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The Synhelion Absorbing Gas Solar Receiver for 1’500 °C Process Heat: CFD Modeling

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Abstract. The present study focuses on the development of a computational fluid dynamics (CFD) numerical model suitable to replicate the thermo-fluid dynamics behavior of an innovative solar receiver developed by Synhelion SA. This new generation solar receiver concept, based on the direct absorption of thermal radiation by a gaseous heat transfer fluid (HTF), phenomena similar to the one responsible of the greenhouse effect, is designed to operate at temperatures higher than 1’000 K. In the proposed CFD model, developed exploiting Fluent code from ANSYS, the radiative heat transfer was described through the discrete ordinates radiation method with spectral variation of the participating medium (water vapor) radiative properties accounted for by the weighted-sum-of-gray-gases model. After being satisfactorily validated, the CFD model was exploited to run several CFD simulations campaigns to evaluate the effect of important parameters, such as operating pressure and HTF mass flow rate, on the absorbing gas receiver performance. Despite the very high operating temperatures considered, promising receiver thermal efficiency values (0.9 and 0.73 at 1’100 K and 2’000 K HTF outflow temperature respectively) were obtained indicating the robustness and effectiveness of this innovative absorbing gas receiver design.

INTRODUCTION

The actual trend for improving the performance of concentrating solar power (CSP) plants, in terms of thermal-to-electricity conversion, is the development of solutions to increase the operating temperature of the power block thermodynamic cycle [1]. To achieve this objective, the maximum operating temperature of commercial receivers, currently lower than 873 K, has to be increased. The major limiting factors of commercial receivers operating temperature are related to: heat transfer fluids (HTF), materials, and heat losses [2]. Synhelion SA, is developing a new generation of solar receivers, meant for large scale installations (> 1 MW_{th}) with high solar flux, suitable to operate at temperatures higher than 1’000 K [3, 4]. As opposed to conventional commercial receivers, which rely on indirect heating of the HTF, the proposed solution is based on the direct absorption of thermal radiation by a gaseous HTF. Because of their favorable optical properties, almost transparent to the high-radiation intensity wavelengths of the solar spectrum and mostly opaque (i.e., strong absorption bands) in the wavelength range of thermal radiation, water vapor and/or carbon dioxide are among the suitable HTF candidates. In the present paper, the computational fluid dynamic (CFD) numerical model, developed to evaluate the performance of the Synhelion absorbing gas receiver concept, will be comprehensively described. Furthermore, the results of different simulations campaigns, aimed at assessing the effect of HTF mass flow rate and operating pressure on the receiver performance, will be presented and thoroughly discussed.

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ABSORBING GAS RECEIVER CONCEPT

The working principle of the absorbing gas receiver, graphically represented in Fig. 1, is similar to the greenhouse effect: a cavity-type receiver is exploited to collect concentrated solar radiation that enters through the quartz-glass window, travels along the entire cavity length and is absorbed by a highly absorptive surface (referred as back plate) located at the back of the cavity. As a result, the surface temperature increases starting to re-emit longer wavelength thermal radiation into the cavity. At the same time, a stream of HTF, with the aforementioned spectral characteristics, flows also from the HTF inlet section towards the back of the cavity absorbing the thermal radiation emitted by the innermost surface (back plate). This causes the temperature of the HTF to increase as it flows through the cavity reaching the maximum value as it approaches the back plate. At this point, the high temperature HTF leaves the cavity receiver from the outlet pipe to be used for subsequent processes. In principle, the absorbing gas receiver can work with radiation as the only heat transfer mechanism, which is particularly effective at operating high operating temperatures and yields a potentially high receiver efficiency up to 2’000 K [3]. In addition, since no forced convection is required, the cost and complexity of a convective heat exchanger are removed.

If the receiver is operated with steam at atmospheric pressure, a large cavity of several meters is required in order to ensure a proper number of gas molecules on the path between the back-plate and aperture to absorb a relevant amount of thermal radiation and thereby minimizing the heat losses from the aperture. This renders the absorbing gas receiver readily applicable to large solar fields on the 100 MW scale. Furthermore, the size of the receiver can be downscaled by increasing the operating pressure without affecting the performance. Operating pressure and path length are inversely proportional: increasing the pressure by a factor of 10 enables the possibility of reducing the cavity size by the same factor.

