5 Task III:
Solar Technology and Advanced Applications

Operating Agent: Peter Heller, DLR

National Representatives:
- Wes Stein, Australia
- Amina El Zalabany, Egypt
- Rolf Oström, European Union
- Alain Ferrière, France
- Robert Pitz-Paal, Germany
- Jakob Karni, Israel
- Carlos Ramos, Mexico
- Diego Martinez, Spain
- Louis van Herden, South Africa
- Aldo Steinfeld, Switzerland
- Thomas R. Mancini, USA

5.1 Nature of Work & Objectives

The objectives of this task deal with the advancement of technical and economic viability of emerging solar thermal technologies and their validation with suitable tools by proper theoretical analyses and simulation codes as well as by experiments in special arrangements and adapted facilities. For this purpose, procedures and techniques are defined for the design, evaluation and use of the components and subsystems to optimize concentration, reception, transfer, storage and application of solar thermal energy. In essence, the goals are to investigate innovative multi-discipline advances needed for the further development of concentrating solar thermal systems. This also concerns, among others, process heat applications, the utilization of solar concentration for the development of improved materials, and the introduction of hybrid solar/fossil power plant concepts.

Task III is an ongoing R&D-oriented effort with clearly defined technical objectives, time schedule and expected results. Activities are cost-shared, task-shared (either through SolarPACES or among SolarPACES participants), and/or information-shared. Cost-sharing and task-sharing activities involve cooperative efforts of two or more participants where either costs of activities or responsibilities for activities, respectively, are mutually agreed upon and shared by the Participants. Information sharing is used for the exchange and discussion of results of projects carried out independently by Participants, but of interest to all.

5.2 Task III Objectives for 2011

In the context of growing commercial CSP project activities, further development and improvement of all CSP plant components is an obvious Task III challenge. The findings of studies like ECOSTAR on the impact of technology R&D on final CSP plant cost reduction should be borne in mind and refined to efficiently allocate R&D funds to the most promising topics.

As our industrial partners competitively pursue project development and R&D on component development, the following activities appear to be appropriate for supportive collaboration, moving the technology forward:

- **Guidelines for component performance measurement**, which can help component suppliers and plant operators qualify and validate their specifications.
- **Prioritization of R&D activities with high impact on cost reduction.** The findings of studies like Ecostar on the impact of technology R&D on reduction in the final cost of CSP plants will be further refined. In addition, SolarPACES Task III will work as a catalyst in setting up international R&D projects by leveraging funds to follow the roadmap laid out.
- **Reliability Evaluation of solar components and systems**. SolarPACES Task III will develop methods and procedures for predicting the life-time performance of solar plant components and systems. This also includes the development of methods for long-term stability testing (e.g., accelerated aging procedures).
- **Concentrator system quality assurance tools and methods**, to assure the optical quality of concentrators during installation and operation, including fast measuring systems for internationally standardized concentrator quality control and component performance characterization, including harmonization of simulation tools to offer investors reliable product and performance data.
- **Comparison and evaluation of storage concepts** Define a methodology for comparing and assessing

storage concepts and collecting design and operation data from systems under testing in different locations

- **Power plant optimization for arid regions.** SolarPACES TaskIII will analyze options to operate solar thermal power plants efficiently at sites with low water availability. This analysis will be based on experience in conventional power plant operation under dry cooling conditions.

Reported Task III Activities in 2008 are summarized in Table 1. The different ways of cost- and/or task sharing are marked in the last column:

1. Cost-shared activities created and coordinated through SolarPACES (C in Table 5.1)
2. Task-shared activities created and coordinated through SolarPACES (T in Table 5.1)
3. Task-shared activities created and coordinated by SolarPACES member countries (eventually with participation of non-member countries) which are of interest to SolarPACES (M in Table 5.1)
4. Activities of individual member countries, which are of interest to SolarPACES (I in Table 5.1)

5.3 Summary of Achievements in 2008

5.3.1 Components and subsystems

5.3.1.1 STORAGE

ITES – Storage System for Direct Steam Generation

Contact: Doerte Laing,
German Aerospace Center (DLR)
Pfaffenwaldring 38-40,
70563 Stuttgart, Germany, Doerte.Laing@dlr.de

Participants: German Aerospace Center (DLR), Ed. Züblin AG, Siemens Energy Sector;

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

Cost effective storage systems demand the adaptation of the storage technology to the heat source and the consumer. For direct steam generation, there is a significant advantage when storage modules specially adapted for preheating, evaporation and superheating are applied.

