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Linear focus solar simulator test bench for non-destructive optical efficiency testing of parabolic trough receivers

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Abstract

This paper describes a new 2nd generation linear focus solar simulator test bench. The test bench is used for the non-destructive calorimetric measurement of relative optical efficiency of parabolic trough receivers. Compared to the predecessor, the test bench has been optimized for faster measurement, better long term stability and easier operation. The test bench optics is an elliptical shaped glass mirror trough with flat end mirrors. The receiver and six solar simulator lamps, metal halide lamps with 2.5 kWe each are located in their respective focal lines. Absorbed power is measured via temperature increase of the water flowing through the receiver and the mass flow rate. By comparison to the absorbed power of a reference receiver, the optical efficiency of a sample can be determined relative to the optical efficiency of the reference receiver.

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1. Introduction

The receiver is a key component in the parabolic trough solar thermal power plant. Hence test benches for the non-destructive measurement of the thermal and optical performance of parabolic trough receivers have been developed at several institutions in the last years. A non-destructive measurement, in contrast to a destructive measurement of the absorber and glass envelope individually – offers two main advantages: The receiver is

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measured as a unit; hence the measurement can include all interactions within the receiver. Secondly the intellectual property of the manufacturer can be protected more easily.

For the optical measurement a variety of test methods have been developed: At CENER, Spain a spectrophotometric measurement system was developed [1], [2], compare Fig. 1 a. Optical heads, which are connected to a light source and a spectrophotometer, are used to measure transmittance of the glass envelope and the reflectance at the absorber surface trough the glass. From these measurements the absorptance of the absorber can be deduced. At NREL, USA an outdoor test bench for the calorimetric measurement of the alpha-tau product was developed and tested [6], compare Fig. 1 b. The receiver is filled with aluminum, positioned in the sun, and the aluminum temperature is measured. The alpha-tau-product can be calculated from the heat-up speed, heat capacity and irradiance.

At DLR, Germany, the development of an elliptical solar simulator receiver test bench, called ElliRec, was started in 2008 [3], [4], [5], compare Fig. 1 c. This test bench also works on a calorimetric principle. The enthalpy increase of water flowing through an irradiated receiver is used as a measure of optical efficiency. The advantage of the approach is that due to the laboratory-type measurement reproducibility is achieved ~0.2 % (1σ). The disadvantages, on the other hand are, that the spectrum of the lamps only approximate that of relevant norms like the ASTM 173 d and that the incidence angles on the receiver are basically given from the test bench design and can only be influenced with difficulty.

The 1st generation test bench has successfully approved in a multitude of industrial assigned test campaigns. Hence it was decided to develop an optimized 2nd generation test bench, called OptiRec, which is based on the same principles, but is improved regarding the handling and measurement accuracy. This paper describes basic features of the test bench. 1st measurements at DLR are scheduled for late summer 2014 and could not be part of this paper.

Nomenclature

C_p	Specific heat capacity in J/(kg K)
P_{coll}	Enthalpy increase of heat transfer fluid in collector or receiver in W
$P_{coll,sample}$	Enthalpy increase of heat transfer fluid in sample receiver in W
$P_{coll,DLR70-1}$	Enthalpy increase of heat transfer fluid in reference receiver DLR70-1 in W
P_{in}	Radiation power incident on the receiver in W
$P_{th,loss}.$	Heat loss power of the receiver in W
$\eta_{opt,rec}$	Optical efficiency of the receiver, including geometric losses at the bellows, without unit
RT	Room temperature in K
ΔT	Temperature increase of water in K
$\dot{V}$	Flow rate of water in m^3/s

2. Method

The fundamental parameters, that describe the performance of parabolic trough receivers in the field, are optical efficiency $\eta_{opt,rec}$ and heat loss $P_{th,loss}$. Both are part of the energy balance of the receiver

$$P_{coll} = \eta_{opt,rec} \cdot P_{in} - P_{th,loss}. \quad (1)$$

In the equation P_{coll} is the enthalpy increase in the heat transfer fluid and P_{in} the radiation power intercepted by the receiver.

