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Ciemat

Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

PLATAFORMA SOLAR DE ALMERÍA

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PLATAFORMA SOLAR
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TABERNAS
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1. General Presentation

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

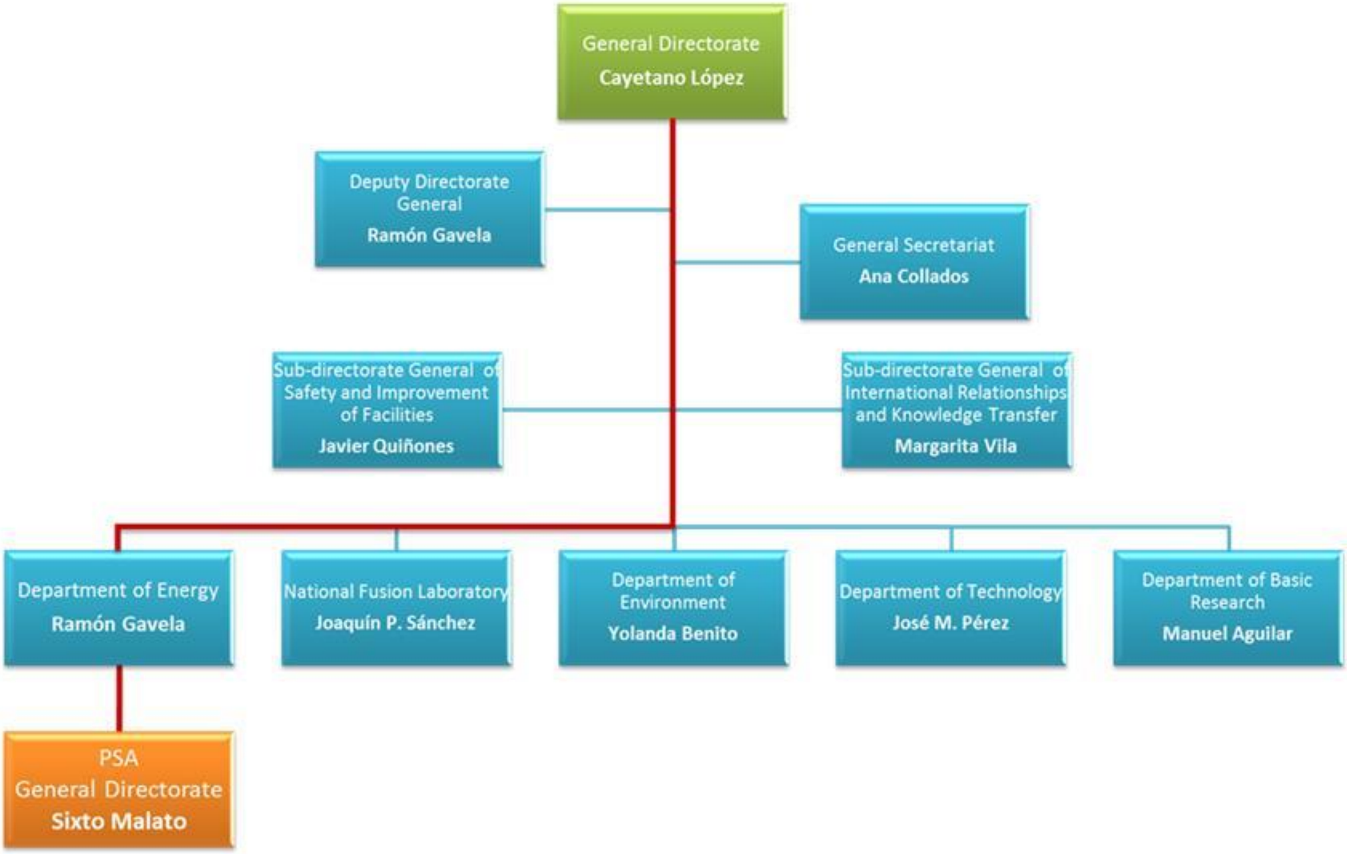


Figure 1.1. Integration of the PSA in the CIEMAT organization

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.
- Environmental Applications of Solar Energy. Its objective is to develop brackish water and seawater solar desalination.
- Solar Water Treatment. 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 137 persons that as of December 2012 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 121 persons who work daily for the PSA, 60 are CIEMAT personnel, 12 of whom are located in the main offices in Madrid.

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 34 persons, 15 work in operation, 14 in maintenance and 5 in cleaning. The auxiliary services contract is made up of 6 administrative personnel and secretaries, 7 IT technicians for user services, and another 4 persons from the security contract, what makes a total of 17 persons.

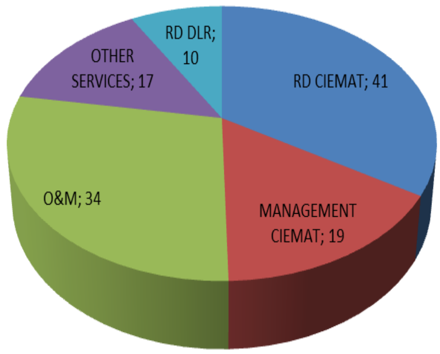


Figure 1.4. Distribution of permanent personnel at the PSA as of December 2012

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 2012 totals 5.25 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.
- SSPS-DCS 1.2-MWth parabolic-trough collector system, with associated thermal storage system and water desalination plant.
- 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.
- HTF test loop, a complete oil circuit for evaluation of new parabolic-trough collector components.
- The FRESDEMO "linear Fresnel" technology loop.
- The "Innovative Fluids Test Loop" for parabolic-trough collector systems using pressurized gas as working fluid and provided with a thermal storage pilot plant with two molten salt tanks.
- 6-unit DISTAL dish/Stirling facility.
- 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 rotating platform for concentrating modules and parabolic trough components under a permanent 0º incident angle.

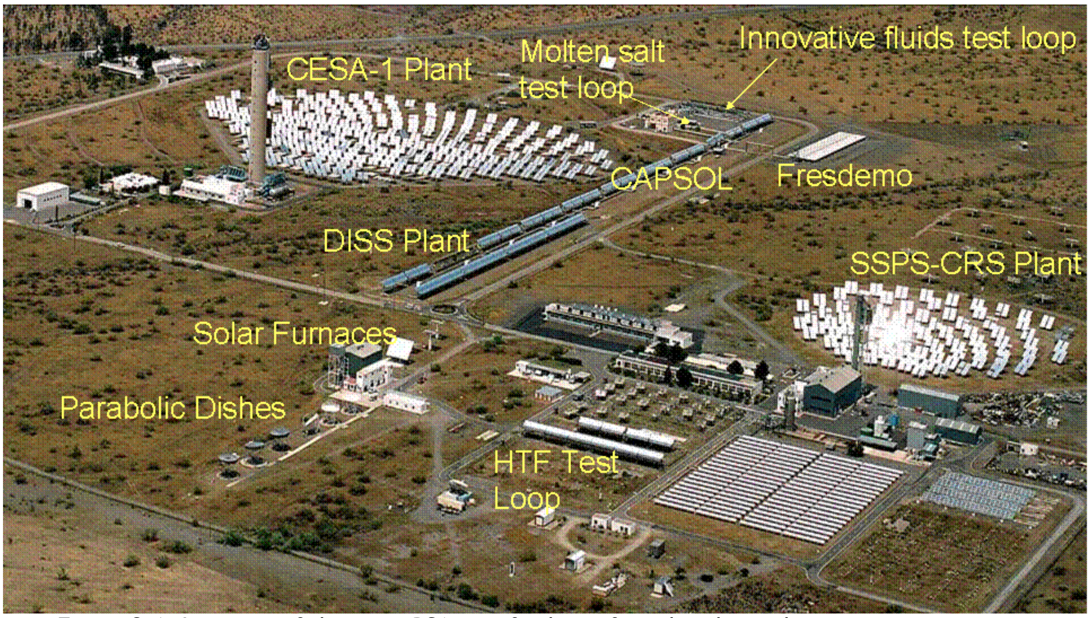


Figure 2.1. Location of the main PSA test facilities for solar thermal concentrating systems

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.

Figure 2.4. An autonomous heliostat in the CRS field

The nominal average reflectivity value of the field is actually 90%, the solar tracking error is 1.2 mrad per axis and the optical reflected beam quality is 3 mrad. Under typical conditions of 950 W/m^2, total field capacity is 2.5 MWth and peak flux is 2.5 MW/m^2. 99% of the power is collected in a 2.5-m-diameter circumference and 90% in a 1.8-m circumference.

The 43-m-high metal tower has three test platforms. The two first are located at 28 and 26 m and prepared for testing new receivers for thermochemical applications. The third test platform is at the top of the tower at 43 m, and houses an enclosed room with crane and calorimetric test bed for the evaluation of small atmospheric-pressure volumetric receivers, and solar reactors for hydrogen production. The tower infrastructure is completed with a 4-TN-capacity crane and a 1000-kg-capacity rack elevator.

The SSPS-CRS tower is equipped with a large quantity of auxiliary devices that allow the execution of a wide range of tests in the field of solar thermal chemistry. All test levels have access to pressurized air (29dm^3/s, 8bar), pure nitrogen supplied by two batteries of 23 standard-bottles (50dm^3/225bar) each, steam generators with capacity of 20 and 60kg/h of steam, cooling water with a capacity of up to 700 kW, demineralized water (ASTM type 2) from a 8m^3 buffer tank for use in steam generators or directly in the process, and the data network infrastructure consisting of Ethernet cable and optical fibre.

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.

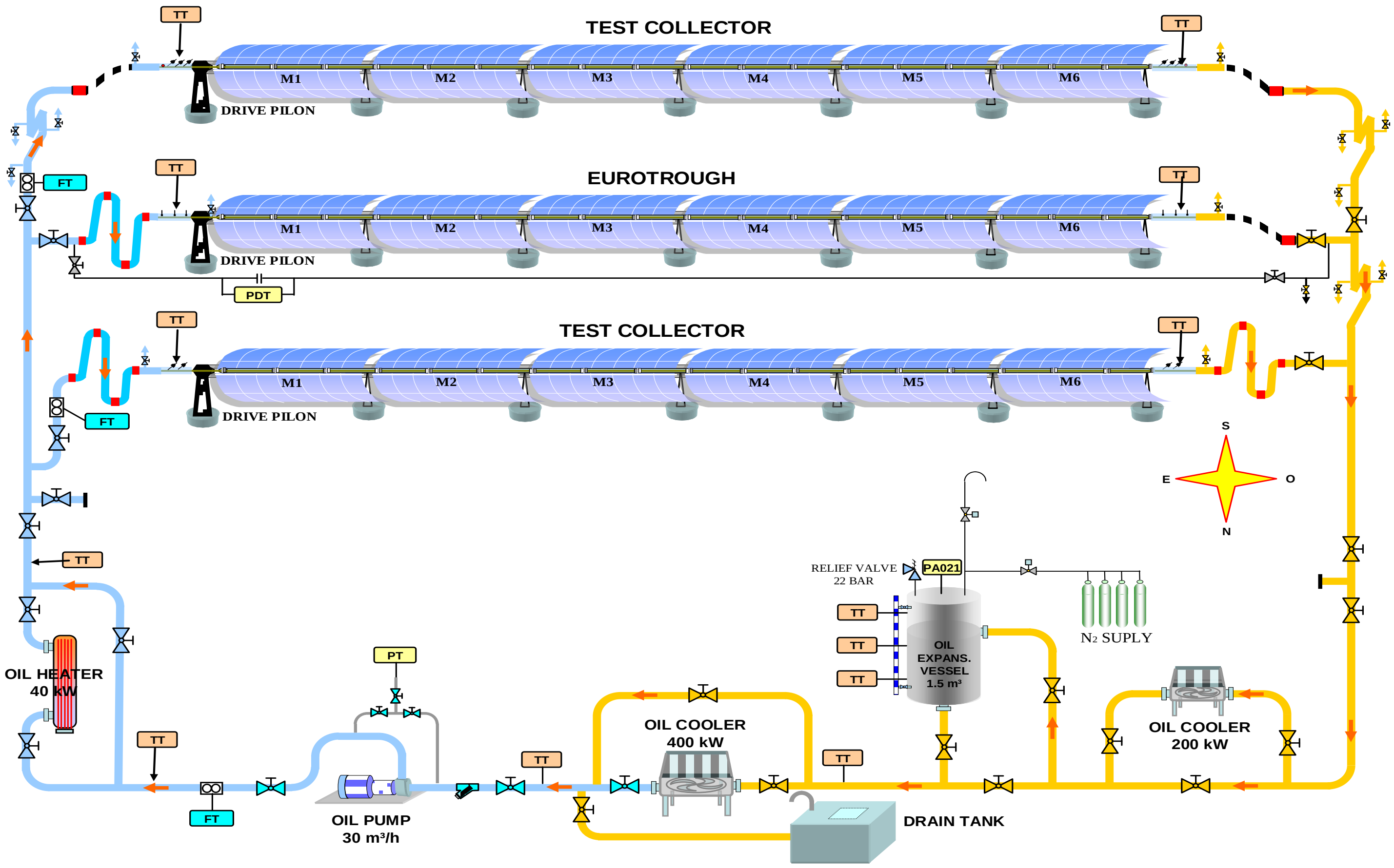


Figure 2.5. Diagram of the PSA "HTF test Loop".

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.

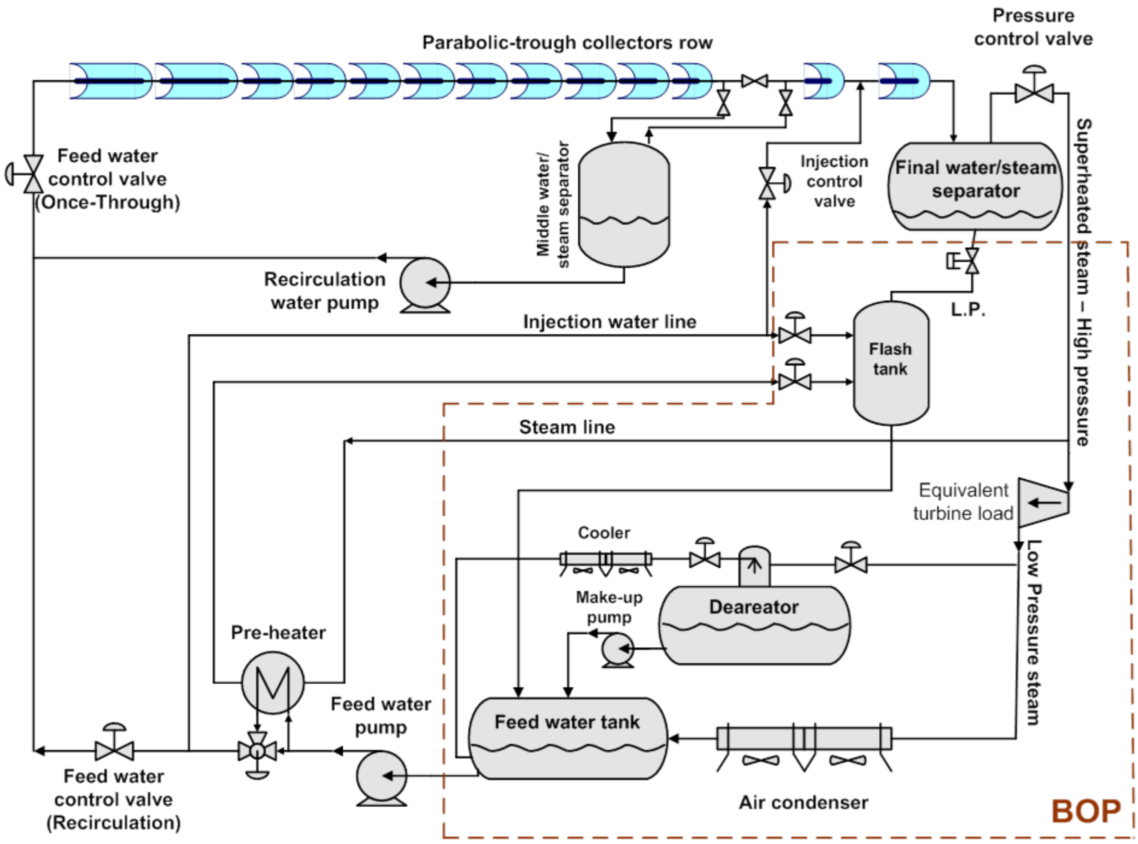


Figure 2.6. Simplified flow diagram of the PSA DISS loop

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).

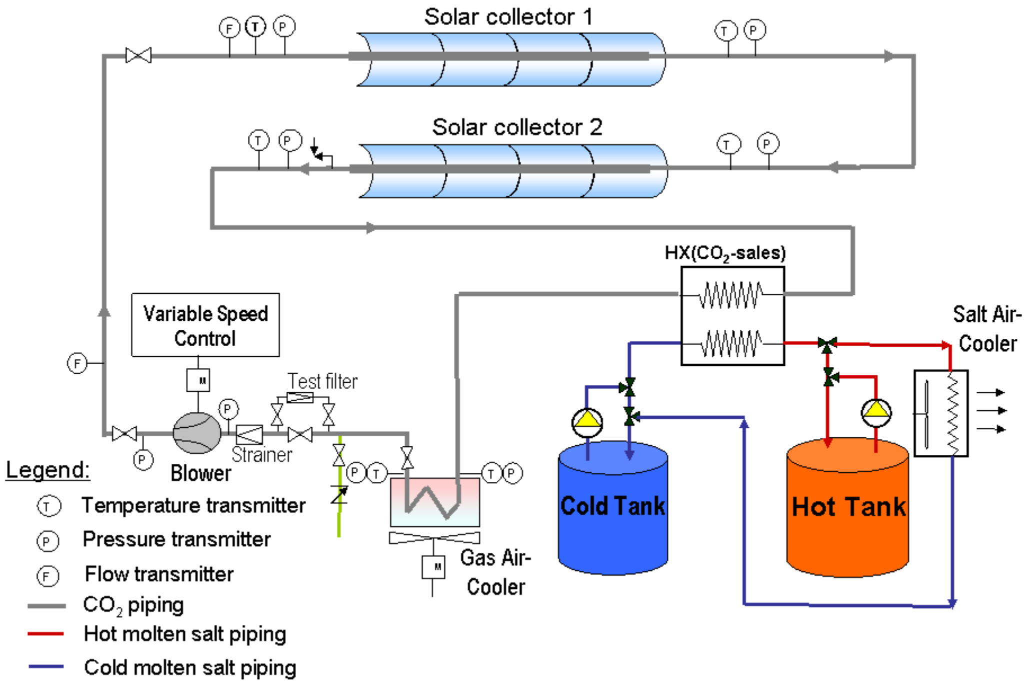


Figure 2.9. Simplified system diagram of the innovative fluids test loop connected to a molten-salt thermal storage system.

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.

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 2.10. 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 2.11. 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 2.12. 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. 2.13) 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. 2.14) 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.

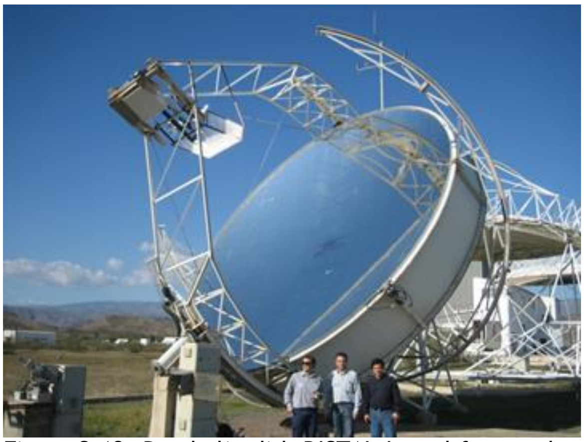


Figure 2.13. Parabolic-dish DISTAL-I used for accelerated materials ageing at PSA.

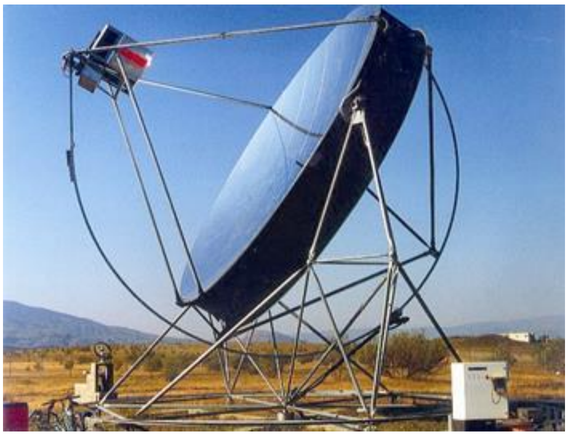


Figure 2.14. View of a parabolic-dish DISTAL- II.

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 EURОdish 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.