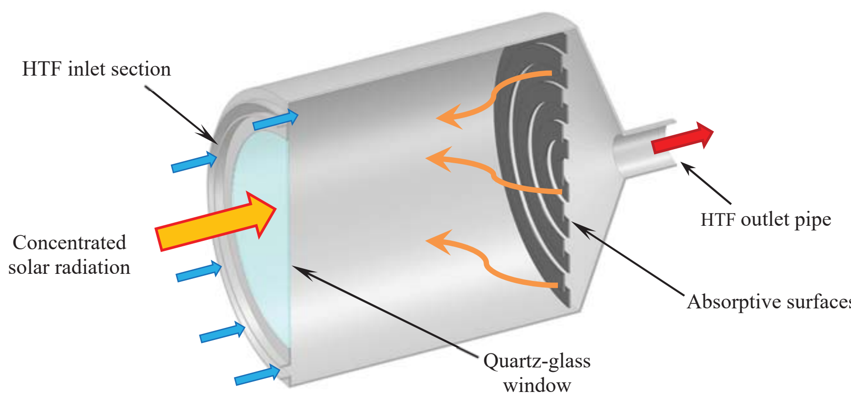

FIGURE 1. Schematic and working principle of the absorbing gas receiver.

MODELING RADIATIVE HEAT TRANSFER IN PARTICIPATING MEDIA

Thermal radiation heat transfer in flowing “radiatively participating” media (i.e., absorbing, emitting and scattering media), is, by nature, a complicated topic that is normally addressed by means of modelling methods which, depending on the desired accuracy, can be computationally very expensive or applicable to very simple and idealized cases only. The modelling complexity rises with the need of solving the radiative transfer equation (RTE) which describes how a radiation intensity field varies, within the domain under investigation, as a function of location, direction and spectral variables (wavenumber) [5]:

$$\frac{dI_\eta}{ds} = \kappa_\eta I_{b\eta} - \kappa_\eta I_\eta - \sigma_{s\eta} I_\eta + \frac{\sigma_{s\eta}}{4\pi} \int_{\Omega_i=0}^{4\pi} I_\eta(\hat{\mathbf{s}}_i)\, \Phi_\eta(\hat{\mathbf{s}}_i, \hat{\mathbf{s}}) d\Omega_i \quad (1)$$

Without going much into details, the terms on the right-hand-side indicate how the radiation intensity, travelling along a direction $\hat{\boldsymbol{s}}$, is augmented by emission and/or in-scattering (first and fourth term respectively) and attenuated by absorption and/or out-scattering away from $\hat{\boldsymbol{s}}$ (second and third term respectively).

Currently, four different methods are commonly exploited for the analysis of radiative heat transfer [5]: (i) the spherical harmonics method, (ii) the discrete ordinates method, (iii) the zonal method and (iv) the Monte Carlo (MC) method. In the spherical harmonics method, the RTE directional dependence is not discretized but it is described by a truncated series of spherical harmonics. This method allows to obtain an approximate solution of arbitrarily high order (i.e., accuracy) of the RTE by transforming it into a set of simultaneous partial differential equations. Accuracy can be the major limitation of this method since low-order approximation is only accurate in media with almost isotropic radiative intensity. Accuracy increases slowly for higher order approximation while mathematical complexity increases extremely rapidly. The most known approximation belonging to this method is the so-called P1-approximation. The discrete ordinates method can also be used to transform the RTE into a set of simultaneous partial differential equations carried out to any arbitrary order and accuracy. This method is based on a discrete representation of the directional variation of the radiative intensity with the RTE solved for discrete parts (directions) of the total solid angle. In the zonal method, the enclosure is subdivided into a set of isothermal sub-volumes and surface area zones. An energy balance is then applied for the radiative transfer between these zones to derive a set of simultaneous equations for determining the unknown temperatures and heat fluxes. Monte Carlo method is the most accurate, and the most computational demanding, method to evaluate radiative heat transfer. It is a statistical method in which a bundle of photons are physically traced from their point of emission to their point of absorption. As of today [5], the most popular RTE solvers are the spherical harmonics method, with P1-approximation, and the discrete ordinates method; however, Monte Carlo methods have received an increased attention during the past years thanks to the high accuracy, the capability of dealing with effects of irregular radiative properties and the fact that they can be easily adapted for parallel computing.

