of the platform, in the framework of Task 5. This task has involved the following works:

- Improvement of the communication of heliostats. We complete the task to wire all heliostats of the field, in order to improve the radio previous communication.
- Remodelation of control room (Fig. 3.19). This work has finished recently. Furthermore, CIEMAT added some additional functionalities of the heliostat control program.
- Besides, a complete renovation of the facets has started lately in order to improve the performance of the heliostat field.

Figure 3.19. Photograph of the new control room

Solar hydrogen production by using solar thermal power, SolH2

Participants: Abengoa Hidrógeno S.A., IMDEA Energía; Universidad de Sevilla and CIEMAT

Contacts: Alfinso Vidal, alfonso.vidal@ciemat.es

Funding agency: MICINN through the INNPACTO subprogramme.

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. A somewhat different approach is investigated at the INNPACTO/SolH2 project where the reactor used to drive the ferrites cycles is a cavity receiver using tubular reactors.

Objectives: SolH2 pursues to develop clean technologies for solar hydrogen production based on water splitting by mixed-ferrites thermochemical cycle and bioethanol steam reforming. To achieve this aim, two independent installations (one for each hydrogen production route) will be designed, constructed, commissioning and tested in the framework of this research program.

Achievements in 2014: The multi-disciplinary research group on this project moved forward during this year in different activities of the project, such as construction and commissioning of the solar plant. SolH2 facility of 200 kWth solar receiver located at 28 m height in the CRS plant (Fig. 3.20).

Figure 3.20. Experimental platform for SolH2 tests at CRS Plant

Besides this, the plant includes the equipment necessary for the water splitting process, that is, auxiliary services, N2 inert gas supply, water, steam generator, compressed air and electricity supply and communications wiring. An additional task has been taken: implementation of the control system by adding some new functionalities of the heliostat control program. It is expected that both facilities will be evaluated next year.

Oxygen from Lunar Regolite with Solar Concentrating Energy, ORESOL

Participants: CIEMAT-PSA (Spain).

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

Funding agency: CIEMAT.

Background: The project Oresol has its origin in the EU "ERA-STAR Regions" programme (ERA – Space Technologies Applications & Research for the Regions and Medium-Sized Countries - CA-515793 - ERA-STAR REGIONS), funding by the European Commission, where it was part of a joint initiative between Andalusia (Spain) and Bremen (Germany). When this program finished, PSA continued the activity due to its advanced stage of development and the unique possibility to investigate a promising type of solar chemical reactor for reactions that need the handling and processing of large quantities of solids.

Objectives: The principal goal of the Oresol project is the development and testing of a solar powered fluidized bed reactor for the extraction of oxygen from lunar regolith.

Achievements in 2014: The basic fluidization parameters of the main bed were evaluated in a provisional setup without heating. This included the determination of the minimum fluidizing gas velocity, the gas flow for useful fluidization, the optimum configuration of the tuyeres including pressure drop and homogeneity, operation strategies for varying gas flow demand, etc. These tests were performed with both, air and argon. Also included were the in- and out-flow pipes needed for continuous particle feed and removal.

An important step was the outfitting of the solar reactor (Fig. 3.21). The insulation was completed, and internals for gas-solids separation, TC-holder, and a new reactor wall were designed, purchased, and installed.

Additional hardware like the diagonal mirror, an air duct for its cooling, the stand pipe hopper for the particle feed, and some piping like e.g. the window protection gas lines were built.

A challenging task was the amplification of the instrumentation and the data acquisition hardware. In a very cramped space, electronics for 80 thermocouples, 27 analogue sensors, and 11 digital signals was installed.

Finally, with the now nearly completed system (Fig. 3.22), the cold tests were initiated needed to prepare the solar tests scheduled to start in spring 2015.

Figure 3.21. Oresol Reactor: Left: Insulation mounting. Center: Internals. Right: With window.

Figure 3.22. Oresol experimental system.

Clean hydrogen production. Carbon dioxide free alternatives, AlCConES

Participants: IMDEA Energia (Coordinator), University J. Carlos I, ICP-CSIC and CIEMAT. SENER (Spanish petroleum company) and ABENGOA Hidrógeno S.A.

Contacts: Concha Caravaca, concha.caravaca@ciemat.es

Funding agency: Comunidad de Madrid

Background: The AlCConES project focuses its R&D objectives onto the heart of CSP systems, which 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: The program of the work carried out by CIEMAT aims to analyse the feasibility of using thermochemical cycles for the production of hydrogen as well as new receiver configurations, such as particles receiver (Fig. 3.23).

Achievements in 2014: A kick of meeting was held at the beginning of the project in order to establish the main priorities of the project in some areas of activity. Some working groups have been created in order to identify critical factors for development of those technologies.

Besides the mentioned activities related to receiver configuration and new storage systems, another important task, aims to analyse the feasibility of using thermochemical cycles with potential integration to solar electricity production at high temperatures. Furthermore, the utilization of two-step water splitting process using oxides, such as perovskites, is considered a very attractive candidate to hydrogen production.

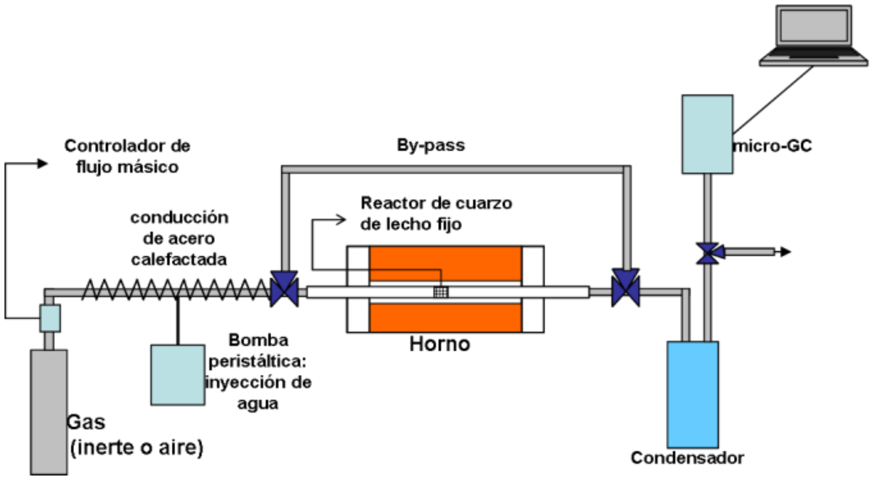


Figure 3.23. Diagram of bench test bed for the evaluation of the synthetized materials.

Our research efforts are driven to preparation of new materials, improving kinetics and reducing working temperatures. These perovskites will be synthesised in the laboratory and assayed for the thermochemical cycles under different reaction conditions. Materials with formula LaxSr1-xMnyAl1-yO3 and LaxSr1-xFeyAl1-yO3 are some examples of materials which have been studied by CIEMAT.

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 RO desalination systems into Organic Rankine Cycle (ORC) processes, also driven by solar thermal energy.
G) Development of solar polygeneration integrated solutions (power/cooling/water/heat production) based on small parabolic trough technology.

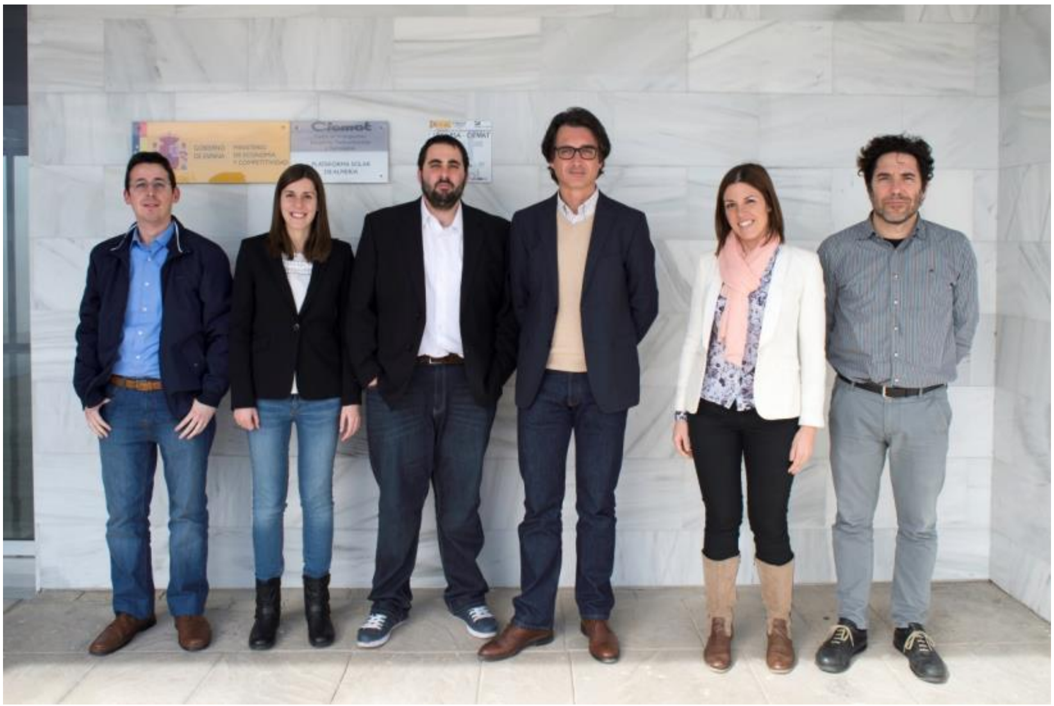


Figure 4.1. Members of the UDeS Unit.