In the laboratory test described in this paper, the primary measurement instruments are three temperature sensors at the water inlet and at the outlet each and a mass flow meter. From mass flow rate $\dot{m}$, specific heat capacity C_p and temperature increase ΔT the enthalpy increase P_{coll} is calculated, while pressure drop is neglected using $P_{coll} = \dot{V} C_p \Delta T$. As water temperature is slightly below ambient temperature during the test, heat loss $P_{th,loss}$ is

a b c

Fig. 1 (a) Optical path of transmittance and reflectance measurement at CENER [2] (b) Calorimetric outdoor test bench at NREL [6] (c) Scheme of linear focous solar simulator receiver test bench at DLR

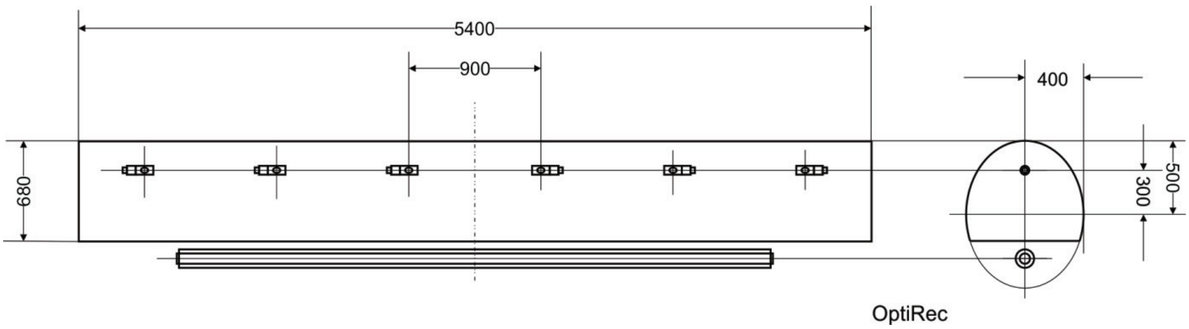


Fig. 2 Dimensions of the test bench optics

neglected. The incoming power is difficult to measure with the necessary accuracy. Therefore a reference receiver DLR70-1 is measured at the same day to serve as a stable reference. Hence the optical efficiency is given relative to the optical efficiency of a reference receiver DLR70-1 at room temperature RT.

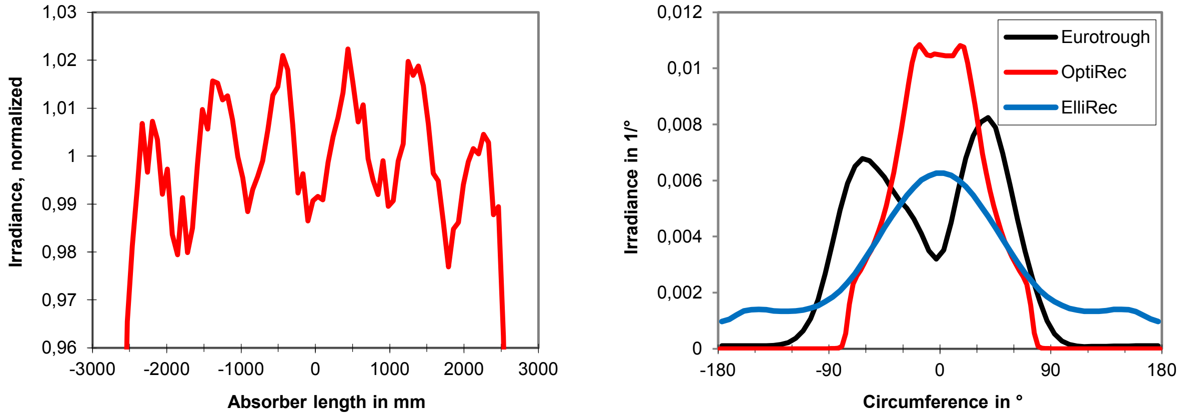
$$\eta_{opt,rec}(\text{sample}, RT) = \frac{P_{coll,sample}}{P_{coll,DLR70-1}} \cdot \eta_{opt,rec}(\text{DLR70-1}, RT) \quad (2)$$

3. Test bench

The goals for the development of the new test bench were to reduce test bench size, achieve better long term stability, allow for an exchange of the receiver during lamp operation and simplify the test bench for an easier reproduction in industry and other measurement institutes.