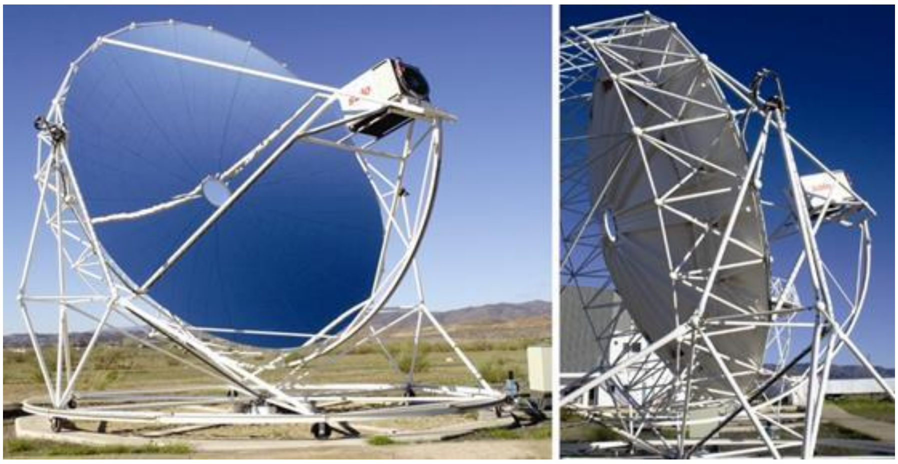


Figure 2.15. Front and back views of the EURODISH

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 2.16. 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.

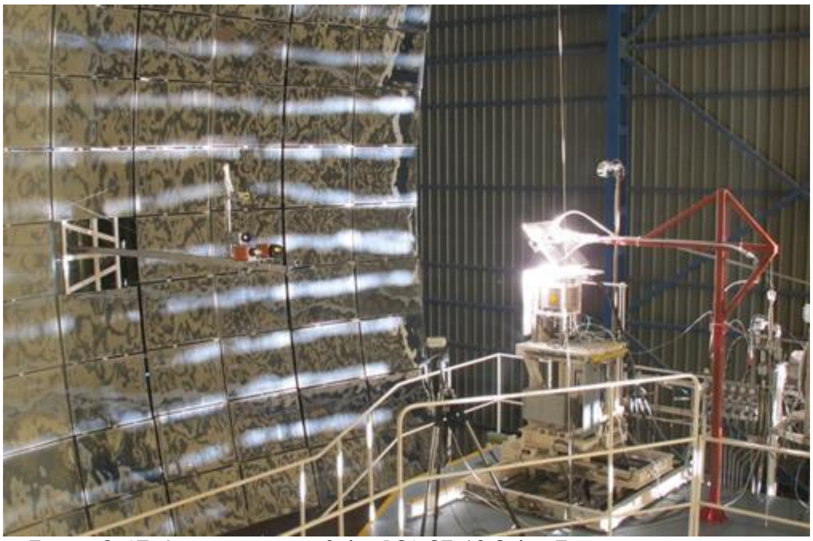


Figure 2.17. Interior view of the PSA SF-60 Solar Furnace in operation.

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 horizontal axis solar furnace, the SF-40, has all the main components installed and it is now being commissioned, expecting to be in operation in 2013.

The new SF-40 furnace, so called because of its 40-kW power, 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.

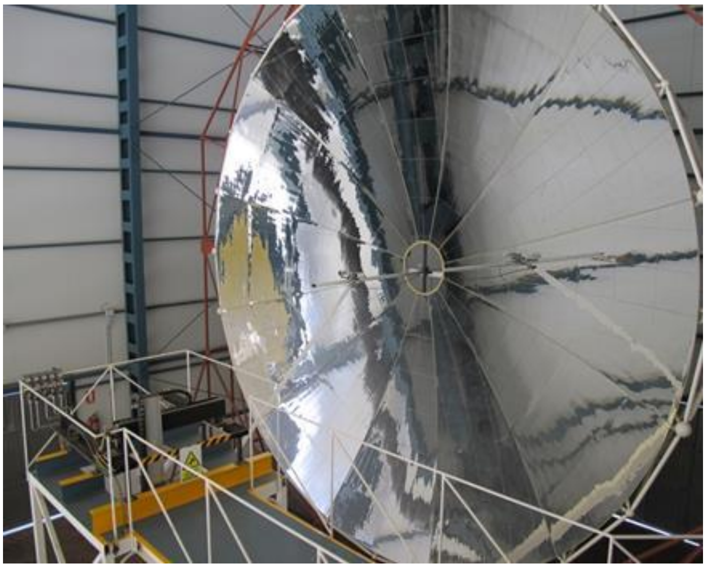


Figure 2.18. Interior of the SF-40 solar furnace, showing the parabolic concentrator.

The test table, in the centre of the SF-40 furnace test room in front of the concentrator and in its focal zone, is moveable on three axes. It is comprised of three linear modules with operative runs of 1000 mm on the X axis, 700 mm on the Y axis and 600 mm on the Z axis, and is able to move a150-kg load. On the north face of the test room, like a large Venetian blind, is the 11 m x 11 m louvered shutter, which controls the amount of light incident on the concentrator. Finally, the flat heliostat with a 100-m^2 reflective surface, which is still under construction, completes the installation.

SF-5 Solar Furnace

The vertical axis Furnace, the SF-5, has been recently designed and erected at the PSA. It has been designed to test high radiant flux, high gradients and high temperatures. This new solar furnace consists basically of a concentrator, located in inverted position (reflecting surface floor-oriented) onto an 18-m high metal tower; in the centre of the base of the tower is a flat heliostat, which rotating centre is aligned with the concentrator optical axis.

The test table is in the upper part of the tower of the SF-5 furnace, inside the test room and 2 m below the concentrator vertex. Finally, and as the test room "floor", is the shutter in horizontal position, which is located between the heliostat and the concentrator, and completes the main components of the vertical axis solar furnace. This solar furnaces started operation in 2012.

Figure 2.19. Exterior view 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 2.20. 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 2.21. 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. 2.22a).
- Nicolet Magna IR Spectrophotometer (Fig. 2.22b).
- *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. 2.22e).
- QUV weathering chamber, Q-PANEL, for accelerated ageing tests (Fig. 2.22d).

- BROOKFIELD LVDV-I+ Viscometer.
- KSV CAM200 goniometer for measuring contact angles (Fig. 2.22f).
- 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 2.22. 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 have the equipment necessary for complete study of the materials used as reflectors in solar concentrating systems. These labs allow the characteristic optical parameters of solar reflectors and their possible deterioration to be determined. These labs have the following equipment for both quantitative and qualitative measurement of the reflectance of reflective surfaces:

- Four portable specular reflectometers, Devices and Services Model 15R, for measurement of specular reflectance at 660 nm at different aperture angles (7, 15, 25 and 46 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 68º incidence angles (URA).
- Nikon D3 camera and 90 cm Cubalite kit for photos of specular surfaces without parasitic reflections.
- Zeiss Axiomicroscope model CSM 700 (with magnifications of 5, 10, 20, 50 and 100) for finding the profiles and roughness of highly reflective surfaces.
- Optical bench with advanced features for mounting optical devices for the development of new measurement instruments.

The solar reflector durability analysis lab is designed for accelerated ageing tests of these materials for the purpose of predicting in a short time, the behaviour of these materials during their useful lifetime. To do this, the environmental variables producing deterioration 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 installed for these accelerated ageing tests:

- ATLAS SC340 weathering chamber for temperature (from -40 to+120ºC), humidity (from 10 to 90%), solar radiation (from 280 to 3000 nm) and rainfall of 340L.
- Control Técnica CSF 500A 500-L salt spray chamber with temperatures from 10 to 50ºC
- Erichsen salt spray chamber with temperatures from 10 to 50ºC
- Humidity and ultraviolet radiation chamber, ATLAS UV-Test 340 nm
- Hönle UVA Cube Ultraviolet radiation chamber
- Acid rain chamber, 300 L and temperatures up to 70ºC and humidity up to 100%, Ineltec CKEST 300
- Sandstorm chamber with speeds up to 30ºm/s and concentrations up to 2.5 g/m3
- Erichsen 494 cleaning abrasion device, with several cleaning accessories.
- Two Nabertherm LT 24/12 and LT 40/12 Muffle Furnaces

- Several devices for application of thermal cycles specially designed at the PSA.

Figure 2.23. 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.

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).

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.

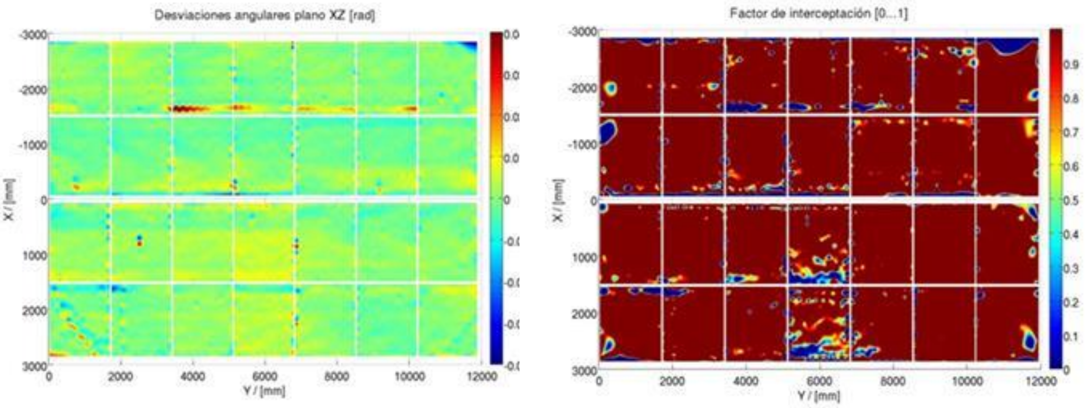


Figure 2.24. Angular deviations (left) and intercept factor (right) of a parabolic-trough collector module analysed by photogrammetry

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).

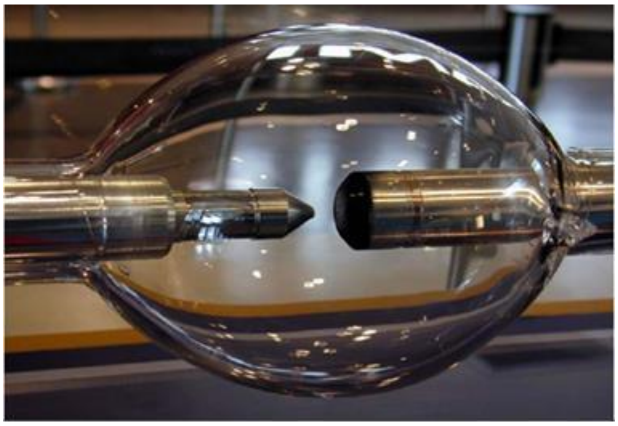
2.1.2.5 Accelerated ageing and durability of materials lab

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. 2.25) that can reach fluxes of up to 1400 kW/m^2



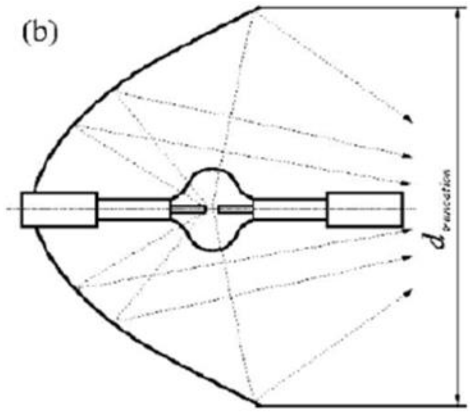


Figure 2.25. Xenon lamp used in the solar Simulator and configuration of the lamp and concentrator

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) **Volumetric test-bed**

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

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

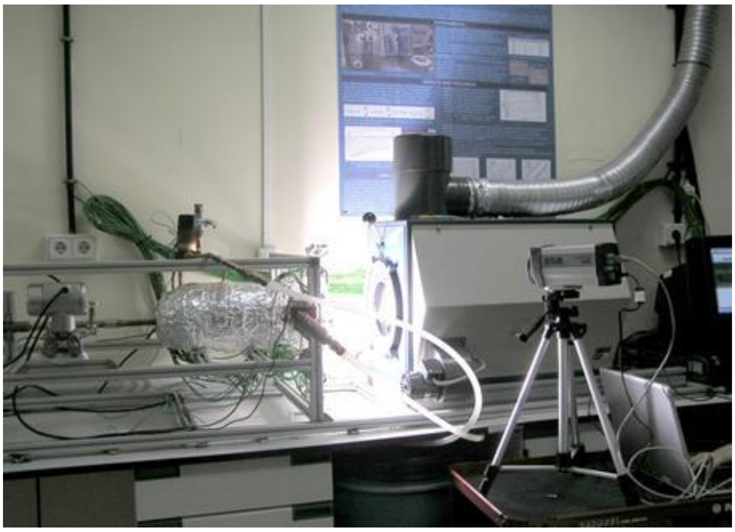


Figure 2.26. Operation of the 4 kW Xenon lamp

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) **Regenerative thermal storage test-bed**

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. 2.27) and dynamic (Fig. 2.28) thermal characterization of porous beds.

The two possible configurations are:

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

The system consists of six power heating resistor with a total power of 15000 watts electric energy. They heat the air up to a target temperature (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.

Figure 2.27. Front view of the lab-scale regenerative storage system in static arrangement

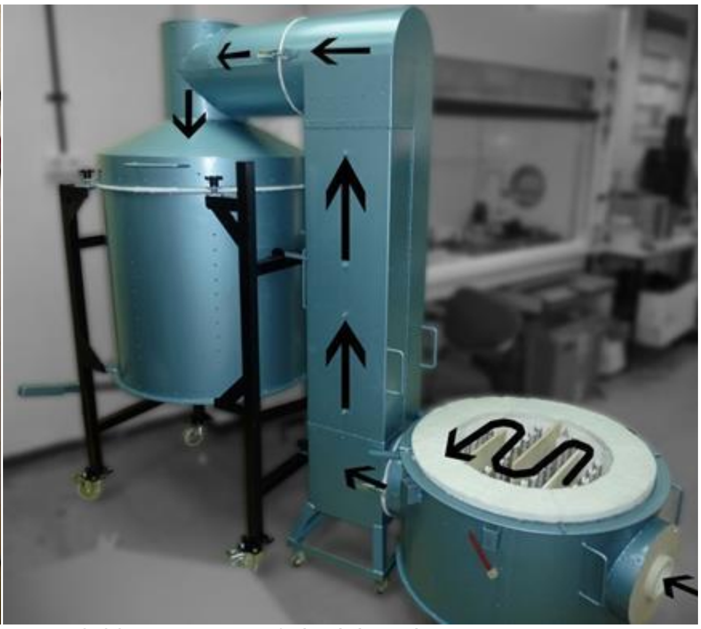


Figure 2.28 Front view of the lab-scale regenerative storage system in dynamic arrangement

The total power consumption is recorded, with a three-phase electrical measurement, to match the energy balances and the heat losses. Moreover, the external surface temperature mapping is registered by a thermograph camera, which offers a complete image of the external chassis of the tank.

2.1.2.7 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 2.29.

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.

Figure 2.29. Solar Simulation Loop for evaluation of hydrogen production processes

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.

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.

Figure 2.30. View of the PSA Radiometry laboratory.

2.2 Experimental Installations for Environmental Applications of Solar Energy

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 252 stationary solar collectors (CPC Ao Sol 1.12x) with a total surface area of 500 m^2 arranged in four rows of 63 collectors. The maximum working temperature of the solar field is 100˚C since the collectors are connected to atmospheric pressure storage tanks in an open loop. The thermal storage system consists of two water tanks connected to each other for a total storage capacity of 24 m^3. This volume allows the sufficient operational autonomy for the fossil backup system to reach nominal operating conditions in the desalination plant.

Figure 2.31. 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 of a concentrating solar thermal power plant (CSP) and a water desalination plant (CSP+D), which makes use of the steam turbine (extracted or exhausted) to drive the thermal desalination process. The basic purpose is to simulate and analyse the various possible configurations for integrating a thermal desalination plant in a solar thermal power plant. The test bench enables the operating conditions of different types of commercial turbines and interconnection configurations to the PSA multi-effect (MED) desalination plant to be simulated.

The system power supply is thermal energy coming from an existing parabolic-trough collector field able to deliver thermal oil with temperatures up to 400°C and an auxiliary electrical power system that raises the temperature when necessary. The facility makes it possible to simulate any turbine that could be used for simultaneous production of electricity and water from concentrated solar energy on a scale up to 500 kW.

Figure 2.32. 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)

There are a series of steam ejectors for this purpose that can operate with motive and exhaust steam for a variety of Rankine Cycle turbine outlet conditions. Other types of steam from other intermediate extractions can also be reproduced. The test bed is also designed to study the possibility of using a part of the exhaust steam from the turbine outlet by regenerating it with steam from an intermediate extraction to power an MED desalination plant. The main underlying idea is to attempt to use the first MED plant cell as the condenser in the power cycle, reducing Rankine Cycle cooling requirements and making use of that thermal energy to produce desalinated water. The facility is also ready to serve as a test bed for small turbines (up to 500 kWth).

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).

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.

Figure 2.33. NEP PolyTrough 1200 solar field

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 Solar ORC Facility

This facility, erected in 2009, was designed to evaluate the feasibility of solar organic Rankine cycles for electricity production at medium temperatures. The facility currently implements a 5-kW$_e$ prototype organic Rankine cycle generator manufactured by the Swiss company Eneftech. The prototype presents an internal heat regenerator and condenser cooling system based on water. The three-phase electricity generated, once measured and the wave analysed, is dissipated through a resistance system which is also cooled by the before-mentioned water circuit. The prototype proposes two innovations for improving energy transformation process efficiency:

1) The turbine is a scroll expander, specially designed for this application. To date, the scroll expanders used for ORC power applications have been the reverse cycle compressors used for cooling.

2) Solkatherm SES36 working fluid is used, so the cycle inlet temperature is higher than other similar facilities, thereby reaching a higher theoretical performance.

To evaporate the working fluid, the cycle requires thermal input power of 25 to 30 kW, with evaporator inlet temperature of around 200°C. To supply this energy, the prototype is connected to the thermal oil tank in an existing parabolic-trough collector solar field that is able to deliver temperatures up to 300°C. The dimensions and type of connection made enable close control over prototype inlet temperature stability and operating conditions. This facility therefore provides the infrastructure necessary for evaluating mid-temperature solar ORC schemes.

Figure 2.34. Solar ORC experimental facility

2.2.5 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 90ºC.

Figure 2.35. 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 but allows for testing other thermal desalination applications. Two membrane distillation units have been evaluated: the Oryx 150 supplied by the German company Solar Spring GmbH, which is a spiral-wound permeate gap distillation module, and the WTS-40A unit from Dutch company Aquaver, which is based on multi-stage vacuum membrane distillation technology using modules fabricated by Memsys.

2.3 Experimental Installations for Solar Detoxification and Disinfection of Water

2.3.1 Solar Treatment of Water Facilities

The solar detoxification and disinfection facilities consist of several pilot CPC (compound parabolic-trough collector) plants and a PTC (Parabolic-Trough Collector) which has a 32 m^2 collector surface with two-axis solar tracking and a concentration factor of 10.5 suns. The 56-mm-diameter absorber tube is made of 2 mm thick borosilicate glass.

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 small twin prototypes (refitted in 2007 and called SOLEX) for parallel experiments. Each 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. The cover may be removed to compare the effect of temperature in similar experiments. 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. 2.41) consisting of three tanks: a 165 L conical tank for wastewater conditioning before treatment, a 100 L conical recirculation tank and a 170L 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.

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.

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.

There are also four ultraviolet solar pyranometers, one for measuring direct radiation with solar tracking, and three for global radiation: one placed horizontally and two tilted 37º (the same angle as the CPCs) to the Earth's surface. Registered information is stored in a database for later evaluation.

Additionally, in 2010, as one of the activities co-funded by the Ministry of Science and Innovation (MICINN) under the Special State Fund for Dynamization of Economy and Employment (*Fondo Especial del Estado para la Dinamización de la Economía y el Empleo* – Plan E) and FEDER, the facilities were updated and new scientific instrumentation was acquired for solar water treatment (SolarNova Project - ICT-CEPU2009-0001). The solar water detoxification facility, auxiliary systems and piping and instrumentation for the CPC photo-reactors known as SOLEX and CADOX (described above), were modified (Fig. 2.36 (a) and (b)). Furthermore, the tanks that had been used up to then for distilled water storage and supply for the pilot plants were replaced.