During 2014 research activities were developed within the framework of projects covering both national and international activities with academic and industrial involvement.

This year has meant a very important growth in the research capacity of the Unit with the renovation of some of the existing experimental infrastructures and the incorporation of new ones that will guarantee an avant-garde scientific activity in this field within the PSA and the interest of external solar desalination research organizations and companies in order to establish cooperation agreements. Indeed, the PSA Solar Desalination Unit has become a world reference in the field of solar thermal desalination receiving numerous invitations to participate in international seminars, workshops, courses, etc. about this topic.

The interest about solar desalination processes and technologies has increased a lot during the last years. The prospects of more expensive energy and more scarce water resources, especially in countries/regions with high solar resource availability, are helping to look for the development of more competitive solar desalination technologies, trying to reach a full commercial development. In this context, the international relevance of the developed activities is clearly demonstrated by the current following positions hold by the unit:

- 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).

4.2 Projects

Zero Carbon Resorts (ZCR)

Participants: Gruppe Angepaste Technologie GrAT (A) (Coord.), Philippine Green Building Council PhilGBC (PH), Palawan Council for Sustainable Development PCSD (PH), CIEMAT-PSA (E), Asia Society for Social Improvement and Sustainable Transformation ASSIST (PH).

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

Funding agency: European Commission, SWITCH-Asia Programme.

Background: Energy supply in remote settlements usually relies heavily on fossil fuels. This is the case of the Philippines, a country with more than 7000 islands which is undergoing a fast-development of the tourism sector. The high consumption of water and energy associated to tourism SMEs has a strong environmental impact.

Objectives: The specific objective is to enable tourism SME companies to provide their services in an energy efficient, cost effective and sustainable way by making use of locally available, CO_2 neutral resources and green technologies.

Achievements in 2014: The project concluded with the building of the Zero Carbon Showcase Bamboo Cottage, a totally energy self-sufficient building which showcases sustainable building principles and energy systems using appropriate technology solutions. The design output is the collaboration with the ZCR project team and the design team from the ZCR capacity building program. CIEMAT-PSA was in charge of the energy issues of the building.

The main results of the project were presented at the 4th project Conference on May 21, 2014 in Manila. Application of the ZCR method in the Philippines has led to annual savings of Php 241,878,143.41 with limited investment. Savings for energy are 17,712,976.20 kWh; fuel savings are 1,776,733.73 L; water savings are 476,824,036.43 L; and the avoided carbon emissions 11,860,373.72 $kgCO_2$. Reasons for these significant improvements were alternative ways to achieve thermal comfort, identification and elimination of energy and resource wastage and a smart realization of energy services. Another highlight of the conference was the awarding of ZCR members from all over the Philippines that gained the highest energy and resource savings following the unique methodology of the project. The award is based on the number of energy and resource implementations and the monetary savings per room.

Figure 4.2. ZCR Conference "Resorts" in Philippines (May 2014)

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

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

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

Funding agency: European Commission, SWITCH-Asia Programme.

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

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

Achievements in 2014: The project officially conducted its kick-off meeting on May 22, 2014 in Manila, Philippines. The meeting served to develop a common understanding of the project objectives, get to know each other and discuss the activities and expected results. A further meeting took place subsequently in Bangkok on July (28-30) to plan the training activities and present the project to the Associated Partners in Thailand.

The schedule for the training course during the first two years of the project was set up and the materials for the first course Reduce have been elaborated by CIEMAT-PSA during 2014: a comprehensive manual dealing with the effective use of energy and water in tourist resorts. Also, contacts were initiated through the Thailand embassy in Spain towards the collaboration with governmental institutions dealing with renewable energy and water issues in Thailand. Furthermore, the first steps towards the establishment of an academic network with ASEAN partners working on water desalination and treatment were made associated to the 3W Expo and Conference organized biannually in Bangkok.

Figure 4.3 kick-off meeting (May 2014)

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 2014: 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 solar 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.

Figure 4.4. NEP PolyTrough 1200 solar collector for process heat applications up to 220 ºC

Improving the Performance of Concentrating PV by Exploiting the Excess Heat through a Low Temperature Supercritical Organic Rankine Cycle (CPV/RANKINE)

Participants: Agricultural University of Athens (coordinator) (GR), CIEMAT-PSA (E), University of Ghent (B), Lumicum (SE), Sistemas de Calor S.L. (E), Hellas Energy (GR), Deconinck N.V. (B).

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

Funding agency: European Commission, SME Actions

Background: The project is based on the fundamental principal that heat, produced by concentrating photovoltaic/Thermal (CPV/T) system, can be effectively converted into mechanical work and finally to electricity through a Supercritical Organic Rankine Cycle (SCORC) process.

Objectives: The scope of the project is to extensively study this integrated configuration and to develop, construct and test a hybrid CPV/T- SCORC system with capacity of 14 kWp, where CPV/T heat is effectively recovered by the SCORC process for additional electricity generation.

Achievements in 2014: The project has concluded in 2014 with the implementation and experimental assessment, at the facilities of Agricultural University of Athens, of a combined CPV/T-SCORC system operating under real climatic conditions. The solar field is composed of 10 parabolic trough CPV/T collectors able to produce up to 10 kWp of electricity. The thermal energy generated during the refrigeration process of the CPV panels has been recovered by means of a supercritical heat exchanger increasing the temperature of an organic working fluid (R404a) up to 95 °C for expansion in a SCORC unit obtaining 3 kWp added electrical production. The full system has been operated under steady and unsteady conditions demonstrating the feasibility of the concept and providing an alternative use of CPV/T technology. Techno-economic assessment has showed that it is required a reduction in the investment costs of the SCORC technology in order to reduce the final cost of the electricity produced.


Figure 4.5: Absolicon CPV/T collectors in CPV/Rankine pilot plant

Scientific and Technological Alliance for Guaranteeing the European Excellence in Concentrating Solar Thermal Energy (STAGE-STE) – WP10: Solar Thermal Electricity + Desalination

Participants: CIEMAT-PSA (WP10 coordinator) (ES), FISE (DE), ENEA (IT), CEA (FR), CYI (CY), LNEG (PT), CENER (ES), UEVORA (PT), UNIPA (IT), SENER (ES), HITTITE (TR), FBK (IT)

Contact: Dr. Diego-César Alarcón-Padilla (diego.alarcon@psa.es)

Funding agency: European Commission, IRP 7th FP

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 of STAGE-STE WP10 (STE+Desalination) 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 2014: During 2014 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 & MSF), new developments in low-temperature thermal distillation processes as well as reverse osmosis process. During the first year of the project, the tasks related with the state of art and model development of LT-MED and MSF processes have been successfully concluded.

5. WATER SOLAR TREATMENT UNIT

5.1 INTRODUCTION

The main objective of the Unit for Water Solar Treatment (WST) 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 (Fig. 5.1). 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.

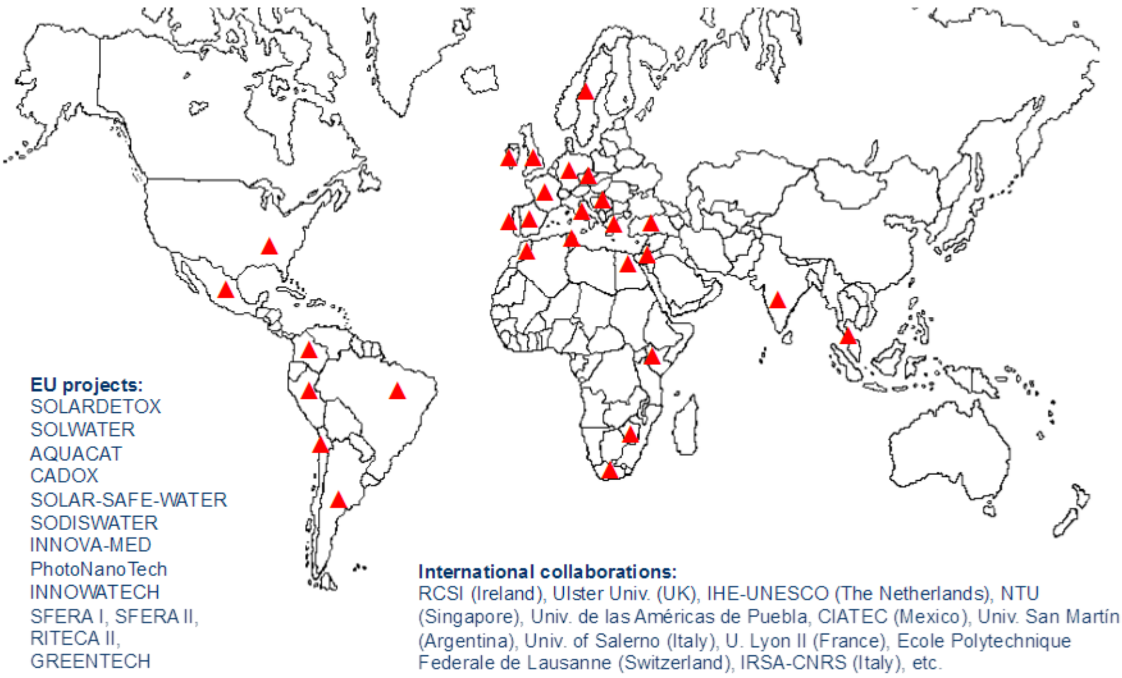


Figure 5.1. Collaborations of the WST Unit with different groups around the world.

