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MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

PLATAFORMA SOLAR DE ALMERÍA

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ALMERÍA


PLATAFORMA SOLAR
DE ALMERÍA
TABERNAS
ALMERÍA

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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.

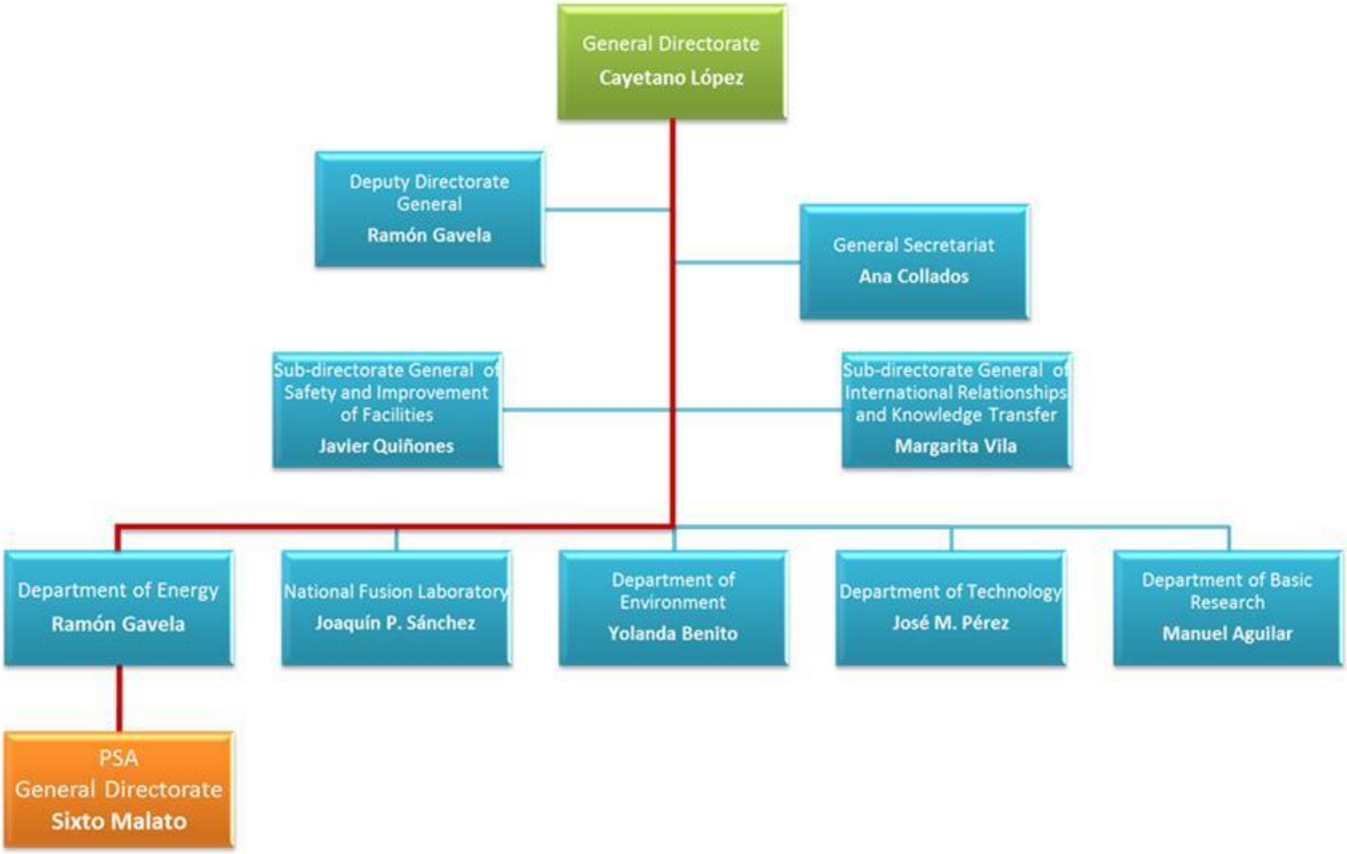


Figure 1.1. Integration of the PSA in the CIEMAT organization

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 2013 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 120 persons who work daily for the PSA, 62 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 32 persons, 15 work in operation, 13 in maintenance and 4 in cleaning. The auxiliary services contract is made up of 5 administrative personnel and secretaries, 7 IT technicians for user services, and another 4 persons from the security contract, what makes a total of 16 persons.

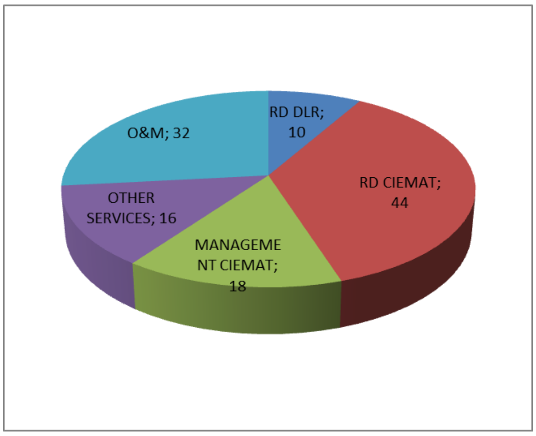


Figure 1.4. Distribution of permanent personnel at the PSA as of December 2013

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

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

The PSA operating budget in 2013 totals 4.4 M Euros (not including R&D personnel or new infrastructure).

2. Facilities and Infrastructure

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

2.1.1 PSA Experimental facilities for solar thermal concentrating systems

At present, the main test facilities available at the PSA related to solar thermal concentrating systems are (see Fig. 2.1):

- CESA-1 and SSPS-CRS central receiver systems, 5 and 2.5 MWth respectively.
- DISS 2.5-MWth test loop, an excellent experimental system for two-phase flow and direct steam generation for electricity production research with parabolic-trough collectors in different working conditions, up to 500ºC and 100bar.
- The FRESDEMO “linear Fresnel” technology loop.
- A parabolic-trough collector test facility with thermal oil (the so-called HTF Test loop) for qualification of components and complete collectors.
- 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.
- 4-unit dish/Stirling facility, named DISTAL, and 2 EuroDish units.
- A group of 3 solar furnaces, two of them with horizontal axis 60 kWth and 40 kWth and a third one with vertical axis 5 kWth.
- A test stand for small evaluation and qualification of parabolic trough collectors, named CAPSOL.

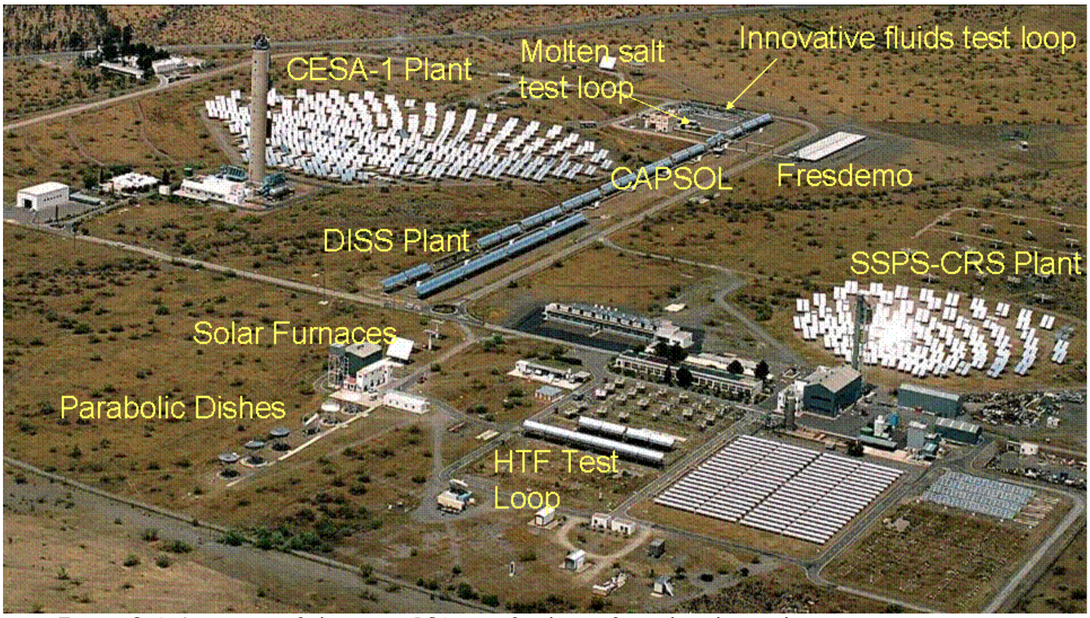


Figure 2.1. Location of the main PSA test facilities for solar thermal concentrating systems

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

2.1.1.1 Central Receiver Facilities: CESA-1 and CRS

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

The 5 MWth CESA-1 Plant

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

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

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

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

The maximum thermal power delivered by the field onto the receiver aperture is 5 MWth at a typical design irradiance of 950 W/m^2, achieving a peak flux of 3.3 MW/m^2. 99% of the power is focused on a 4-m-diameter circle and 90% in a 2.8-m circle.

The SSPS-CRS 2.5 MWth facility

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

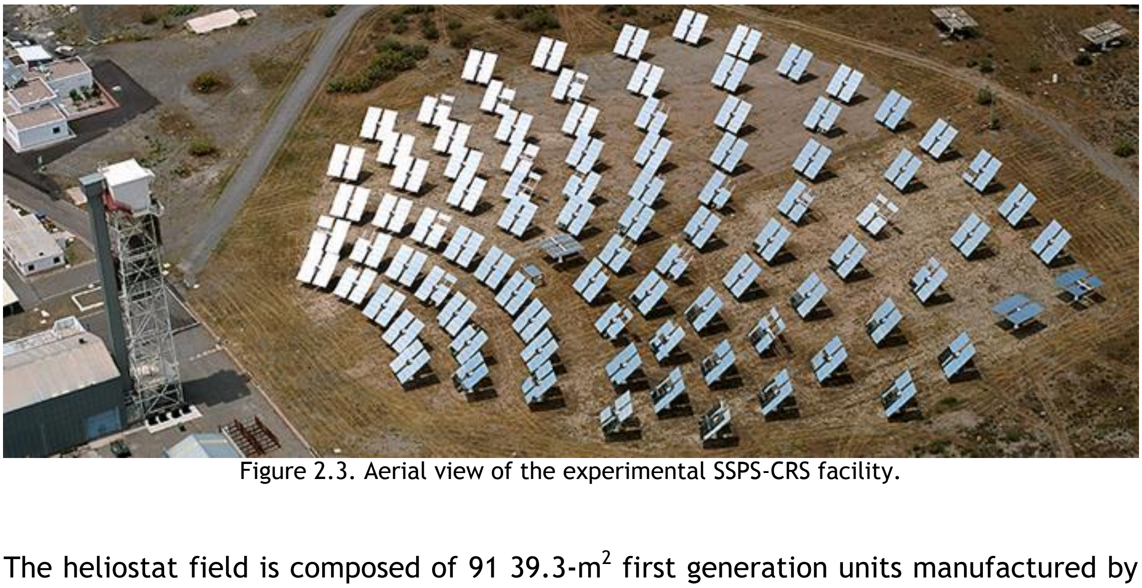


Figure 2.3. Aerial view of the experimental SSPS-CRS facility.

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

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

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.

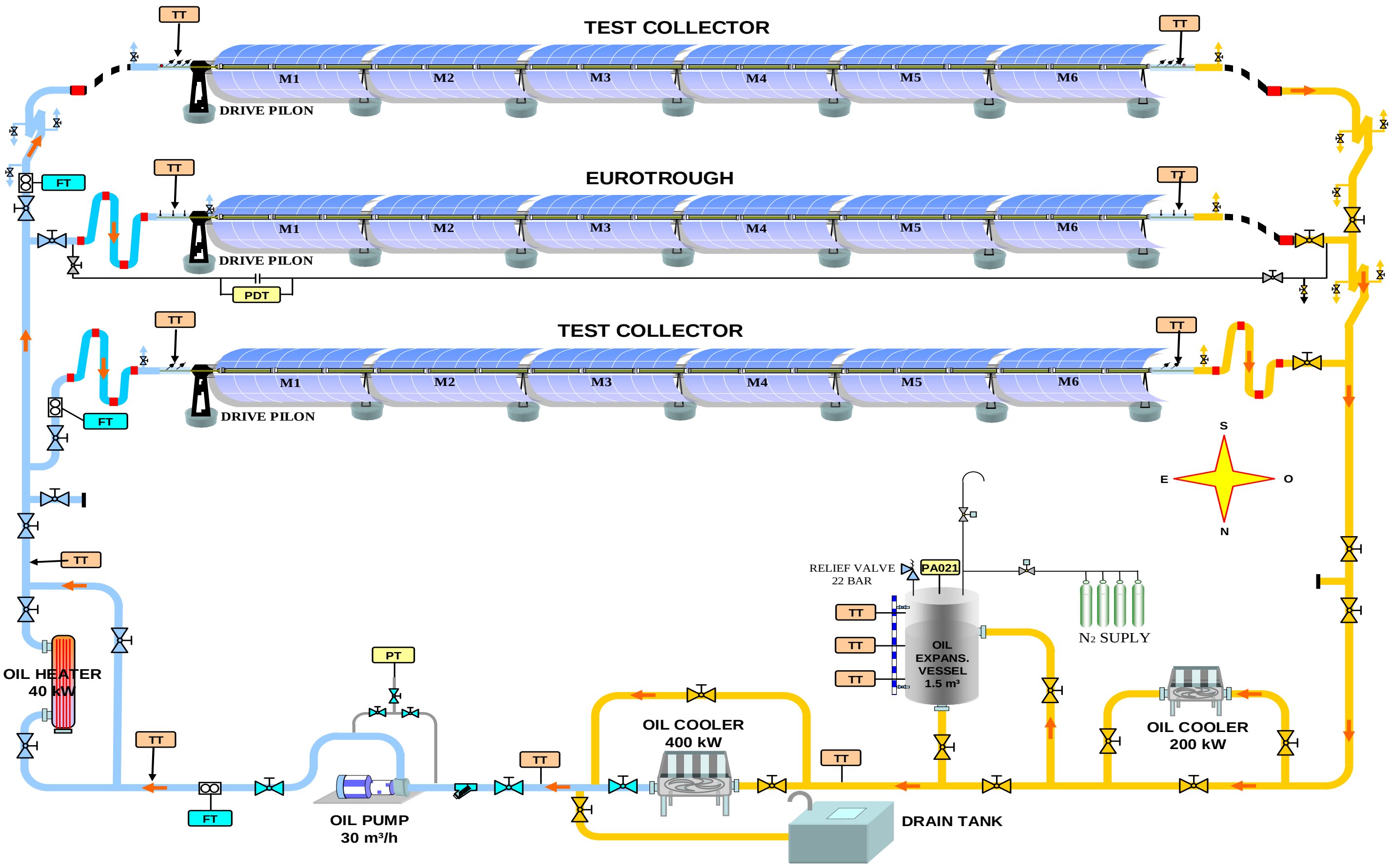


Figure 2.5. Diagram of the PSA "HTF test Loop".

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.

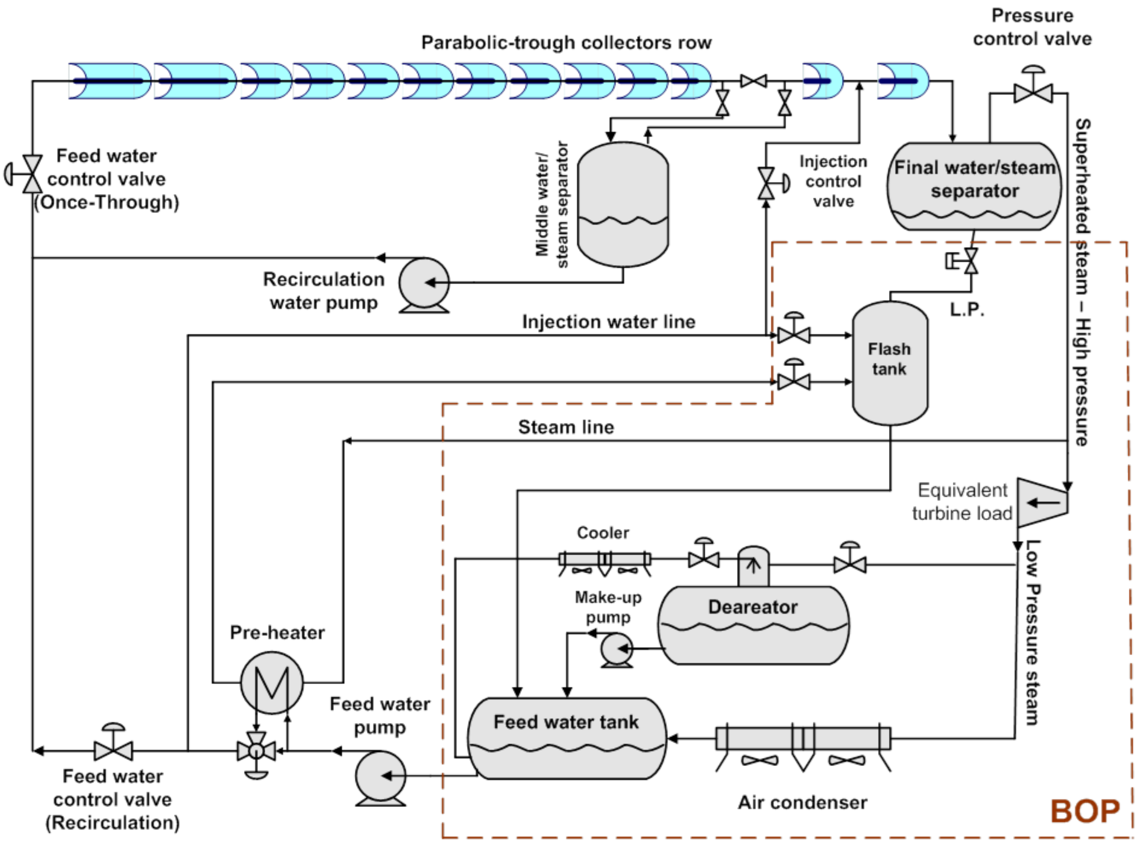


Figure 2.6. Simplified flow diagram of the PSA DISS loop

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).

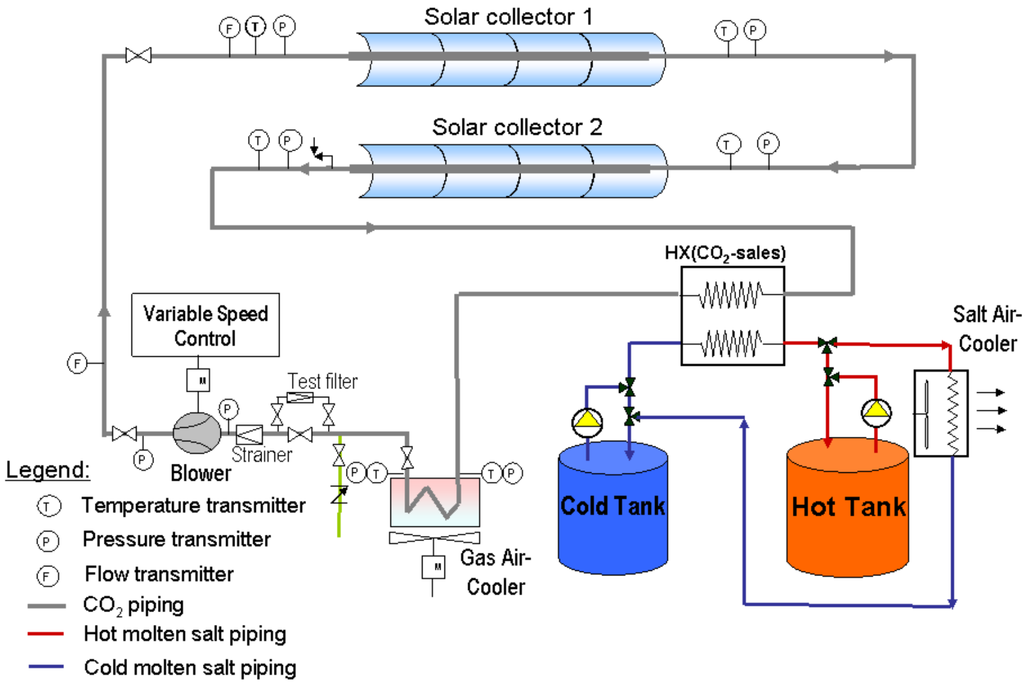


Figure 2.9. Simplified system diagram of the innovative fluids test loop connected to a molten-salt thermal storage system.