In the ITES project, a complete storage system for

Table 5.1. Summarized Task VI reported activities organized by Sector

	Concentrating Solar Technology and Applications	***Contact***	***Sharing***			
	Components and Subsystems		**I**	**M**	**T**	**C**
Storage	ITES – Storage System for Direct Steam Generation	Doerte Laing	x			
Trough	Reflector Optical Properties Measurement	Eckhard Luepfert	x			
	Reflector Shape Analysis	Eckhard Luepfert/Steffen Ulmer				
Tower	Solar hybrid power and cogeneration plants (SOLHYCO)	Peter Heller	x			
	A 200 kWe Solar Thermal Power Tower Development	Yong-Heack Kang/ Moon-Hee Park	x			
	Korea-China Co-Project 1-MWe Solar Power Tower Plant	Yong-Heack Kang/ Moon-Hee Park	x			
	A Novel Pressurized Air Receiver for Concentrated Solar Power via Combined Cycles	Aldo Steinfeld	x			
Fresnel	Fresnel process heat collector for industrial applications and solar cooling	Christian Zahler	x			
	Fresquali-Qualification for Linear Fresnel Collector Technology-Development and Modification of Optical and Thermal Measurement Systems	Anna Heimsath	x			
	Supporting Tools and Test Facilities					
	National Laboratory of Solar Concentration Technology and Solar Chemistry	Claudio Estrada	x			
	HFSF-High Flux Solar Furnace for Production of Solar Fuel	Yong-Heack Kang/ Jin -Soo Kim	x			
	Advanced Technologies and Applications					

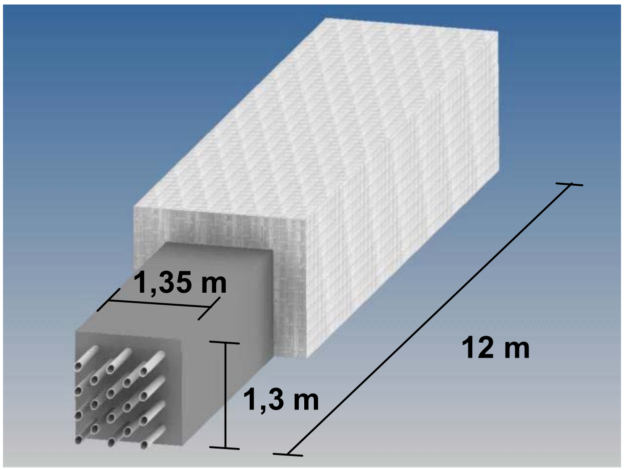

Figure 5.1 Drawing of concrete superheater demo-module

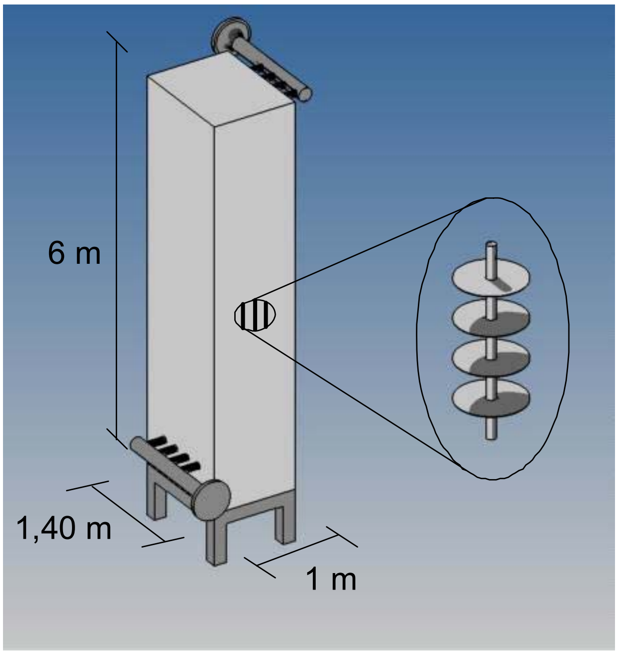

Figure 5.2 Drawing of PCM-storage demo-module

direct steam generation with specially adapted storage modules is developed. The concrete storage technology developed by Ed. Züblin AG and DLR is applied for preheating and superheating, while PCM storage was developed by DLR for the evaporation section. Adaptation of the process control system to the specific requirements of solar thermal power plants was developed by DLR and Siemens Energy Sector.

The concrete storage technology developed for trough power plants with thermal oil as the heat transfer fluid was successfully demonstrated in 2008 in a 100 kW test loop in Stuttgart, Germany. At the same time, the technology was adapted to the requirements of the water/steam heat transfer fluid and to a 500ºC storage temperature. A 300 kWh superheating storage module designed for demonstration in Spain is currently under construction (see Figure 5.1).

For condensation and evaporation of the heat transfer carrier, a PCM-storage unit with sodium nitrate as the phase-change material was developed. The PCM storage module uses a specially developed sandwich design to reach the high heat transfer rates required. The PCM has a melting temperature of 306°C, which leads to a steam pressure of 112 bars during charging and 78 bars during discharging. A first 4-kW test module with approx. 140 kg of salt was successfully tested in the DLR laboratory in 2008. The design was scaled up to about 14 tons of salt with a latent heat capacity of approx. 700 kWh (see Figure 5.2), and is currently under construction.

The 1-MW demonstration storage system, made up of the PCM storage module and the concrete superheater module will be tested in 2009 in a DSG test facility specially erected at a conventional ENDESA power plant in Carboneras (Spain). Commissioning is scheduled for May 2009. Facility operation and thus investigation of the storage system will start in June 2009.

