7th SOLLAB Doctoral Colloquium on Solar Concentrating Technologies

March 21-23, 2011, Grindelwald, Switzerland

Book of Abstracts

ETH Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

PAUL SCHERRER INSTITUT PSI

MINISTERIO DE CIENCIA E INNOVACIÓN

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

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Optical design of a solar trough concentrating system for medium- and high-concentration photovoltaics

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The optical design and performance analysis of a novel solar trough concentrating system for medium (50 suns) and high concentration photovoltaics (500 suns) are presented. In both cases, the primary mirror is a one-axis tracking linear trough concentrator constructed from an inflated multilayer stack of aluminized polyester films enclosed in a transparent ETFE envelope. The desired geometrical profile of the primary mirror is obtained by adjusting the differential pressure between the envelope and each polyester layer. This concept has been successfully demonstrated in a CSP thermal application, for which a 42 m-length 10 m-aperture prototype has been constructed in Biasca, Switzerland [1, 2]. The technology is now being adapted for medium- and high-concentration CPV. An optimization approach using the Monte Carlo ray-tracing technique is applied to determine the mirror configuration providing the best compromise between the four main figures of merit: concentration, optical efficiency, intercept factor, and irradiance uniformity. The medium-concentration system has a design concentration of 50 suns, utilizing concentrator silicon cells with efficiency approaching 20%. Although this level of concentration is easily attainable without secondary concentration, non-imaging secondary optics are utilized to improve the uniformity of irradiance on the PV cell. The high-concentration system has a design concentration of 500 suns, utilizing III-V multijunction cells with efficiency approaching 40%. Since the maximum theoretical concentration of a 2D linear concentrator is ~215 suns, a novel design utilizing of an array of 3D concentrators at the focal line is developed. The secondaries collect the line-focused radiation from the primary concentrator, and further focus it to a point, thus augmenting the overall concentration. Design of the primary and secondary are carried out simultaneously to optimize the four figures of merit.

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Linear Fresnel Reflector based Concentrating Solar Power plant: Influence of the optical accuracy of the concentrator's components

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Linear Fresnel Reflector is an interesting solution to concentrate sun light on a pipe in which a heat transfer fluid circulates. The thermal energy thus collected can supply a cogeneration system. This scalable and relatively low cost concentrator can provides both heat and power to residential buildings or industries. One issue is the temperature that one can reach with the optical concentrator. The higher the temperature, the higher the efficiency of the thermodynamic cycle can be. This study focuses on the optical design of the power plant. The aim is to determine the relative influence of the optical accuracy of the different elements.

The self-developed coding environment EDStar is used for the simulations. It is based on Monte-Carlo methods taking advantage of advanced rendering techniques. A typical geometry is chosen for the concentrator: it is composed of the primary mirror field with oriented mirror bands, a secondary concentrator on top of a single tube receiver and a glass sheet for thermal insulation on the lower side.

The maps of the power collected on the receiver illustrate the effect of lower accuracy on the optical components. The comparison of the calculated power output shows different trends. It is confirmed that the accuracy of the secondary concentrator is much more critical than the one of the other elements.

Determination of circumsolar radiation and its effect on focusing collectors

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Due to forward scattering of direct sunlight by aerosol and cloud particles, the circumsolar region close to the solar disk contains a considerable amount of irradiance. The radiation coming from this region, the so called circumsolar radiation, is nearly completely detected by pyrheliometers, but only partially intercepted by the receiver of focusing collectors. Hence the available Direct Normal Irradiance (DNI) is systematically overestimated depending on the collector type.

Circumsolar radiation can be described quantitatively by the radiance of the sky close to the sun as a function of the angular distance to the center of the sun - the sunshape. At a given site, the variation of the sunshape over time can be high. Additionally, the average sunshape for different locations may vary significantly, but representative sunshape measurements are only available for a few locations.

Therefore, sunshape measurements are carried out in different climates using a reference system consisting of the Sun and Aureole Measurement system (SAM, [1]) and a sun photometer [2]. As the SAM instrument was designed for the investigation of cloud properties, spectral DNI measurements and further post processing of the data are necessary to obtain the broadband sunshape. In order to provide a sufficient database, alternative methods for the determination of the sunshape are developed using common solar resource measurements. One approach is based on the different angular acceptance functions of solar radiation measurement instruments. With Rotating Shadow band Radiometers (RSR) information about the sky radiance can be obtained from a high frequency measurement carried out during the rotation of the shadow band. A model for the determination of the sunshape from satellite data which is developed at DLR-IPA will be enhanced with common ground measurements.

In order to determine the effect of circumsolar radiation on focusing collectors, the analytical model from Bendt and Rabl [3] is used. For more precise evaluations and for solar tower plants as well as for Fresnel collectors calculations are performed with the raytracing tool Spray. The investigated plants are designed as characteristic state-of-the-art CSP plants for two locations of different latitudes and climates.

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Experimental characterization of 3-dimensional heat flux distribution of a 7 kW_e solar simulator

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Solar simulators recreate the high radiation heat fluxes commonly found in concentrated solar technologies *e.g.* paraboloidal dish and central receiver. These devices are mainly used in laboratory-scale experiments and they make possible avoiding the influence of meteorological conditions. In their simplest configuration, an electric arc discharge inside a lamp emits radiation that is reflected by an elliptical mirror. The arc discharge is place on one of the ellipsoid focal points; therefore radiation is directed toward the second focal point at which the highest concentration is reached. It is usually considered that stationary conditions on heat fluxes are achieved in experiments involving solar simulators, however power supply and arc discharge motion can cause heat flux fluctuations. Consequently, these variations should be taken into account in order to obtain reliable heat flux values. In addition, heat flux distribution on a flat target is usually a Gaussian-like function that promote a non-homogenous temperature distribution, causing thermal stresses in target materials and undesirable effects in some applications *e.g.* volumetric solar receivers for solar tower technology [1]. For overcoming these disadvantages, it has been proposed to adapt the target plane to a 3-dimensional surface on which the flux distribution is homogenous, called protosurface [2].

In order to characterize the heat flux reaching the target, two different measurement techniques could be applied: (i) the direct method, which is based on single-point heat flux measurements with a Gardon-type calorimeter placed on target position; and (ii) the indirect method, which recovers the heat flux map on a lambertian flat target from an image acquired with a CCD camera, providing a multiple-point measurement. In this work, both techniques were combined for obtaining the fluctuations produced by a 7 kW_e-solar simulator, as well as the 3-dimensional heat flux distribution. The direct method was used to quantify light fluctuations, providing the minimum CCD camera integration time for retaining the time average heat flux distribution as well as the local heat flux variations. The indirect method was applied to measure the heat flux distribution in different parallel planes, and, after data treatment, the protosurfaces shape and their location were determined.