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.

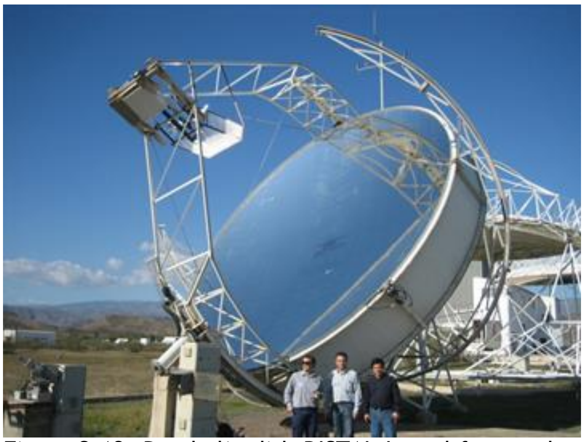


Figure 2.13. Parabolic-dish DISTAL-I used for accelerated materials ageing at PSA.

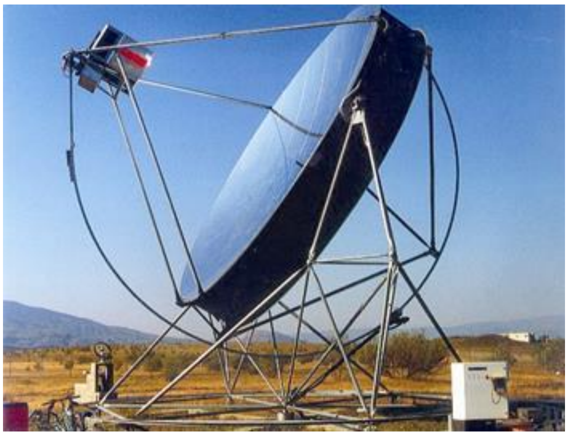


Figure 2.14. View of a parabolic-dish DISTAL- II.

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

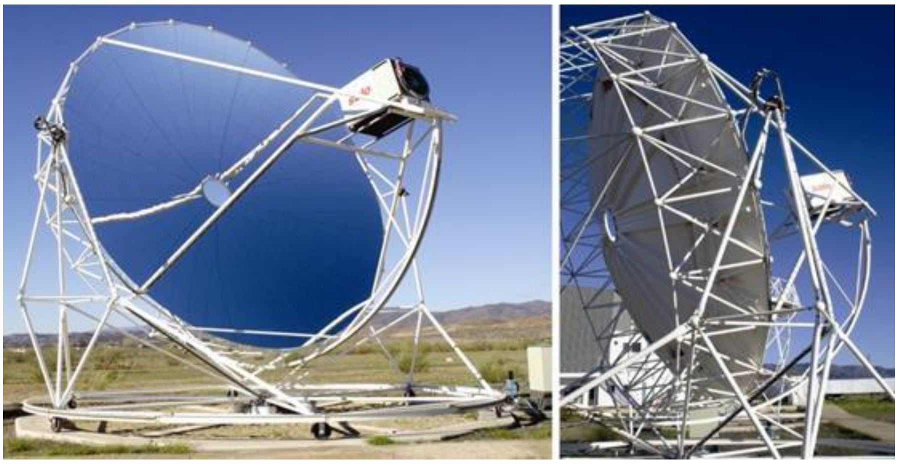


Figure 2.15. Front and back views of the EURODISH

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.

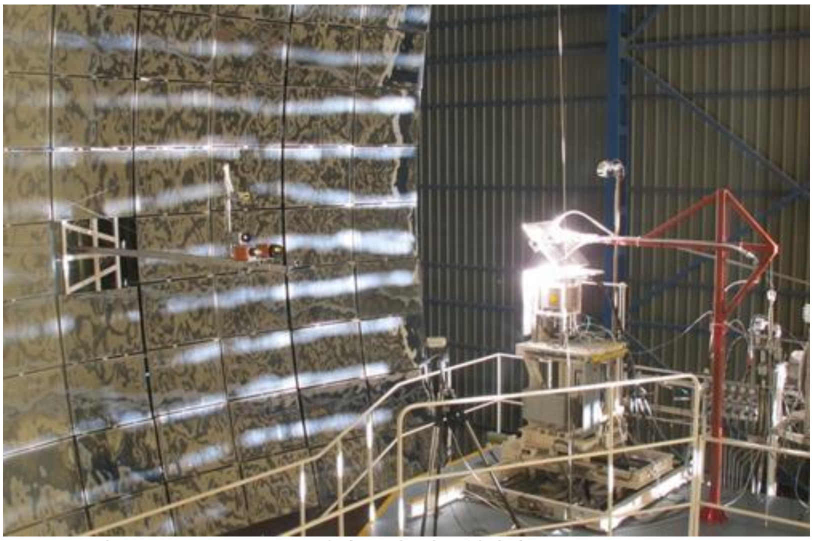


Figure 2.17. Interior view of the PSA SF-60 Solar Furnace in operation.

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.

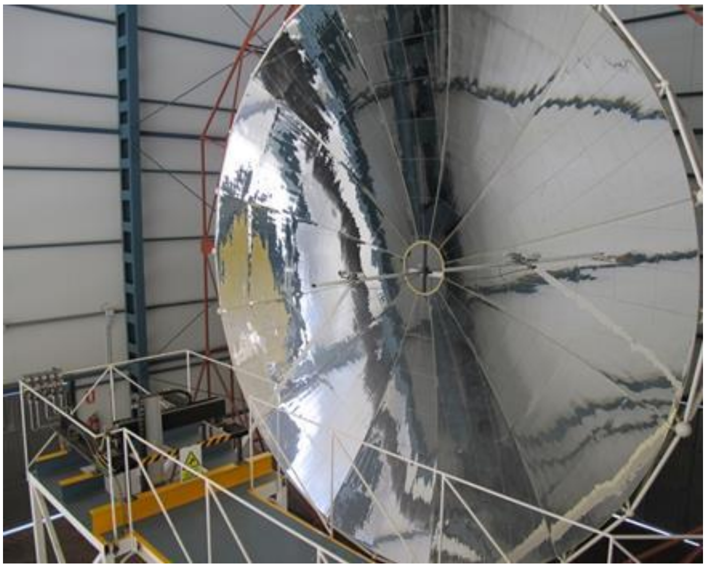


Figure 2.18. Interior of the SF-40 solar furnace, showing the parabolic concentrator.

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.


Figure 2.19. Exterior view of the SF-5 Furnace.

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.

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.

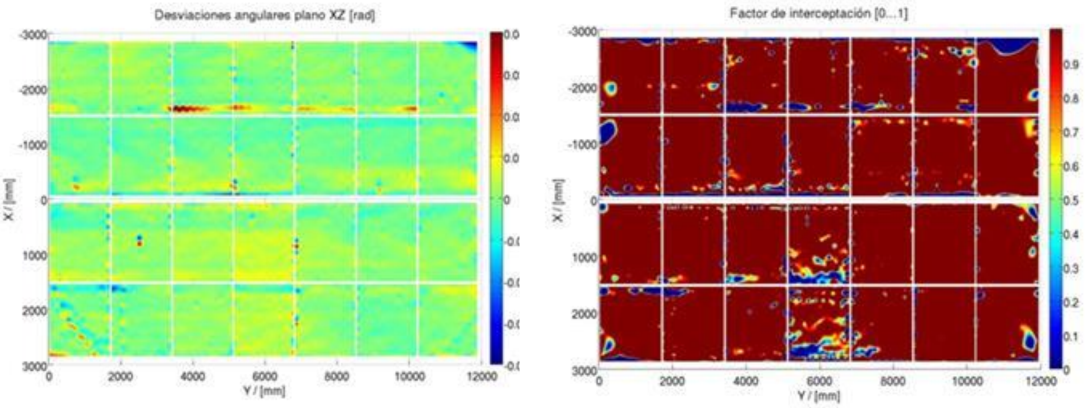


Figure 2.24. Angular deviations (left) and intercept factor (right) of a parabolic-trough collector module analysed by photogrammetry

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

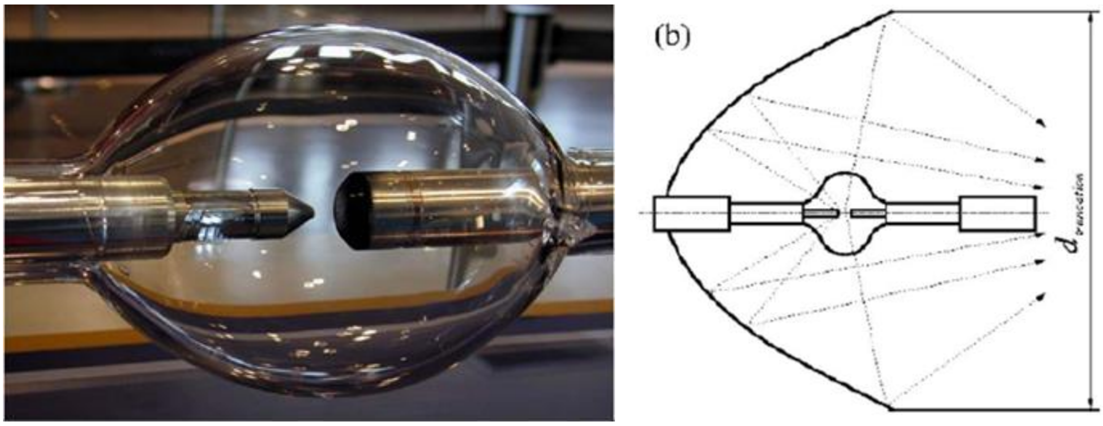


Figure 2.25. Xenon lamp used in the solar Simulator and configuration of the lamp and concentrator

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.

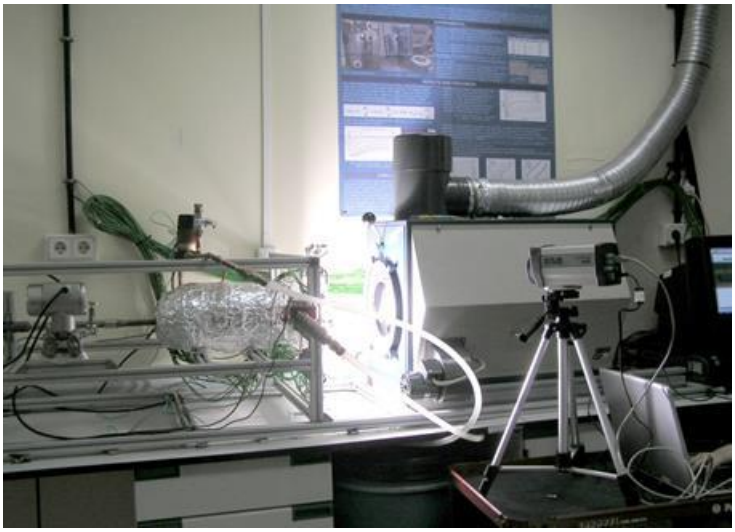


Figure 2.26. Operation of the 4 kW Xenon lamp

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

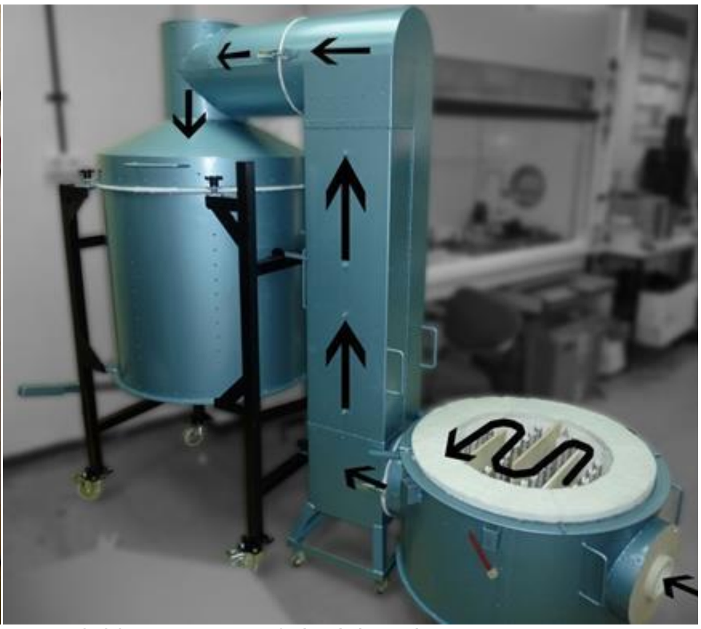


Figure 2.28 Front view of the lab-scale regenerative storage system in dynamic arrangement

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

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

1. Plate and frame AGMD commercial modules from Scarab (total membrane area 2.8 m^2).
2. Two plate and frame LGMD prototypes from Keppel Seghers (both with total membrane area 9 m^2), a compact one (M33) and another which is split in three separate modules connected in series for higher energy recovery (PT5).
3. Spiral-wound LGMD commercial modules Oryx 150 from Solar Spring (10 m^2).
4. Spiral-wound AGMD prototype from Aquastill (24 m^2).
5. WTS-40A and WTS-40B unit from Aquaver, based on multi-stage vacuum membrane distillation technology using modules fabricated by Memsys (5.76 m^2 and 6.4 m^2 total membrane area respectively).

2.2.5 Laboratory unit for testing membranes on vacuum membrane distillation

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

Figure 2.35. Laboratory unit for testing membranes on vacuum MD

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

Regarding the pilot plants employing CPCs, the oldest (1994) consists of three 3 m^2 modules tilted 37º from the horizontal. The total system volume is about 250 L and the absorber tube holds 108 L (illuminated volume). In 2002, a new 15 m^2 collector for experiments of volumes up to 300 L was installed. There are also two twin prototypes (refitted in 2007 and called SOLEX) to facilitate simultaneous experiments under same experimental conditions. Each SOLEX prototype consists of two CPC modules with a total illuminated collector surface of 3.08 m^2, a total volume of 40 L (22 L illuminated). The photo-reactor tube external diameter is 32 mm. This facility can be covered with Plexiglass transparent to solar-UV, allowing to work at higher temperatures for photo-Fenton process (Fig. 2.36 (a)). Since 2004 other CPC system (with 50 mm tubes diameter, more suitable for photo-Fenton applications), with a tank and a recirculation pump (75 L), has been hooked up to a 50L ozonation system with an ozone production of up to 15 g O_3/h. It is completely monitored (pH, T, ORP, O_2, flow rate, H_2O_2, O_3) and controlled (pH, T, flow rate) by computer. Besides, and connected to this photo-reactor, there is a biological water treatment system (Fig. 2.36(b)) consisting of three tanks: a 165 L conical tank for wastewater conditioning before treatment, a 100 L conical recirculation tank and a 170 L flat-bottom fixed-bed aerobic biological reactor. The fixed-bed reactor is filled with Pall®Ring polypropylene supports that take up 90-95 L and can be colonized by active sludge from a MWWTP.

The process is completely automatic and is instrumented with pH, REDOX potential, dissolved oxygen, and temperature sensors. Furthermore, pH and dissolved oxygen are automatically controlled by dose pumps.

a) b)

Figure 2.36. CPC photo-reactors (a) SOLEX and (b) CADOX.

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. This CPC photo-reactor has been improved in 2013 with the financial support of the national grant SolarNOVA (ICT-CEPU2009-0001). A heating and cooling system was designed and installed in this photo-reactor to maintain the water temperature constant between 15 and 45ºC. Different air injection points have been also added to photo-reactor to increase the oxygen dissolved in the system as well as several sampling points.

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 three solar pyranometers to measure the global UVA component of the solar irradiance at the location where the solar photo-reactors are placed. They are installed with two inclinations: 0 and 37º (the same angle as the CPCs) with reference to the horizontal plane. 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. 2.37 (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 2.37. 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. 2.38 (a)).
2) Two CPC (CPC-SODIS) photo-reactors for discontinuous operation. Both static batch systems can treat 25 L of water completely exposed to solar radiation. The reactors have 0.58 m2 of aperture CPC mirror, a photo-reactor borosilicate glass tube (outer diameter = 20 cm). (Fig. 2.38 (b)).
3) A CPC photo-reactor for water disinfection (FITOSOL-2) made of 20 borosilicate glass tubes with a 60 L total treatment capacity and an illuminated area of 4.5 m^2. It is used for disinfection tests with water polluted by all kinds of microorganisms and aimed for the reuse of water from wastewater treatment plants. It has a temperature control system that allows working at constant temperatures ranging from 20 to 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. 2.38. (c)).

In addition, a hangar (Fig. 2.39 (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.

a)

b)

c)

Figure 2.38. New CPC photo-reactors installed in 2010 for solar water disinfection applications: (a) CPC25, (b) CPC-SODIS and (c) FITOSOL-2.

a)

b)

Figure 2.39. North (a) and south (b) view of the new hangar to accommodate new installations.

The new pilot plants installed in the hangar (Fig. 2.39) 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 reactor exhaust in order to avoid its release into the working area (Fig. 2.40 (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 45° C, a maximum pressure of 41 bar and a maximum flow rate of 1.4 m^3 h^{-1}, whereas operation pH range is 2-11. The main parameters of the nanofiltration process are monitored by a SCADA system (Fig. 2.40 (b)).

a)

b)

c)

d)

Figure 2.40. 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. 2.40 (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. 2.40 (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 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. 2.41).

Figure 2.41. Filtration/flocculation pilot plant for treating raw water.

A pilot plant for photocatalytic hydrogen production was also acquired. This plant is connected to a CPC photo-reactor for the simultaneous removal of organic contaminants contained in aqueous solutions. The pilot plant for photocatalytic generation of hydrogen consists on a stainless steel tank with a total volume of 22 L, fitted with gas and liquid inlet and outlet and a sampling port. Two parallel mass flow controllers are used to control the desired N_2 gas flow into the reactor headspace during the filling step (Fig. 2.42 (a)). The CPC photo-reactor is composed by 16 Pyrex glass tubes (inner diameter of 28.45 mm, outer diameter of 32.0 mm and length of 1530.0 mm) mounted on a fixed platform tilted 37º. The total volume for working in the system is 25 L, in which 14.24 L constitute the irradiated volume and the total area irradiated is 2.1 m^2 (Fig. 2.42 (b)).

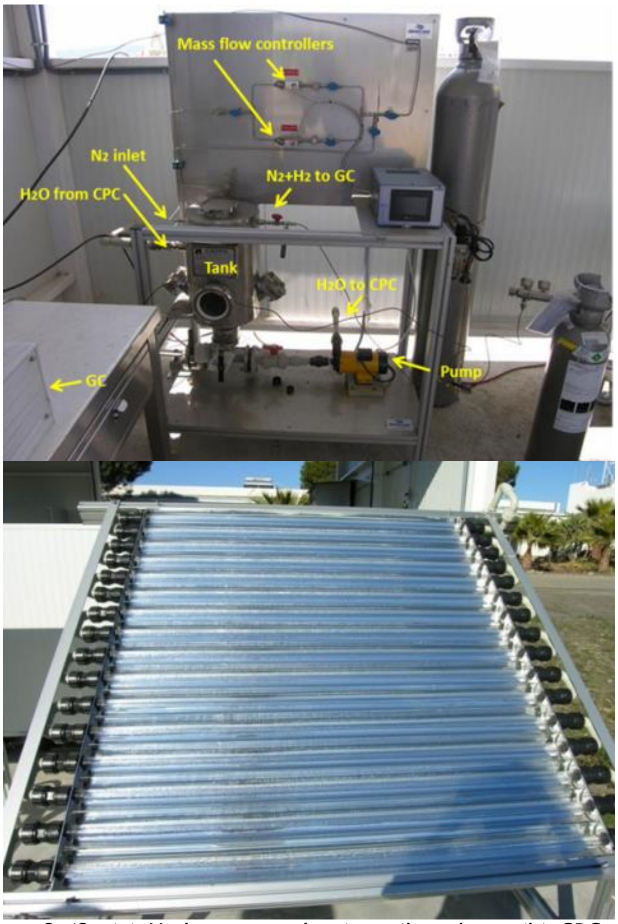


Figure 2.42. (a) Hydrogen production pilot plant. (b) CPC collector connected to the hydrogen production plant.