Publications: [5.1], [5.2], [5.3]

5.3.1.2 PARABOLIC TROUGH

Reflector Optical Properties Measurement

Contact: Eckhard Lüpfert, e.luepfert@dlr.de, Stephanie Meyen, stephanie.meyen@dlr.de
DLR

Participants: DLR

Funding: German Federal Ministry for the Environment (BMU) and DLR

The optical performance of reflective materials for application in concentrating solar collectors was characterized using their spectral hemispherical reflectance ρ_{hem} and direct reflectance ρ_{direct}. The hemispherical reflectance spectra of different samples were weighted with the direct solar spectrum according to ASTM G173 (respectively ISO 9050) to get the solar weighted hemispherical reflectance ρ_{SWH}. ρ_{direct} was measured at 660 nm and allocated with the hemispherical measurements to get the solar weighted direct reflectance ρ_{SWD}. This is the relevant parameter for solar applications because it describes the fraction of the solar energy that can be concentrated onto the absorber by the mirrors.

Table 5.2. Solar-weighted hemispherical reflectance ρ_{hem} and direct reflectance ρ_{direct} .of different reflector materials

	Glass	Polymer	Alu1	Alu2
ρ_{SWH} ASTM G173	0.939	0.922	0.903	0.868
ρ_{SWH} ISO 9050	0.937	0.913	0.901	0.866
$\rho_{SWD,25}$ ASTM G173	0.939	0.874	0.830	0.837
$\rho_{SWD,25}$ ISO 9050	0.937	0.866	0.827	0.833
$\rho_{direct,r}$ after 100 cycles	0.995	0.320	0.920	0.66

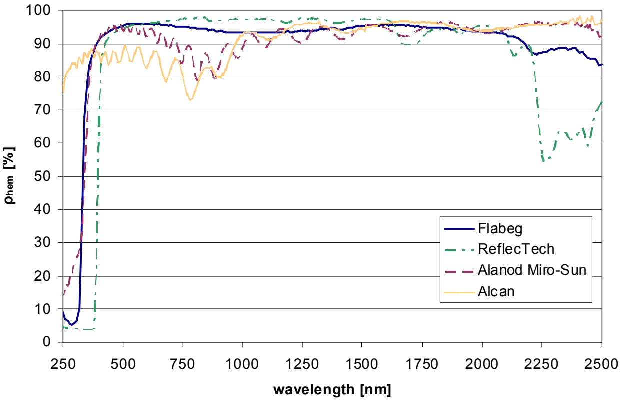

Figure 5.3 Hemispherical spectra of reflector materials

A mechanical durability test, making use of the linear movement of abrading rubber on the optical surface, was defined. Based on DIN ISO 9211-4, the parameters of the test have been systematically optimized to be able to resolve differences between mirror materials.

All measurement-techniques were used in combination as a tool for comparative evaluation of different reflective materials. The results demonstrate the optical advantage of silver reflector layers and also the excellent durability of glass as front reflector material compared to coated aluminum and polymer films. The tests described are proposed as standardized procedures for component testing for concentrating solar collectors.

Reflector Shape Analysis

Contact: Eckhard Lüpfert, e.luepfert@dlr.de,
Steffen Ulmer, steffen.ulmer@dlr.de

Participants: DLR, CIEMAT, industry

Funding: German Federal Ministry for the Environment (BMU), and DLR

The performance of concentrating solar collectors depends to a significant extent on accurate shape of the mirrors reflecting the sunlight onto the absorber. On the basis of previous work on shape measurement and ray-tracing, a quality parameter has been defined for parabolic trough mirrors, which quantifies the average deviation of the reflected beam from the design focal line. It was demonstrated that the standard distribution (Gaussian distribution) is sufficiently related to derive the relevant performance intercept factor from it.

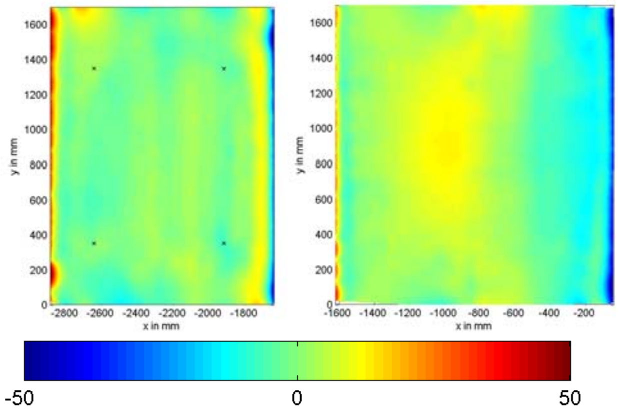

Figure 5.4 Example of a measurement result of the spatial distribution of the transversal focal deviation for the surface analysis of a pair of mirrors, scale in mm Tower

Based on measurement results and ray-tracing analyses it is proposed to specify mirror shape quality with the transversal standard focus deviation parameter FDx in horizontally and FDy vertically. This specification can replace previously used standard slope deviations and definitions related to laser-beam intercept factors on the receiver size without changing measurement procedures, but much more significantly, as a quality parameter for this key element of CSP technology.

As objective for the glass reflector for high performance trough collectors a typical value for the standard focus deviation in transversal direction is about 15% of the absorber diameter.