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Methods to analyze the durability of solar reflectors

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Thick glass mirrors are commonly used in concentrating solar power plants to concentrate the sunlight onto the absorber. It is estimated that 25% of the total cost of a CSP plant is invested in the reflector material. In order to achieve competitive costs of electricity generation it is desirable to replace the expensive thick glass mirrors by low cost reflective surfaces. It is rather unclear if those newly developed materials will withstand the rough outdoor conditions without a significant loss of reflectance for more than twenty years. In this work accelerated aging tests are carried out in order to estimate the service life time of reflectors. Testing includes exposure to corrosive atmospheres, increased UV-radiation and simulation of desert sand storms. The work is focused on an enhanced anodized aluminum reflector protected by a sol-gel coating. Three different variations of coatings are compared to each other. Samples are optically analyzed with a newly developed reflectometer that enables to measure the specular reflectance at different acceptance angles. The system is based on a photographic method which allows to evaluate the reflectance characteristics of flat mirrors on any point of its surface with a spatial resolution of 10 pixels/mm. The instrument is especially employed to monitor corrosion processes of naturally and accelerated aged aluminum reflector samples.

Study of solar material accelerated aging to perform durability predictions

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Solar receivers used in CSP power plants are subjected to intense and cyclic thermal stresses. Though those are made of resistant materials like alloys or ceramics, the extreme conditions in which they work are responsible for the early degradation of their thermal and mechanical performances. In particular, their capacity to optimally absorb solar energy and then transmit it to the working fluid is diminished. The principal cause of this is the evolution of some material properties over time. It is then necessary to determine what are these properties, what is their influence on receivers' thermal performances, and what are the main factors of their evolution.

As the lifetime of a receiver may be several years, receiver's material aging cannot be assessed quickly in normal working conditions. That is why we need to accelerate it by achieving higher-than-normal thermal stresses inside the material.

The material of interest is a multilayer material (metal + absorbing paint) composing tubes of a solar tower receiver. To study the thermal behavior of this material when exposed to high solar irradiation, a 2D-model of a material sample has been implemented in a first part. The influence of several parameters on temperatures and gradients has been quantified in real-life conditions and for three other configurations of boundary conditions.

From these results, a second part will be to design an assessment rig to allow the identified aging factors to be amplified, entailing high thermal gradients, and yielding to accelerated material's degradation.

The third part will concern the assessment of properties' evolution. After the irradiation processes, several key properties will be observed like thermoradiative properties (emissivity, reflectivity), measured with an optical fiber reflectometer ; and bulk properties (diffusivity, effusivity and thermal contact resistance between paint and metal), measured with a laser flash method coupled with an inverse problem algorithm. The follow up of those material properties will allow us to detect cracks or delaminations resulting of its aging.

The aim of this work is to understand material's aging mechanisms and to develop methodologies to perform accelerated aging test. We will then be able to predict the service lifetime of a selected material and enhance solar receiver's durability.

Parametric analysis of receiver durability and efficiency at high solar flux

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The reliability of the solar receiver that work, not only at high temperature, but also support high solar flux and sometimes high pressure involves the efficiencies at what the solar energy is transferred to the heat transfer fluid (HTF) and the durability of the receiver.

In order to study the influence of the HTF, geometry and selected material in the reliability of the receiver, a computer tool has been developed. This flexible tool allows to pre-design more reliable receivers for a given solar flux map. A numerical model of the receiver efficiency and durability is presented and a parametric study of diameter is shown for the main HTF's (saturated water, air and molten salt) and materials**.**

Air has the lowest heat transfer coefficient and therefore requires high areas, or high temperature difference between the air and inside wall. That can be translated in higher thermal losses or less fatigue life. The pressure drops are highly dependent on the inside diameter and for small diameters force to operate at high pressure, being this high pressure a mandatory parameter on fatigue life and must be avoided.

Main results for the three different HTF's analyses are:

- To get good exergetic efficiency, low pressure drops are required, not being the best option for the air small diameters.

- Saturated water has the best cooling properties of the three compared fluids but its high pressure when operating might call into question the operational safety of the receiver. In terms of durability and thermal efficiency, small diameter tubes are desirable, otherwise, the pressure losses increase some factors faster for a small diameter reducing the output pressure and consequently the saturation temperature, meaning a lowest exergetic efficiency.

- The low conductivity of molten salts force to reach high velocities in order to achieve good thermal efficiency and avoid elevated wall temperatures. The enthalpy of the molten salts is just function of temperature, thus, pressure losses are not mandatory in exergetic efficiency, improving all analysis indicators for small diameters.

Keywords: tube receivers, reliability, durability, fatigue, efficiency, materials

Optical and thermodynamic considerations for a solar water splitting model

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The project HYDROSOL-3D aims to design a $1MW_{th}$ plant based on a thermo-chemical water splitting cycle. The current 100 kW_{th} reactor in Almeria resulted from the previous project HYDROSOL 2. It was built mainly to show how the cycle can be integrated into a solar tower. However, it was not designed in an optimal way from a thermodynamic point of view.

For the next reactor generation, the reduction of thermal losses will be one main task to complete. Most heat loss of the current reactor design is due to thermal re-radiation of the absorber surface. Therefore, a secondary concentrator needs to be applied to reduce the aperture area.

Another important aspect is to achieve a flux profile on the receiver which is as homogeneous as possible. This is important since the kinetics of the reaction is relatively temperature-sensitive. In this study, different absorber shapes are applied and compared.

To analyze the effect of the above mentioned changes, ray-tracing calculations were carried out. A criterion to determine the quality of a flux distribution on the absorber was elaborated in order to compare the results.

The absorber shape showing the best results for the current requirements is hemispherical. Between the outlet of the secondary concentrator and the upper rim of the hemisphere, there should be a cylindrical spacer made out of aluminum oxide or similar material. This is important for the homogenization of the flux profile.

Thermal dissociation of ZnO using concentrated solar power - Reactor modeling, optimization and scale-up

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Solar H_2 and syngas production via a two-step H_2O/CO_2-splitting thermochemical cycle based on Zn/ZnO redox reactions using highly concentrated solar energy is considered. The closed cycle consists of: (1) the solar-driven endothermic dissociation of ZnO to Zn and O_2; and (2) the non-solar exothermic re-oxidation of Zn with H_2O and CO_2 to produce H_2, CO, and the initial metal oxide, with the latter recycled to the first step. The first solar step has been experimentally demonstrated using a 10 kW reactor at PSI's high flux solar simulator. Based on this prototype, a 100 kW scaled-up solar reactor, currently under construction, has been designed at PSI and will be tested at the CNRS' 1 MW solar furnace in Odeillo, France. The performance of the scaled-up reactor has been investigated by applying a 3D transient heat transfer numerical model which couples radiative, conductive, and convective heat transfer to the endothermic ZnO dissociation reaction occurring in a shrinking bed under a transient ablation regime. Validation of the model was accomplished by comparing predicted to measured temperature profiles and reaction extents for the 10 kW reactor prototype. The radiative flux distribution within the cavity was computed using an in-house Monte Carlo ray-tracing code adapted to the geometry of the CNRS' 1 MW solar furnace. The accuracy of the model was enhanced by: (1) implementing a three-band semi-gray approach, treating the quartz window as a semi-transparent spectrally selective surface; and (2) simulating the transient effect of the ZnO screw conveyor on the radiative exchange within the reactor cavity. The reactor model predicts the reradiation losses to account for 20% of the total incident radiation, and overheating of the reactor front cone due to the large portion of heat absorbed by this component. To circumvent the latter challenges, two alternative designs were modeled and evaluated: (1) the incorporation of a compound parabolic concentrator (CPC) into the reactor's aperture; and (2) the replacement of the Al_2O_3 front cone by a ceramic-coated water-cooled copper equivalent. A novel design for the rotating cavity was devised, consisting of hexagonal-shaped insulation layers and a circular innermost composite layer of ZnO on top of Al_2O_3 tiles. This arrangement provides increased mechanical stability and allows operating temperatures exceeding 2000 K, thus accelerating the ZnO dissociation kinetics and augmenting the reactor efficiency.