This CPC photo-reactor has illuminated surface of $2m^2$, it consists of ten borosilicate glass tubes (50 mm outer diameter), with a total treatment volume of 40 L, of which 25L is illuminated (Fig. 2.43 (a)). This new pilot plant has been installed for experimental research on electro-photo-Fenton processes for decontamination and disinfection of wastewater.

A new concept of solar photo-reactor (so called NOVO75) for water treatment has been designed and constructed. This photo-reactor has a new configuration of the solar mirror that permits to increase the illuminated volume in the photo-reactor (borosilicate glass tube of a wider diameter: 75 mm). This photo-rector consists of 12 tubes connected in series, with an illuminated surface of 2 m^2, total volume of 74 L with 68.5 L of illuminated volume (92.5% of illuminated/total volume ration). It is equipped with a system to control the temperature into the system in a range of 20 to 55ºC. Several dissolved oxygen measurement and air injection points have been also installed in line to facilitate the operation of this photo-reactor (Fig. 2.42 (b))

Figure 2.43 (a) 2-m^2 CPC pilot plant. (b) New design of solar pilot plant (NOVO75) for solar photocatalytic treatment of wastewater.

A cooling storage room (9 m^2) has been built to properly conserve large volumes of water samples between 4-10ºC to preserve the chemical and microbiological qualities of wastewater samples for a certain period of time for the experimental works carried out in this facility. The front door aperture permits entering large storage water tanks up to 1m^3. This chamber is also provided with shelves for small containers.

Figure 2.44. (a) Front view of 9-m2 cold storage room. (b) Back extension for new facilities location.

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. 2.45):

1) The main laboratory is 94 m^2 (Fig. 2.45). 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 2.45. General view of the new PSA Water Technologies Lab

2) The chromatography room is 23 m^2 (Fig. 2.46 (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. 2.46 (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. 2.46 (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 2.46 New water technology labs: (a) Chromatography lab, (b) Microbiology Lab and (c) SEM (Scanning Electron Microscope) Lab.

Recently, in 2013, new equipment has been acquired within the frame of SolarNOVA Proyect (ICT-CEPU2009-0001):

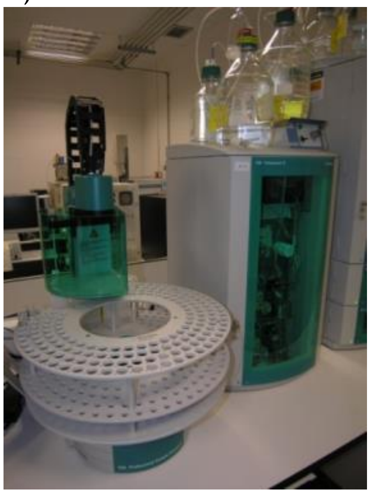
1) Microscope with a fluorescence module to develop the FISH (Fluorescent in situ hybridation) technique of molecular biology. This technique permits the visualization of DNA hibrydation with specific probes in live cells used for monitoring of key microorganisms within a heterogeneous population, like the

case of activated sludge of municipal wastewater treatment plants. This system consists on an optical microscope with several magnitude positions. It is coupled with a fluorescent module using different light filters for stain differentiation. In addition, the system is completed by a station for photographic documentation (Fig. 2.47 (a)).

2) Ionic chromatographic system for anions and cations measurements. This equipment consists of a module of sequential chemical suppression for simultaneous measurement of anions and cations in isocratic operation mode with low operational time. The ionic concentration measurement may range from µL/L to g/L. This system is equipped with a sampler for 147 positions (Fig. 2.47 (b)).

a)

b)



c)

d)

Figure 2.47. (a) Microscope for FISH technique. (b) Chromatographic ion system. (c) Documentation system for conventional PCR. (d) Jar-Test system for physic-chemical studies at laboratory scale.

3) Documentation system for conventional PCR technique. It consists of an UV-trans-illuminator to detect and visualize DNA, RNA and proteins. It also includes a documentation station with a camera to take images of DNA, RNA and proteins. The documentation system permits to detect presence of DNA at different sizes after PCR standard protocol and electrophoretic separation. This technique adds information on modifications of microbial populations in a heterogeneous community, like in activated sludge systems of wastewater treatment plants.

4) Jar-Test system for the experimental analysis and optimization of physic-chemical processes for water treatment at laboratory scale has been also acquired. This equipment will be used for different coagulation and flocculation regimes at different pHs and agitation speed. It has six positions for 1 L total volume flasks and an automatic injection of the reagent (Fig. 2.47 (d)).

A module of total nitrogen measurement has been installed to an already available TOC analyser to increase the capability of the laboratory sampling measurement.

Other small equipment has been acquired during 2013 to improve the methodologies and protocols used in this laboratory, for example: a multiple agitator, a new analytical balance with a precision weight of 0.1 mg, mini-centrifuge for Eppendorf, etc.

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 five test cells, each of them made up of a high-thermal-insulation test room and an auxiliary room. The test room's original south wall can be exchanged for a new wall to be tested. This makes experimental characterisation of any conventional or new building envelope possible.
2) PASLINK Test cell: The Spanish PASLINK test cell incorporates the Pseudo-Adiabatic Shell (PAS) Concept. This system detects heat flux through the test cell envelope by means of a thermopile system, and compensates it by a heating foil device. The inner surface in the test room consists of an aluminium sheet which makes it uniform to avoid thermal bridging. It also has a removable roof that enables horizontal components to be tested. The cell is installed on a rotating device for testing in different orientations.
3) CETeB Test cell: This is a new test cell for roofs. The design of this test cell solves some practical aspects related to roof testing, such as accessibility and structural resistance. An underground test room allowing easy access to the test component is used for this.
4) Solar Chimney: This was constructed for empirical modelling experiments and validating theoretical models. Its absorber wall is 4.5 m high, 1.0 m wide and 0.15 m thick, with a 0.3-m-deep air channel and 0.004-m-thick glass cover. A louvered panel in the chimney air outlet protects it from rodents and birds. The air inlet is protected by a plywood box to avoid high turbulences from wind. The inlet air flow is collimated by a laminated array so that the speed component is in the x-direction only.
5) Monozone building: This is a small 31.83 m^2 by 3.65 m high simple monozone building built in an area free of other buildings or obstacles around it that could shade it except for a twin building located 2 m from its east wall. Its simplicity facilitates detailed, exhaustive monitoring and setting specific air conditioning sequences that simplify its analysis for in-depth development and improving energy evaluation methodologies for experimental buildings.

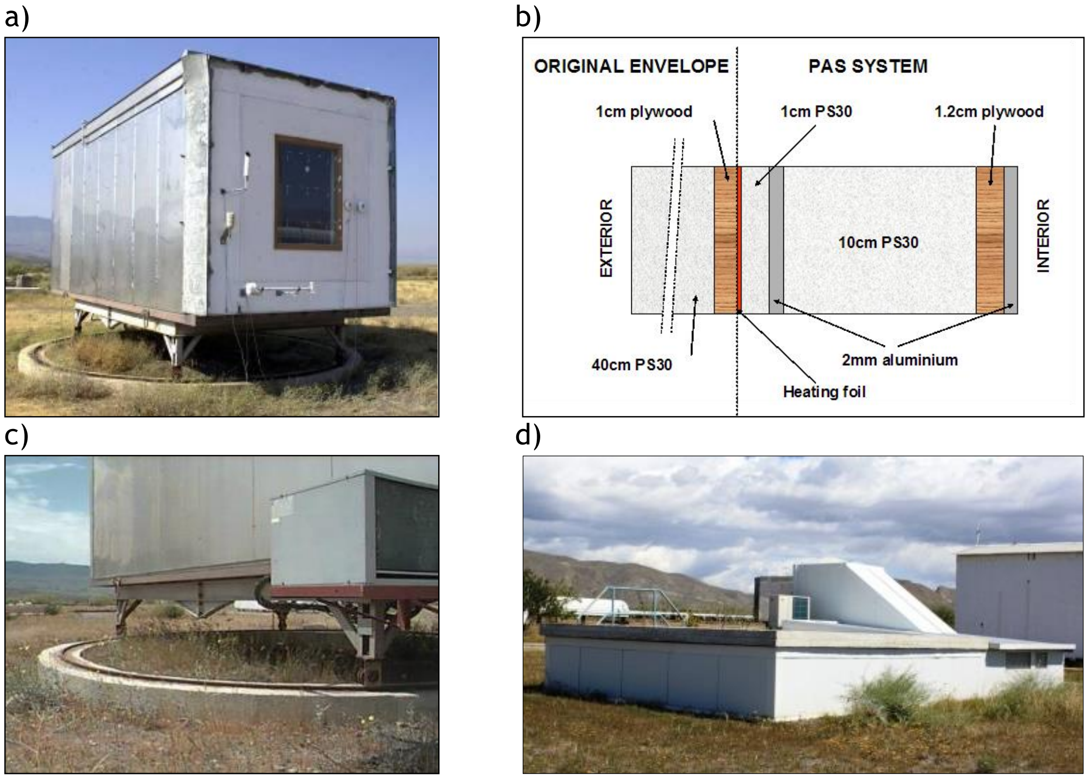


Figure 2.43. (a) CIEMAT's PASLINK test cell, (b) Schematic drawing of the PAS system, (c) Detail of the rotating device, (d) Exterior of the CETeB Test cell.

6) The PSE ARFRISOL C-DdIs are fully instrumented Energy Research Demonstrator Office Building Prototypes which are in use and monitored continuously by a data acquisition system. The CIEMAT owns 3 of 5 of these "Contenedores Demostradores de Investigación, C-DdIs" (Research Energy Demonstrators Building Prototypes), built under the ARFRISOL Project. Each of them is an office building with approximately 1000 m2 built area. One of them is also at the PSA and the others in different locations representative of Spanish climates. These C-DdIs are designed to minimize energy consumption by heating and air-conditioning, whilst maintaining optimal comfort levels. They therefore include passive energy saving strategies based on architectural and construction design, have active solar systems that supply most of the energy demand (already low), and finally, conventional auxiliary systems to supply the very low demand that cannot be supplied with solar energy, using renewable energy resources, such as biomass insofar as possible.

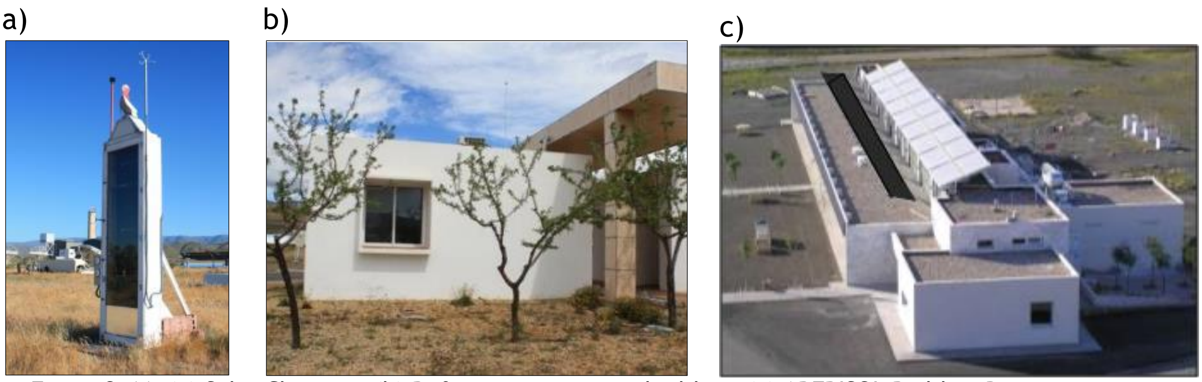


Figure 2.44. (a) Solar Chimney, (b) Reference monozone building, (c) ARFRISOL Building Prototype in use.

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

3. Solar Concentrating Systems Unit

3.1 Introduction

The 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

Year 2013 has consolidated the change in the portfolio of activities in the USCS Unit, because international activities performed within the framework of either R+D projects or collaboration agreements have become the more significant part of our activities and incomes. Since the Spanish Government introduced in 2013 additional changes in the legal framework for solar thermal electricity (STE) plants to limit their profitability further, the priority of Spanish STE sector now is not the innovation or technology improvements, but the survival in the very aggressive economic environment imposed by the new legal framework.

This discouraging situation has significantly reduced the R+D effort devoted by Spanish private companies of this sector. It has also significantly reduced the participation of private companies in the national and international committees implemented three years ago to develop standards for the STE sector (i.e., the AEN/CTN Subcommittee 206/SC and the IEC/TC-117 committee).

Fortunately, this bad internal situation in Spain has been compensated by the growing interest of many other countries on the STE technologies, simultaneously with the launching of European projects aimed at checking the feasibility of a joint management of R+D activities and facilities at European level to increase the efficiency and competitiveness of the European STE sector. Since the USCS Unit is playing a significant role in these new European Projects (i.e., SFERA-II, EU-SOLARIS and STAGE-STE) our activities at international level are significantly increasing, while our activities at Spanish level are decreasing. The sections below summarize the most important activities and results achieved in 2013 within the three R&D Groups that compose the USCS Unit.

3.2 Medium Concentration Group.

3.2.1 Introduction

Activities carried out by the Medium Concentration Group (MCG) in 2013 are framed by a diversity of fields such as development, testing, and evaluation of components for line-focusing solar collectors, solar heat integration in industrial processes (RITECA-II project), research on direct steam generation in PTCs (DUKE and GEDIVA projects), modelling and simulation of solar power plants with PTCs using DNI now-casting as input of the models (DNICast project), and thermal energy storage systems both sensible and latent heat storage concepts (OPTS and REELCOOP projects).

Relevant projects of the MCG in 2013 are summarized below.

a) 

b) 

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

3.2.2 Projects

Research and development of optical layers for solar receivers

Participants: *CIEMAT-PSA, International and Spanish private companies*

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Gema San Vicente gema.sanvicente@ciemat.es

Funding agency: CIEMAT and International and Spanish private companies.

Background: The development of new antireflective and selective coatings for solar receivers with improved optical and mechanical properties contributes to promote the solar thermal electric (STE) technology. Moreover, the use of cheaper and easily scalable deposition methods as sol-gel and dip-coating represents an advantage decreasing the cost of the solar energy.

Objectives: Development of selective coatings for being used as absorbers stable in air at high temperatures, on cheap metallic substrates with improved optical properties. Development of durable antireflective coatings on glass covers for its application in solar systems.

Achievements in 2013: A new selective absorber for solar receivers has been developed, stable in air at 400°C, with a solar absorptance of 0.95 and a thermal emittance as low as 0.18 at 400°C. It consists of only two layers on AISI 304 stainless steel produced by sol-gel technology. Using an additional aluminium infrared reflector, thermal emittance is reduced to 0.06 at 400°C. This preparation method is protected by Spanish and European patents. Two-meter long prototypes have been successfully prepared. Antireflective coatings have been deposited on soda-lime glass (tubes and flat substrates) for being used in low temperature solar applications. This type of glass contains sodium and calcium which tends to diffuse in to the AR coating getting worse the stability and the optical properties of the coating. The preparation process has been modified for avoiding this diffusion and an increase of the solar transmittance values of 6% has been obtained.

Figure 3.2. Two-meter long absorber prototypes.

Optical Characterization and Durability Analysis of Solar Reflectors, OPAC

Participants: CIEMAT and DLR

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Funding agencies: German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), Abeinsa Energía S.A., ALANOD GmbH & Co. KG, Flabeg GmbH and Rioglass Solar S.A.

Background: The feasibility of CSP 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.

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

Achievements in 2013: A productive research activity was performed under the framework of the Alumir project, started in 2012 and 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. During 2013, and in the framework of the OPAC Project, great advancement has been achieved in finding artificial aging tests (both extending the testing time of traditional experiments and proposing innovative ones) that correlate to degradation processes in outdoor exposure of front-surface aluminium reflectors with special top coatings and deriving a lifetime prediction model.

Figure 3.3. Outdoor test bench in Abu Dhabi (Alumir project).

Concerning glass based reflectors, an extensive testing campaign covering a large set of accelerated aging conditions has been started to define a standard test method with its corresponding pass/fail criteria to be able to predict possible material failure in the field.

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 under several accelerated aging conditions in order to improve their performance. Highly relevant are the studies with two 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. One of these studies was initiated in 2011 and interesting results have been obtained in 2013, after 2 years of exposure, while the second study started by the end of 2013 with promising achievements.

Optical and Thermal Performance of Parabolic-Trough Collectors and Components

Participants: CIEMAT

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

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 parabolic-trough collectors of large-size and their components, mainly solar receivers. The activity includes the testing and evaluation of this type of solar components in different outdoor test benches.

Achievements in 2013: The outdoor testing of solar receivers supplied by the Spanish company Aries has been performed. A set of 18 Beijing TRX's receivers were installed in one of the PTC collectors of the HTF PTC test loop for their characterization. The optical performance (combined value of the absorptance and transmittance) and thermal performance (heat loss up to 400°C) have been measured during the test campaign.

During the second semester of 2013 the HTF PTC test facility has been improved with the installation of new equipment. A second 40 kW electric heater was installed to get more flexibility, especially during the thermal testing of solar receivers. Furthermore, a Coriolis mass flow meter has been installed in series with one of the existing Vortex flow meters to improve the accuracy of HTF mass flow measurement; in addition, the new flow transmitter allows the on-line measurement of the synthetic oil's density (Syltherm 800®).

The construction of a new test facility for testing PTC units (up to 150 m-long), oriented in East-West direction, and another one for testing complete PTC loops (up to 600 m-long), oriented in North-South direction, has progressed significantly in 2013. The construction and start-up of this test bench, the so-called PTTL facility (acronym of Parabolic Trough Test Loop), will end in 2014.

Figure 3.4. View of Beijing TRX's receiver pipes installed in a EuroTrough type collector at the PSA.

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.

Contacts: Aránzazu Fernández García, arantxa.fernandez@psa.es
Lourdes González Martínez, lourdes.gonzalez@ciemat.es

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: CIEMAT-PSA 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 2013: CIEMAT-PSA participates with the development, in the TRN-SYS program, of some simulation models (CCStar collector, and solar installations in ECOTRAFOR and IPROCOR) and the dimensioning of the solar field in the ECOTRAFOR installation. The simulation model of the CCStar collector has led to the study of yield production of a solar field coupled to the installation of cork boiling placed in ECOTRAFOR (San Vicente de Alcántara, Badajoz, Spain), as well as the simulation of the prototype installed in IPROCOR (Mérida, Badajoz, Spain). In both works, the whole model simulates the thermal and hydraulic behaviour of the solar system coupled to each process of boiled cork, including the solar collector (CCStar), pipes, as well as heat exchangers, pumps and storage tank.

The model of IPROCOR system has been validated using some data reported in the installation. After the adjustment of the model, the study of yield power production from the installation has been done. That includes the calculation of the incident solar energy, as well as the useful heat energy available in the different components of the installation (collector, heat exchangers, storage tank, etc.). The annual efficiency of the whole installation is too low (7.8%), considering the collector efficiency (33.2%), because of the thermal losses in the components of the secondary circuit (pipe, pump, tank, etc.) of the system.