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, 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 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.

Figure 5.2 Staff of the Water Solar Treatment Unit

5.2 Projects

Assessment of solar photocatalytic processes for water regeneration, AQUASUN

Participants: CIEMAT-PSA; Univ. Santiago de Compostela, Univ. Rey Juan Carlos (co-ordinator).

Contacts: Pilar Fernández Ibáñez, pilar.fernandez@psa.es

Funding agency: Ministerio de Ciencia e Innovación, Plan Nal. I+D+i 2008-2011. Sub-programa de Proyectos de Investigación Fundamental.

Background: The high hydric stress and the water demand lead us to explore new alternative water sources like municipal wastewater effluents. However, the presence of emerging pollutants (chemical and biological) limits their use. These uses in

Spain are regulated by the Spanish Directive RD 1620/2007. The assessment and development of advanced technologies such as solar photocatalytic processes to enhance the water contaminants removal appears as a good choice.

Objectives: This project aims to investigate the viability of an advanced integrated system to control microbial agents (*Escherichia coli*, *Legionella* spp., nematodes and *Cryptosporidium* spp) in WW by solar promoted photocatalytic processes. The coupling of biological processes with photocatalytic reactors will be studied for optimising the photo-reactors design and build an improved semi-pilot scale prototype.

Achievements in 2014: During last year of this project, the efficiency of solar photocatalytic and solar added-H_2O_2 processes for inactivating L. pneumophila in distilled water was evaluated using two quantification techniques: for the first time real time q-PCR and culture enumeration technique in plates (one of the bacterial quantification standard methods). Different concentrations of TiO2 (50-500 mg/L) and H_2O_2 (10-50 mg/L) were investigated with spiked L. pneumophila in distilled water at laboratory scale (200 mL) under natural solar radiation. The best inactivation results found according to the pour plate technique were found for 500 mg/L of TiO_2. On the other hand, a significant difference on the inactivation results was observed for solar with H_2O_2 added process when was evaluated with both enumeration techniques: real time q-PCR (protocol previously developed in our lab using EMA-dye for the detection of only viable L. pneumophila) and pour plate technique (Fig. 5.3). These differences could be attributed to different ways of inactivation of this process compared with TiO_2; i.e. the damages generated with this process are attributed to the influx of H_2O_2 by bacteria and the subsequent internal reactions with available cell iron (internal photo-Fenton reactions) which lead to cell death. This inactivation mechanism won't produce physically alteration of the cell wall and therefore, EMA-dye cannot act and the discrimination between viable and non-viable Legionella cells during the DNA extraction phase will occur. On the other hand, EMA q-PCR analyses with cells treated by TiO_2 photocatalysis are have been also studied to finalise our tasks in this project.

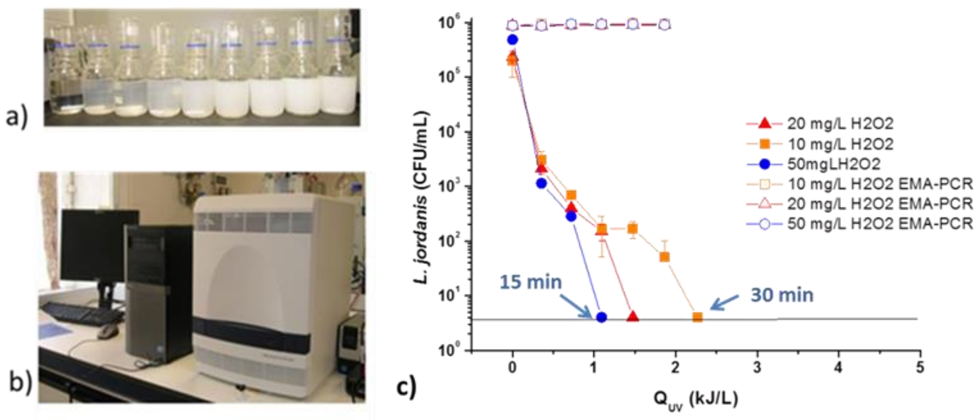


Figure 5.3. (a) Photocatalytic experiment using suspended TiO2 (P25) at different concentrations. (b) Real time q-PCR (7500-Fast, Applied Biosystem) at PSA laboratory. (c) Inactivation of L. jordanis in distilled water using two enumeration techniques: real time q-PCR with EMA dye (empty symbols), and 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. This goal could be achieved by a proper combination of different advanced processes: membranes, advanced oxidation and bio-treatment.

Objectives: The main objective of this project 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 Advanced Oxidation Processes (AOPs) with membrane technologies for contaminants concentration and so increasing the reaction rate; (ii) combination of those technologies with biological treatments for the complete removal of transformation products and so reducing operating costs coming from reagents and energy; (iii) the use of solar energy for carrying out the selected AOPs (iv) the use of organic photo-sensitizers, which are normally contained in complex wastewater as landfill leachates, for promoting contaminants oxidation reactions.

Achievements in 2014: During this second year of this national project the final optimization of target parameters in the physic-chemical pre-treatment step of complex industrial wastewater such as cork boiling wastewater has been completed (Fig. 5.4 (a) and (b)). In this first step, not only laboratory scale experiments in Jar Test were performed, but also pilot plant scale pre-treatments of more than 200 L of actual wastewater.

Afterwards, during the second half of the year one of the main objectives of the project was attained when the most convenient treatment line for cork boiling wastewater remediation was found. In the first half of the year solar photo-Fenton experiments were carried out after the physic-chemical pre-treatment with the aim of determining the best treatment point in which toxicity will be reduced and biodegradability enhanced enough for facing the complete depuration by and advanced biological treatment based on an immobilised biomass reactor (Fig. 5.5). Respirometric assays showed medium to high toxicity through the whole solar photo-Fenton process and biodegradability assays (by measuring the oxygen uptake rate) were never higher than 0.15 (low biodegradability). Initially it was decided to test the possible adaptation of immobilised biomass to the partially oxidized cork boiling wastewater when 0.15 of biodegradability was attained. Nevertheless, after several batches in the immobilised biomass reactor chronic toxicity was detected and biomass started being detached from the supports. Therefore, it must be concluded that the combination of chemical and biological oxidation for reducing costs in the remediation process of cork boiling wastewater was not feasible. In consequence, an advanced oxidation treatment after an optimized physic-chemical pre-treatment must be applied for cork boiling wastewater possible reuse in the own production process. Solar photo-Fenton process has been applied until achieving the 86% reduction in the chemical oxygen demand with a consumption of 4.3 g/L of hydrogen.

a) b)

Figure 5.4. Optimization of the physic-chemical pre-treatment of cork boiling wastewater: (a) pre-treatment at pilot plant scale (500 m3/h) (b) Turbidity and total suspended solids elimination through the physic-chemical step.

Figure 5.5. Biological post-treatment in an Immobilized Biomass Reactor at pilot plant scale of cork boiling wastewater partially oxidized by solar photo-Fenton process

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.

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: (1) To determine the semiconductor "composite" that yields a larger efficiency of hydrogen generation from water and organic pollutants at pilot-plant scale, (2) to scale-up the process from laboratory to pilot-plant scale, and (3) to perform mechanistic studies of the process.

Achievements in 2014: A pilot plant for photocatalytic generation of hydrogen has been setup. It 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 (Fig. 5.6). The CPC photo-reactor is composed by 16 Pyrex glass tubes (inner diameter of 28.5 mm, outer diameter of 32 mm and length of 1530 mm) mounted on a fixed platform tilted 37°. 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. During this year we have studied the efficiency of different TiO_2-based catalysts in the production of H_2 using formic acid as sacrificial agent at pH 3 (Fig. 5.7).

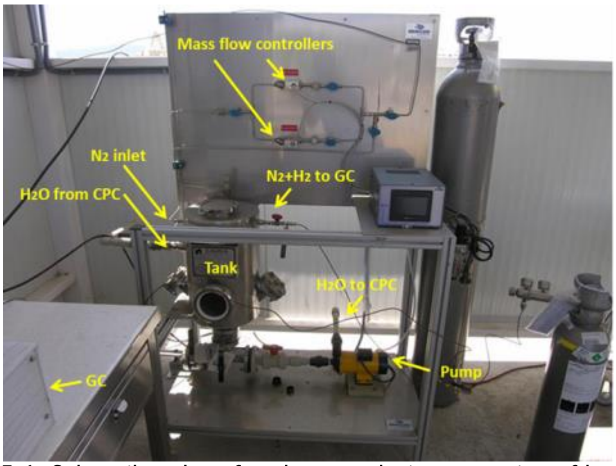


Figure 5.6. Solar pilot plant for photocatalytic generation of hydrogen.

