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Second Generation Linear Focus Sun Simulator to Test Optical Performance of Parabolic Trough Receivers - OptiRec

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Abstract. This paper presents results from a characterization of DLR's second generation sun simulator test facility (OptiRec) for determining the optical performance of parabolic trough receivers. The configuration of the test bench is an elliptical mirror trough with flat end mirrors. Solar simulator lamps are situated in one focal line, the receiver in the other focal line. Water at ambient temperature flows through the receiver and allows for a calorimetric measurement of the absorbed power. Compared to the first generation test bench (ElliRec) the mirror material is changed from aluminum to glass, the ellipse size is changed and the handling is improved. Based on 34 measurements of the absorbed power the repeatability for OptiRec measurements is measured to 0.13% (1σ), compared to 0.2% in the ElliRec. Seven receivers from different manufacturers are measured in both test benches yielding consistent relative optical efficiency with <1.1% deviation. Particular differences are larger than the repeatability, which are attributed to differences in spectra and incidence angles between both test benches.

INTRODUCTION

Parabolic trough receivers being one of the key plant components, their performance is of interest to all parties involved in CSP power plant projects from component manufacturers to project developers and investors. Hence, a number of test facilities and procedures for parabolic trough receivers have been established outside of the manufacturers own quality control [1-6]. The main focus typically lies on measurement of thermal loss, optical performance, testing for optical and thermal degradation and bellow fatigue.

The optical performance of parabolic trough receivers is typically characterized by means of nondestructive tests with spectrophotometric [1, 2], calorimetric measurements using solar simulators [3-5] or outdoor tests [6]. At DLR a first generation linear focus solar simulator (ElliRec) was built in 2009. The ElliRec enables the assessment of sample receivers relative to a reference receiver. A successor test bench to the ElliRec, the OptiRec, first presented 2015 in [5], enables similar tests, but is optimized for better short- and long-term stability resulting in higher accuracy and repeatability as well as improved handling that results in shorter testing times.

SET-UP

The test facility optics consists of an elliptical shaped glass mirror trough with flat end mirrors. Radiation of six metal halide lamps in the first focal line with a total power of 15 kW_e is concentrated on a parabolic trough receiver in the second focal line. A view into the test facility is shown in Figure 1. Using glass mirrors, the OptiRec optics

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achieves better form stability and durability of the reflector compared to the aluminum mirrors in the ElliRec test bench. Additionally, glass mirrors improve the spectral match to conditions in the solar field by cutting IR-radiation from the lamps. Two parallel receiver support assemblies placed on a linear stage allow for the continuous operation of the test facility keeping the lamps turned on while changing receivers.