Syngas production from H_2O and CO_2 over Zn particles in a packed-bed reactor

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The solar thermochemical production of H_2 and CO (syngas) from H_2O and CO_2 is examined via a two-step cycle based on Zn/ZnO redox reactions. The first, endothermic step is the thermolysis of the ZnO driven by concentrated solar energy. The second, non-solar step is the exothermic reaction of Zn with a mixture of H_2O and CO_2 yielding syngas and ZnO; the latter is recycled to the first step. A series of experimental runs of the second step was carried out in a packed-bed reactor where ZnO particles provided an effective inert support for preventing sintering and enabling simple and complete recycling to the first, solar step [1]. Experimentation was performed for Zn mass fractions in the range of 33–67 wt% Zn-ZnO and inlet gas concentrations in the range 0–75% H_2O-CO_2, yielding molar Zn-to-ZnO conversions up to 91%. A 25 wt% Zn-ZnO sample mixture produced from the solar thermolysis of ZnO was tested in the same reactor setup and exhibited high reactivity and conversions up to 96%.

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Two-step solar thermochemical cycle for splitting H_2O and CO_2 via ceria redox reactions – Experimental investigation with a 3 kW solar reactor

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We report on recent experimental studies for splitting H_2O and CO_2 using concentrated solar energy. The two-step thermochemical cycle can be represented by:

High-temperature reduction $$CeO_{2-\delta} \xrightarrow{\Delta H} CeO_{2-\delta-x} + \frac{x}{2} O_2 \quad (1)$$

Low-temperature oxidation $$CeO_{2-\delta-x} + xH_2O/CO_2 \longrightarrow CeO_{2-\delta} + xH_2/CO \quad (2)$$

The solar reactor consists of a cavity-receiver with a small windowed aperture for efficient radiation capture and absorption. A highly-reflective compound parabolic concentrator (CPC) is incorporated at the aperture to augment the solar flux concentration and reduce re-radiation losses. The cavity contains a porous absorber made of ceria fibers, which is directly exposed to concentrated solar radiation and subjected to multiple heat-cool cycles under appropriate gases to induce fuel production. Experiments with a 3kW solar reactor prototype were conducted at ETH's High-Flux Solar Simulator under conditions that closely approximates the heat transfer characteristics of highly concentrating solar systems such as solar towers and parabolic dishes. The reactor engineering design, fabrication, and experimental setup are described in detail and measured product compositions and solar-to-fuel energy conversion efficiencies are presented.

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A solar cavity-receiver packed with an array of thermoelectric converter modules — Experimentation, modeling and optimization

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We report on the novel design of a solar cavity-receiver packed with an array of thermoelectric converter (TEC) modules, which enables efficient capture of concentrated solar radiation entering through a small aperture. A 1 kW demonstrator (proof-of-concept) containing 18 TEC modules, each consisting of Al_2O_3 absorber/cooler plates, and p-type $La_{1.98}Sr_{0.02}CuO_4$ and n-type $CaMn_{0.98}Nb_{0.02}O_3$ thermoelements, was subjected to peak solar concentration ratios exceeding 600 suns over its aperture. The TEC modules were operated between 900 K and 300 K. The measured solar-to-electrical energy conversion efficiency was twice that of a directly irradiated TEC module. A heat transfer model was formulated to simulate the solar cavity-receiver system and experimentally validated in terms of open-circuit voltages measured as a function of the mean solar concentration ratio. Vis-à-vis a directly irradiated TEC module, the cavity configuration enabled a reduction of the re-radiation losses from 60% to 4% of the solar radiative power input [1, 2].

The heat transfer model is applied to optimize a 50 kW solar cavity-receiver packed with segmented TEC modules. Considered are low-temperature modules based on Bismuth telluride alloys having a figure-of-merit of 1, and high-temperature modules with assumed figure-of-merit up to 1.7. The optimized square parallelepiped (box) cavity-receiver has a circular aperture with diameter of 20.6 cm, a width of 60 cm and a height of 50 cm. The model predicts power outputs up to 10.4 kW and theoretically maximum solar-to-electricity energy conversion efficiencies up to 21% when operated at 1200 K.

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High temperature heat storage for thermal protection of solar power plants

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The PEGASE project (**P**roduction of **E**lectricity with **GA**s turbine and **S**olar **E**nergy) consists in the design, installation and experimentation of a hybrid solar gas power plant, using the solar facilities existing at THEMIS solar site (Targasonne, France). The solar radiation delivered by the heliostats field is pointed toward the receiver where the pressurized air is heated up and sent downstream to the expander of the gas turbine. The operating conditions are: a pressure of 8 bar, a mass flow rate of 8 kg/s, and a targeted temperature increase of 400°C (from 350°C to 750°C).

High temperature heat storage for thermal protection of solar power plants aims at protecting the facilities from brutal variations of solar amount. This mode of storage has to answers special needs, for example limited storage capacity, short characteristic time, high thermal conductivity, and high energy density. Moreover, the addition of such a system on the existing receiver leads to further geometrical needs.

A thermal protection module has to be designed to increase the thermal inertia of the receiver, in order to level its temperature and, therefore, the outlet temperature of the air. The targeted decrease of the outlet temperature is of 150°C after 15 minutes without solar amount.

Latent heat storage has been preferred to sensible heat storage or bond energy storage because it offers an acceptable compromise between a high energy density – consequently a low storage volume – and a short-term feasibility.

A storage system based on a composite architecture including a highly conductive matrix and a phase change material (PCM) has to be designed. More particularly, the PCM has to be chosen according to several criterions, like phase change temperature, energy density, compatibility with other construction materials or toxicity. Finally, the geometry of the matrix is a key point of the system efficiency.

Simulation of combined parabolic-trough solar power plants and desalination facilities in arid regions

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The novel combination of Concentrated Solar Power (CSP) and desalination processes has a huge potential for producing water in arid regions suffering from fresh water scarcity and facing the current energy challenge. In this study, different configurations for electricity and water production have been simulated and compared to each other. The CSP plant consists of a parabolic trough (PT) power plant based on Reheat Rankine cycle with water as the working fluid. The desalination technologies considered for the combination with the PT-CSP plant are multi-effect distillation (MED) and reverse osmosis (RO). Two MED plants configurations have been taken into account: a low temperature multi-effect distillation (LT-MED) unit using the exhausted steam from the CSP plant as the source of heat, and a low temperature multi-effect distillation plant powered by the steam obtained from a thermal vapor compressor (TVC). In this case, unlike in the conventional thermal vapor compression MED process (TVC-MED), the entrained vapor to be used in the steam ejector comes from the exhausted steam of the CSP plant instead of an intermediate effect of the distillation unit. Within the latter concept (LT-MED-TVC), different schemes have been studied: one using the high exergy steam from the high pressure turbine outlet as motive steam in the TVC, and others using steam extracted at different pressures from the low pressure turbine as the motive steam in the ejector. This paper shows the thermal performance assessment of several plant configurations, with an identical 50 MW_e net power production, 58ºC (0.18 bar) as exhausted steam outlet turbine conditions and the resulting fresh water production capacity of 46615 m^3/day. The parameters evaluated have been the net output thermal capacity, the overall thermal efficiency, the cooling requirements and an estimation of the solar field size required to provide the corresponding thermal capacity. Further experimental simulations will be carried out at a test bed that is being installed at the Plataforma Solar de Almería (PSA), consisting of a Rankine Power Cycle simulator that will be coupled to a LT-MED pilot plant located at the PSA.