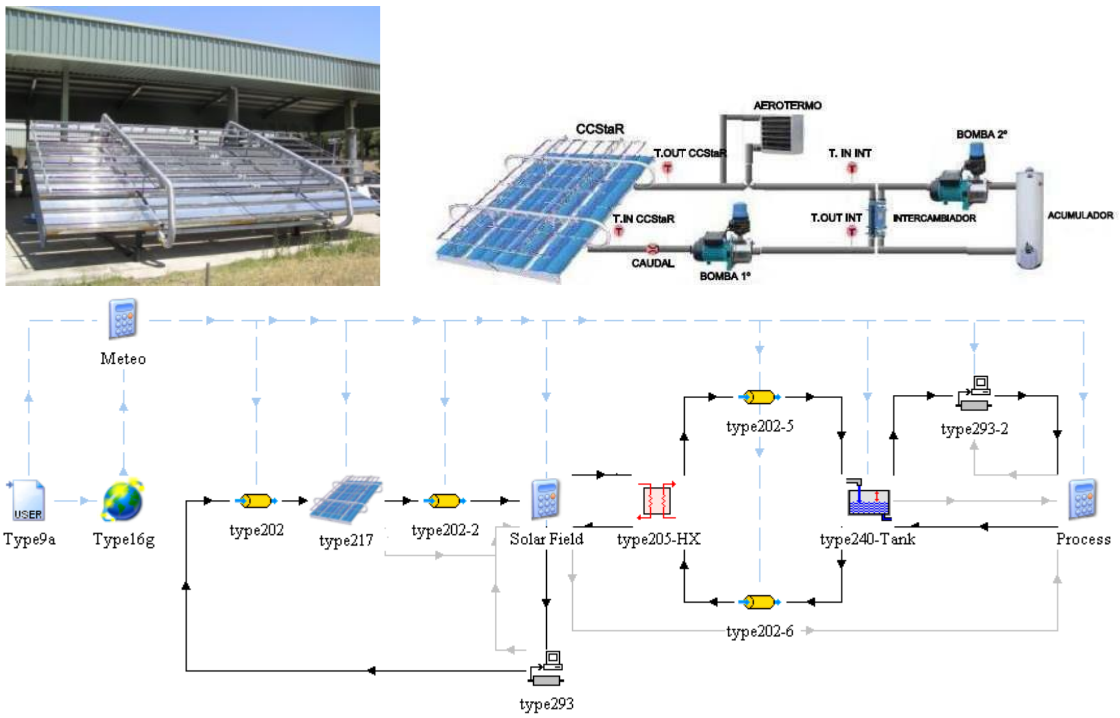

Figure 3.5. Prototype of CCStar collector and circuit scheme (up), and simulation model in TRNSYS of the solar installation of IPROCOR (down).

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

Participants: Institute of Solar Research - DLR (coordinator), 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 2013: During this year the modifications of the DISS test facility and commissioning of the plant has been completed and the first test period started in May 2013.

The DISS facility has been extended to a gross length of now 1000 m. Three new SL4600+ type collectors have been installed, two of them are located at the inlet and one collector is located at the outlet of the loop. The collectors have a length of 100 m each and an aperture of 4.6 m. All the receivers have been replaced by new Schott PTR70-DSG receivers for 500°C and 120 bar. The collectors' loop is now divided into two design sections: the first section is designed for about 140 bar/400°C and the second section for 120 bar/500°C. At design conditions, the plant now provides more than 3 MW of thermal power.

Efficiency tests with subcooled water have been performed to analyse the optical behaviour together with the receivers of the new collectors installed. The results of the first efficiency tests show that their optical efficiency is in the range of 77%. However, the uncertainties of the measurements are still high and further experiments are needed. After summer, the testing of an existing control scheme that was designed during the DISS project for the once-through mode has been performed. The scheme has been modified to take into account the new plant configuration. In addition, it has been translated from the existing C code to a new and improved code programmed in MatLab®, which offers new functionalities. New advanced control schemes will be tested in the ending phase of the project.

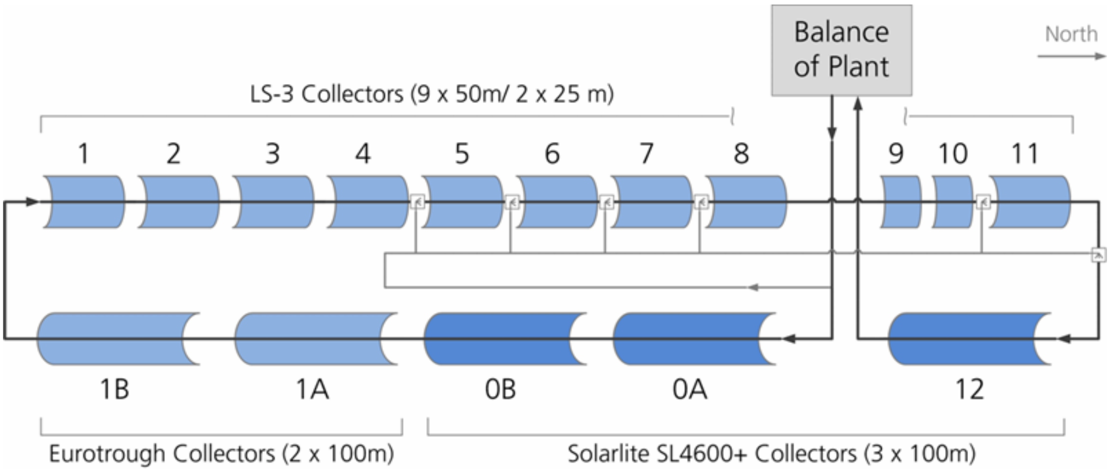

Figure 3.6. Scheme of the new DISS test facility in once-through configuration.

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

Participants: CIEMAT-PSA

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

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

Background: Modelling the behaviour of parabolic-trough collectors (PTCs) using water-steam as working fluid represents a particular challenge such as simulating the phase transition of the two-phase flow in the tubes, where different flux patterns can exist and even more, the non-homogenous heat flux (up to 40 kW/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 2013: A one-dimensional model has been developed and implemented in MatLab® to study the thermo-hydraulic steady-state behaviour of PTCs fields with direct steam generation (DSG). A sensitivity analysis has been conducted to analyse the influence of different working conditions in the pressure loss in solar fields using small-sized PTCs for DSG. For systems that works even at low pressure (below 25 bar) the solar receiver diameter, collectors' loop length and working pressure have a strong impact in results and direct steam generation could be unfeasible in some cases.

The computational fluid dynamics software package STAR-CCM+ has been also used to implement an efficient multiphase model (3D model) capable of simulating the behaviour of DSG in PTCs. The implemented modelling approach can be described as a Locally Homogeneous two-phase flow Model (LHM), which is based on the assumption that all phases have the same velocity and are in thermodynamic equilibrium at each computational cell. The LHM model solves the Reynolds averaged Navier-Stokes equations for continuity, momentum, energy for each phase, and further solves the turbulent kinetic energy k and the turbulent dissipation rate e. Therefore only one set of closure equations is solved for the effective mixture fluid, and an additional transport equation is solved for the volume fraction of one of the phases. During this year the modelling approach has been applied to simulate both the steady-state and dynamic behaviour of the DISS test facility. A description of the modelling approach and comparisons of the simulation results and measurements have been published.

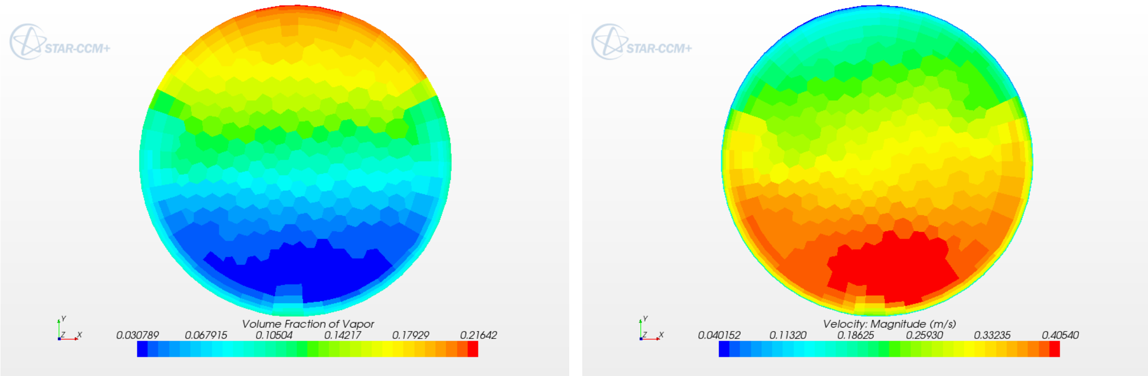

Figure 3.7 Cross sectional view of the computed (left) volume fraction of vapour and (right) fluid velocity at 200 m from the start of the first DISS collector using STAR-CCM+ (system pressure = 3 MPa).

OPtimization of a Thermal energy Storage system with integrated Steam Generator, OPTS

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

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

Funding agency: FP7-ENERGY-2011-1

Background: Reducing cost of the storage system is a priority within the 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 2013: Within this project, the multipurpose test facility with molten salts as heat transfer fluid erected at the PSA has been used for the experimental evaluation of components, equipment and procedures to check their reliability in molten salt circuits. The specific components, their manufacturers and specific testing procedures were already defined in 2012 while some of the components have been tested along 2013.

The CIEMAT's numerical model for characterizing the behaviour of thermocline tanks using liquid was the base to define an equivalent analytical function. This function allows introducing TES with thermocline system in annual simulations of power plants with no mayor computing time. Running annual simulations of different solar thermal power plants (STPP) based on parabolic trough technology and with a thermocline storage system has given the definition and analysis of the operation strategies that could be applied to this type of TES. This analysis has taken into account the different operation possibilities associated to the particular behaviour of a thermocline storage system.

Figure 3.8. Checking a control valve in the two-tanks molten salts TES facility.

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. Using store materials that change phase from solid to liquid statically, 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.

Objectives: CIEMAT proposes to solve this problem with a new concept where store material changes phase from one liquid state to other. Thus, a nearly constant power curve is possible, and an efficient exchange of energy is assured since convection is the main heat transfer mechanism.

Achievements in 2013: With the list of potential materials to be used, the main activity in 2013 has been to look for collaborations with research institutions and companies to manufacture this type of materials.

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

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

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Funding agency: European Commission (EU-7FP- ENERGY.2013.2.9.1).

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

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

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

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

Achievements in 2013: The first week of September 2013 the Kick of Meeting of the REELCOOP project took place in Brussels, at the Covent Garden 2 EC Building. Representatives of all Partner Organisations attended this meeting, as well as the EC Project Officer. CIEMAT-PSA contributes with the development of the, already patented, own design of thermal storage for latent heat with low-thermal conductivity phase change materials. The size and operation will be optimized according to the working conditions of the solar field and biomass boiler. After manufacturing the module it will be

Figure 3.9. Participants in the Kick off meeting of the REELCOOP project (Brussels, September 2013).

tested at PSA and send to Tunis for being part of Prototype #3 installation.

Direct Normal Irradiance Nowcasting methods for optimized operation of concentrating solar technologies, DNICast

Participants: OME (leader), CENER, UNIPATRAS, METEOTEST, ARMINES, RIUUK, SMHI, DLR, TROPOS, CIEMAT-PSA, METEOSWISS, CYI.

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

Funding agency: European Commission (EU-7FP- ENERGY 2013.2.9.2).

Background: Concentrating solar technologies (CST) have proven to be very efficient sources of "clean" power for the electrical grid. The efficient operation of concentrating solar technologies requires reliable forecasts of the incident irradiance. Therefore, the project proposes innovative or improved methods to reduce the uncertainty in the forecast of the DNI.

Objectives: The CIEMAT-PSA participates in the development of some simulation models of CST plants (CSP and CPV) or typical collector loops, used to validate the spatial and temporal nowcasts and to assess the influence of improvement in DNI nowcasting on nowcasting of CST plant output. Within this objective, the DNI nowcasting is used as input of the models to calculate the yield production of the CST plants/systems.

Achievements in 2013: CIEMAT-PSA participates in this project in collaboration with the Solar Radiation Group, and the Unit of Solar Photovoltaic Energy of CIEMAT.

The first steps in the work package 1 of the project have been the collection of requirements for nowcasting method, providing the view of the power plant operators, but also the view of solar system designers and electricity grid operators. A focus is laid on the transient behavior of the technology and power plant operations.

Figure 3.10. A partially cloudy sky with corresponding shadow pattern (left) and a parabolic trough plant (right) to study the influence of the cloud's shadow over the solar field.

As the nowcasting method development is pushed forward mainly by non-solar energy experts, a description of some basics in concentrating solar technologies (thermal and photovoltaic solar technologies, direct normal irradiance, definitions of nowcasting related terms, etc.) are included in the work, together with an explanation of the background why nowcasting is needed. Based on that, a quantification of requirements for the method development is provided.

3.3 High Concentration Group.

3.3.1 Introduction

Activities developed by the High Concentration Group (HCG) during 2013 framed by financed projects are mainly focused on the integration of point focus technology in modular systems (SOLGEMAC). We have also supported the testing and evaluation of the HF-ISO project, focused on the evaluation of thermal isolation for a pressurized air tube receiver. SFERA project has implied too, on the joint research activities, manpower dedication of HCG people.

In 2013 we have also started the modelling and evaluation of the AORA's demonstration power plant installed at PSA. AORA's plant used the pressurized volumetric air technology coupled to a gas turbine to generate 100kW electric power and 170 kW thermal to drive industrial processes (desalination, solar cooling, etc.)

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 2013, thus supporting companies on the product development.

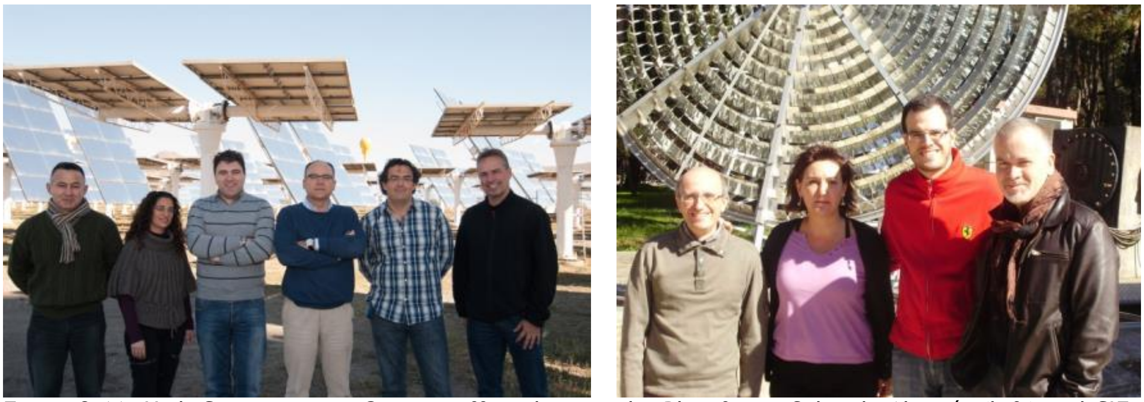

Figure 3.11. High Concentration Group staff working at the Plataforma Solar de Almería (left) and CIEMAT-Madrid (right).

3.3.2 PROJECTS

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

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

Contacts: Mónica Álvarez de Lara Sánchez, monica.alvarezdelara@ciemat.es
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: Concentrated Solar Power is focused in the cost reduction by means of increasing efficiencies. In order to identify high-efficient configurations and geometries for the absorbers used as volumetric receivers developed a lab-scale test bed used for the evaluation of open volumetric receivers to identify configurations and geometries to optimize the generation and thermochemical process.

Objectives: Establish the knowledge to develop modular, efficient and manageable concentrated solar energy systems, addressing dish-stirling and multitower solar systems to be installed on urban areas. Objectives can be reached by taking advantage of the higher efficiencies obtained by volumetric receivers and reactors at ultra-high solar fluxes/temperatures.

Achievements in 2013: Ciemat HCG is the coordinator of the task named “Solar receivers/reactors for high fluxes and high temperatures. In this period, the SiC channels absorber, alloy 601mesh absorber, with homogeneous porosity, and alloy 310, with different gradual porosity, were evaluated with different flux (peak 1936 kW/m^2 and average 220 kW/m^2), depending on the material. Next table shows some results. When comparing the results is observed that for medium to high incident radiation/air flow ratio, the gradual porosity absorbers present similar or better behaviour than the others. To select the better candidates to optimize the design, pressure drop test of each absorber design have been carried out and, in addition, after test materials evaluation, fluid dynamic and thermal simulation have been carried out.

Table 3.1. Test matrix for the different absorber configurations tested.

Material	SiC			601 alloy			61-54 % 310 alloy			61-38 % 310 alloy			54-38 % 310 alloy		
Incident radiation / air flow, kJ/kg*	260	440	700	250	430	580	260	420	720	250	430	760	290	470	720
Air outlet temperature, °C	270	420	530	260	380	430	260	380	530	260	390	580	310	430	560
Thermal eff., %*	87.5	86.8	73.5	88.2	79.8	69.5	84.8	80.2	70.1	87.1	80.5	72.0	92.2	85.5	75.4

*A. L. Avila-Marin, et al. Energy Procedia, 2013

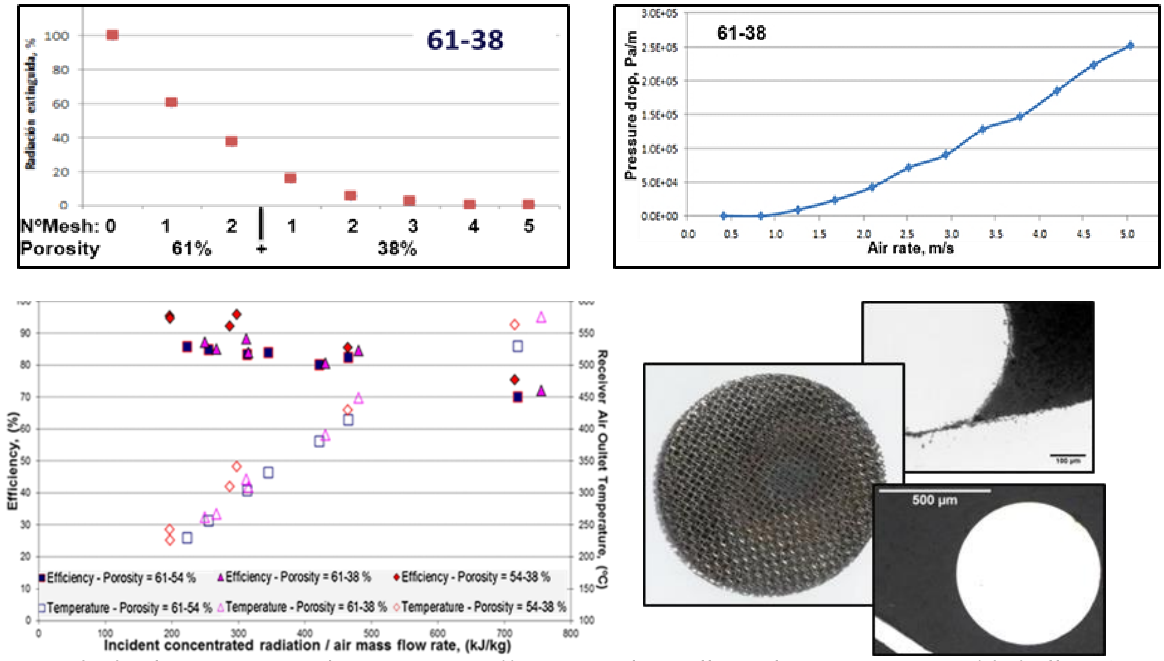

Figure 3.12. Flux extinction, drop pressure, efficiency and metallographic cross section of 310 alloy, 61-38% porosity absorber.

HF-ISO

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

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

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

Background: In the EU-project SolHyCo, a solar-hybrid micro-turbine system with a solar receiver (tube receiver) for pressurized air was built and tested. During the tests, the receiver had excessive heat losses (>30% of the nominal thermal power). As primary reason, the insulation cavity of the receiver was identified. After only a few operation cycles, the very simple design showed gaps due to the thermal expansion and contraction of the material that allowed the hot air inside the cavity to escape (convective losses).

Objectives: The principal goal of the HF-Iso project is the design, construction, test, and evaluation of an improved insulation cavity for the SolHyCo receiver. The thermal losses should remain below 7%. As the gas turbine is not available in this project, the tests are performed with a blower and an electrical heater. Solar powered tests are done at 500, 600, 700, and 800°C gas outlet temperature. Total operation time shall exceed 100 hours. Some additional non-solar tests with closed aperture are interspersed to determine the possible changes of the insulation properties during the test campaign.

Achievements in 2013: In 2013, all mechanical work to make the system ready for solar operation was done. This consisted of dismantling the old (SolHyCo) cavity, disconnecting the gas turbine (compressor outlet and combustor inlet), installing the new cavity, connecting the electric heater, the blower, and the escape pipe, and renewal of the passive radiation shield to protect the test room from the concentrated solar radiation. Furthermore, the complete data acquisition system was checked and (where necessary) renewed or adapted. The software tools for the so-called "Quick-Analysis" were developed and refined. They are very useful during solar operation, because they offer very quickly a good overview about the previous test day. After completing all installation work, a non-solar test campaign of 12 tests within two months was undertaken to characterize the initial thermal behaviour of the new insulation cavity. Due to bad weather, the beginning of the solar tests shifted to January 2014.