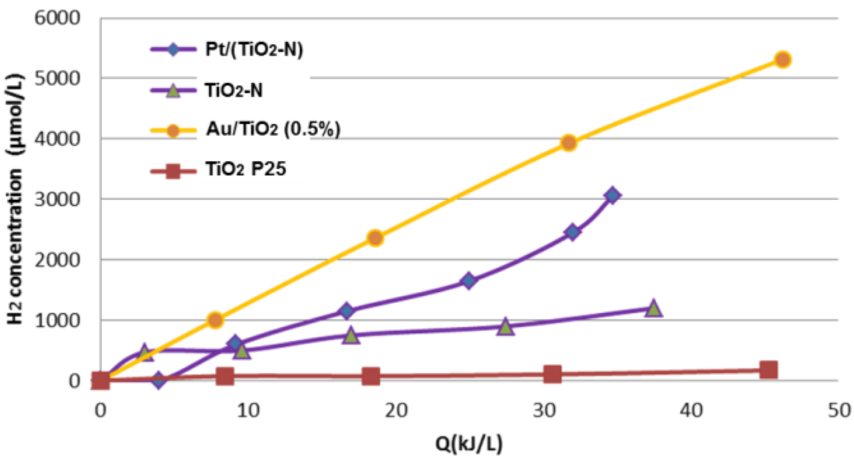


Figure 5.7. Hydrogen generated vs. accumulated solar UV energy (305-385 nm) for different photocatalysts at 0.2 g/L concentration. Reaction conditions: 25 L of 0.05 M formic acid aqueous solution at pH 3. Data corresponding to 5 hours of irradiation.

6 Horizontal R&D&i 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), CNIM (France), HITTITE (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).

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

Funding agency: European Commission (FP7-INFRASTRUCTURES-2013)

Background: STAGE-STE project is consequence of the European Commission IRP (Integrated Research Programmes) call of July 2012 addressed to a number of EERA (European Energy Research Alliance) Joint Programmes, being CSP one of them (there are about 15). EERA (http://www.eera-set.eu) is an organization involving more than 150 European energy research organizations to reinforce the collaboration in the development of energy technologies (through joint R&D) and support the competitiveness of European industry at international level.

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 2014: Taking into account the large number of activities and partners involved into the project, the detailed operational plans were initially defined to all project Work Packages. From the real work performed and with regard to the results obtained in 2014, of special relevance is considered the creation of a repository of Intellectual Property results, within the website of EERA, to allocate know-how and project results. This repository has been feed with a total of 179 know-how elements initially provided by the 23 EU research organizations involved into the project, and offered to be shared between them, creating joint collective knowledge. The objective of this sharing is to substantially increase the real collaboration among the EU research organizations of relevance to CPS/STE technologies, aiming to advance in the creation, in the frame of EERA, of a reference organization with regard to the research on STE/CSP in Europe.

On the technical side, CIEMAT is leading WP11 "Line-focusing STE technologies", being the scientific and technical activities committed in this work package were launched in 2014. Coordination and management activities are combined with scientific and technical work. CIEMAT has contributed to the review of medium temperature line-focusing collectors, has advanced in the development of a model to study DSG in parabolic troughs solar fields in TRNSYS and has been analysing different types of portable IR cameras that could be installed on unmanned aerial vehicles and would serve to check the status of PT receivers in large solar fields, among other activities also linked to this WP. In the field of advanced thermal storage systems (WP7), CIEMAT has developed a preliminary estimation of the figures of merit of potential LC candidates, in terms of phase change enthalpies and specific cost; they have been calculated by comparison with latent storage systems with low-k inorganic salts plus a heat transfer enhancement mechanism.

On the field of CSP+D (WP10), main activity of Solar Desalination Unit within 2014 was focused in the development of mathematical models for the different desalination processes that can be coupled to a concentrating solar power plant for simultaneous production of fresh water and electricity. During this period, tasks related with modelling of low temperature multi-effect distillation (LT-MED) and multi-stage flash evaporation (MSF) processes have been finished.

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

Participants: CTAER. CIEMAT-PSA, MINECO, CyI, ESTELA, CNRS, DLR, APTL, CRES, ENEA, Weizmann, LNEG, UEVORA, GUNAM, SELKUK U

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.

Achievements in 2014: Activities in 2014 were mainly devoted to the definition of the legal structure for EU-SOLARIS and the rules and procedures to be adopted after its legal implementation. Taking into consideration the importance of the documents, it is worthwhile to mention here the following documents elaborated in 2014 regarding the future new entity EU-SOLARIS:

- "Motivational report on the legal organism selected to host EU-SOLARIS", alaysing several legal forms that could be adopted for EU-SOLARIS, with the advantages and disadvantages of every option.
- "Extensive report on funding sources: EU-SOLARIS Grant Map", identifying the existing funding sources at regional, national and European level which EU-SOLARIS could benefit from.
- "Business Plan for EU-SOLARIS", describing a feasible plan to support the activities planned for EU-SOLARIS, with balanced yearly incomes and expenses

Additionally to the reports related to legal and financial aspects of EU-SOLARIS, two major technical reports were prepared in 2014:

- "First Project Periodic Report", covering the period November 2012 – April 2014
- "Mid-Term Project Report", covering the period November 2012 – October 2014

A major Milestone in 2014 was the Mid-Term Review meeting (Seville, November 7th) and the approval by the E.C. Project Officer of the Mid-Term Project Report.

Another important event in 2014 were: the Workshop on Financing Sources (hosted by MINECO on June 24th), the 4th and 5th Steering Committee meetings (hosted by GUNAM and CTAER in March and November respectively).

Figure 6.1. 4th EU-SOLARIS Steering Committee Meeting, Istanbul.

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

Participants: CIEMAT-PSA (coordinator), DLR, CNRS, PSI, ETHZ, ENEA, CEA, INESC-ID, UEVORA, UNILIM, ESTELA and UTV.

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

Funding agency: European Commission (FP7-INFRASTRUCTURES-2008-1)

Background: Solar Energy, as the primary source of renewable energy, will contribute a major part of this share, and its conversion by concentrating technologies for concentrating solar power (CSP) and heat generation has long been proven cost-effective for a wide range of applications. CSP Research Infrastructures in Europe have served through the last 30 years as research tools in order to demonstrate the concept feasibility by exploring different pathways on how to produce high temperature heat, electricity and, more recently, solar fuel using concentrating solar radiation. Nowadays, the key point is to cooperate with the industry in order to reach the technology objectives listed above and 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 2014: SFERA II project began the 1st of January 2014 and will last until the 31st of December 2017. As in SFERA project three main activities are included in the general work plan: Networking, Transnational Access and Joint Research. Official Kick off meeting of SFERA II project took place in CIEMAT´s headquarters the 27th of January 2014 lead by Dr. Isabel Oller (as technical coordinator) and Dr. Ricardo Sanchez (as the project manager) (Fig. 6.2). Representatives of each one of the partners involved in this project attended the kick off meeting.

Results obtained through 2014 in Research Activities lead by CIEMAT will be gathered in this annual report within activities of E42 unit. In general terms, main objective of Joint Research Activities for the whole project is to improve the quality and service of the existing infrastructure and to extend their services taking benefit from the specific competences and experiences of the individual labs and jointly achieve a common level of high scientific quality and service through this synergistic approach.

Networking and Transnational Access activities carried out during 2014 are summarized here:

- Networking: Aiming at the creation of a stable Framework for co-operation in which resources are shared, common standards developed, duplication of research effort is avoided and interaction with European research, education and industry is encouraged.

Figure 6.2. SFERA II Kick off meeting held in CIEMAT-PSA headquarters in Madrid (27th January 2014).

Within this activity, the **10th SolLab Doctoral Colloquium** (within WP4) on Solar Concentrating Technologies (http://www.sollab.eu/doctoralcolloquium10/) took place between the 23rd and 24th of June, 2014 in Odeillo (CNRS-PROMES laboratory), France. The recent results of PhD students preparing their thesis in the various laboratories members of the project were presented. Directly following this event, the 5th SFERA Summer School was organized from the 25th to the 27th of June, and it was dedicated to solar receivers and reactors. Those lectures aimed at disseminating results of general interest in the scientific and industrial communities, and towards the general public.

Another networking activity coordinated by CIEMAT-PSA in October within WP3 (task 3.3) was the first "**Training for industries**" under the topic "Operation & Testing of Direct Steam Generation in Linear Focusing Collectors, Reflector Characterization (Theoretical and Practical Modules)" (Fig. 6.3).

Figure 6.3. First Training Course for Industries held in the Plataforma Solar de Almería in the frame of SFERA II project (29th of September to the 3rd of October, 2014).

- Transnational access: Opening the doors of the most relevant R&D infrastructures (**CIEMAT-PSA** (UAL-CIESOL as third party), CNRS-PROMES, SOLTERM-ENEA, and STL-PSI) to interested users (public and private bodies), optimizing the use of the facilities and creating critical mass for new research and innovation initiatives. CIEMAT-PSA received in SFERA 2014 access campaign 17 user proposal forms. After the user selection panel decision, and taking into account the relevant information given by each specific facility manager on the technical feasibility of the proposed projects, all of them were finally accepted.

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 2014: The main technical barriers in the Mediterranean regions that can be improved through a products certification scheme were identified by means of a series of questionnaires submitted to stakeholders in each Mediterranean region. A report titled 'Regional SWOT Analysis and barriers' was drafted and submitted to the partners in order to start working on the weaknesses and threats and success in removing the barriers preventing the take up of distributed solar energy in the target regions. Furthermore, CIMEAT started giving support to the national standardization bodies and the national accreditation bodies in the three target regions in order to adopt and adapt the international standards for testing photovoltaic components and systems, and in order to agree with them the content of the capacity building activities aimed to policy makers and stakeholders. To do so, three technical missions to each of the target countries have been carried out, starting in October 2014.