Design and implementation of a new 5 kWe solar ORC pilot plant at the PSA

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Solar organic Rankine cycle (ORC) converts solar thermal energy into electricity, offering an alternative to PV systems for applications in areas where regular power supply does not exist. A variety of solar ORC systems have been investigated in previous scientific works through theoretical models and simulations, but very few experimental setups have been reported. Among them, two types of systems can be identified. The first ones are large plants for power production in the MW range fed with solar fields with areas in the order of thousands of m^2 and maximum cycle temperatures between 200-300ºC, which allows them to reach efficiencies over 20%. The others are tens of m^2 solar fields coupled to kW sized installations working at T_{max} lower than 150ºC. These small systems efficiencies are committed by their T_{max}, lower than on MW plants. Consequently, the efficiency reached on the experimental kW size setups is no more than 13%. However, there is still another SORC concept (not yet implemented), where a kW sized installation works with high working temperatures (around 200ºC), attaining higher efficiencies.

This work presents a description of the test facility installed at the Plataforma Solar de Almería (PSA), which implements a solar ORC cycle in a pilot plant that keeps the power production in the kW range but working with temperatures around 200ºC to raise the efficiency. The test bed consists of an ORC pilot unit coupled to an existing parabolic through solar field (Figure 1). The main objective is to assess the stationary and dynamic behavior of the solar ORC system under real solar conditions in order to develop a generic model for this kind of systems.

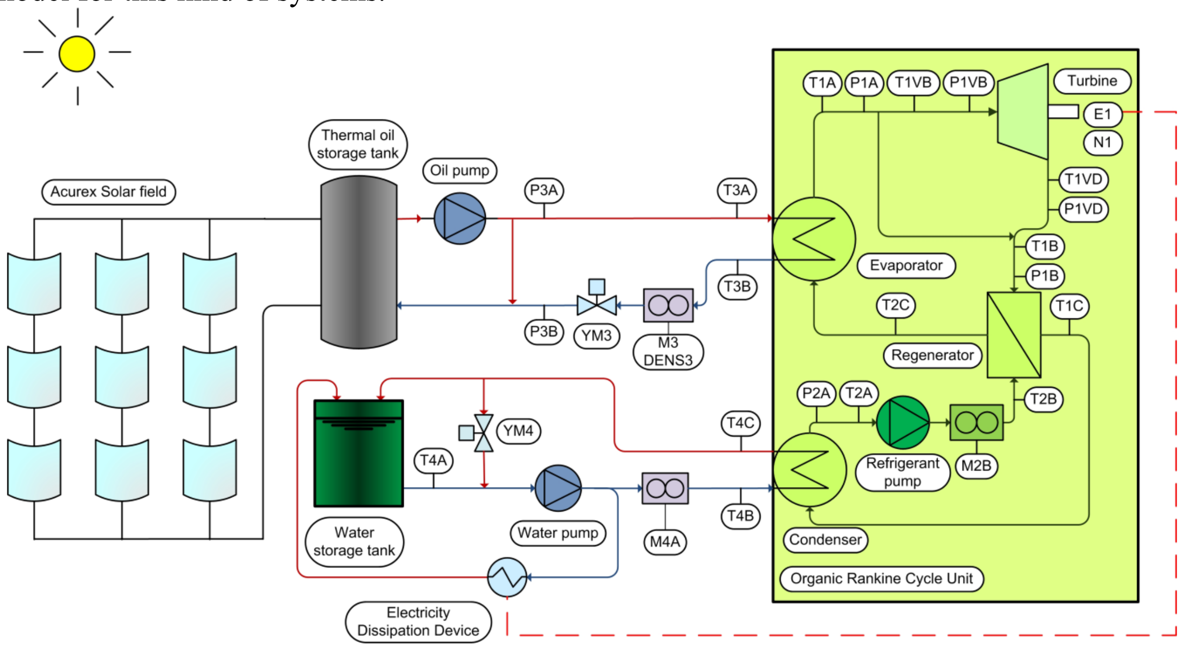

Figure 1: Layout of the solar ORC test bed

CO_2 capture from ambient air

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Most CO_2 capture technologies deal with the scrubbing of CO_2 from flue gases [1], although stabilization of global CO_2 emissions is unlikely to be achieved without CO_2 capture from atmospheric air [2,3]. The minimum amount of energy required for gas separation, given by the Gibbs free energy change of the process, is 5.2kJ/mol for 12% CO_2 concentration in flue gases, and 18.9kJ/mol (4 times more energy) for 430 ppm CO_2 concentration in air (280 times more diluted). However, the capture of CO_2 from air can be performed conveniently at locations with high solar energy resources and coupled to its recycling for the production of solar liquid fuels [3]. Previous studies considered adsorbers based on calcium [4], sodium [5,6], amines [7], and ion-exchange resins [8,9,10].
Herein, an amine-modified solid sorbent was studied as CO_2 capture structure. Experiments were performed for CO_2 adsorption at 25°C and atmospheric pressure using an air stream with 430 ppm CO_2 concentration and 40% relative humidity, followed by pure CO_2 desorption upon heating to 95°C. The sorbent showed to be fully recyclable during consecutive CO_2 adsorption-desorption cyclic runs. We describe in detail the experimental setup and results.

Acknowledgement - This work is being partially financed by the GEBERT-RÜF-STIFTUNG.

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Temperature-vacuum swing regeneration of amine-functionalized solid sorbents for CO_2 capture from air

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We report on a combined temperature and vacuum swing process capable of extracting pure CO_2 from dry and humid atmospheric air. Adsorption/desorption cycles utilizing a packed bed of a sorbent material made of a diamine-grafted commercial silica gel (ZEObeads™ B2) are experimentally investigated under equilibrium and non-equilibrium (short-cycle) conditions. Thereby, the cyclic CO_2 capture capacity of the material is determined over a wide range of parameters, namely 10-150 $mbar_{abs}$ desorption pressure, 75-95°C desorption temperature, 0-80% relative humidity during adsorption. Results are compared to the capacities obtained when using an inert purge gas for desorption. Up to 150 ml of CO_2 with a purity up to 97% is recovered per cycle, with less than 2.5% variation in capacity among cycles.