(a) (b)

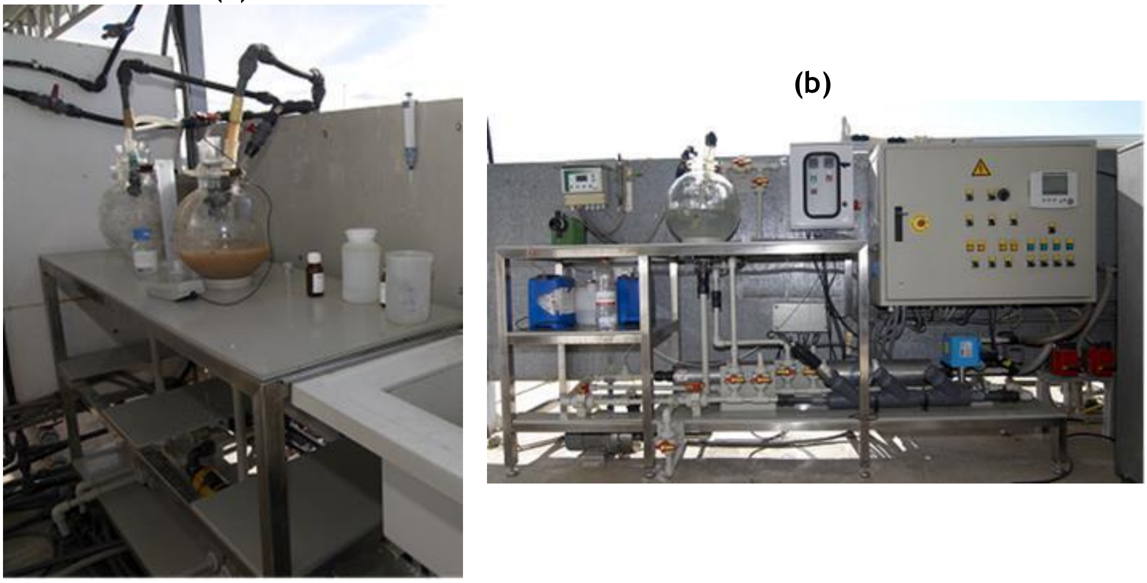


Figure 2.36. New auxiliary facilities and instrumentation in the CPC photo-reactors (a) SOLEX and (b) CADOX.

Another action performed within the Plan E, was the acquisition of new pilot plants destined to the solar water disinfection program:

1) Two CPC photo-reactors (CPC25) for duplicate photocatalytic disinfection experiments (suspended and immobilized TiO_2) and photo-Fenton with volumes of 7 to 25 L. Each of these solar reactors is made up of five borosilicate glass tubes and has a total illuminated surface of 1 m^2, an illuminated volume of 11.25 L and a total volume of 25 L (Fig. 2.37 (a)).
2) Two CPC (CPC-SODIS) photo-reactors for discontinuous operation. These two 25 L stationary reactors are completely exposed to solar radiation. Each of the reactors has a large 0.58 m^2 aperture CPC mirror, in the focus of which it is a 20 cm (outer diameter) borosilicate glass tube. (Fig. 2.37 (b)).
3) A new CPC (FITOSOL-2) photo-reactor similar to that installed in 2008 (known as FITOSOL and described above). This collector has 20 borosilicate glass tubes with a 60 L total treatment capacity and an illuminated area of 4.5 m2. It is used for disinfection tests with water polluted by all kinds of microorganisms and aimed for the reuse of water from wastewater treatment plants. It has a temperature control system that allows working at constant temperatures ranging from 20 to 55ºC, several dissolved oxygen measurement points and air injection points to analyze the effects that oxygen injected in the line has on photocatalytic disinfection (Fig. 2.37. (c)).

In addition, a hangar (Fig. 2.38 (a), (b)) has been constructed near to the laboratory so that the new installations described below could be placed there. The hangar has a gas distribution system, an UPS (Uninterruptible Power Supply), three-pin plugs, a centralized system of tap and demineralized water and an optical fiber connection. Recently, a sinkhole has been built to collect all wastewaters after the experiments.

Figure 2.37. New CPC photo-reactors installed in 2010 for solar water disinfection applications: (a) CPC25, (b) CPC-SODIS and (c) FITOSOL-2.

Figure 2.38. North (a) and south (b) view of the new hangar to accommodate new installations.

The new pilot plants installed in the hangar (Fig. 2.38) are:

1) A 10 L Anseros PAP ozonation system (Anseros Klaus Nonnenmacher GmbH, Germany) for batch operation (with ozone production of up to 44 g O_3/Nm^3 for a gas flow of 0.2 Nm^3/h), with a thermic ozone destructor coupled to the re-

actor exhaust in order to avoid its release into the working area (Fig. 2.39 (a)).

2) The nanofiltration (NF) system consists 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 45º 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. The main parameters of the nanofiltration process are monitored by a SCADA system (Fig. 2.39 (b)).

Figure 2.39. New pilot plants located in the new hangar: Ozonation (a), Nanofiltration (b), Biologic system (c) and disinfection UV/filtration (d).

3) A biological pilot plant with a double depuration system. It has an IBR (Immobilised Biomass Reactor) system with a total volume of 60-L: three IBRs of 20-L each one; and a SBR (Sequencing Batch Reactor) system: two SBRs 20-L each

one. These modules use the same reception tank (200L) as well as the pH and oxygen dissolved control systems and electronic equipment (Fig. 2.39 (c)). In addition, this plant can be operated in continuous or in batch mode. For the batch operation, two conical decantation tanks (40-L) are used. Data acquisition of the three MULTIMETERS (M44 CRISON) is done by means of programmable relays and the main parameters are monitored by a SCADA system.

4) A UV/filtration pilot plant (Fig. 2.39 (d)) for microorganisms' removal from water prior to any disinfection test with spiked bacteria, spores or cysts. The maximum operation flow is 200 L/h.

Thanks to the SolarNOVA project (ICT-CEPU2009-0001), co-funded by MICINN and FEDER, a filtration/flocculation plant was also acquired for raw wastewater pre-treatment. This plant is designed to treat 1 m^3/h of water and it has two centrifugal pumps that can operate in manual or automatic mode. Raw wastewater is stored in a 0.5 m^3 tank, equipped with an automatic control to stop pumping in case the low level alarm becomes active. Water goes through a silex filter (75 µm) and then through two microfilters (25 and 5 µm) and it is finally stored in a second 0.5 m^3 tank. The silex filter has a device for automatic operation and washing, as well as a flow regulator and manometers for pressure reading (Fig. 2.40).

Figure 2.40. Filtration/flocculation pilot plant for treating raw water.

2.3.2 PSA Water Technologies Laboratory

Under the SolarNova Project (ICT-CEPU2009-0001), co-funded by MICINN and FEDER, a new laboratory was built (Fig. 2.41). The new Solar Treatment of Water Research Group Laboratory is located in a recently remodeled building for laboratories (RES09-SGPICYT-09), formerly an office building which was transformed under this activity.

The new PSA water technologies laboratory is about 200 m^2 distributed in six different rooms (Fig. 2.41):

1) The main laboratory is 94 m^2 (Fig. 2.41). It is equipped with all of the conventional laboratory equipment: four work bench islands, 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.

Figure 2.41. General view of the new PSA Water Technologies Lab

2) The chromatography room is 23 m^2 (Fig. 2.42 (a)). It contains all the analytical equipment related to environmental chemistry: two liquid chromatographs (quaternary pump and diode array detector with automatic injection, HPLC-DAD and UPLC-DAD), gas chromatograph/mass spectrometer with purge and trap system (analysis of volatile compounds dissolved in water), four ion chromatographs: one configured for isocratic analysis of cations (Dionex DX-120) and another configured for isocratic analysis of amines and cations (Metrohm 850 Professional IC), and two for gradient analysis of anions and carboxylic acids (Dionex DX-600 and Metrohm 872 Extension Module 1 and 2). All of them have conductivity detectors (Dionex ED50 and Methrom 850 Professional IC detector). Besides, in this room, there are two total organic carbon (TOC) analyzers with their corresponding autosamplers (total carbon analysis by catalytic combustion at 670º C) and a total nitrogen analyzer. In addition, an ultrafast real-time quantitative PCR (Polymerase Chain Reaction) equipment is installed in this room. Recently, new equipment has been acquired: a fluorospectrometer and spectrophotometer NanoDrop used to quantify micro-volumes. All of these systems are computerized and integrated in a complete information network.

3) The 27-m^2 microbiology laboratory has a biosafety level of 2 (Fig. 2.42 (b)). All the equipment related to microbiological analysis for disinfection of water containing different kinds of microorganisms (bacteria, fungi, etc.) is located here: four microbiological safety cabinets, two autoclaves, three incubators, two fluorescence and phase contrast combination optical microscopes with digital camera attachment, turbidimeter and pH, dissolved oxygen and conductivity multi-sensor. Besides, automatic grow media preparer and plaque filler, and a filtration ramp with three positions are available.
4) The Scanning Electron Microscope (SEM) room is 11 m^2 (Fig. 2.42 (c)). For the preparation of microbiological samples and catalysts to be analyzed in the SEM, the system is completed with a metal coater and critical point dryer.
5) A 30-m^2 storeroom with direct access from outside for chemicals and other consumables storage. It is organized on numbered and labeled stainless steel shelving with refrigerators and freezers for samples and standards keeping.
6) A 17-m^2 office with three workstations where visiting researchers can analyze the data from the experiments carried out at the PSA.

(a) **(b)** **(c)**

Figure 2.42 New water technology labs: (a) Chromatography lab, (b) Microbiology Lab and (c) SEM (Scanning Electron Microscope) Lab.

2.4 Experimental Installations for 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 four 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.

(a) **(b)** **(c)**

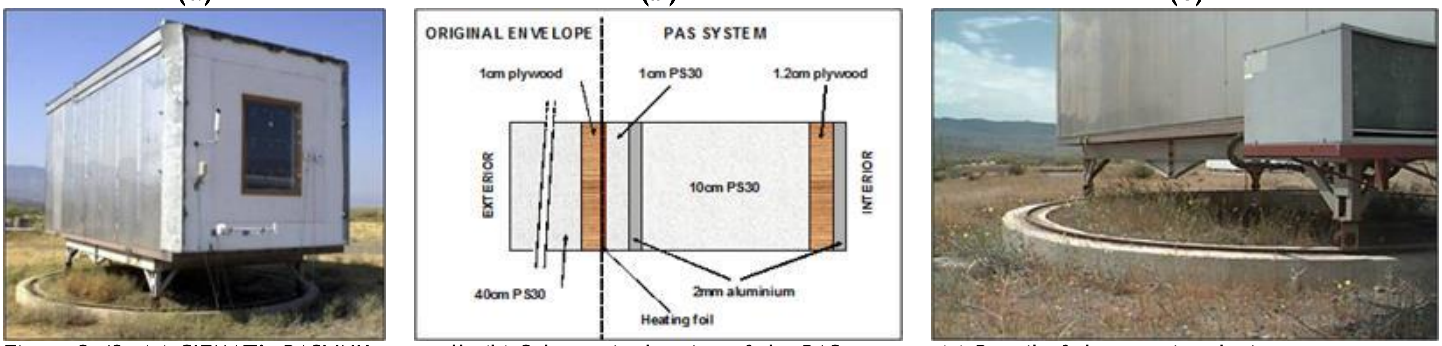


Figure 2.43. (a) CIEMAT's PASLINK test cell, (b) Schematic drawing of the PAS system, (c) Detail of the rotating device

3) 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.

4) 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.
5) 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.

(a)

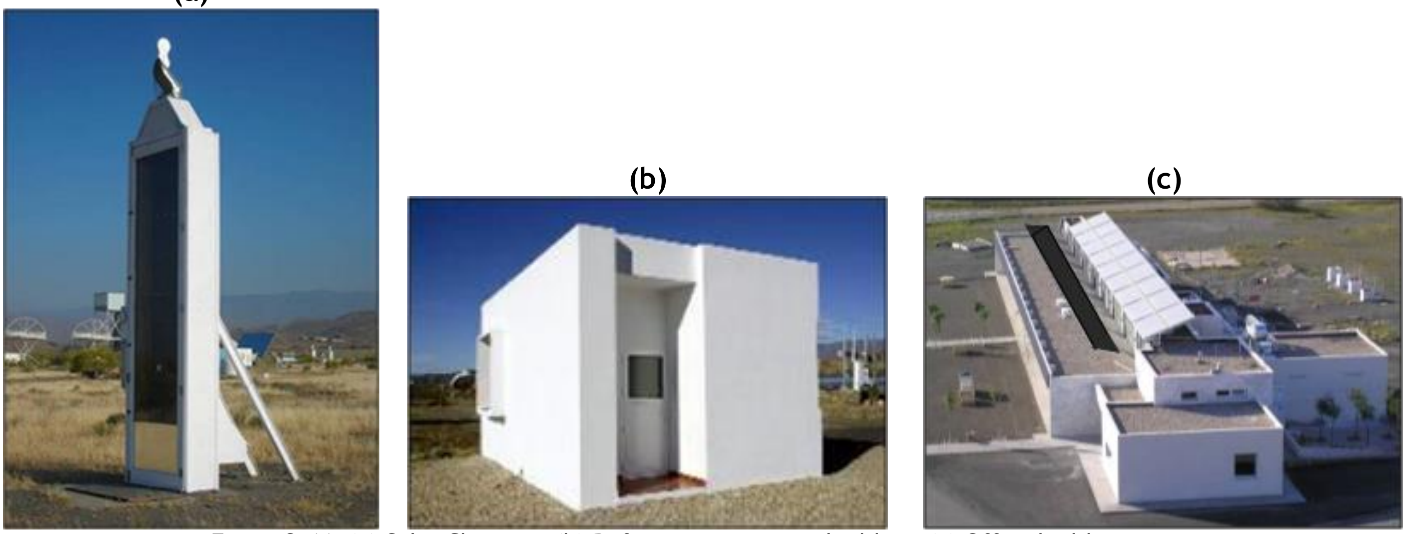


Figure 2.44. (a) Solar Chimney, (b) Reference monozone building, (c) Office building in use.

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 Solar Concentrating Systems unit (USCS in its Spanish acronym) is one of the PSA's R&D units. The Unit's main purpose is to promote and contribute to the development of solar concentrating systems, both for power generation and for industrial processes requiring solar concentration, whether for medium/high temperatures or high photon fluxes. This Unit consists of three R&D Groups:

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

Although the changes introduced in the Spanish legal framework for solar thermal electricity (STE) plants have significantly reduced the profitability of these solar systems, the high number of plants already in operation in Spain kept alive in 2012 a strong collaboration between the STE sector and the USCS Unit. The reduction of the R+D activities promoted by Spanish companies in 2012 was compensated by the growing interest shown by foreign Companies on R+D activities for technology improvement and development of new components for projects promoted in other countries.

A large number of components were evaluated and characterized in 2012 (reflectors, selective coatings, new parabolic-trough designs, and so forth). And at all times, it was attempted to give the many companies that asked us for it, the scientific and technological support they required.

Two other important activities were performed by the USCS Unit in 2012:

- Training and knowledge dissemination: participating in many seminars, Master courses and Congresses related to renewable energies.
- Standardization activities for STE.

Concerning standardization, we participated in all of the forums and working groups that are active for this purpose:

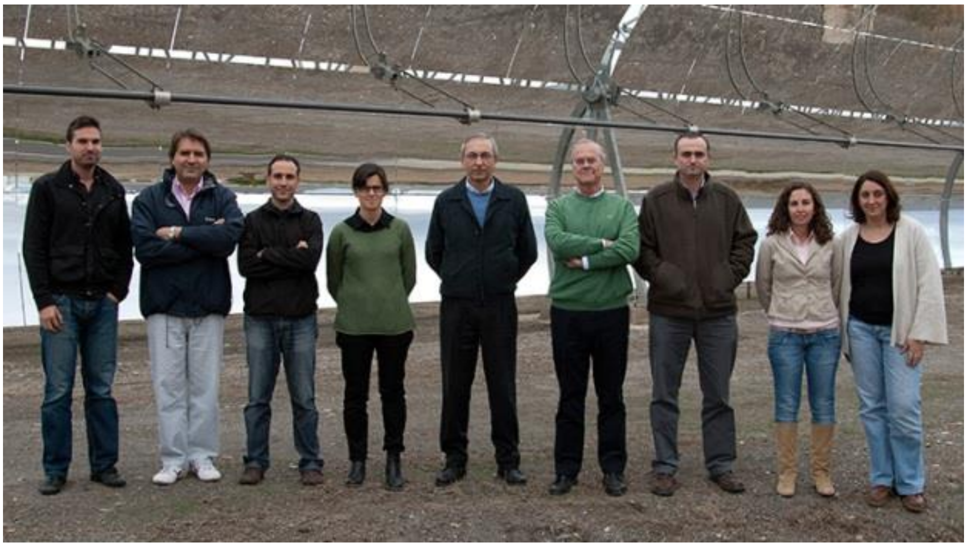
- The ASME PTC-52 standardization committee created in the USA.
- AEN/CTN Subcommittee 206/SC "Solar Thermal Power Systems", jointly created in Spain by AENOR, PROTERMOSOLAR, CENER and CIEMAT
- The STAMP Working Group, created within the framework of SolarPACES
- The IEC/TC-117 "Thermal Electric Plants" Committee launched in 2012. The kick-off meeting of this committee was hosted by CIEMAT on 7th-8th March, 2012

3.2 Medium Concentration Group.

3.2.1 Introduction

Activities carried out by the Medium Concentration Group (GMC in its Spanish acronym) in 2012 are framed by a diversity of fields such as component development for parabolic-trough collectors (PTCs), solar heat integration in industrial processes (RITECA-II project), research on direct steam generation in PTCs (DUKE and GEDIVA projects),and thermal energy storage systems (OPTS project).

The number of technical services given by the MCG continued to be significant, with over 12 contracts underway for activities, such as technology transfer of selective coatings for receivers, characterizing PTCs components, and studying thermal performance and annual production of solar thermal power plants.

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*

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Gema San Vicente gema.sanvicente@ciemat.es

Funding agency: CIEMAT and International and Spanish private companies.

Background: Glass covers of solar systems are coated with antireflective coatings, increasing transmittance around 5%. Self-cleaning properties of the antireflective coatings are also required. Selective absorbers, with good optical properties and high thermal stability are needed to provide optimal thermal performance and plant reliability.

Objectives: Development of sol-gel coatings that increase the transmittance of the glass covers with self-cleaning properties, and selective absorbers with high solar absorptance, low thermal emittance and good durability, aiming to decrease the solar plant maintenance costs derived from collectors cleaning and absorber tubes replacement and to increase thermal efficiency.

Achievements in 2012: Most of the commercial self-cleaning glasses use TiO_2 films. However, the deposition of these films on glass means an increase in the glass reflectance due to the refractive index of this material (above 2). Tailoring the porosity and thickness of these films has made possible to obtain antireflective layers with self-cleaning properties. These properties have been obtained by the deposition of sol-gel SiO_2/TiO_2 bilayers. Values obtained for solar transmittance were around 0.965 and the self-cleaning properties of the materials were confirmed by studying the degradation of both an organic dye and a pollutant present in the air, under UV illumination. A new selective absorber for vacuum receivers has been developed, stable in air at 400°C and in vacuum at 500°C, with a solar absorptance of 0.95 and a thermal emittance at 400°C as low as 0.06. It is protected by a Spanish and European patent and it has been licensed to Weihai Golden Sun Company in China.

Optical Characterization and Durability Analysis of Solar Reflectors, OPAC

Participants: CIEMAT and DLR

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Funding agencies: CIEMAT, German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), AbenerEnergía S.A., ALANOD GmbH & Co. KG, Saint-Gobain Solar, Flabeg GmbH, and TG-Yueda Solar Mirror Co., Ltd.

Background: The feasibility of STE technologies strongly depends on the material used to achieve a suitable solar reflector. Suitable accelerated ageing tests are needed to predict the durability of solar reflectors under outdoor conditions. In addition, guarantees required for high efficiency and durability of the components can only be given by using appropriate standardized testing methods.

Figure 3.2. Dr. Gema San Vicente and Dr. Ángel Morales at Weihai Golden Sun solar receivers pilot manufacturing plant in Beijing.

Objectives: This collaborative project between CIEMAT and DLR is dedicated to establish appropriate optical qualification and durability test methods of solar reflectors. The degradation processes of materials used as solar reflectors under accelerated conditions and outdoor exposure with the goal of establishing lifetime prediction models are investigated.

Achievements in 2012: A significant research activity has started in 2012 under the framework of the ALUMIR project, funded by the BMU, the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. Projects partners are DLR, CIEMAT and three aluminium manufacturers. The goal is to develop new accelerated test standards for aluminium mirrors that correlate with outdoor tests and allow a proper characterization of the materials.

A productive discussion with solar industry was carried out on the topic of reflectance measurement methods using commercially available instruments, based on the interim guideline published in 2011 and develop0ed by DLR, CIEMAT and NREL, in the SolarPACES Task III framework. This led to a second version of the guideline.

Great advancement has been achieved in finding artificial aging tests that correlate to degradation processes in outdoor exposure of front-surface aluminium reflectors with special top coatings and deriving a lifetime prediction model.

Technical support and services have been offered to industry, through specific agreements with several companies to evaluate the optical quality and the durability of their products in order to improve their performance. Highly relevant are the studies with different companies to evaluate the effectiveness of new anti-soiling coatings for silvered-glass reflectors to reduce the soiling rate outdoors and to reduce the cleaning effort (see Fig. 3.3). These studies were initiated in 2011 and interesting results have been obtained in 2012, after 1 year of exposure.

Figure 3.3. Outdoor test stand with reflector samples at PSA in Tabernas, Spain.

Optical and Thermal Performance of Parabolic-Trough Collectors and Components

Participants: CIEMAT

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Funding agencies: URSSA Corp., ARIES Ingeniería y Sistemas S.A., Archimede Solar Energy.

Background: The deployment of parabolic-trough collector technology for solar thermal electricity (STE) in last years has originated the need of redesign testing protocols for determining the optical and thermal performance of large parabolic-trough collectors which is defined by the peak optical efficiency, incidence angle modifier and heat losses.