In the case of participating media, the radiative heat transfer analysis is even more complicated by the fact that spectral variations of the participating media radiation properties have to be taken into account since the gray participating medium assumption (i.e., the radiative properties do not vary across the electromagnetic spectrum) may lead to substantial errors in the analysis. According to Modest [5], exact and approximate methods to evaluate spectral models for radiative heat transfer calculations can be divided into 4 groups: (i) line-by-line (LBL) calculations, (ii) narrow band calculations, (iii) wide band calculations and (iv) global (gray gas) models. Among the latter, line-by-line is by far the most accurate and complex method relying on very detailed knowledge of every single spectral line (data not always available). The computational effort is remarkable due to the fact that the spectral radiative transfer problem must be solved for up to one million of wavenumbers. For this reasons, line-by-line method has only a very limited applicability in problems of practical interest. The other aforementioned methods, are less complex less computational expensive and less accurate than line-by-line but still reliable enough for a good radiative heat transfer analysis. On the basis of the good compromise between accuracy and computing time, the weighted-sum-of-gray-gases (WSGG) model is the one commonly exploited for deriving the radiative properties (total emissivity and absorptivity) of the participating medium.

The basic assumption of this approach is that the participating medium total emissivity can be computed as the sum of a certain number of fictitious gray gases emissivities properly weighted with a temperature dependent weighting factor. Therefore, the total emissivity "ε" over a path length "S" can be defined as [6]:

$$\varepsilon = \sum_{i=0}^{I} \alpha_{\varepsilon,i}(T)[1 - e^{-k_i p S}] \tag{2}$$

where "$\alpha_{\varepsilon,i}$" is the temperature-dependent emissivity weighting factor of the *i-th* fictitious gray gas, the bracketed quantity represents the *i-th* fictitious gray gas emissivity with absorption coefficient "k_i" and partial pressure-path length product "pS".

NUMERICAL MODEL DEVELOPMENT AND VALIDATION

Although the receiver working principle is straightforward, a clear understanding of the physical phenomena occurring into the system, as well as their interactions, is rather complex. For this reason, a CFD model, including fluid flow and heat transfer, has been developed exploiting Fluent code from ANSYS. The 2D axisymmetric computational domain considered for the CFD simulations campaigns, depicted in Fig. 2, is a simplified geometry of the absorbing gas receiver including the internal (fluid) volume only. The latter is composed by two different domains: (i) the cavity domain wherein the absorption of thermal radiation by the participating HTF takes place and (ii) the rear domain in which the high-temperature HTF is guided towards the outlet section. The separation between these two domains is given by the back plate disks.

In the case of receiver operating at atmospheric pressure, the diameters of the cavity and aperture are 15.96 m and 11.28 m, respectively. The surface area of the back plate is 200 m^2 while the aperture area is 100 m^2. The cavity length is equal to its internal diameter.

Mesh-independent results were achieved with a grid of about 90'000 quadrilateral cells. The back plate disks were modelled as flat surfaces, without thickness, but with the possibility of defining different emissivity values on the two sides (towards the cavity domain and vice versa).