Figure 3. 13. New cavity of HF-Iso receiver. Left: View from outside. Right: View into aperture.

AORA SOLAR demonstration plant evaluation

Participants: AORA SOLAR S.L., CIEMAT-PSA.

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

Funding: AORA SOLAR, CDTI.

Background: Since 2010, AORA SOLAR S.L. is present on the PSA with a demonstration facility. This facility consists on its modular concept of hybrid solar power plants: a central tower solar plant using a pressurized volumetric receiver coupled to a small gas turbine to drive a Brayton Cycle. This solar tower concept delivers 100kWe power and uses the exhaust of the turbine (170kW thermal) to feed heat industrial process: desalination, solar heating and cooling, process heat, etc.

Objectives: The main goal is to help them in developing the AORA's solar technology, by means of an evaluation campaign of the facility (analysis of the optical and thermal efficiency of the heliostats field) and a complete test campaign to evaluate the overall system efficiency as well as partial efficiencies of plant subsystems.

Achievements in 2013: In 2013, the field work has been just started and pictures of the solar radiation reflected for every single heliostat have been collected. From these pictures is possible to calculate the optical performance of the single heliostats that will be used as input to the simulation model. In parallel, the reflectance of the solar field is being analysing with the aim of offering a statistical methods that allow having a mean reflectance value of the solar field without measuring every heliostat facets. The work will be continued in 2014 to finalize the whole evaluation of the demonstration plant.

Figure 3.14. AORA SOLAR demonstration plant and Tonatiuh model of the facility

Optical and tracking performance of heliostats and heliostats components

Participants: CIEMAT

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Raúl Enrique, raul.enrique@psa.es

Funding agency: Several Spanish and foreign companies

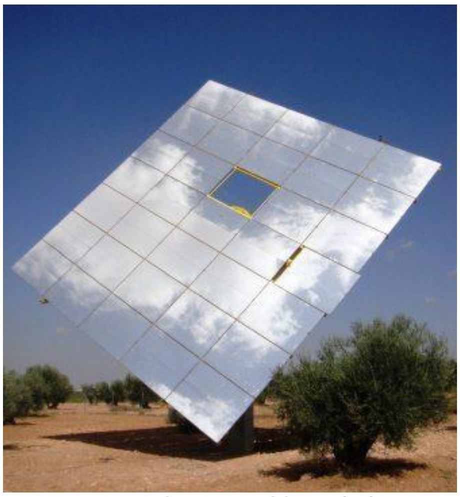
Background: Deployment of Solar Central receiver power plants has induced companies to design and build heliostat prototypes to be installed in different projects that are currently under development worldwide. Since the beginning of PSA activity, CIEMAT has been developing testing procedures for characterizing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

Objectives: Completely characterization of heliostat prototypes performance, including optical (focal distance, canting, normal vector deviations from the model), energy (total power, flux mapping) and tracking (low and high frequency effects, control deviation, wind influence) performance.

Achievements in 2013: This activity has required an additional effort from the HCG staff in 2013 due to the interest of the industrial sector to develop new heliostat prototypes that increase performance, reducing component and on-site deployment costs at the same time. Three different heliostat prototypes have been tested during 2013 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 its behaviour under wind loads.

Special significance has the agreement reached with ARISOLAR for the development of a new heliostat concept (patented by ARISOLAR): innovation is that one of the tracking axes is pointed to the receiver and a close-loop control is developed using a solar sensor on the heliostat.

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).



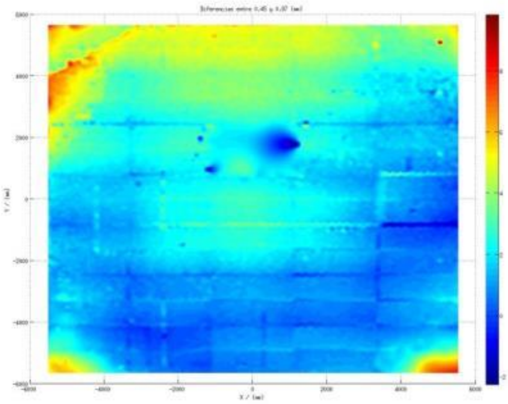


Figure 3.15. ARI SOLAR heliostat prototype and reflecting surface geometrical results.

CESA-I facility Refurbishing

Participants: CIEMAT

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

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

Background: The CESA-I project, was promoted by the Spanish Ministry of Industry and Energy and inaugurated on May 1983 to demonstrate the feasibility of central receiver solar plants and enable the development of the necessary technology. At present, the CESA-1 does not produce electricity, but it is a very flexible facility operate for testing subsystems and components such as heliostats, solar receivers, thermal storage systems, solarized gas turbines, control systems and concentrated high flux solar radiation measurement instrumentation. It is also used for testing some other applications that require high photon concentrations on relatively large surfaces, such as chemical or high-temperature processes, materials surface treatments or astrophysics experiments.

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

Achievements in 2013: The main works that have been made during 2013 were the renovation of 150 heliostats tracking mechanisms, the change of the heliostats structures and the re-canting of the heliostats facets. With this action, the CESA-I heliostat field is completely refurbished, improving the accuracy, optical quality and whole thermal power of the CESA-I facility.

Finally, a new air blower has been installed on the Phoebus loop at the top of the tower which allows reaching higher air flows at higher recirculation temperatures (up to 400^0C). This new equipment will allow to further experiment for in-depth assessment of the influence of recirculation on the volumetric receivers behaviour.

Figure 3.16. Tracking mechanism replacement on the CESA-I solar field (left) and new instrumentation on the Phoebus atmospheric air loop (right).

Radiometry Laboratory Activities

Participants: CIEMAT

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

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

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

During execution of the MEPSOCON Project (MEdida de Potencia Solar CONcentrada-Measurement of Concentrated Solar Power in solar power plants, Reference DPI2003-03788) a procedure for calibrating high-solar irradiance radiometers was drafted. Up to now, there had been no established procedures for calibrating these sensors. A systematic error was detected and corrected in measurement of high solar irradiance. The calibration of high solar irradiance radiometers is habitually done in this radiometry laboratory; in this sense, services are provided to national and foreign companies and institutions, such as Solucar, CENIM, DLR, CIEMAT, etc.

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

Achievements in 2013: The most promising lines of research propose the use of infrared sensors that work in shortwave spectral ranges with H_2O and CO_2 atmospheric absorption bands, so band-pass filters can detect the hot surface radiation even through quartz without any distortion by the reflected solar radiation. It has been shown that although pass-band filters in the atmospheric solar absorption zones of 1900, 2700 and 4300nm are "solar-blind", any variation in the distance and humidity that differs from the calibration conditions affects measurement. An IR camera with pass-band filters in two narrow "solar-blind" spectral regions outside of the atmospheric absorption bands, and therefore, insensitive to changes in distance and humidity, has been defined, designed and validated. The filter is changed automatically by filter wheel control software.

In collaboration with the meteorology station group at the PSA, spectral solar irradiance characterization studies continue. Studies of atmospheric attenuation of the solar radiation with the MODTRAN code have been begun.

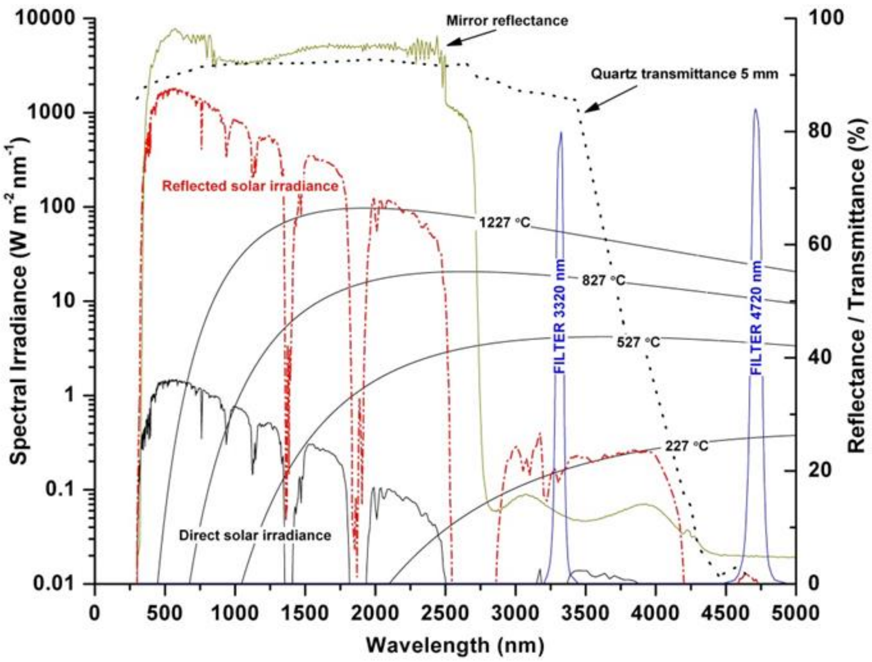

Figure 3.17. Issues of the surface temperature measurement on the Solar radiation context

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.

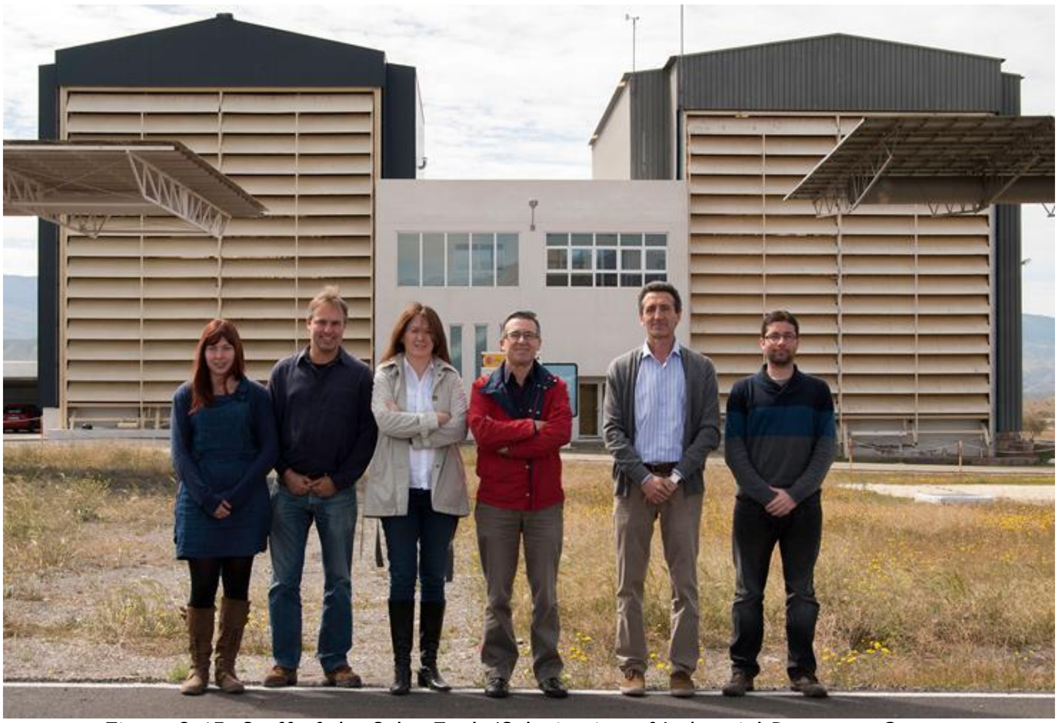

Figure 3.15. Staff of the Solar Fuels/Solarisation of Industrial Processes Group.

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-CRS (Small Solar Power System – Central Receiver System) 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 2013: Over the last three years an experimental campaign in the framework of this research project has been performed at SSPS-CRS tower with a 500 kW Solar Gasification Plant. Part of this experimental campaign focused on certain sensible parts of the SYNPET reactor, like the ceramic cone and the window. In 2012, chemical testing campaign was initiated by injecting a mixture of steam + coke, showing a H_2 concentration above 30% in the outlet stream. Fig. 1 shows the receiver during the chemical tests.

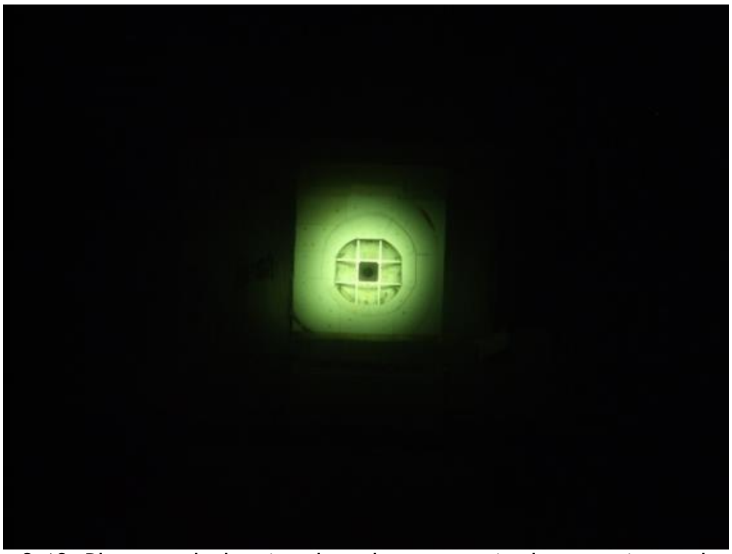

Figure 3.19. Photograph showing the solar reactor in the experimental tests.

During 2013, CIEMAT has been evaluating different alternatives to the initial proposal of window. To detect the operational limits of the window, a comprehensive thermal evaluation has being included in the test campaign of this project. This innovative window design for solar reactors – applicable for large focal spots – represents a technical challenge for advancing in thermochemical applications in Central Receiver Systems. However, during the last testing campaign the reactor window suffered some damages after several hours of operation.

Some new proposals are being considered to solve the problem that occurred during the testing campaign with the window. A final decision will be taken along 2014.

Scale Up of Thermochemical HYDROgen Production in a SOLar Monolithic Reactor: a 3rd Generation Design Study, 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 concerned with the pre-design of a 1MW plant including a solar hydrogen reactor and all necessary upstream and downstream units.

Achievements in 2013: CIEMAT has supported the validation of the control program by experiments and simulation. For the model, The Knapsack strategy based control program combined with a PI has been used.

For the real experiments, the target was the regeneration and hydrolys temperatures in the east reactor whose coordinates are 26.45 m height, and 0.9 m East.

Irradiance during a typical experiment, i.e. October, 2013 between 12:27 h and 15:05 h, is shown in the top graph of Fig.3.20, the reactor temperature in the middle graph, and the number of heliostats focused in the bottom one.

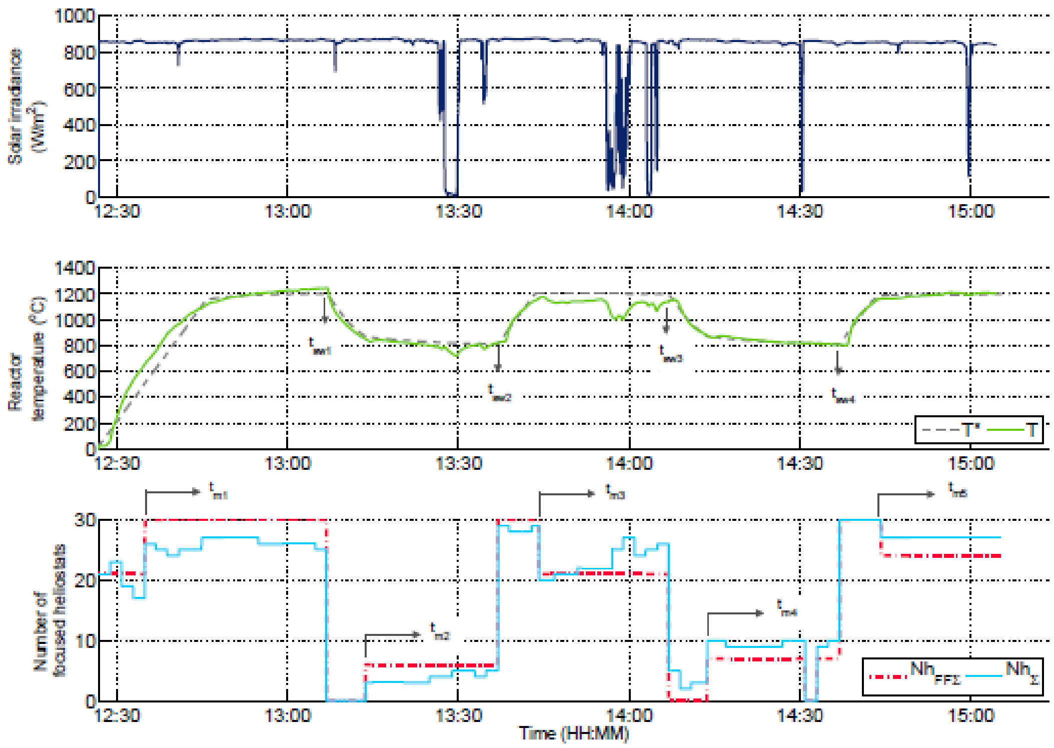

Figure 3.20. Experimental test at HYDROSOL facility with the automatic control.

As can be observed, the temperature reference is followed quite well with the proposed control strategy. In the start-up an offset is observed because of a delay in the heliostat movement caused by a communication failure. As a consequence, the PI acts sending a message to focus two more heliostats trying to follow the reference. When the heliostats are really focused, the temperature increases quickly and the controller tries to take heliostats out of focus. Nevertheless, with the high inertia of the system, the PI should be more aggressive to reduce the slope in the reactor temperature. Despite the start-up, the thermochemical cycle follows the desired reference and it switches in a low time.

Assuming that hydrogen production can be started when temperature is below 850°C, the elapsed time in the switching is 10.5 minutes. On the other hand, hard irradiance disturbances cause a temperature fall of almost 100°C which cannot be avoided.

Hydrogen Production and Fuel Cells: Development and Applications, H_2 PLAN_E

Participants: CIEMAT

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

Funding agency: MICINN through the 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 solar tower to provide organizations and research groups with the best research and test infrastructure to produce hydrogen by solar thermochemical technologies.

Achievements in 2013: Project was finished in March 2013. A reinforcement work of the steel structure and the cementations of the CRS were finished. Some new equipment has been added in order to increase the overall operating capacity of the plant, i.e., pressurized air compressor (29 dm^3/s, 8 bar), two batteries of 23 standard-bottles (50 dm^3/225 bar) to supply nitrogen, cooling tower with a capacity of up to 700 kW, a 8 m^3 demineralised water buffer tank (ASTM type 2) to be used in steam generators or directly in the process, and a data network infrastructure consisting of Ethernet cable and optical fibre.

Solar hydrogen production by using solar thermal power, SolH2

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

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

Funding agency: MICINN through the INNPACTO subprogramme.

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

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 2013: During this year the preparation of solar tower platform was concluded. Fig. 3 shows the new room at 29 m. that the installation of the solar reactor is expected in 2014 as well as the installation of the rest of the peripherals. Testing campaign for evaluation of the ferrite thermochemical cycles is expected at the end of 2014.

Figure 3.21. Photograph of the room at 29 m.

Oxygen from Lunar Regolite with Solar Concentrating Energy, ORESOL

Participants: CIEMAT-PSA (Spain).

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

Funding agency: CIEMAT.

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

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

Achievements in 2013: Among the numerous activities, the most significant were the continuation of the hardware installation and testing of components, the development of the data acquisition and control software including sensor calibration, and the beginning of the fluidization tests of the main bed. Hardware installation included a major modification of the upstream section to save space for additional flow sensors and the recirculation pump. Piping and hardware components needed for closed loop operation were designed and installed. Great importance was placed on the programming of the data acquisition system in the programming language LabVIEW (fig. 3.22). Besides displaying and logging of the data and adjustment of the set points, a lot of automatic functions were included to improve the safety of the system and the outcome of the tests.