Objectives: Definition of adequate outdoor testing methods for determining the optical and thermal performance of large parabolic-trough collectors and their components, mainly solar receivers, and qualification of this type of components in testing facilities under real solar conditions.

Achievements in 2012: The qualification of the URSSATrough parabolic-trough collector has finished in 2012. A prototype of the collector is installed in the HTF PTC test loop at PSA, which uses Syltherm 800® as heat transfer fluid. Test involved the analysis of the geometry to determine its intercept factor by photogrammetry and efficiency tests, following a test method defined by CIEMAT, to obtain the peak optical efficiency, incidence angle modifier and heat losses up to fluid temperatures of 390°C. Furthermore, outdoor testing of solar receivers has been also performed in 2012. Different solar receivers developed by the Spanish company Aries and the Italian company Archimede Solar Energy (ASE) have been tested.

Aries patented a new design of receiver with dynamic vacuum produced in the inter-annular space between the absorber and the glass cover. Several units of this receiver type where provided, installed and tested in the EuroTrough type collector of the HTF PTC test loop.

A total of 18 ASE model HCE0I12 receivers were installed in one of the PTC collectors of the PSA HTF PTC test loop for their qualification. The optical performance, concerning absorptance and transmittance, and thermal performance, in term of heat losses (emittance), have been analysed.

Figure 3.4. View of the HTF PTC test loop a) during the testing of solar receivers and b) preparing a PTC collector for geometrical qualification.

Red de Investigación Transfronteriza de Extremadura, Centro y Alentejo (FASE II), RITECA II

Participants: Junta de Extremadura, CETIEX, RECET, CENTIMFE, CTIC, CEVALOR, Universidade de Évora, INRB, Instituto Politécnico de Portalegre, Instituto Politécnico de Beja, Centro Operativo de Tecnología de Regadío, ICTVR, CATAA, CEBAL, CSIC, CIEMAT.

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Funding agency: FEDER funding charged to Programa de Cooperación Transfronteriza España-Portugal (POCTEP) 2007-2013. Cooperation area: Centro-Extremadura-Alentejo. Technology transfer and cooperation network improvement.

Background: The Research networking cross-border of Extremadura, Centro y Alentejo and Spain must be strengthened. This networking gathers research centres and promotes coordinated works which encourage synergies and complementarities in terms of Investigation, Development and Innovation.

Objectives: PSA-CIEMAT participates in the fourth activity of this project (Patrimony, renewable energies and health projects), in action 1 (Renewable Energies) and in task 1. The objective is the integration of renewable energies in the cork boiling process for its optimization. Medium Concentration Group role within task 1 is the design and simulation of a concentrating solar thermal plant to supply the thermal energy demanded by the cork boiling process.

Achievements in 2012: During 2012 it was designed a small-sized parabolic-trough collectors pilot plant for supplying process heat to the ECOTRAFOR plant, located in Badajoz (Spain), which belongs to the *Instituto Tecnológico del Corcho, la Madera y* *el Carbón Vegetal* (ICMC). In the ECOTRAFOR plant, raw cork is processed by immersion in hot water at 98°C for one hour to eliminate any taste before being used in the food industry.

A simplified model of the solar field was developed to take design decisions, such as optimum size and configuration of the solar field and piping layout. Based on the real data supplied by the ICMC, it was calculated that the thermal demand required by the industrial process (including parasitic loads) is 1470 kW. Field size obtained, taking into account the available land, was 10 loops with 4 Polytrough 1200 by NEP Solar collectors per loop. Heat transfer fluid used is thermal oil. The total aperture area of the solar field is 1152 m^2 and its thermal energy is 588 kW. Therefore, the size of solar field that can be fixed in the available land is less than the half of the required by the industrial process.

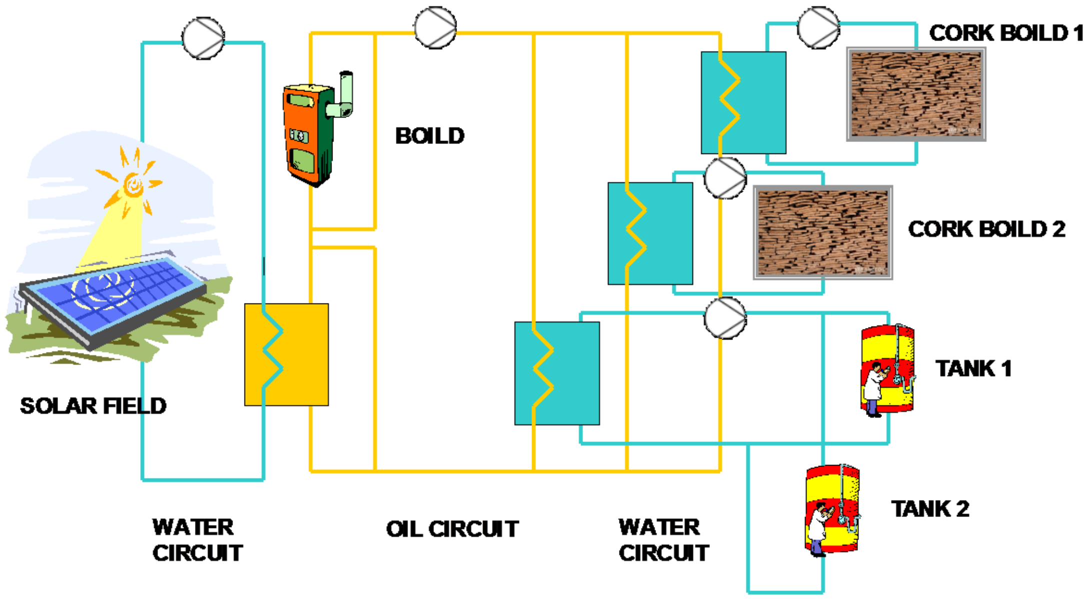

Figure 3.5. Scheme used for the solar field design for a cork industry.

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

Participants: DLR (partner), Solarlite GmgH (partner), CIEMAT (subcontract)

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Loreto Valenzuela, loreto.valenzuela@psa.es

Funding agency: German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU).

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 DISS project three solar field concepts were studied, i.e. recirculation, once-through and injection modes. The currently favoured concept is the recirculation mode, in which the evaporation and the superheating collector 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
- Demonstration of solar direct steam generation at 500°C
- Detailed system analysis with profound cost determination considering the Solarlite SL4600 collector

Achievements in 2012: During this year the detailed engineering, modifications of the DISS test facility, installation of three SL4600 type parabolic-trough collectors, manufactured and installed by the German company Solarlite, and commissioning and start-up of the upgraded DISS facility have been done. Two of these three new collectors are installed at the inlet of the collectors loop, for water pre-heating and beginning of the evaporation process, and the third one in the end of the superheating section. After these works the length of the DISS test loop is 1000m (Fig. 3.6).

The modifications of the DISS test facility have included a complete renovation of the solar receivers. 240 units of Schott PTR70-DSG receivers were installed and 23 of them are equipped with thermocouples to monitor the outer wall temperature of the absorber pipe. Interconnection and other elements in the original test facility have been also modified to meet the requirements of the new working conditions, i.e. increase the outlet steam temperature from 400°C to 500°C.

Figure 3.6: View of the DISS test facility including Solarlite's SL4600 collectors installed for the DUKE project.

Furthermore, the collectors located at the end of the evaporation section and beginning of the superheating section have been equipped with temperature sensors to measure the fluid temperature and detect the end of evaporation, which in the once-through concept is not exactly defined. This information will be useful to improve the process controllers developed.

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 (Jan 2012- Dec 2014)

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/m^2) 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 2012: A simulation code was developed in MatLab to study the thermo-hydraulic steady-state behaviour of a PTC loop. Different geometries of small-sized PTCs were chosen and sensitivity analysis conducted to demonstrate the feasibility of direct steam generation in solar fields for industrial process heat (IPH) applications demanding steam in the range of 200°C.

Furthermore, the RELAP5 code has been used to simulate the behaviour of the PSA DISS test facility. Simulation results have been validated with experimental results. This work has been performed in collaboration with CENIDET from Mexico.

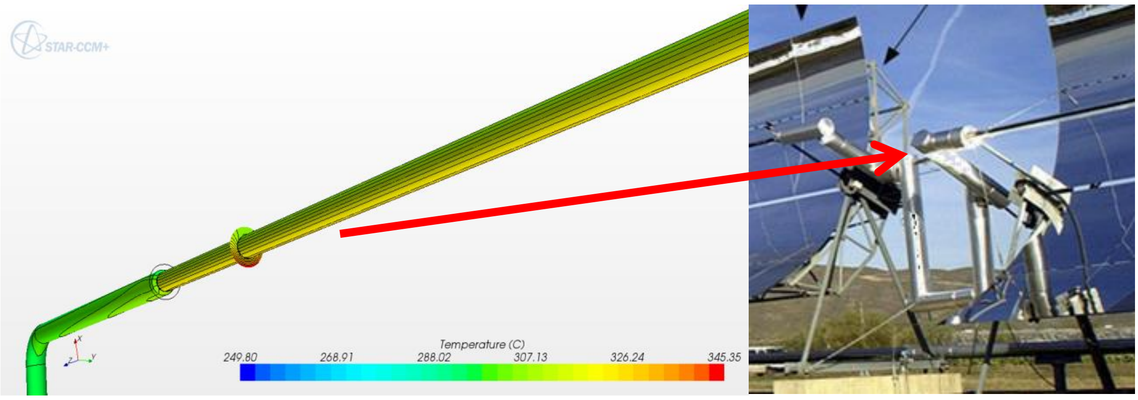
Creating a fully detailed CFD model of direct steam generation (DSG) in PTCs presents a large number of challenges and it requires a multi-stage approach development. The CFD package STAR-CCM+ (see Fig. 3.7) is used to implement the Roshsenow model for nucleate boiling, seamlessly switching to the Volume of Fluid (VOF) approach for film boiling and to perform the investigation. A particular advantage of this approach is the future capability of quickly implementing geometrical changes and new concepts to verify their influence on the DSG performance.

OPtimization of a Thermal energy Storage system with integrated Steam Generator, OPTS (2012-2014)

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



(a) **(b)**

Figure 3.7. a) Temperature profile in a solar pipe calculated using the STAR-CCM+ CFD code, and b) view of a similar pipe section of the DISS test facility modelled and simulated.

Background: Reducing cost of the storage system is a priority within the STE community since it can contribute up to 20% of the total STE 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 2012: In this project, the multipurpose test facility with molten salts as heat transfer fluid erected at the PSA will be used for the experimental evaluation of components, equipment and procedures to check their reliability in molten salt circuits. The specific components and their manufacturers have been chosen in 2012: control valve with special packing, electrical heat tracing systems with two different control approaches, thermal insulation of two different types –and manufacturers- and immersion electrical resistances from two different manufacturers. The specific testing procedures for every type of component have also been defined this year.

The Ciemat's model for characterizing the behaviour of thermocline tanks using liquid as heat transfer fluid has been adimensionalized, resulting in the introduction of a new critical parameter that we called dimensionless velocity, v*. The influence of v* in the thermocline thickness and initial discharge efficiency has been studied, establishing the design equation for building thermocline storage tanks with maximum theoretical efficiency. This equation demonstrates that small thermocline tanks and hence prototypes, are not expected to behave in the same way as large or real-size tanks. Therefore maximum efficiency guideline plots relating tank dimensions, porosity and thermal power have been presented for different temperature intervals.

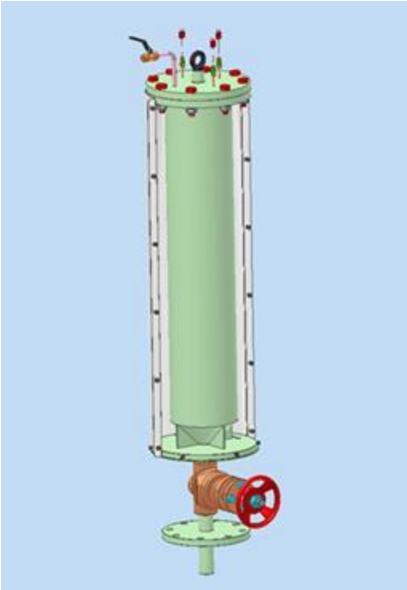


Figure 3.8. Furnace for melting salts

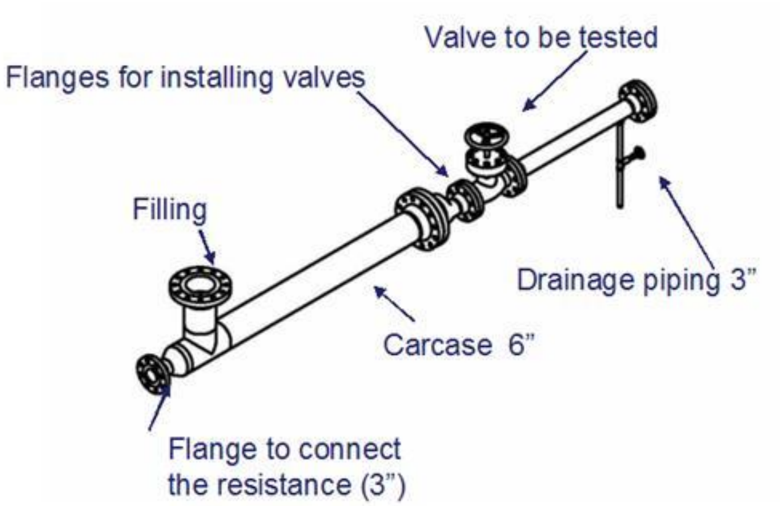


Figure 3.9. Device for testing valves with molten salts

Solving Energy Storage for DSG plants

Participants: CIEMAT

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

Funding agency: CIEMAT (Spanish ministry of Economy and Competitiveness)

Background: Direct Steam Generation (DSG) is seen as one of the most promising approaches to reduce LEC for Solar Thermal power plants. Apart of other technological challenges, a suitable and optimized storage system is still missing.

Objectives: This project aims to contributing resolving the problems of storage system for DSG solar thermal plant by innovative and novel approaches. Up to now, the main focus has been placed on the latent storage component that any storage system for DSG-STE should have.

Achievements in 2012: A new concept design for latent heat storage with phase change materials with low thermal conductivity is under development (see Fig. 3.10). Being an alternative to the actual fin tube design and steam drums, this design assures an efficient heat transfer between the two-phase HTF flow and PCM due to its high heat exchange area, it acts also as steam separator in discharge and implies a low steam HTF pressure drop in charge. The dimensioning of a 100kWth module using a CFD software (STAR-CCM+ v7.02) has been carried out during 2012 and it was presented in the SolarPACES conference 2012.

Using store materials that change phase from solid to liquid statically cause electrical power decreases during discharge due to a diminution of either transferred heat at constant temperature and pressure of the heat carrier, or efficiency when working with sliding pressure. Ciemat proposes to solve this problem with a new concept where store material keeps in a liquid matrix while changing phase. Thus, a nearly constant power curve is possible, and an efficient exchange of energy is assured since convection is the main heat transfer mechanism. A scanning of potential materials to be used has been done.

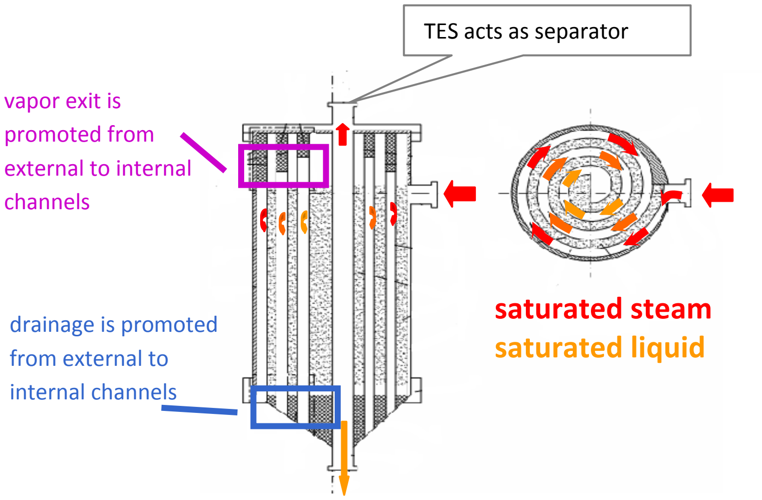


Figure 3.10. CIEMAT latent module with spiral geometry

3.3 High Concentration Group.

3.3.1 Introduction

Activities developed by the High Concentration Group (HCG) during 2012 framed by financed projects are mainly focused on the integration of point focus technology in

Figure 3.11. High Concentration Group staff working at the Plataforma Solar de Almería.

modular systems (SOLGEMAC), and the support of GEMASOLAR plant during his first operational year (HELITOSAL). Success of GEMASOLAR plant implies the success of the HCG because we have been deeply involved on the project: CIEMAT is co-owner of the molten salt receiver design and the HCG has provided technical/scientific support for heliostat design, among other activities. SFERA project has implied too, on the joint research activities, manpower dedication of HCG people.

Other important role of the HCG 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 2012, thus supporting companies on the product development.

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
Antonio Ávila Marín, antonio.avila@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: Current solar thermal power plants are based on conservative devices in relation to the potential of concentrated solar energy. Some consequences are low efficiency regarding to the conversion of direct solar radiation and energy storage systems, lack of schemes for integration in distributed generation and limitations to reach temperatures for generation by thermochemical processes.

Objectives: Establish the knowledge to develop modular, efficient and manageable concentrated solar energy systems. Modular designs are addressing dish-Stirling and multi-tower solar systems for urban areas. Higher efficiencies obtained through volumetric receivers and reactors at ultra-high solar fluxes/temperatures. Improve power management developing thermochemical and electrochemical storage systems.

Achievements in 2012: CIEMAT-HCG is the coordinator of the task named "Solar receivers/reactors for high fluxes and high temperatures", aiming to design and test ceramic and metallic volumetric receivers for these operating conditions. In this period, we have developed two facilities to test receivers and the first characterizations of thermal efficiency have been done. The facility consists of a 4kw solar simulator, a 60mm diameter and 80mm length receiver bed, coil heat exchanger (air-water). The tests were carried out at different incident flux and different air and water flows. To have a good thermal qualification of whole facility, the temperature was measured by 28 thermocouples distributed among the loop: at the receiver surface, along his depth and at air/water heat exchanger inlet and outlet. Metallic receivers were fabricated with AISI310 stainless steel with different wire diameter (0.13 -1.0mm) and precisely woven wire mesh from coarse to micron openings. These configurations allow to test receivers with different constant and/or gradual porosities, in order to investigate the optimal receiver design since the point of view of the thermal efficiency and material durability, able to operate between 700-850ºC.

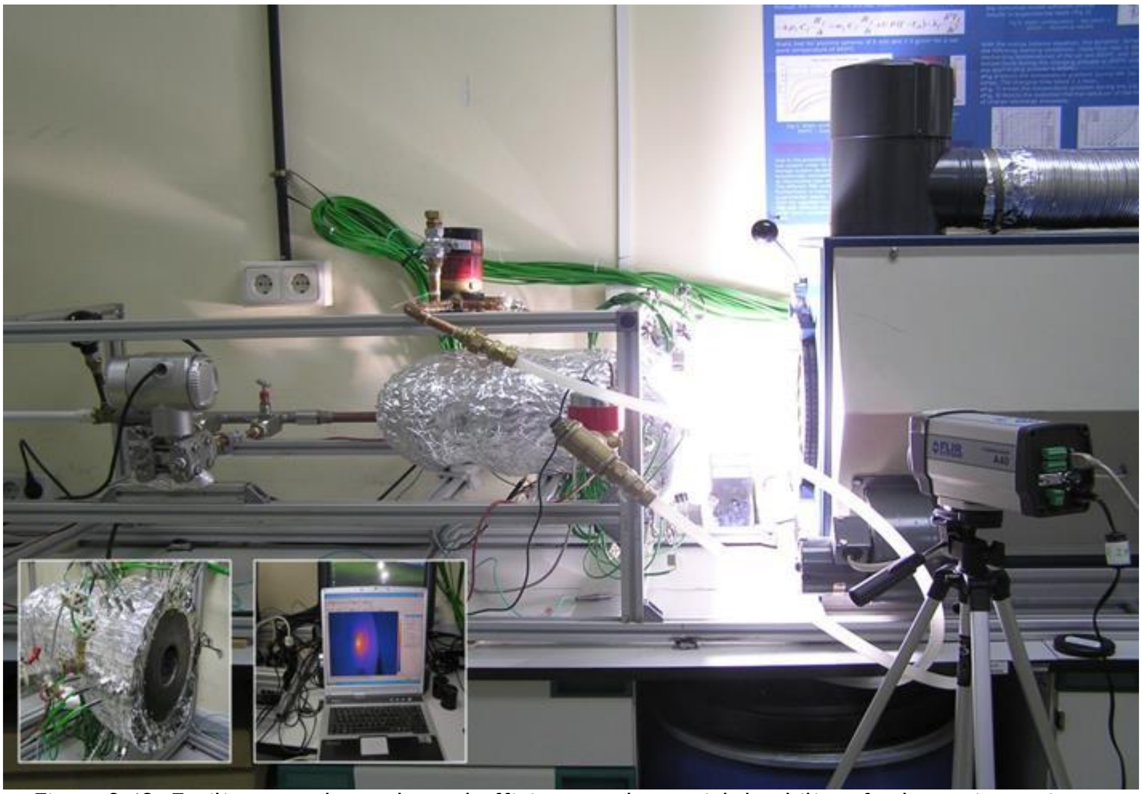


Figure 3.12. Facility to evaluate thermal efficiency and material durability of volumetric receivers.

