DEVELOPMENT OF RECEIVERS FOR THE DSG PROCESS

Nikolaus Benz[1], Markus Eck[2], Thomas Kuckelkorn[1], Ralf Uhlig[2]

[1]SCHOTT Rohrglas, Erich-Schott-Str. 14, 95660 Mitterteich, Germany

[2]*German Aerospace Center (DLR), Institute of Technical Thermodynamics, Pfaffenwaldring 38-40, 70569 Stuttgart, Germany, Tel.: +49 (0) 711/6862 429, Fax: +49 (0) 711/6862 747, markus.eck@dlr.de*

Abstract

The direct steam generation (DSG) in parabolic trough collectors is a promising option for improving the mature SEGS type parabolic trough solar thermal power plant technology. The European DISS and INDITEP projects have proven the feasibility of the DSG process in parabolic trough collectors under real solar conditions at the life size DISS test facility at the Plataforma Solar de Almería (PSA). Because of this successful demonstration the erection of the first DSG demonstration plant is expected for the near future. So far no commercial parabolic trough receivers, also known as heat collecting elements (HCE), are available for the DSG process. These receivers would have to withstand a higher operation pressure since the operation pressure of the receivers is equal to the life steam pressure of the power cycle which can be 100 bar and more. Furthermore the thermal load of the receivers is higher since the heat transfer in the superheating section of a DSG collector loop is worse than that of SEGS type collector loops. To solve this problem SCHOTT Rohrglas has decided to adapt their receivers to the specific needs of the DSG process. In collaboration with the German Aerospace Center (DLR) necessary modifications were identified and integrated into the design of the SCHOTT receiver. Prototypes of the receivers have been manufactured. The paper presents the design of the DSG receivers for the first time.

Keywords: parabolic trough receiver, parabolic trough, direct steam generation

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Introduction

A new feed-in-law in Spain from March 2004 supports the erection of solar thermal power plants in Europe for the first time [1]. Due to this feed-in-law several projects are under development to utilize the huge solar thermal power potential in Spain. These projects use different solar thermal power technologies such as a solar tower in the PS-10 project [2] or SEGS type parabolic troughs in the so called ANDASOL project [3].

In the European R&D project INDITEP a Spanish/German consortium, lead by Spanish utility Iberdrola, has performed the detailed engineering of a 5 MW parabolic trough plant applying the direct steam generation (DSG) in the collector field [4]. The DSG process is a promising option to reduce costs of parabolic trough solar thermal power plants. The feasibility of the DSG process in horizontal parabolic trough collectors was already proven in the DISS project [5] and the valuable experience and know how acquired in DISS was applied in the project INDITEP to design the first pre-commercial DSG solar power plant, where superheated steam directly produced in a solar field will be used to feed a Rankine cycle. The detailed engineering resulted in life steam parameters of 65 bar and 400ºC [1].

The applied direct steam generation in the receivers make greater demands on the stability of the receivers used. So far no receivers are available on the market place that withstand the higher operation pressure and thermal load of the DSG process. To close this technological gap the German R&D project DIVA aims at the development of a DSG receivers for an operation temperature of 400°C and an operation pressure of 100 bar. This higher operation pressure is chosen since is the design pressure of the DISS test facility at PSA where the receivers will be tested under real solar conditions.

In another work package of DIVA basic research is conducted to develop a receiver and selective coating for an operation temperature of 500°C. Furthermore the economic benefit of the DSG process is investigated for different plant sizes and operation parameters. This paper focuses on the development of receivers for near term applications with an operation temperature of 400°C.

Time Schedule

The schedule planned for the receiver development is presented in table 1. The activities have started in August 2005. DLR has designed the receivers in August and September. SCHOTT has ordered the receiver material in October. Due to the long delivery time of three to four months of the receiver material the receivers were manufactured by SCHOTT in February and March. Thereafter the receivers have been delivered to the PSA and integrated into the DISS test facility. The test program has started in April and will last until September 2007.

	2005					2006						2007	
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May		Aug	Sep
Design of receivers	■	■											
Ordering of Tube Material			■	■	■	■							
Manufacturing of Receiver Tubes							■	■					
Delivery and Integration into DISS								■	■				
Test Program										■	■	■	■

Table 1: Schedule planned for the receiver development

Receiver Design

The main difference between the DSG process and the state-of-the-art parabolic trough technology with a heat transfer fluid is the higher operation pressure and the lower heat transfer coefficient between fluid and receiver. These differences cause a higher thermal and mechanical load of the receivers. DLR has developed a three dimensional finite element model (FEM) to investigate the thermal and mechanical load of receivers for all relevant boundary conditions. Based on the results of the FEM analysis SCHOTT has designed and manufactured prototypes of DSG receivers.

