SOLLAB
ALLIANCE of EUROPEAN LABORATORIES on solar thermal concentrating systems

6th Sollab Doctoral Colloquium on Solar Concentrating Technologies
7th - 9th of June 2010
PROMES Odeillo, France

6th SOLLAB Doctoral Colloquium on Solar Concentrating Technologies

7th – 9th June 2010 at PROMES Odeillo, France

Book of Posters and Abstracts

PAUL SCHERRER INSTITUT PSI

ENEA Italian National Agency for New Technologies, Energy and Sustainable Economic Development

ETH Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

MINISTERIO DE CIENCIA E INNOVACIÓN
Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

PROMES

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

Program of the 6th SOLLAB Doctoral Colloquium

Odeillo, 7th – 9th of June 2010

Monday, 7 June 2010		
8h30-9h00	**Welcome and Presentation**	
	Solar fuels	
9h00-9h25	Solar syngas production from H_2O and CO_2 via two-step thermochemical cycles based on Zn/ZnO and FeO/Fe_3O_4 redox reactions: kinetic analysis	Anastasia STAMATIOU
9h25-9h50	Coproduction of Hydrogen and Carbon Black from Natural Gas Cracking under Concentrated Solar Radiation	Sylvain RODAT
9h50-10h05	Optical analysis of a solar concentrating facility for the design of a solar cavity receiver	Thomas COOPER
10h05-10h20	Design of a 100 kW reactor for the solar thermal dissociation of ZnO	Willy VILLASMIL
10h20-11h00	**Coffee break**	
	Solar electricity and energy storage	
11h00-11h25	Modelling of Concentrating Solar Thermal Power system based on Linear Fresnel Reflector for Cogeneration	François VEYNANDT
11h25-11h40	Solar particle receiver for small gas turbines	Wei WU
11h40-12h05	Modeling a Free Falling Particle Receiver	Birgit GOBEREIT
12h05-12h30	Study, characterization and optimization of concentrated photovoltaics systems	Loïc PUJOL
12h30-14h00	**Lunch**	
	Solar components	
14h00-14h25	Development of a solar receiver for a thermoacoustic cooler system	Sophie CORDILLET
14h25-14h50	Optimizing operations of an open volumetric air receiver	Nils AHLBRINK
14h50-15h15	Experimental and Numerical Analyses of a Novel Pressurized Air Receiver for Concentrated Solar Power	Illias HISCHIER
15h15-15h45	**Coffee break**	
15h45-17h45	**Themis Visit**	
18h00-19h30	**Natural warm bath-Dorres**	
19h30	**Barbecue**	

Tuesday, 8 June 2010		
	Solar components	
9h00-9h25	Thermal Dispersive Effects in Sintered Metal Foams	Stefan BRENDELBERGER
9h25-9h50	Experimental and numerical study of a concentrated solar fluidized bed receiver	Germain BAUD
9h50-10h15	Simplified method for the geometrical optimization of a solar thermochemical reactor. Application to a real case.	Stefania TESCARI
10h15-10h30	radiation effect on the fatigue of metal tube receivers.	Eneko SETIEN
10h30-11h00	**Coffee break**	
	Solar fuels	
11h00-11h25	A lab-scale solar reactor for thermal dissociation of compressed ZnO and SnO_2 powders as part of 2-step thermochemical cycles	Marc CHAMBON
11h25-11h40	Dynamic modeling of a two step thermochemical water splitting process Preliminary considerations and objectives	Matthias LANGE
11h40-12h05	Development of mixed metal oxides for thermochemical hydrogen production from solar water splitting	Alex LE GAL
12h05-12h30	Solar Steam Reforming of Methane using Molten Salts as heat carrier	Isabelle LABACH
12h30-14h00	**Lunch**	
	Solar resources	
14h00-14h15	Retrival of circum solar radiation parameters from Meteosat Second Generation observations	Bernhard REINHARDT
14h15-14h40	Effect of Circumsolar Radiation on Focusing Collectors. Determination of the Usable DNI from Common DNI Measurements	Stephan WILBERT
	Solar fuels	
14h40-15h05	Development and evaluation of a two step thermochemical cycle for hydrogen generation	Jan SäCK
15h05-15h30	Modelling and Simulation of the Hybrid Sulphur Cycle	Nicolas BAYER BOTERO
15h30-16h00	**Coffee break**	
	Solar electricity and energy storage	
16h00-16h25	Numerical and experimental study of a distributor configuration for uniform flow distribution in an elemental absorber of air solar receiver	David BELLARD
16h25-16h50	Modeling and conception of a solar receiver carrying pressurized air for the PEGASE project	Benjamin GRANGE
16h50-17h15	The once through concept in parabolic trough plants with direct steam generation	Fabian FELDHOFF
17h30-19h30	**Sports**	
20h00	**Dinner**	

Wednesday, 9 June 2010		
	Solar electricity and energy storage	
8h30-8h55	Experimental investigations on thermoelectric solar cavity receiver	Clemens SUTER
8h55-9h20	Optimized Operation Strategies for Solar Trough Power Plants with Integrated Storage	Michael WITTMANN
9h20-9h45	Sustainable thermal storage material for CSP tested under concentrated solar flux	Antoine MEFFRE
9h45-10h10	Assessment of a novel direct absorption receiver for solar towers and USC steam cycles	Csaba SINGER
10h10-10h35	Pressurized receiver in ceramic in order to heat air at high temperature	Xavier DAGUENET
10h35-11h05	**Coffee break**	
	Solar detoxification and desalination	
11h05-11h30	Solar photocatalytic reactor experimental and modelisation results	Franck CORREIA
11h30-11h55	Preliminary assessment of a solar driven membrane distillation desalination system	Elena GUILLéN BURRIEZA
11h55-12h20	Treatment of municipal waste water effluents with modified solar photo-Fenton	Nikolaus KLARMETH
12h20-12h45	Steady State Mathematical Modeling of a Solar Multi-effect Distillation Plant at the Plataforma Solar de Almería	Patricia PALENZUELA ARDILA
12h45-14h00	**Lunch**	
	Solar components	
14h00-14h25	Methods to characterize the degradation of solar reflectors	Florian SUTTER
14h25-14h50	An air based cavity receiver for solar trough concentrators	Roman BADER
14h50-15h05	DSG in Parabolic Trough Study of Pressure Drop	David HERNANDEZ LOBON
15h05-15h30	Optimization of PTC Concentrator Geometry based on Optical Shape Measurements	Siw MEISER
15h30-16h00	**Coffee break**	
16h00-18h00	**Solar Furnace Visit**	
18h00	**Free time**	

Solar syngas production from H_2O and CO_2 via two-step thermochemical cycles based on Zn/ZnO and FeO/Fe_3O_4 redox reactions: kinetic analysis

A. Stamatiou[1], P. G. Loutzenhiser[1], A. Steinfeld[1,2]

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[2] Solar Technology Laboratory, Paul Scherrer Institute, 5232 Villigen PSI, Switzerland

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Syngas production via a two-step H2O/CO2-splitting thermochemical cycle based on Zn/ZnO and FeO/Fe3O4 redox reactions is considered using highly concentrated solar process heat. The closed cycle consists of: 1) the solar-driven endothermic dissociation of ZnO to Zn or Fe3O4 to FeO; 2) the non-solar exothermic simultaneous reduction of CO2 and H2O with Zn or FeO to CO and H2 and the initial metal oxide; the latter is recycled to the first step. The second step was experimentally investigated by thermogravimetry for reactions with Zn in the range 673 – 748 K and CO2/H2O concentrations of 2.5-15% in Ar, and for reactions with FeO in the range 973 – 1273 K and CO2/H2O concentrations of 15-75% in Ar. The reaction mechanism was characterized by an initial fast interface-controlled regime followed by a slower diffusion-controlled regime. A rate law of Langmuir-Hinshelwood type was formulated to describe the competitiveness of the reactions based on atomic oxygen exchange on active sites, and the corresponding Arrhenius kinetic parameters were determined by applying a shrinking core model.

Solar methane dissociation

Rodat Sylvain, **Stéphane Abanades, Gilles Flamant**
PROMES-CNRS, France

Solar methane decarbonization aims at dissociating methane into two valuable products: hydrogen and carbon black.

The main reaction is: $CH_4 \rightarrow 2H_2 + C$

After the operation of a 10 kW solar reactor (see 5th Sollab DC), a 50 kW reactor was designed, built and tested at the 1 MW solar furnace of the laboratory. The indirect heating reactor is composed of a graphite cavity (approaching the black-body behaviour) crossed by seven single graphite tubes (80 cm length). The cavity is separated from the ambient oxidizing atmosphere by a domed quartz window. A filter bag permits to separate carbon particles from the gaseous products.

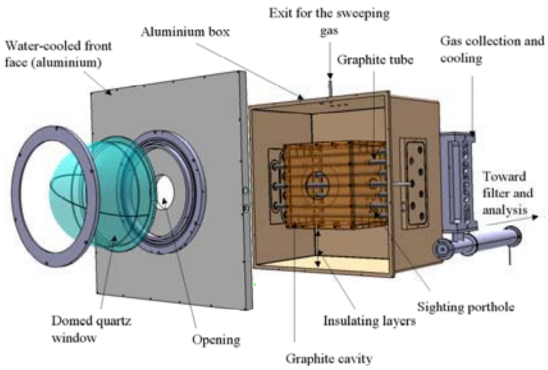

Figure 1: 50 kW solar reactor

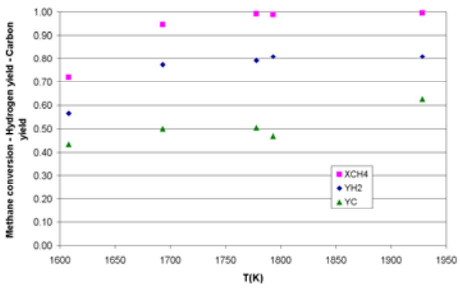

Figure 2: CH_4 conversion, H_2 yield, and C yield versus temperature for the first experimental series (Ar: 31.5 NL/min, CH_4: 10.5 NL/min)

Results show the strong influence of temperature and residence time on the chemical conversion, C_2H_2 is the main by-product. Significant quantities of carbon black were recovered and analysed: the higher the temperature, the higher the specific surface area.

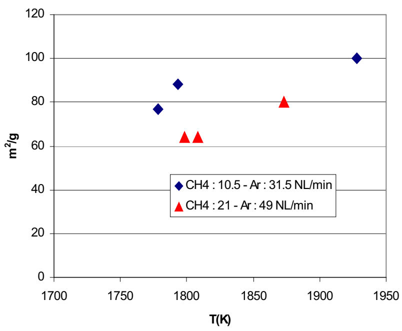

Figure 3: Carbon black specific surface area versus temperature

For 900 g/h of CH_4 injected (50% molar, the rest being argon) at 1800K, this reactor produced 200 g/h H_2 (88% H_2 yield), 330 g/h CB (49% C yield) and 340 g/h C_2H_2 with a thermal efficiency of 15%. A 2D thermal model of the reactor was developed. It showed that the design of the reactor front face could be drastically improved to lower thermal losses. The optimized design could reach 77% of the ideal black-body absorption efficiency (86% at 1800K), i.e. 66%.

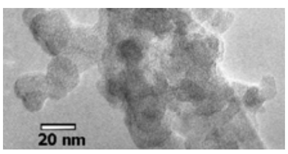

Figure 4: TEM image (APTL, Greece) of a carbon black sample (CNRS, France)

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Optical analysis of a solar concentrating facility for the design of a solar cavity receiver

Thomas Cooper[1], Aldo Steinfeld[1,2]

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[2] Solar Technology Laboratory, Paul Scherrer Institut, 5232 Villigen PSI, Switzerland

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A Monte Carlo ray-tracing model of the Megawatt Solar Furnace at Odeillo was developed using the in-house VeGaS code. Parameter tuning of the mirror reflectivity and angular dispersion error was performed to obtain close agreement between ray-tracing predictions and experimental data provided by PROMES. The best agreement was obtained for rms Gaussian dispersion errors of 3.5 and 6.5 mrad for the heliostats and the parabolic dish respectively, and total hemispherical reflectivities of 80.8%. The tuned model was then used to aid in the optical design of a 100 kW solar cavity receiver/reactor for the solar thermal dissociation of zinc oxide. Two configurations were studied: 1) a baseline design with a 20 cm aperture and a 45° cone angle operating with 25 heliostats; and 2) an alternative design with a 28 cm aperture and a 30° cone angle operating with 14 heliostats. The power admitted to the aperture was calculated to be 158 kW and 144 kW for the baseline and alternative designs resulting in average concentrations of approximately 5000 suns and 2300 suns respectively. Analysis of the distribution of absorbed flux on the receiver surfaces indicated a large amount of spillage radiation absorbed by the front cone. To remedy this problem, secondary concentrators were designed in replacement of the plain front cones. The optimal secondary concentrator for the baseline 20 cm aperture was found to be a 46° CPC operating with 17 heliostats; the corresponding optimal secondary concentrator for the alternative 28 cm reactor aperture was a 44° CPC operating with 12 heliostats. In both cases the design power of ~150 kW was recovered with a reduced number of heliostats. The intercept factors for the CPC receivers 20 and 28 cm apertures were 53% and 76% respectively, compared to 31% and 47% respectively for receivers with no secondary. The results of the analysis suggests that the design utilizing a 20 cm aperture coupled with a 44° CPC provides the best compromise between high solar concentration and a high intercept factor. It is recommended that this configuration be pursued for the design of the 100 kW pilot reactor.