Adsorption isotherms of the sorbent material are modeled and validated with experimental results. The model is applied to predict the cyclic CO_2 capture capacity of the analyzed material under a range of temperature-vacuum swing regeneration conditions. Further, a significant influence of humidity during adsorption on the effects of desorption pressure is observed: While for dry adsorption conditions desorption pressures up to only 50 $mbar_{abs}$ yield feasible cyclic CO_2 capture capacities, for humid adsorption conditions the desorption pressure can be raised to 150 $mbar_{abs}$ without substantially reducing the cyclic capacity.

Air decontamination by heterogeneous photocatalysis

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A bad indoor air quality is thought to be the cause of diseases like allergies, asthma or sick building syndrome (SBS). Average citizens spend most of their time indoors and could be exposed to elevated pollutants content present in the air. Microorganisms and volatile organic compounds (VOCs) are significant sources of indoor air pollution. The active investigation field of photocatalysis applied to these pollutants has remained very scarce outside liquid-phase applications. There is a clear demand for efficient air and surface purification and disinfection systems to control the quality of the indoor air and surfaces. Qualitative and quantitative analytical techniques able to characterize the indoor air and the performance of these devices are also necessary.

Characterization of VOCs, bacterial and fungal species commonly found in the indoor air has been done. The analytical techniques used were colony counting, microscopy and Polymerase Chain Reaction (PCR) with subsequent sequencing -for microbial quantification and identification- and Automated Thermal Desorption coupled to Gas Chromatography with Mass Spectrometry detection (ATD-GC-MS) -for chemical analysis-.

This work studies the photocatalytic and photolytic elimination of microorganisms and VOCs in indoor air at laboratory scale with different irradiation sources: lamps of UVA, UVC and visible irradiation. As photocatalyst we have use TiO_2 obtained by sol-gel at low temperature and supported on different structures: metallic, polymeric and ceramic honeycomb monoliths. Different pre-treatments of the monoliths surface were tested to obtain structures with good photocatalytic properties. Deposition was done by dip-coating technique. Characterization and optimization of the process was done using X Ray Diffraction (XRD), Scanning Electron Microscopy with Energy-Dispersive X-ray spectroscopy (SEM-EDX) and N_2 adsorption-desorption isotherms. Attenuated Total Reflection Fourier Transform Infrared (ATR-FTIR) was used to follow the photocatalytic reaction with VOCs. The efficiency of the photocatalytic treatment of microorganisms was assessed by colony counting.

The goal of this project is to obtain an effective system to reduce simultaneously the chemical and biological pollution in indoor air and surfaces using heterogeneous photocatalysis based in TiO_2 and a combination between natural and artificial solar radiation (lamps) as irradiation source.

Optimization of Solar Photo-Fenton treatment for WWTP effluents containing emerging contaminants

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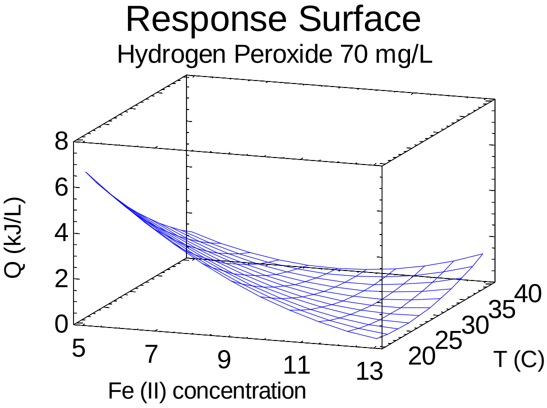
Nowadays, one of the main sources of water for potential reuse comes from municipal wastewater treatment plants (MWWTPs). However, quality demands for reusable water not to contain the so called Emerging Contaminants (ECs): pharmaceuticals, pesticides, hormones and others organics that escape conventional wastewater treatment techniques. ECs are mostly unregulated compounds that have been found in MWWTP effluents at concentrations higher than 1 µg/L.

The objective of this work is the optimization of a photo-Fenton process as a potential tertiary treatment for MWWTP effluents containing ECs. With this purpose, a battery of experiments were performed with real MWWTP from El Ejido (Almería, Spain) which was spiked with 100 µg/L of four ECs typically found in such effluents: Carbamazepine, Flumequine, 2-Hydroxy Fenil, and Progesterone. Photo-Fenton experiments were carried out under sunlight at the Plataforma Solar de Almería in a pilot plant based on compound parabolic collectors (CPCs) specially developed for photo-Fenton applications. The concentration profile of each compound during degradation was monitored by UPLC-UV (series 1200, Agilent technologies).

This study evaluates the influence of some important parameters involved in the practical operation of solar photo-Fenton processes such as hydrogen peroxide initial dosage, iron concentration and temperature. A spherical central composite design (CCD) was employed to evaluate the influence of these three parameters, (H_2O_2, Fe^{2+} and T). This design puts all the factorial and axial design points on the surface of a sphere of radius $\sqrt{k}$, where k =3 (number of parameter).

Seventeen runs were performed according to this experimental design, 2^k factorial runs, $2k$ axial and 3 centre runs. Statgraphics software statistical tool was employed to analyze the central composite design and to plot the response surfaces. The response factor considered in this study is the accumulated energy Q (kJ/L) necessary to remove more than 95 % of the added ECs. In this case, the response factor must be minimized to attain the optimum situation as the required accumulated energy governs the up-scaled solar plant design, i.e., total surface of solar CPCs field, which make up the most important investment cost.

Figure on the right side shows the response surface of CCD, where it is observed the high dependence of Q with iron concentration and temperature, more than hydrogen peroxide initial concentrations.



Tomography-based determination of permeability and Dupuit-Forchheimer coefficient of characteristic snow samples

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A tomography-based methodology [1,2] for the mass transport characterization of snow is presented. Five samples, characteristic for a wide range of seasonal snow, are considered. Their 3D geometrical representations are obtained by micro-computer tomography and used in direct pore-level simulations to numerically solve the governing mass and momentum conservation equations, allowing for the determination of their effective permeability and Dupuit-Forchheimer coefficient. The extension to Dupuit-Forchheimer coefficient is useful near the snow surface, where higher Reynolds numbers than unity can appear. Simplified models of porous media are also examined. The methodology presented allows for the accurate determination of snow's effective mass transport properties, which are strongly dependent on the snow microstructure and morphology and can, in turn, readily be used in snowpack volume-averaged (continuum) models, such as strongly layered samples with macroscopically anisotropic properties.

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Dynamic wind loads on heliostats

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The power tower technology is one of the most important concepts among the solar thermal power plants. Its main advantage compared to other technologies is the large concentration of solar radiation, which leads to high overall efficiencies. The concentration is done by a large number of mirrored collectors, called heliostats, which track the sunlight during the day and focus it onto a heat exchanger located at the top of a central tower. The heliostat field is one of the main cost factors of the power plants. Hence, the effort on developing new designs to reduce the investment costs of this component is a key task for future developments in the power tower technology. Thereby, the accuracy of the concentrators must be guaranteed. This accuracy is provided by a stiff structure with high precision drives. The main input for the design of these elements is the reliable information about the loads acting on the structure. Overestimating the design loads leads to high costs and underestimating them causes the failure of the heliostats.

