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# Experimental evaluation of a novel solar receiver for a micro gas-turbine based solar dish system in the KTH high-flux solar simulator

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ABSTRACT

This work presents the experimental evaluation of a novel pressurized high-temperature solar air receiver for the integration into a micro gas-turbine solar dish system reaching an air outlet temperature of 800 °C. The experiments are conducted in the controlled environment of the KTH high-flux solar simulator with well-defined radiative boundary conditions. Special focus is placed on providing detailed information to enable the validation of numerical models. The solar receiver performance is evaluated for a range of operating points and monitored using multiple point measurements. The porous absorber front surface temperature is measured continuously as it is one of the most critical components for the receiver performance and model validation. Additionally, pyrometer line measurements of the absorber and glass window are taken for each operating point. The experiments highlight the feasibility of volumetric solar receivers for micro gas-turbine based solar dish systems and no major hurdles were found. A receiver efficiency of 84.8% was reached for an air outlet temperature of 749 °C. When using a lower mass flow, an air outlet temperature of 800 °C is achieved with a receiver efficiency of 69.3%. At the same time, all material temperatures remain below permissible limits and no deterioration of the porous absorber is found.



## 1. Introduction

Small-scale concentrating solar power plants such as micro gas-turbine (MGT) based solar dish systems have the potential to harness solar energy in an effective way and supply electricity to customers in remote areas.

One of the key components in such a solar dish system is the solar receiver as it is exposed to high light fluxes and needs to operate at high temperatures to achieve a high conversion efficiency. Previous studies have mainly focused on receivers coupled with Stirling engines [1,2], which are not compatible with MGTs. Studies concerning solar receivers for gas-turbine application mainly investigated designs for solar towers with largely different radiative boundary conditions [3–7]. Additionally, most of the studies aim at large-scale applications, with sizes ranging from 250 $kW_{el}$ [8] up to around 25 $MW_{el}$ [9] as compared to solar dish MGTs with an electrical output in the region of 10 $kW_{el}$. As such, these receiver designs are not directly usable for the integration with a solar dish concentrator.

Previous receiver design studies specifically targeting the integration into a solar dish system often focus on numerical evaluations without experimental validation [10–13]. The investigation conducted by Zhu et al. [14] tests a solar air receiver for MGT-coupling but only reaches air outlet temperatures in the region of 450 °C, which is too low to operate a MGT efficiently [15]. Another recent experimental air receiver investigation performed by Wang et al. [16] reaches more significant temperature levels in the region of 730 °C. However, the radiative boundary conditions in terms of the solar flux distribution and power available at the receiver aperture are not fully characterized, which are essential to determine the receiver performance, especially the efficiency. Furthermore, the study does not present the pressure drop across the receiver, which is necessary for a full characterization of the receiver performance as gas-turbines are particularly sensitive to pressure losses [17,18]. At the time of writing, no experimental data is available measuring the absorber front surface temperature of a pressurized volumetric solar receiver designed for the integration into a solar dish concentrator. This temperature strongly affects radiation losses and thus the receiver performance. For a

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meaningful validation of numerical models the front surface temperature of the directly irradiated surface is crucial.

In light of the above, the main objective of this work is to evaluate the performance of a novel high-temperature solar air receiver capable of reaching air outlet temperatures of up to 800 °C experimentally in the controlled environment of the KTH high-flux solar simulator (HFSS) with well-characterized boundary conditions. Special focus is placed on determining the boundary conditions present during the experiments. Additionally, a large number of measurement points is included in the test-setup to allow a complete performance analysis. Finally, detailed specifications of the solar receiver design, the measurement points taken and boundary conditions are included to offer readers the possibility to use the experimental data for validation of their numerical models.

## 2. Solar receiver

### 2.1. Prototype

In this work a receiver concept established in previous publications [19,20] is used. Initially, the concept was developed for the integration into a solar dish concentrator similar to the Eurodish [21] and was then adapted for the integration into the OMSoP solar dish concentrator [22–25]. In the full-scale OMSoP system, a parabolic dish concentrator provides heat input to the solar receiver, which is coupled to a recuperated MGT power conversion cycle as was shown in previous work [20].

The concept is outlined in Fig. 1 where the porous absorber (red) is placed behind a transparent glass window (yellow) to separate the working fluid from the exterior. The absorber is heated by concentrated solar radiation that passes through the window and is absorbed inside the volume of the absorber. Preheated air enters the receiver at the side, is distributed around the circumference in an inflow mixing box and is then redirected towards the glass window, cooling it. The inflow mixing box was specifically designed to ensure circumferentially uniform flow distribution through the absorber. It can be seen in Fig. 1 that flow dividers (transparent green) are installed at the symmetry plane to improve the flow distribution. Finally, the air is heated by the porous absorber as it passes through. Two exemplary streamlines are shown in Fig. 1 denoted by black dotted lines.

