Thrust Area 4: Solar (Thermal)

Solar Fuels from Thermochemical Cycles at Low Pressures

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Description: The project focuses on the production of solar fuels from solar thermochemical cycles employing metal/metal oxide redox pairs. These thermochemical cycles consist of a high temperature endothermic solar driven reduction step and a low temperature, slightly exothermic water or CO_2 splitting step. The high temperature step typically proceeds at temperatures above 2000 K. Hence, it poses a range of material and design challenges. According to Le Chatelier's principle, the temperature for the solar dissociation reaction decreases as the pressure inside the reactor is reduced. The central hypothesis of the project is that operating the high temperature step of metal/metal oxide solar thermochemical cycles at reduced pressures will lead to significantly relaxed temperature requirements, while the work necessary to produce the pressure difference will not significantly reduce the overall efficiency of the process.

The main goal of the project is to demonstrate the feasibility of carrying out high temperature thermal reduction of metal oxides in rarefied conditions using high intensity solar radiation from UF's solar simulator.

Budget: $100,000.00
Universities: UF
External Collaborators: Wojciech Lipinski, University of Minnesota

Progress Summary

Since October 2010, we have made significant progress in *two areas*. Firstly, the construction and commissioning *UF's high flux solar simulator* has been successfully completed. UF's solar simulator is a 56 kWe high flux solar simulator providing peak flux levels in excess of 5000 kW. It provides a unique platform for concentrating solar thermal research. Secondly the design of the solar thermogravimeter has been completed and ready for construction. The solar thermogravimeter (STG) consists of a high precision analytical balance with a sample holder that can be heated using high flux radiation emanating from the solar simulator. The STG can be evacuated to test chemical reactions under rarified conditions.

Funds leveraged/new partnerships created

Proposals						
Title	Agency	Reference Number	PI, Co-investigators and collaborators	Funding requested ($)	Project time frame (1 year, 2 years, etc.)	Date submitted
Solar Thermochemical Fuel Production via a Novel Low Pressure, Magnetically Stabilized Bed, Non-Volatile Iron Oxide Looping Process	DOE	DE-FOA-0000471	James Klausner, Jörg Petrasch, David Hahn, Renwei Mei	3,132,639	3 years	18 July 2011

Grants Awarded

Title	Agency	Reference Number	PI, Co-investigators and collaborators	Period of Performance	Funding awarded ($)
Solar Thermochemical Fuel Production via a Novel Low Pressure, Magnetically Stabilized Bed, Non-Volatile Iron Oxide Looping Process	DOE	DE-FOA-0000471	James Klausner, Jörg Petrasch, David Hahn, Renwei Mei	negotiations ongoing	negotiations ongoing (2’975’920 according to award notice

2011 Annual Report

This report summarizes the activities related to the investigation of solar thermochemical processes at low pressures carried out in my group during the reporting period (December 2011 through October 2011). The main focus has been the completion of a high flux solar simulator and the design of a low pressure solar thermogravimeter as well as a low pressure dual cavity solar reactor prototype. FESC funding has been successfully leveraged to obtain a 3 million dollar DOE ARPA-E award. Concepts originally devised and demonstrated within this FESC grant will be further persued within the ARPA-E project. I have accepted a position in Europe and will leave UF in December 2011, I have therefore tried to minimize utilization of FESC funds.

Solar simulator

A solar simulator system has been constructed and tested. It provides highly concentrated radiation (5000 kW/m^2) to investigate high temperature solar thermal processes for the production of solar fuels. In particular metal/metal-oxide cycles at low pressures are of interest. The solar simulator provides highly controlled boundary conditions to the experiment.

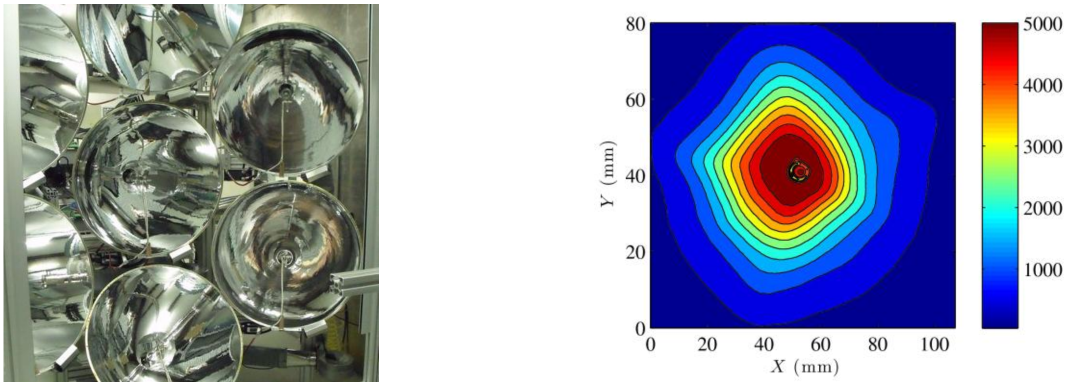


Figure 1a UF’s High Flux Solar Simulator.