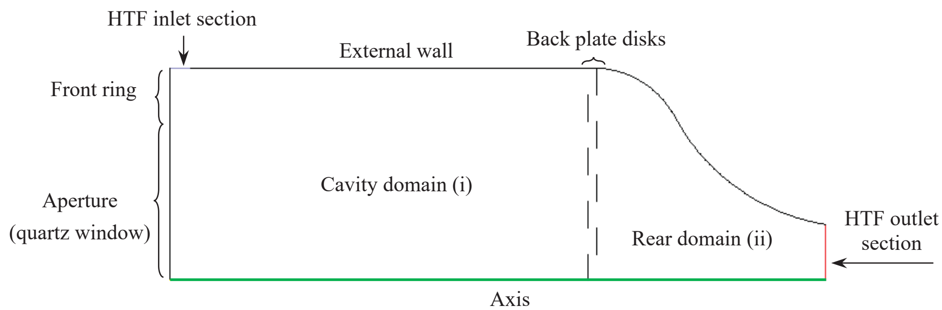

FIGURE 2. Reference receiver geometry – Computational domain.

Boundary Conditions and Fluid Properties

A mass flow inlet boundary condition was assigned to the HTF inlet section; a homogeneous velocity profile of the incoming HTF was assumed with an inclination of the velocity vector of 27° from aperture. The HTF inlet temperature was set to 1'000 K. The effect of gravity was not accounted for.

The concentrated solar radiation entering the cavity, and impinging on the back plate, is modelled as uniform heat flux (600 kW/m^2), leading to an input power of 120 MW, directly applied on the back plate disks facing the aperture; therefore, no ray-tracing was performed during the CFD simulations.

Since for all the simulations campaigns the thermal radiation absorption by the participating gas was assumed to take place into the cavity domain only, the emissivity values of the two sides of the back plate, the one facing the cavity domain and the other facing the rear domain, were set to 1 and 0 respectively. For coherence, the emissivity of the rear domain lateral wall was also set to 0; while, the emissivity of the cavity domain lateral wall and front ring were set to 1. Heat losses were assumed to take place from the aperture only, modelled as semi-transparent surface without thickness and with external emissivity of 1, by means of thermal radiation towards a blackbody ambient at 300 K. All the other external surfaces of the receiver were assumed adiabatic.

The reference HTF was water vapor modelled as incompressible ideal gas, i.e. density is calculated with ideal-gas law considering actual fluid temperature and a fixed pressure value, with temperature-dependent physical properties.

Numerical Details

Apart from the RTE, the CFD model solves the mass, momentum and energy conservation equations, along with turbulence transport equations, in order to have a detailed description of heat transfer and fluid flow within the computational domain. The Discrete Ordinates (DO) radiation model was selected for the solution of the RTE. Despite DO is the most demanding model in terms of computational resources, it is at the same time, the only one that allows to model semi-transparent interior or exterior walls (e.g., the receiver aperture), it can be applied for parallel computing and without any restrictions in terms of medium optical thickness. The spectral variation of the participating medium radiative properties was accounted for by the WSGG model. However, since the latter is not available in the reference commercial software product selected, it was implemented through a purpose-built user-defined function (UDF), i.e. a "C" routine properly written to be linked to the CFD solver.

Turbulence effects were accounted for through the realizable k-epsilon model [8] with enhanced wall treatment [9] as near-wall modeling approach.

SIMPLE algorithm [5] was exploited to couple the pressure and velocity fields and to solve the pressure correction equation. The pressure values at the cell faces were interpolated through PRESTO! (PREssure STaggering Option) scheme [6] and the spatial discretization of the transport equations were performed with a second order accurate upwind scheme. Convergence was considered to have been achieved when the mass, momentum and turbulent quantities residuals were below 10^{-5}, the DO and energy residuals were below 10^{-8} and 10^{-9} respectively.

Numerical Model Validation with Benchmark Monte Carlo Line-by-Line (MC-LBL) Results

Since at the time of the project no experimental data were available, the outcomes of a MC-LBL numerical model, developed by Synhelion [3], were exploited as benchmark results for evaluating the accuracy, reliability, and eventual limitations, of the CFD model especially concerning the simplified spectral radiative properties treatment of the participating HTF. To be as accurate as possible with the MC-LBL model, a simpler computational domain, consisting of a cylindrical cavity only, was considered. The other important simplification was related to the HTF that was considered to be inviscid.

To evaluate the capability of the developed CFD model to replicate the behavior of the absorbing gas receiver, a series of CFD simulations were performed varying the HTF mass flow rate. The CFD simulations results obtained were compared not only with the benchmark results of the MC-LBL model but also with those obtained with a second and simpler 2D model, still developed by Synhelion, wherein the WSGG model was implemented.