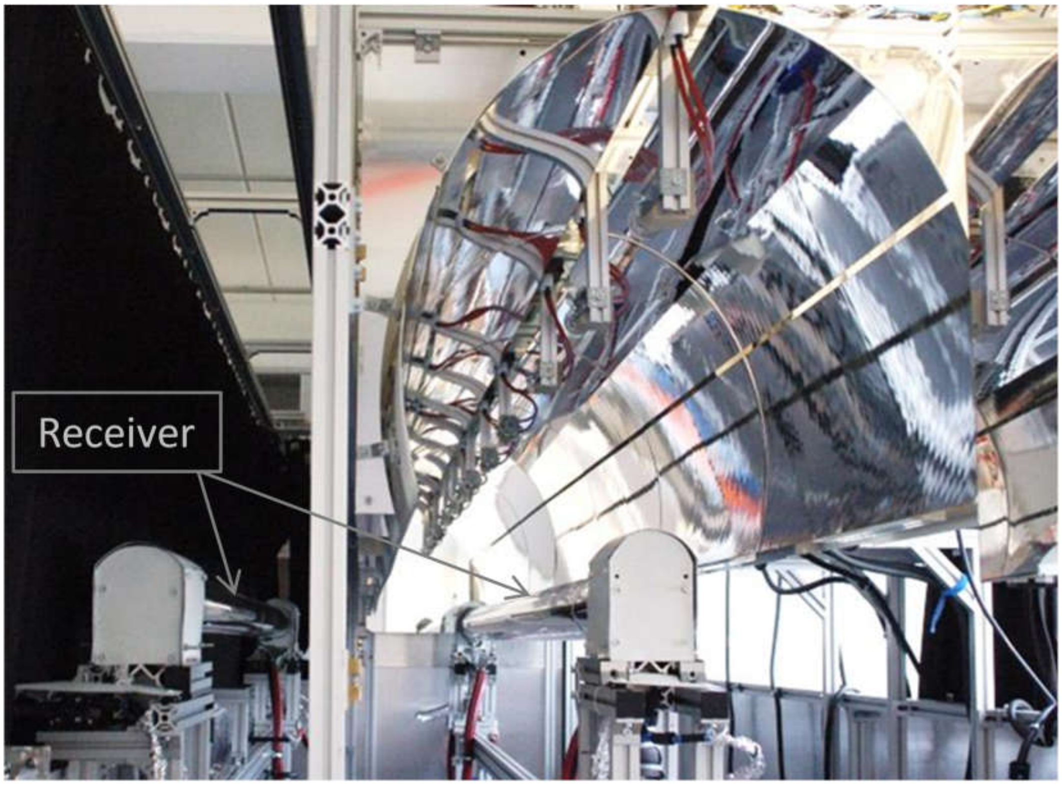

FIGURE 1. OptiRec test facility with mounted receivers
(left receiver corresponds to position A and right receiver to position B in Figure 2)

The absorbed power is determined from the measured temperature increase of water flowing through the receiver and its mass flow rate, as shown in Figure 2. The hydraulic circuit is designed to provide a constant mass flow rate and constant water temperature at the inlet of the receiver.

The measurement of optical efficiency of a sample receiver consists of a comparison of the absorbed power for the sample receiver to that of a reference receiver. The resulting value for the absorbed power of a receiver corresponds to the mean value of a five minute testing period after a five minute equalization phase. The optical efficiency of the sample is hence determined relative to the optical efficiency of the reference receiver.

In the current operation mode receiver position A is used for both the measurement of the reference receiver and the sample receiver, compare Figure 2. A typical receiver test for optical efficiency at the OptiRec consists of three calorimetric measurements in receiver position A: first reference measurement, sample receiver measurement and second reference measurement.

The receiver mounted in position B is used to monitor the stability of the OptiRec in terms of lamp radiation and ambient conditions.