Heat transfer model of a 100 kW reactor for the solar thermal dissociation of zinc oxide

W. Villasmil[1], T. Cooper[2], A. Steinfeld[1,2]

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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 and CO, and recover the initial metal oxide, which is recycled to the first step. A 10-kW solar reactor prototype for the thermal dissociation of ZnO has been experimentally demonstrated at PSI's high-flux solar simulator to reach over 3% solar-to-chemical energy conversion efficiency. Based on this tested design, the performance of a 100-kW scaled-up solar reactor is investigated by applying a 3D transient heat transfer numerical model. The reactor model 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 accuracy of the model was enhanced by implementing a three-band semi-gray approach, treating the quartz window as a semi-transparent spectrally selective surface. The radiative flux distribution within the cavity was computed using an in-house Monte Carlo ray-tracing code adapted to the geometry of the 1-MW Solar Furnace at the CNRS-PROMES research facility where the reactor is planned to be tested. A secondary concentrator (CPC) was incorporated into the design to decrease re-radiation losses and boost efficiency. The numerical reactor model predicts over 50% solar-to-chemical energy conversion efficiency for the scale-up design. The re-radiation losses account for 50% of the total heat losses and over 20% of the total incident radiation. Up to 10% of the incoming solar radiation is expected to be lost at the window due to reflections at its outer surface. Of the water-cooled components the quench unit represents the largest heat sink, accounting for nearly 70% of the total conduction losses.

Design optimization of a solar power plant based on linear Fresnel reflector

François Veynandt
PROMES-RAPSODEE, France

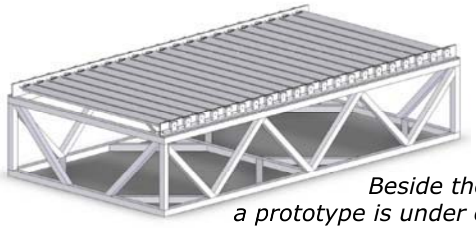

Figure 1. Beside the simulation a prototype is under construction

A global simulation tool under development

Jointly with EDF a design optimization tool is under development in our research center. The simulation tool enables generic simulation of the whole power plant (fig. 2) by chaining:

- *the optical model:*

Based on integral Monte Carlo method. A rendering tool is used to accelerate the calculation. Optimization study can be done.

- *the thermal and thermodynamic model:*

An analytical model is implemented in the software Thermoptim. A specific model is used for the receiver which converts radiative energy into thermal energy to evacuate it towards the thermodynamic cycle.

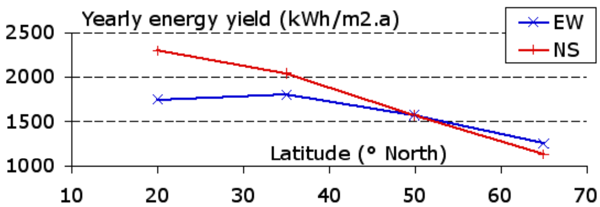

Figure 3. Effect of orientation for different latitudes

Introduction

Linear Fresnel Reflector (LFR) based concentrator is a promising alternative to parabolic trough. Simplicity and robustness of LFR enable lower costs. Compactness leads to better land use which compensate LFR lower efficiency.

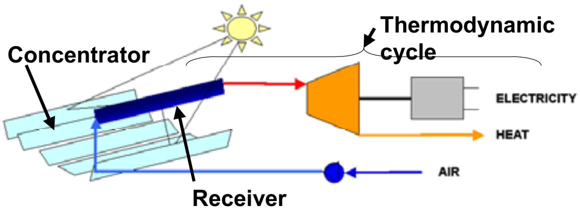

Figure 2. Principle of the LFR power plant

Examples of results obtained with the model

- *Mirror axis orientation depending on latitude*

The mirror axis orientation impacts the system performance differently depending on the latitude. It is shown the best orientation is North-South up to around 50°N. So except for specific climate conditions and demand profile the concentrator will be oriented North-South. (Figure 3)

- *Investigation of different receiver design*

The receiver is a key element of the process. Its design must be looked at in details to achieve high system efficiency. For a given concentrating system and an optimized thermodynamic cycle different receiver concepts are compared. (Figure 4, Table 1)

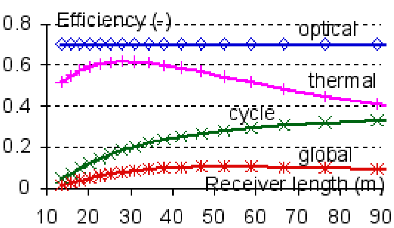

Figure 4. Efficiency of the system

	1 tube, 200 mm	2 tubes in parallel, 100 mm	3 tubes, 66	1 tube, 141 mm
Optimal length (m)	51	37	32	52
Global efficiency (%)	9.6	10.8	10.2	10.7
Heat exchange coef. (W/m^2K)	36	71	107	67
Absorber temperature (°C)	641	570	538	571
Receiver head loss (Pa)	0.00413	0.02368	0.06945	0.02384

A solar particle receiver for small gas turbine systems

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Almost one quarter of the world population is still without power. Especially in third world regions without connection to a central grid, but with high insolation levels decentralized small-scale CSP systems (100kW_{el} – 1MW_{el}) are a promising way for sustainable power generation. Therefore, a new solar particle receiver for the small-scale application will be developed and optimized with regard to high efficiency, high durability and low cost. The inherent feature of storage is an important advantage against wind and PV technologies, providing dispatchable power.

In combination with a small gas turbine the concept of a rotary kiln particle receiver is preferred where the particles are circulated and gradually heated up caused by the kiln rotation. Advantages of this receiver design are high working temperatures (up to 1000°C) due to direct absorption of solar radiation by particles, a pressure-less storage of the hot particles in insulated tanks and a relative simple receiver design leading to low investment costs.

Analytical calculations and numerical simulations based on the Discrete Element Method (DEM) are used in order to investigate particle motion in the rotating kiln. Parameters, like kiln speed, inclination and hold-up as well as different internal geometries are varied to find the ideal configuration for an equally distributed particle curtain across the kiln. In addition, an experimental set-up is designed with a kiln geometry of approx. 0.5m diameter and 1.1m length for verification and validation of the analytical and numerical results. For the feasibility proof of the preferred receiver concept “hot tests” are conducted by heating up 1mm particles with two 10 kW_{el} radiators. Accurate measuring methods have to be implemented in order to determine the temperature distribution within the drum as well as the particles’ outlet temperature. One of the main goals in the experimental study is to heat the particles up to 1000°C.

Modeling a Solid Particle Receiver

Birgit Gobereit
DLR Institute of Technical Thermodynamics, Stuttgart, Germany

Ceramic particles as heat carrier medium have the following advantages:
- High working temperatures possible.
- Direct absorption of the solar radiation.
- Can be used as storage material.

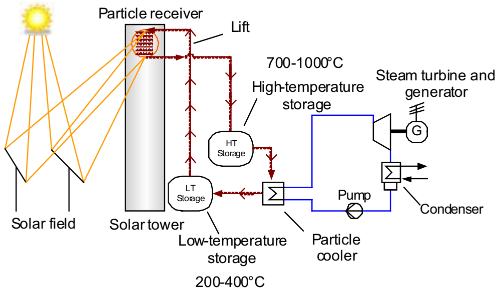

Figure 1: Power plant with solid particle receiver and storage.

Models for receiver layout and optimization are developed with a commercial CFD Code (CFX).

Modeling the wind impact is important to estimate convective losses and dislocation of particles.
First model parameters and assumptions:
- Cylindrical cavity 2 m height, 3 m diameter.
- 3 MWth design power.
- Atmospheric, open cavity with face down aperture, 2 m diameter.
- Cavity and surrounding are modeled as air without particles.
- Cavity walls at constant temperature, T=1050 K

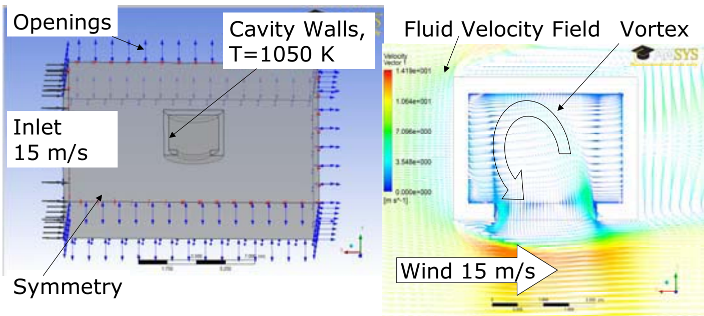

Figure 2: CFD model for assessment of convective losses and wind impact, model (left) and results (right).

To assess the **particle movement** an Euler-Lagrange model is used:
- Fluid modeled as continuous phase.
- Particles as dispersed phase.
- Two-way coupled.
- Governing equations are solved for a representative number of particles.
- Particle velocity is determined by gravity and drag force.

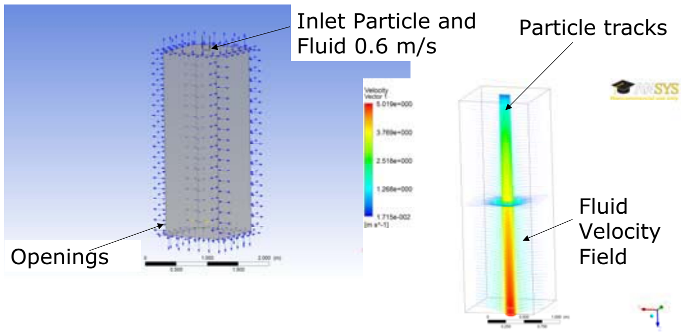

Figure 3: Free falling particle curtain modeled with CFD, model (left) and results (right).

Results
- Between 2.5 % and 6.5% convective losses at 5 m/s to 15 m/s wind speed.
- 2.5 m/s maximum horizontal air speed in the cavity at 15 m/s wind speed.
- Good agreement between numerical and available experimental data for cold particle flow.

Next steps
- Reduction of convection losses by advanced designs.
- Investigation of interaction between horizontal air flow and falling particle curtain.
- Further validation for cold flow calculations.
- Assessment of hot particle flow and heat transfer.
- Implementation of solar radiation.

Outdoor characterization and performance evaluation of CPV mini-modules

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This work presents an experimental procedure for characterizing CPV mini-modules based on Fresnel lenses. The main originality is that most measurements were performed in real sunlight conditions: either the complete module or only its optical components had to be mounted on the tracker in operation, and then were characterized outdoor.

Results of measurements performed for assessing the very first version of a future commercial module developed by the French company Integra-Sun are presented to illustrate our procedure. The prototype mini-module which was characterized used a point focus PMMA Fresnel lens to concentrate solar radiation onto a GaInP/GaInAs/Ge commercial solar cell (provided by Emcore). The module has been designed to operate at ≈ 570 suns. A secondary optical element made of BK7 was used for homogenizing the concentrated light flux received by the cell, which was mounted on a ceramic receiver fixed on a copper back plate serving as a heat sink. The secondary optics and the cell mounted on its receiver are precisely assembled and placed in the module plastic envelop. The passive cooling system used to dissipate the non-converted fraction of the solar energy received by the cell is based on a heat pipe transporting the heat from the Cu plate to a series of aluminum fins where it is removed by natural convection to ambient air. Under typical operating conditions, that is, for a direct normal irradiation (DNI) of 1,000 W/m^2, the heat flux to remove from the module is around 45W.

A 2-axis tracker with 0.1° accuracy was used for performing the outdoor characterizations. DNI was measured by using a pyrheliometer in order to estimate the energy flux received on the lens surface. Intensity vs voltage measurements were recorded by means of an electronic load, in order to estimate the power at maximum powerpoint and then calculate the maximum conversion efficiency of the module. The acceptance angle of the system was also simply derived by measuring the short circuit current delivered by the cell vs time while stopping the tracker, and calculating the sun position at time t.

The optical efficiency and quality of the lens were assessed as follows: CCD images of the concentrated beam focused on a Lambertian (opal) diffuser placed in the focal area were first recorded in order to get the light distribution function of the concentrated beam produced by the lens (mounted on the tracker in operation, with solar cell and secondary optics removed); second, the transmitted power was measured by means of a powermeter, whose sensor was fixed at the focus of the lens; third, from the DNI measurements, the overall optical efficiency of the lens was calculated; and fourth, the lens transmission spectrum was obtained by using a spectroradiometer for recording the spectrum of the sunlight in front (DNI spectrum) and just behind the lens.

Finally, the efficiency of the heat-pipe cooling device was assessed separately, by exposing the heat sink mounted on the heat-pipe to increasing solar flux intensity.

Part of this work has been presented as the last CPV 6 Conference (Freiburg, April 2010)

Theoretical proof of concept of an optimal solar receiver to produce low-temperature (-40°c) cooling using a thermoacoustic tri-thermal machine

S. Cordillet[1]

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The innovative part of this project is to develop an industrial thermoacoustic refrigeration system driven by concentrated solar energy. The principle of this system is as follows. Solar radiation is collected by a parabolic dish and focused into a receiver in a cavity. This receiver heats a thermoacoustic prime mover to a sufficient temperature, thus generating a traveling wave with large acoustic power (1.2kW). This power is then used to pump heat into a thermoacoustic refrigerator. The direct conversion between solar energy and mechanical energy without any moving component makes the process simple and reliable. Moreover, the working fluid that is used to develop the acoustic motion is usually a noble gas with no environment hazard. Such a thermoacoustic system is an alternative to systems based on absorption or adsorption cycles in the solar thermal field. One advantage is that it can easily reach a large range of low temperature compared to existing thermal systems: from ambient to cryogenic levels.

It was considered that 1.2 kW of cooling power - considering targeted performances for both the thermoacoustic prime-mover and heat pump of 40% of the ideal Carnot's efficiency - was a challengeable proof of concept. To obtain such a cooling power at the design temperature of -40°C, the modulator has to transmit between 8 and 12 kW to the receiver out of the experimental 50 kW parabolic dish intended for the subsequent experiment. The receiver consists in a hot heat exchanger placed in a cavity that surrounds the focused image of the sun. The gas which circulates in the hot heat-exchanger tubes has to absorb a power of about 4.4 kW at a temperature of 1000 K. Such a high temperature is necessary to obtain large efficiency of the thermoacoustic prime-mover.