Thermal FE- model

Because of the inhomogeneous flux distribution of the concentrated solar radiation a non-uniform temperature distribution in the receivers will appear. Accordingly a reliable analytic calculating of heat losses is not possible. For this reason a detailed analysis of the thermal behavior was performed using a three dimensional FEM tool considering the receiver and the glass envelope (see figure 1)*. The model was fully parameterized so variations of geometry, material and loads are easy to handle. The absorbed solar irradiation is modelled using the heat flux distribution of previous ray tracing calculations (see figure 2).

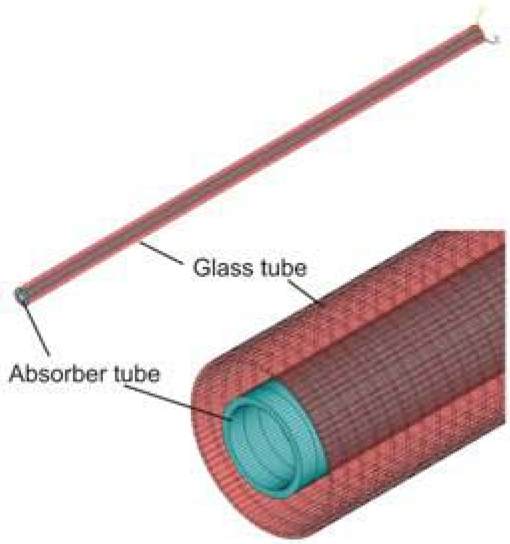

Figure 1: FEM model used for the analysis

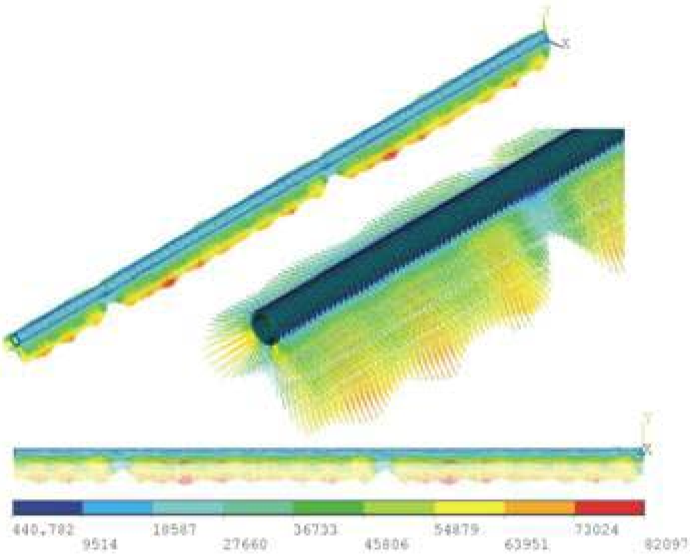

Figure 2: Distribution of the heat flux absorbed by the receiver (W/m^2K)

Infrared grey diffuse radiation exchange is modelled between the receiver and the glass envelope and between the glass envelope and the ambient. Finally the inner heat transfer is modelled with a heat transfer coefficient and a pre-defined fluid temperature. Heat conduction to other components (like suspension) is neglected. To show the possibilities of this tool it is applied to an receiver a parabolic trough collector with direct steam generation. The dimensions of the investigated receiver are displayed in table 2.

Description	Units	Value
outer diameter receiver	m	70e-3
wall thickness receiver	m	5.6e-3
outer diameter glass tube	m	125e-3
wall thickness glass tube	m	3e-3
tube length	m	4.06

Table 2: Dimensions of the investigated receiver

* For detailed information on receivers for parabolic trough collectors see e.g. [6] or [7]

Previous investigations (e.g. [8]) have shown that the most critical load of the receiver occurs in the superheating section with the lowest heat transfer coefficient and the highest operation temperature. Accordingly the presented study focuses on the superheating section of the collector loop only. The boundary conditions chosen for the FEM analysis are summarized in table 3.

Description	Units	Value
heat transfer coefficient (inner side receiver)	W/m^2K	1000
fluid temperature (inner side receiver)	°C	400
heat transfer coefficient (outside glass tube)	W/m^2K	7 / 15
fluid temperature (outside glass tube)	°C	20

Table 3: Boundary conditions for the FEM Analysis

The main result of the FEM analysis is the determination of the temperature distribution within the receiver. According to figure 3 the inhomogeneous heat flux distribution causes an inhomogeneous temperature distribution within the receiver. The temperature minimums in circumferential direction are caused by the gap between two adjacent mirrors of the collector (also visible in figure 2 as minimums in the heat flux distribution). The hot spots on the surface are likely caused by the wavy surface of the mirror facets used.