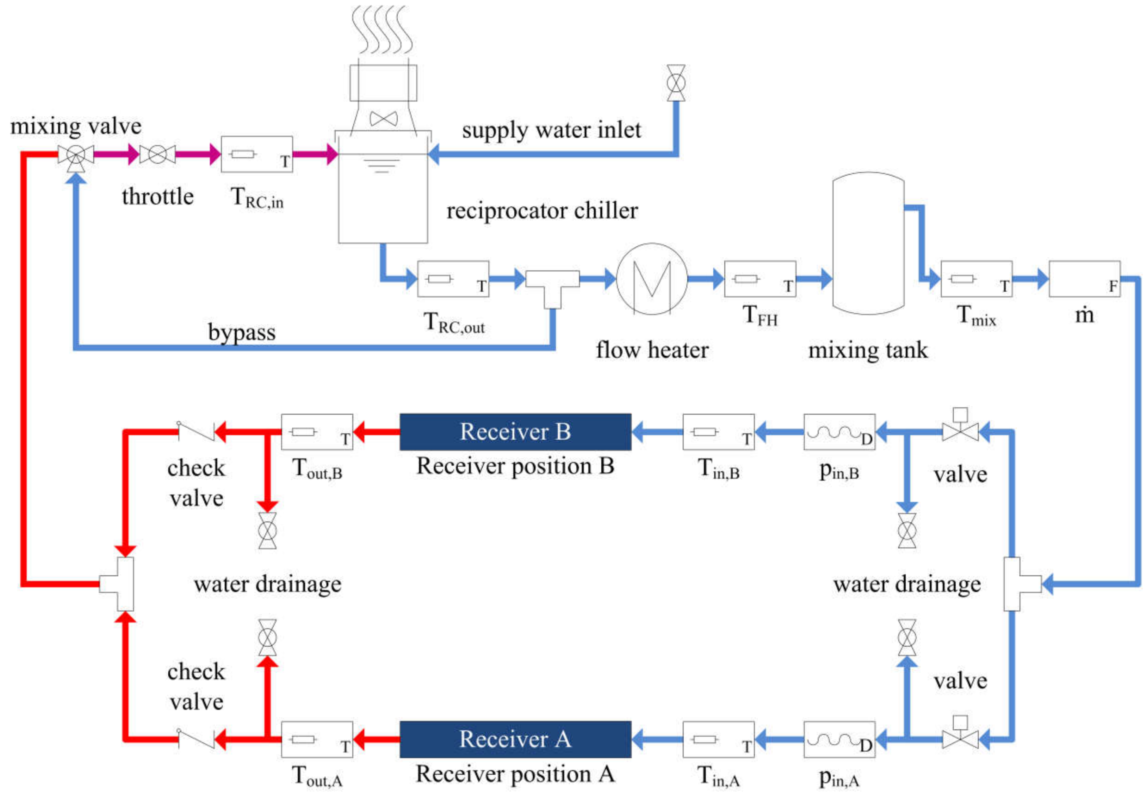

FIGURE 2. Hydraulic circuit

CHARACTERIZATION OF THE TEST BENCH

Following commissioning and start-up described in [5], the test facility is characterized with regard to the influence of the receiver shields, the repeatability of a measurement, and a comparison between the first and the second generation test bench.

Influence of Receiver Shields

In sun simulator tests, just like in the solar field, shields are used to protect sensitive areas of the receivers from concentrated radiation. Hence, in the standard procedure of the first generation test bench, shields provided by the manufacturers are considered being part of the receiver and thus are included in the measurements. However, it was discovered, that there can be distorting effects at the shields that occur in the solar simulator test bench, but not in the solar field. These effects can be related to shadowing at shields due to differences between incidence angles in field and test bench, or radiation reflected at the shields reflected back into the aperture of the receiver due to the optical properties of the ellipse. To minimize these influences, test bench related shields (OptiRec shields) were developed, that are adjusted to each receiver design. OptiRec shields are white-painted, cylindrical aluminum sheets that are latched around the receiver bellow, as can be seen in Figure 3. The shields cover the gap between receiver and receiver mount and thereby protect this region from additional heat intake. The length of the shield can be expanded in order to protect the glass-to-metal seal and the bellow of the receiver – without changing the effective aperture of the receiver.