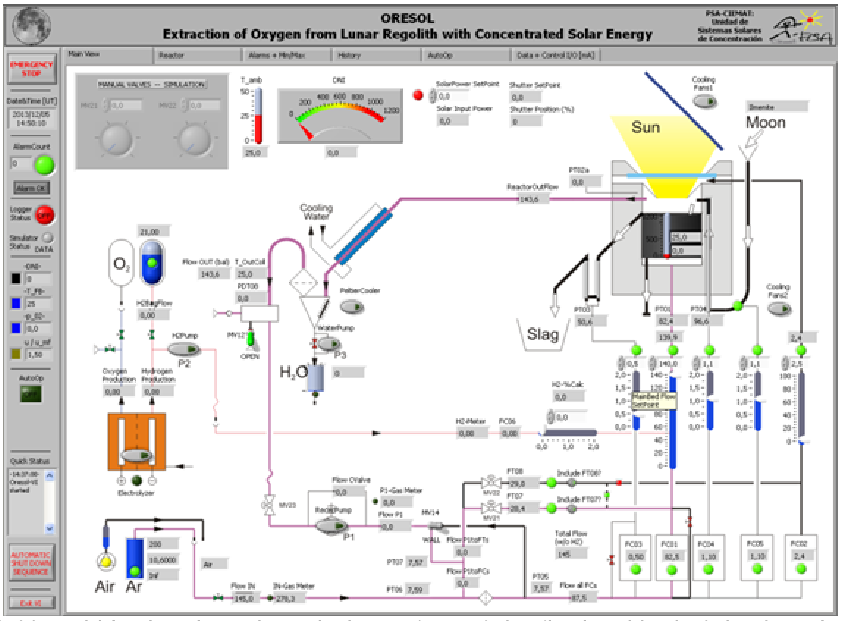

Figure 3.22. Bubbles breaking through the surface of the fluidized bed of the Oresol reactor.

Development of preindustrial prototypes for solar generation of high-temperature process heat: Testing and characterization of application to production processes and waste elimination, SolarPRO Project

Participants: CIEMAT-PSA (Spain).

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

Funding agency: MICINN through the 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: The purpose of "SolarPRO" is to demonstrate the technological feasibility of the use of solar thermal energy for energy supply in different industrial processes with high temperature as the common denominator.

Achievements in 2013: The final test campaign was carried out at the beginning of 2012. 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. Finally, characterization tests for a cylindrical prototype solar volumetric receiver system based on the finite elements simulations have been completed at PSA Solar Furnace. The results indicate the most suitable geometry, wall-thickness, and material for the process conditions.

Based on this preliminary study carried out during 2013, a preliminary configuration is given and it consists of a tubular geometry with a baffle plate located at the outlet and three material layers: refractory material of 15 cm thickness, insulating material of 15 cm thickness, and frame material of 5 mm thickness. This prototype enables to carry out several high-temperature industrial processes, such as material treatments. Construction and experimental analysis of this prototype are going to be developed in the PSA Solar Furnace.

Figure 3.23. 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.

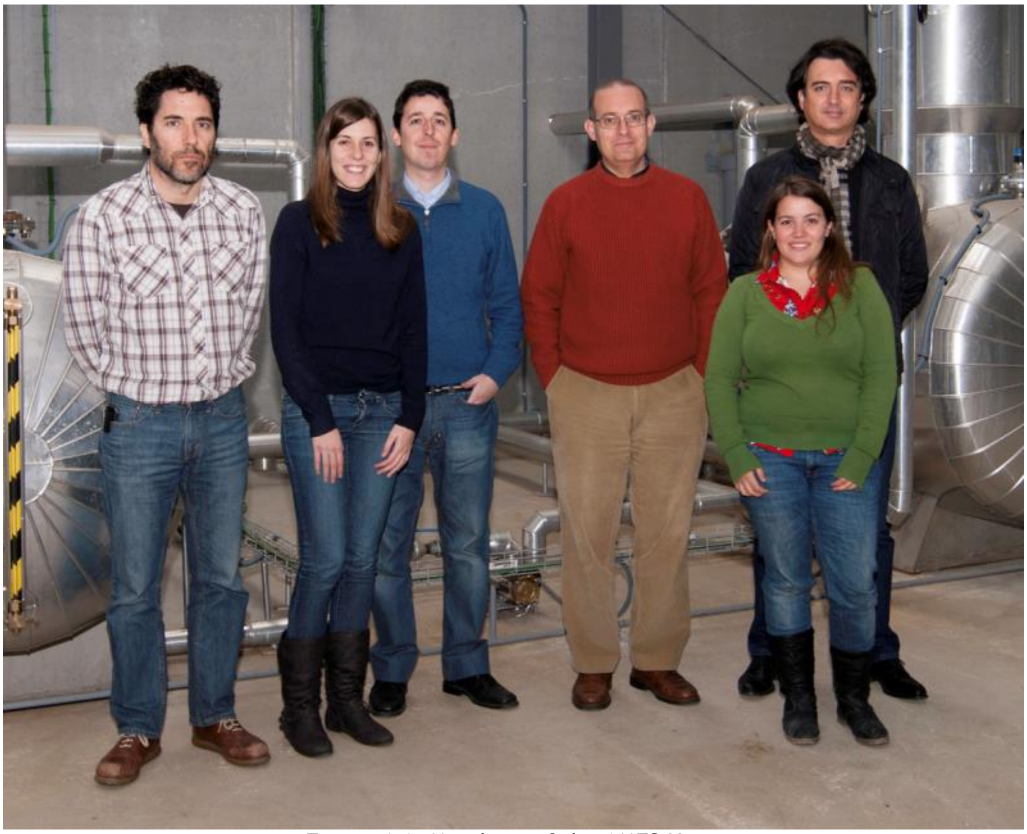

Figure 4.1. Members of the AMES Unit.

During 2013 research activities were developed within the framework of projects covering both national and international activities with academic and industrial involvement.

This year represents the consolidation of CIEMAT-PSA as a point of reference in the field of membrane distillation, both in its coupling with solar energy and life-size prototype implementation. This work was recognized in the International Conference of the International Desalination Association (Best Presentation in Thermal Desalination award to Dr. Guillermo Zaragoza). Regarding the simultaneous production of solar thermal electricity and desalinated water, 2013 represents a transition year between the elaboration of the final reports of the projects concluded in 2012 and the presentation of new research proposals. One of the most significant has been the IRP (Integrated Research Project) STAGE-STE that has been approved and the start of its activities is scheduled for the beginning of 2014.

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).
- Coordination of the Renewable Energy Desalination Action Group of the European Innovation Partnership on Water of the European Commission.

4.2 Projects

Zero Carbon Resorts (ZCR)

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

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

Funding agency: European Commission, SWITCH-Asia Programme.

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

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

Achievements in 2013: A layout of the energy supply for the Zero Carbon showcase building was finalized and simulations performed.

The analysis of solar thermal applications in Palawan was completed and a report elaborated and presented at the stakeholders conference "Redesign" in Manila (April 2013), during which the ZCR showcase cottage was introduced. Also, a software tool was developed to help designers.

Figure 4.2. ZCR Conference "Redesign" in Manila (April 2013)

The energy system and monitoring of the building was designed. Tools for simulating the thermal system were developed, and simulations of the PV system were carried out for different framework conditions.

Evaluations of autonomous small-scale solar desalination systems based on membrane distillation (MD) were finished with the publication of a summary paper and its presentation in the International Conference on Applied Energy (July 2013) and in the International Desalination Association Conference in China (October 2013). The main result was that when coupling MD with solar thermal energy, spiral-wound modules or multi-effect systems should be considered for improved efficiency.

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

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

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

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

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

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

Achievements in 2013: During this period a prototype of steam engine has been implemented to be driven by saturated steam at 10 bar (abs) generated by a solar field composed of parabolic trough solar collectors of small aperture. During the expansion process of this saturated steam, pressure will be transmitted to the saline water in order to reach the required nominal pressure to drive a desalination process based on reverse osmosis process. After the conclusion of the expansion process, the energy content of the steam will be use within a crystallization process of the brine obtained from the desalination plant. Testing of the prototype under real climatic conditions will be carried out at PSA during 2014.

Figure 4.3. NEP PolyTrough 1200 solar collector for process heat applications up to 220 ºC

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

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

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

Funding agency: European Commission, SME Actions

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

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

Achievements in 2013: The design and optimization methodology was developed for the adapted CPV/T collectors, which are operating at temperature up to 100 ºC, producing electricity from the PV cells and heat. Various parameters were investigated, such as their orientation, the materials used, and the flow rate of the heat transfer fluid (relevant to the inlet/outlet temperatures). The developed optimization methodology was followed, using common boundary conditions (e.g. flow rates, fluid temperature, etc.), in order to conclude to the design of each process.

After the simulation and optimization of each technology, a numerical platform under the same software was developed, enabling the calculation of the combined process. The necessary input parameters were the weather data, simulating the system operation and obtaining some first proof of its productivity. The annual/daily simulations of the combined system showed that it had superior performance, in comparison to a conventional CPV/T system, although its operational temperature was higher, and the PV cells show decreased efficiency.

5. Solar Water Treatment Unit

5.1 Introduction

The Water Solar Treatment Unit was created 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 group 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

The research group knowledge about solar detoxification and disinfection processes at pilot and pre-industrial scale is backed up by 20 years of research activity, after been involved in the 4th, 5th, 6th and 7th EC FPs, (SODISWATER, AQUACAT, INNOWATECH, PHOTONANOTECH, GREENTECH, RITECA II, SFERA, etc.). At present several European projects are running in collaboration with different International Institutes and Universities (GREEN-TECH, RITECA II, SFERA and SFERA II).

At national level, this group has been involved in different projects and contracts with private companies due to its expertise in environmental technologies (HIDROCEN, Janssen Pharmaceutica, DERETIL, ALBAIDA, AQUALIA INDUSTRIAL, ACCIONA, BEFESA, etc).

The research activities already consolidated by this unit 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 removal of both emerging pollutants and pathogens are investigated.

2) Using solar photocatalytic and photochemical processes for the remediation of industrial wastewaters contaminated with several types of pollutants and water reclaim for different applications. Pharmaceuticals, pesticides, landfill leachates, textile and wine industry wastewaters, and other complex wastewater 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 operating 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.

Developing new solar photo-reactors for different purposes (drinking water, water reclamation, irrigation, etc.), either water decontamination or water disinfection.

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: 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 (WW) effluents. However, the presence of emerging pollutants (chemical and biological) limits their use. These uses in Spain are regulated by the Spanish Directive RD 1620/2007. The assessment and development of advanced technologies such as solar photocatalytic processes to enhance the water contaminants removal appears as a good choice.

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

Achievements in 2013: The efficiency of several solar promoted treatments on the inactivation of *E. coli* cells was evaluated. A wide range of reagents concentrations for TiO_2 (10-500 mg/L), TiO_2/H_2O_2 (10-500/10 mg/L), H_2O_2 (5-50 mg/L) and photo-Fenton (5-20/10-50 mg/L of Fe^{2+}/H_2O_2) treatment were investigated for spiked *E. coli* in distilled water and simulated urban wastewater treatment plant (SMWWTPE); and naturally occurring *E. coli* in real urban wastewater (UWW) effluents. All treatments were conducted at laboratory scale (200 mL) under natural solar radiation yielding very good inactivation kinetics. Among all treatments, the best inactivation results were found for 500/10 mg/L of TiO_2/H_2O_2 in distilled water and SMWWTPE, respectively; while photo-Fenton was a better choice in UWW. 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 by detection and enumeration bacteria with culturing method in selective agar and real-time PCR (Polymerase Chain Reaction) using a protocol that permits identified only alive cells. To do so, a protocol using EMA has been developed successfully for the detection of viable *L. pneumophila* by PCR.

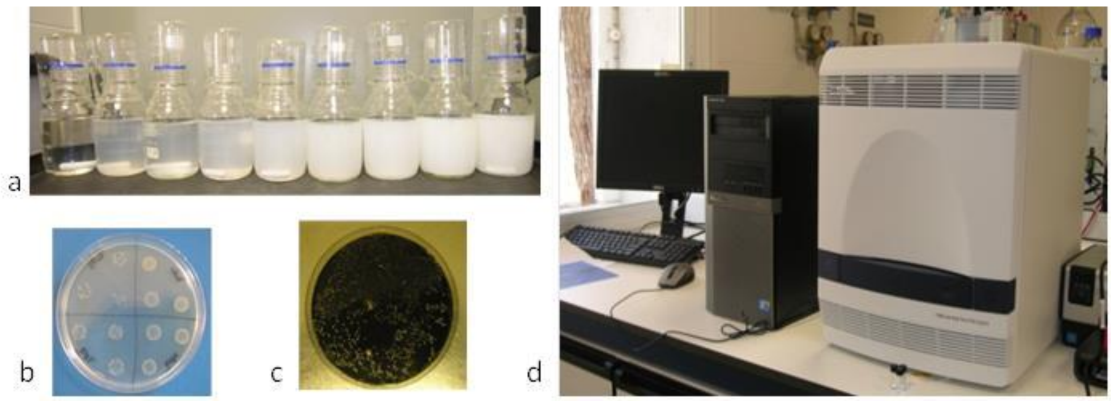

Figure 5.2. (a) Photocatalytic experiment using slurry TiO2 with different concentrations of photocatalyst. (b, c) Petri dishes for E. coli and Legionella colonies growth. (d) Real time PCR (7500-Fast, Applied Biosystem) at PSA laboratory.

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

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

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

Funding agency: MICINN through the National R&D&i Plan (2012)

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

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

Achievements in 2013: During this first year of this national project several tasks have been started. First of all the state of the art regarding the treatment of complex industrial wastewater has been tackled. Regarding the experimental part of the project, during spring and summer 2013 around 400 L of cork boiling wastewater and 1000 L of landfill leachate were received at the PSA facilities. A complete characterization of these wastewaters as well as the optimization of physic-chemical processes for the pre-treatment of landfill leachate at different pHs and agitation speeds, and the sequential addition of flocculants and coagulants, were carried out (figure 5.3 (a)). Those tasks were performed at laboratory scale in the Jar-Test device. Afterwards, solar photo-Fenton experiments for the remediation of landfill leachate were done (figure 5.3 (b)). In addition, toxicity and biodegradability assays during the treatment were carried out, with the aim of detecting an increase enough in the biodegradability of the wastewater to finish its treatment in a conventional biological process. After the solar photo-Fenton oxidation, elimination of 52% for chemical oxygen demand and 37% for dissolved oxygen was attained after a consumption of 21 g/L of hydrogen peroxide and 117 kJ/L of accumulated UV energy.

a)

b)

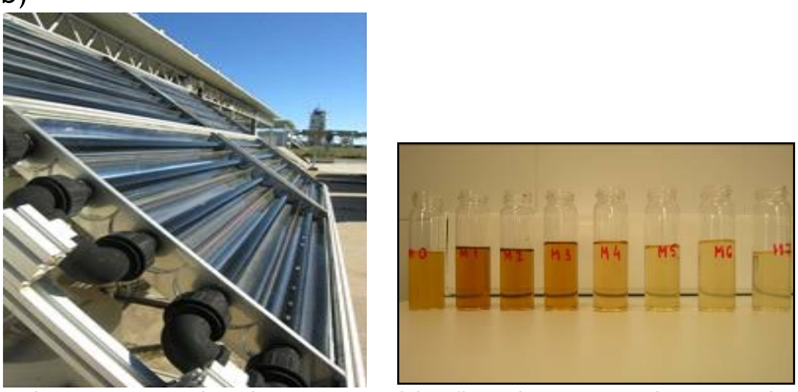

Figure 5.3. (a) Complex industrial wastewater already pre-treated by flocculation/coagulation in the Jar-Test equipment. (b) Solar CPC photo-reactor pilot plant employed for solar photo-Fenton treatment of complex wastewater and detail of wastewater colour elimination during the process.

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: 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 2013: Assessment of the TiO_2-coated glass beads prepared (Fig. 5.4) proved to be photocatalytically active and mechanically stable, even in real municipal wastewater treatment plant (MWWTP) secondary effluent using acetaminophen as a test compound. Moreover, their photocatalytic activity remained practically the same after being reused five times. As expected, the presence of organic/inorganic compounds in the matrix reduced the photocatalytic degradation rate of acetaminophen, and similar behaviour was observed when a mixture of thiabendazole, acetamiprid and imazalil was treated.

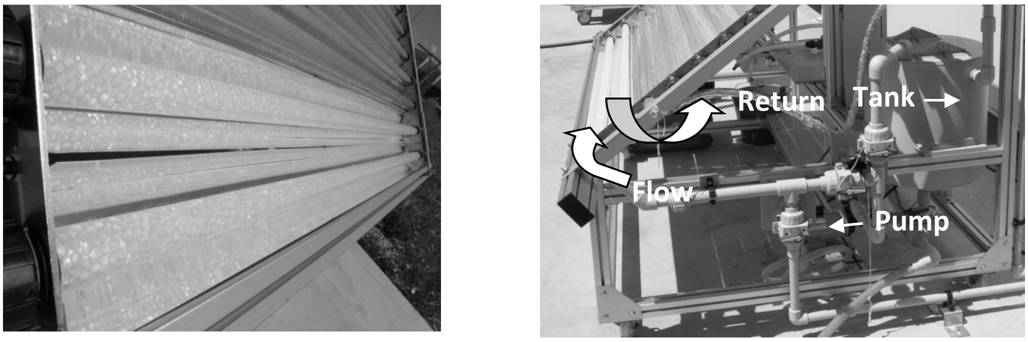

Figure 5.4. CPC solar pilot plant for solar photocatalytic degradation experiments

On the other hand, the results of adding different scavengers (Table 5.1) in distilled water indicate that direct photolysis and oxidation by $HO^{\cdot}$ in the bulk are mainly responsible for thiabendazole degradation by the TiO_2/sunlight system. $HO^{\cdot}$ in the bulk also seems to be most responsible for acetamiprid degradation, but does not seem to participate in degradation of imazalil, for which photolysis, adsorption and reaction with $O_2^{\cdot\cdot}$ are the main degradation pathways. Generation of intermediates able to act as photosensitizers could also be promoting the degradation of the pesticides in the mixture.

These results indicate that solar photocatalysis using glass beads coated with TiO_2 can be applied as a tertiary treatment in the citrus fruit processing industry for removal of emerging contaminants from effluents. This study helps optimize pilot and full-scale processing conditions in this industry by solving the problem of the presence of this type of compound in the effluents.

Table 5.1. Strategy followed to determine the main reactive species involved.

Reactive species	Scavenger added	Evaluation Strategy
$HO^{\cdot}$	2-propanol (0.01 M)	If degradation occurs, other species are involved (e^-, $O_2^{\cdot-}/HO_2^{\cdot}$, H_2O_2, h^+)
$h^+$and $HO^{\cdot}$	KI (10^{-4} M)and 2-propanol (0.01 M)	If degradation occurs, other species are involved (e^-, $O_2^{\cdot-}/HO_2^{\cdot}$, H_2O_2)
$O_2^{\cdot-}$ and $HO^{\cdot}$	Tiron ($2x10^{-5}$ M) and 2-propanol (0.01 M)	If degradation occurs, other species are involved (e-, H_2O_2, h^+)

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.

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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 2013: From January to June of 2013 the tasks related to the modelling and simulation of the photo-Fenton treatment of cork boiling wastewater, have been performed by subcontracting an expert group of the mixed centre CIESOL (in the University of Almería). The application of a dynamic model based on photo-Fenton kinetic reactions and previously designed for the treatment of simulated wastewater containing a mixture of commercial pesticides was reported. Within this model the most characteristics parameters affecting the photo-Fenton treatment and reusing of complex wastewater generated during the cork boiling process, have been simulated. From July 2013 to the end of the project (31st December 2013), it has been justified the selection of the best treatment option for the remediation of cork boiling wastewater between ozonation and solar photo-Fenton process. According to toxicity and biodegradability assays, it was decided to perform the solar photo-Fenton process until the improvement of the wastewater biodegradability for being disposed finally to a conventional biological treatment. Consequently, it has been carried out the design of a solar photo-Fenton plant at high scale for the treatment of the target wastewater (19 m^3/week), with the aim of attaining the quality required for its reuse in the own production process. In table 5.2 it is shown the solar CPC field characteristics finally calculated.

Table 5.2. Main design parameters for the solar photo-Fenton plant selected for the partial treatment of all the cork boiling wastewater generated in the region of Extremadura.