On the basis of the results obtained, reported in Fig. 3, it is evident that the simplified approach given by the WSGG model leads to a slight overestimation of the receiver efficiency with respect to the more accurate MC-LBL prediction. Furthermore, the receiver efficiency overestimation increases as the HTF mass flow rate decreases; the difference with respect to the benchmark MC-LBL results is of about 2.6% and 5.4% for the maximum and the minimum HTF mass flow rates respectively. Concerning the two models with the WSGG approximation, as expected, a very good agreement (0.38% maximum variation) was observed for the receiver thermal efficiency prediction. As final consideration of the validation process, despite the slight overestimation of the receiver thermal efficiency, the WSGG model resulted to be an appropriate solution for minimizing the computational resources required by keeping, at the same time, a reasonable accuracy of the results.

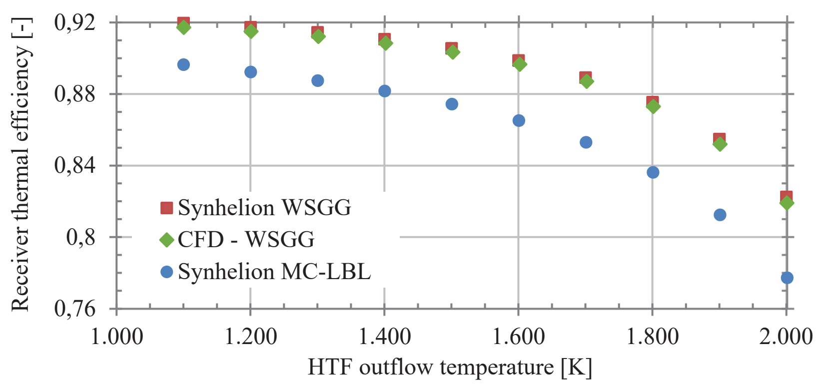

FIGURE 3. Comparison between CFD simulations results with the reference MC-LBL and WSGG simulations results.

CFD SIMULATIONS CAMPAIGNS

The validated CFD model was exploited to run several simulations campaigns on the reference absorbing receiver design (Fig. 2). In particular, the effect of the HTF mass flow rate on the receiver performance was evaluated. Furthermore, two scenarios of receiver operating pressure (ambient pressure and 10 bars respectively) were also considered and compared. The beneficial effect of operating at higher pressure is the increased density of the HTF, which leads to a downsizing of the receiver proportional to the operating pressure increase.

Atmospheric Pressure Receiver

In this first CFD analysis, the atmospheric pressure receiver is analyzed and, in detail, the effect of the HTF mass flow rate on the absorbing gas receiver behavior is evaluated. A total of ten CFD simulations were performed varying any time the HTF mass flow rate between 37.8 kg/s and 471.7 kg/s respectively.

The resulting temperature distribution of the atmospheric pressure receiver, for some of the HTF mass flow rates considered, is depicted in Fig. 4. Looking at the pictures, it is possible to observe that the temperature stratification into the cavity is sensibly affected by the HTF mass flow rate. When the latter is low, an almost axial temperature stratification is obtained; as the mass flow rate increases, the temperature stratification changes arriving, in the case of the highest HTF mass flow rate, in an almost radial configuration. As expected, the average internal temperature of the cavity is also affected by the HTF mass flow rate in the sense that it reduces as the mass flow rate increases. Furthermore, due to a flow stagnation point, located at the contact region between the outermost back plate ring and the lateral wall, a hot-spot can be observed for all the HTF mass flow rates considered. To mitigate this important temperature gradient in the radial direction of the back plate, a gap between the outermost back plate ring and the lateral wall should be implemented allowing hence the HTF stagnation point to be removed.