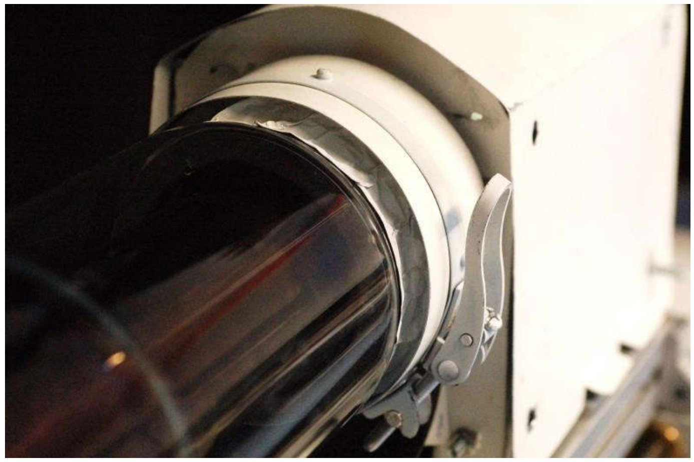

FIGURE 3. OptiRec receiver shield

Three receivers from two different manufacturers were measured repeatedly both with detachable manufacturer shields (MS) and with OptiRec shields (OS) in order to compare the results obtained using the two test benches (with the former MS configuration) and characterize the impact of the new OS configuration used for future OptiRec testing. For the shields of manufacturer a, a significant influence due to shadowing effects was expected. For manufacturer b, the influence of shields was supposed to be minor. Table 1 shows normalized average optical efficiency $\eta_{opt,rec}$ and standard deviations. Each average value is based on two to eight individual independent measurements (each individual measurement itself is consisting of a series of three measurements reference-sample-reference, compare description of the set-up above).

TABLE 1. Normalized optical efficiency in OptiRec with detachable shields from the manufacturer $\eta_{opt,rec,MS}$ and with OptiRec shields $\eta_{opt,rec,OS}$, both related to the mean optical efficiency $\eta_{opt,rec,mean}$ for each receiver i, ii, and iii

Rec-eiver	Manu-facturer	Manufacturer shields			OptiRec shields			Deviation
		$\frac{\eta_{opt,rec,MS}}{\eta_{opt,rec,mean}}$	no of meas.	Stdv	$\frac{\eta_{opt,rec,OS}}{\eta_{opt,rec,mean}}$	no of meas.	Stdv	$\frac{\eta_{opt,rec,OS}-\eta_{opt,rec,MS}}{\eta_{opt,rec,mean}}$
i	a	0.996	2	0.007	1.003	3	0.002	0.007
ii	a	0.992	2	0.002	1.008	2	0.001	0.015
iii	b	0.999	6	0.004	1.001	8	0.000	0.001

As shown in Table 1, standard deviations of the measurements results are larger with detachable manufacturer shields compared to the use of OptiRec shields. Furthermore, detachable shields form the manufacturer decrease optical efficiency. Therefore, OptiRec shields will be used in OptiRec measurements. The impact of a particular shield on the performance in the solar field must be analyzed separately. As OptiRec shields only cause a minor shadowing effect, the analysis of conditions in the field can be reduced to adding geometric considerations to the measurement results.

Repeatability

The repeatability of optical receiver tests in the OptiRec test bench was characterized by a measurement series on five testing days. The absorbed power of a receiver was measured repeatedly in receiver position A, including reassembly. During reassembly in position A, another receiver was measured in receiver position B. That receiver was not reassembled between measurements yielding information about the repeatability of the assembly process. The resulting standard deviation for receiver position A is 0.13%, compare Figure 4 a), while standard deviation for receiver position B is 0.10%, compare Figure b). As the deviation between both receiver positions is small, a further optimization of the assembly process is not considered necessary. Compared to the standard deviation of approximately 0.2% in the ElliRec test bench, the precision of the OptiRec is distinctively higher.