5.3.1.3 TOWER

Solar hybrid power and cogeneration plants (SOLHYCO)

Contact: Peter Heller, DLR, Apartado 39,
04200 Tabernas, Spain,
peter.heller@dlr.de

Participants: DLR (D), Turbec (Sw), CEA (F), CIEMAT (E), Solucar (E), Ormat (I), GEA (Pol), NEAL (Alg), FUSP (Bra), Vitalux (Bra), IIE (Mex)

Funding: EC FP6 STREP: 3.4 M€ total cost,

Duration: 42 months

Purpose: The SOLHYCO project focuses on the development of a 100-kW$_e$. prototype solar-hybrid microturbine conversion system for cogeneration. Project innovations are:

- Development of a solar-hybrid microturbine prototype unit based on a commercial microturbine
- Development of a new receiver based on a new high- performance tube technology
- Development of biofuel combustion system

During the third year of the project, development of the multilayer tube manufacturing technology was delayed due to insolvency of one of the partners FTF (SME). A new manufacturer started producing the first samples of an inconel-copper-inconel tube. These have already been thermally tested in the CEA test furnace and showed promising results. The layers seemed to withstand the thermal stress without delamination. Extensive lab tests up to 850°C are planned, first with the tube samples and later on with complete tubes.

Meanwhile, manufacturing of the prototype 100-kW cogeneration system receiver has begun. The tubes are made of monolayer Inconel, but may be replaced by multilayer tubes. The turbine package is finished and is

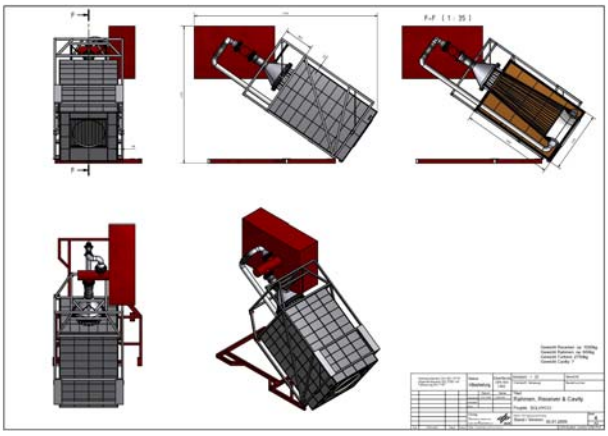

Figure 5.5 Solar receiver (cavity not shown) design for TURBEC microturbine (100 kW$_e$) for cogen applications

now ready to be shipped to the test site in Almeria, Spain, for testing in a 6-month solar-hybrid operation. Tests are scheduled to start in June 2009.

Figure 5.5 shows details of the turbine and receiver package design.

Apart from 100-kW cogen system development, a new, modified biofuel combustion system was put into operation in the former SOLGATE test bed using the OST3 turbine (250 kWe) system with the 3 solar receivers. In the first tests, the modified system was run without problem. The test setup was then modified to integrate two different additional mass-flow measurement systems, a rotameter and a system based on the tracer gas method, allowing the pitot tube used throughout the former turbine tests to be compared to these alternative methods. The rotameter could only be used for lower turbine power levels due to its upper range limit. Tests with the turbine and solar components were done at lower powers, for which the tracer gas method showed good precision. Full load tests are planned as the next step. Therefore the rotameter were dismantled and a second test phase started. Results are expected by March 2009.

Website: www.solhyco.com

Publication: [5.4]

A 200-kW$_e$ Solar Thermal Power Tower Development

Contact: Yong-Heack Kang, yhkang@kier.re.kr
Moon-Hee Park, mhpark@taegugas.co.kr,
102 Gajeong-ro, Yuseong-gu,
Daejeon, 305-343, Korea

Participants: Daegu City Gas, DIC, CMSTech, Max Tech, KIER; IHU, SNUT, CNU.

Funding: Approx. $9,600,000 from Korea MKE funded project, cost shared with Participants

The 200 kW$_e$ solar thermal power tower plant project started at the end of 2008. The final goal of the project is to develop a cost-effective small-scale (200 kW$_e$) solar power system which adapts high-temperature volumetric air receiver, thermal storage and steam generator to operate a steam turbine for electricity production.

Four industrial, one research (KIER) and three university partners are collaborating for this project and the Daegu City Gas Co. Ltd. is leading this project. This three year project will hopefully deliver the first power tower system in Korea in 2011. It will be utilized as a mid-scale test bed for concentrated solar technologies after termination of the project.

Korea-China Co-Project for 1-MW Solar Thermal Power Tower Plant

Contact: Yong-Heack Kang, yhkang@kier.re.kr
Jong-Kyu Kim, rnokim@kier.re.kr,
102 Gajeong-ro, Yuseong-gu,
Daejeon, 305-343, Korea

Participants: KIER, Halla Energy & Environment, Shinyang Energy, Kopacets, SNUT, IHU

Funding: Approx. $2,500,000 from Korea MKE funded project, cost shared with Participants

This project is an international Korean and Chinese collaboration project for development and operation of a 1-MW power plant in China. For this project, the Korean and Chinese governments are contributing major research funding and some academic and industrial partners are collaborating. The project was started in Korea at the end 2005, and in China in the middle of 2006, respectively. KIER and IEE (Institute of Electrical Engineering) CAS (Chinese Academy of Science) are leading both sides of the project. The Korean role is to develop a solar receiver and a thermal storage/transportation system. After some years of fundamental research, designing, and component development research in China, actual building of the solar field