As graphically represented by the contours of velocity magnitude depicted in Fig. 5, the fluid dynamics behaviour of the HTF through the receiver has similar characteristics for all the mass flow rates considered. Based upon the assumed orientation of the HTF inlet velocity vector (27° from the aperture), two important flow recirculation zones can be observed within the cavity domain (Fig. 5): the first one in the vicinity of the lateral wall and the other one close to the aperture. A relatively high flow velocity is reached in the outlet region due to a combination of the cross-section reduction of the outlet pipe and the reduced density of the high-temperature HTF.

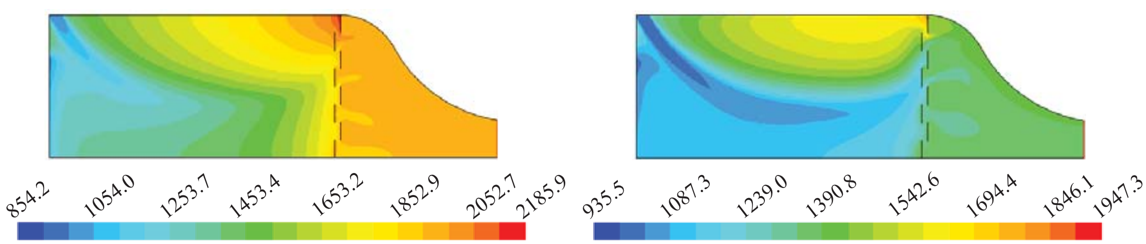

FIGURE 4. Temperature contours of the atmospheric pressure receiver operating at two reference HTF mass flow rates: 37.8 kg/s (l.h.s.) and 111.7 kg/s (r.h.s.). Temperature values are [K].

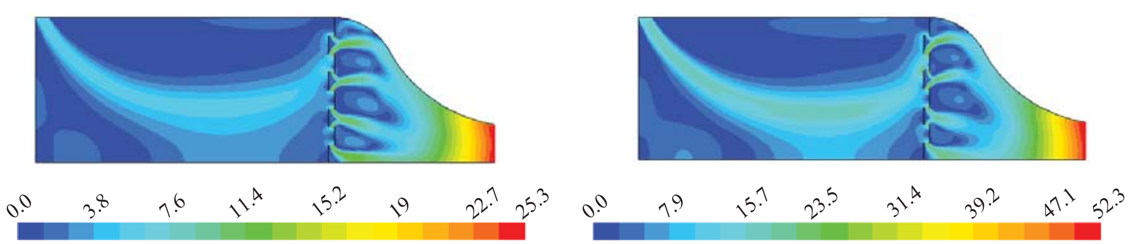

FIGURE 5. Contours of velocity magnitude for the atmospheric pressure receiver operating at two reference HTF mass flow rates: 37.8 kg/s (l.h.s.) and 111.7 kg/s (r.h.s.). Velocity values are [m/s].

Pressurized Receiver

Pressurized solar receivers are intrinsically more complex than atmospheric pressure receivers especially from the point of view of the pressure-induced mechanical stresses into the quartz-glass aperture window. On the other hand, a relevant advantage of pressurized receivers using gaseous HTFs is the higher density of the working fluid, which enables higher piping system compactness and lower insulation material use. In addition, increasing the operating pressure allows for downscaling the cavity size of the absorbing gas receiver while maintaining a sufficient number of gas molecules for absorption of thermal radiation. In this CFD simulations campaign, the thermo-fluid dynamics behavior of a pressurized receiver, operating at 10 bars absolute pressure, is accurately evaluated. The same receiver geometry, presented in Fig. 2, is considered for this analysis with the only exception that the dimensions are downsized with a scaling factor of 22.36. Therefore, the cavity domain of the pressurized receiver is characterized by an internal radius of about 0.36 m and an internal length of 0.72 m leading to a back plate surface area of 0.4 m^2. In this simulations campaign also, the HTF mass flow rate was varied for each simulation between 0.07 kg/s and 0.92 kg/s respectively.

Looking at the resulting temperature and velocity magnitude contours, Fig. 6 and Fig. 7 respectively, it can be observed that similar considerations, in terms of temperature stratification and flow characteristics, can be drawn with respect to the case of receiver operating at atmospheric pressure. In the case of pressurized receiver, a low HTF mass flow rate leads to an almost axial thermal stratification into the receiver; while, as the mass flow rate increases, the thermal stratification develops in the radial direction.