The Beirut Energy Forum (BEF) was held from 17 to 19 September, and MED-DESIRE took advantage of this event to organise at the same time the 4th Technical and Scientific Committee Meeting and to introduce the project to BEF attendances by organising a roundtable and a press conference on MED-DESIRE project. Besides, along with the other two Spanish partners, CIEMAT participated with a MED-DESIRE booth in the Greencities & Sostenibilidad Forum, 2-3 October.

Finally, during the 1st Capitalization event, 13-15 November, CIEMAT had the opportunity to introduce to a large number of stakeholders present in the event a general overview of CIEMAT and specifically, the units involved in this project, namely, the Photovoltaic Solar Energy Unit and the Energy Efficiency in Buildings Research Unit.

Figure 6.4. Meeting at the Egyptian Organization for Standardization and Quality in October 2014.

6.5 Concentrating Solar Thermal Energy for Iberoamérica, ESTCII

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 2014: 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. Four major activities have been developed in 2014:

- The official web page of ESTCI (www.redcytedestci.org) has been implemented with information about the objectives, work plan, the partners and the activities planned and already performed within this network.

- A survey of the legal framework existing in Argentina Brazil, Chile, Colombia and Mexico regarding solar concentrating systems installation and use. A preliminary report with the results was published in December.

- A survey of the solar radiation data currently available in these countries. Although global radiation data are usually available, a significant lack of on-site measured data of direct normal irradiance has been detected by this survey. A preliminary report with the results of the survey was published in December.

- Dissemination activities by PSA researchers, who gave a 2-day training course in Santiago de Chile (Chile) to explain the basic principles, different technologies, applications and commercial potential of concentrating solar systems. A workshop on commercial projects for solar thermal electricity (STE) plants in Chile was also organized by PSA in collaboration with the Chilean partners.


Figure 6.5. ESTCI Project partners in the meeting held at Santiago de Chile (October 2014)

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

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

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

Funding agency: CIEMAT (80%) and European Commission via FP7 ENERGY-2013-IRP Grant Agreement 609.837 (20%)

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 2014: PSA has participated in the international and national standardization committees IEC/TC-117 and AEN/CTN-206 coordinating several working groups and participating in all the other groups.

PSA has coordinated the development of three new standards within the committee AEN/CTN-206 of AENOR In 2014:

- "*Tests for the verification of the performance of solar thermal power plants with parabolic trough collectors*"
- "*Tests for the assessment of the solar field efficiency of solar thermal power plants with with parabolic trough collectors*
- *"Characterization of thermal storage systems for concentrating solar thermal systems with parabolic trough collectors"*

PSA has also participated within the framework of AEN/CTN-206 in the development of several standards related to qualification of components (e.g., parabolic trough collectors, receiver tubes for parabolic trough collectors, solar reflectors, working fluids and solar concentrators), for concentrating solar thermal systems, as well as the evaluation of thermal storage systems. PSA has also participated in the development of the standard UNE-206011 "*Solar Thermal Electric Plants. Procedure for Generating a Representative Solar Year*" issued in 2014.

Within the framework of IEC/TC-117, besides the coordination of the Team PT62862-1-1, in 2014 PSA has also participated in the submission of two new proposals for international standards related to "*Qualification of Parabolic-Trough Collectors*" and *"General requirements and test methods for linear solar receivers"*

Figure 6.6. Working Team of the standardization committee IEC/TC117 launched in 2012

6.7 Automatic Control Group

6.7.1 Introduction

The Automatic Control group belongs to the Direction unit and its purpose is to collaborate with the different R+D units on the research activities carried out by developing dynamic models of solar thermal plants and designing control algorithms to improve the operation of the systems. In 2014, the Automatic Control group addressed diverse activities related with its main research lines and summarized as follows:

1. Dynamic models based on first principles for components used in solar thermal facilities (heat exchangers, parabolic-trough collectors, multi-effect distillation units, heat pumps, solar reactors, heliostats,…).
2. Chattering problems in two-phase flow models.
3. Automatic control techniques (predictive control, adaptive, robust, feedback linearization) applied to solar thermal plants (solar furnaces, hydrogen production, desalination units).

Figure 6.7. Picture of the group staff

6.7.2 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: HYSOL plant will be designed to validate the electricity production using biomass derived gas fuel and CSP technologies. A pre-industrial scale demonstrator will be studied, designed and implemented in an existing CSP plant. The demonstrator is based on an aeroderivative gas turbine (AGT) exhaust gases simulator with a heat recovery system (HRS) (gas-molten salt). The installation will become a full renewable plant because gas fuel used in the AGT simulator will be produced from biomass.

Achievements in 2014: By the end of 2014, the following main achievements have been obtained.

1. 1. Detail engineering of the HYSOL demonstrator at Manchasol power plant almost completed.
2. 2. Aeroderivative gas turbine exhaust simulator acquisition. It considers all the operation modes estimated on the power plant.
3. 3. Set-up of a small size mock-up of the heat recovery system on the MOSE loop at ENEA Casaccia Research Centre close to Rome.
4. 4. Improvements in the object-oriented dynamic heat recovery system model and its main components. Simulation results have been exchanged and compared among partners.
5. 5. Different control strategies, for the heat recovery system startup, have been proposed, analyzed and studied in simulation.
6. 6. First experimental campaign has been carried out at PSA molten salt testing facility.

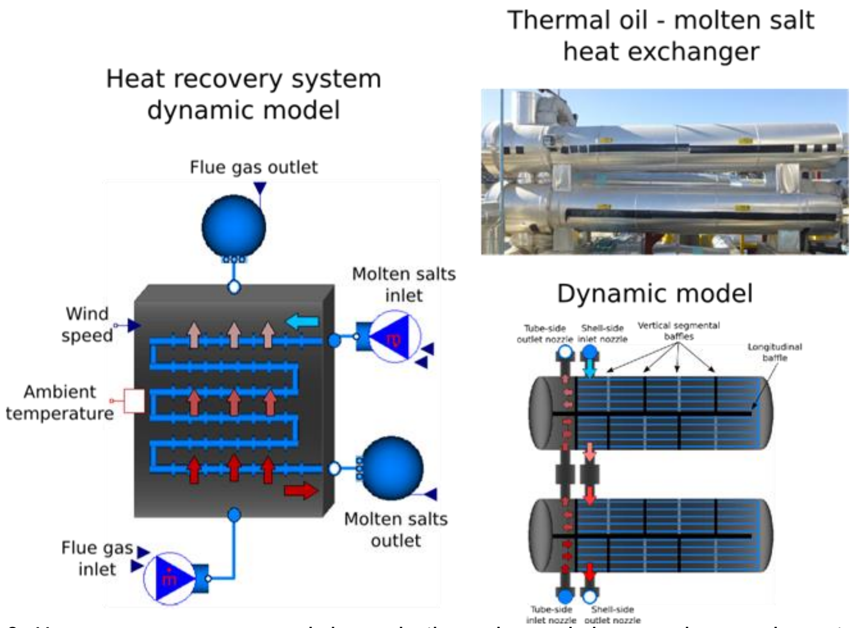


Figure 6.8. Heat recovery system and thermal oil – molten salt heat exchanger dynamic models.

Control Techniques for Efficient Management of Renewable Energy Micro-Grids, POWER

Subproject title: Estrategias de modelado y control para una desaladora solar híbrida

Participants: ISA-USE, UAL, TMT-USE, UVA, CIEMAT

Contacts: Luis Yebra, luis.yebra@psa.es

Funding agency: Ministerio de Ciencia e Innovación, Plan Nal. I+D+i 2008-2011.

Background: Micro-grids require optimal control strategies that guarantee the fulfilment of the demand, taking into account operating constraints and disturbances. Solar desalination plants can be a main part in micro-grid environments when freshwater is demanded by buildings or greenhouses. The Automatic Control group has a wide experience related to modelling and control of hybrid solar desalination plants due to the background reached within the AQUASOL project funded by the European Commission.

Objectives: The objectives are the natural continuation of those planned in previous projects:

1. Dynamic modelling and validation of solar gas hybrid desalination plants.
2. Implementation and experimentation of model predictive controllers.
3. Development of low level control algorithms to correct some unstable behaviour detected in previous experiences.

Achievements in 2014: In this fourth year of the project, the following relevant results have been obtained:

1. Dynamic model development of a solar-assisted multi-effect distillation unit, MED, using an object-oriented methodology. This model is based on physical principles and it has been calibrated and successfully validated against experimental data from the PSA solar thermal desalination plant.

2. The dynamic model of the MED unit has been used to perform a preliminary study of the feasibility of osmotic energy harvesting from brine produced by multi-effect distillation through a pressure retarded osmosis technique.

3. Dynamic model development of the Double Effect Absorption Heat Pump (DEAHP) located at AQUASOL pilot plant using an object-oriented methodology. This model, based on physical principles, has been calibrated using experimental data.

4. A predictive control strategy for a renewable energy micro-grid has been tested in simulation. The case study is the combination of a greenhouse (water demand system) and a solar desalination plant (water production system). The challenge has been to properly operate the desalination plant to produce the daily water demanded by the crop with an efficient energy management and taking into account solar irradiance disturbances.