Since acoustic waves are very sensitive to external perturbations (e.g., spatial or temporal changes in the temperature of the hot heat exchanger), the goal of this study is to investigate ways to maintain as constant as possible both this temperature and the power transferred to the gas, despite natural variations in the solar flux. The main difficulty here is to design the hot heat exchanger so that its temperature distribution remains spatially homogenous even though the focal image of the sun has a Gaussian shape, and therefore does not irradiate the exchanger's top surface symmetrically. The solar receiver's purpose is thus to allow an efficient energy transfer from the solar concentrator to the working gas. A detailed theoretical study is necessary to optimize the prototype's dimensions. In particular, it is necessary to characterize the thermal behavior of the solar receiver by modeling the heat transfer processes around it, i.e., from the cavity to the hot heat exchanger.

Optimizing operation of an open volumetric air receiver

Nils Ahlbrink[1], Robert Pitz-Paal[1]

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In the field of solar thermal power towers, systems using an open volumetric air receiver are a promising option for a renewable electricity generation. The technology uses ambient air to be heated up in the absorbing structure of the receiver [1, 2]. The resulting hot air stream is utilized in a regular steam generator or a storage system. During operation, the receiver outlet temperature is set by demands of the consumers, storage system and steam generator respectively. The power block for example needs a specific step wise increasing air temperature during start up procedure and a constant process temperature during regular operation.

The receiver outlet temperature is adjusted by controlling the overall mass flow rate of the receiver. Internal, the receiver performance can be manipulated by aim point control of the heliostat field and by mass flow rate distribution control. The first option adjusts the aim points of the heliostats to create a desired flux density distribution. As the receiver is normally equipped with subreceivers having controllable air flaps, the second option influences the mass flow rate distribution of the subreceivers.

In this contribution, a method is presented, which optimizes the overall mass flow rate of the receiver with demanded receiver outlet temperature by means of dynamic programming [3]. Dynamic programming is a powerful optimization method for decision making problems, where a complex problem can be split up into a sequence of simpler ones. It guaranteed delivers the optimal solution. Therefore, a model was developed in C++ for an absorber module as the smallest unit of a subreceiver and used in STRAL for the calculation of subreceiver performance and optimization [4].

The optimization will be applied as a part of a continuous, dynamic simulation of the receiver system [5]. It delivers the desired mass flow rates of the subreceiver control in a periodic application. The inputs of the optimization like air input temperatures, return air mass flow rates and temperatures are forwarded from the continuous simulation to the optimization model. STRAL calculates the flux density distribution and provides it for the continuous simulation as well as for the optimization. The optimization will be extended to aim point optimization in the next step.

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Experimental and Numerical Analyses of a Novel Pressurized Air Receiver for Concentrated Solar Power

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A novel design of a high-temperature pressurized solar air receiver is proposed for power generation via solar-driven combined cycles (SCC). It consists of an annular reticulate porous ceramic (RPC) bounded by two concentric cylinders. The inner cylinder, which serves as the solar absorber, has a cavity-type configuration and a small aperture for the access and efficient capture of concentrated solar radiation. A 3D compound parabolic concentrator (CPC) is incorporated at the aperture to boost the solar concentration ratio and, consequently, reduce the aperture size and re-radiation losses. Absorbed heat is transferred by combined conduction, radiation, and convection to the pressurized air flowing across the RPC. The governing steady-state mass, momentum and energy conservation equations are formulated and solved numerically by coupled CFD and Monte Carlo ray tracing techniques. Validation is accomplished with experimental results using a 1 kW solar receiver prototype subjected to a peak radiative flux of 4800 kW m^{-2} at PSI's High Flux Solar Simulator. Experimentation was carried out with air and helium as working fluids, heated from ambient temperature up to 1300 K at an absolute pressure of 5 bars. The validated model is then applied to optimize the receiver design and to analyze the thermal performance of 100 kW and 1 MW scaled-up versions. Key results include the temperature distribution and the thermal efficiency as a function of the geometrical and operational parameters.

Keywords: concentrated solar power; solar energy, pressurized receiver; cavity receiver; reticulate porous ceramic; Monte Carlo; radiation; conduction; convection; Fluent; CFD, combined cycle.

Thermal Dispersive Effects in Sintered Metal Foams

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The combustion chamber walls of gas turbines are exposed to a high heat flux. In order not to exceed critical temperatures of the materials used active cooling of the wall elements is applied. One effective cooling mechanism is effusion cooling where a cooling gas is driven through a porous wall into the combustion chamber. A finite element model of the wall elements is used to calculate the temperature distributions. In this model effective material properties are used which describe the thermophysical and fluid dynamic behavior of the porous wall. The work presented here focuses on the impact of the surface gas velocity on the effective material properties. Due to local variations of the gas velocity and a mixing of the gas along its path through the porous material the effective material properties depend on the gas velocity. This is known as thermal dispersion. A combined experimental and numerical approach is introduced which allows determining the dispersive contribution to the effective properties. In the experiment sintered metal foams are exposed to a defined heat flux while gas is driven through the foam. The temperature is recorded and compared to simulation results. By minimizing the difference between experimental results and the numerical simulation, the effective material properties are characterized.

Numerical and experimental study of a concentrated solar fluidized bed receiver

Germain Baud*, Jean-Jacques Bézian*, Gabriel Olalde**

* RAPSODEE, UMR-CNRS 2392, Ecole des Mines d'Albi - Carmaux, Albi, France.
**PROMES, UMR-CNRS 5213, Université Paul Sabatier, Toulouse, France.
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Over the last few years, there has been a rising interest for solar thermal power plant which appears to be a promising alternative to green electricity production. Most of them use water-steam cycles with working temperature around 500°C and annual efficiency around 15 and 20%. In order to increase the efficiency of solar tower stations (fig.1), and make a better use of the solar resource, there is a need to develop processes using gas turbines or combined cycles which efficiency can reach 30% when using hot source temperatures around 1000°C.

As a consequence, to improve the performance of thermodynamic cycles for solar electricity production, a technological gap will be the direct gas heating in solar receiver, to obtain at the entrance of the turbine temperature at a level higher than 800°C. One of the solutions to reach high temperature trough concentrated solar radiation would be to use solid particles directly irradiated in a fluidized bed (fig.2).

Fig 1. A Central Receiver Solar Power Plant in France

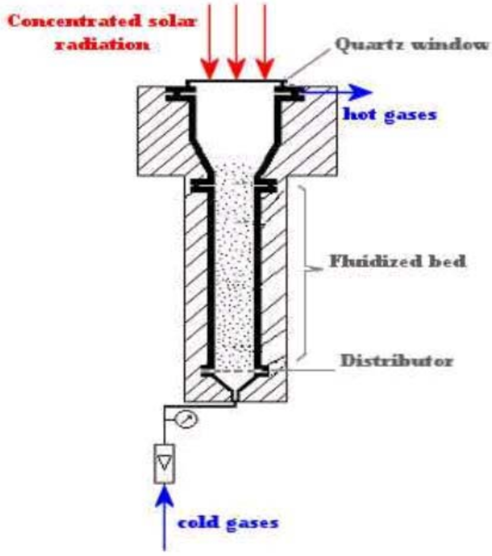


Fig 2. Schema of the fluidized bed receiver

My thesis deals with the experimental and numerical study of this solar receiver in the field of high temperature processes, in order to solve some technical issues and optimize its efficiency.

The good repartition of the incoming solar radiation into the fluidized bed appears to be crucial for the thermal efficiency of the receiver. To understand such mechanisms of radiative transfer, we use a 1D code based on the Monte Carlo Method. The next step will be to adapt the code to solve 3D cases.

At the same time, the numerical simulation of the multiphase flow and heat transfer in the fluidized bed solar receiver is under study, using an Eulerian model.

The numerical results will be compared to the experiment and used to design a new optimized prototype which will be tested in the focus of a 6kW solar furnace in France.

Simplified method for the geometrical optimization of solar thermochemical reactor. Application to real cases.

<u>Tescari S.</u>, Mazet N., Neveu P.

PROMES-CNRS Processes, Materials and Solar Energy

Perpignan, France

Objective: Pre-designing of high efficiency solar reactor. Application to the project "CO2fuel" for the production of solar fuel

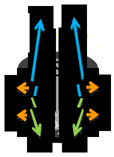
Volatile oxide (reactive surface). Reactor constituted by reactive material:

$ZnO \rightarrow Zn + 1/2\, O_2$

Hypotheses:

- **uniform temperature** on S_1
- isotropic radiation on S_0
- gray body material
- adiabatic external walls
- Arrhenius kinetics law

$$\varepsilon \cdot I_0 = (1 - F_{1-1} \cdot (1-\varepsilon)) \cdot k(T_1) \cdot S_1 \cdot \frac{\Delta H}{M_{ZnO}} + \varepsilon \cdot \sigma_B \cdot S_0 \cdot \left[\left(T_1^4 - T_{amb}^4\right) + \left(T_1^4 - T_2^4\right) \right]$$

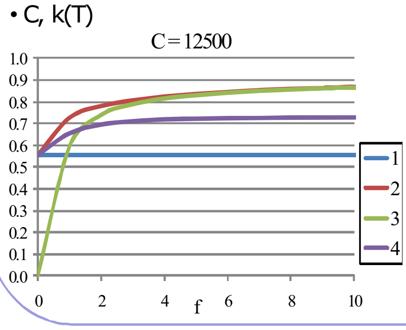


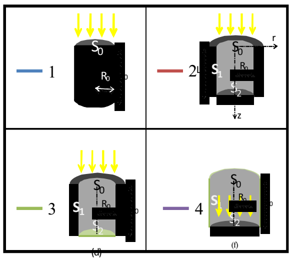
Operating parameters:

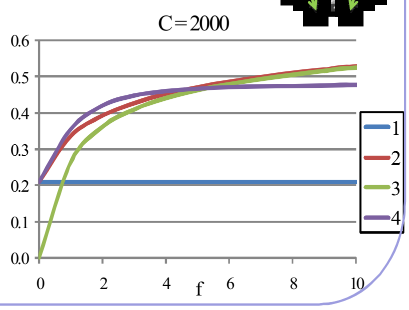
- C, k(T)

$$\eta = \left(k(T_1) \cdot S_1 \cdot \frac{\Delta H}{M_{ZnO}} \right) \Big/ I_0$$

$$f = L/R$$







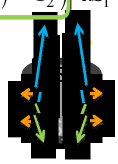
Non volatile oxide (reactive volume) fixed on a ceramic support:

$Fe_3O_4 \rightarrow 3FeO + 1/2\, O_2$ or $2CeO_2 \rightarrow CeO_3 + 1/2\, O_2$

Hypotheses:

- **non uniform temperature** on S_1
- isotropic radiation on S_0
- black body material
- adiabatic external walls
- radial conductivity

$$I_0 \cdot F_{0-1} = \sigma_q \cdot V_m + \sigma_B \cdot \int_0^L \left[F_{d1-0}(z) \cdot \left(T_{(R,z)}(z,\sigma_q)^4 - T_{amb}^4 \right) + F_{d1-2}(z) \cdot \left(T_{(R,z)}(z,\sigma_q)^4 - T_2^4 \right) \right] \cdot dS_1$$



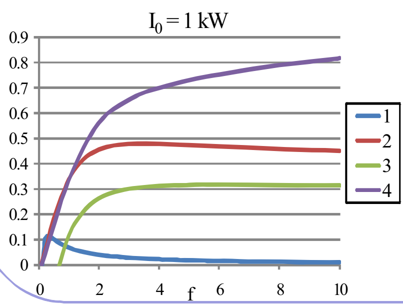
Operating parameters:

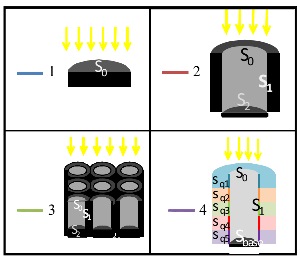
- I_0, V_m, ?, T_r

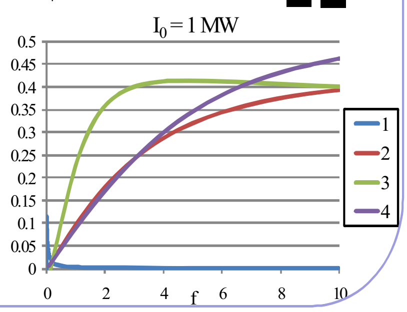
$$\eta = \left(\sigma_q \cdot V_m\right) / I_0$$

$$f = L/H$$

$$\varphi = R^2 / H^2$$







Durability of the receiver materials under high solar radiation fluxes

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To achieve a secure and sustainable energy supply, and considering the growing climate change concerns, the EU has taken on the role of Kyoto protocol promoter by setting out ambitious goals to reach a large share of renewable energy in the European market.

With this goal one of the most promising technology is the solar thermal tower technology due mainly to its high thermal conversion efficiency and its dispatchability of energy. Nevertheless this technology need to improve the reliability associated to one of the principal elements of this kind of solar plants; the receiver. The receiver must be able to transfer the maximum power coming from the solar field to the heat transfer fluid (HTF) with the minimal thermal losses along operating life of a commercial plant (30 years).The durability of receiver materials that work under severed conditions, high temperature, pressure and high radiation flux has a notably relevance in commercial plants performance.

The main objective of the work to be developed at the PSA will be to analyses de influence of high solar flux in the durability of materials and to develop testing for accelerating aging and comparative durability prediction for selected materials.