Fig. 2 shows the solar receiver prototype during the assembly without the front window flange. In order to avoid non-uniform deformation of the glass window, distance washers limiting the axial movement were designed and installed. Moreover, to minimize thermal stresses within the porous absorber it is mechanically decoupled from the surrounding components. This allows the absorber to expand independently with changing material temperatures.

### 2.2. Specifications

The solar receiver prototype used for the experimental evaluation was manufactured out of 253 MA with the main parameters summarized in Table 1. It shows that the aperture diameter as the most characteristic parameter is 152.5 mm. The company Heraeus supplied a 10 mm thick synthetically fused Suprasisl CG silica glass window with a diameter of 240 mm and Engicer a SiSiC open cell absorber with an average porosity of 85% and a cell diameter of 5 mm. In this prototype the absorber is mounted at a fixed depth inside the supporting pipe and is placed 11.5 mm behind the glass window. Thus, the distance $L_n$ restricting the air inlet to the cavity between the glass window and the absorber is 11.5 mm as well.

In previous work the effects of scaling were investigated to ensure that the receiver testing results in the HFSS are representative compared to tests performed in the full-scale solar dish [20]. Therefore, the receiver is placed 56 mm behind the HFSS focal plane.

## 3. Experimental setup

In this section, the main experimental equipment used for the receiver evaluation is presented. This includes the setup for the receiver testing as well as the setup for the determination of the radiative boundary conditions.

All tests are performed in the KTH HFSS [26,27] which is based on a circular array of 12 high-power xenon-arc lamps fitted with Fresnel lens concentrators. At full capacity it delivers a peak radiative flux of almost 7 MW/m$^2$ and radiative power of 18 kW at the focal plane within an aperture diameter of 300 mm [28]. The main

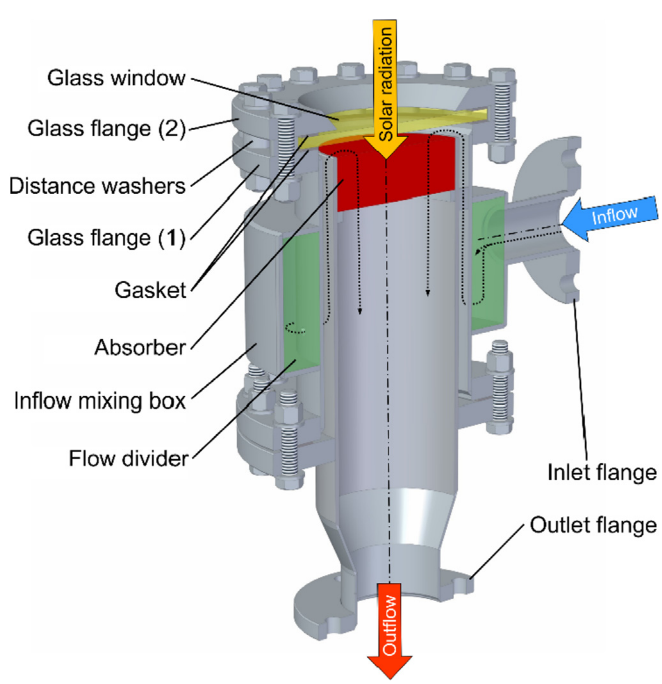


**Fig. 1.** Solar receiver design.

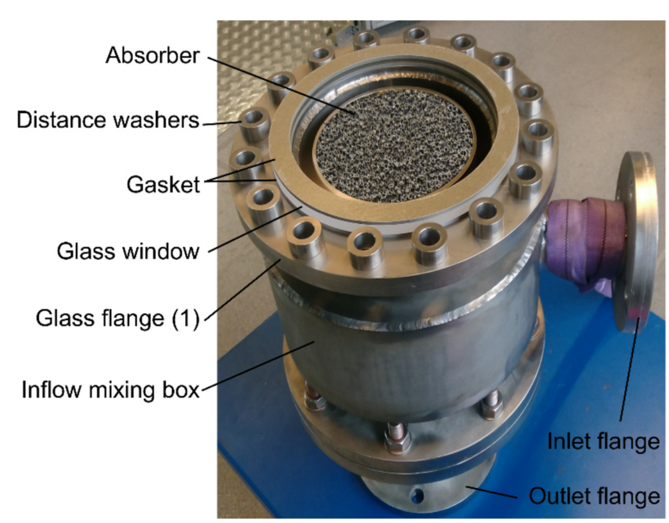


**Fig. 2.** Solar receiver prototype.