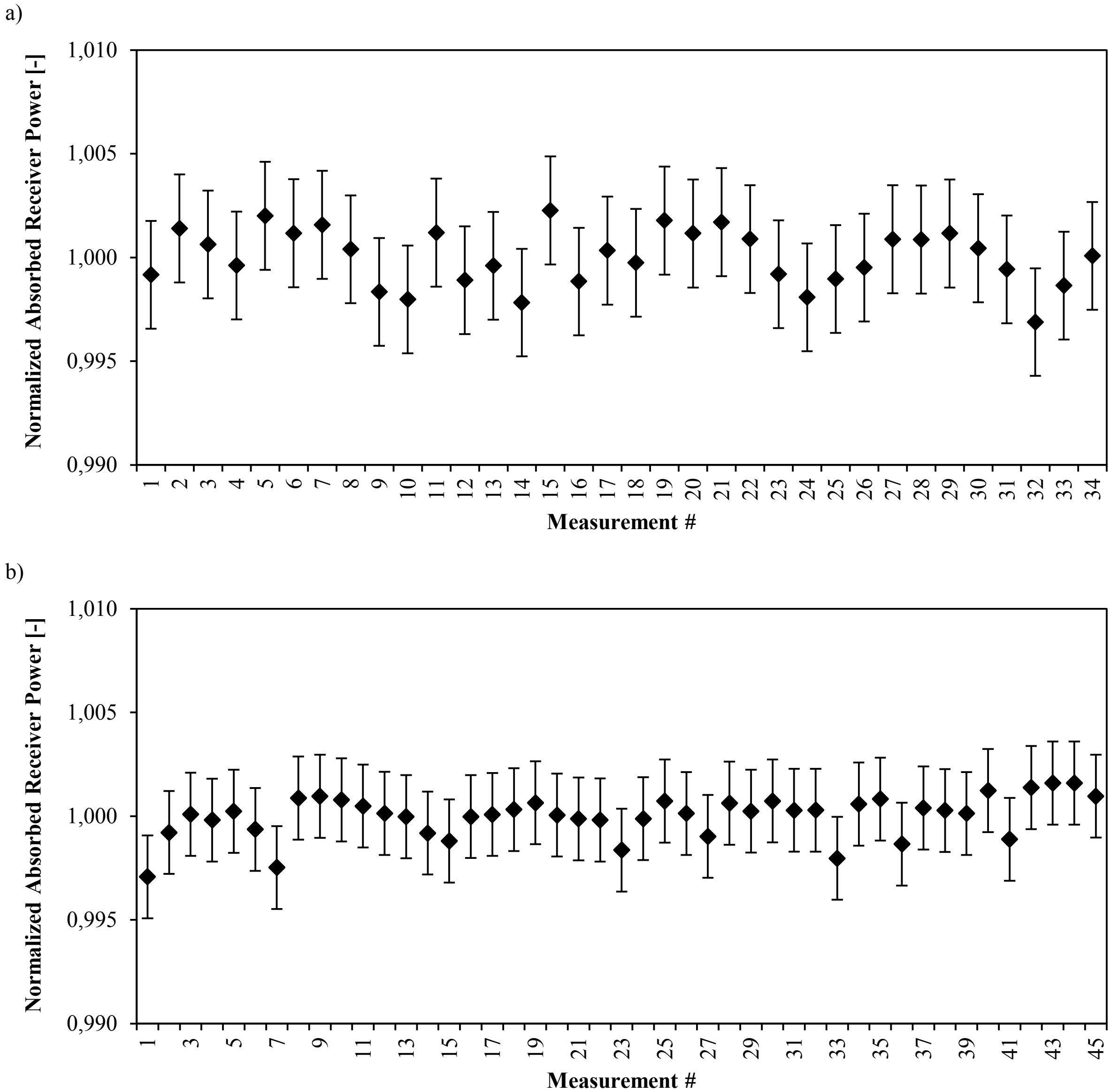

FIGURE 4. Repeatability study of the OptiRec test facility, a) including reassembly of the sample receiver and stdv: 0.13%, b) without reassembly of the reference receiver and stdv: 0.10%, error bars are 2σ measurement repeatability

Validation

First and second generation test benches differ in reflector material and geometry of the ellipse. This results in slight changes in incidence angle distribution and spectrum. The glass reflectors of the OptiRec, compared to the aluminum reflectors in the ElliRec, provide a higher reflectance in the UV, VIS, NIR, and a lower reflectance at wavelengths > 2600 nm. For a comparison, seven receivers from four manufacturers are measured in both test benches. In order to be able to directly compare the results, the detachable shields provided by the manufactures were used in the ElliRec and the OptiRec for this campaign, while in future campaigns the OptiRec shields will be used. Results are shown in Figure 5. Error bars indicate repeatability according to the previous section and results shown in Figure 4a), which include one measurement of a sample receiver and two measurements of the reference receiver. According to the propagation of uncertainty, the repeatability of the optical efficiency that is calculated from these three measurements is 1.22 times the repeatability of one single measurement.