A lab-scale solar reactor for thermal dissociation of compressed ZNO and SNO$_2$ powders as part of 2-step thermochemical cycles

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The high-temperature thermal dissociation reaction of ZnO and SnO_2 was investigated, as part of a 2-step thermochemical cycle for H_2 production. Two-step thermochemical cycles (TC) have the potential for high solar-to-hydrogen energy conversions and should be more efficient than water electrolysis from solar thermal electricity (25% for solar-to-electricity efficiency and 80% for electrolysis efficiency). They consist of redox reactions based on metal oxide redox pairs, enabling separate production of hydrogen and oxygen from water as follows:

High-temperature reduction (solar): $M_xO_y \rightarrow M_xO_{y-1} + ½\, O_2$ (endothermal) (1)

Low-temperature water-splitting: $M_xO_{y-1} + H_2O \rightarrow M_xO_y + H_2$ (exothermal) (2)

Previous studies showed that ZnO is a promising candidate oxide owing to its relatively low reduction temperature (below 2200K). In addition, large amounts of H_2 can be obtained from the produced Zn (equivalent to a 3 wt% H_2 storage) and rapid kinetics for the water-splitting step was observed (Zn hydrolysis below 700K). A similar TC based on SnO_2/SnO redox pair was also demonstrated. A lab-scale rotary cavity-type reactor (1 kW) was previously developed for continuous solar thermal dissociation of volatile oxides under reduced pressure. This reactor, however, entailed several issues such as (1) the lack of measurements because the cavity rotation prevents the use of thermocouples and the induced air leakages at the sealing make the O_2 monitoring difficult; (2) the low recovery yield of reduced species at the filter (max. 21%) due to the long path between the reactor cavity output and the filter promoting deposition on the walls; and (3) the low efficiency because of heat losses (mostly at the front face and water-cooled reactor walls). The first issue makes this reactor irrelevant for detailed characterization, while the other complicate subsequent powder characterizations and reactivity tests due to scarcely available solar-produced powder.

The goal of this study was to design and qualify a novel and more efficient solar reactor suitable for the ZnO/Zn and SnO_2/SnO TCs. First, the study on this new reactor aimed at collecting more data (temperature and O_2 concentration measurements) for ZnO and SnO_2 dissociations to determine the chemical and thermochemical performances. In addition, there was a need for significant and representative amounts of reduced species (solar-produced Zn and SnO) produced reproducibly for hydrolysis tests and morphological characterizations. Numerical simulations were also performed to quantify the main energy losses and the thermochemical efficiency of the solar reactor.

Development of an integrated dynamic system model of a 1 MW solar hydrogen generation unit within the project HYDROSOL 3D

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In the European project HYDROSOL a thermo-chemical process for solar hydrogen generation from water has been developed. In the most recent project phase, a 100 kW_{th} pilot reactor has evolved from the research activities and hydrogen was produced on the PSA in numerous test runs.

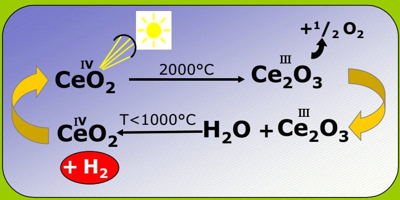
In January 2010, the next project phase called HYDROSOL 3D has started with the goal to design a 1 MW_{th} reactor. For an optimized reactor design, it is crucial to understand the dynamics of the process, because transient behavior is inherent to the HYDROSOL process. Thus, in the PhD work, a dynamic model of the integrated process is being developed. The aim of the model is to optimize different aspects such as heat recovery schemes, cycle times, control schemes and the reactor design itself. In addition to that, the influence of disturbances such as clouds can be analyzed in detail.

Further, the solar field layout will be designed and tuned to meet the special solar flux requirements of the HYDROSOL reactor. With in house DLR software, the annual solar flux distribution on the absorber can be calculated for any location and used as input data for the process model.

At the end of the PhD work, annual simulations will be carried out and sensitivity analyses will support the economic evaluation of the process.

Doped Ceria for solar Hydrogen production

Alex Le Gal, Stéphane Abanades, Gilles Flamant
PROcesses, Materials and Solar Energy laboratory (PROMES-CNRS)



Advantages → Direct solar energy conversion; No gas separation (two step)

Obstacles → Materials thermal stability; Materials reactivity during cycling

Too high reduction temperature

↓

partial sublimation = mass loss

↓

chemical efficiency decrease during cycling.

solution ⇒

Doping Ceria with a metallic cation

↓

Induce { **Structural defects**; **Oxygen vacancies** }

↓

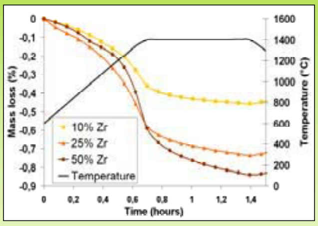
Enhanced O^{2-} difusion during the reduction step

=

Decrease of reduction temperature
Improved reduction yield

Zirconium doped Ceria

Influence of Zr quantity:



Start of reduction: 1050°C

↗Zr quantity
↗ reduction yield

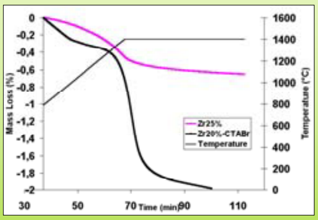
Thermogravimetric analysis of Zr-doped ceria

Influence of the synthesis method:

Template addition (CTABr) during synthesis gives smaller particles

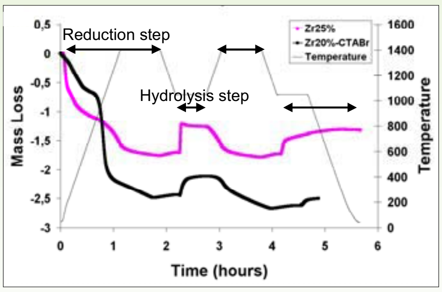
↓

Improvement of the reduction yield
17%→46%



Thermogravimetric analysis of Zr-doped ceria with and without template

Cycling experiment



Thermogravimetric analysis of Zr-doped ceria with and without template during cycling experiment

CTABr Zr-doped ceria (*black*) ⇒ Strong reactivity decrease; Sintering phenomena

25%Zr-doped ceria (*pink*) ⇒ **Good cyclability**
No sintering
313 µmol H_2/g (1^{st} cycle)
300 µmol H_2/g (2^{nd} cycle)

Solar Steam Reforming of Methane using Molten Salts as Heat Carrier

Isabelle Labach
ENEA – Cassacia Research Center, Rome

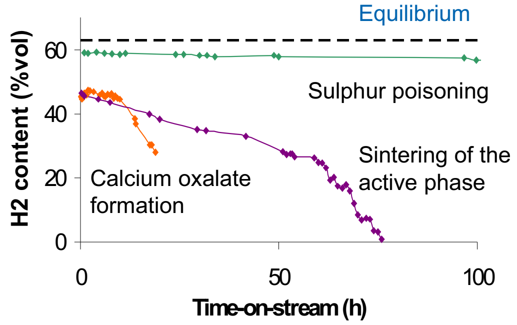


Figure 1: Reforming of methane on different Ni/Al_2O_3 commercial catalysts at 500°C,1 atm, S/C = 3, GHSV = 5700h^{-1}

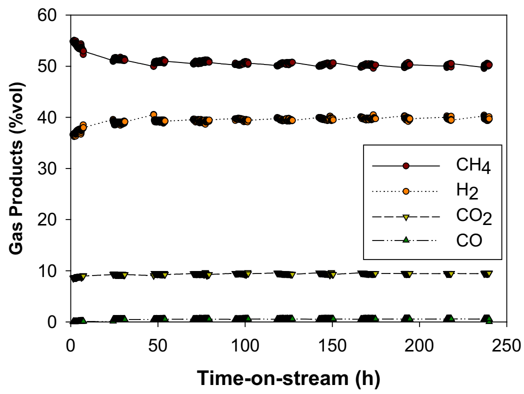


Figure 2: Stable Ni/Al_2O_3 catalyst S/C=3, T=500°C, GHSV = 32 000 h^{-1}

The exploitation of concentrated solar energy as external heat source for the Steam Methane Reforming (SMR) process for hydrogen production is here presented. The aim of this project is to use a molten salts mixture at 550°C as storage medium and heat transfer fluid to power a heat exchanger reformer. The first issue to be investigated is dealing with the identification of stable and active catalysts for low temperature SMR.

Bench testing of reforming catalysts is carried out in a fixed-bed reactor under atmospheric pressure at about 500°C. To date, commercial alumina-supported Ni-based and home-made CeO_2-ZrO_2-alumina-supported Ni-based catalysts have been evaluated. Even though carbon formation is a major problem in the SMR process, so far the catalysts deactivated for different causes (Figure 1). In particular, one containing CaO in its support to prevent coking, was fouled because of the formation of a calcium oxalate on its surface.

However several catalysts were successfully tested during 250h and showed good activity and stability (Figure 2). The low CO content in the outlet gas confirms that the Water-Gas-Shift is effective in the reactor. This has a positive effect on the reformer heat demand and will allow more compact and costless equipments.

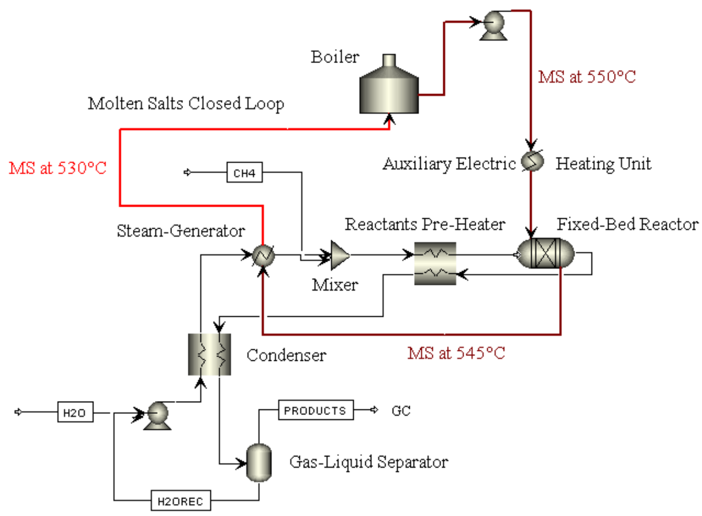
Thus the following global reaction takes place :

$$CH_4 + 2H_2O \longrightarrow 4H_2 + CO_2$$

Future work in catalyst screening will focus on monoliths in order to minimize heat transfer resitances which limit rates in packed bed.

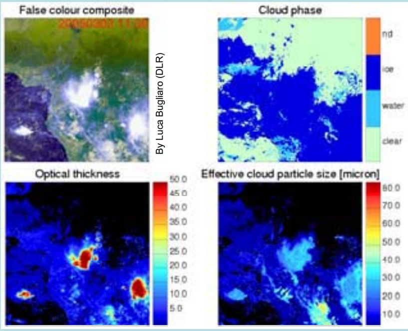
We are now proceeding with a kinetic study in order to design a prototype with a capacity of 5 Nm^3/h of hydrogen. The molten salts closed loop facility available at ENEA-Casaccia will provide heat to the reformer as well as the steam-generator which represents 2/3 of the process global heat duty. Also the possibility to integrate the reformer with a hydrogen-selective membrane will be finally assessed.

Figure 3: Flowsheet of 5Nm^3/h prototype



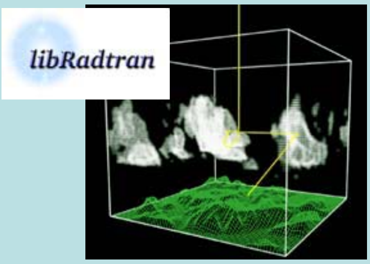
Derivation of Sun Shape from Space

Bernhard Reinhardt
DLR, Institute of Atmospheric Physics, Oberpfaffenhofen



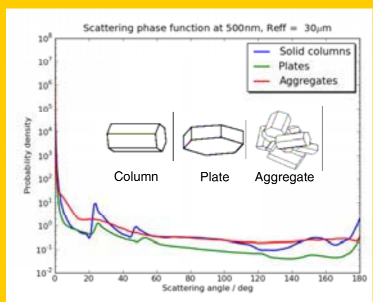
Retrieval of cloud type, optical thickness and effective radii from MSG observations using lookup tables built with forward radiative transfer simulations.

The SEVIRI instruments [2] aboard the geostationary satellites MSG-8 & MSG-9 allow a retrieval of optical cloud properties every 5min for Europe and every 15min for the full disc

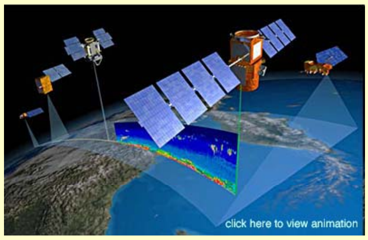


MYSTIC: Accurate Monte Carlo 3D radiative transfer simulations by tracing photons through the cloudy atmosphere. [1]

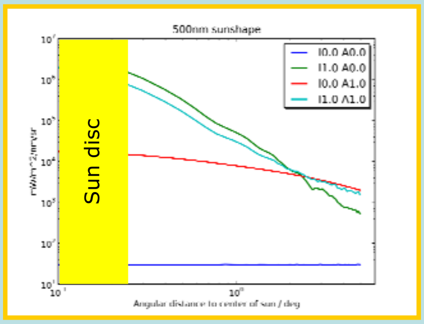
Development of fast retrieval



The sun shape is strongly influenced by single scattering on large particles which have a strong forward peak in the scattering phase function. Thus, an accurate treatment of the phase function is necessary! [3]



Aerosol optical depth (AOD) and ice crystal shape may be derived on daily basis from the polar orbiting satellites of the A-TRAIN



Simulated diffuse radiance (sun shape) for cirrus clouds (I) and typical desert aerosol (A) at various optical depths for a sun zenith angle of 0°.