Figure 1b Measured flux distribution in the focal plane in kW/m^2.

Figure 3: The partially assembled solar simulator at UF.

Design and Specifications

The simulator consists of seven, 6 kW Xe-arc lamps, which closely approximate the spectral distribution of the sun. Each lamp is close coupled to an ellipsoidal mirror. All lamp/mirror assemblies focus the light onto a common focal point. The measured peak flux is 5000 kW/m^2. Higher fluxes are possible however have not been demonstrated yet since the flux target's coating quickly degrades at fluxes in excess of 5000 kW/m^2.

Construction

Construction of the simulator has been completed. The simulator comprises:

- An extruded, adjustable aluminum frame,
- Seven, 6 kW lamps close-coupled to elliptical mirrors to focus the radiation,
- Air cooling system to keep the lamp and mirror assembly cool,
- A power rack containing power supply equipment,
- A safety wall with a retractable door (controlled from a separate room),
- A fully controllable and customizable x-y table to mount and position experiments,
- Adequate DAQ systems as required (flux measurement, thermocouples, pressure sensors, etc.)
- Comprehensive, redundant safety systems.

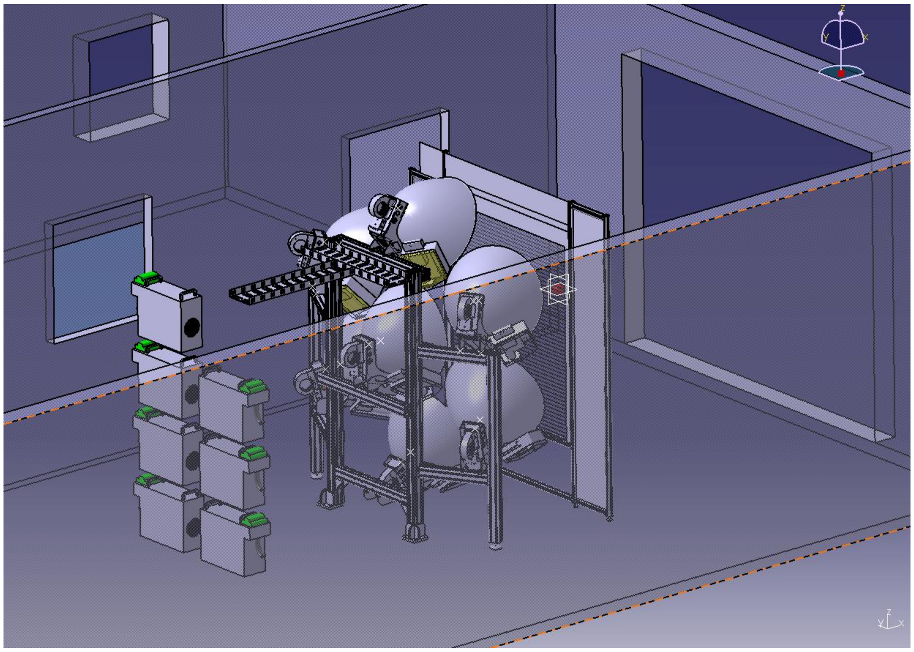


Figure 4 Three dimensional model (rear view) of the solar simulator.

Flux measurement system and Monte Carlo Simulation

In order to characterize the spatial and directional intensity distribution of concentrated radiation in the simulator's target plane, a combination of camera-based flux mapping (figure 3) and Monte Carlo ray tracing simulations is carried out. An in-house Monte Carlo ray-tracing program [1], [2] has been employed for simulating radiative transfer in the UF solar simulator. Monte Carlo calculations will be validated using flux measurements.

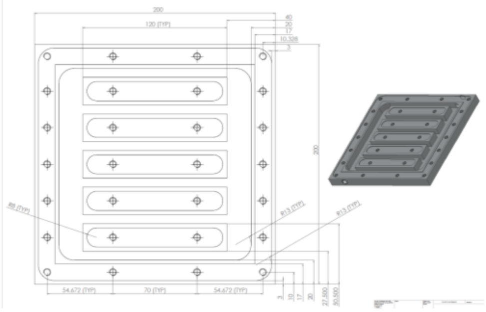


Figure 5 Drawing of Al flux target.

Solar thermogravimeter

The design of a solar thermogravimeter has been completed. Figure 2a shows the conceptual layout. Figure 2 shows an exploded view of the final design. Currently, different manufacturing options are being evaluated and quotes are obtained from manufactures of vacuum equipment.