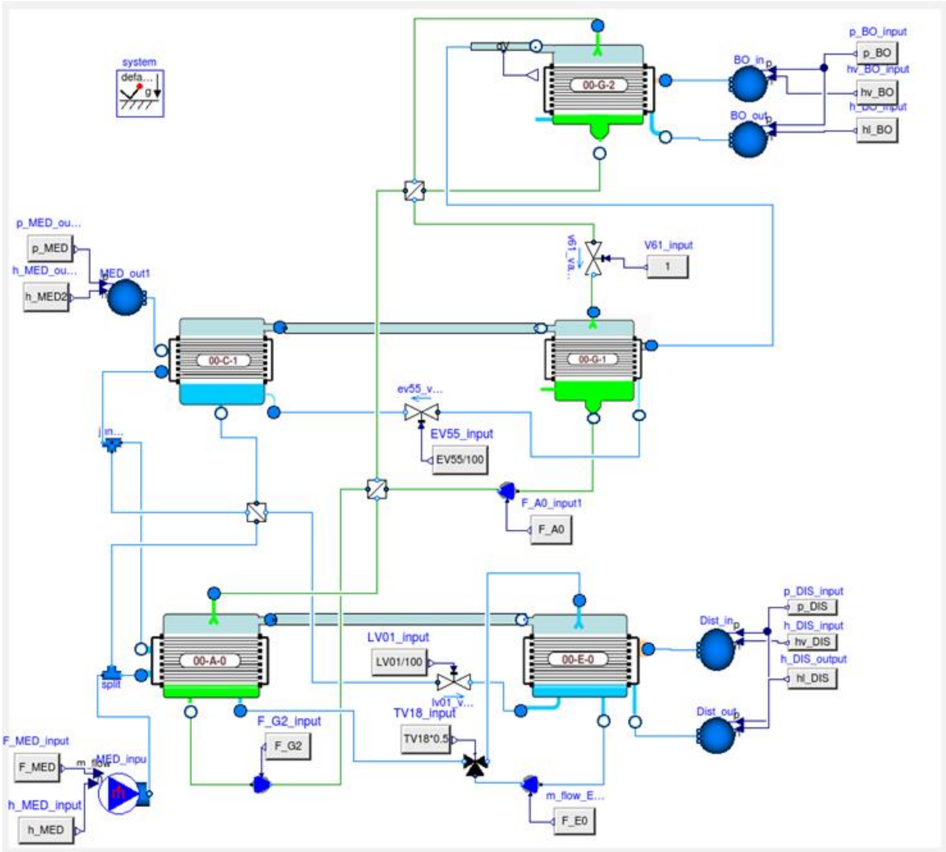


Figure 6.9. Component diagram of the DEAHP model.

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 deployment 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.

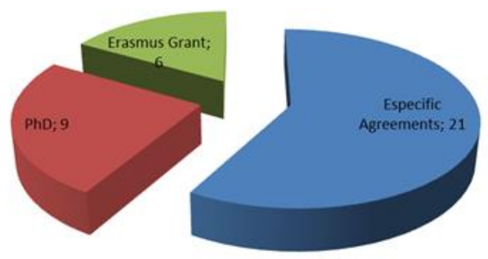


Figure 7.1. Distribution of PSA students (2014)

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 'Leonardo da Vinci' 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 Perpignan-France, Cagliari- Italy, Salerno-Italy, Chlef-Algeria, UNAM-Mexico, Minas Gerais-Brazil, TU-München-Germany, CIATEC-Mexico, URJC-Madrid, Centre of Energy- Tunisia, Dalarna-Sweden, Unesco-IHE-Netherlands, NTU-Singapore 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 (Switzerland), the Paul Scherrer Institute in Zurich (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 (Solar Facilities for the European Research Area) at the same time. The 10th SolLab was organized by the PROMES-CNRS (France) and took place at the Solar Furnace in Odeillo, part of the village of Font-Romeu in France. The Colloquium was held from the 23rd to the 25th of June 2014. Afterwards, the SFERA Summer School was hosted at the same location between the 25th to the 27th of June, 2014. It was focused on solar receivers and reactors.

8. Events

22/01/2014

Lecture

Invited lecture of Sixto Malato at meeting on "Nanomaterials for photocatalytic depollution: science and engineering" organised by project coordinators of three EU funded projects, PCATDES, 4GPHOTOCAT and LIMPID as part of ASEAN-EU Science, Technology and Innovation Days. Bangkok, Thailand 21-23rd January 2014. http://www.stidays.net/

29/01/2014

Doctoral Thesis

Alejandro Cabrera defended the Doctoral Thesis "Combinación de fotocatálisis solar con biorreactores de membrana para el tratamiento de aguas tóxicas. Modelado del proceso foto-fenton como herramienta de diseño y optimización". University of Almeria.

31/01/2014

Conference

Conference of Sixto Malato in Multidisciplinary Seminar Program at Escola Tecnica Superior d'Enginyeria Quimica (ETSEQ) at Universitat Rovira i Virgili, Tarragona.

11/02/2014

Doctoral Thesis

Iban Naveros defended the Doctoral Thesis "Análisis y evaluación energética de sistemas constructivos ventilados a partir de datos experimentales medidos en condiciones reales de uso y utilizando métodos de análisis de series temporales". University of Granada.

20/02/2014

Lecture

Invited lecture of Julian Blanco at the Yearly Assembly of Hassan II Academy of Science and Technology (Rabat, Morocco, 19-21 February). Lecture topic: "Coupling of Concentrating Solar Power Technologies with Water Desalination".

24/02/2014

Conference

Participation of Sixto Malato en "Jornadas provinciales de presentación de la Estrategia Energética de Andalucía 2020". Andalucía Regional Government Office, Almería.

25/02/2014

International committee attendance

Participation of Julian Blanco (as Joint Program Coordinator) and Loreto Valenzuela and Diego Alarcon (as Subprogramme Coordinators) in the external international review of the EERA JP-CSP held in Brussels.

03-04/03/2014

Technical visit

A high level delegation from K.A.CARE (King Abdullah City for Atomic and Renewable Energy) of Saudi Arabia visited PSA facilities having detailed information about installations and research activities to reinforce the knowledge and experiences on CSP plants implementation.

12/03/2014

Lecture

Invited lecture of Pilar Fernández Ibáñez in the Academia de Ciencias Matemáticas, Físico-químicas y Naturales de Granada, “Agua potable y energía solar: un cóctel que funciona” organized by Universidad de Granada, Spain.

12/03/2014

Institutional visit

Hosted by Dr. Cayetano López, a Delegation headed by the General Secretary of Science, Technology and Innovation, Mrs. Mª Luisa Poncela, and accompanied by the General Director of Innovation and Competitiveness, Mrs. Mª Luisa Castaño, visited in detail the PSA installations and research facilities receiving technical information on the activities from PSA scientists.

19/03/2014

Official visit

A group of 38 persons from the Government Sub-Delegation in Almeria and Provincial Authorities of the State General Administration (AGE) involving multidisciplinary local social agents, visited the PSA installations to know in deep about the research and technology development activities.

20/03/2014

Dissemination and divulgation

A team from the “Invest in Almeria” Project recorded an audiovisual of the PSA installations to be included in the initiatives to promote the productive development of the province.

31/03/2014

Lecture

Invited lecture of Eduardo Zarza in the Congresso Brasileiro de Energía Solar (V CBENS) “Tecnologia Solar Térmica com Concentração”, held in Recife (Brazil) from March 31st to April 3rd.

8/04/2014

Round table participation

Participation of Julian Blanco in round table “EERA Joint Programme reviews Synthesis Reports”, within the 2014 EERA Yearly Congress, held in Brussels.

12-18/04/2014

Proposals evaluation

Participation of Julian Blanco in the international panel to the evaluation of project proposals to the development of scientific infrastructures in the Czech Republic, organized by the Managing Authority OP RDI of the Ministry of Education, Youth and Sports of Czech Republic.

16/04/2014

Lecture

Invited lecture of Pilar Fernández Ibáñez in the Institute of Nanotechnology (NIBEC) “Solar Disinfection of Water using Nanomaterials” organized by University of Ulster, UK.

24/04/2014

Doctoral Thesis

David Hernández defended the Doctoral Thesis "Contribución al modelado termo-hidráulico de captadores solares cilindricoparabólicos para la generación directa de vapor”. University of Almeria.

24/04/2014

Workshop

F. Martin attended the meeting in Sevilla in the frame of the activities corresponding to the participation of PSA in the elaboration of the Andalucía Energy Strategy (2014-2020), promoted by the Andalucía Energy Agency.

25/04/2014

Technical visit

A group of 60 students from the last course in Physics Sciences of the University of Granada, coordinated by Prof. Modesto López, visited PSA, mainly focused on solar water treatment, as part of the training activities.

30/04/2014

Lecture

Prof. Luis C. Martorelli, Director of Optics Laboratory from the Universidad Nacional de La Plata in Argentina, gave a conference entitled “Nuevos paradigmas en Argentina y Sudamérica en energía solar”. PSA Arfrisol Auditorium.

05/05/2014

Technical visit

A Delegation headed by Prof. R. Palma-Behnke, Director of the Solar Energy Research Center (SERC) of the University of Chile, involving 17 professors representing different universities, visited the PSA installations to know about recent advances in concentrated solar thermal power and to identify possible future collaborations.

05-06/05/2014

Scientific Committee

Participation of E. Zarza in the third meeting of the Scientific Committee of CIC-Energigune (Energy Cooperative Research Centre) organized by CIC-Energigune and held in Vitoria (Spain) on 5-6 May, 2014.

13/05/2014

Advisory Committee

Participation of E. Zarza in the meeting of the Scientific Advisory Committee of KIC-InnoEnergy held in Barcelona and organized by KIC-InnoEnergy on May 13th, 2014.