CPC field surface	
S_{CPC} (m^2)	212
Reactor tubes	
D_e (mm)	50
R_e (mm)	25
D_i (mm)	46.4
R_i (mm)	23.2
Thickness (mm)	1.8
L_T (m)	1.5
L_i (m)	1.41
Material	Pyrex Glass: Borosilicate
CPC dimensions	
C_{CPC}	1
θ_a(º)	90
Material	Anodized Aluminum
CPC opening (cm)	14,6
Collectors field disposition	
Number tubes	10
Files	4
Number modules	104
$S_{illuminated\ tube}$ (m^2)	0.21
$S_{illuminated\ module}$ (m^2)	2.05
$V_{illuminated\ field}$ (m^3)	2.5

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 2013: During this year the major results have been:

WP1 - Governance and financial issues:

- A contract with the consulting firm Garrigues, in collaboration with IAT, was signed, for work to be carried out in both WP1 and WP2.

WP3 - Capacity building and services:

- Preliminary investigation into existing technical services and human resources in EU-SOLARIS partner facilities has been initiated;
- Preliminary research identifying the state of the most significant scientific research facilities (EU & internationally) has been initiated.

WP4 - Innovation and contacts with industry:

- Preliminary investigation into current EU-SOLARIS contact and projects with industry has been undertaken resulting in the completion of project internal deliverable Annual report of RTD centre industry contacts.

WP5 - Distributed facility activity and logistical work:

- Identification of existing users of EU-SOLARIS partner facilities has been undertaken, resulting in the completion of project internal deliverable Report (listing) of existing users amongst EU-SOLARIS partners.

WP6 - Dissemination and outreach:

- A Communication Plan for the Preparatory Phase of EU-SOLARIS has been devised, resulting in the completion and submission of project deliverable 6.1 Report on Communication Plan.

WP8 - Management:

- The governance structure for the Preparatory phase of EU-SOLARIS, consisting in the Steering Committee (SC), the Project Management Committee (PMC), and the Advisory Boards, has been defined and implemented;
- Quality assurance procedures for the Preparatory Phase have been defined and implemented, resulting in the achievement of project milestone 4 Quality Assurance Plan defined and implemented.

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 2013: SFERA project finished the 31st December 2013 and it concerned three activities. General results attained during 2013 in each 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 developed, duplication of research effort is avoided and interaction with European research, education and industry is encouraged.

Within this activity (within WP3), the **9th SolLab Doctoral Colloquium** on Solar Concentrating Technologies (http://www.sollab.eu/doctoralcolloquium9/) between the 13th and 14th of May, 2013 was held in Hornberg Castle in the Black Forest, Germany. The recent results of PhD students preparing their thesis in the various laboratories members of the project were presented. The topics approached were "Thermal Storage technologies", "Solar Fuels", "Solar Desalination, detoxification and disinfection processes", "Materials for concentrating technologies", "Point focusing systems", "Linear Focusing systems" and "Fundamental research". For this 9th Doctoral Colloquium, the fourth one performed under SFERA frame, 46 PhD students participated.

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

In the frame of WP5, **exchange of personnel** between SFERA partners for harmonization of procedures was scheduled. In this activity the PhD student at CIEMAT-PSA, Esther Rivas, carried out her second stay in ENEA (Casaccia, Italy) from the 13th to the 24th of May, 2013. In that stay she explored diverse simulation possibilities, evaluating the most appropriate for a complete description of the molten salt tank with immersed SG, and the most affordable at the time. In addition, a PSA´s researcher, Margarita Rodríguez, also enjoyed a three month stay in DLR (Stuttgart, Germany) from the 1st of October to the 31st of December, 2013. She analysed three different approaches for preheating a storage tank previous to the molten salt entrance. The equations for the thermal analysis were solved using computational fluid dynamics software (FLUENT).

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

CIEMAT-PSA received in SFERA 2013 access campaign 17 user proposal forms. After the user selection panel decision, and taking into account the relevant information given by each specific facility manager on the technical feasibility of the proposed projects, all of them were finally accepted. In summary, PSA gave access to 17 Research Groups (35 users in total) in the frame of 17 user projects during 40 working weeks during 2013.

– Joint Research: developing common standards and procedures for better consortium performance and development of advanced instrumentation and new RI thus improving the services offered to the user community.

Within this activity, PSA coordinates WP 14 (Infrastructure improvements to perform durability predictions of CSP components by accelerated aging). During 2013, three different kinds of test and validations have been addressed on task 2 after the selection of a common material to be tested. Alloy 625 was selected due to its use in most of the precedent projects for high concentration solar receivers. With this material, CIEMAT-PSA has investigated the degradation of the material itself and the behaviour of the coating under high solar concentration at high temperature. Third approach investigates the aging of Ceramic (SiC) volumetric receivers. Finally, from the test results of task 2, preliminary guidelines to test several solar absorber materials can be established.

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. The main achievement was the flux intercomp, in which several flux sensors from multiple partners were compared. It showed that the comparison of flux meters for CSP applications still requires work in order to further improve the method in order to match the expected metrological performance. Sensors and their surrounding should be further upgraded to enhance their characterisation and the fairness of their comparison. Such improvements have been started at CIEMAT-PSA (heat flux sensor calibration procedures) and at CNRS-PROMES (calorimeter electric calibration).

- WP13. In 2012, a prototype of a measurement system using pyrheliometers with different acceptance angles was tested at PSA and its acceptance angle was adjusted to better match that of concentrating collectors. In 2013, the data collected then was further analysed and compared to the reference data from PSA’s SFERA system (the SAM plus the sun photometer and post-processing software).

Moreover, 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 and its purpose is to collaborate with the different R+D units on the research activities carried out by developing dynamic models of solar thermal plants and designing control algorithms to improve the operation of the systems. In 2013, the Automatic Control group addressed diverse activities related with its main research lines and summarized as follows:

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

Figure 6.3. Picture of the group staff

6.3.2 Projects

Innovative Configuration for a Fully Renewable Hybridcsp Plant, HYSOL

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

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

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

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

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

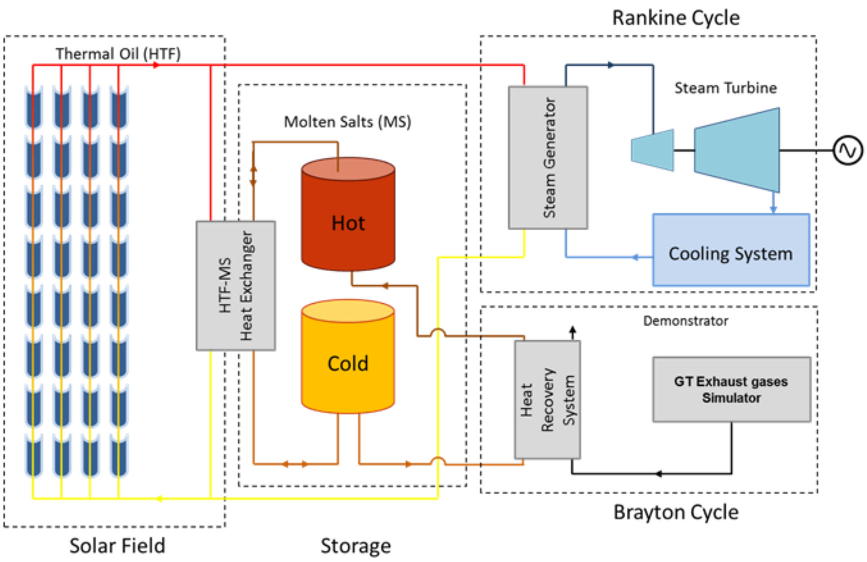

Figure 6.4. HYSOL configuration.

Achievements in 2013: During the first year of the project, the following achievements have been obtained:

1. HYSOL website has been lunched at http://www.hysolproject.eu/
2. The installation of the HYSOL demonstrator has started in an innovation complex owned by COBRA.

3. A technical manual has been defined to be used as a design data book. This document defines different configurations to be evaluated within the project and it includes general data sheets and demonstrator equipment.
4. With the aim of sharing modelling information between partners, a standard has been defined to efficiently share simulation results and static/dynamic models. This standard takes into account the simulation tools to be used between participants within this project and establishes procedures and mechanisms to exchange data.
5. Object-oriented first principle design and development of the dynamic heat recovery system model and its main components have been carried out. The model considers as well the principal heat transfer processes in the system by means of empirical heat transfer correlations.

Figure 6.5. HYSOL participants during the 6th month meeting at Manchasol solar power plant.

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

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

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

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

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

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

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

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

Achievements in 2013: In this third year of the project, the following relevant results have been obtained:

1. The operational problems of the Double Effect Absorption Heat Pump (DEAHP) located at AQUASOL pilot plant have been studied in an experimental campaign, with the aim of designing new control strategies to improve the behaviour of the system and to increase its thermal efficiency.
2. This DEAHP has been set up for modelling and control purposes. Three mass flow meters have been installed to measure mass flow, temperature and density of the LiBr solution at different points of the heat pump. An additional flow meter has been included to measure water flow in the evaporator chamber.
3. A dynamic model based on physical principles has been developed for the first cell of a solar assisted MED plant.
4. Economic optimal control techniques applied to freshwater production have been tested in simulation with promising results.
5. Preliminary results have been obtained in the case of the control applied to a micro-grid composed by a greenhouse and a solar desalination unit.
6. Award to the best research work in the field of Modelling and Simulation given at "Jornadas de Automática 2013".
7. A Special Session called "Control Techniques for Efficient Management of Renewable Energy Micro-grids" was organized in the frame of IECON 2013 (the 39th Annual Conference of the IEEE Industrial Electronics Society).

Figure 6.5. Picture of a mass flow meter installed at the heat pump.

7 Training and educational activities

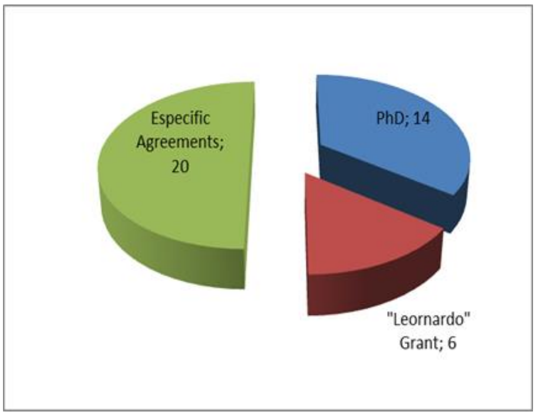

Figure 7.1. Distribution of PSA students (2013)

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.

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 Frankfurt-Germany, San Martín-Argentina, Fundaçao Oswaldo Cruz, ESTIA-France, CIATEC-Mexico, URJC-Madrid, Centrer of Energy- Tunisia, Dalarna-Sweden, 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 9th SOLLAB was organized by the German Aerospace Center (DLR) and took place at the Hornberg Castle located in the Black Forest in Germany. The Colloquium was held from the 13th to the 14th of May, 2013. Afterwards, the SFERA Summer School was hosted at the same location between the 15th and 16th of May, 2013. It was focused on Concentrated Solar Power.

8. EVENTS

23/01/2013

Technical visit

Dr. Thomas Law and Dr. Thomas Smith from Thermofluidics Ltd. (UK) visited PSA to have detailed information about the installations and activities of the Solar Desalination group, as well as to discuss possible collaborations.

24/01/2013

Technical visit

Mr. Najib Cherai, from L.S.A. Technologies (Morocco) visited PSA to know details about the PSA solar desalination facilities and discuss the participation of CIEMAT in a project financed by IRESEN to set-up a solar desalination pilot plant in Morocco.

24/01/2013

Lecture

Invited Lecture of Sixto Malato in scientific workshop "Heterogeneous catalysis: from electronic processes to photocatalysis" organized by IRCELYON (Lyon, FRANCE) dedicated to Prof. Jean-Marie Herrmann, recently retired.

01/02/2013

Technical visit

A group of 25 students and professors participating in the Course on Sustainable Energy in Buildings from University of Granada, visited PSA as a part of the course training activities, with special interest on bioclimatic architecture.

12/02/2013

Dissertation

Malato, Sixto."La energía solar como aliada en la regeneración del agua" Dissertation at the IES El Palmeral (Vera, Almeria).

16/02/2013

Lecture

Invited lecture of Pilar Fernández Ibáñez in the Institute of Nanotechnology (NIBEC) "Solar Water Treatment Technologies" organized by University of Ulster, UK.

22/02/2013

Technical visit

A group of 4 top managers of SWCC (Saline Water conversion Corporation) from Saudi Arabia visited PSA facilities to reinforce the knowledge on Desalination and CSP plants technology.

26/02/2013

Dissertation

Zarza, Eduardo. "Líneas de Desarrollo Tecnológico y Gestión a nivel Europeo de la I+D". Dissertation at the *Feria de la Energía y del Medioambiente GENERA-2013*, held in Madrid on February 26th, 2013.

06/03/2013

Technical visit

A group of 15 persons representing different professional organizations from Uzbekistan visited

PSA facilities to reinforce the knowledge on CSP plants implementation.

12/03/2013

Dissertation

Zarza, Eduardo. “Proyectos Integrados de Investigación dentro del SP-CSP de EERA”. Dissertation at the *Jornada de Difusión de las Actividades de EERA*, held in Madrid on March 12th, 2013.

11-13/03/2013

Lecture

Blanco, Julián. “The Water-Energy Nexus and the Role of Solar Energy into the 21st Century”. Dissertation at the Workshop *Capital Avanzado en Recursos Hídricos y Energias Renovables No Convencionales*, held in Arica (Chile), March 11-13, 2013.

12/03/2013

Technical visit

A group of 20 persons representing Eskom Committee from South Africa visited PSA facilities to have detailed information about installations and research activities on CSP plants.

18-22/03/2013

Scientific visit

Pilar Fernandez gave Invited Lecture in the scientific workshop ‘Encuentro de Técnicas Fotocatalíticas para la Purificación de Aguas’ organized by the Faculty of Engineering of the University of Medellin. She acted also as invited professor for the Advanced Degree on Engineering of the University of Medellin with the course entitled ‘Solar techniques for water disinfection: principles, solar reactors and applications’ (15 h). Technical assessment for a project of surface water remediation.

22-23/04/2013

Lecture

Blanco, Julián. “Solar Desalination: a Key Issue in the Water-Energy Global Problem Context”. Dissertation at the Global Water Summit 2013, held in Seville (Spain), April 22-23, 2013.

23/04/2013

Doctoral Thesis

Aranzazu Fernández defended the Doctoral Thesis "Optimización de herramientas de diseño y evaluación de captadores solares cilindroparabólicos para el suministro de energía térmica a temperaturas inferiores a 250 ºC. Aplicación práctica al prototipo CAPSOL". University of Almeria.

08/05/2013

Doctoral Thesis

Javier Bonilla defended the Doctoral Thesis "Modeling of two-phase flow evaporators for parabolic-trough solar thermal power plants". University of Almeria.

09/05/2013

Technical visit

A Delegation from China involving technologists and scientists linked to local administration, utilities and CSP sector from China, in collaboration with a company working under ENEA license represented by Mr. L. Zunarelli, visited the PSA installations to know about recent advances in concentrated solar thermal power.

13-16/05/2013

Lectures

Invited Lecture of Pilar Fernández Ibáñez in the Faculty of Sciences of the Dublin City University "Solar Water Treatment Technologies at Plataforma Solar de Almería" (DCU, IRELAND). Invited Key-note in the scientific workshop Photochemistry Early Career Researchers Meeting organized by University of Ulster, UK.

24/05/2013

Technical visit

Agroup of 30 students from the UNESCO-IHE Institute for Water Education, from the Environmental Engineering and Water Technology Department in Delft, coordinated by Mr. H. García and G. Ferrero, visited PSA facilities as a part of their programmed training activities focused on research and development of energy and environmental aspects of water treatments.

27/05/2013

Technical visit

A delegation from the New Energy and Industrial Technology Development Organization (NEDO) in Japan visited PSA to know details about the scientific installations and ongoing research activities on CSP technologies, and envisage possibilities of collaboration in some topics of line-focus solar technologies.

30/05/2013

Technical visit

Mr. O. Murtuza, from the Electrical Engineering Department of the College of the North Atlantic in Qatarvisited PSA to know details about the scientific installations and ongoing research activities on CSP technologies.

27-31/05/2013

Lectures

S. Malato and M.I. Maldonado gave different invited lectures at CIATEC (León, Guanajuato) "Evento científico México-España en procesos avanzados de oxidación" and at 6th Meeting of the Mexican Section of the Electrochemical Society held in Santiago de Querétaro, Mexico.

07/06/2013

Institutional visit

In the frame of the Spain-Morocco Collaboration Program on Science and Technology, an institutional delegation headed by the State Secretary of Innovation Mrs. C. Vela, attended the plenary bilateral meeting at the Academy of Sciences in Rabat, focused on the evaluation of the proposals for the different areas of collaboration. F. Martin represented the PSA for contributions on electricity generation CSP technologies.

06/06/2013

Official inauguration

New scientific installations named DUKE (for improving the research on DSG parabolic-trough technology) and METAS (devoted to the characterization of solar radiation for solar technologies applications) were inaugurated at PSA, in the frame of Ciemat-DLR collaboration join activities, with the presence of Mr. R. Gavela, Ciemat Energy Department Head, and Mr. U. Wagner, DLR Board Member.

11/06/2013

Technical visit

A Delegation of 8 persons from Morocco and Spain had a working meeting on CSP technologies and visited the PSA installations in the frame of bilateral collaboration.

12/06/2013

Technical visit

Mr. I. Sigalas, from the Technological Education Institute of Piraeus in Greece, visited PSA to know details about the PSA facilities and ongoing research activities on bioclimatic architecture technologies.

18/06/2013

Technical visit

Mr. G. Nathan, director of the Centre for Energy Technology and professor of Mechanical Engineering in the University of Adelaide, Australia, visited PSA installations and also gave a lecture entitled “Direct hybrids between solar thermal and combustion/gasification processes”.

20/06/2013

Technical visit

A Delegation of 9 persons consisting of local government officials and senior corporate executives from Regional Government and Private Companies of Pingyuan (China), invited by Mr. S. Sun of CBI BIZ and headed by Mr. H. Wang, County Magistrate, visited PSA to receive information about ongoing research activities on CSP technologies, and envisage possibilities of collaboration regarding the great potential development of CSP in China.

21/06/2013

Technical visit

Mr. P. Xiao, on behalf of Prof. L. Guo, from the Department of Thermal Engineering at the Xian Jiaotong University in China, headed a group of 5 persons in the visit to PSA installations, carrying out meetings with research groups to share scientific experiences in concentrating solar systems and applications, with the aim of improving academic exchanges.

24/06-05/07/2013

Technical visit

Hosted by DLR, a group of engineers from MENA countries received detailed technical lectures from PSA researchers and technicians and visited the PSA installations, under the frame of the International Course on CSP technologies organized by DLR with the collaboration of the PSA.

25-28/06/2013

Lecture

S. Malato participated as invited lecturer in 14th EuCheMS International Conference on Chemistry and the Environment (ICCE 2013), held from the 25th -28th June, World Trade Center located in Barcelona.

25-26/06/2013

Dissemination and divulgation

A team from the National Laboratory of Energy and Geology, LNEG, Lisbon, Portugal, recorded an audiovisual of PSA installations to be included in the Support Platform for Communication Network, in the frame of EnerGeo Operation.

25/06/2013

Technical visit

Mr. D. Suresh, adviser and consultant in Solsen Solar, a manufacturing company in Madurai, India, visited PSA to share information about ongoing research activities on CSP technologies, and envisage possibilities of collaboration.

26/06/2013

Official visit

Hosted by Dr. C. López, General Director of Ciemat, Members of EERA (European Energy Research Alliance) had a meeting at the PSA installations, and visited in detail the diverse research facilities receiving technical information from PSA scientists.

05/07/2013

Lecture

Blanco, Julián. “Los Retos de la Investigación en Energía Solar en el Siglo XXI”. Dissertation at the Ceremony of Solar Energy Research Center (SERC) presentation and launching, held in Santiago de Chile (Chile), July 5th, 2013.

08/07/2013

Lecture

Prof. M. A. López-Quintela, from the Univerity of Santiago de Compostela, gave a conference entitled “Ingeniería de bandas prohibidas con clústeres subnanométricos: síntesis y propiedades fotocatalíticas”. PSA Arfrisol Auditorium.