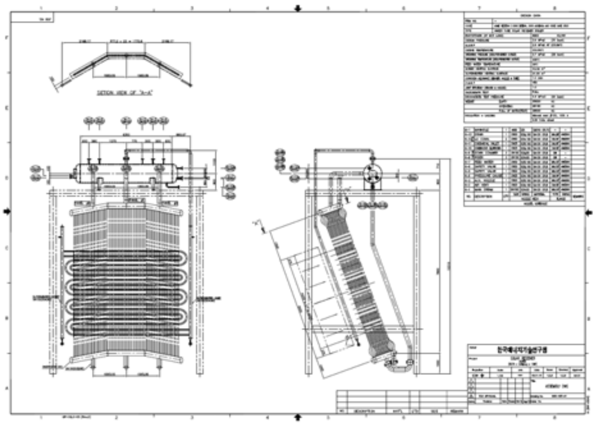

Figure 5.6 Assembly drawing of receiver for production of superheated steam of 2.8 MPa and 400 °C.

and tower will take place during 2009. A water/steam receiver will be adapted for the power tower system and a designed receiver (Figure 1) is ready for manufacturing by KIER. Major thermal energy storage is now under detailed design by KIER as well. The power tower system is expected to start operation and produce electricity in 2010.

A Novel Pressurized Air Receiver for Concentrating solar power via Combined Cycles

Contact: Aldo Steinfeld,
ETH Zurich/PSI
aldo.steinfeld@eth.ch,

Participants: ALSTOM, ETH Zurich/PSI

Central receiver systems using solar tower technology can achieve solar concentration ratios exceeding 2000 suns, and therefore, supply solar process heat at above 1000°C. Significant improvement in terms of solar-to-electricity efficiency can be achieved by supplying high-temperature thermal energy directly to the topping Brayton cycle in combined cycle power generation. The key component of such a solar-driven combined cycle (SCC) is the solar receiver, where concentrated solar thermal energy is absorbed and transferred to pressurized air (or any other working fluid expanded in the gas turbine). The receiver requirements for an SCC are defined by the gas turbine inlet conditions, i.e., temperatures in the range 1000–1400°C and pressures in the range 8–30 bars.

Previous designs of solar receivers for SCC were based on windowed concepts which use directly-irradiated volumetric absorbers made of ceramic fins or foams. The direct irradiation was proven to provide an efficient means of heat transfer. Nevertheless, windows are critical and troublesome components. Alternative designs use opaque heat exchangers. The indirectly-irradiated concepts eliminate the need of a window at the expense of having less efficient heat transfer by conduction through the absorber walls. Thus, the disadvantages, such as the maximum operating temperature, thermal conductivity, resistance to thermal shocks, and inertness to oxidation by air, are linked to limitations imposed by the metal/ceramic absorber construction materials.

A novel design of an indirectly-irradiated solar receiver is shown schematically in Figure 5.7. It consists of an annular reticulate porous ceramic foam (RPC) bounded by two concentric cylinders. The inner cylinder has a small aperture to let in concentrated solar energy. Because of its cavity-type configuration, it can efficiently capture incoming radiation that undergoes multiple internal reflections. A 3D compound parabolic concentrator (CPC) is incorporated at the aperture to boost the solar concentration ratio and reduce the aperture size and re-radiation losses. Absorbed radiant heat is transferred by conduction, radiation, and convection to the pressurized air flowing across the RPC. The outer cylinder is made of non-porous insulating material and is surrounded by a metal shell to maintain the 10 bar internal pressure.

This solar receiver design offers several intriguing advantages: 1) high apparent absorptivity due to cavity-type geometry; 2) high convective heat transfer from the RPC to air; 3) homogeneous and monotonously increasing temperature profile; 4) uniform compressive load on the cavity; 5) reduced re-radiation losses at the cavity inlet due to entering cold air; and 6) scalability as a single or multi-receiver array. The disadvantages are those common to indirectly-irradiated receiver concepts, i.e., the limitation associated with the thermal transport properties of the construction materials. Candidate materials for the cylindrical cavity and RPC are ceramics (SiC, Al_2O_3) and high-temperature metal alloys.

A 2D steady-state energy conservation equation coupling the three heat transfer modes has been formulated and solved by the finite volume technique and by applying the Rosseland diffusion, P_1, and Monte Carlo radiation methods. The model allows identification of critical material properties and optimization of geometrical dimensions as a function of desired air outlet temperature and mass flow rate. For a solar concentration ratio of 3000 suns, the outlet air temperature reaches 1000°C at 10 bar, yielding a 77% thermal efficiency. In general, the dominating loss mechanism is re-radiation through the cavity's aperture, which can be reduced to some extent by incorporating a CPC. Increasing air mass flow rates across the RPC lead to a beneficial cooling effect at the cavity entrance, further minimizing re-radiation losses. For solar concentration ratios above 3500 suns, conduction through the cavity becomes the limiting heat transfer mode. The cavity wall thickness will have to be minimized in accordance with its mechanical and thermal stability to withstand the operating pressures and temperatures.

