High Flux Solar Simulator for the Investigation of Solar Thermochemical Cycles at Low Pressures

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Background

Introduction

·Metal/Metal oxide cycles at low pressures are a promising route to carbon neutral fuel production:

Solar step

$Fe_3O_4 \rightarrow 3FeO + \frac{1}{2}O_2$

Dark steps

$3FeO + H_2O \rightarrow Fe_3O_4 + H_2$

or

$3FeO + CO_2 \rightarrow Fe_3O_4 + CO$

·Endothermic solar step requires a high intensity source of solar radiation
·Solar simulator provides a more controlled environment
·Based on earlier optical design for ETH Zurich
·Several design improvements
·Adapted for University of Florida requirements
·Currently under construction at the University of Florida

Overview

·The simulator is comprised of seven, 6 kW Xe-arc lamps which closely mimic the spectral distribution of the sun
·Expected peak flux levels are 5000 kW/m^2, equivalent to a stagnation blackbody temperature of approximately 3000 K
·Each lamp is placed at the focal point of an elliptical mirror (see figure 4)
·All lamp/mirror assemblies focus the light to a common focal point

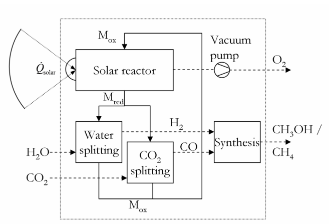

Figure 1: Conceptual layout of a solar thermochemical plant with low pressure solar reactor.

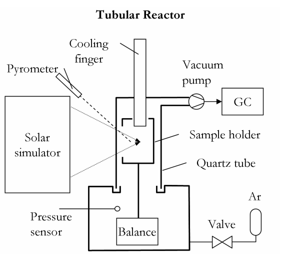

Figure 2: Schematic diagram of a low pressure experiment.

Justification

Purpose and Advantages

A solar simulator system is designed to provide highly concentrated radiation for the experimental investigation of high temperature solar thermal processes for the production of solar fuels, in particular metal/ metal-oxide cycles at low pressures. The solar simulator provides highly controlled boundary conditions to the experiment.

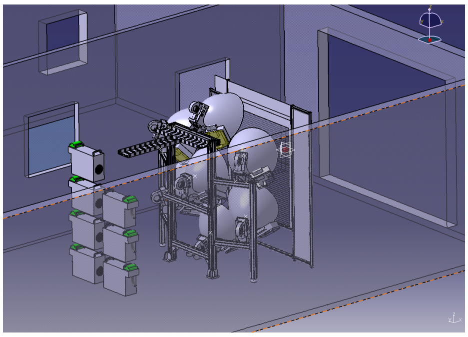

Figure 3: Three dimensional model (rear view) of the proposed solar simulator as drawn in Catia®.

Design and Specifications

Design Stage

The simulator is currently under construction. Completion of the construction phase is expected in December 2010.

Specifications

The solar simulator at UF will include:

- 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 transformers and converters
- A safety wall with a retractable door (controlled from a separate room) to block radiation on the reactor until the experiment is ready to begin
- 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 system.

Figure 4: The partially assembled solar simulator at UF. The frame has been constructed and anchored to the ground . Six of the seven mirror assemblies have been mounted , with the seventh (bottom middle) to be mounted soon. Lamps will be mounted at the center of each mirror and will be supported by the tie rods (seen in front of each mirror). The cooling system will also be integrated onto the frame.

Flux Mapping System

Definition

An important element of any solar system is the measurement of the input flux. Knowing the flux distribution at the aperture allows for mass and energy balances. Consequently, these values can be used to compare the effectiveness of various processes and reactor designs. To accomplish this task a flux measurement system has been designed and will be implemented on the UF solar simulator. An industrial grade CCD camera will be mounted on the frame of the simulator with a line of sight nearly perpendicular to the opening of the reactor.

Calibration

To calibrate the CCD camera, a water cooled, diffusely coated, flux target (shown below) will be placed at the focal point with a point radiometer capable of measuring flux levels upwards of 5000 kilowatts per square meter in the center. A picture will be taken of the target and, knowing the flux at a specific point, the gray scaling on the image will be translated into a flux scale.

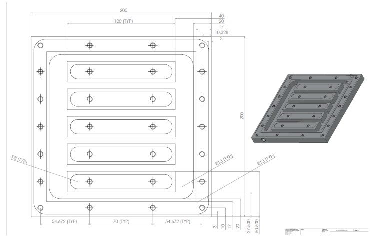

Figure 5: Schematic drawing of the aluminum flux target showing the internal channels used for water cooling. A plain aluminum plate will be attached to the back of the target to provide a seal. The front of the target will be coated with a diffuse, highly reflective Al_2O_3 coating. The water cooling will remove any heat absorbed by the target, keeping it near room temperature.

Other Work

Monte Carlo Program

A free and open source Monte Carlo ray tracing program will be used to verify the results from the CCD camera flux measurement system. This program has been used extensively in the past during the optical design of the simulator.

Inverse Problem

It is crucial to know an intensity distribution at the aperture rather than a flux distribution. The intensity distribution gives a directionality that the flux map lacks. However, the intensity distribution cannot be measured directly. A method for translating multiple flux maps at varying distances from the focal point into an intensity distribution is currently being developed. The solar simulator at UF will be used to verify the forthcoming mathematical representation of this transformation.

Bibliography

[1] J. Petrasch, "A free and open source Monte Carlo ray tracing program for concentrating solar energy research", Proceedings of the ASME 2010 4th International Conference on Energy Sustainability, ES 2010, May 17-22, 2010 Phoenix, Arizona, USA
[2] J. Petrasch et al., "A Novel 50 kW 11,000 suns High-Flux Solar Simulator Based on an Array of Xenon Arc Lamps," Journal of Solar Energy Engineering, vol. 129, no. 4, pp. 405-411, Nov. 2007.