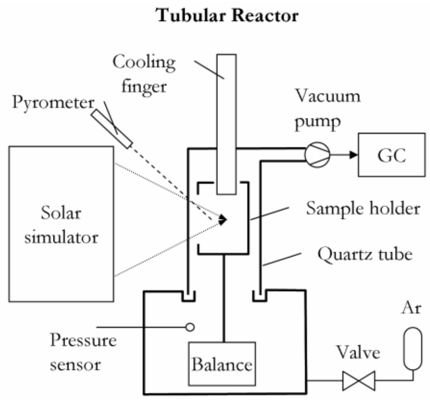


Figure 4a Schematic of low pressure experimental setup.

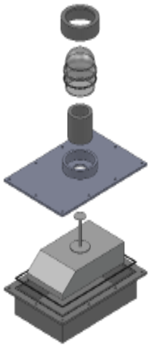
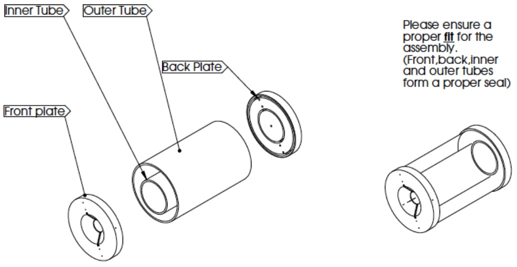


Figure 4b Solar thermogravimeter design, exploded view.

Low pressure solar reactor

A low pressure dual cavity receiver-reactor has been designed and built (Fig. 3). It consists of two concentric Alumina tubes held together by grooved faceplates. The assembly is currently being tested.



Please ensure a proper fit for the assembly. (Front,back,inner and outer tubes form a proper seal)

Figure 5a Dual cavity reactor design

Figure 5b Dual cavity reactor prototype

Journal Papers:

[1] A. Singh, F. Al-Raqom, J. Klausner, and J. Petrasch "Hydrogen Production via the Iron/Iron Oxide Looping Cycle", International Journal of Hydrogen Energy, in preparation.

Conference Proceedings:

[1] J. Petrasch, "A free and open source Monte Carlo ray tracing program for concentrating solar energy research," presented at the ASME 4th International Conference for Energy Sustainability, Phoenix, AZ, 2010.

[2] A. Singh, F. Al-Raqom, J. Klausner, and J. Petrasch "Hydrogen Production via the Iron/Iron Oxide Looping Cycle", Proceedings of ASME 2011 5th International Conference on Energy Sustainability & 9th Fuel Cell Science, Engineering and Technology Conference ESFuelCell2011, August 7-10, 2011, Washington, DC, USA

Presentations:

[1] B. Erickson, J. Petrasch"High Flux Solar Simulator for the Investigation of Solar Thermochemical Cycles at Low Pressures", Poster presentation at the Florida Energy Systems Consortium, Summit, Orlando, FL, 2010.

[2] B. Erickson, J. Petrasch "Inverse identification of intensities from multiple flux maps", Poster presentation at the Florida Energy Systems Consortium, Summit, Gainesville, FL, 2011.

References:

[1] J. Petrasch, "A free and open source Monte Carlo ray tracing program for concentrating solar energy research," presented at the ASME 4th International Conference for Energy Sustainability, Phoenix, AZ, 2010.
[2] J. Petrasch and P. Coray, "A free and open source Monte Carlo ray tracing program for surface exchange," *Journal of Solar Energy Engineering*. In preparation
[3] S. Abanades, P. Charvin, G. Flamant, and P. Neveu, "Screening of water-splitting thermochemical cycles potentially attractive for hydrogen production by concentrated solar energy," *Energy*, vol. 31, no. 14, pp. 2805-2822, Nov. 2006.
[4] T. Kodama and N. Gokon, "Thermochemical Cycles for High-Temperature Solar Hydrogen Production," *Chem. Rev.*, vol.107, pp. 4048-4077, 2007.
[5] C. Perkins and A. W. Weimer, "Likely near-term solar-thermal water splitting technologies," *International Journal of Hydrogen Energy*, vol. 29, no. 15, pp. 1587-1599, Dec. 2004.
[6] A. Steinfeld, P. Kuhn, A. Reller, R. Palumbo, J. Murray, and Y. Tamaura, "Solar-processed metals as clean energy carrier and water-splitters," *International Journal of Hydrogen Energy*, vol. 23, no. 9, pp. 767-774, Sep. 1998.
[7] A. Roine, *HSC Chemistry*. Outotec.
[8] A. Steinfeld and R. Palumbo, "Solar thermochemical process technology," in *Encyclopedia of physical science & technology*, vol. 15, 2001, pp. 237-256.
[9] S. Abanades, P. Charvin, F. Lemont, and G. Flamant, "Novel two-step SnO2/SnO water-splitting cycle for solar thermochemical production of hydrogen," *International Journal of Hydrogen Energy*, vol. 33, no. 21, pp. 6021–6030, 2008.