TEL AVIV UNIVERSITY

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Analysis of a ceramic foam solar volumetric receiver

A thesis submitted toward the degree of
Master of Science in Mechanical engineering

by

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This research was carried out at the School of Mechanical Engineering
under the supervision of Prof. Abraham Kribus

October 2014
Abstract
High conversion efficiency is a key to the success and competitiveness of solar thermal power plants, and it can be achieved with cycles based on gas turbines and combined cycles that may reach around 30% solar-to-electricity efficiency. This requires the difficult task of heating air with solar radiation to over 1,000°C for the gas turbine inlet. Volumetric receivers made from porous ceramic structures can reach these temperatures but currently their radiation-to-heat conversion is low, typically around 70% rather than the desirable range of over 90%. Modeling of radiative and convective heat transfer in a volumetric receiver enables analysis and optimization of the various geometric and material-dependent properties to achieve a significant performance improvement.

This study investigates the possible performance of a ceramic foam based volumetric absorber as a function of geometric and material properties. A simplified one-dimensional model with effective homogeneous properties was developed using MATLAB, to represent the porous medium of the absorber. The method of Discrete-ordinates was used for modeling the radiative transport problem and non-equilibrium heat transfer correlations were applied. A validation of the model was initially made against a more detailed Monte-Carlo simulation and secondly via experiments.

This model is simple enough for fast computation and parametric study and the results reveal several guidelines for improving the receiver design. Optimization of geometry is insufficient. Improved efficiency requires a significant increase in convection heat transfer beyond the normal behavior of ceramic foams, and a reduction in thermal conductivity. Finally, spectral selectivity of the absorber material can also contribute in further increase of efficiency, in contrast to the common opinion that it is effective only at relatively low temperatures.

A significant conclusion revealed by the results of this study shows that there is no actual physical barrier that defines the upper limit of an absorber performance. Therefore, with proper selection of parameters including perfect spectral selectivity, the absorber performance can reach close to 100% efficiency. This conclusion indicates that poor performances recorded in real volumetric absorbers tested up to date, was due to a lack of proper optimization in geometrical and material properties.

Commercially available ceramic foams used as volumetric absorbers offer a limited range of materials and geometry, and insufficient heat transfer capabilities. In order to
increase absorbers efficiency, a future development of tailored ceramic porous structures with recommended features and properties is essential. This task will require new fabrication methods to achieve the desired properties of the porous structure.