Research, Innovation and Development for GEMASOLAR Solar Central Receiver Power Plant, HELITOSAL

Participants: Torresol Energy Investment, CIEMAT, Tekniker

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

Funding agency: CDTI-TORRESOL

Background: The good results achieved during the construction, testing and evaluation of the molten salt solar receiver prototype, under a SENER-CIEMAT development agreement - with the support of CDTI - were the starting point of GEMASOLAR plant: a 19MWe central receiver power plant, cooled by molten salt as working and energy storage fluid, promoted by Torresol Energy in Fuentes de Andalucía (Seville).

Objectives: Main objective of the collaboration is to accompany Torresol in the starting-up and first operation years of the GEMASOLAR power plant, carrying out the following activities: operation and maintenance of the plant, prediction and follow-up of meteo data at plant site, aging of materials and components, among others.

Achievements in 2012: Despite the official project ended in December 2011, some remaining tasks have been developed during 2012, focused on the performance and operation of the GEMASOLAR plant. CIEMAT has prepared and teach a course for the operation staff of GEMASOLAR to instruct them on the solar operation aspect of the plant as well as on weather forecast. A 3 dimensional heliostat model of two different GEMASOLAR heliostats has been built in order to corroborate canting activities on-site. The visual impact of solar radiation around the tower plant has been analysed and technical/scientific support has been given to GEMASOLAR staff concerning daily operation and maintenance.

Figure 3.13. Aerial view of GEMASOLAR plant under operation

Optical and tracking performance of heliostats and heliostats components

Participants: CIEMAT

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

Funding agency: Several Spanish and foreign companies

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

Objectives: Objective is 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).

Achievements in 2012: This activity has required an additional effort from the HCG staff in 2012 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 2012 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 prepare and is ready to share with the I+D centres who participate in the different standardization groups (AENOR, SOLARPACES, IEC).

Figure 3.14. Central control room of the 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.

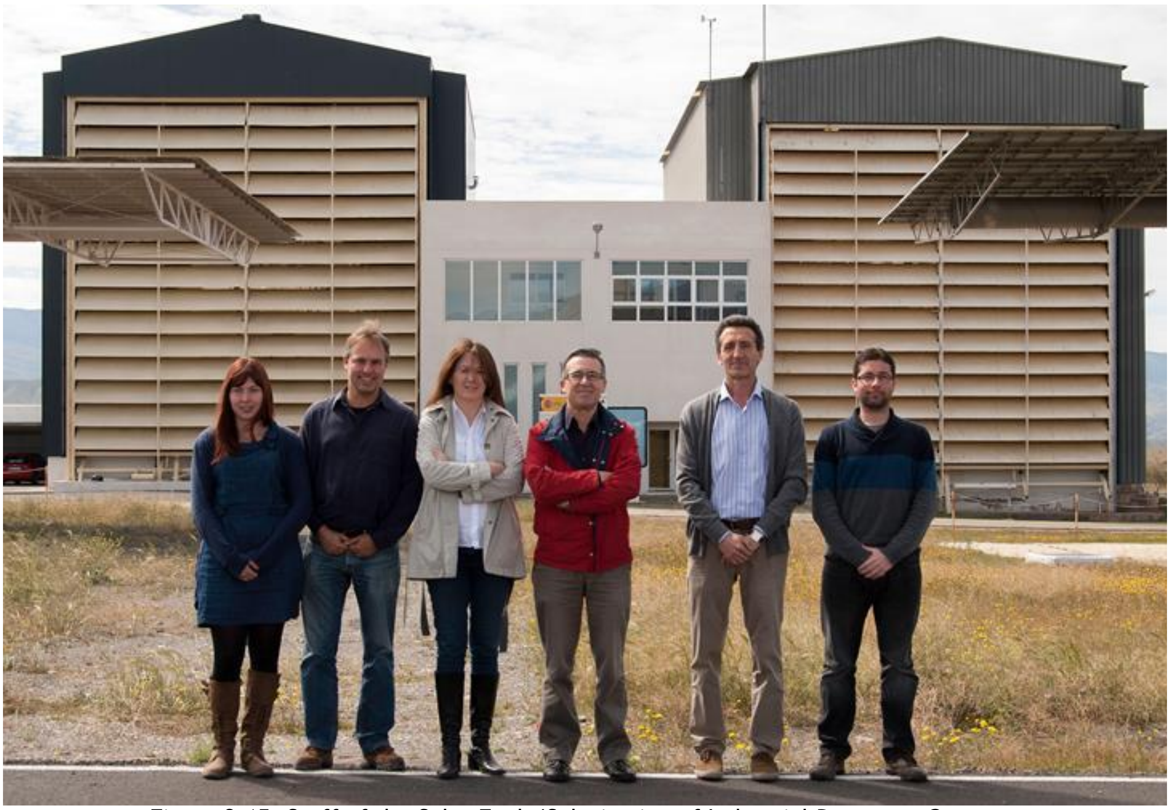


Figure 3.15. Staff of the Solar Fuels/Solarisation of Industrial Processes Group

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 have already been carried out in previous years. A 500 kW plant installation was completed at the SSPS-tower of the Plataforma Solar de Almería in 2009.

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.

Achievements in 2012: During 2012, CIEMAT has continued with the evaluation of performance of the 500 kW Solar Gasification Plant at SSPS/CRS tower. Over the last three years an experimental campaign in the framework of this research project has been performed. Part of this experimental campaign focused on certain sensible parts of the SYNPET reactor, like the ceramic cone and the window. In general, we have confirmed a good behaviour of both parts of the reactor during thermal tests which were performed introducing air to the receiver at flux density near 1.5 MW/m^2 which amounts a total absorbed power of 300 kW at the aperture. Chemical testing campaign was initiated in June by injecting a mixture of steam +coke. Typical mass flow rates on these preliminary experiments were 15 and 90 kg/h of coke and water, respectively. After, several chemical tests some coke particles were deposited on the quartz window and it became broken. In fact 7 out of 9 quartz pieces became broken after several hours of operation causing a general failure of the window configuration (Fig. 3.16). Preliminary results show H_2 concentration above 30% in the outlet stream. Some new proposals are being considered to solve the problem that occurred during the testing campaign with the new window configuration.

Figure 3.16. Photograph showing the reactor window after experimental tests.

HYDROSOL-3D

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

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

Funding agency: FCH-JU-2008-1

Background: The successful testing and the suitable behaviour of the large-scale reactor in the earlier stages of the project HYDROSOL II have provided a basis for the design of a whole plant.

Objectives: This project aims to prepare the erection of a 1 MW solar demonstration plant as it is concerned with the pre-design and design of the whole plant including the solar hydrogen reactor and all necessary upstream and downstream units needed to feed in the reactants and separate the products.

Achievements in 2012: CIEMAT has been in charge of providing a simulation tool and a pre-design of the whole control system for HYDROSOL plant of 1MW. CIEMAT has also supported the validation of the work by experiments and simulation.

For the evaluation, the proposed control system, which has been implemented in MATLAB® and integrated in a LabVIEW® interface, has been connected to the main SCADA (Supervisory Control And Data Acquisition) system by means of an OPC server. During 2012, validation of the control software in the Hydrosol demonstration plant has been carried out. First, the model of the system has been validated with real data. Then, a simulation of the control process has been carried out with the aim of improving the process operating. Finally, an adaptive control strategy has been tested in the real plant with promising results.

An experiment performed in the test campaign carried out in 2012 shown that the reactor temperature is maintained quite well in the two desired references by modifying the number of heliostats which are focused on the target.

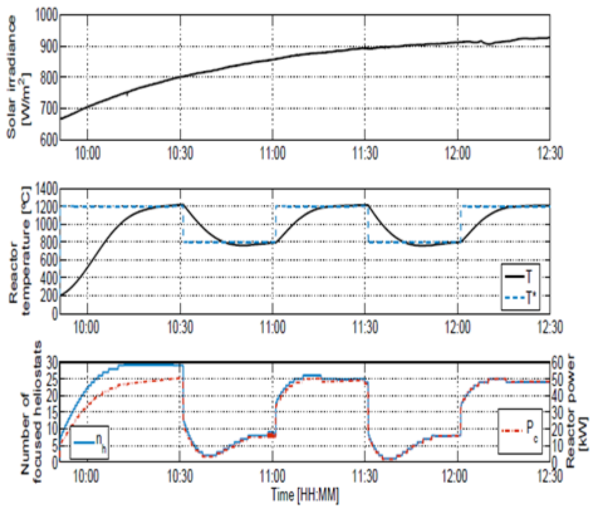


Figure 3.17. Experimental test at HYDROSOL facility with the automatic control

H_2 PLAN_E

Participants: CIEMAT

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

Funding agency: Spanish Ministry of Science and Innovation through the National Plan for Scientific Research, Development and Technological Innovation (National R&D&i Plan).

Background: Research in recent years has demonstrated the efficient use of solar thermal energy for driving endothermic chemical reactions Some high temperature endothermic reactions for converting solar energy to chemical fuels have been investigated by CIEMAT-PSA throughout several National and International projects.

Objectives: Main objective of this project is to tackle major accomplishments and challenges in the SSPS-CRS (small solar power system – central receiver system) solar tower (Fig. 3.17) to provide organizations and research groups the best research and test infrastructure to produce hydrogen by solar thermochemical technologies.

Achievements in 2012: The PSA has two exceptional facilities for the testing and validation of central receiver technology components and applications, the SSPS-CRS and the CESA-1 towers. Both facilities enable projects to be undertaken and technologies validated in the hundreds of kilowatts to megawatt range. They are outdoor laboratories specially conditioned for scaling and qualifying systems prior to commercial demonstration.

Funding through the National Plan for Scientific Research, Development and Technological Innovation offered financing to enable major modifications at the SSPS-CRS test facility solar tower intended to support the increased load caused by the new test banks, installations, and the 4-ton-capacity crane.

A detailed structural analysis carried out at the beginning of this year of the steel structure and the cementations revealed that some reinforcement work was needed before installation of the additional equipment. Fig. 3.18 shows (in green) the additional structure that has been built along this year. In order to increase the overall operating capacity of the plant, some new equipment have been included, i.e. access to pressurized air ($29dm^3/s$, 8bar), pure nitrogen supplied by two batteries of 23 standard-bottles ($50dm^3/225bar$), cooling water with a capacity of up to 700 kW, demineralized water (ASTM type 2) from a $8m^3$ buffer tank for use in steam generators or directly in the process, and the data network infrastructure consisting of Ethernet cable and optical fibre.

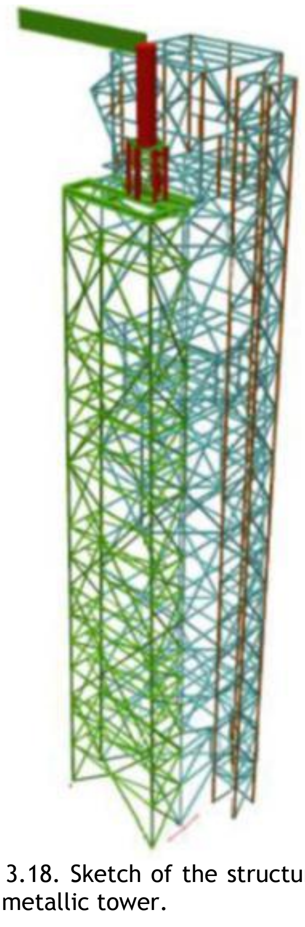


Figure 3.18. Sketch of the structural analysis of the metallic tower.

SolH2

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

Contacts: Raquel Diaz, raquel.diaz@psa.es

Funding agency: Spanish Ministry of Science and Innovation (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 2012: The multi-disciplinary research group on this project moved forward during this year in different activities of the project. In 2012, CIEMAT started some tasks focused on defining a map flux on the reactor aperture at the position where the receiver will be placed, by using “Fiat Lux” software (In-house ray tracing code). This information has been valuable to advance in the conceptual and detailed mechanical design of solar receiver. Universidad de Seville by means of thermal and fluid dynamic analysis and related equipment performed with the aid of CFD (Computational Fluid Dynamics) tools some simulations to allow to determine heat fluxes and reactor efficiencies. In addition, IMDEA contributed to solar receiver conceptual design by taking in charge of the optical-energetic coupling between the heliostat field and cavity receiver. Finally, completed the reinforcement works at the SSPS tower as well as the installation of a third platform to accommodate the SolH2 reactor.

In the year 2013, it is expected that both facilities, based on different technologies, will be designed, constructed and commissioned: bioethanol steam reforming and water splitting through thermochemical cycles with ferrites.

ORESOL

Participants: CIEMAT-PSA (Spain).

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

Funding agency: European Commission 6th Framework Programme ERA-STAR Regions (ERA – Space Technologies Applications & Research for the Regions and Medium-Sized Countries - CA-515793- ERA-STAR REGIONS), ESP2007-29981-E.

Background: The project Oresol has its origin in the EU "ERA-STAR Regions" program, 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 2012: An important detail in the operation of fluidized beds is the control of bubble formation and behaviour. On one hand, bubbles are desired because they are one of the principal drivers of the so-called gulfstreaming, which is the flow pattern of the solids within the bed, and they are also the cause of the excellent homogeneous temperature distribution. On the other hand, bubbles offer a convenient shortcut way for the reaction gas through the bed, worsening this way the usually good solids-gas contacting in fluidized beds. An additional possible problem arises from the contamination of the quartz window by the ejecta from the bubbles exploding on the surface of the bed. To learn about the bubble behaviour in the Oresol reactor, initial tests with an open reactor and air as fluidizing gas were performed at ambient conditions with varying gas flow and different bed heights (fig. 3.19). Size and frequency of the bubbles breaking through the surface of the bed were measured and compared with theoretical predictions.

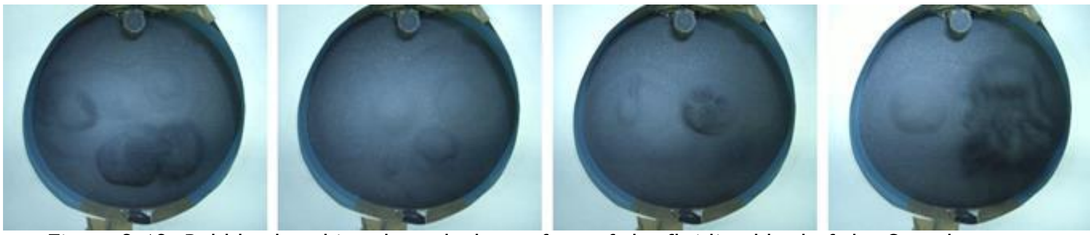


Figure 3.19. Bubbles breaking through the surface of the fluidized bed of the Oresol reactor.

Further activities carried out in 2012 include: the characterization of the particles, the assembly and testing of the electrolyser test rig, the commissioning of the hardware and software of an initial version of the data acquisition system, the acquisition of the gas recirculation pump, and the design and acquisition of several reactor components found to need an improvement over the initial design.

SolarPRO Project

Participants: CIEMAT-PSA (Spain).

Contacts: Inmaculada Cañadas, i.canadas@psa.es
José Rodríguez, jose.rodriguez@psa.es

Funding agency: Spanish Ministry of Science and Innovation through the National Plan for Scientific Research, Development and Technological Innovation (National R&D&i Plan).

Background: Solar thermal energy (STE) is the renewable energy which, because of its characteristics, can and must acquire a significant role in industry, as it can provide the thermal energy necessary for many industrial processes, either directly or through its transfer to a fluid or absorbent material, at different temperatures. In the initial phase of SolarPRO-I some different solar prototypes were developed to study the high-temperature solar process heat generation.

Objectives: During this phase of the project, it is intended to evaluate a new solar simplified prototype reactor, based on the original SolarPRO solar receiver process plant prototype, in which 1180ºC were reached.

Results in 2012: Thermal evaluation of a prototype for a cylindrical volumetric solar receiver system has been carried out by means of commercial Computational Fluid Dynamics (CFD) software for 3D numerical simulation. In this phase of the project, a new selection of insolate material was doing, based on the fluid dynamics simulations, as well as the design and construction of a cylindrical prototype -based on the previous SolarPRO volumetric process plant design- which has been tested at PSA Solar Furnace. The final test campaign was carried out at the beginning of 2012. Characterization tests for a cylindrical prototype solar volumetric receiver system based on the finite elements simulations were completed at PSA Solar Furnace. The cylindrical volumetric solar receiver system was tested with internal modifications such as new shape cavity, refractory material selection, etc., and temperatures up to 1027°C were reached.

Figure 3.20. Experimental test of cylindrical volumetric solar receiver system prototype at PSA Solar Furnace

4. Environmental Applications of Solar Energy Unit

4.1 Introduction

The Environmental Applications of Solar Energy unit (AMES 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 technologies driven by solar thermal energy.
E) Integration of Reverse Osmosis (RO) into Organic Rankine Cycle (ORC) processes, also driven by solar thermal energy.
F) Development of solar polygeneration integrated solutions (power/cooling/water/heat production) based on small parabolic trough technology.

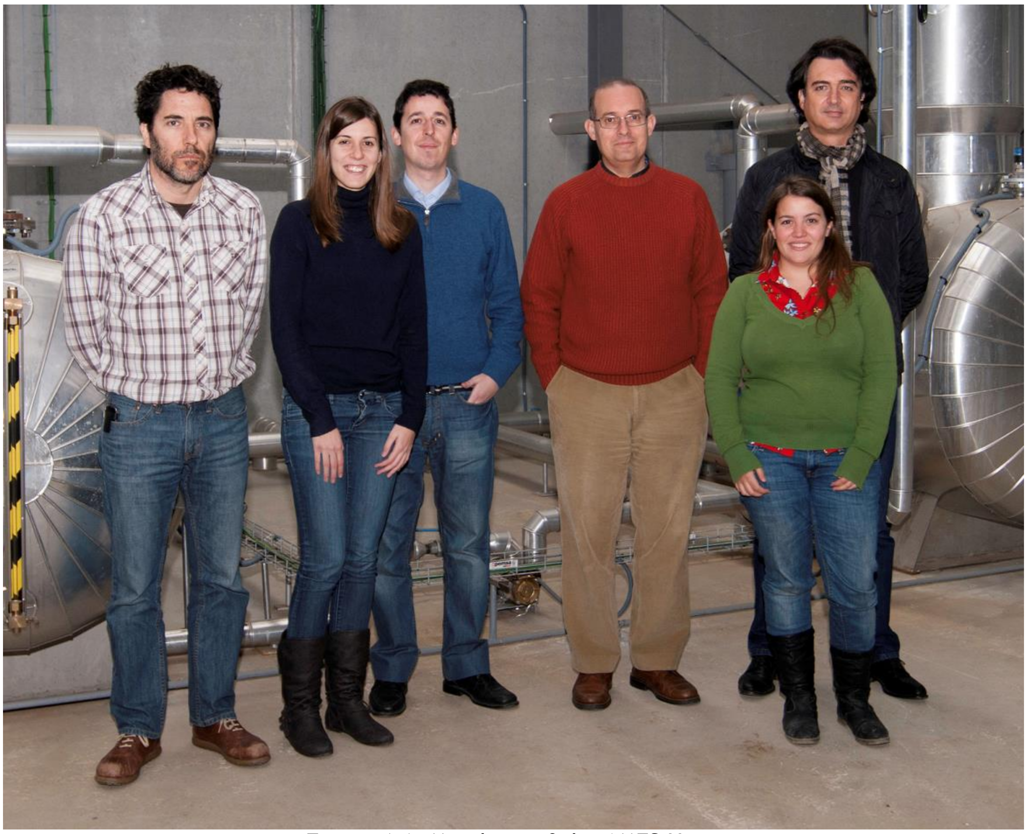


Figure 4.1. Members of the AMES Unit.

During 2012 research activities were developed in all these lines with the only exception of line E (RO driven by ORC) in a portfolio of projects covering both national and international (basically EU funded projects) activities and academic and industrial involvement.

A clear increase in the interest about Solar Desalination processes and technologies have been observed during the last years. The prospects of more expensive energy and more scarce water resources, especially in the countries/regions with higher solar resources availability, is driven the necessity to accelerate the development of more competitive solar desalination technologies, up to the verge of start the launching of the very first large solar desalination projects. In this context, the international relevance of the developed activities is clearly demonstrated by the current following positions hold by the unit:

- Operating Agent of SolarPACES (Solar Power and Chemical Energy Systems) Task VI (Solar Energy and Water Processes and Applications).
- Coordination of EERA (European Energy Research Alliance) Joint Programme on Concentrating Solar Power (JP-CSP).
- Coordination of EERA Subprogramme on CSP and Desalination (CSP+D).