Validation against ground based measurements of sun shape (e.g. Visidyne SAM or AERONET)

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SOLAB
ALLIANCE of EUROPEAN LABORATORIES on solar thermal concentrating systems
6th Sollab Doctoral Colloquium on Solar Concentrating Technologies
7th - 9th of June 2010
PROMES Odeillo, France
DLR Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

Effect of Circumsolar Radiation on Focusing Collectors: Determination of the Usable DNI from Common DNI Measurements

Stefan Wilbert
DLR, Institute of Technical Thermodynamics, Solar Research, Tabernas/Almería

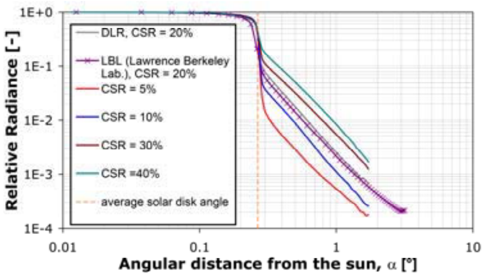

Fig. 1: Averages of measured radiance profiles (sunshapes) for two different instruments and various CSR (ratio of circumsolar irradiance to the sum of circumsolar and disk irradiance) [1], [2].

Due to forward scattering of direct sunlight by aerosol and cloud particles a considerable amount of irradiance is contained in the circumsolar region close to the solar disk (Fig. 1).
Circumsolar radiation is nearly completely detected by pyrheliometers, but only partially reflected to the receiver by focusing collectors (Fig. 2). Hence the usable Direct Normal Irradiance (DNI) is systematically overestimated depending on the collector type.
A model will be developed to determine the sunshape und thus the usable DNI from common DNI measurements and other anyway available data. As a basis for this, new sunshape measurements with parallel measurements of the sky conditions are necessary. Aerosol properties will be monitored with a sun photometer (Fig. 3). Information about thin clouds will be extracted from the sunshape measurements themselves or from satellite data.

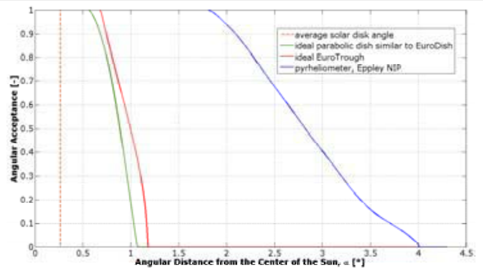

Fig. 2: Angular acceptance functions f vs. α calculated according to [3], [4]. f is the fraction of parallel rays incident on the aperture at an angle α which reaches the sensor/receiver.

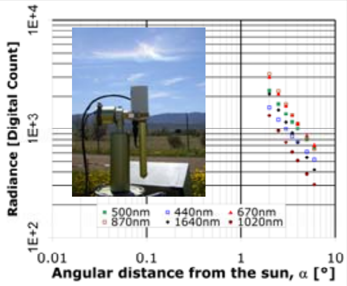

Fig. 3: CIMEL CE318N-EBS9 sun photometer and central values of a principal plane measurement.

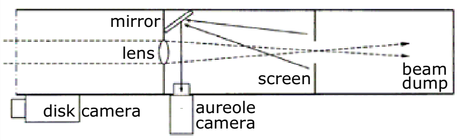

Fig. 4: Schematic diagram of the SAM (sun and aureole measurement) instrument [5].

The commercially available SAM instrument (Fig.4) was designed for the investigation of cloud properties. A detailed analysis showed that it can be used as a sunshape camera after manageable enhancements.
Spectral sunshapes deviate strongly from the broadband sunshape. Because of the inhomogeneous spectral response of CCD and CMOS sensors, spectral measurements and scaling of the spectral sunshapes are planned (Fig. 5).

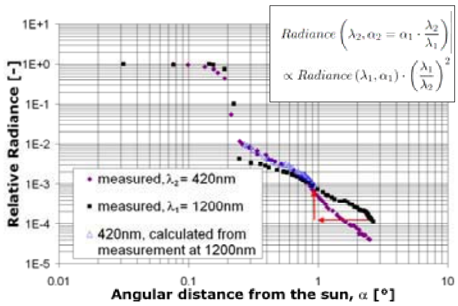

Fig. 5: Spectral sunshapes at two wavelengths measured by LBL and scaling between spectral sunshapes.

[1] Noring, J. et al. (1991). Circumsolar radiation data: The Lawrence Berkeley Laboratory reduced data base, Lawrence Berkeley Lab., USA.
[2] Neumann, A. et al. (1998). Measurements of circumsolar radiation at the Plataforma Solar (Spain) and at DLR (Germany), ASME.
[3] Bendt, P. et al. (1980). Determining The Optical Quality of Focusing Collectors without Laser Ray Tracing. JSE 102(2): 128-133.
[4] McArthur, L. J. B. (2005). Baseline Surface Radiation Network, Operations Manual Version 2.1. WCRP-121 WMO/TD-No. 1274, WCPR.
[5] DeVore, J. et al. (2009). Retrieving Properties of Thin Clouds From Solar Aureole Measurements, JAOT 26: 2531.

Development and evaluation of a two step thermochemical cycle

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DLR Institute of Technical Thermodynamics, Solar Research, Cologne

The aim of the doctoral thesis is the simulation of the thermo-chemical two-step water splitting process using redox systems directly generating hydrogen with a solar tower system. The simulation tool consists of three main parts, the simulation of the solar flux, the simulation of the temperatures in the reactor modules and the produced hydrogen. It can be used for the online process control and for the analysis of the operational behavior.
In this process firstly the redox system is in a reduced form while the concentrated solar energy hits the ceramic absorber. By adding water vapor at 800°C, oxygen is abstracted from the water molecules, bond in the redox system and hydrogen is produced. When the metal oxide system is completely oxidized it is heated up for regeneration at 1100-1200°C in an oxygen-lean atmosphere. Under those conditions oxygen is set free from the redox system again, so the metal oxide is now reduced again.
With the simulation tool it is possible to calculate the insolated power on the receiver module every minute (See figure 1). The heliostat configuration and the DNI data can be given to the tool either manually, or via OPC for an online simulation or as ASCII file for analysis. The position of the sun (azimuth and elevation) is calculated in the simulation tool.
In the next step the simulated power is used for the calculation of the temperatures in the reactor modules. The input data like mass flows can be fed to the tool like described above in the power simulation part. These temperatures are compared in figure 2 with the measured temperature (thermocouples) in the real system.
The third step (ongoing) is the implementation of a experimentally determined kinetic model of the redox reaction allowing the simulation of the produced hydrogen in the two reactor modules. Figure 3 represents a comparison of the hydrogen concentrations measured in a pilot-scale reactor over some cycles of a typical day and the calculated ones.

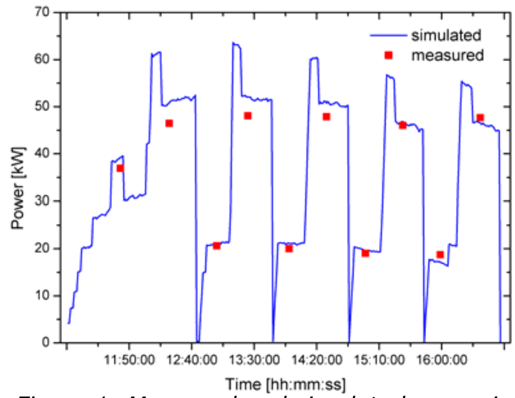

Figure 1: Measured and simulated power in one pilot-scale reactor module

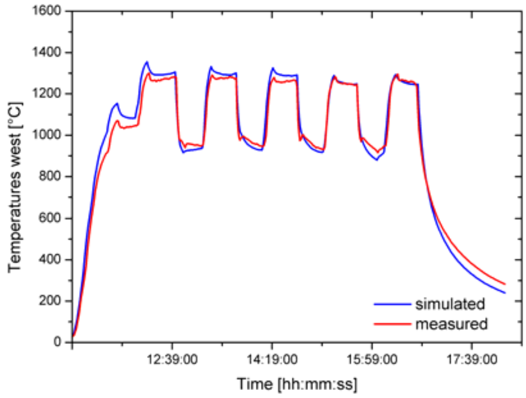

Figure 2: Measured and simulated temperature in one pilot-scale reactor module

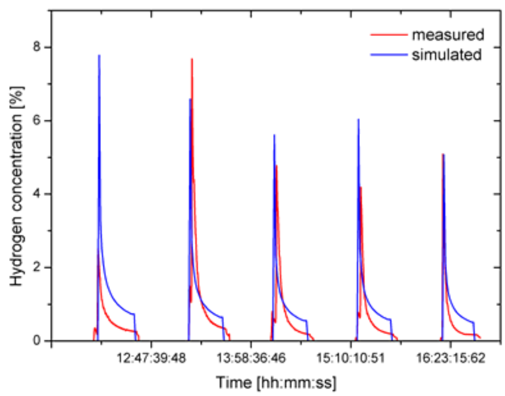

Figure 3: Measured and simulated hydrogen concentration in one reactor module

Modeling and Simulation of the Hybrid Sulfur Cycle

Nicolas Bayer Botero[1], Robert Pitz-Paal[1]

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Nicolas.Bayer-Botero_at_dlr.de

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 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 complete 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 and compared to other process layouts. The assessment of the energy requirements of the process is given and the distribution of heat sources and sinks across different process sections is shown. Potential for further optimizations of the concepts and obstacles are identified. The route to a complete process model including the solar energy source is pointed out.

Numerical and experimental study of a distributor configuration for uniform flow distribution in an elemental absorber of air solar receiver

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[2] Laboratoire Optimisation de la Conception et Ingénierie de l'Environnement, CNRS FRE3220, Université de Savoie, Campus Scientifique, Savoie Technolac, 73376, Le Bourget-Du-Lac cedex, France

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David.Bellard_at_promes.cnrs.fr

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 is focused on the air receiver where the compressed air is heated and directed downstream to the expander of the gas turbine. The operating conditions are: pressure of 8 bar, mass flow rate of 8 kg/s, and targeted temperature increase from 350°C to 750°C. In addition to these conditions, a critical specification is the pressure drop in the receiver. A maximum pressure drop of 300 mbar is targeted in order to save the good overall efficiency of the turbine. Therefore, the pressurized air solar receiver is a key component of the PEGASE project. The solar absorber technology is based on compact heat exchangers. The air stream is divided and distributed in a set of small pipes arranged in parallel. The solar radiation is absorbed onto a flat surface. The distribution system for the air has been carefully designed with the double objective of minimizing the pressure drop and offering a compact design.

A major point to minimize the pressure drop inside the exchanger is the configuration of the distributor and of the collector. A flat distribution of mass flow rate in the pipes is also targeted in order to control the heat transfer. A configuration allowing to homogenize the flow rate in each pipe while minimizing the pressure drop was determined using the constructal theory. CFD simulations show that the insertion of a perforated baffle in an arc type distributor yields a uniform flow distribution in the pipes with a little penalty on the pressure drop.

An experimental study is being processed using a "cold" model of the system. The size of the model is similar to the real size of an absorber module. The overall pressure drop and the pressure drops in the distribution and in each individual pipe are measured in a wide range of air mass flowrate. The objective is to validate the results of the simulations.

The MINI-PEGASE Project

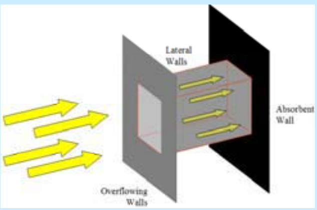
Benjamin Grange, Alain Ferrière

PROMES - Processes, Materials and Solar Energy laboratory , Font-Romeu

PEGASE Project

Production of **E**lectricity with **GA**s turbine and **S**olar **E**nergy

Solar Receiver Technology (Mini-Pegase, 360 kWth)



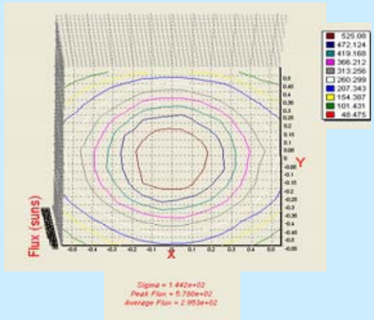
Scheme of the cavity

Targets

- Air outlet temperature 750 °C
- Air temperature increase +400 °C
- Pressure 8 bar
- Peak solar flux 600 kW/m²

Features

- Cavity
- Square shaped absorber (120 x 120 cm)
- Passive lateral walls
- Modular and multi-stages approach



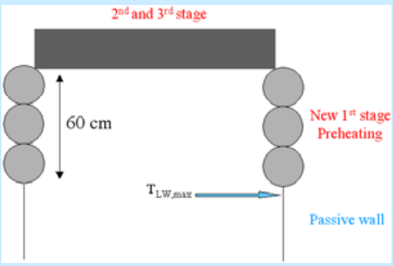
Example of flux density pattern estimated using the software SolTrace

Coupling optical/thermal analysis: estimation of air and metal temperature distributions

→ Use of a code relying on thermal exchange within the receiver
→ Thermal performances issued from experimental tests on mock-up → **h_{glob} = 1500 W/m².K**
→ Estimation of receiver efficiency

2 stages, h=1500 W/m².K				
$T_{outlet,air1}$ (°C)	$T_{outlet,air2}$ (°C)	$T_{abs,max}$	η_{en}	$T_{LW,max}$ (°C)
624	**732**	840	74.4 %	**794**

Results of the simulation for a receiver with two stages



Top view of the receiver : Addition of an extra stage

Optimisation of the receiver performances

3 stages, $D_{cylinder}$=20 cm, h=1500 W/m².K					
$T_{outlet,air1}$ (°C)	$T_{outlet,air2}$ (°C)	$T_{outlet,air3}$ (°C)	$T_{abs,max}$	η_{en}	$T_{LW,max}$ (°C)
392	653	**751**	861	78.2 %	**695**

Results of the simulation for a receiver with three stages

→ Desired air outlet temperature reached
→ Maximal temperature of the lateral wall acceptable
→ Additional pressure drop due to preheating : 3 mbar

Perspectives (2010-2011)

Expectations (2010/2011):

→ Measurement of the fluxes to validate the SolTtrace simulations
→ Aiming strategy study
→ Manufacturing of solar receiver (CEA/CNIM)
→ Installation at Themis tower (no turbine)
→ Experimental test of receiver

The once-through concept in direct steam generation power plants – An efficiency analysis

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Parabolic troughs are currently the most mature solar concentrating systems and power plants using synthetic oil as heat transfer fluid can be considered as commercial standard. Applying the direct steam generation (DSG) concept in parabolic troughs can offer further cost reductions without the environmental impacts of the oil.