Publication: [5.5]

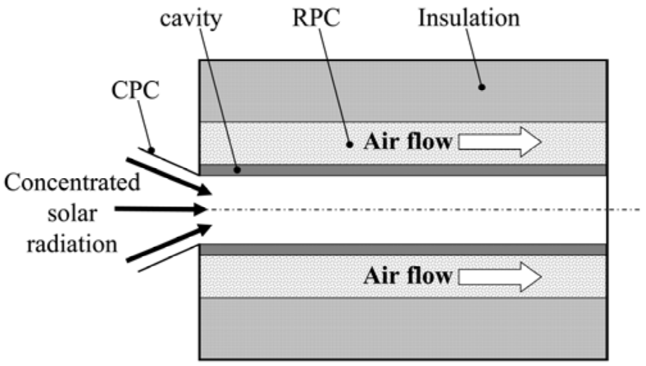

Figure 5.7 Solar receiver concept featuring an annular reticulate porous ceramic foam (RPC) bounded by two concentric cylinders. Concentrated solar radiation absorbed by the inner cylindrical cavity is transferred by conduction, radiation, and convection to the pressurized air flowing across the RPC.

5.3.1.4 FRESNEL

Fresnel process heat collector for industrial applications and solar cooling

Contact: Mirroxx GmbH, Christian Zahler,
Emmy-Noether-Str.2,
79110 Freiburg, Germany,
christian.zahler@mirroxx.com

Participants: PSE AG (D), Gas Natural (E), ESI (E);

Funding: Deutsche Bundesstiftung Umwelt DBU

Industrial process heat in the temperature range of up to 250°C is a huge but almost untouched field for solar thermal technologies. State-of-the-art non-tracking collectors are limited to a maximum operating temperature of 150°C. Higher temperatures can be reached with concentrating collectors with operating temperatures above 300°C and a field size of at least several MW_p., mostly developed for solar thermal power generation. Only a handful of companies and institutes target the enormous potential for solar industrial process heat, which can be defined by an operating temperature range of 100°C to 250°C and a power range from around 50 kW_{th} to a few MW_{th} (peak capacity). Plenty of applications for this power and temperature range can be found, e.g., in the food and textile industries, but presently, the most attractive option is solar thermal air conditioning.

PSE AG developed a linear concentrating Fresnel collector, which uses individually tracked reflector rows to concentrate direct solar radiation to a stationary linear receiver. The Fresnel approach offers a relatively simple and low cost construction with low wind loads and high ground coverage, which makes this technology well suited to installation on flat roofs.

In December 2005, a first prototype of the PSE linear Fresnel process heat collector was installed in Freiburg, Germany. The collector was operated and evaluated in cooperation with the Fraunhofer Institute for Solar Energy Systems.

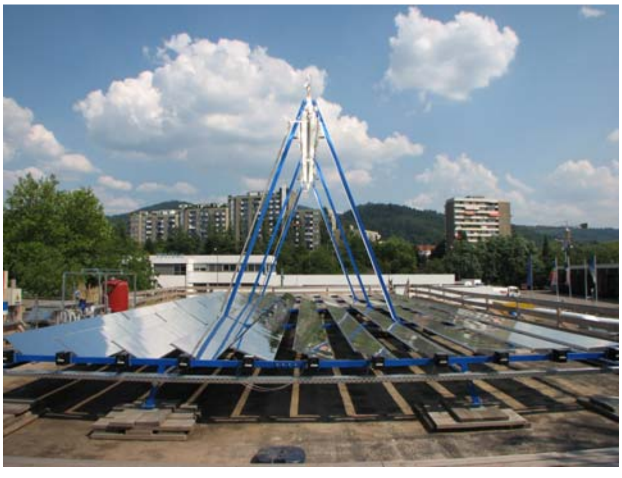

Figure 5.8 First prototype of PSE Fresnel process heat collector (2005, Freiburg, Germany)

Figure 5.9 *PSE Fresnel process heat collector powering two NH_3/H_2O absorption chillers (2006, Bergamo, Italy)*

Figure 5.10 PSE Fresnel process heat collector powering a NH_3/H_2O absorption chillers (2008, Grombalia, Tunisia)

A second prototype with an aperture area of 132-m^2 (66 $kW_{p,th}$) was installed in Bergamo, Italy to power an ammonia-water absorption chiller. The complete solar cooling system has been operated and monitored since August 2006 to evaluate system performance as well as the performance of the individual components.

The third installation, with 352 m² (176 $kW_{p,th}$) was installed in late 2007 to power a double effect $H_2O/LiBr$ chiller at the University of Seville, Spain. The latest installation is a solar cooling system with a NH_3/H_2O chiller at a winery in Tunisia.

A water circuit pressurized at 16 bar is a cost-effective and efficient way to transfer process heat with temperatures up to 200°C. For temperatures above 250°C, a thermal oil circuit is the appropriate technology. The maximum output temperature of the Fresnel collector is only limited by the vacuum absorber tube, a PTR 70 receiver manufactured by Schott Solar GmbH, which is approved for 400°C and 40 bar pressure.