4.2 Projects

Assessment of Combined Solar Thermal Electricity and Desalination potential in the MENA area (SolarPACES)

Participants: CIEMAT-PSA, DLR (Germany), NREA (Egypt)

Contact: Dr. Julián Blanco Gálvez, julian.blanco@psa.es

Funding agency: Solar Power and Chemical Energy Systems (SolarPACES).

Background: Tapping Solar Energy for electricity generation & water desalination is considered an issue with growing interest, in view of the limited water supplies in all MENA (Middle East and North African) area. In the specific case of Egypt, securing water needs for both sustainable development as well as satisfaction of the domestic needs is considered a crucial issue in view of the expected water and energy demand evolution into the coming years. Therefore, and considering the large existing potential for CSP project development in the area, the use of solar energy to the combined production of power and freshwater is a very attractive option.

Objective: The objective of this project is the realization of a technical assessment of possible configurations of Concentrating Solar Power plants with Desalination facilities (CSP+D) to optimize the production of water and electricity within the MENA region, considering the specific coastal DNI potential and water and energy needs. One location in Egypt will be selected to address a specific case study analysing the considered most suitable technical and economic options.

Achievements in 2012: Different cooling options have been analysed related with the feasibility of a CSP+D integrated facility to power and water cogeneration in Port Safaga area (about 50 km South of Hurghada in the Red Sea coast of Egypt, with a DNI of 2496 kWh/m^2). The following CSP+D configurations were analysed from the thermodynamic point of view:

- LT-MED-TVC (low temperature multi-effect distillation with thermal vapour compression) unit integrated into a parabolic trough solar power plant (PT-CSP), considering steam extractions from the high and low pressure turbine.
- RO (reverse osmosis) unit connected to a PT-CSP plant with Dry Cooling option.
- RO unit connected to a PT-CSP plant with Once-Through cooling.
- RO unit connected to a PT-CSP plant with Evaporative cooling.

Figure 4.2. Selected location, at about 2.5 km from the sea, to carry out the study of combined power and desalination plant in Port Safaga (Egypt).

The CSP+LT-MED configuration avoids the necessity of cooling and define the amount of desalinated water to be produced: 41,290 m^3/day of nominal production, figure also considered to all other RO desalination configurations. Global combined efficiency in this configuration was 31.4 %.

In the case of RO, three different cooling possibilities were analysed: dry cooling, once-through (with seawater) and evaporative cooling (using desalinated water produced at the associated desalination plant). In the case of dry cooling, this configuration is heavily affected by ambient temperatures in addition to the power consumption of the fans. In this case, considering summer temperatures in Port Safaga, achieved global efficiency was 28.2 %. In the case of once-through the limitation is given here by the seawater seasonal temperatures. Nevertheless and besides the heavy penalty to pump an important amount of water, the global efficiency was 32.5 %. This is due to the fact that exhaust turbine steam temperatures could be much lower than in the previous cases and, as consequence, we have more expansion in the turbine and the power produced is significantly higher. Finally, in the case of evaporative cooling, desalinated water should be additionally produced and pumped up to the CSP facility. The main limitation is given here by the wet-bulb temperatures, resulting in global efficiency of around 32 %. The last two options (once-though and evaporative cooling) seems to provide the higher global efficiencies to the combined CSP+D facility.

Sustainable Technologies for the Integral Water Cycle (TEcoAgua)

Participants: BEFESA (CIEMAT-PSA as a subcontractor), Canal de Isabel II, Emasesa, Agua y Gestión, Inclam, Fagor Electrónica, Deimos Imaging, Terranova, Micronet Porous Fibers, ITC and Inabensa.

Contact: Dr. Julián Blanco, julian.blanco@psa.es

Funding agency: CDTI (Ministry of Economy and Competitiveness), CENIT-E Program

Background: During the 20th century, the world population multiplied by four, energy consumption by sixteen and water consumption by nine. All of this has led to a series of environmental consequences, the most obvious effects of which are water shortages, increased waste and dumping and augmented climate change. In view of this, an integrated sustainable water cycle is necessary.

Objectives: The main purpose of the project is to generate knowledge and develop new technologies and processes for the integrated water cycle that contribute to ensuring availability and quality of a sustainable water supply, which means limited resources must be managed efficiently, alternative resources generated and associated CO_2 emissions lowered.

Achievements in 2012: During 2012 an experimental campaign has been performed in order to assess the performance and reliability of a solar thermal desalination system based on the coupling of a double-effect absorption (LiBr-H_2O) heat pump to a multi-effect distillation unit. The heat pump has been powered by a hybrid solar-gas system with a 230-m^2 solar field composed of 8 parabolic trough collectors (NEP Solar PolyTrough 1200) developed for industrial heat applications up to 225°C.

This experimental campaign has allowed to obtain enough data to develop computational models for the multi-effect distillation plant, the absorption heat pump and the solar field, as well as recommendations for the layout and operation of the whole plant. With these computational models, a series of simulations have been performed in order to assess the technical and economic feasibility of a pre-commercial plant based on the technology proposed for three different scenarios with different values of direct normal irradiance. An overall performance ratio of around 20 has been obtained experimentally which makes the multi-effect distillation technology to increase its competitiveness versus other options like reverse osmosis.

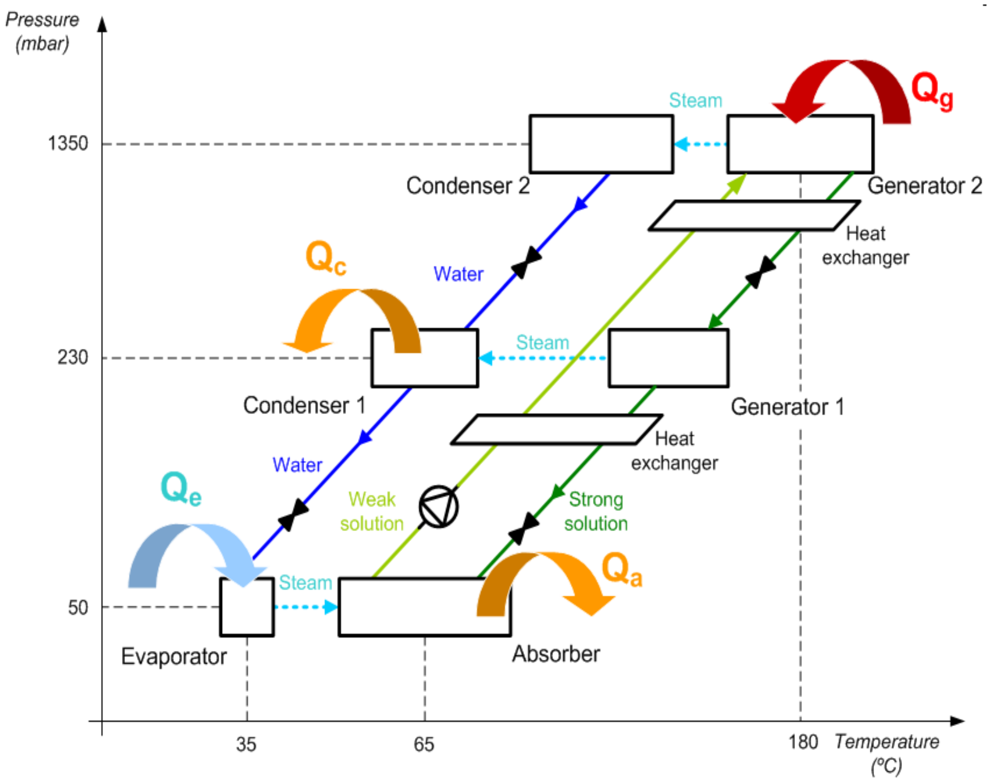


Figure 4.3. PSA double-effect water/lithium bromide heat pump Dühring chart schematic (series flow)

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 2012: Evaluations of autonomous small-scale solar desalination systems (based on membrane distillation) have been carried out at PSA to identify efficient alternatives to electricity consuming desalination. During 2012, tests were done with two prototypes: i) the Oryx 150 from Solar Spring (based on liquid-gap membrane distillation using a spiral-wound module with internal heat recovery); and ii) the WTS-40A from Aquaver (based on innovative vacuum multi-effect membrane distillation modules made by Memsys).

A first analysis of data from the participating SMEs was carried out in order to characterize the improvements achieved after the “Reduce” phase of the project, finding that the data collection needs to be improved and producing guidelines for that.

The Handbook corresponding to the “Replace” phase of the project was elaborated, containing guidelines for the use of alternative energy systems and promoting applications and appropriate technological solutions. Also, PSA participated in the corresponding “Replace” conference organized in Puerto Princesa (Palawan), presenting solar thermal technologies for its use in cooling and drinking water production. In addition, PSA participated on a course for professionals organized in Puerto Princesa (Palawan) in the context of the “Redesign” phase of the project, training architects on the efficient use of solar energy in buildings.

Figure 4.4. ZCR Conference “Replace” in Puerto Princesa (Palawan), June 2012.

Figure 4.5. Participants on the "Redesign" course of ZCR Project, October 2012.

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: Dr. 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 2012: TAAM Project activities have just started in January 2012. The main scientific and technical objectives are to study the effectiveness of the different pre-treatment methods that are required for the use of acid waters with reverse osmosis membranes, the development of an innovative solar thermal system to drive the reverse osmosis process, the development of a zero liquid discharge process using the residual energy from the water pressurization process, and the conceptual design of a thermal storage system appropriate for the temperature levels required by the solar field operation. Activities 1 (State-of-the-art review) and 2 (Design and Assessment of the Process) have been carried out during this first year. The outcome of these two activities will determine the functional and technical specifications of the experimental system that will be implemented and evaluated at the Plataforma Solar de Almería during 2013.


Figure 4.6: NEP PolyTrough 1200 solar collector for process heat applications up to 220 ºC

5. Solar Water Treatment Unit

5.1 Introduction

The unit of Solar Treatment of Water (TSA in its Spanish acronym) was born in 2012, from the Environmental Applications of Solar Energy unit, as a consequence of the strategic plan of CIEMAT to encourage the research activities and applications of solar photochemistry carried out at Plataforma Solar de Almería. The main objective of this research is the use of solar energy for promoting photochemical processes in water at ambient temperature for treatment and purification applications.

Figure 5.1. Staff of Solar Treatment of Water Unit

During 2012, our group consolidated the research activities from previous years, which are:

1) Using solar photocatalytic and photochemical processes as tertiary treatment of the effluents from secondary treatment of municipal wastewater treatment plants, for production of clean water. For this, the presence of both emerging pollutants and pathogens are investigated.

2) Using solar photocatalytic and photochemical processes for treating industrial wastewaters contaminated with several types of pollutants and water reclaim for several applications. Pharmaceuticals, pesticides, and other emerging contaminants are studied.

3) Combining Advanced Oxidation Technologies with other water treatment techniques such as nano- and ultra-filtration, ozonation, biological treatments, etc. for improving the water treatment efficiency and reducing costs.

4) Assessment of photocatalytic efficiency of new materials under real solar light conditions, and their use in solar CPC reactors.

5) Using solar photocatalytic and photochemical processes for water disinfection. Several types of contaminated water sources with a number of water pathogens are under study.

6) Developing solar CPC reactors for different purposes (drinking water, water reclamation, irrigation, etc.), either water decontamination or water disinfection. Experimental models are being used for the design and construction of new solar reactors.

5.2 Projects

Assessment of solar photocatalytic processes for water regeneration, AQUASUN

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

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

Funding agency: Ministerio de Ciencia e Innovación, Plan Nal. I+D+i 2008-2011. Subprograma 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 integral system to control microbial agents (*Escherichia coli*, *Legionella* spp., nematodes and *Cryptosporidium* spp) in wastewater 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 2012: The efficiency of the mere action of solar light and solar photocatalytic inactivation of *E. coli* cells was evaluated. The inactivation kinetics of suspended TiO_2 for *E. coli* in distilled water and simulated effluents of the secondary of a municipal wastewater treatment plant (SMWWTPE) were studied. A range from 10 to 500 mg/L of slurry catalyst was investigated at laboratory scale (200 mL) under natural solar radiation. The best inactivation results were found for 500 mg/L and 300 mg/L of TiO_2 in distilled water and SMWWTPE, respectively. This difference could be attributed to the different physic-chemical characteristics of the waters under study, which may affect the photocatalytic efficiency especially when some chemical species like chloride and carbonates are present. One of the main tasks of this project is to study the inactivation kinetics of *Legionella pheumophila* in water using TiO_2-photocatalysis. For this, two different protocols of detection and enumeration of Legionella in water were used, i.e. the traditional culturing method in selective agar and a special developed protocol based on the use of real time PCR (including

DNA extraction). Up today, we have tested both protocols successfully in distilled water, the culturing method and the protocol for detecting *L. pneumophila* by PCR.

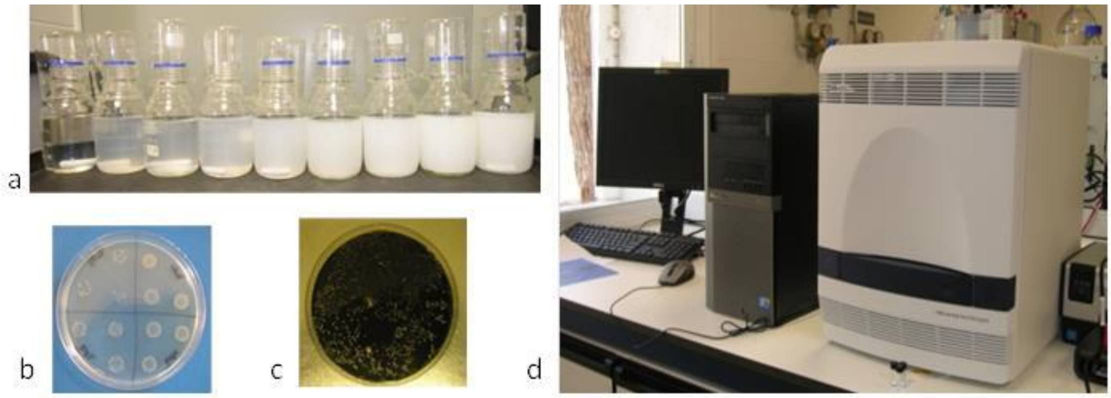


Figure 5.2. (a) Photocatalytic experiment using slurry TiO2 with different concentrations of photocatalyst. (b, c) Petri dishes for E. coli and Legionella colonies growth. (d) Real time PCR (7500-Fast, Applied Biosystem) at PSA laboratory.

Development of new treatment schemes based on solar photocatalysis for wastewater reclamation, FOTOREG

Participants: *CIEMAT-PSA; Univ. of Almeria (Dept. of Analytical Chemistry), Univ. of Almeria (Dept. of Chemical Engineering) (coordinator).*

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

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

Background: The reuse of wastewater requires a physic-chemical treatment which returns water quality to the limits established by regulations. Currently, several technologies may achieve these goals, with different costs and implementation limitations. Therefore, there is a need for research on new technologies which minimize the energy costs and environmental risks.

Objectives: The main goal is to explore solar treatments for wastewater regeneration to be eventually used for agricultural, industrial or recreational purposes. Thus, special attention should be given to both disinfection and decontamination of the effluent of a secondary treatment after standard biological (activated sludge) treatment systems.

Achievements in 2012: During 2012, the durability and photocatalytic activity of supported TiO_2 on glass spheres was evaluated. This was assessed using the degradation reaction of acetaminophen (used as a model compound) spiked in real effluents of municipal wastewater treatment plant (MWWTP). The absence of leached TiO_2 from spheres was discarded on each experiment throughout the measurement of the absorption spectrum (200-400 nm) of the solution. The catalyst coating over spheres showed very good mechanical stability and photocatalytic activity after five cycles of photocatalytic treatment of real MWWTP effluents. These results showed that the 64% of the initial concentration was eliminated in approximately 24-27 min of full sunlight irradiation in solar CPC photo-reactor (Fig. 5.3). No significant differences between the cycles were observed.

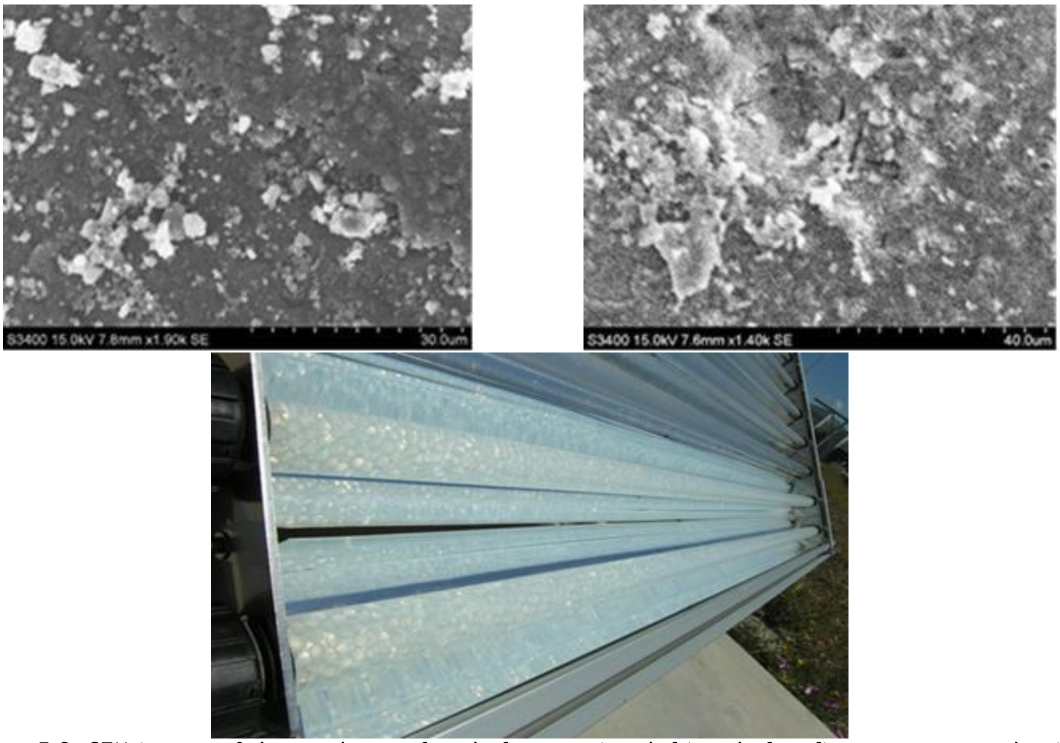


Figure 5.3. SEM images of the catalyst surface before use (top left) and after five treatment cycles (top right). Detail of absorber tubes (CPC) filled with glass spheres TiO2 supported (bottom centre).

Integration of solar photocatalytic and biological treatment processes for the removal of emergent contaminants from wastewaters, EDARSOL

Participants: *Chemical Engineering Department-UEX; Textile Engineering Department-UPV; CIEMAT-PSA (coordinator).*

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Isabel Oller Alberola, Isabel.oller@psa.es

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

Background: Although there is available information about the possibility to treat water contaminants by different technologies, it is also well-known that non-biodegradable substances cannot be treated with standard water treatment technologies. Special attention has recently been given to what are called “emerging contaminants” (ECs). Consequently, the application of more exhaustive wastewater treatment protocols, including the use of new and improved technologies, is a necessary task.

Objectives: The purpose of this project is the study of the combined use of advanced oxidation processes driven by solar energy and advanced bio-treatments for ECs remediation and water reuse (according with Spanish Directive RD 1620/2007). Most of the tasks has been performed at pilot plant scale and applying the most powerful analytical tools.

Achievements in 2012: The optimization (by using Experimental Design tools) of heterogeneous photocatalysis with low amounts of TiO_2 and homogeneous photocatalysis by photo-Fenton (with low iron concentrations) have been performed as tertiary treatment of municipal wastewater treatment plant (MWTP) effluents containing micro-pollutants and ECs. Furthermore, a comparison of these advanced processes with conventional ozonation as tertiary treatment was also carried out from both technical and economical point of view. During 2012 (last year of the project), the optimization of immobilised biomass on packed bed (IBR) systems to reach the effluent quality demanded by legislation in the treatment of real sewage was carried out. The feasibility and degradation efficiency of real municipal wastewaters by IBR system has been deeply studied. The continuous operation of the biological system during more than 30 days showed a maximum treatment capacity in terms of dissolved organic carbon 2.8 L/h (dilution factor of 0.093 h^{-1}). After optimized biological treatment several micro-contaminants (Paraxanthine, Ofloxacine, Hidrochlorothiazide, Gemfibrozil, Furosemide, Diclofenac, Ciprofloxacion, Caffeine, etc.) were determined at concentrations between 28 and 25000 ng/L. This effluent was finally treated by a mild optimized solar photo-Fenton process (10 mg/L of Fe(II), 60 mg/L of H_2O_2 and 32ºC at pH 2.8) with the main objective of eliminating all the micro-pollutants detected and quantified. After 5.47 kJ/L of accumulative UV energy, the 47 micro-pollutants quantified were completely eliminated. Figure 5.4 presents the IBR system combined with the solar photo-reactor employed in for the tertiary treatment of the bio-reactor effluent.