So far, the favored operation mode of DSG is the recirculation mode, in which the solar field is divided into an evaporating and a superheating section. This concept will be applied in a first commercial plant currently under construction in Thailand. The alternative to this design is the once-through concept, whose whole solar field consists of identical parallel loops. This allows a solar field being as easy to scale up as an oil field.

During the thesis, different aspects of the once-through concept need to be analyzed and compared to the recirculation mode. These are investment, reliability, controllability, system complexity, operation and maintenance procedures as well as the overall system performance. The presentation will focus on the latter efficiency comparison of the two modes. Power plants with different live steam parameters have been designed for both modes. With their models certain operation points have been analyzed and yearly energy yield analyses have been performed. The presented results will give detailed reasons for the performance differences and show which potential the once-through concept may offer.

Concentrated Solar Thermoelectric Conversion

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[2]Solid State Chemistry, EMPA, 8600 Duebendorf, Switzerland
[3]Solar Technology Laboratory, Paul Scherrer Institute, 5232 Villigen PSI, Switzerland

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A heat transfer model that couples radiation/conduction/convection heat transfer with electrical potential distribution is developed for a thermoelectric converter (TEC) subjected to concentrated solar radiation. The 4-leg TEC module consists of two pairs of *p*-type $La_{1.98}Sr_{0.02}CuO_4$ and *n*-type $CaMn_{0.98}Nb_{0.02}O_3$ legs that are sandwiched between two ceramic Al_2O_3 hot/cold plates and connected electrically in series and thermally in parallel. The governing equations for heat transfer and electrical potential are formulated, discretized and solved numerically by applying the finite volume (FV) method. The model is validated in terms of experimentally measured temperatures and voltages/power using a set of TEC demonstrator modules, subjected to a peak radiative flux intensity of 300 suns. The heat transfer model is then applied to examine the effect of the geometrical parameters (e.g. length/width of legs) on the solar-to-electricity energy conversion efficiency.

A solar cavity-receiver packed with an array of thermoelectric converter (TEC) modules was designed, fabricated and experimentally tested at ETH's High-Flux Solar Simulator. The temperature distribution in the cavity, open-circuit voltage and power outputs are measured for different external loads and solar flux inputs.

Operation Strategies for STPPs

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DLR German Aerospace Center, Institute for Technical Thermodynamics,
Solar Research Division, Pfaffenwaldring 38-40, 70569 Stuttgart

Operators of Solar Thermal Power Plants (Figure 1) are acting as a profit orientated market participant. Thus, they are intending to maximize their daily net operational result under the actual boundary conditions of irradiation and market price (Figure 2).

Figures 3 shows the optimal storage decisions (charging/discharging) and Figure 4 the optimal bidding strategy for hour 22 depending on the states of storage and power block, respectively. Figure 5 provides a more detailed view of the robustness of the optimal decision for a storage load of 50 %.

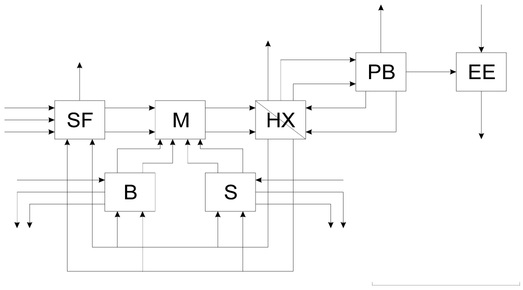


Figure 1: Abstraction of a STPP

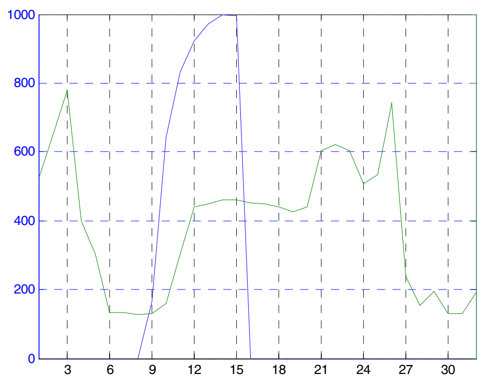


Figure 2: Boundary Conditions

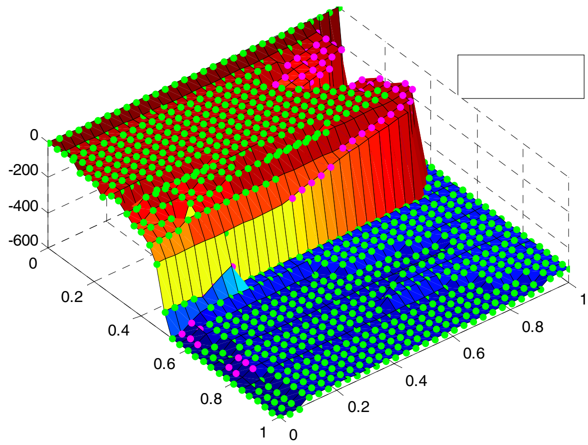


Figure 3: Optimal mass flow of TES pumps at hour 22

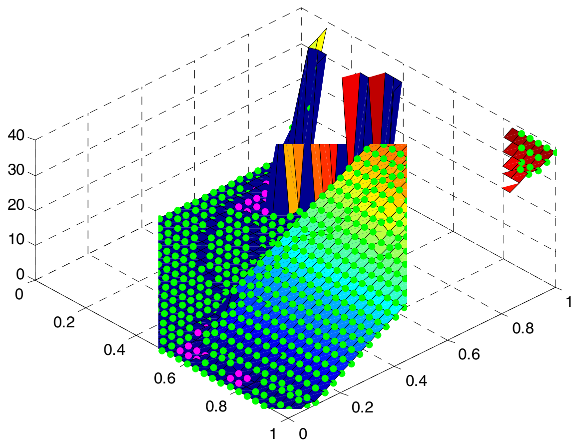


Figure 4: Bidding policy at hour 22

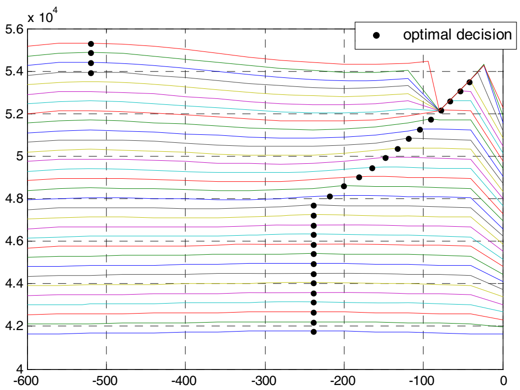


Figure 5: Robustness of optimum for TES state of 50% at hour 22

6th Sollab Doctoral Colloquium on Solar Concentrating Technologies
7th - 9th of June 2010
PROMES Odeillo, France

SOLLAB – ALLIANCE of EUROPEAN LABORATORIES on solar thermal concentrating systems

PROMES – Cemhti – CNRS – ANR – UPVD – EUROPLASMA

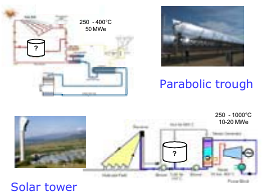
Thermal storage material tested under concentrated solar flux.

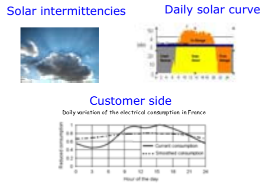
Antoine Meffre*1, Xavier Py[1], Régis Olivès[1], Nicolas Calvet[1], Emmmanuel Guillot[1]

1: PROMES, PROcesses Materials and Solar Energy laboratory, UPR CNRS 8521, UPVD, University of Perpignan, Rambla de la Thermodynamique, Tecnosud, 66100 Perpignan Cedex, France.

* Phd student, antoine.meffre_at_promes.cnrs.fr, +33 (0)4 68 68 22 38

Thermodynamic solar power plants need storage





Consequences : *Storage for protection (~ 0.5h)*

Storage for production (~ 7h)

Conventional approaches

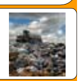
Need in new thermal storage materials for CSP

IAE symposium, Bad tölz, june 2008.

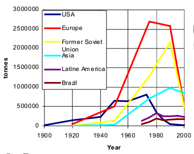
- **(1) Low cost, industrial availability**
- **(2) Low contents in E and CO_2**
- **(3) High acceptability (green process)**
- **(4) Stable up to ~ 1000°C**
- **(5) Life time expectancy ~ 30 years**
- **(6) Storage capacity (~ 1.5 to 3 MJ/(m³ K))**
- **(7) Easy implementation**
- **(8) Easy heat transfer and HTF compatibility**

The approach :

- Millions of tonnes of industrial wastes available
- Some treated at high T
- Should lead to low cost materials and sustainable TES



Extraction and inertization of ACW (Abestos Containing Waste)



In France : Production of ACW of 250.000 tonnes per year

In the world : 174 millions tonnes of Asbestos used during the XXth century

Selected storage material: COFALIT®

1400°C No more fiber = Inert product

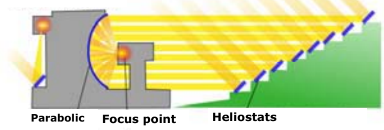
Comparisons with other available materials

Thermal storage materials	Limit Temperatures (°C)		? (kg/m³)	? (W/m.K)	Cp (kJ/kg.K)	?.Cp.?T (kWh_T/m^3) for ?T=100°C	prix/kg (€/kg)	prix/kWh_T (€/kWh_T) for ?T=100°C
	Cold	Hot						
Molten salts	265	565	1870	0.52	1.6	83	0.625	14.06
Castable ceramic	_	1200	3500	1.35	0.866	84	4.5	187.07
High temperature concrete	_	400	2750	1	0.916	70	0.08	3.14
Cofalit®	_	1200	3120	2 - 1.5	0.9	78	0.008	0.32

- **High potential working ?$T_{COFALIT®}$**
- **Thermal shock resistance measurement**

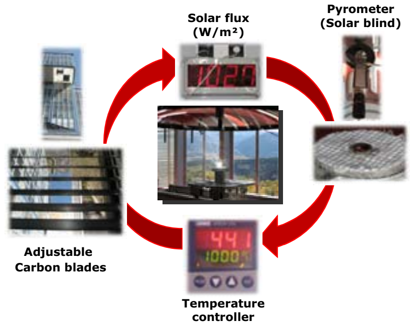
Solar oven

1.5 kW< P < 1 MW

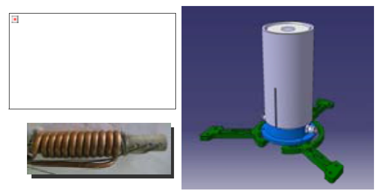


- **15mm < Øfocus point < 800 mm**
- **Concentrating factor < 10 000 suns »**
- **200°C < T °C < 3400 °C**
- **Fast temperature change**
- **Free and renewable energy**

Thermal shocks resistance tests under concentrated solar beam



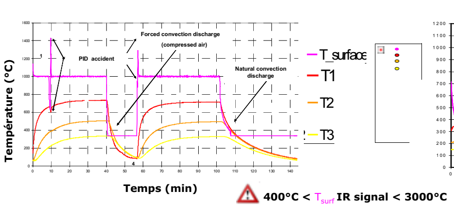
Prototype



- **Cofalit® sample (L = 200 mm, D= 25 mm)**
- **5 Thermocouples**
- **Copper heat exchanger**
- **Heat insulation with mineral wool**
- **Metallic envelope**

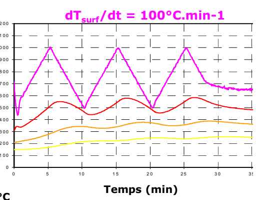
Experimental Results

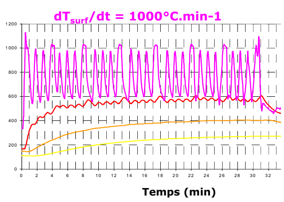
Amplitude thermal shocks 60 °C < T_{surf} < 1000°C

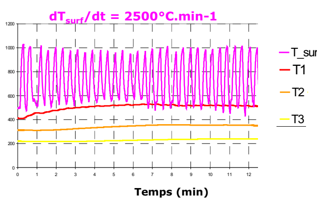


400°C < T_{surf} IR signal < 3000°C

Tests of fatigue under repeated thermal stress 600< Tsurf <1000°C







Conclusions

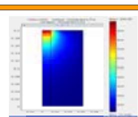
- Approach toward « Sustainable energy storage ».
- Very high storage capacity and very low €/kWh_t
- A unique storage material for the whole T range.