21/05/2014

Technical visit

Like the precedent years, a group of 46 students from the UNESCO-IHE Institute for Water Education, from the Environmental Engineering and Water Technology Department in Delft, coordinated by Dr. Giuliana Ferrero, visited PSA facilities as a part of their programmed training activities focused on research and development of energy and environmental aspects of water treatments.

23/05/2014

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.

27/05/2014

Technical visit

A new group of 30 students from the UNESCO-IHE Institute for Water Education, in this case from the Integrated Water Systems Department, coordinated by Mrs. Mireia Tutusaus, visited PSA facilities as a part of their training activities focused on integrated water treatments systems.

03/06/2014

Technical visit

Invited by the Group of Automatic Control, a clump of 39 students and professors from the Polytechnics University of Cartagena, visited PSA as part of the training activities on the Renewable Energy Master Course coordinated by Prof. A. Urbina.

05/06/2014

Lecture

Invited lecture of Sixto Malato at 2nd International Conference on Recycling and Reuse (R&R, 2014), 4-6 June, 2014, Bogazici University, Istanbul, Turkey. http://rr.istanbul.edu.tr/

18/06/2014

Technical visit

Hosted by DLR, a high level group of representatives of the KA-CARE (King Abdulaziz City for Atomic and Renewable Energy) from Saudi Arabian, visited the PSA facilities and received detailed technical lectures on CSP technologies from PSA researchers.

25-26/06/2014

Dissemination and networking

Dr. Guillermo Zaragoza represented CIEMAT at the General Assembly of the European Technology Platform for Water (WssTP) and the Water Innovation Europe Event organized in parallel in Brussels.

01/07/2014

Technical visit

Invited by ACCIONA, a group of 7 professors and scientists representing several universities and research centers from Mexico visited the PSA installations to know details about the facilities and ongoing research activities on CSP technologies.

02-03/07/2014

International committee attendance

Participation of Julian Blanco, as coordinator of EERA JP-CSP, in Summer Strategy Meeting of Executive Committee of the European Energy Research Alliance (EERA), held in Lisbon.

03/07/2014

National Committee

Participation of Sixto Malato as Advisor of the National Committee in Science Policy. Madrid, MINECO.

04/07/2014

Technical visit

A group of 25 students and professors from the Polytechnics University of Madrid, visited PSA as part of the training activities of the Master Course on Renewable Energies and Environment, coordinated by Prof. J. Amador.

07/07/2014

Technical visit

Invited by CTAER, an important South African delegation involving institutional authorities and social agents linked to energy sector, visited PSA installations with the aim of outlining the possibilities of collaboration in different specific areas regarding the electricity generation CSP technologies.

21/07/2014

Lecture

Invited lecture of Julian Blanco at UK Department of Energy and Climate Change (DECC, Whitehall, London). Specific event to provide information and promote the knowledge of CSP/STE technologies at British authorities in the context of STAGE-STE project. Lecture topic: Concentrating Solar Power Worldwide Status.

21/07/2014

Doctoral Thesis

Inmaculada Cañadas defended the Doctoral Thesis "Desarrollo de prototipos de reactores de lecho fluidizado y horno rotatorio para la generación de calor en procesos industriales de alta temperatura". University of Sevilla.

07/08/2014

Institutional visit

The Director of 'Aerodinámica y Propulsión' Department of INTA, Mr. A. González García-Conde, and Mrs. M. Menéndez Aparicio, from the General Subdirection of Scientific and Technological Infrastructures of MINECO, visited the PSA installations and research facilities.

07/08/2014

Technical visit

Invited by CTAER, the President of CERIMME ('Centro de Estudios e Investigación Metalúrgica, Mecánica, Eléctrica y Electrónica de Marruecos'), Mr. Halouan, heading a group of members of Cluster of Solar Energy of Morocco, visited PSA installations having specific information about concentrated solar thermal power technologies for possible future collaborations.

12/08/2014

Technical visit

A group of 3 technicians from System Development Department of Soitec Solar GmbH in Germany, headed by Mrs. F. T. Rubio, visited PSA to share experiences about research activities on CSP technologies.

08/09/2014

Technical visit

A delegation of 5 persons from the prestigious Indian company 'L&T' invited by Ingeteam Power Technology, visited PSA to receive information about ongoing research activities on CSP technologies, and to envisage possibilities of collaboration regarding the great potential development of CSP in India.

11-12/09/2014

National meeting

The group of Solar Water Treatment organized the 3rd National Meeting of Photocatalysis at PSA facilities. 37 researchers from 15 Spanish research groups related with photocatalysis and applications (materials, air purification, water polishing, industrial wastewater remediation, reactors engineering, CO_2 reduction, disinfection of water and surfaces, and solar applications) attended the meeting. This forum opened discussions and new collaborations between national groups in the field for open calls in the H2020 programme and national R&D calls.

17/09/2014

Lecture

Plenary lecture of Sixto Malato at 12th Pannonian Symp. on Catalysis. Conference Center of the Academy of Sciences of the Czech Republic, Castle Trest, Czech Republic. 16-20 September, 2014. http://pannonia2014.icpf.cas.cz/

19/09/2014

Technical visit

Dr. Nikolaos Xekoukoulotakis, from the School of Environmental Engineering of the Technical University of Crete in Greece, visited PSA to share scientific experiences in solar photochemical systems and applications, with the aim of improving academic exchanges.

25/09/2014

Lecture

Invited lecture of Eduardo Zarza in the II Jornada on New Energy Technology “PSA R+D International Activities”, organized by the Parque Industrial y Tecnológico de Almería (PITA), Spain.

25/09/2014

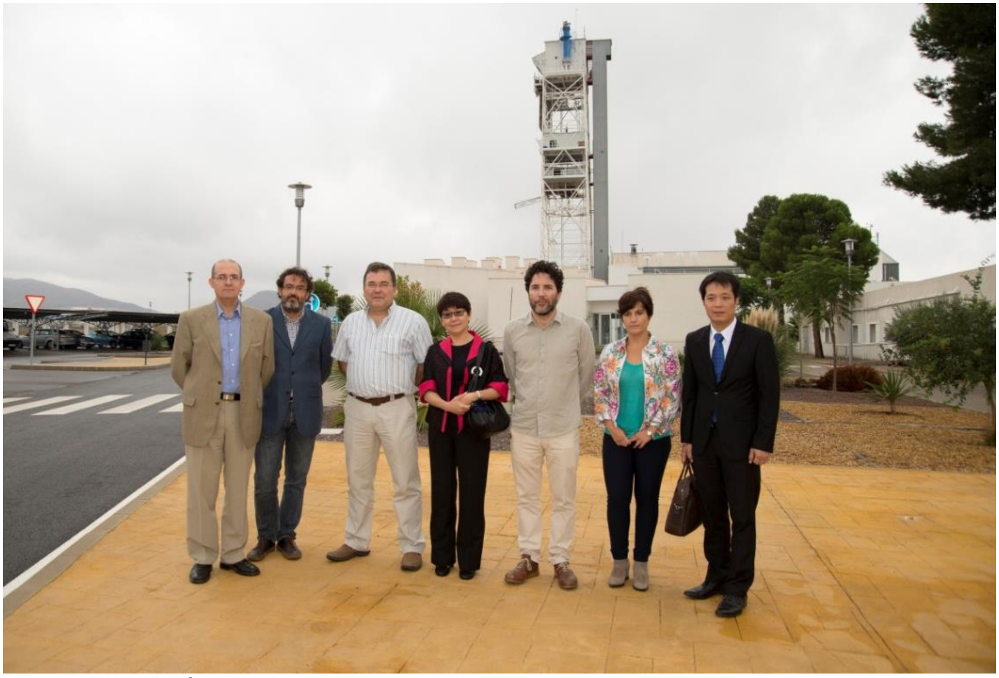
Lecture

H. Heppner made a presentation about the end of career project work carried out during the stage at PSA entitled “A Transient Measurement Method for the Determination of Parabolic Trough Receiver Heat Losses under Field Conditions – Testing and Optimization”. PSA Arfrisol Auditorium.

29/09-03/10/2014

First Training for Industries

As part of the activities scheduled in task 3.3 (WP3) of SFERA II project the “First Training for Industries” was hosted by CIEMAT-PSA in the fa-



cilities of the Plataforma Solar de Almería in Tabernas. The Topic was "Operation & Testing of Direct Steam Generation in Linear Focusing Collectors, Reflector Characterization (Theoretical and Practical Modules)". This course had well acceptance within the private sector and the maximum capacity was achieved with 11 attendants (Engineers, researchers and technicians).

01/10/2014

Institutional visit

A high level Delegation from the Embassy of Thailand in Spain, headed by the Ambassadress Mrs. Busaya Mathelin accompanied by the responsible of the Economic Affairs Office of the Embassy, Mr. Kasem Sailuenam, visited in detail the PSA installations and research facilities receiving technical information on the activities from scientists with the aim of establishing a bilateral institutional collaboration scheme.

10/10/2014

Institutional visit

Hosted by CIEMAT, the Professor in the Collège de France and High Commissioner for Atomic Energy in France, Mr. Y. Brechet, accompanied by the Counsellor of Science and Technology of the Embassy of France in Spain, Mr. B. Bouchet visited in detail the diverse research facilities receiving technical information from PSA scientists about activities carried out at PSA installations and showing the capabilities for potential technological collaborations.