With the Mirroxx GmbH spin-off in December 2008, the structure for industrial series production and strategic marketing of the Fresnel collector technology has been formed. The target group consists of industries in sunny countries which require process heat at temperatures up to 400°C, an enormous market which will be tapped by sales cooperation in the targeted countries and through installation of pilot plants.

In late 2007, a Fresnel process heat collector with a 352-m^2 aperture area (176 kW$_{p,th}$) was installed on the roof of the Escuela Técnica Superior de Ingenieros (ESI), a School of Engineering building in Seville, Spain. The collector has a total length of 64 m (16 4-m-long modules) and otherwise similar in design to the ones in Freiburg and Bergamo. The collector powers a double effect H_2O/LiBr absorption chiller (Broad), with a maximum cooling capacity of 174 kW$_{th}$ for air-conditioning the building. At this site the wet-cooling tower for heat rejection, which is usually necessary for H_2O/LiBr absorption chillers, was substituted by a water heat exchanger fed by water from the nearby Guadalquivir River. The double effect absorption chiller offers a high COP of up to 1.3, which makes this system an even more attractive application of solar process heat for solar thermal cooling. First system operation experience is positive and measurement results are expected soon.

Figure 5.11 Fresnel process heat collector on the roof of Escuela Técnica Superior de Ingenieros, Sevilla

It is possible to provide industrial process heat at 200°C with roof-mounted linear Fresnel collectors, which makes them well suited to power efficient absorption chillers.

Two prototypes and two commercial PSE/Mirroxx linear Fresnel process-heat collector units have been installed so far. Pilot solar-cooling system testing and measurement in Bergamo show reliable automatic operation and typical efficiency of the PSE/Mirroxx Fresnel collector of approx. 40% with respect to DNI at 180°C.

Table 5.3. Technical data of PSE / Mirroxx Fresnel process heat collector

Length	Modular in steps of 4 m
Width of the mirror field	7.5 m
Aperture width	5.5 m
Total height	4,5 m
Number of mirrors	11
Width of mirrors	0.5 m
Optical efficiency	0,62
Thermal loss coefficient	4.3 10^{-4} W/(m^{2}K^2)
Peak capacity	500 W/m²

The system has been in continuous operation since late summer 2006.

In late 2007 and early 2008 the first commercial systems were commissioned in Spain and Tunisia. Both are being evaluated by the customers in the frame of research/demonstration projects.

In spring 2009 a demonstration system for direct production of saturated steam in a linear Fresnel collector with a 132-m^2 aperture area will be installed in Freiburg. Operating pressures will be adjustable in the range of 2 to 16 bars.

Figure 5.12 Fresnel process heat collector in operation

We are gradually upgrading our production facilities in Freiburg, Germany and expect more projects for solar cooling and industrial process heat generation in the near future.

5.3.2 Supporting Tools and Test Facilities

National Laboratory of Solar Concentration Technology and Solar Chemistry

Contact: Claudio A. Estrada,
Centro de Investigación en Energía,
Universidad Nacional Autónoma de México (CIE-UNAM),
A.P. 34 Temixco, Morelos, 62580 México, cestrada@cie.unam.mx

Participants: CIE-UNAM, UNISON, INAOE, UAM, IIE

Funding: CONACYT, UNAM, and UNISON.
40 Million Mexican Pesos.

Duration: 36 months, starting July 2007.

Background: Mexico is ideal for implementing solar technologies due to its favorable geographic location in the Sunbelt. In particular, in the northwest states, insolation has a very important beam solar radiation component. This high quality solar resource makes that area ideal for the implementation of concentrating solar technologies (CST). With the aim of supporting the development of concentrating solar technologies in Mexico, a grant was awarded the CIE-UNAM by the Consejo Nacional de Ciencia y Tecnología (CONACYT), for the creation of three research facilities: a high radiative flux solar furnace (HRFSF), a solar photocatalytic water treatment plant (SPWTP), and a heliostat test field (HTF). The first two will be located at CIE-UNAM, in Temixco, Morelos, and the latter at UNISON, in Hermosillo, Sonora. These facilities are grouped as a National Laboratory of Solar Concentrating Systems and Solar Chemistry, and their development is also partially funded by two of the participant institutions (CIE-UNAM and UNISON).

Purpose: Design and construction of a high radiative flux solar furnace, a solar photocatalytic water treatment plant, and a heliostat testing field.

Achievements in 2008:

High radiative flux solar furnace. The architectural design of the building was finished, and the construction began at the end of 2008. The optical design of the furnace has been completed as well as the mechanical design of the support frame for the concentrator. The concentrator will be made up of 409 hexagonal-shaped spherical mirrors, each with a 40-cm diameter. These mirrors will have 6 different focal distances depending on their position on the frame, which will be spherical. The mirrors are being made at INAOE. The mechanical design of the heliostat is in progress.

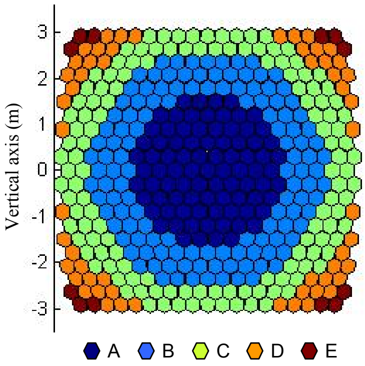

Figure 5.13 Architectonic concept of the high radiative flux solar furnace, and distribution of focal distances of the concentrator mirrors.