- Good surface thermal shock resistance
  Tmax = 1450° C
  30 cycles (?T= 500°C) in 12 min
  13 cycles (?T= 700°C) in 10 min

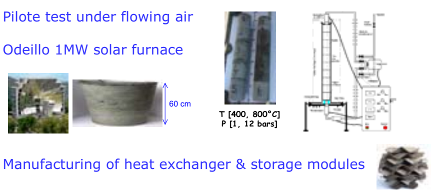
- Stable thermophysical properties

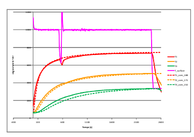
Perspectives

- Thermophysical properties identification by Comsol modelisation



- Pilote test under flowing air
- Odeillo 1MW solar furnace





- Manufacturing of heat exchanger & storage modules

ALLIANCE of EUROPEAN LABORATORIES on solar thermal concentrating systems
Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

Assessment of a novel direct absorption receiver for solar towers and USC steam cycles

Csaba Singer
DLR, Institute of Technical Thermodynamics, Stuttgart

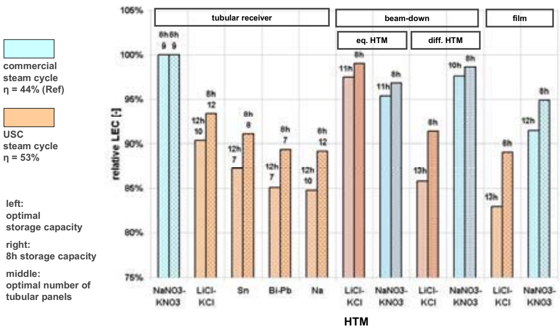


Figure 1: Comparison of the cost reduction potential of various solar receiver concepts.

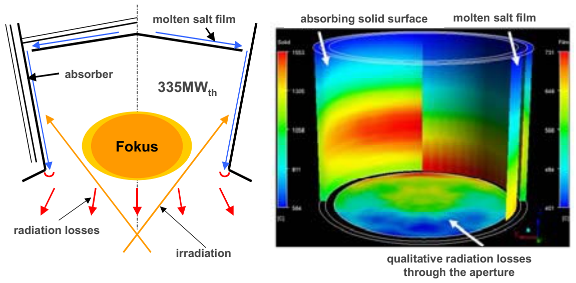


Figure 2: Internal film receiver concept for direct absorption (left), raw discretised CFD simulation for the design point (right)

Recent research concerning the cost reduction potential of possible high temperature receiver concepts for solar tower applications feeding USC steam cycles indicate a possible LEC reduction of up to 17% compared to today's state of the art solar salt receiver concept. The compared concepts comprise tubular receivers with different HTM, beam down concepts and an innovative direct absorbing molten salt film receiver on top of the solar tower.

Figure 1 depicts this comparison, whereas a novel inner cylinder film receiver concept shows in spite of the needed very high tower the highest potential, because of its structural simplicity and thus lower costs, but also because of its better heliostat field and receiver performance. A sketch of this concept and the underlying CFD simulation for the annual performance assessment are shown in Figure 2.

For more detailed performance studies on liquid films a volume of fluid (VOF) simulation was carried out to compare simulation results with empirical correlations regarding the film thickness and the heat transfer coefficient. Figure 3 illustrates the accuracy of the simulations compared to the latest correlation developments. In Figure 4 further experimental intentions are sketched to obtain optical properties of the molten salt such as its refraction index and wavelength and temperature dependent extinction coefficient.

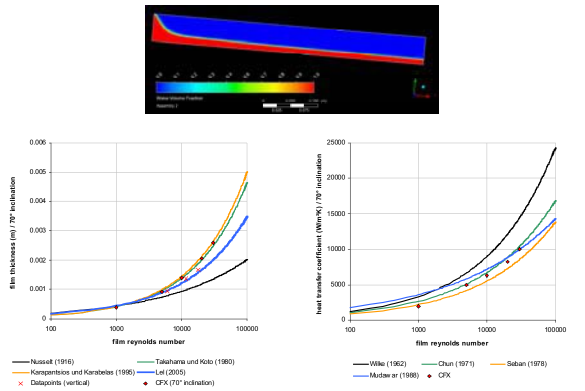


Figure 3: VOF model for film flow (top), comparison of thickness results with correlations (left), comparison of HTC results with correlations (right)

The refraction index of water could already be reproduced with an accuracy of 0.3% with the shown measuring device. Further experimental work will deal with the question of film breakdown and dry out. Based on this a detailed CFD simulation shall then help to answer questions concerning performance and cost reduction potential more in detail.

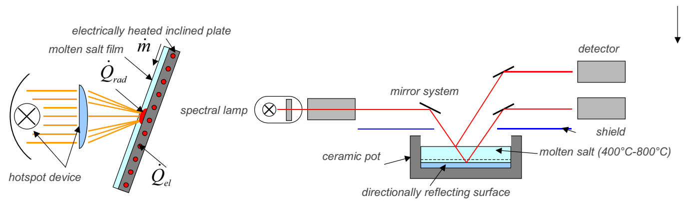


Figure 4: Sketch of experimental device for films under not isothermal conditions, film breakdown and dryout (left), Sketch of experimental devise for optical measurements (right)

High temperature heating of a gas by a pressurized receiver in ceramic

Xavier Daguenet-Frick
PROMES-CNRS laboratory

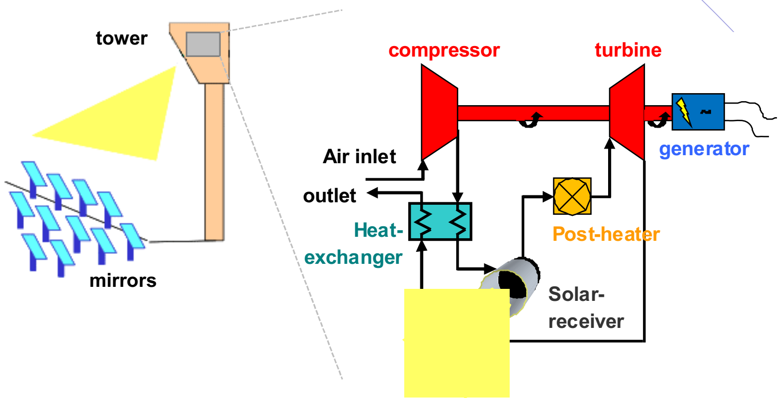


Figure 1: Brayton gaz cyle

Possibility to increase the efficiency of the solar power plants by choosing an effective thermodynamic cycle and the appropriated receiver

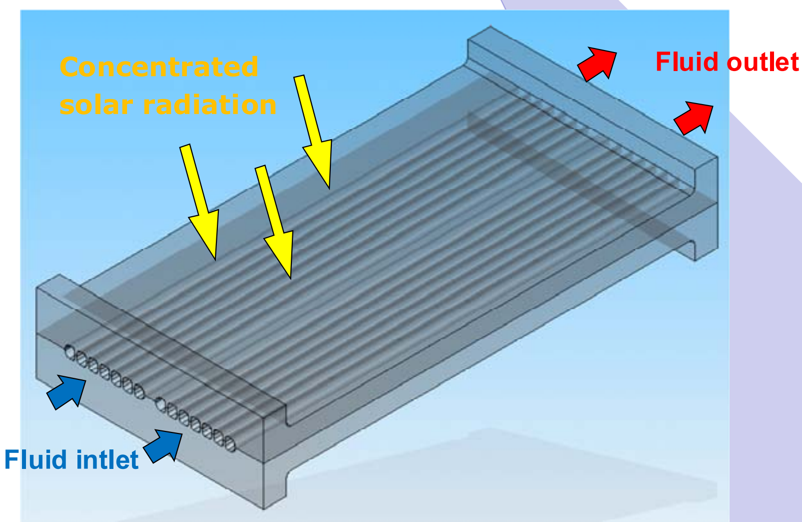


Figure 2: tridimensionnal view of a ceramic module constituting the receiver

Features of the receiver:

✓ Receiver without window
✓ Pressurized receiver: working pressure = 10 bar
✓ Receiver made of ceramic: Silicon carbide -SiC-

Aim of the study:

✓ to improve the internal geometry of the receiver in terms of pressure loss and heat transfer.
✓ to reach greater gas temperature than with a pressurized metal receiver.
✓ to evaluate the thermomechanical behaviour of the receiver under nominal working conditions.

6th Sollab Doctoral Colloquium on Solar Concentrating Technologies
7th - 9th of June 2010
PROMES Odeillo, France

Solar photocatalytic reactor experimental and modelisation results

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Introduction:

The intensive use of biorecalcitrant pollutants allowed to the development of new treatment technologies. Solar Heterogeneous Photocatalysis was a promising Advanced Oxydation Process studied since last decades. This technology is based on the coupling of solar UV irradiation an a semi conductor catalyst.

Objective:

The main objective of this work is to provide a dimensioning tools in the way to scale a solar pilot plant. (Fig 1)

Method:

First step: Laboratory pilot plant:

Modeling the TOC evolution for various conditions and catalyst forms (slurry (SC) and fixed TiO_2 (FC)) Fig 2

Second step: Solar pilot plant:

Simulation of a solar pilot plant operation using the parameters defined in the first step, and validation by the comparison with experimental results.(Fig 3)

Mathematical model:

Slurry catalyst:

$$\frac{dC}{dt} = -\alpha.\frac{S}{V_T}.\frac{I.C}{1+\beta.C}$$

α' = 0,372 β = 0,239

Fixed catalyst:

$$\frac{dC}{dt} = -\alpha'.\frac{S}{V_T}.I^n.C$$

n = 0,63 α' = 0,07

C: TOC concentration (mg.l^{-1})
α: coefficient (l.kJ^{-1})
α': coefficient (lm^{n+1}.kJ^{-n}.s^{n-1})
S: collectors area (m²)
- -Solar (1,4 m²)
- - Lab (0,025 m²)

I: irradiation (kJ.s^{-1}.m^{-2})
β: coefficient (l.mg-1)
VT: total volume to treat (l)
- -Solar (14 l)
- -Lab (1 l)

Experiments

Fig 1: Solar pilot plant (PROMES-CNRS France)

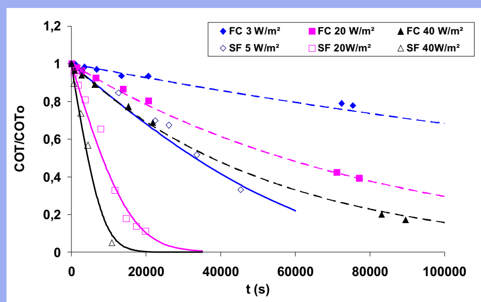

Fig 2: Exp (symbols) model : FC (disc) SC (cont)

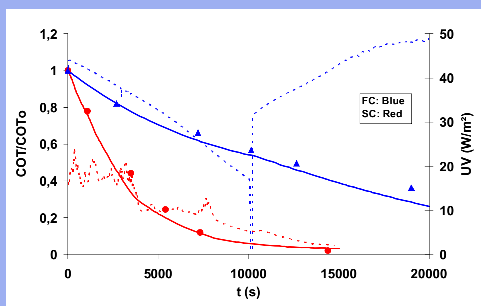

Fig 3: Exp (symbols) model (cont) UV (disc)

Conclusion:

- Experimental results obtained under artificial radiation are correctly modeled for different catalyst forms
- Validation of the model to the solar pilot plant scale operating prediction

Preliminary assessment of a solar driven membrane distillation desalination system

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Freshwater shortage difficulties make it necessary to find new sources of supply. Nowadays desalination is the solution adopted in many countries to solve this problem. All around the planet, regions with lack of freshwater match up with those with large amounts of available solar radiation. Therefore, solar desalination can be a suitable and sustainable option to tackle the water scarcity problems in those particular areas, especially in the coastal ones.

Membrane distillation (MD) is a thermal membrane technology in development since late 60´s which uses low exergy heat to drive a separation process in aqueous solutions. One of its applications is desalination, where thanks to its separation principle very high distillate quality can be obtained. MD is a thermally driven process that differs from other membrane technologies in that its driving force, rather than the total pressure, is the difference in water vapour pressure across the membrane, caused in turn by a temperature difference between the cold and the hot side of it. In comparison with other membrane-based desalination processes like RO, MD shows very high rejection rates and much lower operational pressures. Also the nature of MD membranes (larger pore sizes than RO) makes them much less sensitive to fouling. Compared to conventional thermal desalination processes like MSF or MED, MD is less demanding regarding vapor space and building material's quality [1], leading to potential lower construction costs.

Amongst its advantages, its low operating temperatures (ranging between 60-90º C [2]) make possible the use of low-grade heat, the kind of energy delivered by static solar collectors, as the only thermal supply. This, jointly with its low operational pressure and small footprint, make MD coupled with solar energy (SMD) a very suitable technology for desalination in areas without power distribution. Despite these advantages, SMD has been developed to a lesser extent compared with other solar desalination technologies like Solar PV-driven RO, solar stills or humidification-dehumidification systems, and although many encouraging laboratory experiences can be found in literature, large-scaling and module design is still an issue. It is precisely because of this preliminary state MD is in that low energy efficiency, not commercial and very preliminary prototypes are still found. In MD there is still a trade-off between efficiency (heat consumption) and production (distillate per square meter of membrane), as a result very high specific distillate fluxes can be attained (up to 80 kg h-1 per m2 of membrane [3]) but heat losses (mainly trough the membrane by conduction) are still substantial.

Under the framework of an European project (MEDESOL: Seawater Desalination By Innovative Solar Powered Membrane Distillation) which main objective was to develop a

Degradation of ECs in water with modified photo-Fenton

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Water reuse is a necessary environmental alternative to reduce fresh water use. Quality demands for reusable water are that it not contain toxic, endocrine disrupting or non biodegradable substances, such as pesticides, pharmaceuticals, hormones, etc, which escape conventional wastewater treatments. Advanced Oxidation Processes (AOPs), in this case photo-Fenton, have been reported as effective methods for eliminating these compounds, but their main drawback is their relatively high operating cost. As the concentrations of these substances in reusable water are normally below 10 µg L^{-1}, conventional treatment with high iron concentrations, excessive amounts of H_2O_2 and a pH below 3 would be inefficient. The goal is to adapt the process to a circum neutral pH, low iron and low initial H_2O_2 concentrations.