(a) **(b)**

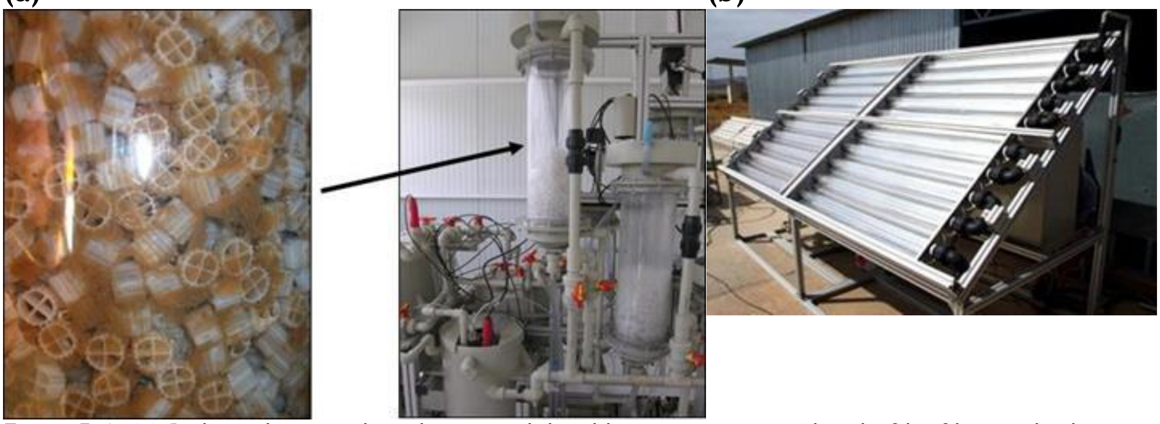


Figure 5.4. (a) Biological system based on immobilised biomass reactors (detail of biofilm inside the reactor) and (b) photo-reactor based on CPC for tertiary treatment of the effluent by solar photo-Fenton process.

Red de Investigación Transfronteriza de Extremadura, Centro y Alentejo (FASE II), RITECA II

Participants: *Junta de Extremadura, CETIEX, RECET, CENTIMFE, CTIC, CEVALOR, Universidad de Évora, INRB, Instituto Politécnico de Portalegre, Instituto Politécnico de Beja, Centro Operativo de Tecnología de Regadío, ICTVR, CATAA, CEBAL, CSIC, CIEMAT.*

Contacts: Aránzazu Fernandez García, arantxa.fernandez@psa.es
Isabel Oller Alberola, isabel.oller@psa.es

Funding agency: FEDER funding charged to POCTEP. *Cooperation area: Centro-Extremadura-Alentejo. Technology transfer and cooperation network improvement.*

Background: The Research networking cross-border of Extremadura, Centro y Alentejo and Spain must be strengthened. This networking gathers Research centres and promotes coordinated works which encourage synergies and complementarities in terms of Investigation, Development and Innovation.

Objectives: PSA-CIEMAT participates in the fourth activity of this project (Patrimony, renewable energies and health projects), in action 1 (Renewable Energies) and in task 1. The objective is the integration of renewable energies in the cork boiling process for its optimization throughout determining the best eco-efficient advanced treatment for cork boiling wastewater reuse by comparing several advanced oxidation technologies (with and without solar light).

Achievements in 2012: In March 2012, around 500L of real cork boiling wastewater were received at our facilities. This wastewater is a dark brown liquor due to a high polyphenols concentration and other corkwood extracts. As a consequence, it presents a high turbidity value, a high dissolved organic charge and a low biodegradability level. First of all, a physic-chemical pre-treatment aimed to stabilize cork boiling wastewater, was carried out in order to eliminate suspended solids (accompanied to a small portion of DOC), as well as to decrease turbidity, in order to increase efficiency of the subsequent chemical oxidation treatment. In a first stage, pH was adjusted to around 2.8. After that, $FeCl_3$ was added in different steps until reaching a final dissolved concentration of 20 mg iron/L. Water was allowed to stand for about 8 hours and, finally, the supernatant was filtered through a 75µm silex filter. Afterwards, the application of ozone alone (at natural and high pH) and in combination with hydrogen peroxide, and solar photo-Fenton process at pilot plant scale have been evaluated (Fig. 5.5).

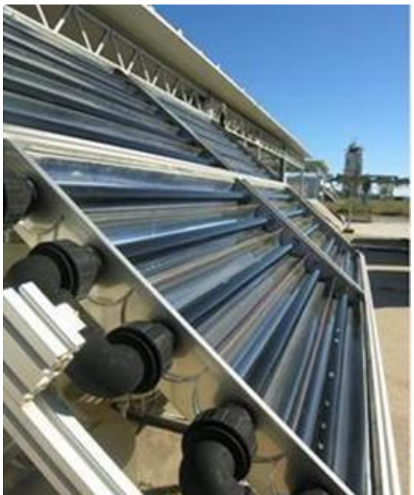
(a)  (b) 

Figure 5.5. Photo-reactor based on CPC for real cork boiling wastewater treatment by solar photo-Fenton process: (a) detail of the borosilicate tubes filled with the wastewater under study, (b) frontal view of the photo-reactor recirculation tank under testing.

The final objective was enhancing real wastewater biodegradability to permit a future combination with a conventional biological system with the consequent reduction of operating costs. In conclusion, both advanced oxidation processes tested have been clearly demonstrated to be able to successfully treat real cork boiling wastewater. The final selection of the best oxidation treatment line must be based on technical and economic analyses.

6 Horizontal R&D&i activities

6.1 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
Ricardo Sánchez (Project Manager), ricardo.sanchez@psa.es

Funding agency: European Commission (FP7-INFRASTRUCTURES-2012-1)

Background: In the Solar Thermal Energy (STE) sector some previous collaborative initiatives have already been undertaken. The SSPS Implementing Agreement, the SolarPACES Implementing Agreement, the SOLLAB Agreement, and SFERA Agreement, an on-going collaborative "Integrating Activity" within the FP7 which may be taken as a successful reference as the main SFERA members have joined EUSOLARIS. More recently an Alliance of research centres, EERA, is being initiated to focus on specific topics.

Objectives: EU-SOLARIS is intended to be a real step forward in the current collaboration models, going far beyond simply networking, small joint projects, exchange of information, personnel, etc., to developing a unique distributed facility. In addition, a joint strategic development plan regarding upgrading, as well as new facilities, will result in maintaining the current leadership of the European Research Infrastructure, Industry and scientific community, and will respond to the requirements in terms of plant concept, fluids and components as well as for new applications of STE thereby representing a step forward in the technology development.

Achievements in 2012: The proposal was submitted for approval on 23rd July, 2012 and the agreement was signed by the commission on 20th November, 2012. Then, the kick-off meeting and the 1st steering committee meeting took place in Seville on 4th December, 2012. In the kick-off meeting several decisions were taken regarding WP detailed work plan, WP leader responsibilities, information management tools and industry needs assessment, among others. In the 1st steering committee meeting some other important decisions regarding the constitution of the Advisory Board for Funding and Public Administration Bodies, and the Advisory Board for Technical and International Cooperation were taken. PSA's legal team began working on the definition of the internal law of the new Entity immediately after the kick-off meeting.

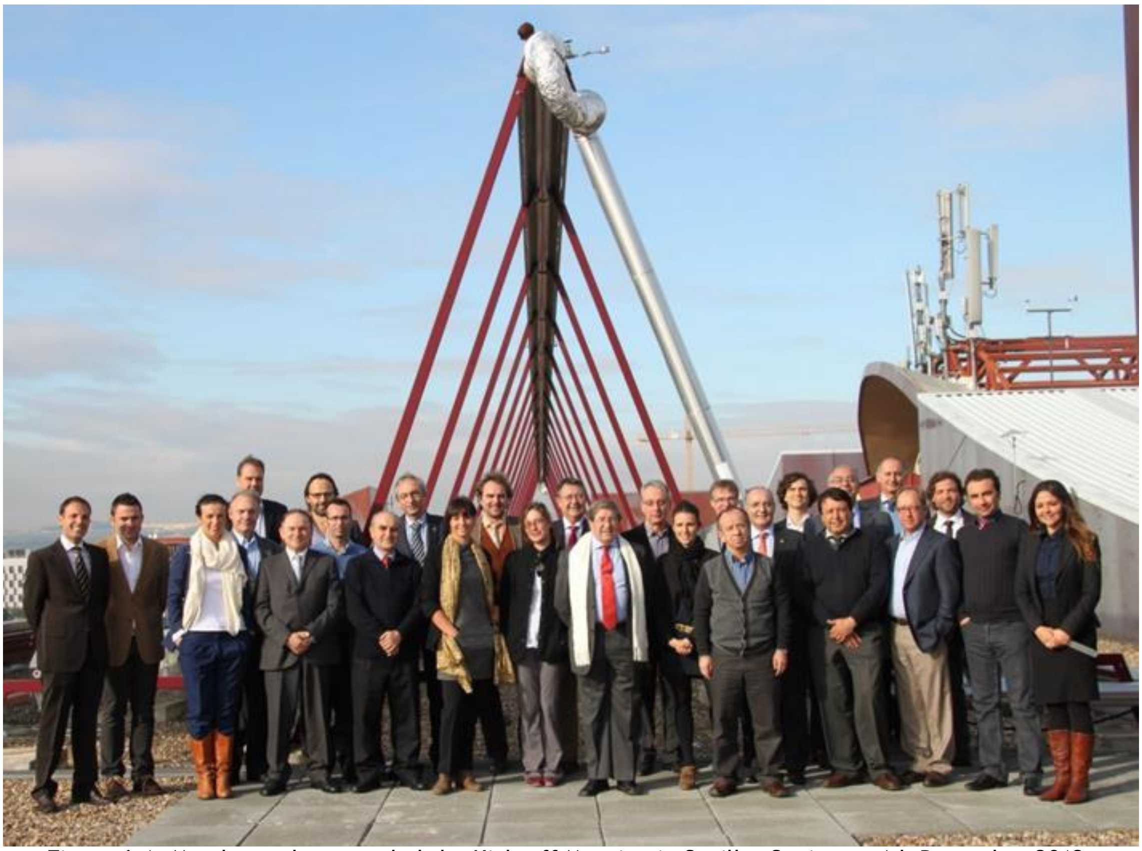


Figure 6.1. Members who attended the Kick-off Meeting in Seville, Spain, on 4th December 2012.

6.2 Solar Facilities for the European Research Area, SFERA

Participants: CIEMAT-PSA (coordinator), DLR, CNRS, PSI, ETHZ, WEIZMANN, ENEA, DIN, UPS, AUNERGY, DEA, INESC-ID.

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: Concentrated solar energy is a very promising renewable source of energy. Europe is a leader in research and development of this technology. Most of the large R&D infrastructures are European and our industry is leading the way in its commercial deployment, now in proposal.

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, which are the partners of this project, and offer European research and industry access to the best-qualified research and test infrastructures.

Achievements in 2012: This project concerns three activities. General results attained during 2012 in each one of these activities are presented here:

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

Within this activity, the organization of the 8th SolLab Doctoral Colloquium on Solar Concentrating Technologies (http://www.sollab.eu/doctoralcolloquium8/) in June 2012 from the 25th to the 26th was carried out by CIEMAT-PSA in Almeria, Spain. One Colloquium is organized every year in order to present the recent results of PhD students preparing their thesis in the various laboratories members of the project and to extract from these results what could be useful for improving services of solar facilities. For this 8th Doctoral Colloquium (the 3rd performed under SFERA frame), 39 PhD students participated.

In addition and together with the SolLab organization, the 3rd SFERA Summer School was also held in June 2012 from the 27th to the 28th by CIEMAT-PSA in Almeria, Spain (http://sfera.sollab.eu/index.php?page=networking_schools). The topic was Solar Thermal Electricity Generation. There were 36 registered participants. In Figure 6.2 a picture of the whole team in the official visit to the PSA is shown.

- Transnational access: Opening the doors of the most relevant R&D infrastructures (CIEMAT-PSA, CNRS-PROMES, SOLTERM-ENEA, SRFU-WEIZMANN, STL-PSI) to interested users, optimizing the use of the facilities and creating critical mass for new research initiatives.

CIEMAT-PSA received in SFERA 2012 campaign 22 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, 14 user proposal forms were finally accepted. In summary, PSA gave access to 14 Research Groups (32 users in total) in the frame of 14 user projects during 55 working weeks during 2012.

- Joint Research: Aiming to develop common standards and procedures for better consortium performance and development of advanced instrumentation and new research infrastructure thus improving the services offered to the user community.

In this activity, PSA coordinates WP 14 (Infrastructure improvements to perform durability predictions of CSP components by accelerated aging). During 2012 the improvement of the CIEMAT-PSA facility consisted on a new Dish movement control which has been installed and verified in the three Distal-II dishes in task 1. In addition, as part of task 2, a large number of Inconel alloy 625 tube samples were exposed to both thermal radiation (in muffle furnaces) and concentrated solar radiation (in distal dish prototypes) at temperatures up to 700°C accumulating more than 1000 hours and 100 hours, respectively, at the DISTAL facility at CIEMAT-PSA.

Figure 6.2. 3rd Doctoral Colloquium/Summer School team at CIEMAT-PSA installations.

Furthermore, it can be highlighted that CIEMAT-PSA participates in other activities in the different joint research Work packages:

- WP12, where CIEMAT's activities include comparison of heat flux gages (Final results are expected for the first quarter of 2013); Development a solar-blind IR camera prototype (based on an couple of band-pass filters centred in two wavelength bands, one that can be used to measure the temperature through quartz windows and another one that can be used to measure the temperature of the quartz window itself); and development of standardization of characterization test to evaluate central receiver systems and components.
- WP13, solar reflectors for secondary concentrators are permanently exposed to environmental conditions and high radiation flux ambient conditions that potentially cause stress and degradation throughout the time. Research has been performed to evaluate the degradation of solar reflectors by simulating these conditions under accelerated ageing.
- WP15, a final internal report was distributed for comments between WP partners.

6.3 Automatic Control Group

6.3.1 Introduction

The Automatic Control Group belongs to the Direction unit. Its purpose is to develop dynamic models of solar thermal plants and design control algorithms to improve the operation of the systems. In 2012 the Automatic Control group addressed diverse activities related with its main research lines. It participated in several projects such as HI-BIOSOLEO, HYDROSOL-3D and POWER. Furthermore our group received researches from different research centres and universities in Spain, Switzerland, Finland, Italy and Chile. The research activity led to 4 publications in impact factor journals and 6 publications in international conference proceedings.

Figure 6.3. Picture of the group staff

6.3.2 Projects

Development of hybrid technologies for renewable energy generation, HI-BIOSOLEO

Participants: IDIE (Spain), UPM (Spain), CIEMAT-SPA (Spain), Gecalsa (Spain)

Contacts: Lidia Roca Sobrino, lidia.roca@psa.es
Luis José Yebra Muñoz, luis.yebra@psa.es

Funding agency: National programme. INNPACTO 2010.

Background: This project is the logical continuation of the research activities carried out in the past within the project SOLBIO (Ref. A1217/1999), in which a theoretical research was developed in order to study the viability of a hybrid solar-biomass plant. Now, the HI-BIOSOLEO project is focused on verifying experimentally the operation when solar systems are coupled to biomass processes.

Objectives: The objective of this project is to develop a hybrid plant that combine different energy sources (solar, biomass and wind) and demonstrate the technological viability of the process. This kind of hybrid plant is an energetic promising solution to contribute to increase the energy produced by renewable sources.

Achievements in 2012: In order to set the hybrid plant up, in this second year of the project the equipment was acquired and the mechanical installation was finished. The hybrid plant (Fig. 6.4) is composed of a biomass boiler coupled to the solar distributed collector experimental plant DCS-SSPS of PSA. The additional equipment installed is mainly: vapour generators and superheaters fed with hot oil from the solar collectors and biomass, a degasifier, an air-cooled condenser and a steam-drum.

Figure 6.4. HI-BIOSOLEO facility

Predictive cOntrol techniques for efficient management of reneWable Energy micro-gRids, POWER

Project subtitle: Modelling and control strategies for a hybrid solar desalination plant

Participants: ISA-USE (Spain), UAL (Spain), TMT-USE (Spain), UVA (Spain), CIEMAT (Spain)

Contacts: Javier Bonilla Cruz, javier.bonilla@psa.es
Luis J. Yebra Muñoz. 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. One micro-grid environment proposed is the bioclimatic building – CIESOL (located at University of Almeria) and the solar desalination plant (located at PSA). The Automatic Control group has a wide experience related to modelling and control of hybrid solar desalination plants which has led to several articles. This background comes mainly from 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 behaviours detected in previous experiences.

Achievements in 2012: In this second year of the project, some relevant results have been obtained related with modelling:

- A library for absorption heat pumps (see picture 1) is being developed with the aim of characterizing the dynamic of the double effect absorption heat pump connected to a desalination unit. This library is developed using an equation-based object-oriented modelling language (Modelica) and includes the following main models:
  - A library for the lithium bromide thermodynamic properties in the temperature range [273-500] K and concentration range [0-100] %.
  - Models of each component: falling-film evaporators, falling-film generators, falling-film absorbers, flooded evaporators and flooded generators.
- Horizontal-tube evaporator and condenser models have been developed using a moving boundary method (MBM). The phase changes in MBMs do not occur within a control volume (CV) but in the boundaries, avoiding the numerical integration of discontinuities in the thermodynamic properties. The Modelica library developed includes MBMs for two-phase flow evaporators and condensers. These components are based in three models: subcooled liquid, two-phase flow and superheated vapour. Stability tests have been carried out to evaluate the stability of all possible flow configurations including switching cases of appearance and disappearance of CVs.

Figure 6.5. Picture of the absorption heat pump in AQUASOL facility.

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.

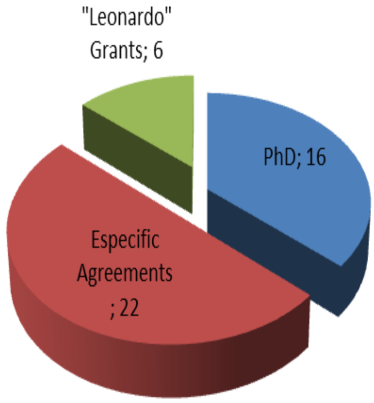


Figure 7.1. Distribution of PSA students (2012)

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 Nuevo León-México, Nápoles, Argelia, Denmark, Antofagasta-Chile, Dalarna-Sweden, Zaragoza, Barcelona, 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 8th Doctoral Colloquium was organized by PSA (see Fig. 6.2), and held in Almería (Spain). It took place in June 2012, from the 25th to the 26th. It was focused on Concentrated Solar Power.

8. Events

11/01/2012
Technical visit
Mr. A. Henry representing the Advanced Research Project Agency-ENERGY, from DOE, USA, visited PSA to gather information about research activities with special focus on desalination and on solar furnace facilities.

17/01/2012
Lecture
Dr. Aliakbar Akbarzadeh, from Energy CARE Group of RMIT University of Melbourne, Australia, presented the work entitled "Applications for Power Generation from Renewable Sources Using Thermo Electric Cells". PSA Arfrisol Auditorium.

02/02/2012
Institutional visit
A Delegation of KA-Care (King Abdullah City for Atomic and Renewable Energy) from Saudi Arabia, headed by Mr. A. Nadjib and accompanied by Mr. Pons from Abengoa Solar visited the PSA facilities to know about recent advances in research and technological development carried out on concentrated solar thermal power.

07/02/2012
Official inauguration
The AORA Project was officially inaugurated with the participation of Spanish and Israelite Authorities and technical researchers involved in the project.

29/02/2012
Technical visit
Mr. S. Arlidge from Faculty of Environment and Technology University of West England, United Kingdom, visited PSA to obtain information about relevant research activities.

01/03/2012
International Seminar
G. Zaragoza was invited to give a seminar ("Renewable Energy Desalination: An Emerging Solution To Close MENA's Water Gap") at the World Bank (Washington).

14/03/2012
Institutional event
E. Zarza participated in the Jornada sobre Centrales Termosolares, organized by the Comunidad de Madrid, to present the book "Guía Técnica de la Energía Solar Termoeléctrica", published by the Fundación de la Energía de la Comunidad de Madrid.
(http://www.fenercom.com/pdf/publicaciones/Guia-tecnica-de-la-energia-solar-termoelectrica-fenercom-2012.pdf)

26-27/03/2012
Workshop
G. Zaragoza was invited to make a presentation ("Water Desalination with Renewable Energy – A Sustainable Way to Tackle the Water Problem in the MENA-Region and to Gain Fertile Land") at the Workshop "Policies for Sustainable Energy and Green Jobs in the MENA-Region" organized by Friedrich-Ebert-Stiftung (FES) at the Dead Sea (Jordan).

27/03/2012
Lecture
S. Malato gave a lecture on "Descontaminación y regeneración de agua mediante energía solar: Desarrollo y Aplicaciones" at Universidad Autónoma de Barcelona, Spain.