The heliostats are exposed to gravitational forces and to wind induced forces. The former depend on the geometry and materials used. Therefore, it can be estimated accurately for a specific design. The latter is much more complex. Wind induced forces depend on the environmental conditions existing in the heliostat field. These conditions are characterized by the following phenomena: the atmospheric boundary layer, transient and localized velocity changes associated with gusts and wake induced pressure fluctuations generated by the heliostats. A good understanding of these phenomena and their effects on the structure is essential for design. In the past, experimental studies (e.g. Peterka et al., 1989) determined the mean and peak values of the wind loads on heliostats. These studies did not examine in detail the flow phenomena mentioned above. Hence, they were not able to give a precise explanation of the results obtained in certain cases and only provided a method for design against structural failure by overstressing.

The objective of the present investigation is to determine the dynamic wind loads on heliostats and to gain insight into the influence of the fluctuating flow. This will provide valuable information especially for designing against fatigue caused by loading cycles. Furthermore, the present study aims to identify critical conditions and propose measures to reduce the dynamic loads. During the present work numerical simulations will be used to model the fluid dynamics, structural mechanics and their interaction. In addition, measurements on real heliostats as well as model prototypes will be performed to validate the simulations.

High temperature thermal storage for concentrating solar power: Model and experimental results

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A one dimensional, two phase numerical model to predict the heat transfer for thermal energy storage for an air-based solar power plant was developed and compared with experimental results. The model considers constant fluid and material properties, convective heat transfer between the fluid and the solid phase and conduction through the solid phase. Losses are considered from lateral walls and the lid. The experimental results are obtained from a storage tank with the shape of a truncated cone with a dodecagon cross section immersed in the ground and a total storing volume of 30 m^3.

The model simulation results are compared to the experimental ones for 30h of charging with an air stream of 0.1 kg/s and 520°C, followed by 15h of discharging with the same mass flow rate and air at ambient temperature. The effects of the different parameters were studied separately to investigate their influence on a good agreement of the data. The heat capacity of the packed bed and the thermal conductivities of the lateral walls and insulating material showed to be the most influential parameters. The void fraction of the packed bed, the effective thermal conductivity of the packed bed and the variation of the mass flow rate within the range of error had minor effects, while the influence of the convective heat transfer method and particle diameter were negligible. For the best results, the input and recovered energy match with the experimental results with an error of 6% and 3% respectively.

Further, a parameter study of the packed bed dimensions and air flow rate is carried out to evaluate the charging/discharging characteristics, daily cyclic operation, overall thermal efficiency and capacity ratio.

Fuel production by reduction of CO_2 using concentrated sunlight – A material study

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Synthesis gas (syngas, $CO:H_2$ 1:2) as an intermediate product is an universal precursor for the production of a very broad variety of chemical substances like gaseous and liquid synthetic fuels, polymers, ammonia, methanol, etc. In order to cover the required heat demand for the generation of carbon monoxide (CO) solely from carbon dioxide (CO2), employing concentrated solar energy may be a viable alternative to the state-of-the-art methods like steam reforming or partial oxidation of fossil resources. This emission-free CO production may be carried out in a two-step thermochemical cycle using an oxide material as the catalyst. The two steps are:

Regeneration of the metal oxide (MO) (1200-1400 °C): $MO_{ox} \rightarrow MO_{red} + O_2$

Splitting of CO_2 into CO (700 to 1000 °C): $MO_{red} + CO_2 \rightarrow MO_{ox} + CO$

For this thermochemical cycle, redox-material groups were identified with the aid of thermochemical calculations and comprehensively presented in an Ellingham diagram. Combined with a framework of thermochemical gas splitting reactions, the thermo-dynamical criteria for two-step CO_2-splitting cycles of redox materials have been estimated. These materials will be synthesized and will undergo further investigations in lab scale experiments (thermo-gravimetric and tube-furnace experiments).

Solar-driven gasification of micro-algal biomass in a two-zone reactor – Thermodynamic analysis and reactor design

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The solar-driven gasification of micro-algae offers a path for producing renewable CO_2 neutral fluid fuels with an upgraded calorific value. Full conversion is reached at above 1300 K yielding a syngas with a molar H_2/CO ratio of 1.32. A Second law analysis for solar and autothermal gasification is carried out to determine maximum energy conversion efficiencies and identify major sources of irreversibility. A two-zone solar reactor is designed, consisting of a cavity-receiver containing a drop tube packed bed tubular reactor, which allows for algae particles to be fed from the top, undergo pyrolysis while falling, and gasification in a packed bed.

Assessment of the hybrid sulfur cycle

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Thermochemical cycles belong to the possible routes for the conversion of solar energy into a chemical energy carrier. The hybrid sulfur cycle is one of the most promising candidates for the production of solar hydrogen on an industrial scale. It is a two-step cycle combining a chemical step, the high-temperature endothermic decomposition of sulfuric acid to sulfur dioxide, with an electrochemical step, the sulfur-dioxide depolarized electrolysis of water. The fundamental reaction steps are coupled by a series of process engineering steps. These intermediate steps have great influence on the overall energy requirements of a technical implementation of the cycle. Therefore an assessment of the efficiency of the cycle has to account for both, the fluctuating solar heat source and the dynamic response of the process.

A conceptual steady state process design as a preparatory step towards a dynamic model is presented. The concept assumes typical operating conditions of solar receiver reactors and simplifies the modeling of the electrochemical step. Otherwise only proven chemical process components are used. As working environment a commercial process modeling tool is chosen. An estimate of the process efficiency in steady state is given.

The benchmark process for the hybrid sulfur cycle is the conventional water electrolysis powered by solar generated electricity. By means of an economical comparative analysis including both the benchmark process and the hybrid sulfur cycle technical parameters are identified and their impact on the competitiveness of the hybrid sulfur cycle is quantified. This approach allows to discuss technical boundaries and development goals.

Vacuum distillation of aluminum via carbothermal reduction of Al_2O_3 with concentrated solar energy

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Using concentrated solar radiation as the energy source of high-temperature process heat, the carbothermal reduction of Al_2O_3 to Al was examined thermodynamically and demonstrated experimentally at vacuum pressures. Reducing the system pressure favors Al(g) formation, enabling its vacuum distillation and avoiding contamination by carbides and/or oxycarbides. When the reducing agent is derived from a biomass source, the solar-driven carbothermal process is CO_2 neutral. Exploratory experimentation in a solar reactor was performed with mixtures of charcoal with alumina in the range of 1300-2300 K at 1-10 mbar by direct exposure to concentrated thermal irradiation.