26/07/2013

Technical visit

A group of 18 students belonging to the Salamanca University-Ciemat Master on Renewable Energies and Energy Efficiency, visited PSA as part of the course training activities, mainly focused on bioclimatic architecture.

09-13/09/2013

Workshop

2nd edition of the DYNASTEE Summer School (Dynamic Calculation Methods for Building Energy Assessment) was organised by DYNASTEE-INIVE in close collaboration with CIEMAT, EC-JRC-IET, DTU-IMM (Denmark) and ESRU (Glasgow, UK) and partially sponsored by KNAUF. It was hosted by Plataforma Solar de Almería and CIESOL (Joint Center University of Almería-CIEMAT). Summer School 2013 on Energy in Buildings Dynamic Calculation Methods for Building Energy Assessment.

10/09/2013

Lecture

M. Kersten made a presentation entitled "KONTAS-cp-flow through calorimeter Evaluation of thermal heat loss mechanism", showing the work carried out during the stage at PSA. Arfrisol Auditorium.

10/09/2013

Lecture

F. Wheringer presented the lecture entitled "Comparison of visibility measuring instruments" and D. Garter presented "Laboratory Heat Loss Measurements of Parabolic Trough Receivers based on Transient Thermography", showing the work carried out during their stages at PSA. Arfrisol Auditorium.

11-13/09/2013

Conference

S. Malato participated as invited lecturer in XXXI Jornadas Nacional de Ingeniería Química at the Universidad de Almeria, with a lecturer entitled Plataforma Solar de Almería, una gran instalación científica española y europea.

15-18/09/2013

Conference

S. Malato participated as invited lecturer in XXXIV REUNIÓN BIENAL REAL SOCIEDAD ESPAÑOLA DE QUÍMICA. Santander, Spain.

17-20/09/2013

Conference

SolarPACES 2013, the leading event on concentrated solar power and chemical energy systems, took place in Las Vegas (USA), from September 17th to 20th. Eight oral presentations were given and three posters were presented by PSA staff. Nine people from PSA staff attended this Congress and participated in the Tasks meetings

held the day before de Congress and the SolarPACES ExCo meeting held on September 22nd.

19-21/09/2013

<u>Conference</u>

G. Zaragoza gave a keynote presentation in the International Conference WIN4Life, which was held in Tinos (Greece), from 19th to 21st September 2013.

24-25/09/2013

<u>Conference</u>

S. Malato participated as invited lecturer in JEP 2013 - the 3rd European Conference on Photocatalysis, which was held in Portorož, Slovenia, from September 25th to September 27th, 2013. He also participated as lecturer in the workshop entitled "Photocatalysis as a tool for sustainability" organised by University of Nova Gorica, 24th-25th September, 2013.

30/09/2013

<u>Dissertation</u>

Zarza,Eduardo. "R+D on CSTP in Spain". Dissertation at the Spanish-Brazilian Workshop on Renewable Energies, held in Rio de Janeiro (Brazil)

06-08/10/2013

<u>Lecture</u>

J. Blanco and D. Alarcón gave different dissertations at the Workshop *Desalination with Solar Energy*, held at the Middle East Desalination Research Center (MEDRC) Training Facility in Muscat (Oman). October 6-8, 2013.

08/10/2013

<u>Award</u>

Ginés García received the Special Mention in the category of Best Patent in the ceremony of Madri+d Foundation Awards, in recognition to the work carried out with the innovative "Interruptor de viento y su método de ajuste y tarado". The event was hosted by the President of the Madrid Regional Government, I. González.

IX premios madri+d

10/10/2013

<u>Lecture</u>

F. Martin gave a lecture entitled "Plataforma Solar de Almería: Solar Energy Research, source of benefits for Andalucía" as invited presentation at the Seminar OPEN DAYS 2013 in the frame of the 11th European Week of Regions and Cities, organized by the DG Research and Innovation of the EC. Centre Borschette, Brussels.

15-18/10/2013

<u>Conference</u>

S. Malato participated as invited lecturer "Solar AOPs for Waste Water Reclamation and Water Disinfection" in VII Brazilian Congress of Advanced Oxidation and 1st Iberoamerican Congress of Advanced Oxidation, which was held in Recife, Brasil, from October 15th to October 18th, 2013.

16/10/2013

Dissertation

Zarza, Eduardo. “Temas de I+D prioritarios para el sector Termosolar”. Dissertation at the *Jornada sobre Energía Termosolar de Concentración*, held in Valencia (Spain) on October 16th, 2013.

20/10/2013

Award

Guillermo Zaragoza received an Special Award at the IDA World Congress on Desalination and Water Reuse, hosted by the International Desalination Association in Tianjin (China), in recognition to the quality of the work presented under the title “Experimental Comparison of Different Prototypes of Solar Energy Driven Membrane Distillation Systems” and to the research developed in desalination by PSA.

22/10/2013

Technical visit

Hosted by DLR, a group of 20 technics and scientists with expertise and responsibility on the Energy sector in Brazil visited the PSA installations, under the frame of the activities of GIZ, the German Society of International Collaboration, to promote CSP technologies in this country, with a growing interest on this area.

21-25/10/2013

Training

A Delegation of 23 technicians from Greece and Cyprus had a training course on CSP technologies and applications, and visited the PSA facilities in the frame of the international technological collaboration.

24/10/2013

Anniversary Event

Blanco, Julián. Participation as Coordinator of Joint Programme on CSP in the “5 years anniversary of EERA”, event held in Brussels (Belgium), October 24th, 2013.

27-30/10/2013

Conference

PSA-CIEMAT jointly with CIESOL (UAL) organized the 3rd EUROPEAN CONFERENCE ON ENVIRONMENTAL APPLICATIONS OF ADVANCED OXIDATION PROCESSES (http://www.eaaop3.com/), held in El Toyo, Cabo de Gata, Almería, with the attendance of around 250 researchers from 30 countries. A delegation of 100 participants visited the PSA facilities.

30/10/2013

Dissertation

Zarza, Eduardo. "R+D on CSTP in Spain". Dissertation at the *Spanish-Brazilian Workshop on Renewable Energies*, held in Rio de Janeiro (Brazil) on September 30th-October 1st, 2013.

30/10/2013

Dissemination

A team of professionals from Conspiraçao Productions hosted by DLR in the frame of GIZ program, visited the PSA installations for the elaboration of a promotional video on CSP technologies for divulgation activities in Brazil. The deliverable audiovisual can be found in the following link: http://www.uni-kassel.de/eecs/remena/downloads.html

5-6/11/2013

Lectures

Loreto Valenzuela. Dissertations at the *Third EU-Australia workshop on research infrastructure*, held in Camberra (Australia).

10-13/11/2013

Forum attendance

Blanco, Julián. Participation into the panel of experts on "Solar Energy" at the Doha Carbon and Energy Forum 2013, held in Doha (Qatar), November 10-13, 2013.

12-13/11/2013

Conference

The 7th International Concentrated Solar Thermal Power Summit (CSP Today Seville 2013) was held on November 12-13, 2013 in Seville (Spain). Two people from PSA scientific staff participated in this event, chairing the opening session and giving an invited presentation. A visit to PSA facilities was arranged by the Organization of this event on November 14th.

21/11/2013

Conference

G. Zaragoza presented the Action Group "Renewable Energy Desalination" in the annual conference organized by the European Innovation Partnership on Water of the European Commission in Brussels (Belgium).

27/11/2013

Technical visit

Mr. G. Wilson from the Australian company CSIRO and hosted by DLR visited PSA facilities with special interest on OPAC and METEO installations, with aim of identify possibilities of scientific and technological collaboration.

10-12/12/2013

Technical visit

A group of 9 persons from national entities of Egypt, Morocco and Tunisia stayed at the PSA installations under the activities in the frame of the ENERMENA training course on Parabolic CSP Systems, organized by DLR.

12/12/2013

Lecture

Zarza, Eduardo. "Accelerating the Learning Curve". Disserttation at the "*7th International Concentrated Solar Thermal Power Summit*", held at Seville on November 12-13, 2013.

12/12/2013

Technical visit

Hosted by DLR, a group of 24 professionals, technics and scientists from Morocco visited the PSA installations, under the frame of the activities of GIZ (German Society of International Collaboration), to improve the promotion of CSP technologies.

19/12/2013

Social Act

With occasion of Christmas Days, it was organized a social act for all PSA staff. Among other issues, the overall resume of R&D activities carried out along 2013 and the planning for next year were exposed with the participation of the heads of PSA units.

20/12/2013

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.

19-22/12/2013

Dissertation

Several dissertations by Rocío Bayón and Eduardo Zarza at the International Workshop on Design of Subsystems for Concentrated Solar Power Technologies, held at Jodhpur (India) on December 19-22, 2013.

9. Publications

PhD Thesis

Bonilla, J. (2013). Modeling of Two-Phase Flow Evaporators for Parabolic-Trough Solar Thermal Power Plants. (Unpublished doctoral dissertation). Universidad de Almería, Almería.

Fernández-García, A. (2013). Optimización de herramientas para el diseño y la evaluación de captadores solares cilindroparabólicos para el suministro de energía térmica a temperaturas inferiores a 250 °C. Aplicación práctica al prototipo CAPSOL. (Published by Ed. CIEMAT). Universidad de Almería, Almería.

Prieto Rodríguez, L. P. (2013) Eliminación de micro-contaminantes orgánicos presentes en aguas residuales urbanas mediante combinación de procesos de depuración biológica y oxidación química. (Unpublished doctoral dissertation). Universidad de Almería, Almería.

Enríquez Miranda, R. (2013). Evaluación energética experimental de edificios en condiciones reales de uso mediante el ajuste de modelos de simulación con aplicaciones al control predictivo. (Unpublished doctoral dissertation). Universidad Complutense de Madrid, Madrid.

Solar concentrating systems unit

SCI PUBLICATIONS

Ávila-Marín, A. L., Fernandez-Reche, J., & Tellez, F. M. (2013). Evaluation of the potential of central receiver solar power plants: configuration, optimization and trends. *Appl. Energy,* 112, 274-288.

Bayón, R., & Rojas, E. (2013). Liquid crystals: A new approach for latent heat storage. *Int. J. Energy Res.*, 37(14), 1737-1742.

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Navarro, A., Cardellach, E., Cañadas, I., & Rodríguez, J. (2013). Solar thermal vitrification of mining contaminated soils, Int. J. Miner. Process., 119, 65-74.

Roldan, M. I., Valenzuela, L., & Zarza, E. (2013). Thermal analysis of solar receiver pipes with superheated steam. *Appl. Energy,* 103, 73-84.

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Ruiz-Bustinza, I., Cañadas, I., Rodríguez, J., Mochón, J., Verdeja, L. F., García-Carcedo, F., & Vázquez, A.J. (2013). Magnetite Production from Steel Wastes with Concentrated Solar Energy. *Steel Res. Int.*, 84(3), 207–217.

Shohoji, N., Almeida Costa Oliveira, F., Cruz Fernandes, J., Guerra Rosa, L., Rodríguez Garcia, J., Cañadas Martínez, I., ...Cestari, F. (2013). Synthesizing higher nitride of molybdenum (Mo) and iron (Fe) in ammonia (NH3) gas stream under irradiation of concentrated solar beam in a solar furnace. *Materialwiss. Werkstofftech.*, 44(12), 959-971.

Shohoji, N., Almeida Costa Oliveira, F., Guerra Rosa, L., Cruz Fernandes, J., Magalhães, T., l Caldeira Coelho, M., ...Martínez, D. (2013). Synthesizing carbonitride of some d-group transition metals using a solar furnace at PSA. *Mater. Sci. Forum*, 730-732, 153-158.

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Silva, R., Pérez, M., & Fernández-García, A. (2013). Modelling and Co-Simulation of a Parabolic Trough Solar Plant for Industrial Process Heat. *Appl. Energy* 106, 287-300.

BOOK CHAPTERS

Fernández-García, A., Zarza Moya, E., Pérez García, M., & Manzano Agugliaro, F. R. Optimización de herramientas para el diseño y la evaluación de captadores solares cilindroparabólicos para el suministro de energía térmica a temperaturas inferiores a 250 °C. Aplicación práctica al prototipo CAPSOL. Ed. CIEMAT. ISBN: 978-84-7834-699-8. Madrid, 2013.

PRESENTATION AT CONGRESSES

ORAL PRESENTATIONS

Aguilar-Gastelum, F., Moya-Acosta, S.L., Cazarez-Candia, O., & Valenzuela, L. (2013). Theoretical study of direct steam generation in two parallel pipes. ISES Solar World Congress 2013, 3-7 November, Cancún, México.

Ávila-Marin, A.L., Alvarez-Lara, M., & Fernandez-Reche, J. (2013). Experimental results of gradual porosity wire mesh absorber for volumetric receivers. 19th SolarPACES International Symposium, 17-20 September, Las Vegas, EEUU.

Ávila-Marin, A.L., Alvarez-Lara, M., & Fernandez-Reche, J. (2013). A regenerative heat storage system for central receiver technologyworking with atmospheric air. 19th SolarPACES International Symposium, 17-20 September, Las Vegas, EEUU.

Bayón, R., & Rojas, E. (2013). Analytical description of thermocline tank performance in dynamic processes and stand-by periods. ISES Solar World Congress 2013, 3-7 November, Cancún, México.

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Eck, M., Hirsch, T., Feldhoff, J.F., Kretschmann, D., Derschc, J., Gavilan-Morales, A., ...& Wagneri, M. (2013). Guidelines for CSP yield analysis – optical losses of line focusing systems; definitions, sensitivity analysis and modeling approaches. 19th SolarPACES International Symposium, 17-20 September, Las Vegas, USA.

Fernández-García, A., Díaz-Franco, R., Martinez, L., & Wette, J. (2013). Study of the effect of acid atmospheres in solar reflectors durability under accelerated aging conditions. 19th SolarPACES International Symposium, 17-20 September, Las Vegas, USA.

Fernández-García, A., Álvarez-Rodrigo, L., Martínez-Arcos, L., Aguiar, R., & Márquez-Payés, J.M. (2013). Study of different cleaning methods for solar reflectors used in CSP plants. 19th SolarPACES International Symposium, 17-20 September, Las Vegas, USA.

García Cambronero, L.E., Cañadas, I., Sanchez-Fernandez, M., Ruiz Román, J.M., & Rodríguez, J. (2013). Aplicación de la energía solar concentrada en la fabricación de espumas de aluminio. 13th International Congress on Energy and Mineral Resources, 3-5 October, Santander, Spain.

Guillot, E., Alxneit, I., Ballestrín, J., Sans, J.L., & Willsh, C. (2013). Comparison of 3 heat flux gauges and a water calorimeter for concentrated solar irradiance measurement. 19th SolarPACES International Symposium, 17-20 September, Las Vegas, USA.

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Rodríguez-García, M.M., & Zarza-Moya, E. (2013). Foundation and internal temperature measurements of an experimental molten salt storage tank. 19th SolarPACES International Symposium, 17-20 September, Las Vegas, USA.

Setien, E., Fernández-Reche, J., Ariza, M.J., & Álvarez de Lara, M. (2013). Long term thermal aging of alloy 625, a candidate material for central tower tube type receivers. European Congress on Advanced Materials and Processes, 8-13 September, Sevilla, Spain.

Sutter, F., Fernandez-García, A., Wette, J., & Heller, P. (2013). Comparison and Evaluation of Accelerated Aging Tests for Reflectors. 19th SolarPACES International Symposium, 17-20 September, Las Vegas, USA.

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Feldhoff, J.F., Eickhoff, M., Keller, L., León-Alonso, J., Meyer-Grünefeldt, M., Valenzuela, L., & Pernpeintner, J. (2013). Once-through operation at the new DISS test facility – status and first results of the DUKE project. 19th SolarPACES International Symposium, 17-20 September, Las Vegas, USA.

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Levinskas, R., Lukosiute, I., Baltusnikas, A., Kriukiene, R., Kuoga, A., Rodriguez, J., & Cañadas, I. (2013) Examination of calcium hydrosilicate (xonotlite) slab under the thermal shock conditions. 2nd Central and Eastern European Conference on Thermal Analysis and Calorimetry - CEEC-TAC2, 27-30 August 2013, Vilnius (Lithuania).

Rivas, E., Rojas, E., Bayón, R., Gaggioli, W., Rinaldi, L., & Fabrizi, F. (2013). CFD model of a molten salt tank with integrated steam generator. 19th SolarPACES International Symposium, 17-20 September, Las Vegas, USA.

Sierra, M.J., López, F.A., Cañadas Martínez, I., Rodríguez, O., Rodríguez, J., Ramos Miñarro, C., ...& Millán, R. (2013). Evaluation of thermal decomposition and desorption of mercury in soils from the old mining district of Almadén (Spain). ICMGP – 11th International Conference on Mercury as a Global Pollutant, July 28th – August 2nd 2013, Edinburgh, Scotland.

Environmental Applications of Solar Energy Unit

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Palenzuela, P., Alarcón, D., Zaragoza, G., Blanco, J., & Ibarra, M. (22013). Parametric equations for the variables of a steady-state model of a multi-effect desalination plant. *Desalin. Water Treat.*, 51 (4-6), 1229-1241.

J. Blanco, P. Palenzuela, D. Alarcón-Padilla, G. Zaragoza and M. Ibarra. Preliminary thermoeconomic analysis of combined parabolic trough solar power and desalination plant in port Safaga (Egypt). *Desalin. Water Treat.*, 51 (7-9), 1887-1899.

OTHER BOOKS AND JOURNALS

P. Palenzuela Ardila, D.C. Alarcón Padilla, G. Zaragoza del Águila, J. Blanco Gálvez. Evaluación del Acoplamiento de Plantas de Destilación Multiefecto a Plantas Solares. Madrid, Spain. Ed. CIEMAT.

PRESENTATION AT CONGRESSES

PLENARY LECTURES

Zaragoza, G., Ruiz-Aguirre, A., & Alarcón-Padilla, D. C. (2013). Review of solar thermal powered membrane distillation for desalination. International Conference WIN4Life, 19-21 September, Tinos, Greece.

ORAL PRESENTATIONS

Guillen-Burrieza, E., Ruiz-Aguirre, A., Zaragoza, G., & Arafat, H. (2013). Effects of long term operation on MD membrane fouling and membrane cleaning strategies. Presentación oral. International Membrane Science and Technology Conference, 25-29 November, Melbourne, Australia.

Gudmundsson, K., Ruiz-Aguirre, A., Dhakal, N., Broers, E, Konijnendijk, E., Kennedy, M., …Mendez, E. (2013). Aquaver pilot projects: seawater desalination & solar driven. Oral. 1st International Conference on Desalination Using Membrane Technology, 7-10 April, Sitges, Spain.

Ibarra, M., Rovira, A., Alarcón, D., Zaragoza, G. & Blanco, J. (2013). Performance of a 5 kWe Solar-only Organic Rankine Unit Coupled to a Reverse Osmosis Plant.

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Palenzuela, P., Zaragoza, G., Alarcón, D., & Blanco, J. (2013). Evaluation of the coupling of multi-effect distillation plants to concentrating solar power plants. International Conference on Applied Energy ICAE2013, 1-4 July, Pretoria, South Africa.

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Zaragoza, G., Ruiz-Aguirre, A., & Guillén-Burrieza, E. (2013). Efficiency in the use of solar thermal energy of small membrane desalination systems for decentralized water production. International Conference on Applied Energy ICAE2013, 1-4 July, Pretoria, South Africa.

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POSTERS

Ruiz-Aguirre, A., Zaragoza, G., Alarcón-Padilla, D. C., & Blanco, J. (2013). Experimental study on the performance of a prototype of liquid-gap membrane distillation using solar energy. 1st International Conference on Desalination Using Membrane Technology, 7-10 April, Sitges, Spain.

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Ruiz-Aguirre, A., Polo-López, M. I., Castro-Alférez, M., Zaragoza, G., Fernández-Ibáñez, P. (2013). Combination Of Solar Membrane Distillation And Advanced Oxida-

tion Processes In Removing Fusarium solani And Clostridium sp From Contaminated Wastewater Effluent. 3rd European Conference on Environmental Applications of Advanced Oxidation Processes, 28-30 October, Almería, España.

Solar Water Treatment Unit

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