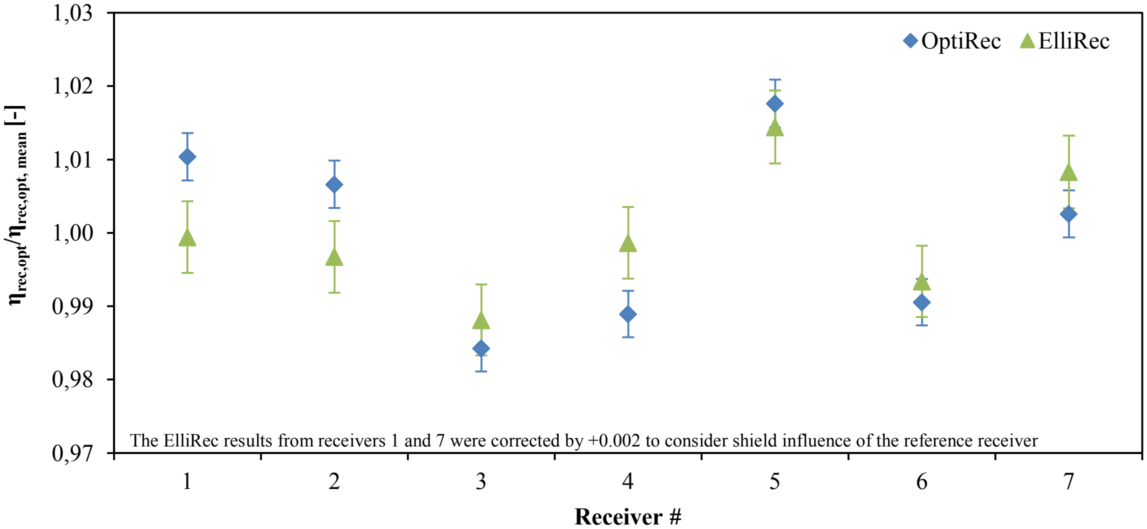

FIGURE 5. Comparison of normalized relative optical efficiencies measured for sample receivers at DLRs sun simulator test benches ElliRec and OptiRec, related to the mean of all results (reference DLR70-1, error bars are 2σ repeatability)

The relative optical efficiencies obtained for the different receivers in both test benches mostly agree within 1.1%. For four of the seven receivers the error bars (2σ) overlap. There is no systematic shift between the results of both test benches and therefore no simple conversion of results possible. OptiRec results are spread more widely for high and low performing receivers as the standard deviation over all receivers within one test bench is 1.2% for the OptiRec and 0.8% for the ElliRec results.

CONCLUSIONS

The OptiRec test bench was thoroughly characterized and validated with the predecessor test bench ElliRec. Through the capability of replacing the receiver without shutdown of the lamps the measurement time could be reduced from approximately three hours in the ElliRec to one hour in the OptiRec. The repeatability of the test bench of 0.13% (1σ) is improved compared to the predecessor with 0.2%. Both factors allow for a better identification of ambient influences on the measurement and better distinction between receivers. The intercomparison campaign showed that the results for relative optical efficiency agree within 1.1%, for most of the receivers the results overlap within the associated repeatability interval. The differences in result values meet expectations and are attributed to differences in spectra and incidence angles. There is no systematic shift between the results of both test benches and therefore no direct conversion of results possible.

Furthermore, the test results confirm a significant influence of the receiver shield configuration favoring standard, diffuse reflecting, tightly fixed shields in order to obtain a high repeatability. Taking into account systematic differences between the irradiance incidence angles in field and test bench, the measurement method to be established for the OptiRec will differ from the one of the ElliRec by using standard white minimum shields.

OUTLOOK

As a validated test facility with high repeatability the OptiRec enables an easier assessment of optical receiver performance with high quality.

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