Doped-ceria materials for hydrogen production via two-step thermochemical water splitting cycles

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Hydrogen does not exist in the nature and thus, it must be synthesized. Steam methane reforming and, to a least extent, steam electrolysis are currently the most developed techniques but the latter is limited by the energy conversion efficiency and the former by the CO_2 emissions. Thermochemical water-splitting is an alternative option that makes use of concentrated solar energy as the primary energy source. Direct water-splitting (thermolysis) needs a very high temperature above 2250°C to reach significant dissociation and so, the use of catalysts is proposed to reduce this temperature. Mixed metal oxides are promising candidates for hydrogen production by solar thermochemical cycles. Such a cycle consists of a two-step process that involves a metallic oxide catalyst and water.

$$M_xO_y \rightarrow M_xO_{y-1} + \frac{1}{2} O_2 \qquad (1)$$

$$M_xO_{y-1} + H_2O \rightarrow M_xO_y + H_2 \qquad (2)$$

During the first O_2 releasing step, the oxide is thermally reduced by solar concentrated heat. Then in the second step producing H_2, the activated metallic oxide reacts with water vapor to be reoxidized and recycled to the first step. Abanades et al. showed that CeO_2/Ce_2O_3 two-step cycle could produce H_2 with a high reaction rate during hydrolysis (2.9 mmol/g), but the reduction temperature of Ce^{IV} to Ce^{III} is high (2000°C) and there are mass losses induced by partial sublimation of ceria, which implies productivity decrease during cycling. Doping ceria with a metallic cation could reduce the reduction temperature by inducing structural defects or oxygen vacancies, whille maintaining the ceria fluorite structure. This study is about the improvement of catalytic activity of Zr-doped ceria by investigating zirconium content and the synthesis method.

A solar particle receiver for small gas turbine systems

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A novel solar particle receiver for small-scale CSP systems ($100kW_{el}$ – $1MW_{el}$) is developed with regard to high efficiency, high durability and low costs. Two different concepts are considered: The rotary kiln, already introduced last year, and the centrifugal kiln. First experiments of the rotary kiln have shown an exceptional dust development which is presumed to arise from high abrasion of the particles. Additional limiting factors of the rotary kiln like unfavorable kiln inclination and therefore high convection losses have led to the decision to dismiss this concept for now. Subsequent investigations will thus concentrate on the centrifugal kiln concept.

The centrifugal kiln concept is based on a fast rotating kiln inclined 0 to 80 degrees to the vertical. Due to centrifugal acceleration particles are forced against the wall and form a thin layer at the whole inner circumference of the receiver. While moving slowly along the wall in axial direction, the particles are gradually heated up by solar radiation entering the aperture. Since the kiln can be inclined arbitrarily convection losses can be reduced significantly and an optimal inclination to the heliostat field can be established. Furthermore, problems caused by dust development are expected to be reduced due to the high rotation speed when smaller dust particles are forced against the wall. An additional advantage is the small relative velocity between particles and receiver wall during the solar radiation absorption process leading to presumably low particle wear. However, abrasion is still a critical point which needs to be investigated thoroughly. Appropriate methods have to be found studying the dominant abrasion mechanisms and - if required - constructive approaches to mitigate them.

Preliminary dimensioning calculations of the receiver for a $1MW_{th}$ plant yield an aperture diameter of approx. 1.2m leading to a minimum rotation speed of 55rpm and a circumferential velocity of 3.4m/s. First experiments on the laboratory scale have proven the feasibility of the concept for the desired application. In order to operate under all load conditions the particle retention time and mass flow can be regulated well by varying the rotation speed. Moreover, CFD simulations of convection in a rotating cavity have been conducted which indicate a positive effect of rotation on convection losses. Extensive studies of convection flow in high rotating cavities are planned in order to understand the governing mechanisms. Additionally, representative experiments will be set up validating the numerical results.

Modeling and Characterizing a Solar Particle Receiver

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Solar thermal power plants can provide a significant amount of the worlds electricity demand, but significant cost reductions are necessary to become competitive. One concept to realize higher efficiencies combined with cheap storage is the Solid Particle Receiver.
The solid particles can be used for direct absorption of the solar radiation and as heat transport and storage media. Power plants using particles can operate at high temperature (up to 1000°C) and provide low electricity generation costs due to a simple and robust design and high process efficiencies. A promising configuration is a receiver with a free falling curtain of ceramic particles with diameters between 0.3 and 1 mm.
To assess the potential of this receiver a model is developed. The main issue is to have a detailed model with affordable computational costs at the same time, to be able to simulate different receiver configurations for design and optimization. Therefore the model is divided into four different modules, to separate the main physical aspects (particle movement, solar radiation, thermal radiation/conduction and convection). The accuracy and computational cost can be separately optimized for every module, for example by using different meshes for different modules. The modules will be coupled iteratively to include the dependency of the different aspects. Details of the model like assumptions and used correlations will be presented.
The modules will be verified and experimentally validated with the available experimental data. Further experiments are planned to gain experimental data under representative conditions. Experiments with ceramic particles at falling lengths up to 10 m are scheduled.

Determination of an internal geometry for a ceramic high temperature pressurized-air solar receiver

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The main target of this PhD is to design a module of a solar receiver (the device that absorbs concentrated solar energy and transmits it to a fluid) sympathetic with high temperature and high pressure. Two principal kinds of receivers coexist: the open receivers and the pressurised receivers. Air at ambient pressure is pumped from the outside through a porous structure in the case of the open receivers. As it is technically difficult to compress a gas which has soon a high temperature, we will bear our interest on the pressurised technology. The volumetric receivers could be distinguished from the other receivers in the pressurised branch. In both cases, the fluid flows under pressure (between 10 and 20 bar) in the receiver. Even if, for the volumetric receiver, the fluid is separated from the outside by a transparent shield window, the operation principle of the receiver is the same as an open receiver: the fluid flows through a porous structure which is irradiated by the sun. The mains drawbacks of this shield window that allows working with a pressurized fluid is to be very brittle and to be one of the more expensive parts of the volumetric receiver. Even if this technology is leading nowadays for plants using a gas cycle, the thermal shocks should be avoided and the smallest smirch can lead to the destruction by the overheating of this window. Therefore, the development of a high pressure receiver which does not use any shield window is very attractive.

The optimisation of the internal geometry of this module of receiver consists in increasing the energy transmitted to the fluid and minimizing the loss of pressure between the entrance and the exit of the receiver, two determinant parameters in order to improve the efficiency of the power plant. In order to reach this goal, a first campaign of experiments was lead on a geometry of textured surface using actuators (a passive device that generates turbulences) and riblets (crop of ribs parallel to the stream of fluid that point the generated turbulences). The measurements were leaded in a large scale boundary layer wind tunnel of a partner lab using the Stereo Particular Image Velocimetry (S-PIV) technology in order to measure the near wall region of the flow with different configuration of textured surface.

In order to fit as well as possible with the real stream in the module, a plate channel wind tunnel was designed and mounted at Odeillo. In addition of the S-PIV optical diagnose mean, this wind channel is equipped with static pressure plugs that enables us to determine the pressure drop generated by the considerate textured surface.

At the same time, a numerical study was done on a reference internal geometry of receiver using straight fins. This study leaded to the determination of an optimal number of stages and straight fines for our application. Design that ended up with the conception of a first prototype of ceramic module of receiver that is presented by A. Colleoni.