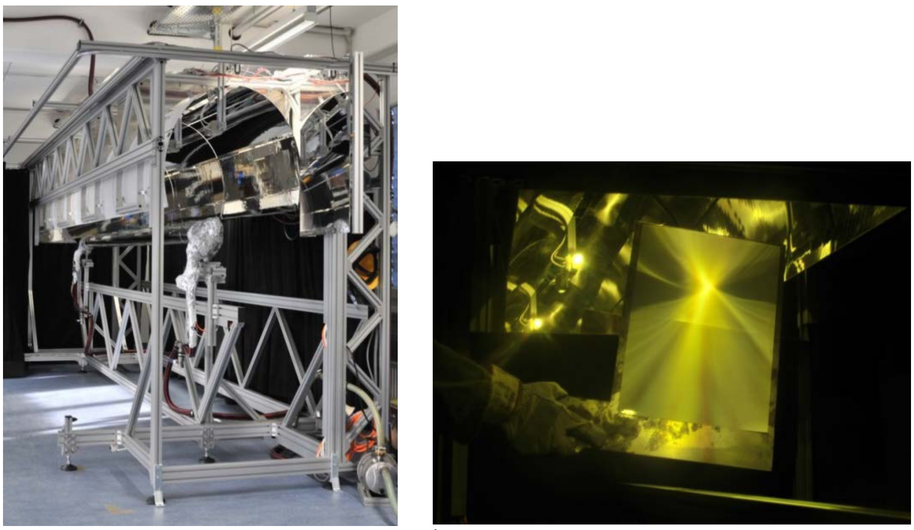
Using the raytracing program OptiCad the optical configuration was optimized for a homogenous flux distribution along the focal line on a length of 5000 mm. The result is shown in Fig. 2: Using six instead of two lamps the ellipse could be significantly reduced in size from 1000 mm to 500 mm for the semi-major axis. A vertical semi-major axis and an opening at the bottom allows for an easy exchange of the receiver.

Fig. 3 a shows the calculated irradiance distributions on a 70 mm receiver in the focal line along the length of the receiver. The fluctuations of the irradiance are at the order of ± 2% at the 5000 mm useful measurement length.



a b

Fig. 3 (a) Irradiance in longitudinal direction, calculated by ray-tracing simulations on a 70 mm absorber along the focal line, normalized for the range -2500 mm to + 2500 mm, (b) Irradiance in circumferential direction, calculated by ray-tracing simulations for the OptiRec, the ElliRec (1st generation solar simulator) and a Eurotrough collector.



a b

Fig. 4 (a) OptiRec: 2nd generation linear focus test bench at DLR (b) Test on focus quality using the camera-target method

Fig. 3 b shows the irradiance distribution in circumferential direction. The data for the Eurotrough is based on measured data which explains the asymmetrical shape. The deviation from the typical two-lobe-pattern in the test bench is considered not problematic as receivers are primarily axi-symmetric devices. Small deviations due to shadowing of the getter for example can be corrected. A picture of the test bench (called OptiRec) is given in Fig. 4 a. The mirrors are glass mirrors manufactured by Flabeg. The opening of the ellipse at the bottom no only allows for an easy exchange of the receiver during operation, but also dust is prevented from settling down due to the mirrors hanging upside down and the chance of falling tools damaging the receiver is vastly reduced.

Solar simulator lamps are UV-block metal halide lamps manufactured by Koto, Japan. Six lamps, each with 2.5 kWe, are distributed equidistantly along the upper focal line. Flow rate is measured with a Coriolis-sensor and adjusted to (0.850 ± 5) kg/h. Temperature at the water inlet and at the water outlet is measured with three PT100 each. In order to achieve a homogeneous absorber temperature at the circumference of the absorber, a displacement cylinder is inserted into the receiver. The displacement cylinder is a cylinder of 55 mm (for receivers with 66 mm inner diameter) and a wire of 3 mm thickness wrapped around, which forces the water on a helical path inside the absorber and homogenized temperature around the circumference. The displacement cylinder has the added benefit of an improved heat transfer from the absorber to the water.

Currently pre-tests are conducted. Fig. 4 b shows a test on focus quality using a sheet of paper of size 30 cm x 21 cm. Fist measurements of receivers are expected for late-summer 2014.

Acknowledgements

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