Application of modified photo-Fenton treatment in a solar pilot plant with real waste water spiked with 15 contaminants at a concentration of 100 µg L^{-1} each. The modification of the photo-Fenton was achieved either with oxalic acid or humic acid. Both substances have the ability to complex dissolved iron, thus making it available for the photo-Fenton reaction.

Humic substances contain several active groups which enable them to support ion exchange, from complexes and support red-ox processes. They contain a high amount of stable free radicals which can react with various substances. The compounds were detected with a UPLC-UV system (Agilent Series 1200) LOD~2-5µgL^{-1}, LOQ~5-13µgL^{-1}.

Figure 1: CPC-reactor used in this study

The photo-Fenton process produces ?OH radicals, which oxidize almost every organic molecule, yielding CO_2, H_2O and inorganic ions (Cl^-, SO_4^{2-}, ..)

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + \cdot OH + OH^-$$

$$Fe^{3+} + H_2O \xrightarrow{h\nu} Fe^{2+} + \cdot OH$$

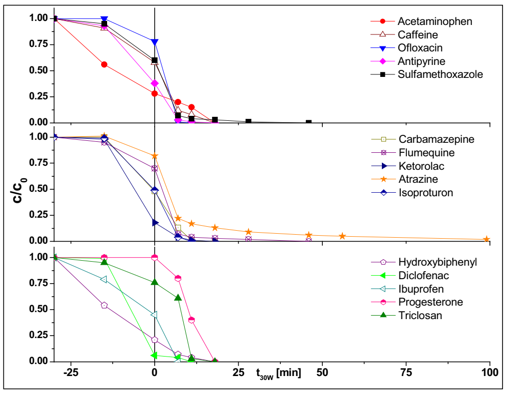

Figure 2: Degradation profile of the 15 ECs using oxalic acid.

Compound	class
Acetaminophen	analgesic
Caffein	stimulant
Ofloxacin	antibiotic
Antipyrine	analgesic
Sulfamethoxazole	antibiotic
Carbamazepine	anticonvulsant
Flumequine	antibiotic
Ketorolac	analgesic
Atrazine	herbicide
Isoproturon	herbicide
Hydroxybiphenyl	biocide
Diclofenac	anti-inflammatory
Ibuprofen	anti-inflammatory
Progesterone	hormone
Triclosan	bactericide

Table 1: The 15 Emerging Contaminants used in this study

Spiked water with 100 mg L^{-1} of each EC, 5 mg L^{-1} Fe, 50 mg L^{-1} H_2O_2 initial concentration, CO_3^{2-} were stripped prior to treatment with acid. Initial pH was between 6.3 and 6.7.

The use of oxalic acid (molar ratio: Ox:Fe=4:1) enhances the process, as the concentration of all compounds was < LOD at t_{30W} = 100 min, but has the disadvantage of lowering the pH of the treated water significantly.

The use of humic acid on the other hand, is slower, (not all ECs are degraded after t_{30W} = 190 min) but has the advantage of a higher pH compared to the use of oxalic acid.

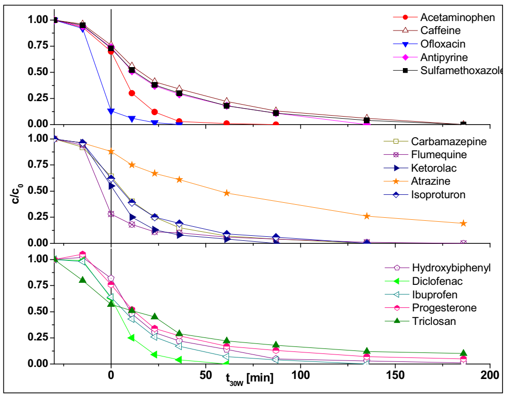

Figure 3: Degradation profile of the 15 ECs using humic acid.

Steady-State Mathematical Modeling of a Solar Multi-effect Desalination Plant at the Plataforma Solar de Almería

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The desalination industry plays a fundamental role in the struggle against the high water stress that many world areas are experiencing. It appears as a solution for providing a sustainable source of fresh water in places with seawater availability. Within thermal desalination processes, multi-effect distillation (MED) has acquired a potential interest over multi-stage flash (MSF), since the former achieves higher energy efficiency and higher performance ratios than the latter ([1, 2]). However, thermal desalination processes are intensive energy consumers, so an effective incorporation of renewable energies is required to guarantee the sustainability of this technological option. The usual coincidence in many locations of fresh water shortage, abundant seawater resources and high isolation levels makes thermal seawater desalination driven by solar energy as one of the most promising processes to obtain fresh water. This can be possible by the coupling of a conventional thermal desalination technology with the solar thermal system [3].

Some authors have published the modeling and simulation of a MED process. El-Dessouky et al. ([4]) carried out a steady-state analysis for the process, assuming constant transfer areas for both evaporators and preheaters in all effects, variation in thermodynamic losses from one effect to another, the dependence of the physical properties of water on salinity and temperature, and the influence of noncondensable gases on the heat transfer coefficients in the evaporators and the feed preheaters. El-Nashar et al. presented a mathematical simulation of the steady-state operation of a MED, which was validated with experimental data from a plant located at Abu Dhabi, UAE [5, 6]). The agreement between the theory and the test results was found to be good. Also, a steady state mathematical model of a multi-effect thermal vapour compression (MED-TVC) has been developed by Amer to evaluate the model system performance [7]. The model validity was examined against three commercial MED-TVC plants showing good results.

The focus of this paper is the development and validation of a mathematical model of the MED plant located at the Plataforma Solar de Almería (PSA). The plant, a forward-feed MED, was installed in 1987 [8], and it consists of 14 effects in a vertical arrangement, with preheaters next to each effect and an end condenser. The original first effect that worked with low-pressure saturated steam (70ºC, 0.31 bars) was replaced ([9, 10]) by a new one working with the hot water coming from a solar field composed of static compound parabolic concentrators (CPC) [11]. The mathematical model has been developed by applying steady state mass and heat balances coupled with the heat transfer rate equations for the heater (effect 1), the evaporators (N-1 effects) and the end condenser. The following assumptions have been taken into account in order to simplify the analysis: steady state operation, negligible heat losses to the surroundings, equal temperature difference across the effects, salt free distillate from all the effects and negligible variations of the boiling point elevation with temperature and salinity. The model has been implemented in MATLAB environment and validated with experimental results obtained from real experimental data. Furthermore, correlations to determine the overall heat transfer coefficient of the heater and the end condenser have been developed by experiments with a top brine temperature which ranges from 50ºC to 74ºC. The results show a good fit between the theoretical and the experimental data.

Methods to characterize degradation of solar reflectors

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DLR Institute of Technical Thermodynamics, Almería

This presentation reports from the aging process of a first surface aluminum reflector for concentrating solar power application. In outdoor weathering at different sites, all exposed samples showed to suffer from localized degradation spots.
A cross section image reveals that the degradation occurs at the aluminum layer (Fig.1). A vertical Energy Dispersive X-ray (EDX) line scan with high spatial resolution indicates a loss of the deposited aluminum in the degraded areas. The void is able to propagate underneath the SiO_2 and TiO_2 layers, without harming them.
In order to monitor and optically characterize local degradation spots a space-resolved specular reflectometer was developed. The instrument can be employed to evaluate the reflectivity characteristics of flat mirrors on any point of its surface. In combination with aging tests gradual changes, like the growing of degraded areas can be monitored. Also, it is possible to analyze the portion of degraded surface in relation to intact surface and to estimate the overall reflectance loss of the mirror.

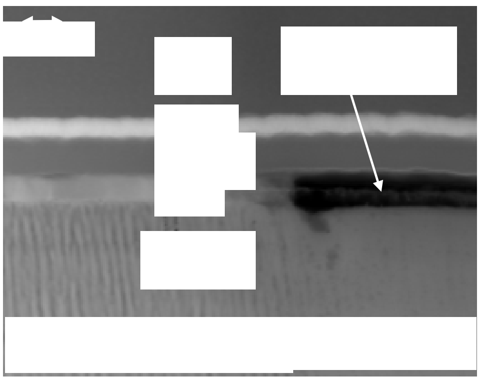

Figure 1: Cross section of a degradation spot (Z-Contrast Image in the Transmission Electron Microscope. Sample preparation occurred by FIB (Focused Ion Beam) in order to not introduce new defects).

Fig. 2 shows the scheme of the instrument. The prototype of this instrument matches measurements taken with the D&S reflectometer at 25mrad and 660nm within 1%. The device was used to measure a sample of aluminum reflector exposed in Miami for 36 months (Fig.3). Its specular reflectance at 25mrad and 660nm is 81.7%. The total degraded area reached 2.1% of the mirror surface, while 46 individual degradation spots were found. The average specular reflectance of the degraded area is only 31.6%, being hence the major reason for losses in reflectance.

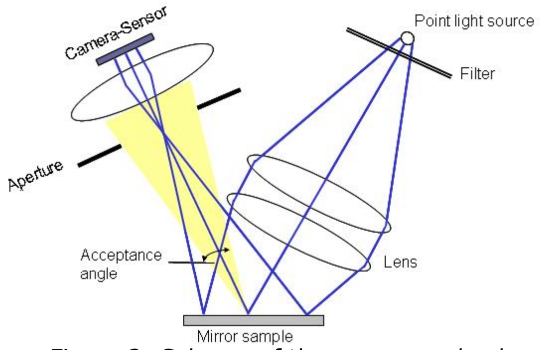

Figure 2: Scheme of the space-resolved specular reflectometer

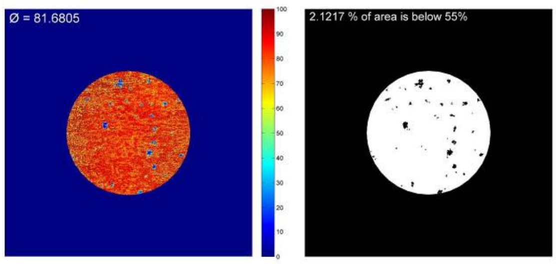

Figure 3: Specular reflectance map at 25mrad and 660nm and detection of degraded area of a sample of aluminum reflector exposed for 36 months in Miami.

An air-based 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. An air gap at ambient pressure between absorber and cavity provides thermal insulation to the absorber. 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.

Pressure drop calculation methods for direct steam generation in parabolic troughs.

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Calculate the pressure drop in hydraulic components by flowing water in both vapor and liquid phase, by using in every single case, the phase density and viscosity (vapor or liquid flow). For the case where there is two phases, water and steam flowing through the pipe, the friction pressure drop that occurs is calculated as follows:

$$\left(\frac{\partial p}{\partial z}\right)_{2p} = \Phi_l^2 \left(\frac{\partial p}{\partial z}\right)_l = \Phi_g^2 \left(\frac{\partial p}{\partial z}\right)_g$$

where:

$\left(\frac{\partial p}{\partial z}\right)_l$: liquid flow pressure drop [Pa/m^2]

$\left(\frac{\partial p}{\partial z}\right)_g$: vapor flow pressure drop [Pa/m^2]

Φ_l^2 : correlation coefficient for two-phase flow for liquid [-]

Φ_g^2 : correlation coefficient for two-phase flow for steam [-]

There are many expressions to calculate the correlation coefficient for two-phase flow, and our aim with this paper is to make a compilation of some correlations that have been found in the literature and are likely to be applied to pipes and hydraulics as those installed in DISS experimental plant for the study of direct steam generation in parabolic troughs.
The selection and evaluation of measurement data correspond to daily PSA records. The analysis consists of measurements taken and evaluated within the period from March 2000 until Agust 2002.

Correlations for two-phase water-steam flow in straight lines, 1975 Friedel correlation [1], 1979 Friedel correlation [2], Correlation Awad [3], Correlation Beattie [4], Correlation de Martinelli-Nelson [5], Correlation Martinelli-Nelson amended by Fitzsimmons [6], Correlation Chenoweth-Martin [7], Correlation Thom [8], Correlation Homogeneous[9], Correlation Chishokm B[10].

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Assessment of PTC mirror shape accuracy based on optical shape measurements

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The optical performance of concentrating solar collectors strongly depends on the shape accuracy of the mirrors reflecting the sunlight onto an absorber. At the QUARZ Test and Qualification Center for CSP Technology a test facility capable of assessing mirror shape accuracy under varying parameters, i.e. mirror orientation and mounting, was constructed. It follows the well-established deflectometric measurement procedure which has been developed at DLR in the last few years[1,2]. The technique of deflectometry is an optical measurement method using the reflected images of a series of stripe patterns in the surface that shall be examined. A computer algorithm then determines spatially resolved mirror slope deviation which serves as input parameter for further calculation of standard focus deviation[3].

After construction and initiation of the test facility, it has been validated as a first step. A mirror panel was evaluated with an existing reference setup. Afterwards, the results in the laboratory in Cologne were used to approve the new installation. Results of measurements of mirrors of common solar collectors as well as of mirrors of a prototype for a smaller parabolic trough will be shown.

As currently installed mirror panels are made of 4 mm float glass mounted on only four support points mirror bending due to dead load and wind load is an issue. First measurement results of the effects of dead load deformation on mirror shape and performance impact will be presented. Further research will quantify these effects and shall lead to optimization approaches for parabolic trough concentrator geometry. Additionally, the impact of mounting support accuracy on the overall shape accuracy shall be examined.

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