Figure 8.1. Official inauguration AORA Project

27/03/2012
Technical visit
A Delegation from Cameroun composed by Mr. Ngapanoun, General Director and Ms. Tchapoya, Technical Director, of HYSACAM (a Residues Management Company), accompanied by Mr. S. Mirabal from STA-Solar, visited the PSA facilities.

10/04/2012
Technical visit
Mr. Corredor from North University (Uninorte) of Barranquilla, Colombia, was invited to know the PSA facilities in the frame of collaboration with CIEMAT's Energy Department.

17-20/04/2012
Institutional visit
The Indian Delegation, headed by Mr. Pradham, Secretary of the Ministry of New and Renewable Energy (MNRE), and composed by Mr. Kapoor (Joint Secretary), Dr. Kumar (Director of Solar Thermal and SPV) and Mr. Janardanam (Asian Development Bank), visited the PSA. The proposed agenda of the meeting at PSA was to have exposure on the R&D activities pursued, status of solar power technologies and policy and regulatory regime in Spain with a view to future cooperation.

Figure 8.2. Visit of the Indian Delegation

20/04/2012
Technical visit
A group of ten members of Design and Architecture Institutes of China, accompanied by Mr. Casado from the Association for Promotion of Economy and Culture España-Asia, visited PSA facilities to know about research activities specially about bioclimatic architecture and the LECE installations.

22-26/04/2012
Conference
Four oral presentations by members of AMES were given at the Desalination for the Environment Clean Water and Energy Conference. Barcelona (Spain).

24/04/2012
Institutional visit
A Delegation from Korea, invited by the Korean Embassy in Spain, and composed by 3 parliamentarians of the National Assembly, headed by Mr. Kim, and 2 members of the State Society of Petrol, represented by Mr. Kwon, visited the PSA facilities in the frame of bilateral relationships.

25/04/2012
Technical visit
A delegation of four people from ALSTOM visited PSA and met people from the Solar Concentrating Systems Unit to become acquainted with those PSA activities on Thermal storage systems.

26/04/2012
Lecture
Dr. Rabi Mohtar gave a lecture about 'Qatar Energy and Environment Research Institute' (QEERI) activities. PSA Arfrisol Auditorium.

29/04/2012
Institutional visit
A Delegation from the Electric Power & Survey Institue of Inner Mongolia, Represented by Mr. Xu Yi, visited PSA to know about research and technological development advances on concentrated solar power technologies.

03/05/2012
Technical visit
A Delegation of five members of China Dongfang Boiler Group Co., Ltd, headed by Mr. Yijun, visited PSA to know about research activities carried out here.

10/05/2012

Technical visit/Lecture

Ms. N. Ozalp, Assistant professor of Mechanical Engineering and Director of the Sustainable Energy Research Laboratory at Texas A&M University in Qatar, was invited to visit the PSA facilities involved in Solar Hydrogen and Process Heat, regarding the implementation of solar flux characterization technologies. Ms. N. Ozalp also presented a lecture entitled "Smart solar reactor for emission-free production of hydrogen". PSA Arfrisol Auditorium.

16/05/2012

Institutional visit

A Delegation from China Power Investment Corporation, headed by their Vice President, Mr. Xiaolu, and composed by 8 members of Hydropower & New Energies, International Business and New Energy Power Generation Departments, visited PSA installations with the aim of identifying lines to establish scientific and technological agreements on concentrated solar power.

24/05/2012

Institutional event

Participation in the Seminar "Solar Thermal Power Plants" organized by CIEMAT and PROTERMOSOLAR in GENERA 2012 (Madrid).

24/05/2012

Institutional visit

A group of 40 students from the UNESCO-IHE Institute for Water Education, from the Environmental Engineering and Water Technology Department, coordinated by Mr. H. Garcia, visited PSA facilities in the frame of their training activities mainly focussed on the research and technological development of energy and environmental aspects of water treatment.

25/05/2012

Lecture

A. Montellano presented the work carried out during the PSA stay entitled "Base de datos de autores y publicaciones" PSA Arfrisol Auditorium.

28/05-01/06/2012

Lecture

S Malato participated as invited speaker in Int. Congress of Environmental Science and Technology. Mar del Plata, Argentina. (http://www.aa2012.com.ar/eng/)

03-05/06/2012

Lecture

Invited lecture by J. Blanco at the ACWUA forum (5th Best Practices Conference: Utilities Perspective on Water Resources Management in the Arab Region. Muscat, Oman).

05-06/06/2012

Technical event

Participation in the CSP Optimization Summit for Solar Thermal Power Plants, organized by CSP Today and held in Madrid on June 5th and 6th. (http://www.csptoday.com/optimisation/).

11-12/06/2012.

Conference

Invited oral presentation by G. Zaragoza at the International Conference on Renewable Energy Desalination, Gammarth (Tunisia).

15/06/2012

Technical visit

Mr. Athiphee from CMI Services, Thailand, visited the PSA facilities accompanied by Mr. Padilla from Aitesa, to share experiences about technological development on concentrated solar power technologies.

10-15/06/2012

Lecture

S. Malato participated as invited lecturer in Cantabria Campus Nobel, held from the 10th through the 15th of June, in Palacio de la Magdalena (Santander, Spain), which brought 100 young researchers, 50 brilliant experts in their respective fields and three Nobel Prize winners together within a scientific context from diverse areas such as heritage, nanotechnology or hydrology. http://www.cantabriacampusnobel.es/en/. Conferences are available in http://www.youtube.com/user/CantabriaCampusNobel#g/u

17-20/06/2012
Conference
The 7th European Meeting on Solar Chemistry and Photocatalysis: Environmental Applications took place in Porto, Portugal from June 17th 20th, 2012. Eighteen works (oral and posters, including one invited lecture) were presented by PSA staff. http://spq.pt/eventos/spea7/

19/06/2012
Lecture
Dr. Paz Gascón, member of the OTRI of CIEMAT gave a lecture about “New Patents Policy at CIEMAT”. PSA Arfrisol Auditorium.

20/06/2012
Lecture
F. Martin gave a lecture entitled “Desarrollo tecnológico de la energía termosolar” in the frame of the activities for the celebration of the “Año Internacional de la Energía Sostenible para todos” organized by the Centro de Ciencia PRINCIPIA, Málaga.

20-22/06/2012
Conference
The “XV Congreso Ibérico y X Congreso Iberoamericano de Energía Solar” (CIES2012) took place in Vigo, Spain.

22/06/2012
Technical visit
A group of 7 members of Robinson Club Group TUI in Germany, headed by the Regional Director Mr. G. Schwarz, visited PSA installations to know about scientific activities on solar energy applications.

25-26/06/2012
Conference
PSA-CIEMAT hosted the 8th SolLab Doctoral Colloquium of SolLab consortium, in the frame of SFERA Project, held in El Toyo, Cabo de Gata, Almería, with the attendance of around 40 postgraduates from associated centres (CIEMAT, DLR, PROMES, PSI, etc.). The general objective was to present and discuss the work carried out in the Doctorate activities.

Figure 8.3. Visit of the Delegation of Thailand

27/06/2012
Meeting
Hosted by R. García, the CTAER’s Patronage Council had a meeting at PSA installations, with the attendance of the Regional Energy Agency, the utilities and local partners, aiming to analyse the situation about research and development on CSP in Andalucía.

27-28/06/2012
Conference
The 3rd Summer School on “Solar Thermal Electricity Generation”, in the frame of SFERA Networking, took place in El Toyo, Almería, hosted by PSA-CIEMAT with intensive participation of PSA’s researchers on specific subjects.

02/07/2012
Technical visit
Invited by IDEA Agency, a group of 4 people of Konica Minolta from Japan, headed by Mr. Mori, visited the PSA installations to find possibilities of collaboration in materials for solar reflectors components.

03/07/2012
Institutional visit
A group of members from ESFRI (European Strategy Forum on Research Infrastructures) from European Commission, accompanied also by CTAER members, visited the PSA installations and facilities, with the general aim of helping the projects on the roadmap to move towards implementation.

03/07/2012
Technical visit/Lecture
Mr. Zanino, from the Energy Department of Polytechnic University of Turin, Italy, invited by DLR, visited PSA to share experiences on thermal-hydraulic modelling activities. The lecture entitled "Know-how and experience on the thermal-hydraulic modeling activities" was also presented PSA Arfrisol Auditorium.

9-11/07/2012
Conference
The first edition of the International Conference of Solar Heating and Cooling for Buildings and Industry (SHC2012) took place in San Francisco, United States, from July 9th to 11th. Three posters were presented by PSA staff. http://www.shc2012.org.

16/07/2012
Doctoral Thesis
Patricia Palenzuela defended the Doctoral Thesis entitled "Evaluación del acoplamiento de plantas de destilación multiefecto a plantas termosolares". University of Almeria.

16/07/2012
Institutional visit
A group composed by 9 members of the Department of Alternative Energy Development and Efficiency, Ministry of Energy of Thailand, represented by Dr. Itsara Masiri from Silpakorn University, visited the PSA facilities on solar thermal concentration and had the chance to see some interactive demonstrations, to know about research and technological development advances on concentrated solar power technologies.

17/07/2012
Doctoral Thesis
Isabel Roldán defended the Doctoral Thesis "Diseño y análisis térmico de un receptor volumétrico para un horno solar de alta temperatura". University of Almería.

25/07/2012
Doctoral Thesis
Aitor Marzo defended the Doctoral Thesis "Medida de temperatura en entornos de radiación solar concentrada". University of Almeria.

27/07/2012
Technical visit
A group of 20 students of the Salamanca University – CIEMAT Master on Renewable Energies and Energy Efficiency interested on bioclimatic architecture, visited PSA as part of the course training activities.

03-13/09/2012
Technical visit
Hosted by DLR, a group of about 20 engineers from MENA countries received detailed technical lectures from PSA researchers and technicians and visited the PSA installations, under the frame of the 10-days International Course on CSP organized by DLR with the collaboration of the PSA.

10-12/09/2012
Conference
An oral presentation was given by members of AMES at the International Conference on Membranes in Drinking and Industrial Water Production, Leeuwarden (Netherlands).

11-14/09/2012
Conference
SolarPACES 2012, the leading event on concentrated solar power and chemical energy systems, took place in Marrakech, Morocco, from September 11th to 14th. Eight oral presentations were given and five posters were presented by PSA staff.

17-28/09/2012.
Workshop
E. Zarza and L. Valenzuela were invited to participate in the European Workshop on Renewable Energy Systems - EWRES (Erasmus IP programme) organized by the Gazi University in Turkey. Dr. Zarza gave two lectures on "Introduction to the solar thermal concentration technologies" and "Commercial potential for solar thermal power plants". Dra. Valenzuela gave a lecture on "Solar

thermal power plants: state-of-the-start and future developments”. http://www.ewres.info.

18/09/2012
Social Event
At this social event the departure of the former director Mr. D. Martínez was addressed and our new director Mr S. Malato was presented.

Figure 8.4. Departure address of Mr. D. Martínez

20/09/2012
Technical visit
A China delegation represented by Mr. Sun of Shanghai CBI Commercial Development Co., Ltd, visited PSA under the action of the 1st Concentrated Solar Power Industry Study Tour. This delegation was composed by around 13 attendees from various kinds of enterprises in solar-thermal power industry from China, who have interest to study advanced technologies, build up a long-term relationship, and also look for the investment opportunities in Spain.

28/09/2012
Institutional visit
The State Secretary on Investigation, Ms. Carmen Vela, headed the high level institutional delegation that visited PSA installations. The group was composed by Mr. S. Rodríguez, Director of State Secretary, Ms. M. González, General Sub-Directorate of OPIS, Mr. C. López, General Director of CIEMAT, accompanied by members of the CIEMAT Staff (M. Vila, Y. Benito, C. Sancho and T. Mendizábal) and with the presence of Mr. A. García and Mr. V. Sabio, representatives of Government Sub-Delegation in Almeria. Mr. S. Malato, Director of PSA, honoured and hosted the visit showing the facilities and exposing the research and technological development carried out at PSA.

Figure 8.5. Institutional visit of the State Secretary of Investigation Ms. Carmen Vela

28/09/2012
Technical visit
Delegates from Clinton Foundation (USA), represented by Mr. Hein, visited PSA with special interest on water treatment research activities.

04-06/10/2012
Conference
Co-organisation jointly with University of Almeria of the Conference X Reunión de la Mesa Española de Tratamiento de Aguas at Hotel Barceló Cabo de Gata, Retamar, Almería.
http://www.meta2012.es/

08/10/2012
Institutional visit
Members of the Thermodynamic Department Examiner Directorate of the European Patent Office, in Germany, composed by Mr. W. Schmid and 5 examiners from different European countries visited the installations of PSA to know more details about the patents on CSP technology.

08-12/10/2012
Lecture
S Malato participated as invited expert in different events and gave several conferences organised by University of Tarapacá and by Government of Región de Arica y Parinacota (Chile).

11/10/2012

Institutional visit

A Delegation of Colombia, integrated by Mr. Robles, Chancellor of La Guajira University (Uniguajira) and several professors from this university, and the North University of Barranquilla (Uninorte), as well as Mr. C. Arismendy, Secretary of Planning Department representing the Government of La Guajira, visited the installations of PSA in the frame of scientific and technological cooperation with the aim of the implementation of the Renewable Energy Centre in La Guajira.

15/10/2012

Doctoral Thesis

Inmaculada Polo defended the Doctoral Thesis "Inactivación de fitopatógenos presentes en agua mediante fotocatálisis solar". University of Almeria.

15-19/10/2012.

Workshop

G. Zaragoza was invited to participate in a Workshop ("Amautas: Energía y Futuro Sostenible") organized by INER (Instituto Nacional de Eficiencia Energética y Energías Renovables) in Ecuador.

16/10/2012

Institutional visit

Delegates from KA-Care (King Abdullah City for Atomic and Renewable Energy) from Saudi Arabia, headed by Dr. Salem Alhajraf and accompanied by some members of DLR staff, visited the PSA facilities to know about recent advances on concentrated solar thermal power.

16/10/2012

Institutional visit

The Director of PSA hosted the meeting of the 15th Sectorial Technical Committee on Energy and Environment organized by Corporación Tecnológica de Andalucía (CTA), with the participation of representatives of PSA, CTAER, Protermosolar, R.E.E., Abengoa Solar, ACS SCE, Torresol Energy and Aora Solar. A technical visit to the PSA facilities was also performed.

19/10/2012

Institutional event

S. Malato participated in the Annual Meeting "Alto Consejo Consultivo en I+D+I de la Presidencia de la Generalitat Valenciana". Palacio de la Generalitat, Valencia.

09/11/2012

Institutional visit

A delegation of representatives of the Regional Government of Antofagasta, Chile, composed by 9 advisers, directives and technicians coordinated by Mr. Calderón from RedSur Consulting, visited PSA with the objective of knowing the actions carried out by Spanish Administration in promoting renewable energies and to envisage the possibilities of collaboration agreements.

13/11/2012

Technical event

Participation in the seminar on Solar Thermal Power plants organized by the Spanish Ministry of Economy and Competitiveness. It was held in Seville on November 13th.

13-14/11/2012

Technical event

Participation in technical sessions and round tables at the CSP Today Seville 2012 Conference (6th International Summit on Solar Thermal Power), held in Seville on November 13th and 14th. http://www.csptoday.com/csp/

15/11/2012

Institutional visit

A delegation composed by Mr. M. Scarone, from National Directorate of Energy of the Ministry of Industry, Energy and Mines of Uruguay, visited PSA with the objective of knowing the activities on CSP technology development for potential future technical collaborations.

16/11/2012

Institutional visit

Coordinated by Mr. C. Hernández, acting as representative of STELA Programme in China, a delegation of 4 persons composed by Dr. Zhihao, Managing Director of SunCan, Dr. Chao from Institute of Electrical Engineering, Chines Academy of Sciences and Mr. Xiang from China

Huadian Engineering Co., visited PSA with the aim of finding some cooperation chance between China and Spain in the CSP field.

18-22/11/2012

Lecture

S. Malato participated as invited expert in different events and gave several conferences organised at Valparaiso and Santiago (Chile) by Fundación para la Innovación Agraria, Ministerio de Agricultura (Chile).

22/11/2012

Technical visit

Mr. Ekua Ondo, Presidential Adviser for Energy Affairs of Equatorial Guinea, invited by Iberogé International of Almeria, visited PSA to know about technological development on solar energy.

13/12/2012

Lecture

Mr. F. Wehringer, from DLR, presented the work carried out during the PSA stay entitled "Comparison of visibility measuring instruments". PSA Arfrisol Auditorium.

20-22/12/2012

Conference

Keynote presentation by G. Zaragoza on the 4th International Renewable Energy Congress, Sousse (Tunisia).

21/12/2012

Social Act

With occasion of Christmas Days, the Director of PSA, S. Malato, invited to all the PSA personnel to a social act where, with the participation of the heads of the different units of PSA, i.e., E. Zarza, D. Alarcón and P. Fernández, the overall resume of R&D activities carried out along 2012 and the planning for next year were exposed.

Figure 8.6. Christmas Day

9. Publications

Dissertations

Marzo Rosa, A. (2012). Medida de temperatura en entornos de radiación solar concentrada (Unpublished doctoral dissertation). Universidad de Almería, Almería.

Palenzuela Ardila, P. (2012). *Evaluación del acoplamiento de plantas de destilación multi-efecto a plantas termo-solares* (Unpublished doctoral dissertation). University of Almería, Almería.

Polo-López, M. I. (2012). *Inactivación de fitopatógenos en agua mediante fotocatálisis solar* (Unpublished doctoral dissertation). Universidad de Almería, Almería.

Roldán Serrano, M. I. (2012). Diseño y análisis térmico de un receptor volumétrico para un horno solar de alta temperatura (Unpublished doctoral dissertation). Universidad de Almería, Almería.

Solar concentrating systems unit

SCI PUBLICATIONS

Ballestrín, J., Marzo, A. (2012) Solar radiation attenuation in solar tower plants. *Sol. Energy*, 86, 388-392.

Fernández-Reche, J., & Valenzuela, L. (2012). Geometrical assessment of solar concentrators using close-range photogrammetry. *Energy Procedia*, 30, 84–90.

Navarro, A., Cañadas, I., Rodríguez, J., & Martínez, D. (2012). Leaching Characteristics of Mercury Mine Wastes Before and After Solar Thermal Desorption. *Environ. Eng. Sci.*, 29, 915-928.

Pinilla, J. L., Torres, D., Lázaro, M. J., Suelves, I., Moliner, R., Cañadas, I., ... & Martínez, D. (2012). Metallic and carbonaceous-based catalysts performance in the solar catalytic decomposition of methane for hydrogen and carbon production. *Int. J. Hydrogen Energy*, 37, 9645–9655.

Pinilla, J. L., Torres, D., Lázaro, M. J., Suelves, I., Moliner, R., Cañadas, I., ... & Martínez, D. (2012). Response to the comments on “Metallic and carbonaceous-based catalysts performance in the solar catalytic decomposition of methane for hydrogen and carbon production” by A. Rollinson. *Int. J. Hydrogen Energy*, 37, 14716–14717.

Quirante, M., & Valenzuela, L. (2012). Dimensioning a small-sized PTC solar field for heating and cooling of a hotel in Almería (Spain). *Energy Procedia*, 30, 967–973.

Roldán, M. I., Cañadas, I., Casas, J. L., & Zarza, E. (2013). Thermal analysis and design of a solar prototype for high-temperature industrial processes. *Int. J. Heat Mass Transfer*, 56, 309-318.

Roldán, M. I., Valenzuela, L., & Zarza, E. (2013). Thermal analysis of solar receiver pipes with superheated steam. *Appl. Energy*, 103, 73-78.

Ruiz-Bustinza, I., Cañadas, I., Rodríguez, J., Mochón, J., Verdeja, L. F., García-Carcedo, F., & Vázquez, A. J. (2012). Magnetite Production from Steel Wastes with Concentrated Solar Energy. *Steel Research Int.*, 29, 915-928.

San Vicente, G., Morales, A., Germán, N., Suarez, S., & Sánchez, B. (2012). Sio_2/Tio_2 antireflective coatings with photocatalytic properties prepared by sol-gel for solar glass covers. *J. Sol. Energy Eng.*, 134, 041011.

Valenzuela, L., Hernández-Lobón, D., & Zarza, E. (2012). Sensitivity analysis of saturated steam production in parabolic trough collectors. *Energy Procedia*, 30, 765–774.

BOOK CHAPTERS

Zarza, E. (2012). Principales retos de I+D y Potencial Contribución a un Mercado energético Sostenible. In *Guía Técnica de la Energía Solar Termoeléctrica* (pp.71-122). Madrid, Spain: Fundación de la Energía de la Comunidad de Madrid.

Zarza, E. (2012). Technology approaches and potential: Parabolic trough concentrating power systems. In *Handbook on Concentrated Solar Thermal Technologies. Principles.* (pp. 197-239). Cambridge, United Kingdom: Woodhead Publishing.

Ballestrín, J. (2012). Heat flux and temperature measurement technologies for concentrating solar power (CSP). In Lovegrove, K., Stein, W., (Eds.), *Concentrating solar power technology. Principles, developments and applications.* (pp. 577-601). Woodhead Publishing Ltd.

PRESENTATION AT CONGRESSES

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