10/10/2014

Official visit

A Delegation composed by 7 examiners of the European Patent Office (EPO) in The Netherlands, coordinated by Mr. F. Mootz, visited the PSA installations as part of the training activities to know in deep about the research and technology development activities carried out at PSA in the field of Concentrating Solar Thermal Systems.

the frame of the international technological collaboration.

13/10/2014

Lecture

Invited lecture of Sixto Malato in Symposium of "nanostructures for water purification "at IEEE Nanotechnology materials and devices conference 2014. October 12-15, 2014. Aci CAstello, Italy. http://www.ieee-nmdc2014.org/

15/10/2014

Technical visit

Invited by CTAER, scientists from the University of La Frontera in Temuco (Chile) represented by Dr. R. Hunter and Dr. B. Pavez, visited the PSA installations, to promote CSP technologies in Chile, with a growing interest on this field.

17/10/2014

Technical visit

A group of professors from the University of Bergamo in Italy represented by Mr. A. Perdichizzi, invited by CTAER, visited the PSA installations in

21/10/2014

Official Meeting

Participation of Julián Blanco, Eduardo Zarza and Sixto Malato in 13th PSA Steering Committee at DLR, Cologne, Germany.

23/10/2014

Lecture

Invited lecture of Dr. Guillermo Zaragoza at the "Membrane Distillation" Seminar organized by DME (German Desalination) and Fraunhofer ISE in Freiburg (Germany).

26/10/2014

Lecture

Invited seminar of Dr. Guillermo Zaragoza to present his work at the King Abdullah University of Science and Technology (KAUST) of Saudi Arabia.

27/10/2014

Technical visit

Dr. Raúl R. Cordero from the Antarctic Research Center (ARC), University of Santiago de Chile, accompanied by Mrs. S. Feron from the University of Leuphana (Luneburg, Germany) visited PSA to share scientific experiences in CSP systems and applications, with the aim of improving scientific exchanges.

28-30/10/2014

Training Course and Industry Workshop

Organization of the First Training Course and Industry Workshop of the Thematic CYTED Network for Concentrating Solar Thermal Technologies for Ibero-American Countries (ESTCI), coordinated by E. Zarza and held in Santiago de Chile (Chile) from October 28th to October 30th, 2014.

30/10/2014

Official visit

Invited by CIEMAT, the General Sub-Director of Coordination of Actions in the Spanish Office for Climate Change (OECC) of the Ministry of Agriculture and Environment, Mr. Eduardo González, visited with a high interest the PSA installations to know in deep about the research and technology development activities.

30/10/2014

International committee attendance

Participation of Julian Blanco, as coordinator of EERA JP-CSP, in the 9th periodic meeting of Joint Programme Coordinators of the European Energy Research Alliance (EERA), held in Brussels.

05-06/11/2014

Dissemination and networking

Dr. Guillermo Zaragoza represented the Action Group "Renewable Energy Desalination", coordinated by PSA-CIEMAT, at the European Innovation Partnership of Water Conference in Barcelona.

06/11/2014

Lecture

Invited lecture of Pilar Fernández Ibáñez in Symposium on UV disinfection in developing countries "SODIS Enhancement Technologies: Pilot testing for developing countries" organized by UNESCO-IHE, Institute for Water Education (Delf, The Nederlands).

07/11/2014

Official Meeting

Participation of Sixto Malato as Spain representation in Managing Committee and coordinator of WG4 of COST Action ES1403: New and Emerging challenges and opportunities in wastewater REUSe (NEREUS). COST Office, Brussels, Belgium.

10/11/2014

Technical visit

Huadian New Energy Development Co. Ltd., a private promoter of renewable systems in China, represented by Mr. Sun Yu, visited the PSA installations invited by Mr. I. Moreno from MS Techno Co. Ltd., to know about the technology developments on CSP plants.

11/11/2014

Lecture

Invited lecture of Eduardo Zarza in the Workshop on Solar Energy in Chile "The Plataforma Solar de Almería (PSA): an example of how public R+D centers can contribute to the commercial deployment of new technologies", organized by the Chile-European Union STI Initiative (CESTI+I) in Seville on November 11-12, 2014, Spain.

12/11/2014

Lecture

Invited lecture of Julian Blanco at the OIE Congreso Iberoamericano de Ciencia, Tecnología, Innovación y Educación 2014 (Buenos Aires, Argentina, 12-14 November). Lecture topic: "La Energía Solar de Concentración como ejemplo de transferencia exitosa de conocimiento: el caso de la Plataforma Solar de Almería".

12/11/2014

Lecture

Invited lecture of Eduardo Zarza in the 8th International Summit on Concentrating Solar Thermal Power-CSP Today "Is Changing the Environment for R+D in Europe?" organized by CSP Today in Seville on November 12-13, 2014, Spain.

14/11/2014

Technical visit

A group of 15 students from the Department of Inorganic Chemistry of the University of Alicante, visited PSA, mainly focused on solar water treatment, as part of the training activities on Energy and Environment.

18/11/2014

Dissemination and divulgation

An audiovisual showing PSA facilities and research activities, directed by P. Buhigas, was broadcast in the Channel 24Horas of TVE, corresponding to the second season of the Lab24 program, devoted to science and technology divulgation in Spain.

28/11/2014

Technical visit

A group of 17 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.

12/12/2014

Official visit

A group of 38 persons from the International Seminar on Design and Implementation of Renewable Energy Action Plans carried out in Granada and organized by the 'Euro-Arabian Foundation of High Studies', coordinated by Mr. Javier Ruipérez, visited the PSA installations to know in deep about the research and technology development activities.

12/12/2014

Technical visit

A group of 30 students from the Department of Physics of the Earth of the University of Murcia, headed by Dr. P. Jiménez, visited PSA, as part of the training activities on Environmental Sciences.

19/12/2014

Social Act

With occasion of Christmas Days, 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 2014 and the planning for next year were exposed, with the participation of the heads of PSA research units.

9. Publications

PhD Thesis

Cabrera Reina, A. (2014). Combinación de fotocatálisis solar con biorreactores de membrana para el tratamiento de aguas tóxicas. Modelado del proceso de foto-Fenton como herramienta de diseño y optimización. Universidad de Almería, Almería. https://www.educacion.gob.es/teseo/imprimirFicheroTesis.do?fichero=46705

Carra Ruiz, I. (2014) Operating strategies for the application of the photo-fenton process to remove persistent pollutants. Universidad de Almería, Almería. https://www.educacion.gob.es/teseo/imprimirFicheroTesis.do?fichero=54319

Hernández-Lobón, D. (2014). Contribución al modelado termo-hidráulico de captadores solares cilindroparabólicos para la generación directa de vapor. (Unpublished doctoral dissertation). Universidad de Almería, Almería.

Naveros Mesa, I. (2014). Análisis y evaluación energética de sistemas constructivos ventilados a partir de datos experimentales medidos en condiciones reales de uso y utilizando métodos de análisis de series temporales. University of Granada, Granada. http://digibug.ugr.es/bitstream/10481/34012/1/23075557.pdf

Solar concentrating systems unit

SCI PUBLICATIONS

Aguilar-Gastelum, F., Moya, S.L., Cazarez-Candia, O., & Valenzuela, L. (2014). Theoretical study of direct steam generation in two parallel pipes. *Energy Procedia* 57, 2265-2274.

Bayón, R., & Rojas, E. (2014). Analytical description of thermocline tank performance in dynamics processes and stand-by periods. *Energy Procedia* 57, 617-626.

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Feldhoff, J.F., Eickhoff, M., Keller, L., León-Alonso, J., Meyer-Grünefeldt, M., Valenzuela, L., ...& Hirsch, T. (2014) Status and first results of the DUKE project – Component qualification of new receivers and collectors. *Energy Procedia* 49, 1766-1776.

Fernández-García, A., Cantos-Soto, M.E., Röger, M., Wieckert, C., Hutter, C., & Martínez-Arcos, L. (2014). Durability of solar reflector materials for secondary concentrators used in CSP systems. *Sol. Energy Mater. Sol. Cells* 130, 51-63.

Fernández-García, A., Díaz-Franco, R., Martinez, L., & Wette, J. (2014). Study of the effect of acid atmospheres in solar reflectors durability under accelerated aging conditions. *Energy Procedia* 49, 1682-1691.

Fernández-García, A., Álvarez-Rodrigo, L., Martínez-Arcos, L., Aguiar, R., & Márquez-Payés, J.M. (2014). Study of different cleaning methods for solar reflectors used in CSP plants. *Energy Procedia* 49, 80-89.

Guillot, E., Alxneit, I., Ballestrin, J., Sans, J.L., & Willsh, C. (2014). Comparison of 3 heat flux gauges and a water calorimeter for concentrated solar irradicance measurement. *Energy Procedia* 49, 2090-2099.

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Lobón, D.H., Valenzuela, L., & Blagietto, E. (2014). Modeling the dynamics of the multiphase fluid in the parabolic-trough solar steam generating systems. *Energy Convers. Manage*. 78, 393-404.

Marzo, A., Ballestrin, J., Barbero, J., Cañadas, I., & Rodriguez, J. (2014). A solar blind pirometry not relying on atmospheric absorption bands. *Sol. Energy* 107, 415-422.

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Silva, R., Pérez, M., Berenguel, M., Valenzuela, L., & Zarza, E. (2014). Uncertainty and global sensitivity analysis of the design of parabolic-trough direct steam generation plants for process heat applications. *Appl. Energy* 121, 233-244.

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