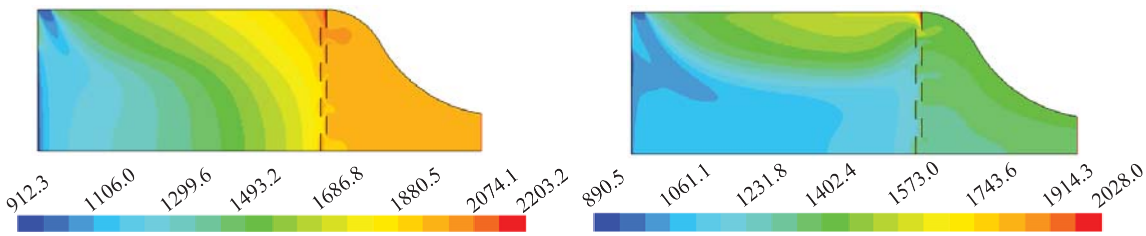

FIGURE 6. Temperature contours of the pressurized receiver operating at two reference HTF mass flow rates: 0.07 kg/s (l.h.s.) and 0.21 kg/s (r.h.s.). Temperature values are [K].

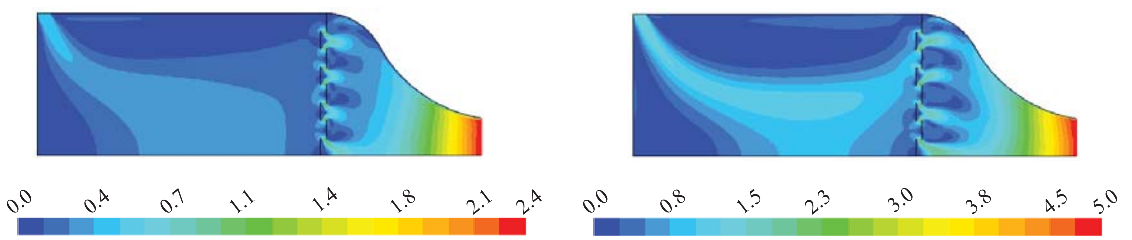

FIGURE 7. Contours of velocity magnitude for the pressurized receiver operating at two reference HTF mass flow rates: 0.07 kg/s (l.h.s.) and 0.21 kg/s (r.h.s.). Velocity values are [m/s].

Receiver Performance Analysis

The absorbing gas receiver performance, in the case of pressurized and unpressurized operating conditions, were also evaluated in terms of thermal efficiency defined as the ratio of the power removed by the HTF divided by the total input power. The resulting evolution of the receiver efficiency for the two cases under investigation, as a function of the HTF outflow temperature, is reported in Fig 8.

According to the results obtained, reducing the HTF mass flow rate (i.e., increasing the HTF outflow temperature) leads to a decrease of the receiver thermal efficiency due to higher heat losses. The efficiency decreases first rapidly as the HTF outflow temperature increases from about 1’100 K to 1’300 K and then stabilizes around the inflection point of 1’500 K. Beyond 1’500 K, the efficiency decreases faster down to the minimum in the case of lowest HTF mass flow rate. An interesting aspect to underline is that, despite the downsizing factor of the receiver was roughly double with respect to the operating pressure increase, the evolution of the pressurized receiver thermal efficiency has the same trend as the receiver operating at ambient pressure. At low HTF mass flow rates, a more pronounced performance reduction of the pressurized receiver (roughly a 6% reduction at most for the lowest HTF mass flow rate considered) can be detected. Nevertheless, promising receiver performance can be observed even at very high HTF outflow temperature.