Solar photocatalytic water treatment plant. The general plant and associated laboratories have been designed. Construction of two laboratories, a chemical analysis laboratory, adjacent to the plant, and a laboratory for the development and characterization of catalysts and photocatalytic processes began in 2008. The plant solar photoreactors, designed as CPC collectors with 2-sun concentration ratio and fixed catalysts, are under construction.

Heliostat test field. The University of Sonora (UNISON) has assigned a plot of land outside the city of Hermosillo for the deployment of the HTS. The layouts for this plant and for other future installations have already been designed. A 6-m^2 heliostat prototype has been designed, built and tested. Based on this experience, a 36-m^2 prototype is being designed.

HFSF-High Flux Solar Furnace for Production of Solar Fuel

Contact: Yong-Heack Kang, yhkang@kier.re.kr
Jin-Soo Kim, jnskim@kier.re.kr,
102 Gajeong-ro, Yuseong-gu,
Daejeon, 305-343, Korea

Participants: KIER, KAU (KOR)

Funding: Approx. $810,000 from KIER

This three- year project started in 2007 based on the solar concentration system and technologies from our previous solar reforming research with some modifications for this solar furnace.

Figure 5.14 High Flux Solar Furnace in KIER

As the first step for solar fuel research, a 40-kW$_{th}$ on-axis solar furnace system was fully built in KIER in 2008. It consists of a 120-m^2 heliostat, a 52.7-m^2 dish concentrator, a secondary concentrator for higher concentration ratio. It also includes a number of control, measuring, and mapping devices for an easy, rapid experiment when required. The highest solar concentration ratio is estimated to be over 10,000 suns. At the moment thermal performance of the furnace is under the test.

5.4 Meetings, Reports, Publications

5.4.1 Meetings

Task meetings were held at the 14th SolarPaces Symposium in Las Vegas, USA on March 8, 2008. These were organized in conjunction with Task I in order to review current tools for assessing component and system performance and identifying the requirements for measurement standards. It was decided to form a joint Task I/III work group to create a roadmap for "Testing guidelines and standards". Twelve participants offered to participate in the group. Afterwards, the roadmap was implemented and existing standards and measurement parameter definitions were identified. These should be used as a basis for discussion in a follow-up standardization workshop to be held at the 15th SolarPaces Workshop in September 2009.

5.4.2 Publications:

[5.1] Steinmann, Wolf-Dieter; Laing, Doerte; Tamme, Rainer (2008): Latent Heat Storage Systems for Solarthermal Power Plants and Process Heat Applications. In: *Proceedings 14th Biennial Solar Paces Symposium*, 14th Solar Paces Symposium, Las Vegas (USA), 2008-03-03 - 2008-03-07

[5.2] Birnbaum, Jürgen; Eck, Markus; Fichtner, Markus; Hirsch, Tobias; Lehmann, Dorothea; Zimmermann, Gerhard (2008): A Direct Steam Generation Solar Power Plant with Integrated Thermal Storage. In: *Proceedings, 14th SolarPACES Symposium*, Las Vegas (USA), 2008-03-03 - 2008-03-07

[5.3] Laing, Doerte; Lehmann, Dorothea; Bahl, Carsten (2008): Concrete Storage for Solar Thermal Power Plants and Industrial Process Heat. In: *EUROSOLAR [Hrsg.]: Conference Proceedings, Third International Renewable Energy Storage Conference* (IRES 2008), Berlin, 2008-11-24 - 2008-11-25

[5.4] Ulmer S., Heinz B., Pottler K., Lüpfert E.: Slope Error Measurements of Parabolic Troughs Using the Reflected Image of the Absorber Tube. *J. Sol. En. Eng*. Vol. 131, 2009, p 011014

[5.5] Hischier I., Hess D., Lipinski W., Modest M., Steinfeld A., "A heat transfer analysis of a novel pressurized AIR receiver for concentrating solar power via combined cycles". *Proc. 2009 ASME Summer Heat Transfer Conference*, San Francisco, July 19-23, 2009**.**

[5.6] A. Häberle, C. Zahler, F. Luginsland, M. Berger: Practical Experience with a Linear Concentrating Fresnel Collector for Process Heat Applications, *14th International SolarPACES Symposium on Solar Thermal Concentrating Technologies*, Las Vegas, 2008

[5.7] A. Häberle, C. Zahler, F. Luginsland, M. Berger: A Linear Concentrating Fresnel Collector for Process Heat Applications, *EUROSUN 2008: 1st International Conference on Solar Heating, Cooling and Buildings*, Lisbon, 2008

[5.8] C. Estrada, D. Riveros-Rosas, J. Herrera-Vázquez, S. Vázquez-Montiel, C. A. Arancibia-Bulnes, C. Pérez-Rábago, F. Granados-Agustín. Optical design of a high radiative flux solar furnace for Mexico, *Proceedings of the EUROSUN 2008 Conference,* October 7th-10th, Lisbon, Portugal, paper 515.