Modeling and conception of a solar receiver carrying pressurized air for the PEGASE project

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In the framework of the French PEGASE project (**P**roduction of **E**lectricity by **GA**s turbine and **S**olar **E**nergy), CNRS/PROMES laboratory is developing a 4 MWth pressurized air solar receiver with a surface absorber based on a compact heat exchanger technology. The first step of this development consists in designing and testing a pilot scale (1/10 scale, e.g. 360 kW_{th}) solar receiver based on a metallic surface absorber. The goal is to be capable of preheating pressurized air from 350°C at the inlet to 750 °C at the outlet, with a maximum pressure drop of 300 mbar. The receiver is a cavity of square aperture 120 cm x 120 cm and 1m deepness. The bottom of the cavity is covered by modules arranged in two series making the modular and multi-stage absorber. The thermal performances of one module are considered to simulate the thermal exchange within the receiver and to estimate the energy efficiency of this receiver.
The results of the simulation show that the basic design yields an air outlet temperature of 732°C under design operation conditions (1000 W/m^2 solar irradiation, 0.8 kg/s air flow rate). Using the lateral walls of the cavity as air preheating elements improves the energy efficiency of the receiver and allows to increase the air outlet temperature.

An air-based cavity receiver for solar trough concentrators

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A cylindrical cavity receiver that uses air as heat transfer fluid is developed for use with parabolic trough concentrators. The absorber tube is contained in an insulated and windowed cavity with highly reflecting inner walls to reduce heat losses. Asymmetric CPCs boost the solar concentration at the receiver's aperture to 100 suns, while allowing for realistic angular dispersion of incident radiation (due to sunshape, tracking errors, and mirror shape errors) of 8 mrad.

A numerical heat transfer model of the receiver has been developed to determine its absorption efficiency and pumping power requirement, and to investigate thermal losses by modes. The 2D steady-state energy conservation equation coupling radiation, convection and conduction heat transfer has been formulated and solved numerically by finite-difference techniques. Monte Carlo ray-tracing of both the concentrator and the receiver, and the radiosity method have been applied to establish the solar radiation distribution and exchange inside the receiver. Hydrodynamic pressure losses and pumping power requirement are calculated using well-known correlations from literature for fully developed turbulent pipe flow.

Simulations have been conducted for a 50 m-long collector section with 120°C air inlet temperature, air mass flow rates in the range m_{air} = 0.4 – 1.2 kg/s, and solar radiation incident on the receiver Q_{solar} = 288.5 kW. As the mass flow rate is increased from 0.4 to 1.2 kg/s the absorption efficiency increases from 49 to 67% while the air outlet temperature decreases from 461 to 276°C. Isentropic pumping power requirement remains < 0.5% of Q_{solar} in all cases.

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Improved high-temperature solar receiver design for parabolic trough concentrators

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This presentation will give an overview of the EU-project “HITECO”, highlight its key motivation and address the major research lines of the project. In order to increase the efficiency of concentrated solar power (CSP) plants and thus reduce electricity production costs, the HITECO project will develop a new design concept of receiver with an increased operating temperature of the heat transfer fluid (HTF) of 600°C. Due to the higher temperature, new solutions for key components will have to be found. These components will allow for an increased overall efficiency at the aforementioned temperature while improving the mechanical, optical and thermal performance of the system.

The investigation in the HITECO project will include several different research lines. Research will be conducted on new materials and selective coating deposition methods in order to cope with the elevated operating temperatures. Better glass geometries and composition together with improved sealing and welding solutions will improve optical performance and guarantee a long life cycle. A new vacuum system will be developed which will allow for better pressure control and monitoring. Inside the absorber tube, a new heat transfer fluid will be introduced to better fit the higher temperatures. In addition, improvements to the mechanical components, such as the supporting structure, union systems and contact points, will be developed to guarantee stability and stiffness while accommodating thermal expansion of the components.

All new designs will be modeled using various approaches and validated through off-sun experiments as well as field tests using lab-scale and field test prototypes. The designs will also be assessed from a manufacturing and operating profitability view point to ensure a system that is manufactured and operated in a technically simple and economically competitive fashion. To meet these high expectations, the HITECO project consists of several leading industrial partners and research organizations from across Europe.

Experimental study of a ceramic solar receiver

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To increase the performance of solar tower, we need to develop new solar receiver reaching high temperature of air outlet. To achieve that, a particular attention must be paid to the exchanger's efficiency to transfer solar heat to the working fluid and to its material.
That's why we are currently developing an innovative, compact and high-performance solar heat pressurized exchanger in ceramic. As a matter of fact, ceramic can withstand high temperatures (up to 1400°C) and should enable to heat the air up to 1000°C. However, ceramic is very fragile and to be able to use such a material we need to minimize the stress and constraints on the receiver, which is a very tricky problem since high temperatures generate dilatations. Hence, the set up of the receiver in the experimental process is quite difficult, especially with the ceramic-metal bond.
In order to qualify the efficiency of our innovative solar heat exchanger, we would like to compare it with a solar receiver filled with fins. Numerical studies have been lead by X. Daguenet to design a receiver of dimensions 400mm x 200mm x 70mm able to transfer 30kW to the working fluid. To validate his results, we are going to test this ceramic receiver with fins in the solar furnace of Odeillo, with several inlet temperatures from ambient up to 500°C, representative of an air return of gas turbine.
The results of this experiment will give us very important information to develop a high-performance heat exchanger: the performance of a referential geometry to beat and information about the thermo-mechanical constraint of ceramic under high temperatures and pressure.

Theoretical proof of concept of an optimal solar receiver to produce low-temperature cooling using a thermoacoustic tri-thermal machine

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Thermoacoustic solar refrigeration devices appear to be among the most environmental friendly low-temperature cooling production process. Based on a Stirling thermodynamic cycle, which is close to the Carnot cycle, it can achieve a conversion efficiency of 30 %. It seems to be an alternative to the existing solar thermal systems based on absorption, adsorption or vapor compression cycles. Another advantage is that it can easily reach a large range of low temperature: from ambient to cryogenic levels. The solar adaptation of thermoacoustic system, usually powered by an electric resistance, requires an appropriate thermal design of solar receiver to reduce spatial and temporal unhomogeneity of irradiation, which disrupts the thermoacoustic prime-mover running.

The solar receiver’s purpose is to allow an efficient energy transfer from the solar concentrator to the working gas. A detailed theoretical study is necessary to optimize the future prototype’s dimensions for the experimental campaign. The whole modeling of the heat transfer process permits to characterize and anticipate the solar receiver thermal behavior. The analyze is divided into two transfer steps: the first one is the transfer by solar radiation from the concentrator to the hot heat exchanger and the second one is drive by thermoacoustic phenomenon from the heat exchanger to the working gas.

The goal of the first step of this study is to investigate ways to maintain as constant as possible both the temperature and the power transferred to the gas, despite natural variations in the solar flux. Several models and simplifying hypotheses are proposed. The results of the simulations permit to determine the receiver main dimensions, its position relative to the concentrator focal plan and the tubular matrix structure composing the exchanger. The double feature of the receiving cavity is studied as well to limit losses as to evaluate the effect of retro-radiation on the temperature homogenization.

The second step focuses on the understanding of thermal transfers in thermoacoustic process by determining an experimental law for the calculation of the transfer coefficient. This study begin by the review of the state of art and continue by the design of a experimental platform which aims to evaluate the influence of the exchanger internal shape (plate, cylinder fins…) and to complete and compare with previous works the influence of the mean pressure and choice of the working gas.