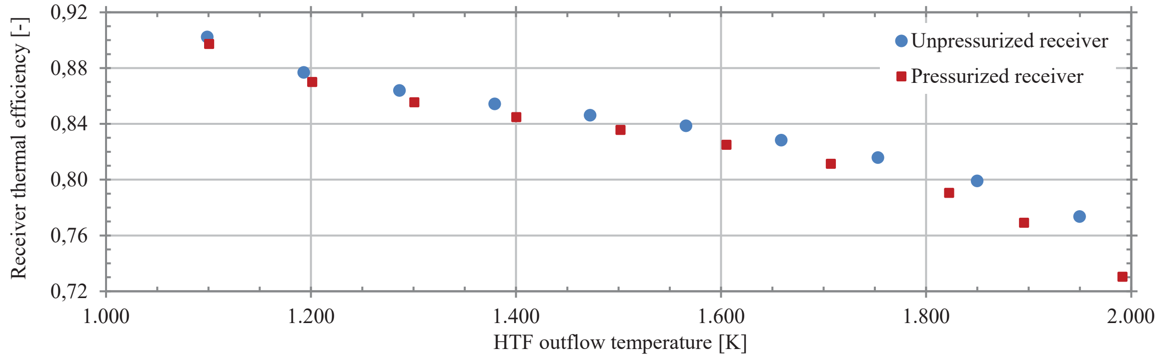

FIGURE 8. Resulting evolution of the receiver thermal efficiency as a function of the HTF outflow temperature.

SUMMARY AND CONCLUSIONS

A CFD-based approach was developed with the aim of replicating the thermo-fluid dynamics behavior of the innovative absorbing gas receiver proposed by Synhelion SA. Since this receiver relies on a gaseous HTF to absorb long wavelength thermal radiation, emitted by the internal surfaces of the receiver, the topic of modeling radiative heat transfer in participating media was introduced. The major modeling approaches to solve the RTE, and to account for the spectral variations of the participating media radiation properties, were described. Discrete ordinates method, for solving the RTE, and the WSGG model, for replicating the HTF spectral properties, resulted to be a viable compromise between expected accuracy of the results, computational resources, and computing time.

The CFD model, developed with Fluent code from ANSYS, was validated against benchmark results obtained, by Synhelion, exploiting Monte Carlo ray-tracing and spectral line-by-line models which are the most accurate and realistic methods available. Despite a resulting slight overestimation of the receiver performance (5.4% at most), observed during the validation process, the simplified CFD modeling approach resulted to be an appropriate solution for minimizing the computational resources required by keeping, at the same time, a reasonable accuracy of the results. Once demonstrated the capability of the CFD model to replicate the physics phenomena governing the absorbing gas receiver behavior, the effect of important working parameters, such as operating pressure and HTF mass flow rate, on the receiver performance were evaluated. As a general consideration, despite the high operating temperature up to 2’000 K, promising receiver performances were observed for all the cases analyzed.

ACKNOWLEDGMENTS

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REFERENCES

1. M. Blanco, L.R. Santigosa, Advances in concentrating solar thermal research and technology, Woodhead Publishing Series in Energy, (2016).
2. C. Ho, Advances in central receivers for concentrating solar applications, Solar Energy **152**, 38-56 (2017).
3. G. Ambrosetti, P. Good, A novel approach to high temperature solar receivers with an absorbing gas as heat transfer fluid and reduced radiative losses. Solar Energy **183**, 521-531 (2019).
4. G. Ambrosetti, P. Good, P. Furler, S. Ackermann, L. Geissbühler, The Synhelion Absorbing Gas Solar Receiver: A Route Towards 1’500 °C Process Heat. Paper submitted to SolarPACES 2019.
5. M. Modest, Radiative heat transfer - Third edition, Academic Press, (2013).
6. T. Smith, Z. Shen, J. Friedman, Evaluation of coefficients for the weighted sum of gray gases model, Journal of Heat Transfer **104** (4), 602-608, (1982).
7. T. Shih, W. Liou, A. Shabbir, Z. Yang and J. Zhu, A new k-epsilon eddy viscosity model for high Reynolds number turbulent flows - Model development and validation, Computers and Fluids **24** (3), 227-283, (1995).
8. J. Tu, G. Yeoh, C. Liu, Computational Fluid Dynamics; A practical approach, Butterworth-Heinemann, (2008).
9. H. Versteeg, W. Malalasekera, An introduction to computational fluid dynamics, Longman Scientific, (1995).