In the presented showcase the maximum temperature in the receiver is 83 K higher then the lowest temperature which is close to the fluid temperature. To reduce the thermal load of the selective coating of the receiver it is desirable to reduce the maximum surface temperature of the receiver. This can be achieved by either increasing the heat transfer coefficient between the receiver and the superheated steam or by modifying the dimensions or the material of the receiver.

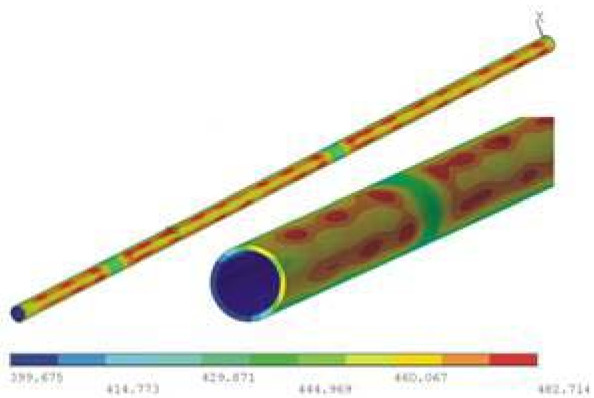

Figure 3: Temperature distribution receiver (°C) (no convection loss to ambient)

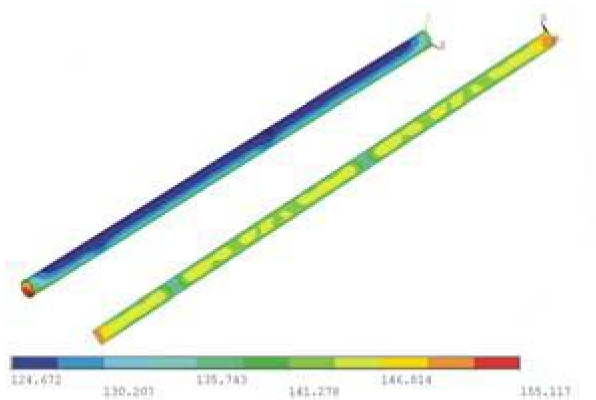

Figure 4: Temperature distribution glass tube (°C) (no convection loss to ambient)

In addition figure 4 displays the temperature of the glass envelope. If there will be no convective heat losses, the glass tube will have temperatures between 125°C and 155°C. Considering heat losses by radiation and convection reduces the temperatures in the glass tube to 84°C to 112°C. The temperatures of the receiver are not affected by considering convection. The results of this show case analysis are summarized in table 4.

		Convection outside glass tube			
Description	Units	α = 0	α = 7 W/m²K T_∞ = 20°C	α = 15 W/m²K T_∞ = 20°C	α = 30 W/m²K T_∞ = 20°C
max. temperature receiver	°C	483	483	483	483
min. temperature receiver	°C	400	400	400	400
max. temperature glass tube	°C	155	112	84	64
min. temperature glass tube	°C	125	84	61	47
absorbed heat receiver	kW	20.794	20.794	20.794	20.794
heat transferred to fluid	kW	19.309	19.237	19.201	19.195
heat loss by radiation (glass tube)	kW	1.664	0.824	0.514	0.315
heat loss by convection (glass tube)	kW	0	0.879	1.167	1.551
total heat losses	kW	1.664	1.703	1.681	1.866
rel. total heat losses	%	8	8.2	8.1	9
model error	%	0.9	0.7	0.4	1.2

Table 4: Results of the FEM Analysis convective heat losses of the glass envelope (α = 0; no convective heat losses)

Based on the presented determination of the temperature field of the receiver it is now possible to analyze resulting deformations and stresses to support the further design and optimization of receivers for parabolic trough collectors.

Manufacturing of Receivers

The Design of the DSG receiver is mainly similar to the Schott PTR 70 receiver with a length of 4060 mm, a glass tube diameter of 120 mm and a receiver diameter of 70 mm. The wall thickness of the absorber tube had to be adapted to the operation pressure of the steam process. The selective coating of the absorber is suitable for operation temperatures up to 400° C. The coating has a solar absorptance > 95% and a thermal emittance < 14%@400°C.

Figure 5: Photo of the SCHOTT Receiver

Conclusion

A FEM tool was developed for the detailed analysis of the thermal and mechanical behaviour of receivers for parabolic trough collectors. This tool is applicable to receivers used for the direct steam generation as well as for the state-of-the-art heat transfer fluid technology. Within the presented German R&D project DIVA this tool is used for the design of a first commercial receiver for the DSG process. Based on these results SCHOTT has manufactured prototypes of this receiver to be tested at the DISS test facility of the Plataforma Solar de Almería (Spain). The experimental investigation of the receivers under real solar conditions will last until end of 2007.

Acknowledgement

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